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**TECHNICAL MANUAL  
ENGINEERING SERIES FOR AIRCRAFT REPAIR**

**AEROSPACE METALS - GENERAL DATA  
AND USAGE FACTORS**

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## **SECTION I**

### **INTRODUCTION**

#### **1-1. PURPOSE.**

**1-2.** This is one of a series of technical or engineering technical manuals prepared to assist personnel engaged in the maintenance and repair of Aerospace Weapon Systems and Supporting Equipment (AGE). Army Personnel: Wherever the text of this manual refers to other technical orders (T.O.'s) for supporting information, refer to comparable Army documents.

**1-3.** This technical manual provides precise data on specific metals to assist in selection, usage and processing for fabrication and repair. It includes such data as specification cross reference; approved designation system for alloys and tempers; temperatures and other controls for heat treatments; mechanical and physical properties processing instructions for basic corrosion prevention; general welding and forming characteristics; and other information required for general aerospace weapon system repair. Procedures for general foundry practice, sand control, gating and risering of both ferrous and non-ferrous castings may be obtained from available commercial handbooks and/or publications. Due to the many types, grades, diversified uses and new developments of metal products, it may not include all data required in some instances and further study and citation of this data will be required. If a requirement exists for information not included, a request for assistance should be made to WR-ALC, MMIRDA.

**1-4.** The information/instruction contained herein are for general use. If a conflict exists between this technical manual and the specific technical manual(s) or other approved data for a particular weapon, end item, equipment, etc., the data applicable to the specific item(s) will govern in all cases.

**1-5.** The use of "shall", "will", "should" and "may" in this technical manual is as follows:

- a. Whenever the word "shall" appears, it shall be interpreted to mean that the requirements are binding.
- b. The words "will", "should" and "may", shall be interpreted as nonmandatory provisions.
- c. The word "will" is used to express declaration of purpose.
- d. The word "should" is used to express nonmandatory desired or preferred method of accomplishment.
- e. The word "may" is used to express an acceptable or suggested means of accomplishment.

**1-6.** Army Personnel: Reporting of Errors. You can help improve this manual by calling attention to errors and by recommending improvements and stating your reasons for the recommendations. Your letter or DA Form 2028, Recommended Changes to Publications and Blank Forms, should be mailed directly to Commander, US Army Aviation Systems Command, ATTN: DRSAV-FR, PO Box 209, St. Louis, Mo. 63166. A reply will be furnished directly to you.

**GLOSSARY**

**ACID BRITTLENESS.** Brittleness of steel resulting from use of acid solutions to remove scale, clean and electroplate. Brittleness is caused by the absorption of hydrogen into the metal from the acid solutions (also called hydrogen embrittlement).

**AGING.** (a) Generally any change in properties with time which occurs at relatively low temperature (room or elevated) after a final heat treatment of a cold marking operation. Aging is a process in which the trend is toward restoration of real equilibrium and away from an unstable condition induced by a prior operation.

(b) Specifically the formation of a new phase by cooling a solid solution to super saturated state and allowing the super saturated solution to partially return to equilibrium by the formation of a less concentrated solid solution and a new phase.

**AIR HARDENING.** An alloy which does not require quenching from a high temperature to harden. Hardening of the material occurs simply by cooling in air from above critical temperature. The term refers only to the ability of the material to harden in air and does not imply any definite analysis or composition.

**AIR COOLING/QUENCHING.** Cooling from an elevated temperature in air, still or forced.

**ALLOY.** A mixture with metallic properties composed of two or more elements of which at least one is a metal. However, a metal is not designated an "alloy" based on elements incidental to its manufacture. For example; iron, carbon, manganese, silicon, phosphorus, sulphur, oxygen, nitrogen and hydrogen are incidental to the manufacture of plain carbon steel. It does not become an "alloy steel" until the elements are increased beyond regular composition or until other elements (metal) are added in significant amounts for a specific purpose.

**ALLOY ELEMENTS.** Chemical elements comprising an alloy, usually limited to the metallic elements added to modify the basic metal properties.

**AMORPHOUS.** Non-crystalline.

**ANNEALING.** Generally it is a controlled heating procedure which leads to maximum softness, ductility and formability. The annealing procedure is utilized for the following:

- a. Remove stresses.
- b. Induce softness.
- c. After ductility, toughness, electrical, magnetic, or physical properties.
- d. Refine crystalline structure.
- e. Remove gases.
- f. Produce a definite micro-structure.

**ANNEALING FULL.** A controlled heating procedure which leads to maximum softness, ductility and formability.

**ANNEALING, ISOTHERMAL.** Heating of a ferritic steel to a austenite structure (fully or partial) followed by cooling to and holding at a temperature that causes transformation of the austenite to a relatively soft ferrite and carbide structure.

**ANODIC OXIDE COATING.** A thin film of aluminum oxide formed on the surface of aluminum and aluminum alloy parts by electro-chemical means.

**AS CAST.** Condition of a casting as it leaves the mold with no heat treatment.

**AUSTENITE.** A solid solution of iron carbide in gamma iron. It forms when the metal solidifies and remains a solution until it cools to about 7320C (1350°F).

Theoretically the solution would remain if the iron or steel were cooled instantaneously from a bright red heat to atmospheric temperature, but in practice, this degree of rapidity is impracticable, and only a portion of the austenite is preserved by rapid cooling. Addition of certain alloying elements such as nickel and manganese preserves austenite below 1°C (0°F).

**BARK.** The decarburized skin or layer just beneath the scale found after heating steel in an oxidizing atmosphere.

**BASE METAL.** The metal to which other elements are added to form an alloy possessing specific properties.

**BESSEMER PROCESS.** A process for making steel by blowing air through molten pig iron contained in a suitable vessel. The process is one of rapid oxidation primarily of silicon and carbon.

**BILLET.** An ingot or bloom that has been reduced through rolling or hammering to an approximate square ranging from 1 1/2 inches square to 6 inches square, or to an approximate rectangular cross-section of equivalent area. Billets are classified as semi-finished products for re-rolling or forging.

**BINARY ALLOY.** An alloy containing two elements, apart from minor impurities.

**BLACK ANNEALING.** A process of box annealing of sheets prior to tinning whereby a black color is imparted to the surface of the product.

**BLUE ANNEALING.** A process of annealing sheets after rolling. The sheets, if fairly heavy, are allowed to cool slowly after the hot rolling; if of lighter gage, as is usually the case, they are passed singly through an open furnace for heating to the proper annealing temperature. The sheets have a bluish-black appearance.

**BLUE BRITTLINESS.** Brittleness occurring in steel when in the temperature range of 1490 to 3710C (3000 to 700°F), or when cold after being worked within this temperature range.

**BOX ANNEALING.** Softening steel by heating it, usually at a sub-critical temperature, in a suitable closed metal box or pot to protect it from oxidation, employing a slow heating and cooling cycle; also called closed annealing or pot annealing.

**BRIGHT ANNEALING.** A process of annealing, usually with reducing gases, such that surface oxidation is reduced to a minimum, thereby yielding a relatively bright surface.

**BRITTLINESS.** Brittleness is the property of a material which permits little bending or deformation without fracture. Brittleness and hardness are closely associated.

**BURNING.** The heating of a metal to temperatures sufficiently close to the melting point to cause permanent injury. Such injury may be caused by the melting of the more fusible constituents, by the penetration of gases such as oxygen into the metal with consequent reactions, or perhaps by the segregation of elements already present in the metal.

**BUTT-WELD.** The welding of two abutting edges.

**CARBON FREE.** Metals and alloys which are practically free from carbon.

**CARBURIZING (CEMENTATION).** Adding carbon to the surface of iron-base alloys by heating the metal below its melting point in contact with carbonaceous solids, liquids, or gases.

**CASE.** The surface layer of an iron-base alloy which has been made substantially harder than the interior by the process of case hardening.

**CASE HARDENING.** A heat treatment of a combination of heat treatments in which the surface layer of an iron-base alloy is made substantially harder than the interior by altering its composition by carburizing, cyaniding, or nitriding.

**CHAPMANIZING.** A process for hardening steel by bubbling ammonia through a cyaniding salt bath and holding the finished part in the gas stream. This method produces a case almost as hard as nitriding at a time factor of slightly longer than required for cyaniding.

**CHARPY IMPACT.** An impact test made by measuring in a Charpy machine the energy required to fracture a standard notched specimen in bending. The values so obtained are merely comparative between different materials tested by the same method.

**COLD DRAWING.** The permanent deformation of metal below its recrystallization temperature; by drawing the bar through one or more dies.

**COLD ROLLING.** The permanent deformation of metal below its recrystallization temperature by rolling. This process is frequently applied in finishing rounds, sheets, strip, and tin plate.

**COLD TREATING.** Cooling to sub-zero temperature for various purposes, but primarily to promote transformation of austenite.

**COLD WORKING.** Plastic deformation of a metal at a temperature low enough to insure strain hardening.

**CORE.** The interior portion of an iron-base alloy which is substantially softer than the surface layer as the result of case hardening. Also, that portion of a forging removed by trepanning; the inner part of a rolled section of rimmed steel as distinct from the rimmed portion or rim; a body of sand or other material placed in a mold to produce a cavity in a casting.

**CONVERSION COATING (CHEMICAL).** A film intentionally produced on a metal by subjection to a selected chemical solution for the purpose of providing improved corrosion resistance or to improve the adhesion of subsequently applied organic coating.

**CYANIDING.** Surface hardening by carbon and nitrogen absorption of an iron-base alloy article or portion of it by heating at a suitable temperature in contact with a cyanide salt, followed by quenching.

**COOLING.** Any decrease in temperature; however, specific term -usually applies to reducing metal temperature in a gaseous environment rather than quenching in a liquid.

**DECALESCENCE.** When a piece of steel is heated, the temperature rises uniformly until it reaches a point between 7180C and 7320C (1,3250F and 1,350°F). At this point the rise in temperature suddenly halts due to the fact that the metal absorbs the heat necessary for the change of state. After this halt the temperature will continue its normal rate of increase. It is the halting in the temperature range that is termed decalescence. At the point of decalescence, the carbon and iron are forming a solid solution and the steel is passing from its annealed condition into its hardened condition.

**DECARBURIZATION.** The removal of carbon (usually refers to the surface of solid steel) by the (normally oxidizing) action of media which reacts with carbon.

The decarburized area is sometimes referred to as the bark.

**DEFECTS IN METALS.** Damage occurring to metal during manufacture/fabrication process. Some typical defects are as follows:

**a. Blister** a defect in metal produced by gas bubbles either on the surface or formed beneath the surface. Very fine blisters are called pinhead or pepper blisters.

**b. Blow hole** a hole produced during the solidification of metal by evolved gas which in -tiling to escape, is held in pockets.

**c. Bursts** ruptures made in forging or rolling.

**d. Fin (Flash)** a thin fin of metal formed at the side of a forging or weld where a small portion of the metal is forced out bet-en the edges of the forging or welding case.

**e. Flake** Internal fissures (cracks or clefts) in large steel forging or large (A88) rolled shapes. In a factured surface or test piece, they appear as sizable areas silvery brightness and coarser grain size thin their surroundings. Sometimes known a "chrome checks" and "hairline cracks."

**f. Ghost** (Ferrite ghost) a faint bud of ferrite.

**g. Lap** surface defect appearing as seam caused from folding over hot metal, fine, or sharp corners and then rolling or forging, but not welding, them into the surface.

**h. Pipe** a cavity formed in metal (especially ingot) during solidification of the last portion of liquid metal causes the cavity or pipe.

**i. Scab** a rough projection on a casting caused by the mold breaking or being washed by the molten metal; or occurring where the sin from a blowhole has partly burned away and is not welded.

**J. Seam** a crack on the surface of metal which has been closed but not welded; usually produced by blowholes which have become oxidized. If very fine, a seam may be called a hair crack or hair seam.

**k. Segregation** a mixture of compounds and elements, which, when cooled from the molten state, solidify at different temperatures.

**l. Ductility** the ability of a metal to withstand plastic deformation without rupture. Ductility is usually determined by tension test using a standard test (2" gauge length) specimen. The test specimen is loaded in tension to rupture. The specimen is then assembled and measured for length and diameter at the fracture. The increase in length is expressed as per cent elongation and the decrease in diameter as per cent reduction of area. The above terms measure ductility and since they are comparative, considerable experience is required for proper evaluation of material for the purpose intended.

**DUCTILITY.** The property that permits permanent deformation before fracture by stress in tension.

**ELASTIC LIMIT.** The elastic limit of a material is the greatest load per unit area which will not produce a measurable permanent deformation after complete release of load.

**ELONGATION.** The amount of permanent extension at any stage in any process which continuously elongates a body.

**EMBRITTEMENT.** Loss of ductility of a metal, which may result in premature failure. (see acid brittleness).

**ENDURANCE LIMIT.** The highest unit stress at which a material can be subjected to a very large number of repetitions of o loading and still show no evidence of failure. Above this limit failure occurs by the generation and growth of cracks until fracture results in the remaining section.

**ENDURANCE RATIO.** The ratio of the endurance limit for cycles of reversed flexural stress to the tensile strength.

**EQUALIZING.** intermediate heat treatment (special) which assists i developing desired properties, primary use is for equalizing/relieving stresses resulting from cold working.

**EUTECTIC ALLOY.** An alloy which has a lower melting point than neighboring compositions. More than one eutectic composition may occur in a given all by system.

**EXFOLIATION.** The cracking or flaking off of the outer layer of an object.

**EXPOSURE.** Heating to or subjecting to an elevating temperature or environment for a certain period of time.

**ETCHING.** Attack of metals structure by reagents. In metallography, the process of revealing structural details by the preferential attack of reagents on a metal surface.

**a. Micro-etching** is for the examination of the sample under a microscope and for this purpose the sample must be very carefully polished (by an experienced person) prior to etching.

**b. Macro-etching** is for the examination of the sample under a low power magnifying glass or by unaided eye. High polishing for this purpose is not absolutely essential; however, a good polish is necessary.

**c. Deep-etching** is a form of macro-etching in which the sample with regular cut surface may be immersed in hot hydrochloric acid (50% aqueous solution) and then examined for major defects such as inclusions, segregations, cracks, etc.

**FATIGUE.** The phenomenon of the progressive fracture of a metal by means of a crack which spreads under repeated cycles of stress.

**FATIGUE LIMIT.** Usually used as synonymous with endurance limit.

**FERRITE.** A solution in which alpha iron is the solvent, and which is characterized by a body centered cubic crystal structure.

**FILLET.** A concave junction of two surfaces usually perpendicular.

**FLAME HARDENING.** A process of hardening a ferrous alloy by heating it above the transformation range by means of a high-temperature flame and then cooling as required.

**FORGING STRAINS.** Elastic strains resulting from forging or from cooling from the temperature.

**FORMING.** To shape or fashion with hand/tools or by a shape or mold.

**FRACTURE TESTING.** A test used to determine type of structure, carbon content and the presence of internal defects. The test specimen is broken by any method that will produce a clean sharp fracture. The fracture is then examined by eye or with the aid of a low former magnifying glass. A trained/experienced observer will determine grain size; approximate depth of carburized or decarburized surface area; the presence of inclusions of dirty steel; and defects such as seams, cracks, pipes bursts and flakes.

**FULLY HARDENED.** Applies generally to the maximum hardness obtainable. (In particular, applies to materials that are hardened by a strain and/or age hardening process).

**FUSIBLE ALLOYS.** A group of nonferrous alloys which melt at relatively low temperatures. They usually consist of bismuth, lead, tin, etc., in various proportions, and iron only as an impurity.

**GALVANIC SERIES.** A list of metals and alloys arranged in order of their relative potentials in a given environment. The galvanic series indicates the tendency of the several metals and alloys to set up galvanic corrosion. The relative position within a group sometimes changes with external conditions, but it is only rarely that changes occur from group to group.

**GRAINS.** Individual crystals in metal. When metal is in molten state, the atoms have no uniform grouping. However, upon solidification they arrange themselves in a geometric pattern.

**GRAIN GROWTH.** An increase in the grain size of metal.

**HARDENABILITY.** The ability of an alloy to harden fully throughout the entire section thickness either by cold working or heat treatment. The maximum thickness at which this may be accomplished can be used as a measure of hardenability.

**HARDENING.** Hardening is accomplished by heating the metal to a specified temperature, then rapidly cooling by quenching in oil, water, or brine. This treatment produces a fine grain structure, extreme hardness, maximum tensile strength, and minimum ductility.

**HARDNESS.** Hardness refers to the ability of a material to resist abrasion, penetration, indentation, or cutting action. The wearing qualities of a material are in part dependent upon its hardness. Hardness and strength are properties which are closely related for wrought alloys.

**HARDNESS TESTING.** Test used to determine the ability of a metal to resist penetration. The test results are usually directly related to tensile and yield strength of the metal involved. An exception would be case hardness. See Section VI for typical testing methods.

**HEAT TINTING.** Heating a specimen with a suitable surface in air for the purpose of developing the structure by oxidizing or otherwise affecting the different constituents.



**HEAT TREATMENT.** An operation, or combination of operations, involving the heating and cooling of a metal or alloy in the solid -state for the purpose of obtaining certain desirable conditions or properties. Heating and cooling for the sole purpose of mechanical working are excluded from the meaning of this definition.

**HOMOGENIZING.** Annealing or soaking at very high temperatures in order to reduce alloy segregation by diffusion.

**HOT SHORTNESS.** Brittleness in metal when hot. In iron when sulphur is in excess of the manganese necessary to combine with it to form manganese sulphide the excess sulphur combines with the iron to form iron sulphide. This constituent has a lower melting point than the iron and the result can be that steel may crack during hot working.

**HYDROGEN EMBRITTLEMENT.** See Acid Brittleness.

**IMPACT TEST.** A test in which one or more blows are suddenly applied to a specimen. The results are usually expressed in terms of energy absorbed or number of blows (of a given intensity) required to break the specimen. See Charpy Impact and Izod Impact.

**INCLUSION.** Particles of impurities, usually oxides, sulphides, silicates, and such which are mechanically held during solidification or which are formed by subsequent reaction of the solid metal.

**INDUCTION HARDENING.** A process of hardening a ferrous alloy by heating above the transformation range by means of electrical induction and then cooling as required.

**MACHINABILITY.** The cutting characteristic of metal and resulting surface finish using standard cutting tools and coolant/lubricants. There are various factors that effect the machinability of a metal such as hardness, grain size, alloy constituents, structure, inclusions; shape, type, condition of tool and coolant. The standard machinability ratings are usually based on comparison to SAE 1112/Aisi B 1112 Bessemer screw stock which is rated at 100% machinability.

**MAGNAFLUX TESTING.** A method of inspection used to detect/locate defects such as cavities, cracks or seams in steel parts at or very close to the surface. The test is accomplished by magnetizing the part with equipment specially designed for the purpose and applying magnetic powder, wet or dry, Flaws are then indicated by the powder clinging to them (see Section VIII for additional data).

**MALLEABILITY.** Malleability is the property of a material which enables it to be hammered, rolled, or to be pressed into various shapes without fracture. Malleability refers to compression deformation as contrasted with ductility where the deformation is tensile.

**MARTEMPERING.** This is a method of hardening steel by quenching from the austenitizing temperature into a medium at a temperature in the upper part of or slightly above the martensite range and holding it in the medium until temperature is substantially uniform throughout the alloy is then allowed to cool in air through the martensite range.

**MARTENSITE.** It is the decomposition product which results from very rapid cooling of austenite. The lower the carbon content of the steel, the faster must be cooling to obtain martensite.

**MECHANICAL HARDNESS.** See Hardness.

**MECHANICAL PROPERTIES.** Those properties that reveal the reaction, elastic and inelastic, of a material to an applied force, or that involve the relationship between stress and strain; for example, tensile strength, yield strength, and fatigue limit.

**MECHANICAL TESTING.** Testing methods by which mechanical properties are determined.

**MECHANICAL WORKING.** Subjecting metal to pressure exerted by rolls, presses, or hammers, to change its form, or to affect the structure and therefore the mechanical and physical properties.

**MODULUS OF ELASTICITY.** The ratio, within the limit of elasticity, of the stress in the corresponding strain. The stress in pounds per square inch is divided by the elongation in fractions of an inch for each inch of the original gage length of the specimen.

**NITRIDING.** Adding nitrogen to iron-base alloys by heating the metal in contact with ammonia gas or other suitable nitrogenous material. Nitriding is conducted at a temperature usually in the range 50205380C (9350-10000F) and produces surface hardening of the metal without quenching.

**NORMALIZING.** Heating iron-base alloys to approximately 550°C (100°F) above the critical temperature range, followed by cooling to below that range in still air at ordinary temperatures. This process is used to remove stresses caused by machining, forging, bending, and welding.

**OVERHEATING.** Heating to such high temperatures that the grains have become coarse, thus impairing the properties of the metal.

**PATENTING.** Heating iron-base alloys above the critical temperature range followed by cooling below that range in air, or in molten lead, or a molten mixture of nitrates or nitrites maintained at a temperature usually between 427°-5660C (800°-10500F), depending on the carbon content of the steel and the properties required of the finished product. This treatment is applied to wire and to medium or high carbon steel as a treatment to precede further wire drawing.

**PHYSICAL PROPERTIES.** Those properties exclusive of those described under mechanical properties; for example, density, electrical conductivity, coefficient of thermal expansion. This term has often been used to describe mechanical properties, but this usage is not recommended.

**PHYSICAL TESTING.** Testing methods by which physical properties are determined. This term is also in advisedly used to mean the determination of the mechanical properties.

**PICKLING.** Removing scale from steel by immersion in a diluted acid bath.

**PLASTIC DEFORMATION.** The permanent change in size or shape of a material under stress.

**POTENTIOMETER.** Potentiometer is an instrument used to measure thermocouple voltage by balancing a known battery voltage against it.

**PROCESS ANNEALING.** Heating iron-base alloys to a temperature below or close to the lower limit of the critical temperature range, followed by cooling as desired. This treatment is commonly applied to sheet and wire and the temperatures generally used are from 5490 to 6490C (10200to 1200°F).

**PROOF STRESS.** The proof stress of a material is that load per unit area which a material is capable of withstanding without resulting in a permanent deformation of more than a specified amount per unit of gage length after complete release of load.

**PROPORTIONAL LIMIT.** The proportional limit of a material is the load per unit area beyond which the increases in strain cease to be directly proportional to the increases in stress.

**PYROMETER.** An instrument for measuring temperature.

**QUENCHING.** Rapid cooling by immersion in liquids or gases.

**QUENCHING MEDIA.** Quenching media are liquids or gases in which metals are cooled by immersion. Some of the more common are brine (10 percent sodium chloride solution), water 180C (650F), fish oil, paraffin base petroleum oil, machine oil, air, engine oil, and commercial quenching oil.

**RECALESCENCE.** When steel is slowly cooled from a point above the critical temperature, the cooling proceeds at a uniform rate until the piece reaches a point between 677°and 7040C (1,2500 and 1,3000°F). At this time, the cooling is noticeably arrested and the metal actually rises in temperature as the change of state again takes place. This change is the opposite of decalescence and is termed recalescence.

**REDUCTION OF AREA.** The difference between the original cross-sectional area and that of the smallest area at the point of rupture. It is usually stated as a percentage of the original area; also called "contraction of area."

**REFINING TEMPERATURE OR HEAT.** A temperature employed in case hardening to refine the case and core.

The first quench is from a high temperature to refine the core and the second quench is from a lower temperature to further refine and harden the case.

**SCALE.** A coating of metallic oxide that forms on heated metal.

**SENSITIZING.** Developing a condition in stainless steels, which is susceptible to intergranular corrosion. The condition is usually formed by heating the steel above 8000F and cooling slowly, e.g., welding.

**SHEETS COLD ROLLED.** The flat products resulting from cold rolling of sheets previously produced by hot rolling.

**SHEETS HOT ROLLED.** The flat-rolled products resulting from reducing sheet bars on a sheet mill, or slabs, blooms, and billets on a continuous stripsheet mill.

**SOAKING.** Holding steel at an elevated temperature for the attainment of uniform temperature throughout the piece.

**SOLIDIFICATION RANGE.** The temperature range through which metal freezes or solidifies.

**SPALLING.** The cracking and flaking of small particles of metal from the surface.

**SPHEROIDAL OR SPHEROIDIZED CEMETITE.** The globular condition of iron carbide resulting from a spheroidizing treatment. The initial structure may be either pearlitic or martensitic.



**SPHEROIDIZING.** Any process of heating and cooling steel that produces a rounded or globular form of carbide. The spheroidizing methods generally used are:

- a. Prolonged heating at a temperature just below the lower critical temperature, usually followed by relatively slow cooling.
- b. In the case of small objects of high carbon steels, the spheroidizing result is achieved more rapidly by prolonged heating to temperatures alternately within and slightly below the critical temperature range.
- c. Tool steel is generally spheroidized by heating to a temperature of 749°-804°C (1380°-1480°F) for carbon steels and higher for many alloy tool steels, holding at heat from 1 to 4 hours, and cooling slowly in the furnace.

**STRAIN.** The elongation per unit length.

**STRESS.** The internal load per unit area.

**STRESS-RELIEF.** This is annealing process which removes or reduces residual stresses retained after forming, heat treating, welding or machining. The anneal is accomplished at rather low temperatures for the primary purposes of reducing residual stresses, without material affecting other properties.

**TEMPERING (ALSO TERMED DRAWING).** Reheating hardened steel to some temperature below the lower critical temperature, followed by any desired rate of cooling. Although the terms "tempering" and "drawing" are practically synonymous as used in commercial practice, the term "tempering" is preferred.

**TENSILE STRENGTH.** The tensile strength is the maximum load per unit area which a material is capable of withstanding before failure. It is computed from the maximum load carried during a tension test and the original cross-sectional area of the specimen.

**TENSION.** That force tending to increase the dimension of a body in the direction of the force.

**THERMOCOUPLE.** Thermocouple consists of a pair of wires of dissimilar metals connected at both ends. When the two junctions are subjected to different temperatures an electric potential is set up between them. This voltage is almost in direct proportion to the temperature difference, and hence, a voltage measuring instrument inserted in the circuit will measure temperature. The voltage measuring instrument is usually calibrated in °C or °F.

**TOLERANCES.** Slight deviations in dimensions or weight or both, allowable in the various products.

**VISCOSITY.** Viscosity is the resistance offered by a fluid to relative motion of its parts.

**WIRE.** The product obtained by drawing rods through a series of dies.

**WORK HARDNESS.** Hardness developed in metal resulting from mechanical working, particularly cold working.

**YIELD POINT.** The load per unit of original cross section at which a marked increase in deformation occurs without increase in load..

**YIELD STRENGTH.** Stress arbitrarily defined as the stress at which the material has a specified permanent set (the value of 0.2% is widely accepted).

**YOUNG'S MODULUS.** See Modulus of Elasticity.

## SECTION II FERROUS (STEEL) ALLOYS

### 2-1. CLASSIFICATION.

**2-2. SAE NUMBERING SYSTEM.** A numeral index system is used to identify the compositions of the SAE steels, which makes it possible to use numerals that are partially descriptive of the composition of material covered by such numbers. The first digit indicates the type to which the steel belongs; for example "1" indicates a carbon steel; "2" a nickel steel; and "3" a nickel chromium steel. In the case of the simple alloy steels, the second digit generally indicates the approximate percentage of the predominant alloying element. Usually the last two or three digits indicate the approximate average carbon content in "points" or hundredths of 1 percent. Thus "2340" indicates a nickel steel of approximately 3 percent nickel (3.25 to 3.75) and 0.40 percent carbon (0.38 to 0.43). In some instances, in order to avoid confusion, it has been found necessary to depart from this system of identifying the approximate alloy composition of a steel by varying the second and third digits of the number. An instance of such departure is the steel numbers selected for several of the corrosion--and heat resisting alloys.

TYPE OF STEEL	NUMERALS (AND DIGITS)
<b>Carbon Steels</b>	1xxx
Plain Carbon	10xx
Free Cutting (Screw Stock)	11xx
<b>Manganese Steels</b>	13xx
<b>Nickel Chromium Steels</b>	3xxx
1.25 Percent Nickel; 0.65 percent Chromium	31xx
Corrosion and Heat Resisting	303xx
<b>Molybdenum Steels</b>	4xxx
0.25 Percent Molybdenum	40xx

TYPE OF STEEL	NUMERALS (AND DIGITS)
<b>Nickel-Chromium-Molybdenum Steels</b>	
1.80 % nickel; 0.50 & 0.80% Chromium; 0.25 % Molybdenum	43xx
0.55% Nickel; 0.50 & 0.65 % Chromium; 0.20 % Molybdenum	86xx
0.55% Nickel; 0.50 Chromium 0.25% Molybdenum	87xx
3.25% Nickel; 1.20 Chromium; 0.12% Molybdenum	93xx
<b>Nickel-Molybdenum Steels</b>	
1.75 Percent Nickel; 0.25 percent Molybdenum	46xx
3.50 Percent Nickel; 0.25 percent Molybdenum	48xx
<b>Chromium Steels</b>	5xxx
Low Chromium	50xx
Medium Chromium	51xxx
High Chromium	52xxx
Corrosion and Heat Resisting	514xx and 515xx
<b>Chromium-Vanadium Steel</b>	6xxx
0.80-1.00 percent Chromium, 0.10-0.15 Vanadium	61xx
<b>Silicon Manganese Steels</b>	9xxx
A Percent Silicon	92xx
Low Alloy, High Tensile	950
Boron Intensified	xxBxx
Leaded Steels	xxLxx

2-3. The basic numerals for the various types of SAE steel are:

2-4. **CARBON STEELS,** Steel containing carbon in percentages ranging from 0.10 to 0.30 percent is classed as low carbon steel. The equivalent SAE numbers range from 1010 to 1030. Steels of this grade are used for the manufacture of articles such as safety wire, certain nuts, cable bushing, etc. This steel in sheet form is used for secondary structural parts and clamps and in tubular form for moderately stressed structural parts.

**2-5.** Steel containing carbon in percentages ranging from 0.30 to 0.50 percent is classed as medium carbon steel. This steel is especially adaptable for machining, forging, and where surface hardness is important. Certain rod ends, light forgings, and parts such as Woodruff keys, are made from SAE 1035 steel.

**2-6.** Steel containing carbon in percentage ranging from 0.50 to 1.05 percent is classed as high carbon steel. The addition of other elements in varying quantities adds to the hardness of this steel. In the fully heat treated condition it is very hard and will withstand high shear and wear, but little deformation. It has limited use in aircraft construction. SAE 1095 in sheet form is used for making flat springs and in wire form for making coil springs.

**2-7. NICKEL STEELS.** The various nickel steels are produced by combining nickel with carbon steel. Some benefits derived from the use of nickel as an alloy in steel are as follows:

- a. Lowers the percentage of carbon that is necessary for hardening. The lowering of the carbon content makes the steel more ductile and less susceptible to uneven stress.
- b. Lowers the critical temperature ranges (heating and cooling) and permits the use of lower heating temperatures for hardening.
- c. Hardening of the nickel alloy steels at moderate rates of cooling has the advantage of lowering the temperature gradients, reducing internal stress/warpage and permits deeper/more uniform hardening.
- d. The low heat treating temperatures required, reduces the danger of overheating, excessive grain growth and the consequent development of brittleness.
- e. The characteristics depth hardening from the addition of nickel to steel as an alloy results in good mechanical properties after quenching and tempering. At a given strength (except for very thin sections/parts) the nickel steels provide greatly improved elastic properties, impact resistance and toughness.

**2-8. CHROMIUM STEELS.** Chromium steel is high in hardness, strength, and corrosion resistant properties. SAE 51335 steel is particularly adaptable for heat-treated forgings which require greater toughness and strength than may be obtained in plain carbon steel.

It may be used for such articles as the balls and rollers of anti-friction bearings.

**2-9. CHROMIUM-NICKEL STEELS.** Chromium and nickel in various proportions mixed with steel form the chrome-nickel steels. The general proportion is about two and one-half times as much nickel as chromium. For all ordinary steels in this group the chromium content ranges from 0.45 to 1.25 percent, while the nickel content ranges from 1 to 2 percent. Both nickel and chromium influence the properties of steel; nickel toughens it, while chromium hardens it. Chrom-nickel steel is used for machined and forged parts requiring strength, ductility toughness and shock resistance. Parts such as crankshafts and connecting rods are made of SAE 3140 steel.

**2-10.** Chrome-nickel steel containing approximately 18 percent chromium and 8 percent nickel is known as corrosion-resistant steel. It is usually identified as aisi types 301, 302, 303, 304, 304L, 309, 316, 316L, 321, 347, 347F or Se, etc., however; the basic 18-8 chrome-nickel steel is type 302. The other grades/types have been modified by changing or adding alloying elements to that contained in the basic alloy. The alloys are varied to obtain the required mechanical properties for some specific purpose such as improving corrosion resistance or forming machining, welding characteristics, etc. The following are examples of variations:

- a. 301-Chromium and Nickel (approx. 0.5 Nickel) is lowered to increase response to cold working.
- b. 302-Basic Type 18 Chromium 8Nickel.
- c. 303-Sulfur(s) or Selenium (se) added for improved machining characteristics.
- d. 304-Carbon(c) lowered to reduce susceptibility to carbide precipitation. This alloy is still subject to carbide precipitation from exposure to temperatures 800-1500F range and this shall be considered when it selected for a specific application.

- e. 304L-Carbon (c) lowered for welding applications.
- f. 309-Cr and Ni higher for additional corrosion and scale resistance.
- g. 316-Molybdenum (Mo) added to improve corrosion resistance and strength.
- h. 316L-Lowered for welding applications.
- i. 321-Titanium (Ti) added to reduce/ avoid carbide precipitation (stabilized grade).
- j. 347-Columbium(Cb), Tantalum (Ta) Added to reduce/avoid carbide precipitation (stabilized grade).
- k. 347F or Se Sulfur(s) or Selenium (Se) added to improve machinability.

The chrome-nickel steels are used for a variety of applications on aircraft and missiles. In plate and sheet form it is used for fire walls, surface skin, exhaust stacks, heater ducts, gun wells, ammunition chutes, clamps, heat shields/deflectors, fairing, stiffeners, brackets, shims, etc. In bar and rod it is used to fabricate various fittings, bolts, studs, screws, nuts, couplings, flanges, valve stems/seats, turn-buckles, etc. In wire form it is used for safety wire, cable, rivets, hinge pins, screens/screening and other miscellaneous items.

**2-11. CHROME-VANADIUM STEELS.** The vanadium content of this steel is approximately 0.181percent and the chromium content approximately 1.00 percent. Chrome vanadium steels when heat-treated have excellent properties such as strength, toughness, and resistance to wear and fatigue. A special grade of this steel in sheet form can be cold-formed into intricate shapes. It can be folded and flattened without signs of breaking or failure. Chrome-vanadium steel with medium high carbon content (SAE 6150) is used to make springs. Chrome-vanadium steel with high carbon content (SAE 6195) is used for ball and roller bearings.

**2-12. CHROME MOLYBDENUM STEELS.** Molybdenum in small percentage is used in combination with chromium to form chrome molybdenum steel; this steel has important applications in aircraft. Molybdenum is a strong alloying element, only 0.15 to 0.25 percent being used in the chrome-molybdenum steels; the chromium content varies from 0.80 to 1.10 percent. Molybdenum is very similar to tungsten in its effect on steel. In some instances it is used to replace tungsten in cutting tools, however; the heat treat characteristic varies. The addition of up to 1% molybdenum gives steel a higher tensile strength and elastic limit with only a slight reduction in ductility. They are especially adaptable for welding and for this reason are used principally for welded structural parts and assemblies. Parts fabricated from 4130, are used extensively in the construction of aircraft, missiles, and miscellaneous GSE equipment. The 4130 alloy is used for parts such as engine mounts (reciprocating), nuts, bolts, gear structures, support brackets for accessories, etc.

### **2-13. PRINCIPLES OF HEAT TREATMENT OF STEELS.**

**2-14. HARDENING.** At ordinary temperatures, the carbon content of steel exists in the form of particles of iron carbide scattered throughout the iron matrix; the nature of these carbide particles, i.e., their number, size, and distribution, determines the hardness and strength of the steel. At elevated temperatures, the carbon is dissolved in the iron matrix and the carbide-particles appear only after the steel has cooled through its "critical temperature" (see next paragraph).

If the rate of cooling is slow, the carbide particles are relatively coarse and few; in this condition the steel is soft. If the cooling is rapid, as in quenching in oil or water, the carbon precipitates as a cloud of very fine carbide particles, which condition is associated with high hardness of the steel.

**2-15.** At elevated temperatures, the iron matrix exists in a form called "austenite" which is capable of dissolving carbon in solid solution. At ordinary temperatures the iron exists as "ferrite", in which carbon is relatively insoluble and precipitates, as described in the preceding paragraph, in the form of carbide particles. The temperature at which this change from austenite to ferrite begins to occur on cooling is called the "upper critical temperature" of the steel, and varies with the carbon content; up to approximately 0.85 percent carbon, the upper critical temperature is lowered with increasing carbon content; from 0.85 to 1.70 percent carbon the upper critical temperature is raised with increasing carbon content. Steel that has been heated to its upper critical point will harden completely if rapidly quenched; however, in practice it is necessary to exceed this temperature by from approximately 28° to 56°C (50° to 100° F) to insure thorough heating of the inside of the piece. If the upper critical temperature is exceeded too much, an unsatisfactory coarse grain size will be developed in the hardened steel.

**2-16.** Successful hardening of steel will largely depend upon the following factors after steel has been selected which has harden ability desires:

- a. Control over the rate of heating, specifically to prevent cracking of thick and irregular sections.
- b. Thorough and uniform heating through sections to the correct hardening temperatures.
- c. Control of furnace atmosphere, in the case of certain steel parts, to prevent scaling and decarburization.
- d. Correct heat capacity, viscosity, and temperature of quenching medium to harden adequately and to avoid cracks.
- e. In addition to the preceding factors. the thickness of the section controls the depth of hardness for a given steel composition. Very thick sections may not harden through because of the low rate of cooling at the center.

**2-17.** When heating steel, the temperature should be determined by the use of accurate instruments. At times, however, such instruments are not available, and in such cases, the temperature of the steel may be judged approximately by its color. The accuracy with which temperatures may be judged by color depends on the experience of the workman, the light in which the work is being done, the character of the scale on the steel, the amount of radiated light within the furnace, and the emissivity or tendency of steel to radiate or emit light.

**2-18.** A number of liquids may be used for quenching steel. Both the medium and the form of the bath depend largely on the nature of the work to be cooled. It is important that a sufficient quantity of the medium be provided to allow the metal to be quenched without causing an appreciable change in the temperature of the bath. This is particularly important where many articles are to be quenched in succession.

#### **NOTE**

**Aerators may be used in the Quench Tanks to help dissipate the vapor barrier.**

#### **2-19. QUENCHING PROCEDURE.**

The tendency of steel to warp and crack during the quenching process is difficult to overcome, and is due to the fact that certain parts of the article cool more rapidly than others. Whenever the rate of cooling is not uniform, internal stresses are set up on the metal which may result in warpage or cracking, depending on the severity of the stresses. Irregularly shaped parts are particularly susceptible to these conditions although parts of uniform section size are often affected in a similar manner. Operations such as forging and machining may set up internal stresses in steel parts and it is therefore advisable to normalise articles before attempting the hardening process. The following recommendations will greatly reduce the warping tendency and should be carefully observed:

- a. An article should never be thrown into quenching media/bath. By permitting it to lie on the bottom of the bath it is apt to cool faster on the top side than on the bottom side, thus causing it to warp or crack.
- b. The article should be slightly agitated in the bath to destroy the coating of vapor which might prevent it from cooling rapidly. This allows the bath to remove the heat of the article rapidly by conduction and convection.

c. An article should be quenched in such a manner that all parts will be cooled uniformly and with the least possible distortion. For example, a gear wheel or shaft should be quenched in a vertical position.

d. Irregularly shaped sections should be immersed in such a manner that the parts of the greatest section thickness enters the bath first.

## 2-20. QUENCHING MEDIUM.

**2-21.** Oil is much slower in action than water, and the tendency of heated steel to warp or crack when quenched may be greatly reduced by its use. Unfortunately, parts made from high carbon steel will not develop maximum hardness when quenched in oil unless they are quite thin in cross section. In aircraft, however, it is generally used and is recommended in all cases where it will produce the desired degree of hardness.

### NOTE

**Alloy steels should never be quenched in water.**

**2-22.** In certain cases water is used in the quenching of steel for the hardening process. The water bath should be approximately 18° C (65°F), as extremely cold water is apt to warp or crack the steel and water above this temperature will not produce the required hardness.

**2-23.** A 10% salt brine (sodium chloride) solution is used when higher cooling rates are desired. A 10% salt brine solution is made by dissolving 0.89 pound of salt per gallon of water.

**2-24.** For many articles such as milling cutters and similar tools, a bath of water covered by a film of oil is occasionally used. When the steel is plunged through this oil film a thin coating will adhere to it, retarding the cooling effect of the water slightly, thus reducing the tendency to crack due to contraction.

**2-25. STRAIGHTENING OF PARTSWARPED IN QUENCHING.** Warped parts must be straightened by first heating to below the tempering temperature of the article, and then applying pressure. This pressure should be continued until the piece is cooled. It is desirable to retemper the part after straightening at the straightening temperature. No attempt should be made to straighten hardened steel without heating, regardless of the number of times it has been previously heated, as steel in its hardened condition cannot be bent or sprung cold with any degree of safety.

## 2-26. TEMPERING (DRAWING).

Steel that has been hardened by rapid cooling from a point slightly above its critical range is often harder than necessary and generally too brittle for most purposes. In addition, it is under severe internal stress. In order to relieve the stresses and reduce the brittleness or restore ductility the metal is always "tempered". Tempering consists in reheating the steel to a temperature below the critical range (usually in the neighborhood of 600 1200°F). This reheating causes a coalescence and enlargement of the fine carbide particles produced by drastic quenching, and thus tends to soften the steel. The desired strength wanted will determine the tempering temperature. This is accomplished in the same types of furnaces as are used for hardening and annealing. Less refined methods are sometimes used for tempering small tools.

**2-27.** As in the case of hardening, tempering temperatures may be approximately determined by color. These colors appear only on the surface and are due to a thin film of oxide which forms on the metal after the temperature reaches 232° C (450° F). In order to see the tempering colors, the surface must be brightened. A buff stick consisting of a piece of wood with emery cloth attached is ordinarily used for this purpose. When tempering by the color method, an open flame of heated iron plate is ordinarily used as the heating medium. Although the color method is convenient, it should not be used unless adequate facilities for determining temperature are not obtainable. Tempering temperatures can also be determined by the use of crayons of known melting point.



Such crayons are commercially available for a wide range of temperatures under the trade name of "Tempilstiks." The above method may be used where exact properties after tempering is not too important such as for blacksmith work. The most desirable method for general aeronautical use, is to determine temperatures by hardness checks, and subsequent adjustments made as necessary to obtain the properties required. For recommended tempering temperatures see heat treat data for material/composition involved.

**2-28.** Steel is usually subjected to the annealing process for the following purposes:

- a. To increase its ductility by reducing hardness and brittleness.
- b. To refine the crystalline structure and remove stresses. Steel which has been cold-worked is usually annealed so as to increase its ductility. However, a large amount of cold-drawn wire is used in its cold-worked state when very high yield point and tensile strength are desired and relatively low ductility, is permissible, as in spring wire, piano wire, and wires for rope and cable. Heating to low temperatures, as in soldering, will destroy these properties. However, rapid heating will narrow the affected area.
- c. To soften the material so that machining, forming, etc., can be performed.

### **2-29. NORMALIZING.**

Although involving a slightly different heat treatment, normalizing may be classed as a form of annealing. This process also removes stresses due to machining, forging, bending, and welding. Normalizing may be accomplished in furnaces used for annealing. The articles are put in the furnace and heated to a point approximately 150° to 225°F above the critical temperature of the steel. After the parts have been held at this temperature for a sufficient time for the parts to be heated uniformly throughout, they must be removed from the furnace and cooled in still air. Prolonged soaking of the metal at high temperatures must be avoided, as this practice will cause the grain structure to enlarge. The length of time required for the soaking temperature will depend upon the mass of metal being treated. The optimum soaking time is roughly one-quarter hour per inch of diameter or thickness.

### **2-30. CASE HARDENING.**

In many instances it is desirable to produce a hard, wear-resistant surface or "case" over a strong, tough core. Treatment of this kind is known as "case hardening". This treatment may be accomplished in several ways, the principal ways being carburizing, cyaniding, and nitriding.

**2-31.** Flame Hardening/Softening. Surface hardening/softening by applying intense heat (such as that produced by an Oxy-Acetylene flame) can be accomplished on almost any of the medium carbon or alloys steel, i.e. 1040, 1045, 1137, 1140 etc. The parts are surface hardened, by applying a reducing flame (An Oxidizing flame should never be used) at such a rate, that the surface is rapidly heated to the proper quenching temperature for the steel being treated. Following the application of the heat, the part is quenched by a spraying of water/oil rapidly. The fast quench hardens the steel to the depth that the hardening temperature has penetrated below the surface. The actual hardness resulting will depend on the rate of cooling from the quenching temperature. In hardening by this method the shape and size/mass of the part must be considered. Most operations will require special adapted spray nozzles to apply the quenching media, which is usually water. Normally, flame hardening will produce surface hardness higher than can be obtained by routine furnace heating and quenching, because surface can be cooled at a faster rate.. If a combination of high strength core and surface is required some of the medium carbon alloy steels can be heat treated and subsequently surface hardened by the flame method.

#### **NOTE**

**This method is not adapted for surface hardening of parts for use in critical applications.**

**2-32.** Surface softening is accomplished by heating the surface to just below the temperature required for hardening and allowing the material to cool (in air) naturally. This method is sometimes used to soften material that has been hardened by flame cutting. Often it is necessary to apply the heat in short intervals to prevent exceeding the hardening temperature.



**2-33.** Induction Hardening/Heating. The induction method of heating can be used to surface harden steels, in a manner similar to that used for flame hardening. The exception is that the heat for hardening is produced by placing the part in a magnetic field (electrical) specifically designed for the purpose. Parts hardened (surface) by this method will be limited to capability and size of loop/coil used to produce the magnetic field.

**2-34.** In some instances the induction method can be used to deep harden; the extent will depend on exposure/dwell time, intensity of the magnetic field, and the size of the part to be treated.

**2-35. CARBURIZING.** At elevated temperatures iron can react with gaseous carbon compounds to form iron carbide. By heating steel, while in contact with a carbonaceous substance, carbonic gases given off by this material will penetrate the steel to an amount proportional to the time and temperature. For example, if mild or soft steel is heated to 732°C (1,350° F) in an atmosphere of carbonic gases, it will absorb carbon from the gas until a carbon content of approximately 0.80 percent has been attained at the surface, this being the saturation point of the steel for the particular temperature. By increasing the heat to 899° C (1,650° F), the same steel will absorb carbon from the gas until a carbon content of approximately 1.1 percent has been attained, which is the saturation point for the increased temperature.

**2-36.** The carburizing process may be applied to both plain carbon and alloy steels provided they are within the low carbon range. Specifically, the carburizing steels are those containing not more than 0.20 percent carbon. The lower the carbon content in the steel, the more readily it will absorb carbon during the carburizing process.

**2-37.** The amount of carbon absorbed and the thickness of the case obtained increases with time; however; the carburization progresses more slowly as the carbon content increases during the process. The length of time required to produce the desired degree of carburization material used and the temperature to which the metal is subjected. It is apparent that, in carburizing, carbon travels slowly from the outside toward the inside center, and therefore, the proportion of carbon absorbed must decrease from the outside to the inside.

**2-38.** Solid, liquid, and gas carburizing methods are employed:

a. The simplest method of carburizing consists of soaking the parts at an elevated temperature while in contact with solid carbonaceous material such as wood charcoal, bone charcoal and charred leather.

b. Liquid carburizing consists of immersing the parts in a liquid salt bath, heated to the proper temperature. The carbon penetrates the steel as in the solid method producing the desired case.

c. Gas carburizing consists of heating the parts in a retort and subjecting them to a carbonaceous gas such as carbon monoxide or the common fuel gases. This process is particularly adaptable to certain engine parts.

**2-39.** When pack carburizing, the parts are packed with the carburizing material in a sealed steel container to prevent the solid carburizing compound from burning and to retain the carbon monoxide and dioxide gases. Nichrome boxes, capped pipes of mild steel, or welded mild steel boxes may be used. Nichrome boxes are most economical for production because they withstand oxidation. Capped pipes of mild steel or welded mild steel boxes are useful only as substitutes. The container should be so placed as to allow the heat to circulate entirely around it. The furnace must be brought to the carburizing temperature as quickly as possible and held at this heat from 1 to 16 hours, depending upon the depth of case desired and the size of the work. After carburizing, the container should be removed and allowed to cool in air or the parts removed from the carburizing compound and quenched in oil or water. The air cooling, although slow, reduces warpage and is advisable in many cases.

**2-40.** Carburized steel parts are rarely used without subsequent heat treatment, which consists of several steps to obtain optimum hardness in the case, and optimum strength and ductility in the core. Grain size of the core and case is refined.

a. Refining the core is accomplished by reheating the parts to a point just above the critical temperature of the steel. After soaking for a sufficient time to insure uniform heating, the parts are quenched in oil.

b. The hardening temperature for the high carbon case is well below that of the core. It is, therefore, necessary to heat the parts again to the critical temperature of the case and quench them in oil to produce the required hardness. A soaking period of 10 minutes is generally sufficient.

c. A final stress relieving operation is necessary to minimize the hardening stresses produced by the previous treatment. The stress relieving temperature is generally around 350° F. This is accomplished by heating, soaking until uniformly heated, and cooling in still air. When extreme hardness is desired, the temperature should be carefully held to the lower limit of the range.

**2-41. CYANIDING.** Steel parts may be surface-hardened by heating while in contact with a cyanid salt, followed by quenching. Only a thin case is obtained by this method and it is, therefore, seldom used in connection with aircraft construction or repair. Cyaniding is, however, a rapid and economical method of case hardening, and may be used in some instances for relatively unimportant parts. The work to be hardened is immersed in a bath of molten sodium or potassium cyanide from 30 to 60 minutes. The cyanide bath should be mainlined at temperature to 760° C to 899° C (1,400° F to 1,650° F). Immediately after removal from the bath, the parts are quenched in water. The case obtained in this manner is due principally to the formation of carbides and nitrides on the surface of the steel. The use of a closed pot and ventilating hood are required for cyaniding, as cyanide vapors are extremely poisonous.

**2-42. NITRIDING.** This method of case hardening is advantageous due to the fact that a harder case is obtained than by carburizing. Many engine parts such as cylinder barrels and gears may be treated in this way. Nitriding is generally applied to certain special steel alloys, one of the essential constituents of which is aluminum. The process involves the exposing of the parts to ammonia gas or other nitrogenous materials for 20 to 100 hours at 950°F. The container in which the work and Ammonia gas are brought in contact must be airtight and capable of maintaining good circulation and even temperature throughout. The depth of case obtained by nitriding is about 0.015 inch if heated for 50 hours. The nitriding process does not affect the physical state of the core if the preceding tempering temperature was 950° F or over.

When a part is to be only partially treated, tinning of any surface will prevent it from being nitrides. Nitrided surfaces can be reheated to 950° F with out losing any of their hardness. However, if heated above that temperature, the hardness is rapidly lost and cannot be regained by retreatment. Prior to any nitriding treatment, all decarburized metal must be removed to prevent flaking of the nitrided case. When no distortion is permissible in the nitrided part, it is necessary to normalize the steel prior to nitriding to remove all strains resulting from the forging, quenching, or machining.

#### **2-43. HEAT TREATING EQUIPMENT.**

Equipment necessary for heat treating consists of a suitable means for bringing the metal to the required temperature measuring and controlling device, and quenching medium. Heat may, in some instances, be supplied by means of a forge or welding torch; however, for the treatment required in aircraft work, a furnace is necessary. Various jigs and fixtures are sometimes needed for controlling quenching and preventing warping.

**2-44. FURNACES.** Heat treating furnaces are of many designs and no one size or type perfectly fills every heat treating requirement. The size and quantity of metal to be treated and the various treatments required determine the size and type of furnace most suitable for each individual case. The furnace should be of a suitable type and design for the purpose intended and should be capable of maintaining within the working zone a temperature varying not more than + or 14° C ( 25°F) for the desired value.

**2-45. HEAT TREATING FURNACES/BATHS.**

**2-46.** The acceptable heating media for heat treating of steels are air, combusted gases, protective atmosphere, inert atmosphere or vacuum furnaces, molten-fused salt baths, and molten-lead baths. The heat treating furnaces/baths are of many designs and no one size or type will perfectly fill every heat treating requirement. Furnaces and baths shall be of suitable design, type and construction for purpose intended. Protective and inert atmospheres shall be utilized and circulated as necessary to protect all surfaces of parts comprising the furnace load.

**2-47.** The design and construction of the heating equipment shall be such that the furnace/bath is capable of maintaining within the working zone, at any point, temperature varying not more than  $\pm 25^{\circ}$  F ( $\pm 14^{\circ}$  C) from the required heat treating temperature, with any charge. After the charge has been brought up to treating/soaking temperature all areas of the working zone shall be within the permissible temperature range specified for the steel/alloy being heat treated (See Table 2-3, MIL-H-6875 or engineering data for material involved).

**NOTE**

**Specification MIL-H-6875, Heat Treatment of Steel, will be the control document for heat treating steel material to be used on aerospace equipment. Where new alloys are involved, it will be necessary to review the involved specification or manufacturer's engineering or design data for the appropriate heat information (temperature, control, atmosphere, times, etc). In case of conflict the Military/Federal Specification will be governing factor or the conflict will be negotiated with the responsible technical/engineering activities for resolution.**

**2-48. HEAT CONTROL, FURNACE TEMPERATURES SURVEY AND TEMPERATURE MEASURING EQUIPMENT.**

**2-49.** Furnaces/baths shall be equipped with suitable automatic temperature control devices, properly calibrated and arranged, preferably of the potentiometer type to assure adequate control of temperature in all heat-treating zones. The resulting temperature readings shall be within  $\pm 1.0$  percent of the temperature indications of the calibrating equipment. Thermocouples shall be properly located in the working zones and adequately protected from contamination by furnace atmospheres by means of suitable protecting tubes.

**2-50.** A survey shall be made before placing any new furnace in operation, after any change is made that may affect operational characteristics, and semi-annually thereafter to assure conformance with temperature and control requirement previously cited. Where furnaces are used only for annealing or stress relieving, an annual survey will be acceptable. The survey may be waived at the discretion of the authorized inspector or representative provided that the results from previous tests, with the same furnace or bath and same type of load, show that the temperature and control uniformity is within specified limits. As a part of the inspection thermocouples should be closely inspected for condition and those severely deteriorated and of doubtful condition should be replaced.

**2-51.** The initial and succeeding (semi-annual and annual) surveys shall be performed with a standard production type atmosphere, controlled if required. A minimum of 9 test thermocouples or 1 per 15 cubic feet, whichever is greater, shall be used for air furnaces except circulating air furnaces used for tempering only. In the tempering furnaces, a minimum of 9 test thermocouples or 1 per 25 cubic feet, whichever is greater, shall be used. Bath furnaces shall be tested by use of a minimum of 5 test locations or 1 per each 15 cubic feet. The locations may be surveyed, using suitable protected multiple or single brake test thermocouples. For distribution of test thermocouples, see Figure 2. Temperature measuring and recording instruments used for controlling the furnace shall not be used to read the temperature of the test temperature sensing elements.

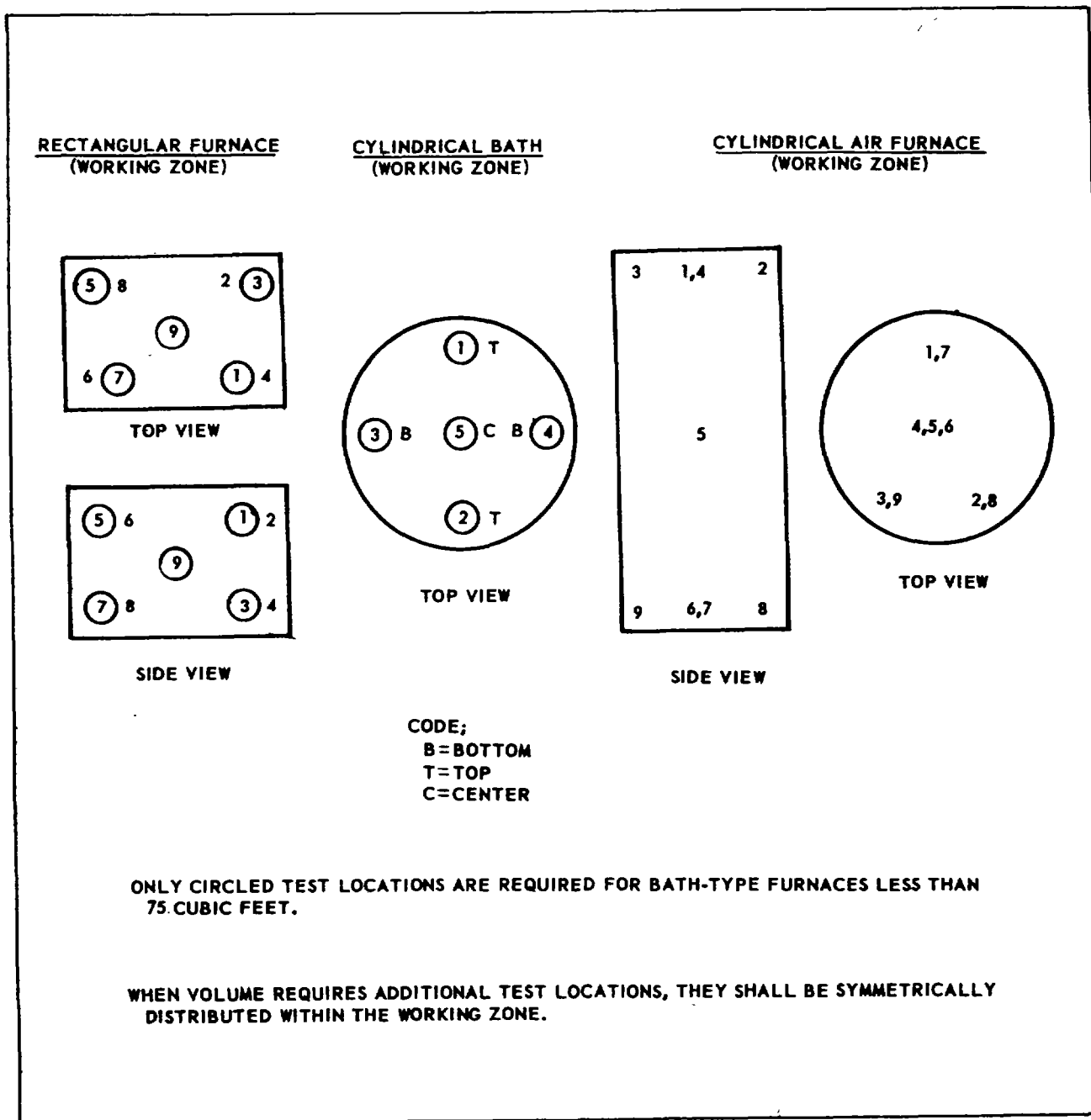


FIGURE 2-1. NUMBER AND DISTRIBUTION OF THERMOCOUPLES.

**2-52.** For all surveys, the furnace or bath temperature shall be allowed to stabilize at the potential test temperature. The initial survey shall be made at the highest and lowest temperatures of the furnace specified operating range. Periodic surveys may be made at a convenient temperature within the operating range. The temperature of all test locations/thermocouples shall be recorded at 5 minute intervals, starting immediately after insertion of the test thermocouples in the furnace or bath. Reading shall be continued for 1/2-hour or more after furnace control thermocouple reads within 25° F of original setting. After all the test thermocouples have reached the minimum of the heat treating range, their maximum variation shall not exceed  $\pm 25^{\circ}$  F ( $14^{\circ}$  C) and shall be within the specified heat treating temperature range in accordance with Specification MILH-6875 or Table 2-3. If the test indicates that conditions are not satisfactory, the required changes shall be made in the furnace and arrangements of the charge. The furnace control couples shall be corrected for any deviation from the standard electromotive force (EMF) temperature chart as determined in calibration of the couples.

#### **2-53. FURNACE CONTROL INSTRUMENTS ACCURACY.**

**2-54.** The accuracy of temperature measuring, recording and controlling instruments shall be checked at regular intervals, not exceeding 3 months or upon request of personnel in charge or authorized (Government) inspector or representatives. The accuracy of the instrument shall be made by comparison tests with a standardized precision potentiometer type instrument of known (tested) accuracy used with a calibrated thermocouple. The test thermocouple shall be located approximately 3 inches from the installed furnace thermocouple(s). The temperature for check shall be at working temperature with a production load. If instruments are replaced or not used for 3 months they shall be checked before use.

#### **2-55. SALT BATH CONTROL.**

**2-56.** The bath composition shall be adjusted as frequently as necessary to prevent objectionable attachment of the steel or alloy to be treated and to permit attainment of the desired mechanical properties of the finished product. The bath will be checked at least once a month.

**2-57.** Temperature recording should be of the automatic controlling and recording type, preferably the potentiometer type. Thermocouples should be placed in a suitable protecting tube, unless the furnace atmosphere is such that undue deterioration of the thermocouples will not result.

**2-58. QUENCHING TANKS AND LIQUIDS.** Suitable tanks must be provided for quenching baths. The size of tanks should be sufficiently large to allow the liquids to remain approximately at room temperature. Circulating pumps and coolers may be used for maintaining approximately constant temperatures where a large amount of quenching is done. The location of these tanks is very important due to the fact that insufficiently rapid transfer from the furnace to the quenching medium may destroy the effects of the heat treatment in many instances.

**2-59.** The quenching liquids commonly used are as follows: Water at 18°C (65°F), Commercial Quenching Oil, and Fish Oil.

#### **2-60. HEAT TREATING PROCEDURES.**

**2-61. INITIAL FURNACE TEMPERATURES.** In normalizing, annealing and hardening where parts are not preheated, the temperature in that zone of the furnace where works is introduced should be at least 149°C (300°F) below the working temperature at the time of insertion of parts of simple design. For parts of complicated design involving abrupt change of section or sharp corners, the temperature should be at least 260°C (500°F) below the working temperature. The furnace must be brought to the proper temperature gradually.

**2-62. SOAKING PERIODS.** The period of soaking is governed by both the size of the section and the nature of the steel. Table 2-1 indicates in a general way the effect of size on the time for soaking. This table is intended to be used as a guide only and should not be construed as being a mandatory requirement. It applies only to plain carbon and low alloy steels.

**TABLE 2-1. SOAKING PERIODS FOR HARDENING NORMALIZING AND ANNEALING  
(PLAIN CARBON STEEL)**

DIAMETER OR THICKNESS INCHES	TIME OF HEATING TO REQUIRED TEMPERATURE HOLDING (APPROX) HOURS	TIME OF (APPROX) HOURS
1 and less	3/4	1/2
Over 1 thru 2	1 1/4	1/2
Over 2 thru 3	1 3/4	3/4
Over 3 thru 4	2 1/4	1
Over 4 thru 5	2 3/4	1
Over 5 thru 8	3 1/2	1 1/2

**2-63. HARDENING.** Temperatures required for hardening steel are governed by the chemical composition of the steel, previous treatment, handling equipment, size and shape of piece to be treated. Generally, parts of heavy cross section should be hardened from the high side of the given temperature range.

**2-64. TEMPERING (DRAWING.)** Tempering consists of heating the hardened steel to the applicable temperature holding at this temperature for approximately 1 hour per inch of the thickness of the largest section, and cooling in Air or quenching in oil at approximately 27° to 66° C (80° to 150°F). The temperature to be used for tempering of steel depends upon the exact chemical composition, hardness, and grain structure obtained by hardening and the method of tempering. The tempering temperatures given are only approximate, and the exact temperature should be determined by hardness or tension test for individual pieces. The final tempering temperatures should not be more than 111° C (200° F) below the tempering, temperature given. If the center of the section is more than 1/2-inch from the surface, the tensile strength at the center will in general be reduced; therefore, a lower tempering temperature should be used for sections thicker than 1 inch in order to obtain the required tensile strength.

**2-65. ANNEALING.** Annealing consists of heating to the applicable temperature, holding at this temperature for approximately the period of time given, and cooling in the furnace to a temperature not higher than 482C (900° F). The steel may then be removed from the furnace and cooled in still air.

**2-66. NORMALIZING.** Normalizing consists of heating the steel to the applicable temperature, holding at this temperature for period of time, removing from furnace and cooling in still air.

**2-67. CARBURIZING.** Carburizing consists of heating the steel packed in a carburizing medium, in a closed container, to the applicable temperature and holding at this temperature for the necessary period of time to obtain the desired depth of case. 1020 steel will require 1 to 3 hours so a carburizing temperature of 899-C (1650F) for each 1/64 inch of case depth, required. Parts may be cooled in the box or furnace to a temperature of approximately 482 C (900° F) then air cool. This treatment leaves the alloy in a relatively soft condition and it is then necessary to condition by heating and quenching, first for core refinement, followed by heating and quenching for case hardness. Alloy may be quenched directly from the carburizing furnace, thus producing a hard case and a core hardness of Rockwell B67. This treatment produces a coarse grain in some types of steel and may cause excessive distortion. Usually there is less distortion in fine grain steels. The core treatment outlined above refines the grain as well as hardens.

**2-68. HARDNESS TESTING.**

**2-69. GENERAL.** Hardness testing is an important factor in the determination of the results of the heat treatment as well as the condition of the metal before heat treatment and must, therefore, be carefully considered in connection with this work. The methods of hardness testing in general use are: the Brinell, Rockwell, Vickers, and Shore Scleroscope. Each of these methods is discussed in section VIII.

**2-70. TENSILE STRENGTH.** Tempering temperatures listed with the individual steels in Table 2-3 are offered as a guide for obtaining desired tensile and yield strength of the entire cross section. When the physical properties are specified in terms of tensile strength, but tension tests are impractical, hardness tests may be employed using the equivalent hardness values specified in Table 8-3.

**2-71. HARDNESS-TENSILE STRENGTH RELATIONSHIP.** The approximate relationship between the tensile strength and hardness is indicated in Table 8-3. This table is to be used as a guide. It applied only to the plain carbon and low alloy steels not to corrosion-resistant, magnet, valve, or tool steels. When a narrow range of hardness is required, the tests to determine the relationship between hardness and strength should be made on the actual part. Hardness values should be within a range of two points Rockwell or 20 points Brinell or Vickers. The tensile strength hardness relationship is quite uniform for parts which are sufficiently large and rigid to permit obtaining a full depression on a flat surface without deflection of the piece. For cylindrical parts of less than 1 inch in diameter, the Rockwell reading will be lower than indicated in the table for the corresponding tensile strength. Any process which affects the surface, such as buffing and plating, or the presence of decarburized or porous areas and hard spots, will affect the corresponding relation between hardness and tensile strength. Therefore, these surfaces must be adequately removed by grinding before measurements are made.

**2-72.** In making hardness measurements on tubular sections, correction factors must be determined and applied to the observed readings in order to compensate for the roundness and deflection of the tubing under the pressure of the penetrator. This may be impractical because every tube size and wall thickness would have a different factor. As an alternate, the following procedure may be used: Short lengths may be cut from the tube. A mandrel long enough to extend out both ends of the tube and slightly smaller in diameter than the inner diameter of the tube is then passed through the section and the ends supported in "V" supports on the hardness tester. Hardness readings may then be taken on the tubing.

**2-73. SPECIFICATION CROSS REFERENCE.**

Table 2-2 is a cross reference index listing the steel and alloy types and the corresponding Federal, Military, and aeronautical material specifications for the different configurations. Where two or more specifications cover the same material, stock material meeting the requirements of a military specification shall be used for all aeronautical structural items. Some of the specifications listed in Table 2-2 are for reference only, and are not approved for Air Force use.



TABLE 2-2 - SPECIFICATION CROSS REFERENCE

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
1005	Rod, welding steel & cast iron, rod & wire, steel welding (A/C appl)	5030		MIL-R-908, C1 1
1008	Steel, sheet & strip, flat, aluminum coated low carbon,			MIL-S-4174 MIL-S-4174
1010	Bars, Billets, Blooms, Slabs			MIL-S- 16974
	Bars (Gen Purpose) Wire		QQ-S-633 QQ-W-461	MIL-S-11310
	Sheet & Strip Sheet & Strip	5047 5040	QQ-S-698	
	Sheet & Strip	5042	QQ-S-698	
	Sheet & Strip	5044	QQ-S-698	
	Tubing, Seamless Tubing, Welded Rivets	5050 5053 7225		
	Wire (Carbon)		QQ-W-409	
	Strip (For Small Arms, Bullets)			MIL-S-13468
	Blooms, billets, Slabs Steel Disks (For Deep Drawn Ammunition items)			MIL-S-16788 C11 MIL-S-13852
	Tubes, Seamless (Marine Boiler application)			MIL-T-16286 C1 A
	Electrodes, Welding			MIL-E-6843 C1 E 6013
	Electrodes, Welding	5031		MIL-E-6843 C1 E 6013
	Electrode, Welding			MIL-E-18193 ty 60
	Rod & Wire (Welding Low Carbon Steel)			MIL-R-5632 C 11
1015, 1016, 1017, 1018 & 1019	Bar (General Purpose) Bar and Billets	5060	QQ-S-633 (Comp C1015-C1019)	
	Tube, Seamless/ Welded		WW-T-?31 comp A	



TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Sheet & Strip Tubing (Seamless and Welded)		QQ-T-830	
1022	Bars & Forgings Plates (Up to 1")  Wire (Carbon) Steel Disk (For deep drawn ammunition items)  Bars, Billets, Blooms, Slabs  Sheet & Strip  Tubing  Tubing, Mechanical	5070	QQ-S-633 QQ-S-691, C1 A  QQ-W-409   QQ-S-640  QQ-S-643  QQ-T-830	MIL-S-11310    MIL-S-13852  MIL-S-16974
1025	Fittings  Bars  Tubing  Tubing Castings  Castings  Bars  Tubing, Seamless  Tubing, Welded  Wire  Casting  Steel Disks  Sheet & Strip  Tubing  Plate	       5075  5077	  QQ-8-633    QQ-S-681, C1 1  QQ-S-681, C1 2    QQ-W-409    QQ-S-643	MIL-F-20236 ty 1   MIL-T-3520  MIL-T-5060   WIL-S-11310  MIL-T-5066  MIL-T-5066   MIL-S-15083 C1 B  MIL-S-13852  MIL-S-7952  MIL-P-20167 C1 C
Corten	Plate, Sheet & Strip (High Str)			MIL-S-7809



TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
1045	Tubes (Welded) Bars Wire (Carbon) Ingots Plate Sheets, Strip, Tubes, Seamless Strip Strip (For ammunition cartridge clips)		QQ-S-633 QQ-W-461 QQ-S-635 QQ-S-640	MIL-T-4377  MIL-S-20145 Gr P  MIL-S-303 MIL-S-3039
1050	Bars (Shatting) Plate (Carbon) Blooms, Billets, & Slabs (For Forgings) Bars, Billets, Blooms, Slabs, Castings Tubing, Seamless/ Welded	5085	QQ-S-633 QQ-S-635 QQ-S-681 QQ-T-880	MIL-S-20137  MIL-S-16788, C1 C5
1055	Ingots Forgings (For Shell Stock) Bars Electrodes		QQ-S-633	MIL-S-20145 Gr R MIL-S-10520  MIL-E-18193 (Ty 201)
1060	Bar Bars, & Wire Wire, Springs, Spring Blooms, Billets, Slabs Bars, Blooms, Billets, Slabs Forgings Sheet, Strip		QQ-S-633  QQ-W-428 Ty 1 & 2  QQ-S- 640	MIL-S-16410 comp 3  MIL-S-2839  MIL-S-16788, C1 C6 MIL-S-16974  MIL-S-10520 comp 3

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
1070-1075	Sheet, Strip Wire, Spring  Steel Tool  Washers  Wire Bars  Steel, Strip (Spring-Time Fuse)  Strip, Spring	MIL-S-8143 5115          5120 (1074)	  QQ-T-580  FF-W-84 C1 A  QQ-S-633	    MIL-S-12504  MIL-S-11713 comp 2
1080, 1086, 1090	Bars  Steel, Tool  Blooms, Billets, Slabs (For Forgings)  Wire, Drawn Metal (Stitching, (Galvanized)  Blooms, Billets, Bars Slabs  Wire, Comm Quality  Wire, Carbon Spring, Music	         5110  5112	QQ-S-633  QQ-T-580 C1 - W1-09       QQ-W-470	    MIL-S-16788 C1 C8  MIL-W-6714  MIL-S-16974
1095	Bars Bars, Wire  Wire, Spring  Sheet, Strip  Wire (High Carbon)  Sheet, Strip Strip  Sheet, Strip Strip  Springs  Wire, Spring (For small arms application)	5132         5121  5122  7340	QQ-S-633   QQ-W-428   QQ-W-470	MIL-S-8559 MIL-S-16410 comp1    MIL-S-11713 comp3   MIL-S-7947 cond A  MIL-S-7947 cond H  MIL-W-13604
1095	Blooms, Billets, Slabs			MIL-S- 16788

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Steel Bars, Round, Square & Flat for Forgings  Strip  Bars, Blooms, Billet & Slabs			MIL-S-46033  MIL-S-17919  MIL-S-16974
1112	Steel, Carbon, Bars Forging & Mech Tubing Bars	5010  5010	  QQ-S-633	
1117	Steel - Carbon, Bars, Forging & Mech Tubing  Bars comp A Bars Forgings	5022   5022	   QQ-S-633	MIL-S-16124, C1 1,   MIL-S-10520
1137	Steel - Carbon, Bars, Forging & Mech Tubing  Bars Bars Tubing, Seamless	5024  5024	  QQ-S-633  QQ-S-643	MIL-S-43 MIL-S-16124, C1 2
2317	Bars  Wire (Alloy)		QQ-S-624  QQ-W-405	
2330	Ingots  Bars Wire (Alloy)  Tubing		  QQ-S-624 QQ-W-405  QQ-S-629	MIL-S-20145
2340	Bars  Tubing  Wire (Alloy) Ingots		QQ-S-624  QQ-S-629  QQ-W-405	MIL-S-20145 Gr V



TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
2515	Bars Wire (Alloy)		QQ-S-624 QQ-W-405	
3115	Bars Wire (Alloy) Bars, Billets (For carburizing)		QQ-S-624 QQ-W-405	MIL-S-866
3140	Bars Wire (Alloy) Bars, Blooms, Billets		QQ-S-624 QQ-W-405	MIL-S-16974
3310	Bars Wire		QQ-S-624 QQ-S-405	MIL-S-7397 comp 1
3316	Bars			MIL-S-1393 comp 2
4037	Bars, Wire Bar Wire	6300	QQ-S-624 QQ-W-405	
4050	Steel, Tool		QQ-T-570 C1 1	
4130	Bars, Rods, Forgings (A/C Quality) Plate, Sheet Strip (A/C Quality) Bars, Blooms, Billets & Slabs Tubing, Seamless 6361 6362 Tubing, Welded Tubing, Mech Plate (Commercial Quality) Sheet, Strips Wire (Alloy)	6370 6350 6351 6360 6371	QQ-S-624 QQ-S-626 QQ-S-627 QQ-W-405	MIL-S-6758 MIL-S-18729 MIL-S-16974 MIL-T-6736 MIL-S-6731

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
4135	Bars		QQ-S-624	
	Plate, Sheet, Strip			MIL-S-18733
	Tubing, Seamless	6365		MIL-T-6735 cond N
	Tubing, Seamless			MIL-T-6735
	Bars, Blooms			MIL-S-16974
	Tubing, Seamless	6372		
	Tubing			
17-22-A(V)	Bar, Forging, Forging Stock	6303		
4137C0 - Alternate designation: Unimuch UCX2, MX - 2, Rocoloy. Mellon XMDR-2, Sheet, Steel.				Specification:
4140	Bars, Rods, Forgings, Plates (Commercial Grade)	6882	QQ-S-624 QQ-S-626	MIL-S-5626
	Tubing	6381		
	Bar, Blooms, Billets			MIL-S-16974
	Wire (Alloy)		QQ-W-405	
4150	Bar		QQ-S-624	
	Bar (For Small arms Weapons Barrels)			MIL-S-11595 MR
	Bar (Special Bar for AF Bullet Cores and Shot)			MIL-S-12504 MR
<del>52100</del>	<del>Bars, Forgings</del>	<del>6440</del>		<del>MIL-S-7420</del>
	Tubing, Mechanical	6441		
Ladish D-6-A - Alternate designation, D-6-A-V - and D-6-A-C.				
Nitalloy 135 Bar, Forging, Forging Stock (Nitriding) Alternate designations, Nitalloy Type G, Modified and ASTM-A355-57T C1 A		6470 Bar & Forgings		MIL-S-6709, comp A
Nitalloy 4330 Bars & Forgings Stock (Mod)				MIL-E-8699

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
Nitalloy 4337	Bars, Forging	6412-6475	QQ-S-624	MIL-S-20145 Gr U
	Tubing, Seamless	6413	QQ-W-405	
	Wire (Alloy)			
	Ingot			
4340	Plate, Sheet & Strip	6359	QQ-S-624	MIL-S-5000
	Bar, Forging and Tubing	6414		
	Bar, Forging and Tubing	6415		MIL-S-8844 C1 1
	Bar, Reforging Bar			
	Bar, Forging and Tubing	6428		MIL-E-21515
	Strip and Sheet			
	Bar, Rod, Plate & Sheet			
	Wire (Alloy)			
Bars, Blooms, Billets		QQ-W-405	MIL-S-16974	
4335 (Mod)	Bars, Plates, Sheets & Strips			MIL-S-21515
HyTuf	Bar, Forging & Mech Tubing	6418		MIL-S-7108
4615	Bars		QQ-S-624	MIL-S-866
	Wire		QQ-W-405	
	Bars, Billets			
4617	Bars			MIL-S-7493
4620	Bars		QQ-S-624	MIL-S-7493
	Wire		QQ-W-405	

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
4640	Bars, Blooms, Billets Bars Bars and Forgings Bars Wire (Alloy)	6312 6317	QQ-S-624 QQ-S-624C QQ-W-405	MIL-S-16974
6150	Sheet, Strip Bars Bar Bars, Forging Wire Wire, Spring comp D Bars, Wire (Spring) Ingots Sheet, Strip (Springs) Springs (Highly Stressed) Sheet, Strip Wire	6448 6450 6455 7301	QQ-S-624 QQ-W-428 QQ-S-627	MIL-S-18731 MIL-S-8503 MIL-S-46033 MIL-S-8503 MIL-S-16410 comp 4 MIL-S-20145 Gr Z MIL-S-18731 MIL-W-22826
8615	Bars, Forgings, Tubing Wire (Alloy) Bars, Billets Bars, Blooms, Billets & Slabs Castings (8615 mod)	6270 5333	QQ-S-624(Bar) QQ-W-405 MIL-S-16974	MIL-S-8B6
8617	Bars, Forgings, Tubing Bars Bars Sheet and Strip Wire	6272	QQ-S-624 (Bar) QQ-S-624 QQ-S-627 QQ-W-405	

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
8620	Bars Bars, Forgings, Tubing Plates (Commercial Grade) Sheet and Strip Wire Bars, Blooms, Billets	6274	QQ-S-624  QQ-S-626 QQ-S-627 QQ-W-405	MIL-S-8690    MIL-S-16974
8630	Plate, Sheet, Strip (A/C Quality) Tubing Bars Bars, Forgings Tubing Tubing, Seamless Tubing, Welded Sheet, Strip Bars, Blooms, Billets Slabs Plate (Commercial Grade) Wire (Alloy) Sheet, Strip (Hot Rolled) Bars, Rods, Forgings	6280 6261 6530 6550 6355	QQ-S-624      QQ-S-626	MIL-8-18728  MIL-T-6732  MIL-S-6050  MIL-T-6732 cond N MIL-T-6734 cond N  MIL-S-16974  MIL-S-6050
8640	Bars Bars, Blooms, Billets Slabs Plate Tubing, Seamless Tubing Wire (Alloy)		QQ-S-624  QQ-S-626  QQ-W-405	MIL-S-16974   MIL-T-16690
8735	Tubing, Seamless Tubing, (Mechanical)	6535 6282 <b>2-25</b>		MIL-T-6733 cond N MIL-S-6098

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Tubing, rods, bars and forging stock (A/C quality)			MIL-S-6098
	Sheet, Strip & Plate	6357		MIL-S-18733
	Bars, Forgings	6320		MIL-S-6098
	Bars, Rods, Forgings			MIL-S-6098
8740	Bars, Forgings	6322		MIL-S-6049 cond C
	Bars		QQ-S-624	
	Bars, Forgings	6325 6327		MIL-S-6049
	Plate, Sheet & Strip	6358		
	Tubing, Mech	6323		
	Plate (Commercial)		QQ-S-626	
	Wire (Alloy)		QQ-W-405	
	Bars, Rods, Forgings			MIL-S-6049
9250	Bars, and Reforging Stock			MIL-S-8844 C1 2/3
9620	Bars		QQ-S-624	
	Bar			MIL-S-46033
	Wire, Spring		QQ-W-474, comp E	
	Bars, Wire (Spring)			MIL-S-16410, comp 5
	Steel, Strip			MIL-S-17919, C1 6
9262	Wire, Spring		QQ-W-428	
	Bar			MIL-S-46033
	Bars		QQ-S-624	
	Sheet and Strip		QQS-627	
9310	Bars, Forgings, Tubings	6260	QQ-S-624 (Bar)	
	Bar, Forgings & Tubing	6265		
	Wire (Alloy)		QQ-W-405	

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
9315	Bars	6263		
Type 301 (30301)	Casting Prec Invest (S+)	5358		
	Sheet, Strip, Plate (ST)	5515		MIL-S-5059
	Sheet, Strip, Plate (1/4 H)	5517		MIL-S-5059
	Sheet, Strip, Plate (1/2 H)	5518		MIL-S-5059
	Sheet, Strip, Plate (Full H)	5519		MIL-S-5059
	Plate, Sheet, Strip Shape		QQ-S-766	
	Wire, (Spring Temper)	5688	QQ-W-423 comp 502	
302 (30302)	Bars (CD to 100000 tensile)	5636	QQ-S-763 CL 303	
	Bars (CD to 125000 tensile)	5637	QQ-S-763 C1 302	
	Bars, Forgings		QQ-S-763, C1 1	
	Sheet, Strip	5516		MIL-S-5059 comp 302
	Plate, Sheet, Strip			MIL-S-5059
	Pins, Cotter	7210	FF-P-386 Type C	
	Rivets (18CR 8N:)	7228		
	Steel, Stainless, Bar & Billets (Reforging Appli- cations)			MIL-S-862 C1 302
	Bars, Forgings			MIL-S-7720
(60302)	Steel, Castings	5358		
	Wire, Annealed		QQ-W-423	
	Castings			MIL-S-17509, C1 1
	Plate, Sheet, Strip		QQ-S-682	
	Plate, Sheet, Strip Wire		QQ-S-766	
	Lockwashers, Helical	7241	FF-W-84 C1 C	MIL-W-17481
		<b>2-27</b>		



TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
303	Bar, Forging	5640	QQ-8-763	
	Bar	5738		
	Bar, Billets, Re-forging			MIL-S-862
	Bars, Forgings			MIL-S-7720
	Bar, Forging (Swaging)	5641		
	Bar, Forging	5642		
304	Tubing	55668		MIL-T-6845
	Tubing	5567		MIL-T-8504
	Castings			MIL-S-867 C1 1
	Plate, Sheet, Strip			MIL-S-4043
	Plate			MIL-F-20138
	Plate, Sheet, Strip		QQ-8-766	
	Castings, Precision Invest	5370		
	Castings, Sand	5371		
	Wire	5697	QQ-W-423	
	Bars, Forgings, Mech Tubing	5647		
	Bar		QQ-S-763	
	Plate, Sheet, Strip	5511		MIL-S-4043
	Tubing, Bar, Forging	5639	QQ-S-7S	MIL-8-7720
	Wire	5697	QQ-W-423	
	Tubing			MIL-T-5695
	Bars, Forging		QQ-8763	
	Tubing, Seamless	5560		MIL-T-8506
Tubing, Welded	5565		MIL-S-8506	
314	Bar, Forging, Mech Tubing & Rings	5652		
	Sheet, Strip, Plate	5522		
316	Casting, Investment	5360		
		<b>2-28</b>		

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Casting, sand, Centrifugal	5361		MIL-S-867 (C1 III)
	Sheet, Strip, Plate	5524	QQ-S-766	MIL-S-5059 comp 316
	Tubing, Seamless	5573		
	Bar, Forging, Tubing	5648	QQ-S-763	MIL-S-7720 comp MCR
	Wire, Screen	5698		
	Wire		QQ-W-423	
	Electrode, Coated, Welded	5691		
	Bar, Forging (Free Machining)	5649		
	Wire		QQ-W-423	
	Pipe, Seamless & Welded			MIL-P-1144
	Bar, Billets, Reforgings			MIL-S-862
321	Bar, Forgings, Tubing Mech	5645	QQ-S-763 C1 321	
	Plate, Sheet, Strip	5510		MIL-S-6721, comp T1
	Plate, Sheet, Strip		QQ-S-766	
	Tubing, Seamless	5570		MIL-T-8606 T1, G321
	Tubing, Welded, Thin Wall			MIL-T-8887
	Tubing, Welded	5576		MIL-T-6737, T 321
	Tubing, Flexible			MIL-T-7880
	Wire, Screen	5689		
	Pins, Cotter	7211		
	Tubing, Hydraulic	5557		
	Tubing, Welded			MIL-T-6737
	Bar, Forgings		QQ-S-763	
	Tubing			MIL-T-8606
	Plate, Sheet, Strip		QQ-S-682	
		<b>2-29</b>		

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Tubing, Hydraulic			MIL-T-8808
	Tubing, Welded, Thin Wall		5559	
347	Tube		MIL-T-8606	
	Rivets	7229		
	Bars, Forgings, Tubing	5646	QQ-S-763 C1 347	
	Castings			MIL-S-867 C1 U
	Sheet, Strip	5512		MIL-S-6721 Type CB + TA) (CB)
	Casting, Sand	5363		
	Casting			MIL-S-17609 C1 II
	Tubing, Seamless	5571		MIL-T-8606, Type 1, G347
	Tubing, Seamless, Welded Drawn			MIL-T-8606
	Tubing, Welded	5575		MIL-T-6737, Type 347
	Tubing, Flexible			MIL-T-7880
	Wire, Welding	5680		MIL-R-5031, C1 5
	Wire, Welding, Electrode Coated	5681		MIL-E-22200, Type 347
	Tubing, Hydraulic	5556		
	Tubing, Welded	5558		
	Plate, Sheet, Strip		QQ-S-682	
	Tubing, Welded			MIL-T-6737
	Bars, Forgings		QQ-S-763	
	Plate, Sheet, Strip			MIL-S-6721
	Castings			MIL-S-17509, C1 2
	Rods, Welding			MIL-R-5031
	Plate, Sheet, Strip		QQ-S-766	
	Tubes, Seamless (Marine Boiler Application)			MIL-T-16286
	Tubes, Hydraulic			MIL-T-8808
		<b>2-30</b>		

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Electrode Coated, Welding			MIL-E-22200
	Casting, sand and Centrif	5362		
410 (51410)	Bars, Forgings, Mech Tubing	5613	QQ-S-763 C1 410	
	Bars, Forging, Mech Tubing (Ferrite Con- trolled Modified)	5612		
410-MO	Bars & Forgings	5614		
410-MOD	Bars & Forgings, Mech Tubing	5609		
410	Plate, Sheet and Strip	5504	QQ-S-766 C1 410	
410	Plate, Sheet & Strip (Ferrite Modified/ controlled)	5505		
410	Wire, Welding (Specialized Gr Modified)	5821		
410 (60410)	Casting Investment	5350		
410 (60410)	Casting, Sand	5351		MIL-S-16933 C1 I
	Wire		QQ-W-423 comp 410	
	Bars			MIL-S-861
	Bars, & Billets (For Reforging)			MIL-S-862
(51410)	Tubing, Seamless	5591		
	Tubing, Flexible			MIL-T-7880
414	Bars, Forgings	5615	QQ--S-763 C1 414	
	Bars			MIL-S-862
416 (51416F)	Bars	5610	QQ-S-763 C1 416 Se (Bar)	
	Bars & Forgings	5610		
	Bars & Billets (Reforging)			MIL-S-862 C1 6

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
420  (51420)	Bars & Billets (For Reforging)  Bars and Forgings (Free Mach)  Bars and Forgings  Bars  Plate, Sheet & Strip  Wire	  5620  5621  5621  5506	    QQ-S-763 C1 420  QQ-S-766 C1 420  QQ-W-423	MIL-S-862 C1 5
431	Bars & Billets (For Reforging)  Bars, Billets, Forgings, Tubing  Castings, Sand  Bars, Forgings	   5372  5682	    QQ-S-763, C1 431	MIL-S-862  MIL-S-18732
431 MOD	Castings, Precision Investment	5353		
440 C	Bars & Forgings	5630	QQ-S-763 C1 440C	
440 A	Bars & Forgings	5631	QQ-S-763, C1	440A
440F	Bars & Forgings	5632	QQ-S-763, C1 440F	
14-4PH	Castings, Investment	5340		
15-7 MO	Bar & Forging  Plate, Sheet and Strip	5657  5520		
17-4 PH	Bar  Castings - Investment (Heat Treated 130,000 PSI)  Castings - Investment (Heat Treated 150, 000 PSI)  Castings - Investment (Heat Treated)	5643  5342  5343  5344		

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Wire, Welding	5825		
	Electrode - Welding	5827		
	Castings - Investment	5355		
17-7 PH	Plate, Sheet & Strip	5528		MIL-S-25043
	Sheet and Strip (Pre-precipitation Hardening)	5530		
	Bar and Forgings	5644		
	Tubing, Welded	5568		
19-9DL	Casting Sand (Solution Treated)	5369		
	Plate, Sheet & Strip	5526		
	Plate, Sheet & Strip (125000TS, Hot rolled, Stress Relieved)	5527		
	Bars (UP to 1.5 inch)	5720		
	Bars (Up to 1 inch)	5721		
	Bars and Forgings	5722		
19-9DX	Bars, Forgings and Rings	5723		
	Bars (Up to 1 inch)	5724		
	Bars (Up to 1.5 inch)	5729		
	Plate, Sheet & Strip	5538		
	Plate, Sheet & Strip, (Hot rolled & Stress Relieved 125, 000TS)	5539		
	Bars, Forgings & Rings	5723		
	Bars, (Up to 1 inch)	5724		
	Bars (Up to 1.5 inch)	5729		
19-9W MO	Wire, Welding	5782	MIL-R-5031, C1 6	
	Electrode, Coated Welding	5783	MIL-E-22200	

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
19-9 MOD	Electrode, Welding, Covered (Armor applications)			MIL-E-13080
AM350	Bar	5745		MIL-S-840
	Sheet and Strip (Cold rolled)	5540		
	Sheet and Strip (High Temp Annealed)	5548		
	Bar and Forgings	5745		
	Tubing, Seamless	5554		
	Wire, Welding	5774		
	Electrode, Coated Wire	5775		
AM355	Bar	5743		MIL-S-8840
	Castings, Investment	5368		
	Sheet and Strip	5547		
	Plate (Solution Heat Treated)	5549		
	Plate (Equalized and Over-Tempered)	5594		
	Wire, Welding	5780		
	Electrode, Coated Welding	5781		
A286	Bars, Forgings, Mech Tubing	5734		
	Bars, Forgings, Mech Tubing & Rings	5735		
	Bars, Forgings, Mech Tubing & Rings (Sol Treated)	5736		
	Bars and Forgings & Mech Tubing (Annealed & Precip Treated)	5737		
	Wire, Welding	5804		
	Wire, Welding	5812		
	Rivets, Steel (Annealed 16500 F and partially precip treated)	7235		
		<b>2-34</b>		



TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
Rene 41	Bars and Forgings (Solution Treated)	5712		
	Bars and Forgings (Solution & Precip Treated)	5713		
	Plate Sheet and Strip (Solution Heat Treated)	5545		
	Wire, Welding	5800		
Greek Ascoloy	Castings, Investment	5354		
	Plate, Sheet and Strip	5508		
	Bars, Forgings, Mech Tubing & Rings	5616		
	Wire, Welding	5817		
Inconel 600	Wire, Annealed	5687	QQ-W-390	
	Plate, Sheet and Strip	5540		MIL-N-6840
	Bars, Forgings & Rings	5665		MIL-N-6710
	Tubing, Seamless	5580		MIL-T-7840
	Electrode, Coated, Welding	5684		MIL-E-22000
62 Inconel	Wire, Welding			MIL-R-5031
42 Inconel Alloy X750	Sheet & Strip	5542		MIL-N-7786
	Bars & Forgings	5667		
	Bars & Forgings	5668		MIL-N-8550 Cond F
Inconel X750	Wire, No 1 Temper	5698		JAN-W-562, C1 1
	Wire, Spring Temper	5699		JAN-W-562, C1 2
Inconel 69	Wire, Welding	5778		MIL-R-5031, C1 14
Hastelloy C	Castings, Prec Invest	5388		
	Casting, Sand	5389		
	Sheet	5530		MIL-N-18088
	Bar, Forgings	5750		

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Wire, Welding			MIL-R-5031, C1 11
Hastelloy W	Bars and Forgings	5755		MIL-R-5031, C1 12 MIL-E-22000
	wire	5786		
	Electrode, Coated Welding	5787		
Hastelloy X	Castings, Alloy Prec Invest	5390		
	Sheet	5536		
	Bar and Forgings	5754		
	Wire	5798		
	Electrode, Coated Welding	5799		
HNM	Bars. Billet, Forging, Wire			MIL-S-17759
WASP Alloy		NONE	NONE	NONE
	<u>MISC STANDARDS/SPECIFICATIONS - METAL PRODUCTS</u>			
	Steel: Chemical Composition and Hardenability		Fed Std 66	
	Metal Test Methods		Fed Std 151	
	Surface Passivation			
	Corrosion Resistant Steel Parts		QQP-35	MIL-STD-753
	X-Ray Standards for Welding			MIL-STD-775
	Electrode Qualification and Quality			
	Conformance Test Welds			
	Identification of Pipe, Hose and Tube Lines for Aircraft, Missile Space Vehicles and Associated Support Equipment and Facilities			MIL-STD-1247
	Preparation of Test Reports			MIL-STD-831
	Marking of Aircraft and Missile Propulsion System Parts, Fabricated From Critical High Temp Alloys			MIL-STD-841

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Procedures for Determining Particle Size, Distribution and Packed Density of Powdered Materials			MIL-STD-1233
	Alloy Designation System for Wrought Copper and Copper Alloys			MIL-STD-455
	Inspection Radiographic			MIL-STD-453
	X-Ray Standard for Bare Aluminum Alloy Electrode Welds			MIL-STD-437
	Mechanical Tests for Weld Joints			MIL-STD-418
	Qualification of Inspection Personal Magnetic Particle			MIL-STD-410
	Alloy, Nomenclature and Temper Designation for Magnesium Base Alloys			MIL-STD-409
	Color Identification Marking of Covered Arc Welding Electrodes			MIL-STD-123
	Tolerances for Copper and Copper Base Alloy Mill Products	FED-STD-146		
	Continuous Identification Marking of Iron and Steel	FED-STD-183		
	Identification Marking of Aluminum Magnesium and Titanium	FED-STD-184		
	Continuous Identification Marking of Copper and Copper Base Alloy Mill Products	FED-STD-185		
	Identification of Pressed Bonds, Forms, Seams and Joints Sheet Metal	FED-STD-187		
	Tolerance for Aluminum Alloy and Magnesium Alloy Wrought Products	FED-STD-245		
	Welding, Flash, Carbon and Alloy Steel			MIL-W-6873

TABLE 2-2 - SPECIFICATION CROSS REFERENCE (CONT'D)

COMP/ALLOY DESIGN	FORM/COMMODITY	AMS	FEDERAL	MILITARY
	Heat Treatment of Steels (Aircraft Practice) Process for			MIL-H-6875
	Welding, Metal Arc and Gas Steels and Corrosion and Heat Resistant Alloy, Process for			MIL-W-8611
	Steel Mill Products Preparation for Shipment and Storage			MIL-STD-163
	Tolerances for Steel and Iron Wrought Products		FED-StD-48	

## 2-74. GENERAL HEAT TREATING TEMPERATURES, COMPOSITION (CHEMICAL) AND CHARACTERISTICS OF VARIOUS STEEL AND STEEL ALLOYS

See supplement data for chemical symbols.

**1010.** Low Carbon steel of this grade is used for manufacture of such articles as safety wire, certain nuts, cable bushings and threaded rod ends, and other items where cold formability is the primary requisite. Heat treatment is frequently employed to improve machinability. Welding is easily accomplished by all common welding methods.

### COMPOSITION RANGE

C%	Mn%	P%	S%	Fe%
0.08 - 0.13	0.3 - 0.6	0 - 0.04	0 - 0.5	Balance

**FORMS.** See Specification Table 2-2.

### HEAT TREATMENT.

Normalize: 1650°-1750°F, cool in still air.  
 Anneal: 1650°F.  
 Harden: 1650°-1750°F, Quench in oil (minimum hardness) Water, and Brine (maximum hardness).

**1015** Low Carbon. This material is similar in content and characteristics to 1010. Of low tensile value, it should not be selected where strength is required.

### COMPOSITION RANGE

C%	Mn%	P%	S%	Fe%
0.13 - 18	0.3 - 0.6	0 - 0.04	0 - 0.05	Balance

**FORMS.** See Specification Table 2-2.

### HEAT TREATMENT

Normalize: 1650°-1750°F  
 Anneal: 1600°-1650°F  
 Harden: 1650°-1700°F  
 Quench with water, oil, brine.

**1020.** Low Carbon. Because of the carbon range this metal has increased strength and hardness but reduced cold formability compared with the lowest carbon group. It finds wide application where carburizing is required. It is suitable for welding and brazing.

### COMPOSITION RANGE

C%	Mn%	P%	S%	Fe%
0.23	0.3 - 0.6	0 - 0.04	0 - 0.05	Balance

**FORMS-SPECIFICATIONS.** See specifications Table 2-2.

### HEAT TREATMENT

Normalize: 1700°F, air cool.  
 Anneal: 1600°F, furnace cool.  
 Carburize: 1600°F, quench in water, oil, or brine.

### CARBO-NITRIDING

Temp	Time	Case Depth	Hardness	Cool	Draw
1560	2.5	0.019	62	OQ	350
1650	2.5	0.018	59	OQ	350

For 1560F, use 35NH<sub>3</sub>d 25CH<sub>4</sub> generator gas\*. For 1650 use 36NH<sub>3</sub> & 24CH<sub>4</sub>

\*Gas - American Gas Assoc Class 302.

**1022.** Low Carbon. This steel is similar in content and heat treatment requirements to 1020. Typical applications are case hardened roller chains, bearing races, cam shafts, etc.

### COMPOSITION RANGE.

C%	Mn%	Si%	P%	S%	Fe%
0.18 - 0.23	0.7 - 0.10	0 - 0.2	0 - .04	0 - .05	Balance

**FORM-SPECIFICATION.** See specification Table 2-2.

### HEAT TREATMENT

Normalize: 1700°F, air cool.  
 Anneal: 1600°F, furnace cool.  
 Carburize: 1550°F to 1650°F, water quench.  
 Tensile: 130,000 psi.  
 Yield: 78,000 psi.

**1025.** Low Carbon. Typical applications are bolts, machinery, electrical equipment, automotive parts, pipe flanges, etc. With this steel no martensite is formed and tempering is not required. This material is not generally considered a carburizing type; however, it is sometimes used in this manner for larger sections, or where greater case hardness is needed.

COMPOSITION RANGE.

C%	Mn%	P%	S%	Fe%
0.22 - 0.28	0.3 - 0.6	0 - 0.04	0 - 0.05	Balance

FORM-SPECIFICATION. See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1600°-1700°F, furnace cool.  
 Hardening: 1575°-1650°F, water quench.  
 Carburize: 1650°-1700°F, water or brine quench.  
 Tempering: 250°-400°F is optional.  
 Tensile strength: hot rolled 67000, cold rolled 80000.  
 Yield strength: hot rolled 45000, cold rolled 68000.  
 This steel is readily welded by common welding methods.  
 Temper: 1150°F for 70,000 psi.

CORTEN Low Carbon, Low Alloy. This steel is not heat treatable, but in the annealed or normalized condition it is stronger than plain carbon steel, is easily formed, welded and machined. In addition, this alloy is 4-6 times more resistant to atmospheric corrosion than plain carbon steel.

COMPOSITION RANGE

C%	Cr%	Cu%	Mn%	Ni%
0 - 0.12	0.30 - 1.25	0.25 - 0.055	0.2 - 0.5	0 - 0.65
Si%	P%	S%	Fe%	
0.25 - 0.75	0.07 - 0.15	0 - 0.05	Balance	

HEAT TREATMENT

Normalize: 1650°F, air cool.  
 Anneal: 1550°F, furnace cool.

Stress relief 1150°F, 1 hour per inch of maximum section thickness. This alloy cannot be hardened. Tensile strength, annealed or normalized 67,000 psi. Yield strength, annealed or normalized 47,000 psi. This alloy is readily welded by the usual gas and arc methods with complete freedom from air hardening. ASTM A233 or E60 electrodes are recommended for shielded arc welding. For gas welding, high strength welding rods such as ASTM A251, CA-25, are recommended. This steel may be resistance welded to itself or other resistance weldable ferrous alloys, using the same methods applied to plain carbon steel.

NAXAC9115 Low Carbon, Low Alloy. This material is usually in the stress relieved condition. Moderate strength is maintained with high toughness up to approximately 800°F. Weldability is excellent and it machines better than carbon steels of the same tensile strengths.

COMPOSITION RANGE

C%	Cr%	Cu%	Mn%
0.1 - 0.17	0.5 - 0.75	0 - 0.35	0.5 - 0.8
Mo%	Ni%	Si%	Zn%
0.15 - 0.25	0 - 0.25	0.6 - 0.9	0.05 - 0.15
P%	S%	Fe%	
0 - 0.04	0 - 0.04	Balance	

SPECIFICATIONS

AMS	FORM
6354	Sheet, strip, plate.
6440	Wire.

HEAT TREATMENT

Anneal: 1625°-1650°F, furnace cool.  
 Normalize: 1650°-1675°F, air cool.

Stress relief anneal 900°-1150°F, air cool, 30 minutes to 8 hours. Typical room temperatures: tensile 76500, yield 53,000. For arc welding, use low hydrogen electrodes E6015 (thin gauges) and E7015. For heliarc welding use drawn filler wire of MIL-R-5032. Perform spot welding by pulsation method for heavier gauges; use post heat cycle for lighter gauges.

1035 Medium Carbon. This steel is selected where higher mechanical properties are needed since it may be further hardened and strengthened by heat treatment or by cold work. Typical applications are gears, clutch pedals, flywheel rings, crank shafts, tools and springs.

COMPOSITION RANGE

C%	Mn%	P%	S%	Fe%
0.32 - 0.38	0.6 - 0.9	0 - 0.04	0 - 0.05	Balance

FORM-SPECIFICATION. See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1575°-1650°F, cool in still air.  
 Anneal: 1575°-1650°F, 1 hour per 1" of section, (Preheat) Temper at 900°F for 100,000 psi.  
 Spheroidize: 1250°-1375°F.  
 Harden: 1525°-1600°F, quench in water or oil. (Brine or caustic may also be used for quenching.)

Weldability is very good by all common welding methods. Cold formability is poor, but hot formability is excellent. Tensile strength, hot rolled 85,000 psi, cold rolled 92,000 psi, yield strength, hot rolled 54,000 psi, cold rolled 79,000 psi, Brinell 183-201, respectively.

1040 Medium Carbon is selected where intermediate mechanical properties are needed and may be further hardened and strengthened by heat treatment or cold work.

**COMPOSITION RANGE**

C%	Mn%	Si%	P%	S%	Fe%
0.37 - 0.44	0.8 - 0.9	0 - 0.2	0 - 0.04	0 - 0.05	Balance

**FORM-SPECIFICATION.** See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1575°-1650°F, air cool.  
 Anneal: 1550°-1625°F, furnace cool. (Tensile 79,000 psi, yield 48,000 psi annealed).  
 Harden: 1500°-1575°F, water or oil quench.  
 Temper: 1100°-1150°F, to obtain tensile 100,000 psi, yield 80,000 psi. For tensile 125,000 and yield 85,000 psi temper at 700°F. Suitable heat treatment is required to permit machining.

1045 Medium Carbon. Forgings such as connecting rods, steering arms, axles, axle shafts and tractor wheels are fabricated from this steel. Not recommended for welding.

**COMPOSITION RANGE**

C%	Mn%	P%	S%	Fe%
0.43 - 0.5	0.6 - 0.9	0 - 0.04	0 - 0.04	Balance

**FORMS-SPECIFICATION.** See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1575°-1675°F, air cool.  
 Anneal: 1550°-1600°F, furnace cool for maximum softness.  
 Harden: 1475°-1550°F, quench, water or oil.

Temper: 1100°F for tensile 100,000 psi, yield 65,000 psi.  
 Temper: 1000°F for tensile 125,000 psi, yield 95,000 psi.

1050 Medium Carbon. This is a medium carbon type steel with high mechanical properties which may be further hardened and strengthened by heat treatment or by cold work. Application is similar to 1045. Not recommended for welding.

**COMPOSITION RANGE**

C%	Mn%	P%	S%	Fe%
0.46 - 0.55	0.8 - 0.9	0 - 0.04	0 - 0.05	Balance

**FORMS-SPECIFICATION.** See Specification Table 2-2.

**HEAT TREATMENT.**

Normalize: 1550°-1650°F, air cool.  
 Anneal: 1450°-1525°F, furnace cool (Tensile 90,000, yield 50,000 annealed).  
 Harden: 1475°-1550°F, oil or water quench.  
 Temper: 1250°F for 100,000 psi tensile, 75,000 for yield.  
 Temper: 1025°F for 125,000 psi tensile, 90,000 for yield.  
 Temper: 700°F for 150,000 psi tensile, 114,000 for yield.

1055 High Carbon. Steels of this type (1060, 1070, 1080 are in same category) have similar characteristics and are primarily used where higher carbon is needed to improve wear characteristics for cutting edges, as well as for manufacture of springs, etc. Not recommended for welding.

**COMPOSITION RANGE**

C%	Mn%	P%	S%	Fe%
0.50 - 0.60	0.6 - 0.9	0 - 0.04	0 - 0.05	Balance

**FORMS-SPECIFICATIONS.** See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1550°-1650°F, air cool.  
 Anneal: 1550°-1575°F.  
 Harden: 1450°-1550°F, water or oil quench.  
 Temper: 1250°F for 100,000 psi tensile, 1050°F for 125,000 tensile, 600°F for 150,000 tensile.



1060, High Carbon. See 1055 for application and characteristics.

COMPOSITION RANGE.

C%	Mn%	P%	S%	Fe%
0.55 - 0.65	0.6 - 0.09	0 - 0.04	0 - 0.05	Balance

FORM-SPECIFICATION. See Specification Table 2-2.

HEAT TREATMENT.

Normalize: 1525<sup>o</sup>-1625<sup>o</sup>F, air cool.  
 Anneal: 1500<sup>o</sup>-1575<sup>o</sup>F (Tensile 104,000 psi, yield 54,000 psi annealed).  
 Harden: 1450<sup>o</sup>-1550<sup>o</sup>F, water or oil quench.  
 Temper: 1125<sup>o</sup>F for 130,000 tensile, 80,000 yield.  
 Temper: 1025<sup>o</sup>F for 139,000 tensile, 96,000 yield.  
 Temper: 925<sup>o</sup>F for 149,000 tensile, 99,000 yield.

1070, High Carbon. See 1055 for application and characteristics. In addition this alloy is used for flat springs and wire form as coil springs.

COMPOSITION RANGE.

C%	Mn%	P%	S%	Fe%
0.65 - 0.75	0.6 - 0.9	0 - 0.04	0 - 0.05	Balance

FORM-SPECIFICATION. See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1525<sup>o</sup>-1625<sup>o</sup>F, air cool, retard cooling rate to prevent hardness.  
 Anneal: 1500<sup>o</sup>-1575<sup>o</sup>F, furnace cool.  
 Harden: 1450<sup>o</sup>-1550<sup>o</sup>F, water or oil quench (Preheat).  
 Hot Working Temperature: 1550<sup>o</sup>-1650<sup>o</sup>F.  
 Temper: 1250<sup>o</sup>F for 100,000 psi tensile.  
 Temper: 1100<sup>o</sup>F for 125,000 psi tensile.  
 Temper: 1000<sup>o</sup>F for 150,000 psi tensile.

The high carbon content of this steel causes difficulties in arc or gas welding processes. Welding by the thermit process is satisfactory. Hot formability is very good at 1550<sup>o</sup>-1650<sup>o</sup>F.

1080, High Carbon. See 1055 for applications and characteristics.

COMPOSITION RANGE

C%	Mn%	P%	S%	Fe%
0.75 - 0.88	0.6 - 0.9	0 - 0.04	0 - 0.05	Balance

FORM-SPECIFICATION. See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1550<sup>o</sup>-1650<sup>o</sup>F, air cool.  
 Anneal: 1475<sup>o</sup>-1525<sup>o</sup>F (Tensile 120,000, yield 86,000 psi annealed).  
 Harden: 1450<sup>o</sup>-1550<sup>o</sup>F, quench oil.  
 Temper: 1200<sup>o</sup>F for 129,000 tensile, 87,000 yield.  
 Temper: 1100<sup>o</sup>F for 145,000 tensile, 103,000 yield.  
 Temper: 900<sup>o</sup>F for 178,000 tensile, 129,000 yield.

1095, High Carbon. See 1055 for applications. In addition these steels are used for flat spring applications and in wire form as coil springs.

COMPOSITION RANGE

C%	Mn%	P%	S%	Fe%
0.9 - 1.03	0.3 - 0.5	0 - 0.04	0 - 0.05	Balance

FORM-SPECIFICATION. See Specification Table 2-2.

HEAT TREATMENT

OIL QUENCH

Normalize: 1550<sup>o</sup>-1650<sup>o</sup>F, air cool.  
 Anneal: 1425<sup>o</sup>-1475<sup>o</sup>F (Tensile 98,000 psi, yield 52,000 psi annealed) furnace cool. To reduce annealing time, furnace cool to 900<sup>o</sup>F and air cool. Spheroidize for maximum softness when required.  
 Harden: 1425<sup>o</sup>-1550<sup>o</sup>F (oil quench).  
 Temper: 1100<sup>o</sup>F for 146,000 psi tensile, 88,000 yield.  
 Temper: 800<sup>o</sup>F for 176,000 psi tensile, 113,000 yield.  
 Temper: 600<sup>o</sup>F for 184,000 psi tensile, 113,000 yield.

WATER QUENCH

Normalize: 1550<sup>o</sup>-1650<sup>o</sup>F, air cool.  
 Anneal: 1425<sup>o</sup>-1475<sup>o</sup>F.  
 Harden: 1425<sup>o</sup>-1500<sup>o</sup>F, quench with water.  
 Temper: 1100<sup>o</sup>F for 143,000 psi tensile, 96,000 yield.  
 Temper: 800<sup>o</sup>F for 200,000 psi tensile, 138,000 yield.  
 Temper: 600<sup>o</sup>F for 213,000 psi tensile, 150,000 yield.

1112 Free Cutting. This steel is used as the standard for rating the machinability of other steels. It is easy to machine and resulting surface finish is excellent. It has good brazing characteristics but is difficult to weld except with the low hydrogen electrode E6015 (AWS). This and similar grades are widely used for parts for bolts, nuts, screws, but not for parts subjected to severe stresses and shock.

COMPOSITION RANGE.

C%	Mn%	P%	S%	Fe%
0 - 0.13	max 0.7 - 0.9	0.07 - 0.12	0.16 - 0.23	Balance

FORM-SPECIFICATION. See Specification Table 2-2.HEAT TREATMENT.

May be surface hardened by heating in cyanide at 1500<sup>o</sup>-1650<sup>o</sup>F, followed by single or double quench and draw. Preheat and soak at 1500<sup>o</sup>F to 1650<sup>o</sup>F and quench in oil or water; tempering is optional.

Tensile strength hot rolled bars 65,000.

Tensile strength cold drawn 83,000.

1117. Carbon (Free Cutting Steel). This material is used where a combination of good machinability and uniform response to heat treatment is needed. It is suited for fabrication of small parts which are to be cyanided or carbonitrided and may be oil quenched after case hardening heat treating.

COMPOSITION RANGE.

C%	Mn%	P%	S%	Fe%
0.41 - 0.2	1.0 - 1.3	0 - 0.04	0.08 - 0.13	Balance

FORM-SPECIFICATION. See Specification Table 2-2.HEAT TREATMENT

Normalize: 1650<sup>o</sup>F, air cool.  
 Anneal: 1575<sup>o</sup>F, furnace cool (Tensile 68,000 psi annealed)  
 Harden: 1450<sup>o</sup>F, quench in water

SINGLE QUENCH AND TEMPER

Carburized 1700<sup>o</sup>F for 8 hours.  
 Pot Cool  
 Reheat to 1450<sup>o</sup>F.  
 Quench in water.  
 Temper at 350<sup>o</sup>F  
 Case depth 0.045.  
 Case hardness 65 RC.

1137. Carbon, Free Cutting. This steel is intended for those uses where easy machining is the primary requirement. It is characterized by a higher sulphur content than comparable carbon steels, which result in some sacrifice of cold forming properties, weldability and forging characteristics.

COMPOSITION RANGE.

C%	Mn%	P%	S%	Fe%
0.32 - 0.39	1.35 - 1.65	0 - 0.04	0.08 - 0.13	Balance

FORM-SPECIFICATION. See Specification Table 2-2.HEAT TREATMENT

Normalize: 1600<sup>o</sup>-1700<sup>o</sup>F, air cool.  
 Anneal: 1400<sup>o</sup>-1500<sup>o</sup>F, furnace cool.  
 Harden 1525<sup>o</sup>-1575<sup>o</sup>, oil or water quench.

TYPICAL STRENGTH OF OIL QUENCHEDTemper: 1100<sup>o</sup>F for tensile 100,000 psi, yield 80,000 psi.Temper: 825<sup>o</sup>F for tensile 125,000 psi, yield 100,000 psiTYPICAL STRENGTH OF WATER QUENCHEDTemper: 1100<sup>o</sup>F for tensile 105,000 psi, yield 90,000 yield.Temper: 975<sup>o</sup>F for tensile 125,000 psi, yield 100,000 psi.

Tensile strength: 85,000 psi, yield 50,000 psi in annealed condition.

2317. Nickel Alloy. These specifications cover steel castings for valves, flanges, fittings and other pressure containing parts intended principally for low temperature parts.

COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Ni%	Fe%
15 - 0.2	0.4 - 0.6	0.04	0.04	0.2 - 0.35	3.25	Balance

FORM-SPECIFICATION. See Specification Table 2-2.HEAT TREATMENT

Normalize: 1600<sup>o</sup>-1700<sup>o</sup>F, air cool  
 Anneal: 1500<sup>o</sup>-1550<sup>o</sup>F  
 Harden: 1375<sup>o</sup>-1525<sup>o</sup>F.  
 Carburize: 1650<sup>o</sup>-1700<sup>o</sup>F, reheat to 1450<sup>o</sup>F to 1550<sup>o</sup>F, temper at 250<sup>o</sup>-300<sup>o</sup>F.

WATER QUENCHTemper: 1100<sup>o</sup>F for tensile 100,000 psi, yield psi 83,000.Temper: 875<sup>o</sup>F for tensile 125,000 psi, yield psi 100,000.Temper: 750<sup>o</sup>F for tensile 150,000 psi, yield psi 124,000.

OIL QUENCH

Temper: 1025°F for tensile 100,000 psi, yield psi 83,000.

Temper: 850°F for tensile 125,000 psi, yield psi 88,000.

Temper: 650°F for tensile 150,000 psi, yield psi 108,000.

This steel may be welded by common welding procedures.

2330. Nickel Alloy. This is a heat treatable steel which develops high strength and toughness in moderate sections. It is used in highly stressed bolts, nuts, studs, turnbuckles, etc.

COMPOSITION RANGE

C%	Mn%	P%	S%	Si%
0.28 - 0.33	0.6 - 0.8	0 - 0.04	0 - 0.04	0.2 - 0.35

Ni%	Fe%
3.25 - 0.75	Balance

FORM-SPECIFICATION. See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1600°F, preheat, cool in air.

Anneal: 1425°-1600°F, furnace cool.

Harden: 1400°-1500°F.

Quench with oil.

Temper: 1200°F-1250°F for tensile 100,000 psi, yield 90,000 psi.

Temper: 900°F for tensile 140,000 psi.

Temper: 700°F for 178,000 psi.

WATER QUENCH

700°F - 190,000 psi

900°F - 150,000 psi

1100°F - 124,000 psi

2340. Nickel Alloy. This metal is similar to 2330, but has greater strength. It is an oil hardening steel.

COMPOSITION RANGE

C%	Mn%	P%	S%	Si%
0.38 - 0.43	0.7 - 0.9	0 - 0.04	0 - 0.04	0.2 - 0.35

Ni%

3.25 - 3.75

FORM-SPECIFICATION. See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1600°-1700°F.

Anneal: 1450°-1600°F.

Harden: 1400°-1550°F, quench in oil.

Temper: 1100°F for 125,000 psi tensile, 105,000 psi yield.

Temper: 900°F for 150,000 psi tensile, 132,000 psi yield.

Temper: 800°F for 182,000 psi tensile, 164,000 psi yield.

2515. Nickel Alloy. This steel is quite similar to SAE 2512 and 2517, both in composition and response to heat treatment.

COMPOSITION RANGE

C%	Mn%	P%	S%	Si%
0.12 - 0.17	0.4 - 0.6	0 - 0.04	0 - 0.04	0.2 - 0.35

Ni%	Fe%
4.75 - 5.25	Balance

FORM-SPECIFICATION. See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1650°-1750°F

Anneal: 1500°F.

Quench: 1425°-1525°F, oil quench.

Temper: 1200°F for tensile 104,000, yield 80,000 psi.

Temper: 900°F for tensile 125,000, yield 106,000 psi.

Temper: 700°F for tensile 152,000, yield 125,000 psi.

WATER QUENCH.

Temper: 1100°F for 116,000 psi.

Temper: 900°F for 138,000 psi.

Temper: 700°F for 165,000 psi.

3115. Steel Nickel Chromium Alloy.

COMPOSITION RANGE

C%	Mn%	P%	S%
0.11 - 0.2	0.37 - 0.63	0 - 0.048	0 - 0.058

Si%	Ni%	Cr%	Fe%
0.18 - 0.37	1.05 - 1.45	0.52 0.78	Balance

FORM-SPECIFICATION. See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1625<sup>o</sup>-1725<sup>o</sup>F

Anneal: 1550<sup>o</sup>-1600<sup>o</sup>F.

Harden: 1425<sup>o</sup>-1525<sup>o</sup>F, with oil.

Temper: 300<sup>o</sup>F for tensile, 125,000 psi, yield 86,000 psi.

CORE PROPERTIES	DRAW TEMP	TENSILE KSI	YIELD KSI
3115 Box cooled 1425 <sup>o</sup> F	300 <sup>o</sup> F	125	88
3120	300 <sup>o</sup> F	155	115
3115 Reheated 1475 <sup>o</sup> F	300 <sup>o</sup> F	125	86
3120	300 <sup>o</sup> F	155	115
3115	300 <sup>o</sup> F	125	86
Oil Quen- ched 1525 <sup>o</sup> F			
3120	300 <sup>o</sup> F	155	110

**3140. Nickel Chrome Alloy.** This is a medium deep hardening steel capable of developing good strength and toughness when oil quenched.

**COMPOSITION RANGE**

C%	Mn%	P%	S%	Si%
0.37 - 0.45	0.6 - 0.95	0 - 0.04	0 - 0.04	0.2 - 0.35
Ni%	Cr%	Fe%		
1.0 - 1.5	0.5 - 0.8	Balance.		

**FORM-SPECIFICATION.** See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1550<sup>o</sup>- 1700<sup>o</sup>F.

Anneal: 1475<sup>o</sup> - 1550<sup>o</sup>F (Tensile 94000 psi, yield 66,000 psi annealed).

Harden: 1475<sup>o</sup>- 1550<sup>o</sup>F, oil quench.

Temper: 1200<sup>o</sup>F for tensile 125,000 psi, yield 105,000 psi.

Temper: 1000<sup>o</sup> for Tensile 14,000 psi, yield 125,000 psi.

Temper: 800<sup>o</sup>F for Tensile 184,000 psi, yield 178,000 psi.

Temper: 700<sup>o</sup>F for Tensile 200,000 psi.

**3310. Nickel - Chromium Alloy.** This steel has exceptionally high hardenability and is well suited for heavy parts which must have high, surface hardness combined with high and uniform properties when heat treated. It is commonly used in case hardened gears, pistons, etc. It is similar to Krupp Nickel Chromium except it contains more nickel.

**COMPOSITION RANGE**

C%	Mn%	Si%	Ni%
0.08 - 0.13	0.45 - 0.6	0.2 - 0.35	3.25 - 3.75
Cr%	P%	S%	Fe%
1.4 - 1.75	0 - 0.025	0 - 0.25	Balance

**FORM-SPECIFICATION.** See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1600<sup>o</sup>-1700<sup>o</sup>F, air cool.

Anneal: 1475<sup>o</sup>-1575<sup>o</sup>F, furnace cool to 700<sup>o</sup>F, air cool.

Quench: 1500<sup>o</sup>F - 1550<sup>o</sup>F, Oil, Cool Slowly

Carburize: 1700<sup>o</sup>F, for 8 hours, reheat to 1500<sup>o</sup>F, oil quench, temper 300<sup>o</sup>F, for tensile 170,000 psi, yield 142,000 typical for 1/2" diameter rod.

PSI. Effective case depth 0.05".

**4037. Molydenum Alloy.** This steel is used for such parts as gears, shafts, leaf and coil springs and hand tools.

**COMPOSITION RANGE.**

C%	Mn%	P%	S%	Si%
0.35 - 0.4	0.7 - 0.9	0 - 0.04	0 - 0.04	0.2 - 0.35
Mo%	Fe%			
0.2 - 0.3	Balance.			

**FORM-SPECIFICATION.** See Specification Table 2-2.

**HEAT TREATMENT**

Anneal: 1500<sup>o</sup>-1600<sup>o</sup>F, furnace cool.

Normalize: 1600<sup>o</sup>F, cool in air.

Harden: 1550<sup>o</sup>F, quench in oil.

Temper: 1225<sup>o</sup>F for 100,000 psi.

Temper: 1100<sup>o</sup>F for 125,000 psi,

Temper: 975<sup>o</sup>F for 150,000 psi.

**4130. Chromium - Molydenum Alloy.** Typical usages for this material is in the manufacture of gear shafts axles, machine tool parts, etc.

**COMPOSITION RANGE**

C%	Mn%	P%	S%	Si%
0.26 - 0.35	0.3 - 0.75	0 - 0.04	0 - 0.05	0.15 - 0.35
Cr%	Mo%	Ni%	Fe%	
0.75 - 1.2	0.08 - 0.25	0 - 0.25	Balance.	

**FORM-SPECIFICATION.** See Specification Table 2-2.

### HEAT TREATMENT

Harden(austenitize): 1550<sup>o</sup>-1600<sup>o</sup> F, water quench, for oil quench 1575<sup>o</sup>-1625<sup>o</sup> F.

Austenitize Castings: 1600<sup>o</sup>-1650<sup>o</sup> F, 1 hour, oil quench.

Spheroidize: 1400<sup>o</sup>-1425<sup>o</sup> F, 6-12 hours, furnace cool.

Temper: 1150<sup>o</sup> F for tensile 132,000, yield 122,000.

Temper: 1025<sup>o</sup> F for tensile 151,000, yield 141,000.

Temper: 950<sup>o</sup> F for tensile 163,000, yield 159,000.

SAE Steels: 8630 and 8730 have similar characteristics.

Annealed: 1525<sup>o</sup>-1585<sup>o</sup> F (tensile 80,000 psi, yield 57,000 psi annealed), furnace cool.

Normalize: (cast) 1900<sup>o</sup> F, 1 hour, A.C. Hardening: 1550<sup>o</sup>-1650<sup>o</sup> F, quench in oil.

Normalize: (wrought) 1600<sup>o</sup>-1700<sup>o</sup> F, air cool.

**4135. Chromium Molydenum Alloy.**

### COMPOSITION RANGE

C%	Mn%	Si%	Cr%
0.32 - 0.39	0.6 - 0.95	0.2 - 0.35	0.8 - 1.15
Mo%	P%	S%	Fe%
0.15 - 0.25	0 - 0.04	0 - 0.04	Balance

### HEAT TREATMENT

Normalize: 1600<sup>o</sup>-1700<sup>o</sup> F, air cool.

Anneal: 1525<sup>o</sup>-1575<sup>o</sup> F, furnace cool.

Harden: 1550<sup>o</sup>-1625<sup>o</sup> F, quench in oil.

Temper: 1100<sup>o</sup> F for 125,000 tensile psi.

Temper: 1050<sup>o</sup> F for 150,000 tensile psi.

Temper: 850<sup>o</sup> F for 180,000 tensile psi.

**17-22A(V).** Structural (Ultra High Strength) Low Alloy. This is a high strength, heat resistant steel with a 1000 hour rupture strength of 1100<sup>o</sup> F (30,000 psi tensile strength). It is used in turbine rotors, and for components of guided missiles, in which high temperatures are encountered for short periods.

### COMPOSITION RANGE

C%	Cr%	Ce%	Mn%	Mo%	
0.25 - 0.3	1.0 - 1.5	0-0.5	0.6 - 0.9	0.4 - 0.6	
Ni%	Si%	V%	P%	S%	Fe%
0 - 0.5	0.55 - 0.75	0.75 - 0.95	0.04	0 - 0.04	Balance

**FORM-SPECIFICATION - AMS6303** Bar, forging, forging stock.

### HEAT TREATMENT

Normalize: 1700<sup>o</sup>-1850<sup>o</sup> F, hold for 1 hour per inch of thickness, air cool. Larger sections may be furnace cooled in order to accelerate cooling. All sections should be so placed as to provide access of air to all surfaces.

Anneal: 1450<sup>o</sup> F, hold at this temperature 1 hour for each inch of section thickness. Cool down 20<sup>o</sup> F per hour to 1100<sup>o</sup> F, then air cool.

Oil Quenching requires prior heating to 1750<sup>o</sup> F, for each inch of thickness. Annealed bars, 1 inch diameter have tensile strength 87,000 yield strength, 67,800. Pancake forgings normalized at 1800<sup>o</sup> F + tempering at 1225<sup>o</sup> F, 8 hours have tensile strength 142,000, yield strength 126,500, hardness BHN 311-321. This alloy may be welded by any of the commercial methods in use. A welding rod corresponding to 17-22A(S) is available. When pre-heating is required depending upon size of section and type of welding procedure, a temperature of 600<sup>o</sup> F is generally used. Post heating or stress relief is recommended.

**4137CO.** This ultra-high strength steel has yield strength in the 230,000-240,000 psi range. It forms and welds readily. It was developed for use in high performances solid rocket motor cases.

Alternate designations are Unimach VC X 2, MX-2, and Rocoloy. Machining characteristics are similar to 4140.

### COMPOSITION RANGE

C%	Cr%	Co%	Mn%
0.39 - 0.4	0.95 - 1.2	0.98 - 1.23	0.6 - 0.79
Mo%	Si%	V%	P%
0.22 - 0.35	0.97 - 1.19	0.14 - 0.16	0 - 0.015
S%	Fe%		
0 - 0.012	Balance		

**SPECIFICATIONS:** None

**FORMS:** Sheet, strip, plate, bar, forging, wire.

### HEAT TREATMENT

Normalize: 1750<sup>o</sup> F, 30 minutes, air cool.

Spheroidize: Anneal: 1420<sup>o</sup>-1460<sup>o</sup> F, 2 hours, fast cool to 1235<sup>o</sup>-1265<sup>o</sup> F, hold 14 to 24 hours, air cool. Resulting hardness RB95 maximum.

Intermediate stress relieve to restore ductility of formed parts, 1250<sup>o</sup> F for 10 minutes, air cool.

Stress relieve after welding 1250°F, 30 minutes minimum.

Austenitize: 1700°F for sections less than 1/2 inch, 1725°F for sections larger than 1/2 inch, 20 minutes minimum to 1 hour maximum per inch thickness, oil or salt quench at 400°F. Maximum time in salt 12 minutes.

Double temper 540°-560°F for two consecutive 2 hour periods with intermediate cooling to room temperature. Weldability characteristics are good using the Tungsten-arc-inert-gas process.

**4140. Medium Carbon Chromium - Molybdenum (Nitriding Grade)** This steel is widely used where the higher strength and higher hardenability of 4340 is not required. It can be nitrided.

C%	Mn%	P%	S%	Cr%
0.38-0.43	0.75-1.0	0-0.040	mx 0-0.040	mx 0.80-1.1
Mo%	Si%	Fe%		
0.15-0.25	0.2-0.35	Balance		

#### SPECIFICATIONS.

TYPE 4140		
AMS	FORM	MILITARY
5336	Precision Investment Castings	
5338	Precision Investment Castings	
6378	Bars	
6379	Bars	
6381	Heavy Wall Tubing	
6382	Bars, Forgings, Forgings, Stock	MIL-S-5626

#### HEAT TREATMENT.

Normalize: 1600°-1650°F (air cool) minimum 1 hour.  
 Anneal: 1550°-1600°F furnace cool  
 Harden: 1550°-1600°F 30 minutes, oil quench  
 Spheroidize: 1400°-1425°F furnace cool.  
 Temper 4 hours to obtain desired strength. See table below.

#### DRAW TEMPERATURES.

1300°F	- 100,000 psi
1175°F	- 120,000 to 140,000 psi
1075°F	- 140,000 to 160,000 psi
950°F	- 160,000 to 180,000 psi
850°F	- 180,000 to 200,000 psi
725°F	- 200,000 to 220,000 psi

SAE 4330 V Mod. This steel is 4330 improved by the addition of vanadium, and is primarily used heat treated to a tensile strength between 220 and 240 KSI. It is highly shock resistant and has better welding characteristics than higher carbon steels.

#### CHEMICAL COMPOSITION.

C%	Mn%	Si%	P%	Si%	Cr%
0.28-0.33	0.75-1.00	0.20-0.35	0.040	0.040	0.75-1.00
Ni%	Mo%	V%	Fe%		
1.65-2.00	0.35-0.50	0.05-0.10	Balance		

#### HEAT TREATMENT

Normalize: 1600° to 1700°F, air cool.  
 Temper: normalized condition for machinability 1250°F maximum.  
 Full anneal at 1525°F to 1575°F furnace cool or cool in ash or lime.  
 Austenitize: 1550° to 1600°F 15 minutes per inch thickness, oil quench 75° to 140°F.)  
 Temper: 180 to 200 KSI, 950° to 110°F, 4 hours.)  
 Temper: 200 to 220 KSI, 750° to 950°F, 4 hours.)  
 Temper: 220 to 240 KSI, 600° to 750°F, 4 hours.)

**4150. Chromium-Molybdenum.** This metal is used for such items as gears, shafts, pistons, springs, axles, pins, connecting rods.

#### COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Cr%
0.48-0.53	0.75-1.0	0-0.04	0-0.04	0.2-0.35	0.8-0.12
Mo%	Fe%				
0.18-0.25	Balance				

FORMS-SPECIFICATIONS. See Specification Table 2-2.

#### HEAT TREATMENT

Normalize: 1550°-1650°F  
 Anneal: 1450°-1525°F  
 Harden: 1475°-1525°F, oil quench  
 Temper: 1200°F for tensile 128,000 yield 116,000  
 Temper: 1100°F for tensile 150,000 yield 135,000  
 Temper: 950°F for tensile 180,000 yield 163,000  
 Temper: 800°F for tensile 200,000 yield 186,000

**5210. High Carbon, High Chromium Alloy.** This steel is used for anti-friction bearings and other parts requiring high heat treated hardness of approximately Rockwell C60, toughness and good wear resistance qualities. It is best machined in the spheroidized annealed condition.



COMPOSITIN RANGE.

C%	Cr%	Mn%	Si%	S%	P%
0.95-1.1	1.3-1.6	0.25-0.45	0.2-0.35	0-0.025	0-0.025
Fe%					
Balance					

FORMS-SPECIFICATIONS. See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1650°-1700°F air cool  
 Anneal: 1250°-1340°F hold 5 hours. Heat to 1430°-1460°F, at 10°F per hour, hold 8 hours. Cool to 1320°F at 10°F per hour. Cool to 1250°F at furnace rate and air cool.

Spheroidize: Slow cool (about 5°F per hour) following austenitizing by extended heating at a temperature near the ACM point or by isothermal transformation at 1275°F following austenitizing.

Harden: Quench in water from 1425°F - 1475°F or quench in oil from 1550°-1600°F, then temper to desired hardness. The Rockwell hardness at various temperatures is listed below:

Temper: 400°F, RC60  
 Temper: 600°F, RC55  
 Temper: 800°F, RC48  
 Temper: 100°F, RC40  
 Temper: 1200°F, RC28

LADISH D-6-A. Low Alloy High Strength. This alloy is suitable for hot work die applications and structural material in aircraft and missiles. It may be heat treated to strength levels up to 300,000 psi, and at 240,000 has excellent toughness. At strength levels below 220,000 psi it is suitable for elevated temperature applications below 900°F. It may readily be welded and cold formed in the annealed or spheroidized condition. It also can be temper straightened.

COMPOSITION RANGE

C%	Cr%	Mn%	Mo%	Ni%	Si%	V%	Fe%
0.46	1.0	0.75	1.0	0.55	0.22	0.05	Balance

SPECIFICATION. None.

FORMS. Available in most wrought forms and forgings.

HEAT TREATMENT

Anneal: 1500°-1550°F, cool down at 50°F per hour to 1000°F.

Normalize: 1600°-1650°F, 30 minutes, air cool.  
 Austenitize: 1550°-1575°F, 30 minutes, oil quench. Sections 1 inch or less in cross sections may be air cooled.

Temper: 300°-1275°F, time and temperature depend on hardness desired.

Stress relieve: 1000°-1250°F one to two hours, air cool.

## TYPE LADISH D-6-A.

FORM	UP TO 1" THICK BAR	
Condition	Vacuum remelt by consumable electrode process.  Normalize 1650°AC 1550°F, air cool + 600°F temper.	
Tensile	282,000 psi	
Yield	255,000 psi	

Nitralloy 135 Mod. Steel ultra high strength (Nitriding Grade). This alloy is well suited for case hardening by nitriding. This process produces a case of extreme hardness without appreciably changing core tensile strength or yield strength. It is also readily machined. After nitriding it may be used where high resistance to abrasion and mild corrosion resistance are required.

COMPOSITION RANGE

A1%	C%	Cr%	Mn%	Mo%	Si%
0.95-1.3	0.38-0.43	1.4-1.8	0.5-0.7	0.3-0.4	0.2-0.4
P%		S%		Fe%	
0-0.04	0-0.04	Balance			

SPECIFICATIONS.

## TYPE NITRALLOY 135 MOD.

AMS	FORMS	MILITARY
5470	Plates, Tubing, Rods, Bar, forgings stock.	MIL-S-6701



HEAT TREATMENT

Anneal: 1450°F, 6 hours, furnace cool.

Normalize by slowly heating to 1790°-1810°F, air cool.

Austenitize: 1700°-1750°F.

Oil quench sections less than 2 inches thick.

Temper: 1000°-1300°F 1 hour minimum per inch of thickness.

(NOTE: Temper 50°F minimum above nitriding temperatures).

Nitride: 930°-1050°F.

## TYPE NITRALLOY 135 MOD.

FORM	BAR		
Condition	1725°F, oil quench sections less than 3 inches, water quench sections greater than 3 inches temper 1200°F, 5 hours.		
SIZE-DIA	LESS THAN 1 1/2 in.	1 1/2 to 3 in.	3 to 5 in.
Tensile	135,000 psi	125,000 psi	110,000 psi
Yield	100,000 psi	90,000 psi	85,000 psi

In welding the major problem to avoid is loss of aluminum and chromium in the weld area, the loss of which would prevent subsequent nitriding.

4337, 4340 Steel Nickel - Chromium Molybdenum Alloy. These two alloys are similar except that carbon content differs slightly. The carbon content of 4337 is minimum 0.35%, maximum 0.4%; good strength, high hardenability and uniformity are characteristics. It can be heat treated to strength values within a wide range. At 260,000 to 280,000 psi tensile this steel has been found superior to other common low alloy steels as well as some of the recently developed more complex low alloy steels. It possesses fair formability when annealed and may be welded, by special processes, which require strict control. No welding shall be performed on this alloy heat treated above 200,000 psi unless specifically approved by design engineer.

COMPOSITION RANGE

C%	Mn%	Si%	P%	S%	Cr%
0.38-0.43	0.65-0.85	0.2-0.35	0-0.04	0-0.04	0.7-0.9
Ni%	Mo%	Fe%			
1.54-2.0	0.2-0.3	Balance.			

FORMS-SPECIFICATIONS. See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1600°-1700°F, 1 hour of maximum thickness, air cool. Temper, normalize condition for improved machinability 125°F maximum.

Anneal: 1475°-1575°F, furnace cool or cool in ash or lime.

Harden: 1475°-1550°F, oil quench.

Spheroidize Anneal: 1425°F, 2 hours, then furnace cool to 1210°F, hold 8 hours, furnace cool or air cool.

Stress relief parts after straightening, machining, etc.

Temper: 1100°F for tensile 150,000 yield, 142,000.

Temper: 900°F for tensile 190,000, yield, 176,000.

Temper: 725°F for tensile 220,000, yield, 200,000.

Temper: 400°-500°F for tensile 260,000, 2 hours per thickness, 6 hours minimum.

Parts heat treated to 260,000-280,000 psi tensile and subsequently subjected to grinding, machining or straightening should be tempered to 350°-400°F, 4 hours minimum. Temperature should not exceed tempering temp or reduce the tensile strength below 260,000 psi. Austenitize 1475°-1575°F, 15 minutes for each inch of thickness. Normalize, welded or brazed parts before austenitizing. Cool after austenitizing.

To heat treat for regular machining, normalize or austenitize, then heat to 1200°F (maximum 1250°F) for 15-20 hours. Resulting hardness should be 229-248 BHN.

Austenitize: 1575°-1625°F, oil quench.

Tempering range is limited to 400°-600°F preferably no higher than 550°F.

Temper: 600°F for 230,000 psi tensile, 194,000 psi yield.

Temper: 550°F for 234,000 psi tensile, 193,000 psi yield.

Temper: 500°F for 235,000 psi tensile, 191,000 psi yield.

Temper: 400°F for 239,000 psi tensile, 183,000 psi yield.

This alloy is easily welded by conventional methods using low hydrogen electrode of similar composition.

4615. Steel Nickel Molybdenum Alloy. This is a high grade carburizing steel for use where reliability and uniformity are required.

**COMPOSITION RANGE**

C%	Mn%	P%	S%	Si%	Ni%
0.13-0.18	0.45-0.65	0-0.04	0-0.04	0.2-0.35	1.65-2.0
Mo%	Fe%				
0.2-0.3	Balance				

**HEAT TREATMENT**

Normalize: 1675<sup>o</sup>-1725<sup>o</sup>F  
 Anneal: 1575<sup>o</sup>-1625<sup>o</sup>F  
 Harden: 1425<sup>o</sup>-1550<sup>o</sup>F oil quench.  
 Carburize: 1425<sup>o</sup>-1550<sup>o</sup>F

Where case hardening is paramount, reheat to 1425<sup>o</sup>-1475<sup>o</sup>F quench in oil. Tempering 250<sup>o</sup>-350<sup>o</sup>F is optional. It is generally employed for partial stress relief and improved resistance to cracking from grinding operation.

**4620. Steel Nickel Molybdenum Alloy.** This is a medium hardenability case steel. Its hardenability characteristics lie between that of plain carbon steel and the high alloy carburized steel. It may be used for average size case hardened automotive parts such as gears, piston pins, crackshafts, etc.

**COMPOSITION RANGE**

C%	Mn%	P%	S%	Si%	Ni%
0.17-0.24	0.45-0.65	0-0.04	0-0.04	0.2-0.35	1.65-2.0
Mo%	Fe%				
0.2-3.0	Balance				

**HEAT TREATMENT**

Normalize: 1650<sup>o</sup>-1750<sup>o</sup>F  
 Anneal: 1550<sup>o</sup>-1600<sup>o</sup>F  
 Quench: (High temperature) 1550<sup>o</sup>F  
 Quench: (Low temperature) 1425<sup>o</sup>F  
 Carburize: 1650<sup>o</sup>-1700<sup>o</sup>F.

Recommend practice for maximum case hardness:  
 Direct quench from pot.

- (1) Carburize: at 1700<sup>o</sup>F for 8 hours.
- (2) Quench: in agitated oil.
- (3) Temper: at 300<sup>o</sup>F  
 Case depth: 0.075.  
 Case hardness: RC62  
 Single Quench and Temper:
  - (1) Carburize: 1700<sup>o</sup>F for 8 hours.
  - (2) Pot cool.
  - (3) Reheat: 1500<sup>o</sup>F.
  - (4) Quench: in agitated oil.
  - (5) Temper: 300<sup>o</sup>F.
 Case depth: 0.075.  
 Case hardness: RC62

**Recommended practices for maximum core toughness:**

- Direct quench from pot.
- (1) Carburize: 1700<sup>o</sup>F for 8 hours.
  - (2) Quench: in agitated oil.
  - (3) Temper: 450<sup>o</sup>F.  
 Case depth: 0.06  
 Case hardness: RC58  
 Single Quench and Temper:
    - (1) Carburize: 1700<sup>o</sup>F for 8 hours.
    - (2) Pot Cool.
    - (3) Reheat: to 1500<sup>o</sup>F
    - (4) Quench: in agitated oil.
    - (5) Temper: 450<sup>o</sup>F.  
 Case depth: .065  
 Case hardness: RC59

**4640 Steel Nickel Molybdenum.** This steel has excellent machinability at high hardness levels, and small distortion in heat treatment. Its application is primarily gears, spline shafts, hand tools, and machine parts.

**COMPOSITION RANGE**

C%	Mn%	P%	S%	Si%	Ni%
0.38-0.43	0.6-0.8	0-0.04	0-0.04	0.2-0.35	1.65-2.0
Mo%	Fe%				
0.2-0.3	Balance				

**FORMS-SPECIFICATIONS** See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1600<sup>o</sup>-1750<sup>o</sup>F  
 Anneal: 1450<sup>o</sup>-1550<sup>o</sup>F  
 Quench: 1450<sup>o</sup>-1550<sup>o</sup>F, oil quench, agitated oil.  
 Temper: 1200<sup>o</sup>F for 100,000 psi.  
 Temper: 1100<sup>o</sup>F for 120 to 140,000 psi.  
 Temper: 1000<sup>o</sup>F for 140 to 160,000 psi.  
 Temper: 900<sup>o</sup>F for 160 to 180,000 psi.  
 Temper: 800<sup>o</sup>F for 180 to 200,000 psi.  
 Temper: 700<sup>o</sup>F for 200 to 220,000 psi.

**6150, 6152. Chromium Vanadium Alloy.** These two steels are essentially the same, differing only in the amount of Vanadium. Alloy 6152 contains a minimum of 0.1% Vanadium. Typical usages are for flat springs under 1/8 inch thick, cold formed, and 1/8 inch and over hot formed; oil quenched, and drawn at 725<sup>o</sup>-900<sup>o</sup>F to 44-48 or 48-52 RC, and for coil springs over 1/2 inch diameter with same heat treatment. It is also used for valve springs, piston rods, pump parts, spline shafts, etc.

COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Cr%
0.48-0.53	0.7-0.9	0-0.04	0-0.04	0.2-0.35	0.8-1.1
V%	Fe%				
0.15 min	Balance				

FORM-SPECIFICATIONS See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1625<sup>o</sup>-1750<sup>o</sup>F, furnace cool.  
 Anneal: 1500<sup>o</sup>-1600<sup>o</sup>F. (Tensile psi 90,000 yield 58,000 psi annealed.)  
 Harden: 1550<sup>o</sup>-1600<sup>o</sup>F, oil quench.  
 Temper: 1100<sup>o</sup>F for tensile psi 150,000 yield psi 137,000 psi.  
 Temper: 800<sup>o</sup>F for tensile psi 210,000 yield psi 194,000 psi.  
 Spheroidized annealed to 183-241 BHN = 45%

8615 Steel-Ni-Cr-Mo Alloy. This is a triple alloy case-hardening steel with medium hardenability. It is primarily used for differential pinions, engine pins, gears etc.

COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Ni%	Cr%
0.13-0.18	0.7-0.9	0-.04	0-0.04	0.2-0.3	0.4-0.6	0.4-0.6
Mo%	Fe%					
0.15-0.25	Balance					

FORMS-SPECIFICATIONS See Specification Table 2-2.

HEAT TREATMENT

Pseudo-Carburize 1650<sup>o</sup>-1700<sup>o</sup>F, box cool, reheat 1550<sup>o</sup>F, oil quench.  
 Temper: 300<sup>o</sup>F for tensile 100,000 psi yield 72,500 psi.  
 Normalize: 1650<sup>o</sup>-1725<sup>o</sup>F.  
 Anneal: 1575<sup>o</sup>-1650<sup>o</sup>F.  
 Harden: 1475<sup>o</sup>-1575<sup>o</sup>F.

8617. Steel Ni-Cr-Mo Alloy. This steel is very similar to 8615, but develops somewhat greater strength.

COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Ni%	Cr%
0.15-0.2	0.7-0.9	0-0.04	0-0.04	0.2-0.35	0.4-0.7	0.4-0.6
Mo%	Fe%					
0.15-0.25	Balance					

FORM-SPECIFICATIONS See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1650<sup>o</sup>-1725<sup>o</sup>F.  
 Anneal: 1575<sup>o</sup>-1650<sup>o</sup>F.  
 Harden: 1474<sup>o</sup>-1575<sup>o</sup>F.  
 Carburize: 1700<sup>o</sup>F for 8 hours, oil quench.  
 Draw at 300<sup>o</sup>F.  
 Tensile: 128,000 psi yield 94,000 psi.

8620. Ni-Cr-Mo-Alloy. This steel is similar to 8615 and 8617 though stronger. It is used for ring gears, transmission gears, cam shafts and for good core properties with high surface hardness after case hardening. It is also used in the heat treated condition as chain, at about 100,000 psi yield strength. It is classed as medium hardenable.

COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Ni%
0.18-0.23	0.7-0.9	0-0.04	0-0.04	0.2-0.35	0.4-0.7
Cr%	Mo%	Fe%			
0.4-0.6	0.15-0.25	Balance			

FORMS-SPECIFICATIONS See Specification Table 2-2.

HEAT TREATMENT

Normalize: 1600<sup>o</sup>-1750<sup>o</sup>F.  
 Anneal: 1575<sup>o</sup>-1625<sup>o</sup>F.

CARBURIZING:

For maximum case hardness: Direct quench from pot.

(1) Carburize: 1700<sup>o</sup>F for 8 hours.

(2) Quench: in agitated oil.

(3) Temper: 300<sup>o</sup>F.

Case depth: 0.075.

Case hardness: RC64.

Single Quench and temper:

(1) Carburize: 1700<sup>o</sup>F for 8 hours.

(2) Pot cooled.

(3) Reheat: to 1550<sup>o</sup>F.

(4) Quench: in agitated oil.

(5) Temper: 300<sup>o</sup>F.

Case depth: 0.075

Case hardness: RC64

Recommended practices for maximum core toughness.

Direct quench from pot.

(1) Carburize: 1700<sup>o</sup>F for 8 hours.

(2) Quench: in agitated oil.

(3) Temper: 450<sup>o</sup>F.

Case depth: 0.050

Case hardness: RC58

Single Quench and Temper.

(1) Carburize: 1700<sup>o</sup>F for 8 hours.

(2) Pot cool.

(3) Reheat: to 1500<sup>o</sup>F.

(4) Quench: in agitated oil.

(5) Temper: 450<sup>o</sup>F.

Case depth: 0.076.

Case hardness: RC61.

**8630. Steel Ni-Cr-Mo Alloy:** This steel has characteristics very similar to 4130. It is used for aircraft engine mounts, and other aircraft parts due to good properties when normalized in light sections, and its air hardening after welding.

#### COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Ni%
0.28-0.33	0.7-0.9	0-0.04	0-0.04	0.2-0.35	0.4-0.7
Cr%	Mo%	Fe%			
0.4-0.6	0.15-0.25	Balance			

FORMS-SPECIFICATIONS. See Specification Table 2-2.

#### HEAT TREATMENT

Normalize: 1550<sup>o</sup>-1650<sup>o</sup>F.  
 Anneal: 1500<sup>o</sup>-1550<sup>o</sup>F (Tensile 90,000 psi, tensile 60,000 annealed), furnace cool.  
 Harden: 1500<sup>o</sup>-1575<sup>o</sup>F, oil or water quench.  
 Temper: 1000<sup>o</sup>F for 150,000 psi tensile, 140,000 psi yield strength.  
 Temper: 700<sup>o</sup>F for 200,000 psi tensile, 180,000 psi yield strength.

**8640. Steel Ni-Cr-Mo.** Typical uses, propeller shafts, transmission gears, spline shafts, heavy duty bolts, etc. 4140 has higher strength and ductility and slightly better machinability.

#### COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Ni%
0.38-0.43	0.75-1.0	0-0.04	0-0.04	0.2-0.35	0.4-0.7
Cr%	Mo%	Fe%			
0.4-0.6	0.15-0.25	Balance.			

FORMS-SPECIFICATIONS. See Specification Table 2-2.

#### HEAT TREATMENT

Normalize: 1550<sup>o</sup>-1650<sup>o</sup>F.  
 Anneal: 1475<sup>o</sup>-1575<sup>o</sup>F.  
 Harden: 1475<sup>o</sup>-1575<sup>o</sup>F, oil quench.  
 Temper: 1100<sup>o</sup>F for 145,000 psi tensile, 130,000 psi yield.  
 Temper: 800<sup>o</sup>F for 200,000 psi tensile, 184,000 psi yield.  
 Temper: 700<sup>o</sup>F for 220,000 psi tensile, 205,000 psi yield.

**8735. Steel Ni-Cr-Mo.** This metal is used for shapes, tubing, aircraft engine studs, knuckles, etc. It is similar in characteristics to 8630 and 8640.

FORMS-SPECIFICATIONS. See Specification Table 2-2.

#### COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Ni%
0.33-0.38	0.75-1.0	0-0.04	0-0.04	0.2-0.35	0.4-0.7
Cr%	Mo%	Fe%			
0.4-0.6	0.2-0.3	Balance			

#### HEAT TREATMENT

Normalize: 1575<sup>o</sup>-1625<sup>o</sup>F.  
 Anneal: 1525<sup>o</sup>-1525<sup>o</sup>F.  
 Harden: 1525<sup>o</sup>-1600<sup>o</sup>F Oil quench.  
 Temper: 1200<sup>o</sup>F for tensile 119,000 psi, yield 93,000 psi.  
 Temper: 1100<sup>o</sup>F for tensile 131,000 psi, yield 107,000 psi  
 Temper: 900<sup>o</sup>F for tensile 149,000 psi, yield 127,000 psi  
 Temper: 800<sup>o</sup>F for tensile 170,000 psi  
 Temper: 775<sup>o</sup>F for tensile 200,000 psi

**8740. Steel Ni-Cr-Mo.** This steel is similar to 4140. It may be satisfactorily used for axles, tool joints, bits, core drills, reamer bodies, drill collars, piston rods, aircraft engine bolts, shapes, tubing etc.

#### COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Ni%
0.38-0.43	0.75-1.0	0-0.04	0-0.04	0.2-0.35	0.4-0.7
Cr%	Mo%	Fe%			
0.4-0.6	0.2-0.3	Balance			

FORMS-SPECIFICATIONS See Specification Table 2-2.

#### HEAT TREATMENT

Normalize: 1575<sup>o</sup>-1625<sup>o</sup>F.  
 Anneal: 1500<sup>o</sup>-1575<sup>o</sup>F (Tensile 103,000 psi, yield 66,000 psi annealed)  
 Harden: 1500<sup>o</sup>-1575<sup>o</sup>F (Quench in agitated oil)  
 Temper: 1100<sup>o</sup>F for tensile 160,000 psi, yield 152,000 psi.  
 Temper: 900<sup>o</sup>F for tensile 190,000 psi, yield 183,000 psi.  
 Temper: 800<sup>o</sup>F for tensile 210,000 psi, yield 198,000 psi.  
 Temper: 725<sup>o</sup>F for tensile 220,000.

**9260, 9281, 9262. Steel Silicon.** These are similar alloy spring steels, oil hardening type. The quantities of chromium in each, constitutes the only chemical variations in these alloys. Typical applications are coil and flat springs, axles, chisels, bolts, etc.

**COMPOSITION RANGE**

	C%	Mn%	P%	S%	Si%
9280	0.55-0.65	-0.7-1.0	0-0.04	0-0.04	1.8-2.2

Cr%	Fe%
---	Balance

	C%	Mn%	P%	S%	Si%
9261	0.55-0.65	0.75-1.0	0-0.04	0-0.04	1.8-2.2

Cr%	Fe%
0.1-0.25	Balance

	C%	Mn%	P%	S%	Si%
9262	0.55-0.65	0.75-1.0	0-0.04	0-0.04	1.8-2.2

Cr%	Fe%
0.25-0.4	Balance

**FORMS-SPECIFICATION.** See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1600<sup>o</sup>-1650<sup>o</sup>F.

Anneal: 1525<sup>o</sup>-1575<sup>o</sup>F

Harden: 1575<sup>o</sup>-1625<sup>o</sup>F quench in agitated oil.

Temper: 1100<sup>o</sup>F for tensile 165,000 psi, yield 144,000 psi.

Temper: 900<sup>o</sup>F for tensile 214,000 psi, yield 192,000 psi.

Temper: 600<sup>o</sup>F for tensile 325,000 psi, yield 280,000 psi.

**9310. Steel NiCr-Mo (Electric Furnace Steel).** This is a high hardenability case steel, since it is a high alloy, both the case and core have high hardenability. This type of steel is used particularly for carburized parts having thick sections such as bearing races, heavy duty gears etc.

**COMPOSITION RANGE**

C%	Mn%	P%	S%	Si%	Ni%
0.7-0.13	0.4-0.7	0-0.025	0-0.025	0.2-0.35	2.95-3.55

Cr%	Mo%	Fe%
1.0-1.45	0.08-0.15	Balance

**FORMS-SPECIFICATIONS** See Specification Table 2-2.

**HEAT TREATMENT**

Normalize: 1625<sup>o</sup>-1725<sup>o</sup>F, air cool.

Anneal: 1475<sup>o</sup>-1575<sup>o</sup>F, furnace cool.

Recommended practice for maximum case hardness:

Direct quench from pot.

(1) Carburize: at 1700<sup>o</sup>F for 8 hours.

(2) Quench: in agitated oil.

(3) Temper: 300<sup>o</sup>F.

Case depth: 0.047 inch

Case hardness: RC62

Single Quench and Temper:

(1) Carburize: 1700<sup>o</sup>F for 8 hours.

(2) Pot cool.

(3) Reheat: to 1450<sup>o</sup>F.

(4) Quench: in agitated oil.

(5) Temper: 300<sup>o</sup>F.

Case depth: 0.047 inch.

Case hardness: RC62.

To obtain maximum core toughness: Direct quench from pot.

(1) Carburize: 1700<sup>o</sup>F for 8 hours.

(2) Quench: in agitated oil.

(3) Temper: 450<sup>o</sup>F.

Case depth: 0.039 inch.

Case hardness: RC54.

Single quench and temper:

(1) Carburize: 1700<sup>o</sup>F for 8 hours.

(2) Pot cool.

(3) Reheat to 1450<sup>o</sup>F.

(4) Quench: in agitated oil.

(5) Temper: 450<sup>o</sup>F.

Case depth: 0.047 inch.

Case hardness: RC59.

**Type 301. Steel Austenitic Stainless.** This steel belongs to the sub-family of 18-8 steels, which vary only slightly in chromium and nickel and contain no other metallic alloying element. This alloy may be strengthened to an exceptional degree by cold work. For best results, cold work should be followed by stress relieving at 400<sup>o</sup>-800<sup>o</sup>F.

**COMPOSITION RANGE**

C%	Mn%	Si%	P%	Cr%	Ni%	S%
0.08-0.15	0-2.0	0-1.0	0-0.04	17.0-19.0	6.0-8.0	0-0.03

Cu%	Fe%
0-0.05	Balance

**FORM-SPECIFICATION.** See Specification Table 2-2.

### HEAT TREATMENT

Anneal: 1950<sup>o</sup>-2050<sup>o</sup>F, 1 hour per inch thickness, water quench.

Cool to 800<sup>o</sup>F within 3 minutes maximum.

To relieve the elastic characteristics and increase the compressive yield strength of cold worked conditions, 400<sup>o</sup>-800<sup>o</sup>F, 36 to 8 hours maximum respectively. After forming in order to prevent stress cracking, full anneal, or alternately 600<sup>o</sup>F, 1/2 to 2 hours. This alloy can be hardened only by cold work. Maximum tensile strength, 1/4 hard 125,000, 1/2 hard 150,000, full hard 185,000 psi. Full anneal is mandatory when, exposed to corrosive media, such as hot chlorides, etc. which may lead to stress corrosion cracking.

**Type 302.** Steel Austenitic Stainless. This alloy is similar to Type 301 in composition and characteristics. It is inferior in strength to 301, however, possesses superior corrosive resistance. It is generally used in the annealed conditions.

### COMPOSITION RANGE

C%	Mn%	Si%	P%	S%	Cr%
0.08-0.25	0-2.0	0-1.0	0-0.045	0-0.03	17.0-19.0
Ni%	Fe%				
8.0-10.0	Balance				

**FORMS-SPECIFICATIONS.** See Specification Table, 2-2.

### HEAT TREATMENT

The heat treatment and resulting strength is similar to that recommended for type 301, except that the temperature range for annealing type 302 ranges between 1925<sup>o</sup>-2075<sup>o</sup>F.

**Type 303, Type 303Se, Steel Austenitic Stainless,** These varieties of the 18-8 austenitic stainless family contain additions of sulphur and selenium for the purpose of improving machining characteristics. However the presence of these elements tend to decrease formability and corrosion resistance. Type 303 Se is superior to 303 in these respects. The cast form of 303Se is also known as CF-16F.

ALLOY	TYPE 303 PERCENT		TYPE 303Se PERCENT	
	Min	Max	Min	Max
C	-	0.15	-	0.15
Mn	-	2.0	-	2.0
Si	-	1.0	-	1.0
P	-	0.04	.12	0.17
S	.18	0.35	-	0.04
Cr	17.0	19.0	17.0	19.0
Ni	8.0	10.0	8.0	10.0
Mo	-	0.75	-	0.5
Cu	-	0.5	-	0.5
Se	-	-	0.15	0.35
Iron(Fe)	Balance		Balance	

### HEAT TREATMENT

Anneal or solution treat: 1900<sup>o</sup>-2050<sup>o</sup>F, air cool or quench, depending on section thickness, cool to 800<sup>o</sup>F maximum within 3 minutes.

Bars, forgings: 1900<sup>o</sup>-1950<sup>o</sup>F, 1/2 hour per inch of thickness, water quench.

Sheet, tubing: 1900<sup>o</sup>-1950<sup>o</sup>F, 10 minutes, air cool up to 0.064 thickness, water Quench 0.065 inch and thicker. Castings: 2000<sup>o</sup>-2100<sup>o</sup>F, 30 minutes minimum.

This alloy may be hardened only by cold work. Welding is not generally recommended.

These steels are subject to carbide precipitation when subjected to temperature over 800<sup>o</sup>F.

**Type 304, Type 304L, Steel Austenitic Stainless,** This steel is produced in two grades, type 304 with 0.08 carbon (maximum) and type 304L with 0.03% maximum carbon. They have properties similar to Type 302 but the corrosion resistance is slightly higher. These metals are available as castings under the designations CF-8 and CF-3 respectively. Welding may be readily accomplished by all common methods.



COMPOSITION RANGE

	TYPE 304 PERCENT		TYPE 304L PERCENT	
	MIN	MAX	MIN	MAX
C	-	0.08	-	0.03
Mn	-	2.0	-	2.0
Si	-	1.0	0.5	1.0
P	-	0.04	-	0.04
S	-	0.03	-	0.03
Cr	18.0	20.0	18.0	20.0
Ni	8.0	11.0	8.0	11.0
Mo	-	0.5	-	-
Cu	-	0.5	-	-
Iron	Balance		Balance	

HEAT TREATMENT

Same as types 303 and 303Se. This alloy can only be hardened by cold work.

**TYPE 314.** Steel-Austenitic Stainless. This is a non-heat-treatable stainless steel generally used in the annealed condition. It possesses high resistance to scaling and carburizing and is used for parts

and welded assemblies requiring corrosion and oxidation resistance to 2000°F. It is subject to embrittlement after long time exposure to temperature in the 1200°-1600°F range.

COMPOSITION RANGE

C%	Cr%	Cu%	Mn%	Mo%	Ni%
0.12	23.0-25.0	0.50	1.0-2.0	0.50	19.0-22.0
Si%	P%	S%	Fe%		
1.7-2.3	0.04	0.03	Balance.		

FORM-SPECIFICATION. See Specification Table 2-2.

HEAT TREATMENT

Anneal (solution treat) 1900°-2100°F using rapid air cooling for sheet and light plate and water quench for heavier sections. Stress relief and best corrosion resistance to high temperatures properties is achieved by final annealing at 1900°F minimum. To restore ductility after embrittlement has occurred, anneal 1900°-1950°F for 10-60 minutes.

This alloy may be hardened only by cold work.

## TYPE 314

FORMS	BAR	PLATE	SHEET	WIRE	
CONDITION	ANNEALED	ANNEALED	ANNEALED	ANNEALED	HARD DRAWN
THICKNESS- IN	1 IN DIA			0.002 to 0.010	0.002 to 0.010
Tensile	100,000	100,000	100,000	95,000-130,000	245,000-275,000
Yield	50,000	50,000	50,000	35,000-70,000	230,000-260,000
Hardness RB	89	89	89	-----	-----

**TYPE 316 & 317.** Steel Austenitic Stainless. Wrought products are readily formable and weldable. Castings are also weldable, and the metal arc method is most often used. These alloys have better corrosion resistance than 30302 or 30304 types.

#### COMPOSITION RANGE

C%	Mn%	Si%	P%	S%	Cr%
0-.08	1.25-2.0	0-1.0	0-0.04	0-0.03	16.0-19.0

Ni%	Mo%	Cu%	Iron%
11.0-14.0	2.0-2.5	0-0.5	Balance

**FORMS-SPECIFICATIONS.** See Specification Table 2-2.

#### HEAT TREATMENT

Anneal wrought products 1850°-2150°F, air cool or quench depending on section size.

For sheet alloys, annealing temperature 1950°F, minimum.

Castings 1950°-2100°F, water or oil quench or air cool. Low side of temperature range is used for CF 8M, (Cast Alloy) but CF 12M castings should be quenched from above 2000°F.

Stabilize for high temperature service 1625°-1675°F, stress relieve 400°-500°F, 1/2 to 2 hours.

This alloy may be hardened only by cold work. In annealed condition, tensile 90,000 psi, yield 45,000 psi.

**TYPE 321.** Steel Austenitic Stainless. This is one of the two stabilized 18-8 steels. Since titanium forms a carbide of low solid solubility, the possibility of intergranular precipitation and of the associated intergranular corrosion is reduced. Therefore, type 321 is used primarily either for parts fabricated by welding without postweld annealing or for service at 800°-1500°F. This steel is available in all wrought forms. Welding rods and castings are not produced in this type.

#### CORROSION RANGE

C%	Mn%	Si%	P%	S%	Cr%
0-0.08	0-2.0	0.4-1.0	0-0.04	0-0.03	17.0-20.0

Ni%	Mo%	Ti%	Cu%	Iron (Fe)%
8.0-13.0	0-0.5	*6XC-0.7	0-0.5	Balance

**FORMS-SPECIFICATIONS.** See Specification Table 2-2.

\* 6 times columbian content.

#### HEAT TREATMENT

Full anneal 1750°-1850°F, 1 hour per inch in thickness, two hours minimum for plate furnace cool or air cool. Stabilizing anneal for service 900°-1500°F, heat to 1500°-1650°F one hour per inch thickness, 2 hours minimum for plate. Stress relieve after fabrication 1300°F.

This may be hardened only by cold work.

#### TYPE 321

TENSILE - YIELD FORM CONDITION THICKNESS IN	SHEET, STRIP ANNEAL --	PLATE --	BAR		WIRE	
			ALL	ANN + CD 1 INCH	SOFT TEMPER	
					0.062	0.50
Tensile	90000	85000	85000	95000	115000	95000
Yield	35000	30000	35000	60000	85000	65000

Full anneal or stabilizing anneal will eliminate sensitized conditions.

**TYPES 347 & 348.** Steel Austenitic Stainless is the second of two stabilized 18-8 steels (see type 321 for other). Since columbian forms a carbide of very low solubility, the possibility of intergranular precipitation and of the associated intergranular corrosion are practically eliminated. Therefore, Type 347 is used principally for parts fabricated by welding without postweld annealing, or for long service between 800°-1500°F. Columbian is usually associated with the similar element tantalum which is included in the columbian analysis, specifying only the total of both elements. Corrosion resistance of this alloy is similar to Type 302, however it has a greater tendency to pitting corrosion and attacks in streaks. Intergranular corrosion is absent in this steel unless it is

overheated to above 2150°F. At this temperature columbian carbides are going in to solid solution and subsequent rapid cooling, followed by heating to 1200°F, will cause precipitation and reduce the resistance to intergranular attack. A stabilizing anneal will restore the corrosion resistance.

#### COMPOSITION RANGE

C%	Mn%	Si%	P%	S%	Cr%
0-0.08	0-2.0	0.5-1.0	0-0.04	0-0.03	17.0-19.0

Ni%	Mo%	Cb1%	Iron (Fe%)
9.0-13.0	0-0.5	*10XC-1.1	Balance

\*10 Times Columbian Content.



FORMS-SPECIFICATIONS See Specification Table 2-2.

#### HEAT TREATMENT

Full anneal wrought products 1800°-1900°F, 1 hour per inch of thickness 2 hours minimum for plate, furnace cool or air cool. Full anneal castings 1900°-2000°F 30 minutes minimum. Stabilizing anneal for service 800°-1500°F, 1500°-1650°F, 1 hour per inch thickness, 2 hours minimum for plate. Stress relieve after fabrication 1300°F.

Alloy may be hardened only by cold work.

Welding. Fusions welding of this alloy is comparable to type 304L. Heavy sections may crack during welding or subsequent heating. Postweld annealing is not required, although a stress relief is recommended. This steel is subject to carbide precipitation at temperatures in excess of 2150°F.

Type 414. Steel Martensitic Stainless. This steel has good resistance to weather and water. It should be passivated. Stainless type 416 has similar mechanical properties, workability and resistance to corrosion, however, corrosion resistance is not as good as the 300 series stainless. It has better machinability but less weldability. Type 420 has higher mechanical properties, similar workability and machinability.

#### COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Cr%
0.08-0.15	0-1.0	0-0.04	0-0.03	0-0.10	11.5-13.5

Ni%	Fe%
1.25-2.5	Balance

FORMS-SPECIFICATIONS. See Specification Table 2-2.

#### HEAT TREATMENT

Annealing: 1200°-1300°F.  
 Hardening: 1800°-1900°F, cool rapidly.  
 Tensile strength in annealed condition 117,000 yield, 98,000 psi.  
 Tensile strength in annealed cold drawn 130,000 yield, 115,000 psi.

TYPES 403, 410, 416, Steel-Martensitic Stainless. This is a free machining type of alloy. Best performance is obtained if heat treated or cold worked to 180-240 BHN. It is magnetic in the hardened condition and is not normally used in the annealed condition.

#### COMPOSITION RANGE

C%	Mn%	P%	S%	Si%	Cr%	Mo%	Si%
0.15	1.25	0.06	0.15	1.0	14.0	0.6	0.6

Fe%  
Balance

FORMS-SPECIFICATION See Specification Table 2-2.

#### HEAT TREATMENT

Anneal: 1500°-1650°F, furnace cool 50°F per hour to 1100°F.

Harden: 1700°-1850°F, cool rapidly, oil and quench.

Tensile - Yield strength is as follows:

- (1) Annealed - Tensile 75,000 psi, yield 40,000 psi.
- (2) Heat Treated - Tensile 110,000 psi, yield 85,000 psi.
- (3) Tempered and Drawn - Tensile 100,000 psi, yield 85,000 psi. Weldability is poor except by use of low-hydrogen electrodes.

Temper: 400°-1300°F. Avoid 700°-1075°F temper range.

Temper: 1300°F for 100,000 psi.

Temper: 1075°F for 120,000 psi.

Temper: 575°-600°F for 180,000 psi.

TYPE 420 Steel Martensitic Stainless. This is a medium carbon grade of martensitic stainless which in the past has been intensively used in the cutlery industry. It has recently proved satisfactory for air weapon application where its high strength permits heat treatment for tensile strength up to 240,000 psi. In the fully annealed condition formability of this alloy almost equals the 1/4 hard austenitic stainless steels. Shearing type operations such as blanking and punching are not recommended. It machines best in conditions having approximately 225 BHN.

#### COMPOSITION RANGE

C%	Mn%	Si%	P%	S%	CR%
0.3-0.4	0-1.0	0-1.0	0-0.04	0-0.03	12.0-14.0

Ni%	Mo%	Fe%
0-0.5	0-0.5	Balance

FORMS-SPECIFICATIONS See Specification Table 2-2.

HEAT TREATMENT

Full anneal 1550<sup>o</sup>-1650<sup>o</sup>F one hour per inch of thickness, furnace cool (50<sup>o</sup>F per hour) to 1100<sup>o</sup>F. Subcritical anneal 1300<sup>o</sup>-1350<sup>o</sup>F, 3 hours minimum, air cool. Austenitize 1800<sup>o</sup>-1850<sup>o</sup>F oil quench, depending on section size. Heavy sections should be preheated at 1250<sup>o</sup>F. Temper 400<sup>o</sup>-1500<sup>o</sup>F, 3 hours minimum. Tempering between 600<sup>o</sup>-100<sup>o</sup>F is not generally recommended due to reduced ductility and corrosion resistance.

TYPE 431 Steel Martensitic Stainless. This alloy is suitable for highly stressed parts in corrosive environment.

COMPOSITION RANGE

C%	Mn%	Si%	P%	S%	C5%	Ni%
0.2	1.0	1.0	0.04	0.03	15.0-17.0	1.25-2.5

Fe%

Balance

FORMS-SPECIFICATIONS See Specification Table 2-2.

HEAT TREATMENT

Type 431 steel must be protected from contamination at furnace temperature by dry inert atmosphere (organ, helium) or vacuum in the furnace working zones, except that air or salt bath furnaces may be employed for tempering operations. Parts shall be transferred from furnace working zones to the oil bath within a 30-second interval prior to quenching. Materials in the solution-treated condition (not more than 2 percent segregated ferrite or austenite in the microstructure) may be hardened by the following heat treatment.

HT-200 CONDITION

Austenitize at 1850<sup>o</sup>±25<sup>o</sup>F for 30 minutes, quickly transfer from furnace to oil quenching bath at not over 100<sup>o</sup>F followed by refrigeration at -100<sup>o</sup>F±10<sup>o</sup>F for 2 hours, tempering at 550<sup>o</sup>F±25<sup>o</sup>F for 2 hours, air cool, and final temper at 550<sup>o</sup>±25<sup>o</sup>F for 2 hours; or austenitize 1850<sup>o</sup>±25<sup>o</sup>F for 30 minutes, marquench into salt bath at 400<sup>o</sup>F, air cool to room temperature, refrigerate at -100<sup>o</sup>±10<sup>o</sup>F for 2 hours, temper 550<sup>o</sup>±25<sup>o</sup>F for 2 hours, air cool, temper 550<sup>o</sup>F for 2 hours.

HT-125 (125,000 tensile)

Austenitize at 1850<sup>o</sup>±25<sup>o</sup>F for 30 minutes, quickly transfer from furnace to oil quench to bath at not over 100<sup>o</sup>F, temper 1200<sup>o</sup>±25<sup>o</sup>F for 2 hours, air cool, temper 1200<sup>o</sup>±25<sup>o</sup>F for 2 hours.



Avoid tempering or holding within range from 700<sup>o</sup> to 1100<sup>o</sup>F.

HT-115 (115,000 Tensile and Yield 90,000 PSI)

Heat cond A material to 1800<sup>o</sup>-1900<sup>o</sup>F for 30 minutes, oil quench from furnace, temper at a temperature not lower than 1100<sup>o</sup>F.

HT-175 (175,000 Tensile and 135,000 Yield PSI)

Heat Cond A material to 1850<sup>o</sup>-1950<sup>o</sup>F, quench in oil from furnace temper at a temperature not higher than 700<sup>o</sup>F.

17-4PH. Steel, Martensitic Stainless, Precipitation Hardening. This stainless steel possesses high strength and good corrosion and oxidation resistance up to 600<sup>o</sup> F.

COMPOSITION RANGE

C%	Cb%	Cr%	Cu%	Mn%
0.07 max	0.15-0.45	15.5-17.5	3.0-5.0	1.0 max
N:%	P%	S%	S:%	Fe%
3.0-5.0	0.04 max	.03 max	1.0 max	balance

SPECIFICATION: MIL-S-81506

HEAT TREATMENT

To condition A-1900<sup>o</sup> ± 25<sup>o</sup> F 30 minutes, air cool or oil quench below 90<sup>o</sup> F.

From condition A to  
 Condition H900(RH-C 40/47) 900<sup>o</sup> ± 10<sup>o</sup> F, 1 hour, air cool.  
 Condition H925(RH-C 38/45) 925<sup>o</sup> ± 10<sup>o</sup> F, 4 hours, air cool.  
 Condition H950(RH-C 37/44) 950<sup>o</sup> ± 10<sup>o</sup> F, 4 hours, air cool.  
 Condition H975(RH-C 36/43) 975<sup>o</sup> ± 10<sup>o</sup> F, 4 hours, air cool.  
 Condition H1000(RH-C 35/42) 1000<sup>o</sup> ± 10<sup>o</sup> F, 4 hours, air cool.  
 Condition H1025(RH-C 35/42) 1025<sup>o</sup> ± 10<sup>o</sup> F, 4 hours, air cool.  
 Condition H1050(RH-C 33/40) 1050<sup>o</sup> ± 10<sup>o</sup> F, 4 hours, air cool.  
 Condition H1075(RH-C 31/39) 1075<sup>o</sup> ± 10<sup>o</sup> F, 4 hours, air cool.  
 Condition H1100(RH-C 32/38) 1100<sup>o</sup> ± 10<sup>o</sup> F, 4 hours, air cool.  
 Condition H1125(RH-C 30/37) 1125<sup>o</sup> ± 10<sup>o</sup> F, 4 hours, air cool.  
 Condition H1150(RH-C 28/37) 1400<sup>o</sup> ± 25<sup>o</sup>F, 2 hours, air cool then 1150<sup>o</sup> ± 10<sup>o</sup>F, 4 hours, air cool.

17-7PH. Steel Martensitic Stainless (Precipitation Hardening). This stainless steel possesses good corrosion resistance, may be machined and formed in its annealed condition, and is used up to temperatures of 800°F.

COMPOSITION RANGE

A%	C%	Cr%	Mn%	Ni%
0.50-1.0	0.10-0.12	16.0-18.0	1.00	6.0-8.0
Si%	P%	S%	Iron	
1.0-5.0	0.045	0.030	Balance	

SPECIFICATION: See MIL-S-25043.

HEAT TREATMENT

Condition A. Solution anneal 1925°-1975°F, 30 minutes per inch of thickness, air cool. Age condition A

to condition TH1050, 1375° to 1425°F, 1-1/2 hour, air cool to 50° to 60°F within 1 hour, hold at 50° to 60°F 1/2 hour (condition T0) +1040° to 1060°F, 1-1/2 hour. Age condition A to condition RH 950, 1735° to 1765°F, 10 minutes, refrigerate (condition A 1750°) to -90° to -110°F 8 hours (condition R100), + 940° to 960°F, 1 hour. Age condition C of cold rolled sheet or cold drawn wire to condition CH 900, 890° to 910°F for 1 hour.

Condition A - 130 to 150 KSI ultimate, 55 KSI yield.  
Condition T - 125 to 145 KSI ultimate 75 to 100 KSI yield.

Condition RH950 - 200 to 215 KSI ultimate 180 to 190 KSI yield.

Condition RH1050 - 180 to 200 KSI ultimate 150 to 185 KSI yield.

Condition C - 200 to 215 KSI ultimate 175 to 185 KSI yield.

Condition CH900 - 240 to 250 KSI ultimate, 230 to 240 KSI yield.

Change 13 2-58A/(2-58 B blank)

**TYPE 440A, 440B, 550C, 440C, Steel Martensitic Stainless.** These steels are similar except for carbon range, therefore they are grouped since heat treatment requirements are the same. These steels are used for cutlery, valves, etc.

#### COMPOSITION RANGE.

C%	Mn%	Si%	P%	S%	Cr%	Mo%
440A						
0.6-0.75 max	1.0 max	1.0 max	0.04 max	0.03 max		
Cr%	Mo%	Fe%				
16.0-18.0 max	0.75 max	Balance				
C%	Mn%	Si%	P%	S%	Cr%	Mo%
440B						
0.75-0.95	1.0	1.0	0.04	0.03	16.0-18.0	0.75
Fe%						
Balance						
C%	Mn%	Si%	P%	S%	Cr%	Mo%
440C						
0.95-1.2	1.0	1.0	0.04	0.03	16.0-18.0	0.75
Fe%						
Balance						

FORMS-SPECIFICATIONS See Specification Table 2-2.

#### HEAT TREATMENT

Anneal: 1550° to 1650°F.

Temper: 300°-800°F.

Harden: 1850°-1950°F, cool rapidly

440A, tensile 270,000 psi, yield 260,000 psi.

440B, tensile 280,000 psi, yield 270,000 psi.

440C, tensile 285,000 psi, yield 275,000 psi.

Welding is not recommended.

15-7-MO. Steel Martensitic Stainless. This alloy is a further development of 17-7PH alloy and due to molybdenum content it can be heat treated to high strength at room and elevated temperature (up to 1000°F). The heat treatment is identical to 17-7PH and other properties are identical or similar to 17-7PH.

FORMS - sheet, strip, plate, bars and forgings.

SPECIFICATION - AMS 5520, AMS 5657.

#### COMPOSITION RANGE

C%	Mn%	Si%	P%	S%	Cr%	Ni%
0.09	1.0	1.0	0.4	0.03	14.0-16.0	6.50-7.75
Mo%	Al%	Fe%				
2.0-3.0	0.75-1.50	Balance				

#### HEAT TREATMENT

Condition A. Solution anneal sheet and strip, 1925°-1975°F, 3 minutes per 0.1 inch thickness, air cool. Bar and forgings solution anneal 1925°-1975°F, 30 minutes per inch thickness, water quench. Age condition A to condition TH1050, 1375° to 1425°F, 1-1/2 hour (austenite conditioning), air cool to 50°-60°F within 1 hour, hold at 50°-60°F, 1/2 hour (condition T) + 1040°-1060°F, 1-1/2 hour, air cool. Age condition A to condition RH 950, 1735°-1765°F, 10 minutes (austenite conditioning), air cool (condition A 1750) + 90° to 110°F, 8 hours (condition R100) + 940° to 960°F, 1 hour, air cool. Age condition C, sheet cold rolled or wire cold drawn to condition CH 900, by heating 890°-910°F for 1 hour, air cool. TH and RH conditions are also used with difference final age hardening temperatures, such as TH1150, RH1050, etc.

#### TYPICAL PROPERTIES FOR VARIOUS CONDITIONS:

Condition A - 130 to 150 KSI ultimate, 55-65 KSI yield, hardness 90-100.

Condition T - 125 to 145 KSI ultimate, 75-90 KSI yield, hardness 28-30.

Condition TH1050 - 190 to 210 KSI ultimate, 170-200 KSI yield, hardness RC40-45.

Condition RH950 - 225 to 240 KSI ultimate, 200-225 KSI yield, hardness RC46-48.

Condition R100 - 180 KSI ultimate, 125 KSI yield, hardness RC40.

Condition C - 220 KSI ultimate, 190 yield, hardness RC45.

Condition CH900 - 265 KSI ultimate, 260 yield, hardness RC50.

PH 14-8 MO This alloy (sheet) is similar to PH 15-7 MO except it has slightly lower tensile and yield strength but considerable higher toughness and superior welding characteristics. In general this alloy is unstable during exposure to temperatures exceeding 500°F, which is a common characteristic of precipitation hardening stainless steels.

FORMS AND CONDITIONS - available - sheet and strip.

Condition A - annealed C cold worker.

#### CHEMICAL CONDITION

C%	Mn%	Si%	Ph%	S%	Cr%	Ni%
0.02-0.05	1.0	1.0	0.015	1.0	13.50-15.50	7.50-9.50
Me%	Al%	Fe%				
2.0-3.0	0.75-1.50	Rem				

**HEAT TREATMENT**

Anneal to Condition A, 1800° to 1850°F, 30 minutes air cool. Age condition A to SRH conditions, 1685°-1715°F, 1 hour, air cool and within 1 hour cool to -100°F, 8 hours + age 1 hour, air cool. Aging at 940°-960°F or 1040°-1060°F is generally used with the higher temperature giving somewhat lower strength but after better toughness. Age cold worked alloy, condition C, 890°-910°F or 1040°-1060°F, 1 hour, air cool.

**MECHANICAL PROPERTIES TYPICAL**

Condition A - 150 KSI ultimate, 65 KSI yield, hardness, RB100 max.

Condition SRH 950 - 220 KSI ultimate, 190 KSI yield hardness RC40.

Condition SRH1050 - 200 KSI ultimate, 180 KSI yield, hardness RC38.

This alloy is subject to salt stress corrosion, however, early test indicate it is superior in this respect to 17-7PH and PH 15-7 MO.

This general welding characteristics is similar to 17-7 PH. Higher toughness may be obtained by annealing after welding and then heat treating.

19-9 DL 19-9 DX. These stainless steels are not heat treatable, but can be hardened to a limited extent by cold working or hot cold working. In chemical composition 19-9DL contains columbium which was replaced by a higher molybdenum and titanium content in 19-9DX.

**CHEMICAL COMPOSITION OF 19-9DL:**

C%	Mn%	Si%	Ph%	Si%	Cr%
0.28-0.35	0.75-1.50	0.30-0.80	0.040	0.030	18.0-21.0
Ni%	Mo%	W%	Cb+Ta	Ti%	Cu%
8.0-11.0	1.0-1.75	1.0-1.75	0.10-0.35	0.10-0.35	0.50
Fe%	Balance				

**CHEMICAL COMPOSITION 19-9DX:**

C%	Mn%	Si%	Ph%	S%	Cr%
0.28-0.35	0.75-1.50	0.30-0.80	0.040	0.030	18.0-21.0
Ni%	Mo%	W%	Ti%	Cu%	Fe%
8.0-11.0	1.25-2.00	1.0-1.75	0.40-0.75	0.50	Balance

**HEAT TREATMENT**

Bar and forgings, 1800° to 2150°F (1/2 to 1 hour) rapid air cool, oil water quench. Sheet/strip, 1650° to 1800°F (1/2 to 1 hour) rapid air cool. Avoid higher temperatures to prevent resolution and precipitation of carbides.

Castings, 1950° to 2050°, 1/2 to 1 hour minimum, air cool.

Solution Treat: Same as anneal.

Stress relief: 1175° to 1225°F (4 hours) air cool. This treatment is applied to hot worked or hot cold worked material for service up to 1300°F. It is also applied to cold worked materials immediately after working to prevent stress cracking.

Age: Bar & forgings, 1200° to 1400°F, casting 1575° to 1625°F, 8 hours minimum, air cool.

**NOTE**

Intergranular corrosion may occur in certain environments unless annealed at 1800°F, followed by rapid cooling.

AM-350. Steel - Age Hardening Stainless. This alloy is one of a series of age hardening steels which combines high strength at temperatures up to 800°F and higher with the corrosion resistance of stainless steels.

**COMPOSITION RANGE**

C%	Mn%	Si%	P%	S%	Cr%
0.08-0.12	0.5-1.25	0-0.5	0-0.04	0-0.03	16.0-17.0
Ni%	Mo%	N%	Fe%		
4.0-5.0	2.5-3.25	0.07-0.13	Balance		

**FORM-SPECIFICATION TABLE 2-2.****HEAT TREATMENT**

Anneal to condition H - 1900° to 1950°F, 3/4 hour minimum per inch of thickness, rapid air cool to 80°F. Anneal to condition L - 1685° to 1735°F, 3/4 hour minimum, per inch of thickness, rapid air cool to 80°F. Subzero cool and age condition L to condition SCT, cool to 100°F, hold 3 hours minimum +850° to 1050°F, 3 hours minimum. Age to condition SCT 850°, 825°-875°F. Age to condition SCT 1000, 975° to 1025°F. Double age either condition H or condition L to condition DA, 1350°-1400°F, 2 hours, air cool to 80°F and heat to 825°-875°F, 3 hours. Thoroughly degreased and cleaned prior to annealing to avoid harmful surface reactions and to facilitate subsequent pickling. Allowance must also be made for growth which will result from heat treating. The expansion on aging from condition H to set amounts to 0.002 -0.004 inch per inch.

**AM-355 Steel - Age Hardening stainless.** This alloy combines high strength at temperatures up to 850°F with the corrosive resistance of stainless steel. This alloy differs from AM-350 by a lower chromium and a higher carbon content. It possesses good formability in the high temperature annealed condition. Corrosion resistance of this alloy is slightly lower than that of AM-350.

**FORM-SPECIFICATIONS** See Specification Table 2-2.

#### HEAT TREATMENT

Anneal to condition H for maximum formability and stability.

Anneal to condition H: Plate and forgings at 1925°-1975°F, 1 hour minimum per inch, water quench; sheet and welded tubing, 1850° to 1900°F, 3/4 hour minimum per inch, rapid air cool. Bar should not be annealed to condition H unless subsequently subjected to forgings. Anneal to Condition L: 1685°-1735°F --- Sheet and strip, 3/4 hour per inch, air cool; plate 3/4 hour inch, oil or water quench. Condition H plate, if not subsequently severely cold formed, should be equalized before annealing to condition L and aging to condition SCT. Bar forgings and tubing, 1 hour minimum per inch thickness, oil or water quench. Equalize and age bar for best machineability, 1350°-1400°F, 3 hours, air cool to 80°F maximum + 1000° to 1050°F, 3 hours. Resulting should be approximately RC38 Subzero cool and age condition L to condition SCT, cool to -100°F, hold 3 hour minimum, 850° to 1050°F for 3 hours minimum. Age condition SCT 850, 825° to 875°F. Age to condition SCT 1000, 975° to 1025°F. Double age condition L to condition DA, 1300° to 1450°F 1 to 2 hours, air cool to 80°F, 825° to 875°F,

3 hours minimum. Homogenize sand and shell mold castings, 2000°F, 2-4 hours, air cool up to 1 inch thick, oil or water quench, section above 1 inch.

**HNM. Steel - Age Hardening Stainless.** This is a precipitation hardening austenitic steel, with high rupture and creep properties in the 1000°-1400°F and not prone to overage at these temperatures. In the solution annealed condition it has a Brinell hardness of 201 maximum. It has a low magnetic permeability, and is suitable for transformer parts, non-magnetic bolts, aircraft structural, engine components, shafts and gears. This material is very susceptible to work hardening. It is somewhat inferior to regular 18cr-8ni stainless types, however, machining requirements are similar requiring heavy positive feeds and sharp cutting tools. Welding is not recommended, however brazing may be successfully accomplished by use of orayacetylene torch and furnace methods, using an alloy conforming to specification AMS 4755.

#### COMPOSITION RANGE

C%	Cr%	Mn%	Ni%	P%	Si%	S%	Iron
0.30	18.5	3.5	9.5	0.25	0.5	0.025	Balance

**FORM-SPECIFICATIONS.** See Specification Table 2-2.

#### HEAT TREATMENT

Anneal 2000°-2150°F, 30 minutes, water quench. Sections 5/8 inches thick may be air cooled. The optimum solution treatment for best properties after aging is approximately 2050°F. Age 1300°F, 16 hours, air cool.

#### AM355

FORM	BAR		SHEET	
	Solution Treat 2050°F 30 minutes oil quench	Solution Treat 2050°F 30 min Water quench	Solution Treat 15 Minutes air cool	Solution Treat 2050°F air cool & age 1300°F, 16 hrs
Tensile PSI	116,000	145,000	106,000	133,000
Yield PSI	56,000	92,000	55,000	90,000
Hardness				
BHN	192	302		
RB			87.5	
RC				33



16-15-6. Steel - Iron - Chromium - Nickel - Alloy  
This alloy was developed as a replacement for 16-25-6 alloy and contains less nickel. However, the lower nickel content is balanced by additional manganese which allows an increase in the nitrogen content that can be retained during melting.

**COMPOSITION RANGE**

C%	Cr%	Mn%	Mo%	Ni%	Si%
0-.07	15.0-17.5	6.5-8.5	5.0-7.0	14.0-17.0	0-1.0
N%	P%	S%	Iron (Fe)		
0.30-0.40	0-0.03	.03	Balance		

**FORM** Bar, forging.

**SPECIFICATION.** None.

**HEAT TREATMENT**

Anneal 1700°-2300°F.  
Solution treat 2125°-2175°F, air cool, water or oil quench, depending on section size. Cold work (about 20% reduction) and age (bar up to 1-1/2 inch 1200°-1300°F, 2 to 8 hours. At a temperature of 1200°F a tensile of 145,000 and yield of 100,000 psi is obtained.

V57. Steel - Nickel Chromium Stainless (Austenitic).  
This alloy has a good combination of tensile and creep rupture properties up to 1500°F at high stresses and is used for some parts of aircraft gas turbines.

**COMPOSITION RANGE**

Al%	B%	C%	Cr%	Mn%	Mo%	Ni%	Si%
0.25	0.008	0.06	15.0	0.25	1.25	25.5	0.55
Ti%	V%	S%	P%	Iron			
3.0	0.25	0.025	0.025	Balance			

**FORM.** Bar, Forging.

**SPECIFICATION.** None.

**HEAT TREATMENT**

Anneal 1700°-2300°F.  
Solution treat 2125°-2175°F, air cool, water or oil quench, depending on section size. Cold work (about 20% reduction) and age (bar up to 1 1/2 inch) 1200°F -1300°F 2 to 8 hours.

At a temperature of 1200°F a tensile of 145,000 and yield of 100,000 psi is obtained.

**SUPPER ALLOYS H/L**

V36. Steel Cobalt Base - Chromium-Nickel-Alloy.  
This is a solid solution - hardening alloy for service at 1300°-1800°F where strength and corrosion resistance is important. Used for guide vanes in gas turbines, after burner parts and high temperature springs. Chiefly furnished in sheet, but may be supplied in billet, bar, forging and wire.

**COMPOSITION RANGE**

C%	Cr%	C1%	Ta%	Iron%	Mn%	Mo%
0.25-0.33	24.0-26.0	1.5-2.5	0-5.0	0-1.2	3.5-4.5	
Ni%	Si%	W%	S%	P%	Cobalt	
19.0-21.0	0-1.0	1.5-2.5	0-0.03	0-0.03	Balance	

**SPECIFICATION.** None.

**HEAT TREATMENT**

This alloy is primarily solid solution hardened and only small strength increases can be obtained by aging. Solution treatment for thick sections 2200°-2275°F, 1 hour, water quench. Age 1400°F for 16 hours. Stress relieve cold worked alloy 900°F, 2 hours.

**TYPE V36**

FORM Condition	SHEET		
	Sol Treat 15 min 2250°F+age	Sol Treat +20%, cool rapidly	Sol Treat +60%, cool rapidly
Tensile	147,000	166,000	279,000
Yield	83,000	127,000	248,000
RC	25	---	---

W152. Steel. Cobalt Chromium Tungsten Corrosion Resistant Alloy. This is a casting alloy generally used in the "as-cast" condition. It is used for investment cast parts requiring high stress rupture properties at elevated temperatures, has excellent castability and foundry characteristics. Primary use has been first-stage turbine vanes.

Alternate Designations. Haynes Alloy No 152, PWA 653, CF 239.

**COMPOSITION RANGE.**

C%	Cr%	C1+TA	Iron%	Mn%	Ni%
0.40-0.5	20.0-22.0	1.5-2.5	1.0-2.0	0-0.5	0-1.0
Si%	W%	P%	S%	Cobalt	
0-0.5	10.0-12.0	0-0.04	0-0.04	Balance	

**SPECIFICATION.** None.

**FORMS.** Available in "as cast condition."

**HEAT TREATMENT**

Stress relief: 1575<sup>o</sup>-1625<sup>o</sup>F, 2 hours, air cool.  
Age hardening: Above 1200<sup>o</sup>F susceptible to age hardening which increases alloy strength but causes loss in ductility.

Tensile Strength: As cast, tensile strength 125,000 psi. Rockwell As cast, RC38.

**HAYNES ALLOY NO 151.** Cobalt Base Corrosion Resistant Alloy. This alloy may be air melted or air cast. It is used as gas turbine blades and rotors within the heat range 1200<sup>o</sup>-1700<sup>o</sup>F.

**COMPOSITION RANGE**

B%	C%	Cr%	Iron%	Mn%	Ni%
0.03-0.08	0.4-0.5	19.0-21.0	0-2.0	0-1.0	0-1.0
Si%	Ti%	W%	P%	S%	Cobalt%
0-1.0	0.05-0.5	12.0-13.5	0-0.03	0-0.03	Balance

**SPECIFICATION.** None.

**FORMS.** Available as castings and investment castings.

**HEAT TREATMENT**

This material is generally used in the "as cast" condition. The best creep rupture properties are in the 1300<sup>o</sup>-1500<sup>o</sup>F range. Solution treat 2170<sup>o</sup>-2200<sup>o</sup>F 1 hour minimum, rapid air cool. This treatment reduces tensile properties below 1400<sup>o</sup>F and lowers creep rupture strength.

Aging 1400<sup>o</sup>F 4 hours air cool after solution treating, results in higher tensile properties than "as cast" material, but creep rupture properties are somewhat lower than the "as cast" alloy.

**Hardenability** As-Cast hardness at room temperature RC33.

**GMR-235.** Nickel Base Corrosive Resistant Alloy. GMR-235 and GMR-235D are nickel based alloys precipitation hardening, high temperature alloys developed for investment cast gas turbine wheels, buckets and vanes, operating above 1400<sup>o</sup>F. They are similar to Hastelloy R-235 but contain more aluminum. The composition with maximum aluminum and titanium content is designated GMR-235D.

**COMPOSITION RANGE**

	GMR-235		GMR-235D	
	MIN	MAX	MIN	MAX
A1	2.5	3.5	3.25	4.0
B	0.05	0.1	0.05	0.1
C	0.1	0.2	0.1	0.2
Cr	14.0	17.0	14.0	17.0
Co	0.1	0.2	0	0
Iron	8.0	12.0	3.5	5.0
Mn	0	0.25	0	0.1
Mo	4.5	6.0	4.5	6.0
Si	0	0.60	0	0.3
Ti	1.5	2.5	2.0	3.0
Ni	Balance	Balance	Balance	Balance

**SPECIFICATIONS.** None.

**HEAT TREATMENT.**

Solution treatment 2050<sup>o</sup>F 1 to 3 hours, air cool (GMR 235) Solution treatment 2100<sup>o</sup>F 2 hours, air cool (GMR-235D). For heavier sections (of both alloys) temperatures should be increased to 2150<sup>o</sup>F, 2 to 4 hours, air cool. Aging at 1800<sup>o</sup>F, 5 hours from the "as cast" condition improves the stress rupture life of the alloy. These alloys precipitation harden rapidly during air cooling and aging treatments are usually unnecessary.

"As-Cast" room temperatures hardness for both alloys is RC36 maximum. Tensile 115,000 psi yield 90,000 psi.

**Form** This material is available in wrought form only, except that GMR235 is available in cast form.

**HASTELLOY ALLOY R-235.** Nickel Base Corrosion Resistant Alloy. This is a nickel base aluminum-titanium precipitation hardening alloy. It possesses high strength up to 1800<sup>o</sup>F with good resistance to oxidation and overaging in high temperature service. This alloy is readily fabricated and welded in the solution treated condition.



**COMPOSITION RANGE**

A1%	B%	C%	Cr%	Co%	Iron%
1.75-2.25	0-0.009	0-0.16	14.0-17.0	0-2.5	9.0-11.0
Mn%	Mo%	Si%	Ti%	P%	S%
0-0.25	4.5-6.5	0-0.6	2.25-2.75	0-0.01	0-0.03
Ni%	Balance				

**SPECIFICATION.** None.**FORMS.** Sheet, Strip, Plate, Bar and Wire.**HEAT TREATMENT**

Solution treatment 1950°-2000°F 1/2 hour, water quench. Material treated at higher solution temperature (2200°F) is subject to strain-age cracking. Final heat treatment after fabrication of sheet and bar depends upon properties desired. To obtain maximum long time stress-rupture life, solution treat at 2175°-2225°F, 15 minutes, water quench. Then heat to 2025°-2075°F, hold at temperature for 30 minutes and cool in still air. To obtain maximum room and high temperature tensile strength or short time rupture strength, solution treat at 1950°-2000°F hold at temperature for 30 minutes and air cool. Then age at 1385°-1415°F hold at temperature for 16 hours and air cool.

**TYPE HASTELLOY ALLOY R-235**

FORM	SHEET	
Condition	Sol Treat 1975°F Water Quench 0.021	Sol Treat 2200°F Water Quench 0.70
Thickness - in		
Tensile, Max psi	150,000	150,000
Yield, Max psi	95,000	95,000
RC-Max	27	25

**INCONEL ALLOY 718.** Steel Nickel Chromium Stainless Alloy. This is a relatively new alloy and heat treatment and fabrication procedures are still under development. It has good properties up to 1300°F, slow response to age-hardening and good ductility from 1200°-1400°F. It is readily welded in either the annealed or aged condition.

**COMPOSITION RANGE**

A1%	C%	Cr%	C1%+Ta%	Cu%	Mn%
0.4-1.0	0-0.1	17.0-21.0	4.5-5.75	0-0.75	0-0.50
Mo%	Ni%	Si%	Ti%	S%	Iron
2.0-4.0	50.0-55.0	0-0.5	.3-1.3	0-0.03	Balance

**SPECIFICATION.** None.**FORMS.** Sheet, Strip, Bar, Investment Castings.**HEAT TREATMENT**

Both single age and double age treatments may be employed, however, the latter is preferred for highest strength up to 1300°F. Solution treat rods, bars and forgings 1800°-1900°F. Somewhat higher creep rupture properties are obtained at the higher temperatures. Solution treat sheet at 1725°F. Single age anneal alloy at 1325°F 16 hours, air cool. Double age anneal alloy at 1325°F 8 hours, furnace cool, 20°F per hour to 1150°F air cool or 1325°F 8 hours, furnace cool, 100°F per hour to 1150°F, hold 8 hours, air cool. Both of these double age treatments appear to give the same results.

**TYPE INCONEL ALLOY 718**

FORM	HOT ROLLED BAR 0.0500 IN DIA		
Condition	Anneal + Age		
	1800°F 1 hour	+	1325°F 16 hour
	8 hour*	8 hour**	16 hour
Thickness - in	0.500		
Tensile PSI	211,000	204,000	193,000
Yield PSI	174,000	173,000	154,000

\*Furnace cool at temperature reduction of 100°F per hour to 1150°F hold 8 hours air cool.

\*\*Furnace cool at temperature reduction of 20°F per hour to 1150°F air cool.

**UDIMET 700.** Highly Alloyed Nickel Base Corrosion Resistant. This alloy has higher elevated temperature tensile and stress-rupture strength than most wrought cobalt or nickel based alloys. It also has superior creep resistance, fatigue strength and high oxidation resistance. Welding is generally not recommended.

**COMPOSITION RANGE**

A1%	B%	C%	Cr%			
3.75-4.75	0.025-0.035	0.03-0.1	14.0-16.0			
Co%	Cu%	Iron	Mn%	Mo%	Si%	
17.0-20.0	0-0.1	0-4.0	0-0.15	4.5-6.0	0-0.2	
Ti%	Zr%	S%	Ni%			
2.75-3.75	0-0.06	0-0.015	Balance			

**SPECIFICATIONS** None**FORMS** Bars, Billets, Castings, Forgings

**HEAT TREATMENT**

Solution annealing for castings 2075<sup>o</sup>-2125<sup>o</sup>F 2 hours air cool.

Solution annealing for forgings 2125<sup>o</sup>-2175<sup>o</sup>F 4 hours air cool.

Solution treat. 1950<sup>o</sup>-2000<sup>o</sup>F 4 to 8 hours, air cool.

Intermediate aging 1535<sup>o</sup>-1565<sup>o</sup>F 24 hours air cool.

Final aging 1385<sup>o</sup>-1415<sup>o</sup>F 16 hours air cool.

Hardenes by aging and cold working.

**RENE 41.** Nickel Base Heat Treatable Stainless Alloy. This alloy possesses exceptional mechanical properties at temperatures up to 1800<sup>o</sup>F. It can be formed and also welded in the annealed condition. If cooled at a slower rate than specified, e.g. in less than 4 seconds from 2150<sup>o</sup>F to 1200<sup>o</sup>F, age hardening results and forming becomes difficult. Distortion is comparatively low if material is subsequently solution treated and water quenched. Best machinability is obtained in the fully aged condition after either oil or water quenching from solution treating temperature. This alloy may be fusion welded if copper and gas backing with a tight hold down is used. Start and finish should be made on metal tab of the same thickness using an inert gas atmosphere of 2 helium to 1 argon. Following the torch with a water spray reduces the hardness and produces maximum ductility in the weld and heat affected zones.

**COMPOSITION RANGE**

C%	Mn%	Si%	Cr%	Ti%	Al%
0.06-0.12	0-0.5	0-0.5	18.0-20.0	3.0-3.3	1.5-1.8

Mo%	B%	Co%	Iron%	Ni%
9.0-10.5	0-0.01	10.0-12.0	0-5.0	Balance

**SPECIFICATIONS:** None

**FORMS:** Sheet, Strip, Plate, Bar, Wire.

**HEAT TREATMENT**

For maximum formability 1950<sup>o</sup>-2150<sup>o</sup>F 30 minutes, water quench or cool from 2150<sup>o</sup> to 1200<sup>o</sup>F in 4 seconds maximum.

Solution treat 1950<sup>o</sup>-2150<sup>o</sup>F 30 minutes, quench or air cool.

Heat treatment for high short time strength: Solution treat 1950<sup>o</sup>F 30 minutes, cool to 1200<sup>o</sup>F in 4 seconds maximum + 1400<sup>o</sup>F, 16 hours.

Heat treat for good ductility and high creep rupture strength, solution treat 2150<sup>o</sup>F 30 minutes + 1650<sup>o</sup>F 4 hours. Hardenability: Alloy must be water quenched to retain soft solution treated conditions.

## TYPE RENE 41.

FORM	ALL	
Condition	2150 <sup>o</sup> F air cooled	2150 <sup>o</sup> F water quenched
Tensile	195,000	130,000
Yield	160,000	65,000
Rockwell Hardness	RC43	RB93

**NICROTUNG.** Nickel Base Corrosion Resistant Alloy. This is a nickel base investment casting alloy which is strengthened by addition of cobalt, aluminum and titanium. It has high creep strength and excellent oxidation resistance in the high temperature range 1500<sup>o</sup>-1800<sup>o</sup>F combined with good room temperature strength.

**COMPOSITION RANGE**

Al%	B%	C%	Cr%	Co%
3.75-4.75	0.02-0.08	0.08-0.13	11.0-13.0	9.0-11.0
Ti%	W%	Zr%	Ni%	
3.75-4.75	7.0-8.5	0.02-0.08	Balance	

**SPECIFICATIONS.** None

**FORMS.** Investment castings.

**HEAT TREATMENT**

Heat treatment is not recommended for this alloy. This material has "as-cast" hardness of RC38-40.

**NIMONIC 105.** Nickel-Cobalt-Chromium Corrosion Resistant Alloy. This alloy has excellent resistance to creep at very high temperatures. It is designed for use as turbine blades and rotors used in gas turbines. Corrosion resistance is good and resistance to oxidation under repeated heating and cooling is very good.

**COMPOSITION RANGE**

Al%	C%	Cr%	Co%	Cu%	Iron%
4.2-4.8	0-0.2	13.5-16.0	18.0-22.0	0-0.5	0-1.0
Mn%	Mo%	Si%	Ti%	Ni%	
0-1.0	4.5-5.5	0-1.0	0.9-1.5	Balance	

**SPECIFICATION.** None.

**FORMS.** Sheet, Strip, Bar.

## HEAT TREATMENT

For maximum stress-rupture life in range 1560°1740°F, fully heat treat solution treat, and double age as follows: Solution treat 21020F 4 hours, air cool. Double age 19220F, 16 hours, air cool and 1526°F, 8 hours, air cool. Where stress rupture strength above 15620F is not the important property, but tensile strength, elongation and impact strength up to 12920F is desired, the following heat treatment is recommended.

Solution treat 21040F, 4 hours, air cool.

Age 15620F, 16 hours, air cool.

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### **2-75. MACHINING OF STEELS (GENERAL)**

**2-76.** There are five basic factors affecting machinability as related to steel: They comprise (1) the capacity and rigidity of the machine tool; (2) cutting fluids; (3) design composition and hardness of the cutting tool; (4) cutting condition with respect to feeds and speeds; and (5) the structure of the steel to be machined.

**2-77.** The cutting tool angles (back rake, side clearance, front clearance, and side rake) are highly important in the machining of metals. The range of values based on general practice for the machining of steel and steel alloys, are as follows: (1) back rake angle, 8-16 degrees; (2) side rake angle, 12-22 degrees; (3) front clearance angle, 8-13 degrees; and (4) side clearance angle, 10-15 degrees.

**2-78.** Regardless of the material of which the cutting tool is made, the cutting action is the same. The main difference is the cutting speed. The carbon-steel tool cuts at low speed. The high-speed tool cuts at twice the speed of carbon-steel, the cast alloys at twice the speed of high-speed steel, and the sintered carbides at twice that of the cast alloys. The cutting speeds listed in Table 2-4 are approximate speeds using high-speed steel tools, and are to be used only as a basis from which proper speeds for a particular part may be calculated. These speeds are based on SAE 1112 steel, which is assigned a machinability rating of 100%. In order to obtain an approximate starting speed for different steels, select the type of operation, the width, depth or diameter of cut and obtain the recommended cutting speed for SAE 1112 from Table 2-3 then refer to Table 2-4 for the percent rating of the metal to be machined, and multiply the SFM value from Table 2-5 by the rating in Table 2-4. The result is the recommended surface feet per minute (SFM) for the cutting operation. For a known diameter and surface feet per minute (SFM) to be used for an operation, the corresponding revolution per minute (RPM) can be obtained from Table 2-5.

**2-79.** The term cutting feed is used to express the axial distance the tool moves in each revolution. A coarse feed is usually used for roughing operations, and a fine feed for finishing operations. In general, the feed remains the same for different cutting tool steels, and only the speed is changed. Approximate cutting feeds are listed in Table 2-3. For tool corrections when improper machining on an operation is encountered, refer to Table 2-6 for recommended checks.

**2-80.** The use of a proper coolant (cutting fluid) often results in an increase of cutting speed for the same tool life, and also acts as a lubricant giving better cutting action and surface finish. Recommended cutting fluids for steels are lard oil, mineral oils, sulphurized oils, and soluble or emulsifiable oils.

TABLE 2-3. CUTTING SPEEDS AND FEEDS FOR SAE 1112 USING STANDARD HIGH SPEED TOOLS.

TOOL NAME	SIZE OF HOLE, IN.	WIDTH OR DEPTH OF CUT, IN.	SURFACE FPM	FEED IN./REV
Form: Circular or Dovetail	--	Width - 0.500 Width - 1.000 Width - 1.500 Width - 2.000 Width - 2.500	165 160 160 155 150	0.0025 0.0020 0.0018 0.0015 0.0012
Twist Drills	0.250 0.500 0.750 1.000 1.250		105 105 115 115 120	0.0045 0.005 0.006 0.007 0.008
Box Tools Blade		Depth - 0.125 Depth - 0.250 Depth - 0.375 Depth - 0.500	165 160 155 150	0.007 0.0065 0.0055 0.0045
Threading & Tapping	Over 25 Pitch 15 to 25 Pitch Less than 15 Pitch		30-40 20-30 15-20	
Hollow Mills		0.062 0.125 0.187 0.250	150 140 135 130	0.010 0.008 0.007 0.0065
Reamers	Under 1/2" Over 1/2"		145 145	0.007 0.010
Cut Off		Width - 0.062 Width - 0.125 Width - 0.187 Width - 0.250	165 175 180 190	0.002 0.0025 0.0025 0.003

TABLE 2-4. MACHINABILITY RATING OF VARIOUS METALS.

SAE DESIGNATION	RATING %	BRINELL HARDNESS
1010	50	131-170
1015	50	131-170
1020	65	137-174
1022	70	159-192
1025	65	116-126
1035	65	174-217
1040	60	179-229
1045	60	179-229
1050	50	179-229
1055	55	192-197
1060	60	183-201
1070	45	183-241
1080	45	192-229
1095	42	197-248
1112	100	179-229
1117	85	143-179
1137	70	187-229
2317	55	174-217
2330	50	179-229
2340	45	187-241
2515	30	179-229
3115	65	143-174
3140	55	187-229
3310	40	170-229
4037	65	170-229
4130	65	187-229
4135	64	170-229
4137	60	187-229
4140	66	179-197
4150	50	187-235
4337	50	187-241
4340	45	187-241
4615	65	174-217
4620	62	152-179
4640	55	187-235
5210	30	183-229
6150	50	197
8615	67	170-217
8617	63	170-217
8620	60	170-217
8630	65	179-229
8640	60	179-229
8735	55	179-229
8740	60	179-229
9260	45	187-255
9262	45	187-255
9310	40	207-217

TABLE 2-5. CONVERSION OF SURFACE FEET PER MINUTE (SFM) TO REVOLUTIONS PER MINUTE (RPM)

DIAMETER IN INCHES	SURFACE FEET PER MINUTE												
	10	15	20	25	30	40	50	60	70	80	90	100	110
1/16	611	917	1222	1528	1823	2445	3056	3667	4278	4889	5500	6111	6722
1/8	306	458	611	764	917	1222	1528	1833	2139	2445	2750	3056	3361
3/16	204	306	407	509	611	815	1019	1222	1426	1630	1833	2037	2241
1/4	153	229	306	383	458	611	764	917	1070	1222	1375	1528	1681
5/16	122	183	244	306	367	489	611	733	856	978	1100	1222	1345
3/8	102	153	204	255	306	407	509	611	713	815	917	1010	1120
7/16	87	131	175	218	262	349	437	524	611	698	786	873	960
1/2	76	115	153	191	229	306	382	458	535	611	688	764	840
9/16	68	102	136	170	204	272	340	407	475	543	611	679	747
5/8	61	92	122	153	183	244	306	267	428	489	550	611	672
11/16	56	83	111	139	167	222	278	333	389	444	500	556	611
3/4	51	76	102	127	153	203	255	306	357	407	458	509	560
13/16	47	71	94	118	141	188	235	282	329	376	423	470	517
7/8	44	65	87	109	131	175	218	262	306	349	393	436	480
15/16	41	61	81	102	122	163	204	244	285	326	367	407	448
1	38	57	76	96	115	153	191	229	267	306	344	382	420
1 1/8	34	51	68	85	102	136	170	204	238	272	306	340	373
1 1/4	31	46	61	76	92	122	153	183	214	244	275	306	336
1 3/8	28	42	56	69	83	111	139	167	194	222	250	278	306
1 1/2	25	38	51	64	76	102	127	153	178	204	229	255	280
1 5/8	24	35	47	59	70	94	117	141	165	188	212	235	259
1 3/4	22	33	44	55	65	87	109	131	153	175	196	218	240
1 7/8	20	31	41	51	61	81	102	122	143	163	183	204	224
2	19	29	38	48	57	76	95	115	134	153	172	191	210
2 1/4	17	25	34	42	51	68	85	102	119	136	153	170	187
2 1/2	15	23	31	38	46	61	76	92	107	122	137	153	168
2 3/4	14	21	28	35	42	56	69	83	97	111	125	139	153
3	13	19	25	32	38	51	64	76	89	102	115	127	140

DIAMETER IN INCHES SURFACE FEET PER MINUTE

DIAMETER IN INCHES	120	130	140	150	160	170	180	190	200	225	250	270	300
1/16	7334	7945	8556	9167	9778	10390	11000	11612	12223	13751	15279	16807	18334
1/8	3667	3973	4278	4584	4889	5195	5500	5806	6111	6875	7639	8403	9167
3/16	2445	2648	2852	3056	3259	3463	3667	3871	4074	4584	5093	5602	6112
1/4	1833	1986	2139	2292	2445	2597	2750	2903	3056	3438	3820	4202	4584
5/16	1467	1589	1711	1833	1956	2078	2200	2322	2445	2750	3056	3361	3667
3/8	1222	1324	1436	1528	1630	1732	1833	1935	2037	2292	2546	2801	3056
7/16	1048	1135	1222	1310	1397	1484	1572	1659	1746	1964	2183	2401	2619
1/2	917	993	1070	1146	1222	1299	1375	1451	1528	1719	1910	2101	2292
9/16	815	883	951	1019	1086	1154	1222	1290	1358	1528	1698	1867	2037
5/8	733	794	856	917	978	1039	1100	1161	1222	1375	1528	1681	1833
11/16	667	722	778	833	889	945	1000	1056	1111	1250	1389	1528	1667
3/4	611	662	713	764	815	866	917	968	1019	1146	1273	1401	1528
13/16	564	611	658	705	752	799	846	893	940	1058	1175	1293	1410
7/8	524	567	611	655	698	742	786	829	873	982	1091	1200	1310
15/16	489	530	570	611	652	693	733	774	815	917	1019	1120	1222
1	458	497	535	573	611	649	688	726	764	859	955	1050	1146
1 1/8	407	441	475	509	543	577	611	645	679	764	849	934	1019
1 1/4	367	397	428	458	489	519	550	581	611	688	764	840	917
1 3/8	333	361	389	417	444	472	500	528	556	625	694	764	833
1 1/2	306	331	357	382	407	433	458	484	509	573	637	700	764
1 5/8	282	306	329	353	376	400	423	447	470	529	588	646	705
1 3/4	262	284	306	327	349	371	393	415	437	491	546	600	655
1 7/8	244	265	285	306	326	346	367	387	407	458	509	560	611
2	229	248	267	287	306	325	344	363	382	430	477	525	573
2 1/4	204	221	233	255	272	289	306	323	340	382	424	467	509
2 1/2	183	199	214	229	244	260	275	290	306	344	382	420	458
2 3/4	167	181	194	208	222	236	250	264	278	313	347	382	417
3	153	166	178	191	204	216	229	242	255	286	318	350	382

TABLE 2-6. TOOL CORRECTION CHART.

<p><b>A. TOOL CHATTER</b></p> <p>Check: 1. Tool overhand (reduce to minimum)  2. Work Support (eliminate vibration)  3. Nose radius (too large a radius may cause chatter)  4. Tool clearance (be sure end cutting edge angle is sufficient)  5. Feed (increase feed if too light a feed has tendency to rub rather than cut)  6. Tool load (vary side cutting edge angle to correct improper load)  7. Chip breaker (widen breaker if chips are too tight.)</p>
<p><b>B. CHIPPING OF CUTTING EDGE</b></p> <p>Check: 1. Edge sharpness (Hone or chamber slightly)  2. Chip Breaker (widen breaker if tight chip causes chipping)  3. Speed (Increase)  4. Coolant (Heating and cooling of tip may cause chipping)</p>
<p><b>C. RAPID TOOL WEAR</b></p> <p>Check: 1. Feed (Increase)  2. Speed (Low and excessive speeds cause tool wear)  3. Relief angles (clearance may not be sufficient)  4. Nose radius (decrease size)</p>
<p><b>D. UNSATISFACTORY FINISH</b></p> <p>Check: 1. Speed (rough finishes can be eliminated by increasing speed)  2. Nose radius (too large a nose radius mats finish)</p>

**2-81. MACHINING CORROSION RESISTING STEEL**

**2-82.** The corrosion resisting steels, especially the 18-8 grades, are more difficult to machine than the carbon steels and most other metals. Even though they are more difficult to machine, the same general methods are used with modification/compensation for the individual characteristics of each type or grade. To improve machining characteristics of some types, their chemical content is modified by adding selenium (Se) and sulfur (S). The modified alloys which are usually designated by a suffix to type number such as 430 F or Se. Exceptions are types 416 and 303.

**2-83.** For comparison and as a general guide to the machining characteristics of free machining screw stock grade B1112 as an 100% machinable "norm. " This table is only intended as a starting point and is not intended to replace any information accumulated through experience or other available data.



**TABLE 2-7. GENERAL MACHINING COMPARISON OF CORROSION RESISTING STEEL TO FREE MACHINING SCREW STOCK B1112.**

<u>GRADE/TYPE</u>	<u>MACHINABILITY RATING</u>	<u>GRADE/TYPE</u>	<u>MACHINABILITY RATING</u>
Group I 430F	80%	Group III 420	45%
416	75%	431	45%
420F	70%	440	45%
303	65%	442	45%
		446	45%
		347	40-45%
Group II 403	55%	Group IV 302	40%
410	50%	304	40%
430	50%	309	40%
440F	50%	316	40%

**2-84.** In machining of the corrosion resisting steels, difficulty will be experienced from seizing, galling and stringing. To overcome these problems requires control of speeds, cutting tools, and lubricants. The following general practices are recommended for shaping/grinding cutting tools, equipment, etc., for cutting corrosion resisting steel:

- a. Select tools of proper alloy/type and keep cutting edges sharp, smooth, free of burrs, nicks and scratches.
- b. Avoid overheating cutting tool when grinding to prevent surface and stress cracking.
- c. Grind tools with generous lip rake and with ample side and front clearance.
- d. Speeds are critical in machining stainless; select speed about 50% slower than those used for carbon steels as a starting point.
- e. In general, use slow speeds and heavy feed to reduce effect of work hardening. Avoid riding of tool on work and intermittent cutting when possible.
- f. Apply proper lubricant/coolant to cutting tool to prevent overheating.
- g. Support cutting tool rigidly near work to prevent lash and other difficulty from use of heavy cutting feeds.

**2-85.** Cutting Tools for Machining Corrosion Resisting Steels. Selection of cutting tool is important for machining stainless due to tough machining characteristics. The following is a recommended guide for selection of tools: a. For general machining and short runs use high speed tool steels such as Tungsten Type T1 (18-41) and Molybdenum-Tungsten Type M3 (6-6-3).

- a. For general machining and short runs use high speed tool steels such as Tungsten Type T1 (18-41) and Molybdenum-Tungsten Type M3 (6-6-3).
- b. For medium runs at approximately 25% higher speed, use Tungsten-Cobalt Type T5 (18-4-2-8) and Tungsten-Cobalt Type T4.
- c. For long production runs at high speed, use Tungsten Carbides. Cutting tool of these alloys can be used at approximately 100% faster speeds than the Tungsten-Cobalt type.

#### NOTE

**Some types of tool steel are available in raw stock IAW Federal Specifications, see paragraph 7-4. Prior to attempting local manufacture of cutting tools, facilities/ equipment must be available to properly heat treat. In addition, from an economic standpoint, it is usually advisable to obtain most cutting tools prefinished to size, etc., and heat treated.**

#### **2-86. TURNING OF THE CORROSION RESISTING STEELS.**

**2-87.** Tools for turning the corrosion steels should be ground with a heavy side rake clearance for maximum cut freedom. The upper surface of the tool should be finished with a fine wheel or hand stoned to prevent galling. For chip disposal or breakage a chip groove is usually necessary except with the free machining grades. In addition, the chip breakage is a safety precaution to prevent difficulty and hazards in breaking the expelled cutting. Do not allow tools to become dull to prevent surface hardening from rubbing and hard spots which are difficult to remove.



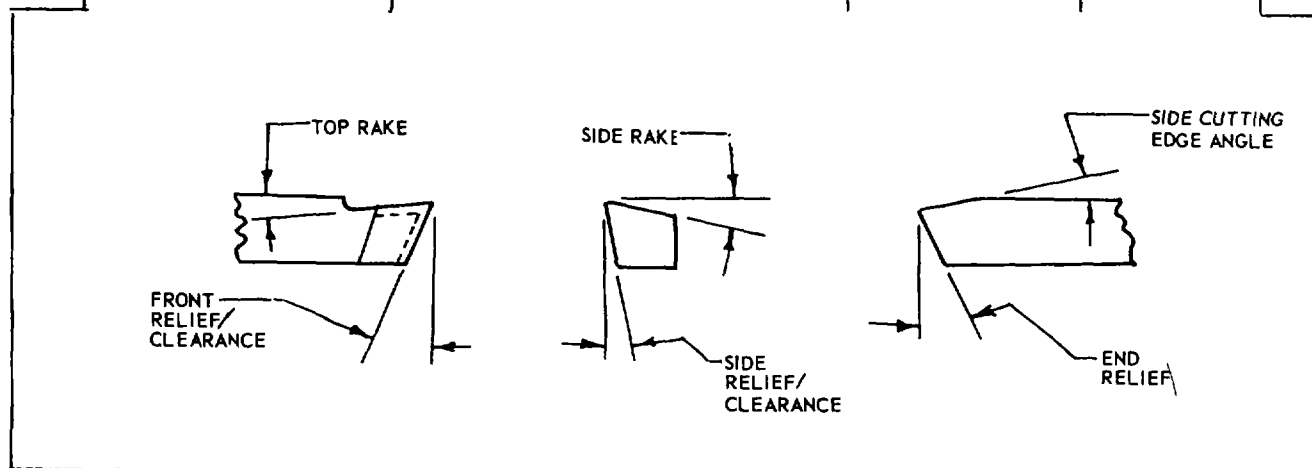
**TABLE 2-8. SUGGESTED CUTTING SPEEDS AND FEEDS.**

<u>ALLOY TYPE/GRADE</u>	<u>FEED INCH 1/</u>	<u>CUTTING SPEED SURFACE FT. PER MIN.</u>	<u>OPER</u>	<u>TOOL MATERIAL</u>
302, 304, 309, 310, 314, 316	0.020-0.040	20-40	Rough	High Speed Steel
	0.008-0.015	50-80	Finish	High Speed Steel
	0.020-0.040	40-60	Rough	Tungsten-Cobalt
	0.008-0.015	90-110	Finish	Tungsten-Cobalt
	0.010-0.030	150-200	Rough	Carbide
	0.008-0.018	150-300	Finish	Carbide
420, 431, 440, 442, 446, 347, 321	0.015-0.040	20-40	Rough	High Speed Steel
	0.008-0.018	55-90	Finish	High Speed Steel
	0.015-0.040	40-80	Rough	Tungsten-Cobalt
	0.008-0.018	100-130	Finish	Tungsten-Cobalt
	0.015-0.030	165-220	Rough	Carbide
	0.005-0.015	165-330	Finish	Carbide
430F, 416	0.015-0.040	30-60	Rough	High Speed Steel
	0.008-0.018	75-120	Finish	High Speed Steel
	0.015-0.040	60-105	Rough	Tungsten-Cobalt
	0.005-0.015	135-180	Finish	Tungsten-Cobalt
	0.010-0.030	225-300	Rough	Carbide
	0.005-0.015	225-450	Finish	Carbide
420F  303	0.015-0.050	25-55	Rough	High Speed Steel
	0.005-0.015	65-105	Finish	High Speed Steel
	0.020-0.050	50-90	Rough	Tungsten-Cobalt
	0.005-0.015	100-155	Finish	Tungsten-Cobalt
	0.010-0.030	175-240	Rough	Carbide
	0.005-0.015	195-350	Finish	Carbide

NOTE: 1/ Feeds cited are based on turning 1 inch stock or larger. Feeds for smaller sizes should be reduced proportionally to size of material being turned.

TABLE 2-9. TOOLS ANGLES - TURNING.

<u>TOOL ANGLES</u>	<u>HIGH SPEED TOOL STEEL</u>	<u>COBALT</u>	<u>CARBIDE</u>
Top Rake	5°-10°	5°-10°	-5°-3°
Back Rake (side)	4°-10°	8°-15°	6°-12°
Side Clearance	5°-8°	6°-10°	6°-10°
End Relief	4°-10°	4°-10°	4°-10°
Side Cutting Lead	5°-15°	4°-12°	3°-12°
Front Clearance	7°-10°	7°-10°	5°-10°

**NOTE**

In grinding chip breakers, allow for chip to clear work or rough finish will result.

**2-88.** The softer condition of stainless is not necessarily the easiest to cut. It is generally preferable that material be moderately hardened (Brinell 200-240) for best machining. Another factor requiring consideration in machining stainless is high coefficient of thermal expansion which will necessitate adjusting (slacking off) centers as material heats up.

**2-89.** The recommended cutting speeds, tool angles and feeds for turning corrosion resisting steel are cited in Tables 2-8 and 2-9.

**2-90. MILLING CORROSION RESISTING STEEL.** The same general procedures/equipment are used in working stainless as those used with carbon steel. However, more power and rigid support of tool is required to accomplish cutting due to inherent strength and toughness of the various stainless alloys.

**2-91.** In milling the corrosion resisting steel, difficulty will be experienced from heat build-up. Heat conduction of the chromium-nickel grades is about 50% slower than the carbon steels. This problem can be controlled in most cases by adjusting cutting speeds, tool angles, method of grinding, and use of proper lubricants in adequate quantities. In close tolerance work, controlling of heat build-up is of utmost importance to meet dimensional requirements.

**2-92.** Cutters for Milling. High speed tool steel is used for most milling on stainless. The other grades are used under certain conditions, such as cemented carbides; however, capacity of equipment and cost of tooling for specific uses requires consideration.

**2-93.** All the standard cutter designs used for cutting carbon steel can be used to cut stainless but preferred design is those with helical (spiral) teeth. The use of helical cutter minimizes vibration and chatter especially when cutter/cut exceeds 1 inch. Chip removal and loading of cutter can be aided when milling slots by staggering teeth to cut successively on alternate sides and half the bottom.

**2-94.** Cutter lands should be ground to narrow width (0.020 to 0.025) with clearance (3°-10° primary angular) behind cutting lip to reduce frictional heat resulting from rubbing. The exact amounts the land is ground will depend on diameter of cutter, material hardness, grade, etc. However, in grinding the lands, care should be taken to avoid unnecessary weakening of support for cutting edge. As a further measure against rubbing, a secondary clearance of 60-120 starting at the back of the land is recommended. On side cutter, angular clearance of 30 to 10° to avoid frictional heat and rubbing is recommended.

#### CAUTION

**Before starting operation/equipment, carefully check for proper set up, safety, rigid support of work and cutters, running condition of equipment, and flow of coolant/lubrication. Once cutting is started, it should be carried to completion to avoid the effects of changes in metal temperature. Naturally the continuous operation will depend on satisfactory operation of equipment and other factors.**

**2-95.** The recommended cutting speeds, tools, angles, and feeds for milling are cited in tables 2-10 and 2-11. The information in these tables is only provided as a starting point, or as a guide.

**TABLE 2-10. SUGGESTED MILLING CUTTING SPEEDS AND FEEDS.**

<u>ALLOY TYPE/GRADE</u>	<u>FEED INCH</u> <u>1/</u>	<u>SPEED</u> <u>SFPM</u>	<u>TOOL MATERIAL</u>
301, 302, 304, 309, 310, 314, 316, 321, 347, 17-4PH, 17-7PH, 420, 431, 440, 442, 446	0.002-0.005	35-70	High Speed Steel
403-410, 430	0.002-0.007	30-95	High Speed Steel
440F	0.002-0.008	35-90	High Speed Steel
303	0.002-0.008	35-70	High Speed Steel
430F, 416	0.002-0.008	50-100	High Speed Steel
420F	0.002-0.006	50-130	High Speed Steel
	0.002-0.006	35-80	High Speed Steel

1/ Use heavy feeds for rough cuts and light feeds for finishing.

**TABLE 2-11. SUGGESTED TOOL ANGLES - MILLING.**

<u>TOOL ANGLES</u>	<u>TOOL MATERIAL</u>		
	<u>HIGH SPEED STEEL</u>	<u>CEMENTED CARBIDE/C</u>	<u>ALLOY</u>
Rake Radial g	10o-20o	Use lower angle	
Rake Axial A/	30o-50o	Use lower angle	
Clearance	4o-8°	Approximately same	
Land Width	1/64"-1/16"	Approximately same	

1/ Saws, form relieved cutters, and miscellaneous profile cutters, etc. , are sometimes used with rake angle as low as 0 degrees.

**2-96.** Lubrication for Milling. The lubrication of milling cutter is very important to control generation of heat which is considerable in cutting all grades of stainless, and to prevent seizing of chips to cutting edges. The cutting oils used should be applied in large quantities directly on the cutter and zone of cut. The sulphurized oils diluted to desired viscosity with paraffin oil are usually satisfactory.

**2-97. DRILLING CORROSION RESISTING STEEL.**

High speed steel drills are commonly used for drilling stainless. Special types are used for drilling grades (420, 440, etc.) that are abrasive due to high carbon content. Speeds for drilling the high carbon types are usually reduced 25-50% in comparison to the other grades.

Drills for use with the corrosion resisting steels are 2-98. prepared with different cutting angles than used with carbon steel. Drill point/tips for use with the chromium-nickel grades are usually ground with 135°-140° (included) angle and 8°-15° lip clearance. The web support for the point should be as heavy as possible; however, thinning of the web at the point will relieve point pressure. When drilling the free machining 400 series grades the angle is reduced to 118°-130°. For general illustration of point designs see Figure 3-2.

2-99. Speeds used for drilling the corrosion resisting steels should be closely controlled to prevent hardening of metal and excessive drill damage from heat. For suggested drilling speed using high speed steel drill bits, see Table 2-12.

**Table 2-12. DRILLING SPEEDS FOR CORROSION RESISTING STEEL.**

GRADE TYPE	SPEED SFPM (APPROX)
301, 302, 304, 310	20 - 40
303	40 - 80
309, 316, 321, 347	30 - 50
403, 410	35 - 75
416, 420F, 430F	60 - 95
420 AB & C	20 - 40
442, 446	30 - 60

**NOTE**

**Do not let drill ride on work to prevent work hardening and heat damage to drill. On larger diameter drills use chip curling grooves to help expel and prevent chip accumulation in area of hole being drilled.**

**2-100.** Lubrication for Drilling Stainless. The recommended lubrication for general use and light drilling is soluble oil, and for heavy work, sulphurized mineral or fatty oils. Utilization of adequate lubrication/coolant is of utmost importance in drilling stainless due to poor heat conduction of this material.

**2-101. REAMING CORROSION RESISTING STEEL.**

The recommended reamer for the corrosion resisting steels is the spiral fluted type which is made from high speed steel/carbide tipped. These spiral fluted reamers are used to help alleviate chatter and chip removal that are associated with the straight fluted reamers.

**2-102.** Due to the work hardening characteristics of the corrosion resisting steel, it is advisable to leave sufficient stock to insure that cutting will occur behind the work hardening surface resulting from drilling. The recommended material to be left for reaming is 0.003-0.007 inch, and feed per revolution should be 0.003-0.005 for holes up to 1/2 inch and 0.0050-0.010 for reamers up to 1 inch diameter.

**2-103.** Reamers for cutting stainless should have a 260-300 starting chamfer with a slight lead angle behind the chamfer of 10--2° for about 1/8-3/16 inch on the land to reduce initial shock of cutting.

The land should be ground with a clearance of 4°70 (and width should not be reduced below 0.0100-0.012 inch) to reduce rubbing and frictional heat.

**2-104.** Speeds for reaming will vary according to type of material being cut. The recommended speed for reaming types 301, 302, 304, 316, 321, 347, 403 and 410 is 20-75 surface feet per minute; for 430F, 420F, 416, 440F and 303 -35-100 SFPM; and for 309, 310, 430, 431, 440, 442, 426 20-60 SFPM. Trial should be conducted to determine best cutting for individual operations.

**2-105. TAPPING CORROSION RESISTING STEEL.**

Conventional or standard type taps are used with stainless; however, better results can sometimes be obtained by modification of taps (in shop) as required and by use of two fluted type taps for small holes. For instance modification of taps can be accomplished by grinding longitudinal grooves along the lands, omission of cutting edges on alternate threads and relieving cutting edges will reduce binding and frictional drag.

These modifications will also aid in distribution of lubrication to cutting area, provide additional clearance for chips and compensate for the swelling which is encountered with the softer temper material. The modification is usually accomplished as follows:

1. Longitudinal grooves are ground down the center of each land about 1/3 to 1/2 thread depth and 1/3 to 1/2 approximately of land width.
2. Cutting edges are relieved by grinding a 2°50 radial taper on each land.
3. Lands are narrowed by removing about half the threading area from each land. The portion removed should trail the foremost cutting edge. Also, cutting edge should be ground to have positive hook/rake 15°-20° for softer material and 10°-15 for harder material.

TABLE 2-13. TAPPING ALLOWANCES (HOLE SIZE TO SCREW SIZE)

<u>THREAD/SCREW SIZE</u>	<u>MAJOR DIA.</u>	<u>MINOR DIA.</u>	<u>DRILL SIZE DECIMAL &amp; NR</u>	<u>THREAD DEPTH PERCENT</u>
4-40	0.1120	0.0871+0.002	0.0810-46	95
			0.827-45	90
			0.0860-44	80
			0.0890-43	71
			0.0960-41	49
6-32	0.1380	0.1100+0.004	0.0995-39	95
			0.1040-37	83
			0.1100-35	72
			0.1160-32	54
6-40	0.1380	0.1144+0.0035	0.1065-36	97
			0.1130-33	77
			0.1200-31	65
8-32	0.1640	0.1342+0.004	0.1250-1/8"	96
			0.1285-30	87
			0.1360-29	69
			0.1405-28	57
10-32	0.1900	0.1593+0.003	0.1520-24	93
			0.1562-5/32"	83
			0.1610-20	71
			0.1660-19	59
			0.1695-18	50
1/4-20	0.2500	0.2010+0.005	0.1850-13	100
			0.1875-3/16"	96
			0.1935-10	87
			0.1990-8	78
			0.2090-4	63

**TABLE 2-13. TAPPING ALLOWANCE (HOLE SIZE TO SCREW SIZE) CONT'D.**

<u>THREAD/SCREW SIZE</u>	<u>MAJOR DIA.</u>	<u>MINOR DIA.</u>	<u>DRILL SIZE DECIMAL &amp; NR</u>	<u>THREAD DEPTH PERCENT</u>
1/4-24	0.2500	0.2143+0.003	0.1960-9 2031-13/64" 0.2090-4 0.2130-3	100 86 75 68
1/4-28	0.2500	0.2193+0.002	0.2090-4 0.2130-3 0.2187-7/32"	88 80 67
5/16-24	0.3125	0.2708+0.0032	0.2610-G 0.2656-17/64" 0.2720-1 0.2770-J	95 86 75 65
3/8-24	0.3750	0.3278+0.002	0.3281-2 1/64" 0.3320-Q 0.3390-R	86 70 66
1/2-24	0.5000	0.4579+0.003	0.4531-29/64" 0.4687-15/32"	86 57

**2-106.** In addition to the above, the tap basically should have a taper/chamfer of about 9° with center line on the starting end to facilitate entry into hole.

The taper should be held short (1st thread) for blind holes, and on through holes, it may extend over 3 or 4 threads.

**2-107.** Due to high strength and poorer cutting quality of the stainless series steels, holes for tapping are usually made as large as possible consistent with fit specified by drawing or other data. Actually due to the higher strength of this material less thread area or engagement is required in comparison to most other metals. Due to the above and the fact that less cutting is required, 75% thread depth is generally used as maximum unless otherwise specified. Higher percentages of thread depth are necessary in material when stock is not thick enough to permit the required number of thread. For tapping allowances of some size screws/bolts see Table 2-13.

**2-108.** The decreased thread depth also reduces tendency to gall and seize, power required to drive tap, tap wear, and effect of swelling in soft material.

#### **2-109. Tapping Speeds Corrosion Resisting Steel.**

Tapping speeds used for stainless should be slower than those used for carbon steel. The 18-8 (300 series) are usually tapped at 10-25 SFPM except for the free machining types which are tapped at 15-30SFPM. The straight-chromium 400 series generally is tapped at 15-25 SFPM, except the free machining grades, which are tapped at 15-35 SFPM.

**2-110.** Lubrication for Tapping. The lubrications recommended for tapping are sulphurized mineral oils with paraffin and lard oil. The lubricant serves to prevent overheating as well as lubrication, and if applied under pressure, aids in chip removal. Oil flow/application should be applied before tapping commences to prevent initial congestion of cuttings.

**2-111. SAWING.**

**2-112.** Hack saws (hand )for cutting corrosion resisting steel should be of high speed steel with approximately 32 teeth per inch for light work and approximately 24 teeth per inch for heavy work. The teeth area should be of wavy construction to increase width of cut area to prevent binding. As with cutting other metal, the blade should not be allowed to drag/ride on the return stroke, especially with the 300 series types to prevent work hardening. The hack saw blade should be lightly lubricated with lard oil/other cutting oil for best results.

**2-113. Hack saws (mechanical drive).** Power hack saws are used for heavy cross-cutting section bars, tubing, etc. With the power hack saw, deeper cuts are made at relatively low speed. The deeper cuts are used to get under work hardened surface resulting from previous cut (stroke). The teeth per inch for saw blades average 8-12 and speed of saw travel usually ranges from 50-100 feet per minute depending on type and temper of material being cut. Coolant/lubrication is essential to prevent excess blade damage from heat. Lubrication recommended is soluble oil/ water mixed about 1 part oil to 4 parts water for heavy work, and for light work, a light grade cutting oil.

**2-114. Band Sawing.** Band saws are well suited for low speed (straight line/contour) sawing of stainless/corrosion resisting steel within prescribed limitation. The saw manufacturer's recommendations should be followed for cutting speed, saw selection, etc. However, speeds usually vary with the physical properties, temper, etc. , of type/grade being cut. As general guide, speeds range from 100-125 feet per minute for material under 0.062 and 60-100 FPM for thickness over 0.062 inch. Saw blades must be kept in sharp condition for effective low speed sawing.

**2-115.** For faster cutting with the band saw, the friction cutting method may be employed. In utilizing the friction method, the band saw velocity ranges from 5000FPM for cutting flat 1/32 inch material to about 10,000 FPM for 1/2 inch and 14,000'for 1 inch material; tubing material is run at slightly higher speed. Feed for this method can be considerably higher than is used for slow speed cutting, rates range from about 100 FPM for light gauge to 15-18 FPM for 1/2 inch material. Saw teeth per inch varies from 18for material below 1/8 inch thick to 10 per inch for thicknesses over 1/2 inch.

**2-116.** Heavy pressure to maintain cut is not usually necessary. Pressure should be just sufficient to create proper heating and softening at cut point without forcing the saw. Lubricants should not be used.

**2-117. WELDING . STEEL (GENERAL)****NOTE**

**For general welding procedures, see T. O. 34W4-1-5.**

**2-118. WELDING, TRAININGANDQUALIFICATIONS.** Prior to citing details requiring control in welding, it is appropriate to cite requirements for welders qualifications. Personnel assigned to accomplish welding shall be trained in the handling of equipment, fabrication procedures, i.e., composition and identification of alloys, jiggling, tacking, cleaning, treating, blue print reading, safety, use of tools (hand and machine), and to meet qualification requirements.

**2-119.** Test for aircraft and missile welding operators qualifications are cited in Spec MIL-T-5021 and for welding pressure systems in T.O. 00-25-224. The requirements set forth are intended to ascertain that welders engaged in welding aircraft, aircraft parts and accessories, missiles, missile parts and accessories, and pressure systems/parts possess and maintain a satisfactory level of proficiency. Periodic tests shall be made to assure that welders qualifications are maintained in addition to test and inspection of parts as required by drawings, specifications, technical orders and other technical data. The primary factors involved in the fabrication of any part is that it will meet requirements set forth and this requirement shall not be waived because the work was accomplished by a qualified welder or/person.

**2-120.** The welding of steels is related to individual characteristics of each type/grade. It is therefore essential to have a working knowledge of the welding characteristics of each type. This point is emphasized by the fact that all grades are affected in some manner by heat. The extent affected will depend upon the exposure time (dwell) and temperature subjected. The results of heating such as in welding will change either physical or modify corrosion resistance properties, or both.

**2-121.** Although each welding process presents problems which are peculiar, steels that have good welding characteristics in one particular process generally can be welded by a similar process. Also it will be found that in a particular process the method and source of heat contributes to a difference in response of the material to the welding operation. For Instance, when gas is used as the heat source, slower temperature changed distributed over a wider area prevail than when electricity is used.

**2-122.** Steels that are subject to high (air) hardening tendencies are the most difficult to weld and if the welding process involves high temperature changes, the rate of cooling from the welding temperature must be controlled (retarded) if high hardness and possible cracking in weld and heat affected area is to be avoided. To overcome this problem preheating of the material is utilized and in some instances preheating and postheating are both employed to properly control heat treat and corrosion resisting characteristics. For additional information on preheating/postheating of various alloys, see Table 2-15 and Table 2-18.



**2-123.** The steels that are considered the most satisfactory for welding are those that do not harden appreciably. In selecting steels for welding it is advisable (if other requirements can be attained) to limit carbon/carbon equivalent to a low value as the maximum hardness attainable is proportional to carbon/ carbon equivalent content. The effect of the alloys usually tends to increase hardness, therefore, an alloy steel hardens more readily than straight carbon steel and this factor is considered in selecting an alloy steel for welding applications. Generally the straight carbon steel with a carbon content of 0.30% or below are the best grades for welding. These grades are usually called "welding grades" and they can be successfully welded without preheat at temperature above 600F, unless material is relatively thick. For welding of thick material, preheat of 100°300F is recommended.

**CAUTION**

**Steel for use on aeronautical equipment or other critical applications, with a carbon equivalent above 0.44% and hardenability greater than 4340 shall not be welded without engineering approval by drawings, Technical Orders, etc. "Carbon Equivalent" is defined as being the properties incurred in steel alloys by other alloying elements that result in the same characteristics (usually to a lesser degree) as the addition of pure carbon. Carbon equivalent is determined by the following formula:  $CE = C + Mn + Mo + Cr + Ni + Cu + P$  in accordance with MIL-W-8611.**

**NOTE**

**No welding shall be performed on 4340 heat treated above 200,000 PSI unless specifically approved by the design engineer or drawing.**

**2-124.** When metal temperature is below 60 F, preheat part or weld area as required to a 60 to 300°F range so that metal is somewhere in this range when starting to weld. Avoid other conditions that would effect the physical/mechanical characteristics of the weld to the extent that the part/weld will not meet specification or established requirements/inspections. In addition to the above, medium/high carbon (straight/alloyed) steel usually requires preheating, post-heating or other heat treatment to control stress, shrinkage, etc, necessary to produce a satisfactory weld. For recommended general pre-heat temperatures, see Table 2-15.

**2-125.** When the weld joint is of such design or material thickness requires that more than one pass (commonly called interpass) be used, the metal temperature shall be below 3000F for low carbon steel or within preheat temperature range for medium/ high carbon (straight/alloyed) grades prior to making the next pass. When cooling is required, it shall be allowed to occur naturally, unless otherwise specified by process specification, engineer, etc. In multiple pass welding, the starting point for each pass should be staggered to prevent metal build-up and heat distortion. Also, each pass/layer should be completed and cleaned before starting the next pass/layer.

**2-126. Preparation for Welding.** Before starting the welding operation the following factors shall be considered:

- a. Machine/equipment capability, alignment condition, and set-up, including jigs, etc.
- b. Safety precaution i.e., fire hazards, grounding, eye protection, etc. (See AFM 127-101 and paragraph 2-205.)
- c. Edge preparation, joint design, and cleaning of material before and during the welding operation.
- d. Electrode/filler metal and flux required.
- e. Sequench for welding, including requirement for preheat, postheat, tacking, distortion, etc.
- f. Inspection/test of finished weld/part.
- g. Cleaning before and treatment of finished weld/ part.

**2-127. Cleaning.** It is important that all surfaces in or near the weld joint be free of scale, oxides, grease, oil, dirt, paint or foreign matter which would contaminate the weld. The presence of the above in the weld can cause porosity, inclusions, poor fusion/ penetration, oxidation, holes and difficulty in weld progression/speed.

**2-128. GAS WELDING OF CARBON STEEL GENERAL**

**2-129.** The gas welding of carbon steel (melting temperature 28000F) is normally accomplished using the oxyacetylene process because of high heat producing capacity. By using properly designed welding torches under controlled conditions the oxyacetylene flame can produce temperature of approximately 6000°F. Other gas heating media can be used to a limited extent, however, they do not produce as much heat as acetylene and may materially effect weld characteristics.



**TABLE 2-14. GENERAL FILLER ROD DIA, TIP SIZE, GAS PRESSURE TO METAL THICKNESS SELECTION CHART**

METAL THICKNESS	FILLER ROD DIA	SIZE TIP	WELDING TIP ORIFICE SIZE	REF PRES-SURE APPROX OXY/ACETYLENE	OXY/ACETYLENE USED CU FT PER HOUR APPROX
3.25 -0.62	1/16	1	0.037	1	4 - 4.5
0.062-0.125	1/16- -1/8	2	0.042	2	4.5 - 5.0
0.125-0.1875	1/8	3	0.055	3	7 - 8
0.1875-0.3125	3/16	4	0.063	4	10- 12
0.3125- 7/16 in	3/16	5	0.076	5	18 - 19
7/16 - 1/2 in	1/4	6	0.086	6	20 - 23
1/2 - 3/4 in	1/4	7	0.098	7	34
3/4 - 1 in	1/4	8	0.1065	8	48
Over 1n	1/4	9	0.116	9	56
Over 1n	1/4	10	0.140	10	95
Over 1n	1/4 - 5/16	11	0.147	10	100
Heavy Duty	1/4 - 5/16	12	0.149	10	100

**2-130.** For best results when welding the low carbon steel, a neutral flame is used, and for medium and high carbon steel (above 0.30%carbon), a slight excess of acetylene (carburizing) flame is recommended. The tip and rod diameter for welding, etc., should also be selected according to amount of heat required and thickness of metal involved. For general data on tip sizes, gas pressures etc., see Table 2-14. For general data on rod type/grade selection see Table 2-15.

**NOTE**









**Table 2-14 also generally applies to gas welding of all alloys, i.e., aluminum, stainless, except tips used for stainless and aluminum are selected 1-2 sizes smaller.**

**2-131. SHIELDED METAL ARC WELDING OF CARBON STEEL**





**2-132.** The weldability of carbon steel by the metal arc process will depend on the carbon content of base metal, as previously stated. Generally "Hydrogen free" coated electrodes are recommended to help prevent (hydrogen embrittlement) cracking in toe and root areas. The medium carbon grade (0.30-0.50% carbon) are usually preheated at 300-500°F to minimize cracking brittleness, and stress relieved after welding by heating to 1100-1200°F. The high carbon grades are not usually recommended for welding because of the adverse effect that welding has on mechanical properties. However, where welding is required, parts should be postheated at approximately 400°F and normalized after welding at 1350-1450°F (except where worn surfaces are being built up, then preheat and postheating can be omitted in most cases).

**2-133.** Electrodes should be carefully selected to obtain a moderate, dense and tough weld deposit. Another consideration in selecting the electrode is absorption of carbon from the base metal into the weld deposit, which decreases the ductility of the joint (For additional information see specification MIL-W-8611 and Table 2-15).

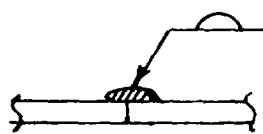
**2-134.** Joints separation (general) for butt welding by the shielded metal arc method should be from 0-1/32 inch for thin material to about 1/8-3/16 inch for 3/8-1/2 inch thickness material. Multi-layer welds with standard V/U joint are used, unless otherwise specified, when material exceeds thickness of 3/16 inch and weld can only be applied to one side, such as for welding tubing/pipe. Each layer/pass should not exceed 1/8 inch thickness, and finishing bead (width) should extend to 1/16 inch minimum (beyond level) on to the base metal on each side. Finish welds shall not be undercut, have depressions below surface of the base metal, or have blow holes. Precautions should be taken to assure starting the arc in the weld area. For joint designs see MIL-STD-22A and Figure 2-2 which shows some of the standard joints.

TYPE OF WELD							
BEAD	FILLET	SLOT	GROOVE				
			SQUARE	V	BEVEL	U	J
							

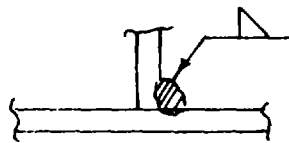
BASIC ARC AND GAS-WELD SYMBOLS

TYPE OF WELD			
SPOT	PROJECTION	SEAM	FLASH OR UPSET
			

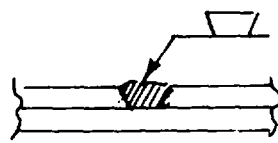
BASIC RESISTANCE - WELD SYMBOLS



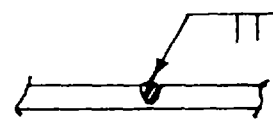
BEAD WELD



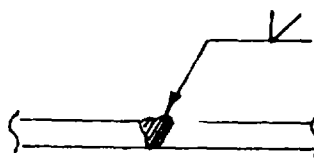
FILLET WELD



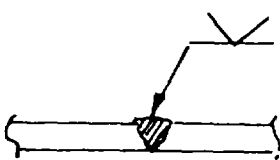
SLOT WELD



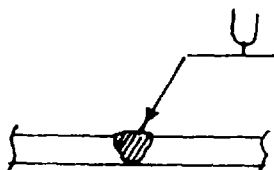
SQUARE GROOVE



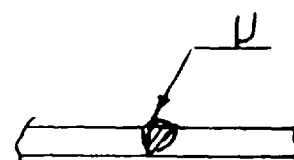
BEVEL GROOVE



V-GROOVE WELD



U-GROOVE WELD



J-GROOVE WELD

NOTE

FOR INFORMATION ON ADDITIONAL JOINT DESIGNS  
SEE MIL-STD-22.

FIGURE 2-2. WELD SYMBOLS AND BASIC TYPES OF JOINTS AND WELDS.

**2-135. WELDING OF LOW ALLOY STEEL GENERAL**

**2-136.** "Low Alloy" steels are defined as steels whose properties are attributed to the presence of one or more elements in addition to those commonly present in carbon steel or to more than usual amounts of elements such as manganese and silicon. Examples of low alloy steels are: Nickel alloy, nickel-copper alloy, manganese -molybdenum, carbon-molybdenum, chromium molybdenum, nickel-chromium-molybdenum, chromium alloy steel, manganese alloy steel and chromium-vanadium steels.

**2-137.** The primary effect of the alloying elements in regard to welding of steel is on the physical properties. The additional element/elements may form invisible oxide film which interfere with fusion or cause cracking and porosity, in addition to the principal effect of increasing hardening tendencies. The effects of the added elements occur primarily because of metallurgical response upon the transformation (austenite) of metal during cooling from the welding temperature.

**2-138.** Due to the effect of the alloy elements, the welder must be familiar with required control factors associated with each grade/type.

**2-139. GAS WELDING (OXYACETYLENE) OF LOW ALLOY STEELS.** Basically there is no difference in procedure for oxyacetylene welding of the alloy steels than those used for welding straight carbon steel. Although the trend is to replace oxyacetylene with the metal arc process using covered electrodes, there are applications where the oxyacetylene method is used to an advantage. The advantage is associated with the fact that heat before, during and after welding can be controlled to some extent (depending on the operator's ability). Using the gas process, heat is applied gradually and the metal is not subject to extreme temperature changes (gradients) in area adjacent to weld as occurs in arc welding. The controlled temperature that can be obtained using gas process can be important in welding the air hardening alloy steels.

**2-140.** Oxyacetylene Welding of the low alloy steels is normally accomplished with a neutral or slightly reducing flame. In most applications filler metal is selected to maintain weld strength, resistance to creep at elevated temperature (characteristics of molybdenum), embrittlement at low temperature (characteristics of nickel steels) and corrosion resistance. Special grades of filler metal, although dually provided in standard types, are selected to maintain weld strength, rather than using rods of the same composition as the base metal. For corrosion resistance, the filler metal is selected to obtain a weld with similar analysis as the parent metal. For a general reference on selection of filler metal to alloy, see Table 2-15. This table is only to be used as a guide and it is not intended to replace requirements specified by blueprints, technical orders or other engineering data. Additional requirements for engineering design are cited in MIL-HDBK-5.

**NOTE**

**Postheat-treatment after gas welding the heat-treatment alloy steels is necessary to stress relieve and to refine grain structure, unless otherwise specified.**

**2-141. SHIELDED METAL-ARC WELDING OF THE LOW ALLOY STEELS.** The structural grades of these steels (tensile 70,000 yield to 50,000) such as nickel-copper alloy are welded in approximately the same manner as used for the structural grades of carbon steel. Low hydrogen carbon steel electrodes (such as flat-work and E6010-7016 for all positions) of equal or slightly higher strength than the base metal are generally used for the applicable grades.

**2-142. Low Carbon Alloy (AISI/SAE) Grades.** The low carbon grades of the low alloy steels (see paragraph 2-126) are also normally welded with low hydrogen type electrode such as E8X15 (DC electrode positive) or EXX16 (AC or DC electrode positive). This series normally will require preheat if carbon content exceeds 0.18%, or when total alloy content is high. Preheat is recommended as follows:

1. Preheat of 200°F if alloy carbon content does not exceed 0.18% and nickel does not exceed 2.25%.
2. 200°-300°F for alloys containing 3.0-3.5% nickel and less than 0.12% carbon.
3. 300°-500°F generally and 600°F in some cases for the higher alloyed types.

**NOTE**

**For additional information on preheat by alloys, see Table 2-15.**

**2-143.** Edge preparation for this series will depend upon the thickness of plate and intended use of the finished part. Typical butt weld joints of material above 3/16 and up to 1/2 inch thick are prepared with about a 14-16 degree level to form a single U joint with an included angle of about 30-34 degrees. Material spacing at the root range from 1/32" to 1/16" for 3/16" material to approximately 1/4" for 1/2" material. A backing plate is usually used and for completion of the weld the plate is removed and a final pass (after chipping) is made to seal the root. Joints for welding heavier sections are usually prepared with a double "U".

TABLE 2-15. WELDING CHARACTERISTICS - GENERAL, STEELS OTHER THAN STAINLESS

STEEL DESIGNATION	ELECTRODE	FILLER RCD	HEAT TREATMENT		REMARKS
			PREHEAT	POSTHEAT	
Low Carbon) 1010 thru 1022	MIL-E-6843 Class A or B E6010	MIL-R-5632 Class 1	None required if above 60° F.	If post heat used do not heat above 300°F and air cool.	These are low carbon steels, not requiring heat treatment.
(Low Carbon) Corten	MIL-E-15599 E7016  or E7018	ASTM A251 CA-25  MIL-R-5632 Class 1	Same	Same	This is a low carbon alloy steel. Not heat treatable.
(Low Carbon) NAX AC 9115	E6015, thin gauge, for arc welding; or MIL-E-18038 Types MIL- 7015 for mul- tipass welding.	MIL-R-5632 Class 2	Same	See Remarks	Light gauges should be normalized.
(Medium Carbon) 1035, 1040, 1045	MIL-8018 E6015 E6016	MIL-R-5632 Class 2	300° - 500°F	1035 should be stress relieved 1100°-1200°F. Normalize 1040 1045	See text
(Medium Carbon) 1050	MIL-8018 E6015 E6016	MIL-R-5632 Class 2	300°-800°	Normalize	This steel is difficult to weld
(High Carbon) 1055, 1060, 1070, 1095	MIL-10018 Class 2	MIL-R-5632	500°-800°F	Normalize	This series is difficult to weld.
(Free Cutting) 1112	F-8015AWS in accordance with ASTM A233		200°F	Normalize	This is a diffi- cult alloy to weld. Best re- sults obtained by use of elec- trode E8015 AWS, direct current reverse polarity braz- ing characteris- tics are good.
(Free Cutting) 1117, 1137	E8015 AWS	MIL-R-5632 Class 2	200°F	Normalize	
(Nickel Alloy) 2317	MIL-E-6843 E10010 C1 D, or E10013 C1 C	Listed for reference only, alloy not currently being produced. MIL-R-5632 Class 2	2000-4000F	Normalize	This steel has good weldability characteristics.

**TABLE 2-15. WELDING CHARACTERISTICS - GENERAL, STEELS OTHER THAN STAINLESS (CONT'D)**

(Nickel Alloy) 2330-2340	MIL-E-18038 AWS E3018-C2	Listed for reference only, alloy not currently being produced MIL-R-5632 Class 2	200°F-500°F	Normalize	Not recommended for welding (This steel has high carbon content).
(Nickel Alloy) 2515	MIL-E-18038 Type MIL-12016 Class 1	Listed for reference only, alloy not currently being reduced. MIL-R-5632 Class 2	200°-400°F	Normalize	
(Ni CR) 3115	MIL-E-18038 Type MIL-11015	MIL-R-5632 Class 2	200°-500°F	Normalize	
(Ni CR) 3140	MIL-E-22200/1C Type MIL-9018	MIL-R-5632 Class 2	200°-500°F	Normalize	
(Ni CR)	MIL-E-22200/1C	MIL-R-5632	200°-300°F	Normalize	Preheating required before welding.
(Cr-MO) 4130	MIL-E-8697 HT-4130 E8011	MIL-R-5632 (See remarks)	200°-500°F	Normalize	Where heat treatment is not required MIL-R-5632 Class 1 rod may be used. If heat treatment is required MIL-R-5632 Class 2 rod which is heat treatable may be used.
(Cr-Mo) 4037	E9015 Class 2	MIL-R-5632	200°-500°F	Normalize	Slightly lower weldability characteristics than 4130
(Cr-Mo) 4135	E-9015	MIL-R-5632 Class 2	200°-500°F	Normalize	
(Low Alloy) 17-22A (V)	MIL-E-6843 Class C or D	MIL-R-5632	600°F Class 2	Normalize	Good weldability by any of the common welding methods.
(Cr-V) 4137 Co	E10015	----- MXW-2 WCX-2		1250°F for 20 minutes	Good weldability using Tungsten-arc-inert-gas method. Stress-relief recommended after welding.
(Cr-Mu) 4140 4150	E10015	MIL-R-5632 Class 2	600°-800°F	Normalize	See 4340

**TABLE 2-15. WELDING CHARACTERISTICS - GENERAL, STEELS OTHER THAN STAINLESS (CONT'D)**

(High Carbon) High Chromium 52100	E10015	----	----	Normalize	
(Low Alloy) Ladish D-6-A	E10015	MIL-R-5632 Class 2	600°F	Normalize	This alloy is weldable. in heavy sections employed techniques for welding high hardenability medium low alloy.
(Low Alloy) Hi-Tuf	E10015	----	600°F	Normalize	Weld by conventional methods using low hydrogen electrodes of similar composition.
4330 VMOD 4337 4340 E10016 E12015	MIL-E-986 Type 260	MIL-R-5632 Class 2	600°F	DO NOT Normalize	Fusion or resistance welding not permitted of parts heat treated to 260, 000-280,000 PSI tensile due to embrittlement of the joint area. Spot/seam welding not recommended due to air hardening.
Nitalloy 136 Mod	See Remarks E8018-C2	See Remarks		Normalize before mach- ining.	Welding is most successful by use of 2.5% chromium rod with the atomic hydrogen process. If nitriding is not required, conventional methods may be used, using MIL-R-5632 Class 2 or MIL-E- 6843 Class C or D.
(Ni-Mo) 4615	E9018G	MIL-R-5632 Class 2	400°F	600°F	
(Ni-Mo) 4620	E9018G	MIL-R-5632 Class 2	600°F	800°F	
(Ni-Mo) 4640	E9018G	MIL-R-5631 Class 2	600°F	800°F	

**TABLE 2-15. WELDING CHARACTERISTICS - GENERAL, STEELS OTHER THAN STAINLESS (CONT'D)**

6150 6152	EAO18G	MIL-R-5632 Class 2			
8615 8617 8620	E9018G	MIL-R-5632 Class 2	200°-300°F	Normalize	Low hydrogen type electrodes particularly when low pre-heat and inter-pass temperatures are employed are generally used for welding this group.
8735	E10018G	MIL-R-5632 Class 2	200°-300°F	Normalize	
8630	E9018G	MIL-R-5632	300°-500°F	Stress Relief 1100°-1200°F or Normalize.	Shielded-arc-carbon molybdenum electrodes are recommended. Bare electrodes produce brittle welds.
D-6-A	-----	-----	450°-550°F	575-625, 1-1/2 hr cool in still air to 300°F followed by immediate stress relief. Alternate, transfer to furnace at preheat temp and normalize at 1725-1775, 30 minutes air cool.	Weldable in heavy section using normal techniques required for welding high hardenable medium carbon low alloy steel. Sections less than 0.125 in some instances may be welded by the tungsten inert gas process without pre-heating.

**2-144.** The medium carbon (AISI/SAE) grades of the low alloy steels are more difficult to weld than the low carbon grades. If welding of this series is to be successful, close control of procedures is required. Preheating is necessary except for thin 8630-4130, and even for these grades if shape of part/assembly is complicated. The medium carbon grades in the as-welded condition are inherently brittle and require normalizing/stress relieving or heat treatment for successful welding. In some instances for the welding of heavy section, intermediate stress relief is used by heating to stress relief temperature from the pre-heat temperature, holding for 5-6 hours, and then lowering to preheat temperature to complete the weld. After weld is completed, part is given a final stress relief or heat treated. For best results, stress relief or heat treatment should be accomplished immediately after welding before material is allowed to cool below minimum interpass/preheat temperature (for some alloys this is a mandatory requirement), and in any case before material is allowed to cool to room or atmosphere temperature. Although thin material in grades 4130 and 8630 can be welded without preheat, a preheat temperature of 200°-300°F is recommended for best results.



**2-145.** Low hydrogen electrodes are used in almost every case for welding material in this group, especially when low preheat and interpass temperature are employed. However, when preheat temperatures above 600°F are used, electrodes with cellulose type coating can be used satisfactorily. The best quality welds are made using direct current (electrode positive) types EXX15, EXX25 but when welding is confined, alternating current electrodes may be the best suited due to less magnetic blow. When welding high strength structural part such electrodes as E10016 and E12015 are used. Welds made with the above electrodes should be stress relieved to prevent embrittlement, see Table 2-15.

**2-146. WELDING OF CORROSION RESISTING STAINLESS STEELS, NICKEL CHROMIUM IRON ALLOY AND HIGH NICKEL ALLOYS.** The welding of the corrosion resisting stainless steels present some problem in fabrication that are not encountered with the more commonly used low carbon/low alloy steels. For instance, the coefficient of thermal expansion of the type 300 series is about 1/2-2/3 less than carbon steel and heat or thermal conductivity is about 1/2-2/3 less than carbon steel. The above will require the use of properly designed jigs fixtures, chill plates and joints to control expansion and contraction for successful welding. In addition tack welding and closely controlled post and preheating will be required in many instances. General composition range of the alloys are as follows:

a. The 300 series of corrosion resisting steels are commonly referred to as the i8-8 series/chromium nickel grades of stainless steel. The various grades normally contain 18% chromium, 8% nickel and balance iron melt small amounts of other elements which vary with the particular alloy.

b. The 400 series of corrosion-resisting (stainless) steels are called the straight chromium grades. The compositions of this series are divided into two groups; hardenable and non-hardenable grade analysis range from 11.50 to 27.00% chromium, 0.50-2.50% nickel, 1.0% manganese and silicon and balance iron with small amounts of other elements varying with the particular alloy.

#### **2-147. COMMON CHARACTERISTICS ASSOCIATED WITH WELDING.**

**2-148.** The 300 series alloys are more susceptible to intergranular carbide precipitation than others. Actual susceptibility is dependent on carbon content and whether the alloy contains stabilizing elements (columbium or titanium). When the stabilized grades (321 and 347) are heated to temperatures (800°-1500°F) where carbide precipitation occurs, the stabilizing elements combine preferentially with carbon to form their own carbides tying up the carbon to avoid the formation of chromium carbide and keeping the chromium in solution. The above is the basis for selecting certain types as preferred welding grades.

**2-149.** Chromium-Nickel, Type 300 series. Of this series the best grades for welding are the annealed stabilized types such as 321, 347 and 348. These grades are stabilized with titanium (321), tantalum plus columbium (347) or columbium (low tantalum) (348). The effect of the addition of the stabilizing element(s) is that they control carbide precipitation which may occur at the grain boundaries in the chromium-nickel steels during heating and cooling in the range of 800°-1500°F. The stabilizing elements combine preferentially with carbon to form their own carbides tying up the carbon to avoid the formation of chromium carbides keeping the chromium in solution. The degree of carbide precipitation occurring, affects the corrosion resisting quality of the material in heat zone or area adjacent to the weld. The extent to which carbide precipitation affects the material depends on several factors. One of the factors is the ratio of the combined percentage of chromium and nickel to carbon percent. Another factor of importance is the length of time the steel is held within the temperature range where carbide precipitation occurs. The shorter the time the less harmful the carbide precipitation will be.

**2-150.** The other types in the 300 series which have fair to good welding characteristics and which can be welded under controlled conditions are 304, 304L and 316L. The carbon content of these alloys is 0.08% or less and with the required ratio of nickel and chromium to carbon percentage required for short time heating, within the carbide precipitation formation range. In these low carbon grades the carbon content is low enough to slow the formation of carbides at grain boundaries and, therefore, can be exposed to the 800-1500°F temperature range, for the relatively short time required for welding. Of these grades the one containing the lowest carbon content are the best suited for welding.

#### **NOTE**

**Exposure of types 304 304L and 316L to temperature of 800-1500°F for an extended period of time shall be avoided. Carbide precipitation is not prevented, it is only delayed or reduced to a slow rate to the extent that will permit welding and a short time stress relieving operations.**

**2-151.** The balance of the 300 series has only fair to poor weldability. Welding of any of the corrosion steels (type 301, 302 and other types) in work hardened condition, i.e., 1/4 hard, 1/2 hard, etc., will only be accomplished as directed by applicable technical order or other approved technical data for the specific equipment, aircraft or missile involved.

**2-152. WELDING OF CORROSION RESISTING STAINLESS STEEL.**

Of the 18-8 series only the types with a maximum carbon content of 0.08% and unstabilized (Type 304, 304L, 316L) or maximum carbon of 0.10% and stabilized with titanium or columbium (Types 321 and 347) in the annealed condition, have excellent welding qualities. The balance of this series has only fair to poor weldability. Welding of any of the corrosion resisting steels (Type 301, 302 and other types) in work hardened condition, i.e., 1/4 hard, 1/2 hard, etc., will only be accomplished as directed by applicable technical order or other approved technical data for the specific equipment, aircraft or missile involved.

**2-153.** The 300 series alloys are more susceptible to intergranular carbide precipitation than others. Actual susceptibility is dependent on carbon content and whether the alloy contains stabilizing elements (columbium or titanium). When the stabilized grades (321 and 347) are heated to temperatures (8000-15000F) where carbide precipitation occurs, the stabilizing elements combine preferentially with carbon to form their own carbides tying up the carbon to avoid the formation of chromium carbide and keeping the chromium in solution. The above is the basis for selecting certain types as preferred welding grades.

**2-154. STRAIGHT CHROME TYPE 400 SERIES.** Welding of the straight chrome corrosion resisting steels is normally limited to hardenable grades 403, 410, 431 and non-hardenable grades 430, 443, and 446. As a group, these grades have certain characteristics which influence their reaction when subjected to welding temperature. The characteristics are as follows:

a. Heat conduction rate in comparison to carbon steel is 50% or less. The low heat conduction rate can contribute to wrapping and the establishment of stress.

b. They are subject to grain growth at temperatures in excess of 1650°F.

c. Tensile strength decreases rapidly with increase in temperature.

**2-155.** Of the hardenable series, the best grades for welding are those containing 11.50-14.00 chromium with 0.15% maximum carbon. To weld these grades preheating and post-heating at a suitable temperature (see Table 2-18) prior to, during and after welding, to reduce or smooth out the effect of sharp heat gradients, accentuated by low rate of heat conductivity, is essential. If appropriate steps are not taken, fracture can result from thermal expansion and volumetric changes. Post-heating, such as annealing expeditiously upon completion of welding will prevent local concentrations of high stress in heat affected zone due to contraction. The necessity for proper thermal treatment of a hardenable material cannot be over emphasized, especially where heavy thicknesses are involved.

**2-156.** Post-heating treatment of the hardenable grades can be accomplished by treating as cited in Table 2-18, and by annealing at 1500°F followed by controlled cooling to 1100°F at a rate of 50 degrees per hour and then air cooling.

**2-157.** The outstanding characteristics/advantage associated with welding of these grades is that welds made with filler metal of same composition can be heat-treated, thus allowing utilization of the material in many important structural applications and other places where high abrasion resistant weld joints are required.

**2-158.** The non-hardenable grades (430, 442, 446) containing chromium between 16-28% are susceptible to intergranular corrosion as a result of the temperature used in welding. The reaction of these grades to intergranular corrosion is opposite of that prevail with the 18-8 grades. These grades are susceptible to intergranular corrosion when rapidly cooled from temperatures above 17000 F, where the 18-8 grades are susceptible when slowly cooled through the 800°-1500°F range (as previously stated).

**2-159.** The heat treatment required to remove precipitation for restoration of corrosion resistance is also different. Instead of controlled cooling in the furnace, the material is air cooled or quenched in water from the annealing temperature. The temperatures (depending) used to restore mechanical properties to fully soft condition and corrosion resistance after welding (particularly in case of Types 430 and 442) as follows:

a. Types 430 and 430F - heat to 1200°-1500°F and air cool.

b. Type 442 - heat to 1450°-1550°F and air cool or water quench.

c. Type 446 - heat to 1575°-1650°F and air cool or water quench (preferably water quench).

**2-160. NICKEL CHROMIUM IRON ALLOY AND NICKEL ALLOYS.** Alloys normally encountered to be welded are MONEL K, Inconel Alloy 600, x 750, Hastalloy "C". and "K" generally good mechanical properties, strength and ductility are inherent in welded joints in all nickel and high nickel alloys. In addition thermal or chemical (passivation) treatment is not usually needed after welding to retain or restore corrosion resistance. However, thermal treatment is required to fulfill other specified requirements and chemical or abrasive cleaning are utilized to remove scale.

2-161. Similar to the welding of other metals, the weld joint area should be clean. All preservatives, dirt, grease, oil, scale, paint, crayon marks, etc. shall be removed before starting the welding operation. The nickel and nickel alloys are susceptible to embrittlement by sulfur and lead which may be contained in the residual contaminants during the welding process.

**2-162.** The co-efficient of thermal expansion of the nickel (high) alloys is about the same as the carbon steels and consequently warpage and stress resulting from heating will be approximately the same. Also the same joint designs used for carbon steels are used to weld the high-nickel alloys.

**2-163.** After welds are completed it is important that all flux or slag be removed especially if the assembly/part is to be used in a high temperature application. The flux becomes progressively more corrosive in the molten state which will occur if part is installed in a heated area which reaches or exceeds the wetting temperature of the flux. The flux used should be clean; flux used with corrosion resisting stainless and other carbon or low alloy steels should not be mixed with that to be used for welding nickel, monel or inconel. If intermixed fluxes are used, welds with low mechanical or unsound properties may occur as a result of contaminants transferred through the flux into the weld joint.

**2-164. GAS WELDING NICKEL AND HIGH NICKEL ALLOYS.** Generally oxyacetylene welding may be used in the fabrication of parts in which high-nickel alloys are used. However welding of some grades such as Inconel is not recommended because of refractory oxides formed during welding.

**2-165.** The welding flame recommended for oxyacetylene welding high-nickel alloys is slightly reducing (carburizing). A soft flame is preferable to a heavy flame like that which will result from use of too small a tip. During welding the end of the filler rod should be in the protective atmosphere of the flame envelope to prevent oxidation of the heated rod. In addition the tip of the inner cone of the flame should contact the pool of molten metal in order to obtain concentrated heat and to prevent oxidation.

**2-166. SHIELDED METAL ARC WELDING NICKEL AND HIGH NICKEL ALLOYS.** The same general practices in layout joint design, jiggling and welding techniques for welding steel are followed in shielded metal arc welding nickel and high-nickel alloys. Nickel and monel can be usually welded in all positions, however, inconel should be positioned for down hand welding when possible.

**2-167.** For data concerning general welding characteristic of Nickel Chromium Iron Alloy, See Table 2-19.

**2-168. ARC WELDING.**

**2-169.** When arc welding the 18-8 (300 series) corrosion resisting alloys and chromium nickel iron alloy, current should be adjusted to the amperage, which will just produce sufficient heat for adequate fusion. A basic rule for starting is to set amperage at 10% less than would be required for the same thickness of carbon steel. The reason for reducing amperage is that stainless melts at a lower temperature and has higher electrical resistance than carbon steel. Also, holding amperage at the minimum required for good fusion, is an important means of reducing effects of excessive heat build-up.

**2-170.** Due to the many variables in welding machines, arc characteristics, inaccuracy of voltmeters and ammeters, differences in individual welders ability and type of weld joint exact currents will not be recommended. The values cited in Table 2-16 are being provided as a guide in starting and adjusting welding current.

**2-171.** The corrosion resisting and nickel chromium iron alloy are generally welded with reverse polarity. The electrode tip is positive and the work negative, which results in faster heating and melting of the electrode. Concurrently, because of the fast heating and melting of electrode, temperate buildup in the base metal is held to a minimum. Thin sheet may, however, be welded with straight polarity to prevent blow through, if required. Preferred method for welding thin sheet unless otherwise specified is the inert gas shielded arc. This method will be explained in further details in paragraph 2-177.

**2-172. JOINT DESIGNS AND PREPARATION FOR ARC WELDING.** Generally flat butt/square edges are satisfactory for welding of corrosion resisting and nickel chromium iron alloy up to about 0.125 inch thick. Thickness from 3/16" to 1/2" are usually prepared with a single V beveled edges with 300 bevel on a side and a 1/16" root opening and throat. For thicknesses over 1/2" a double V with 300 bevel on both sides and a 1/8" gap and throat. The use of the double V beveled edge with thicknesses over 1/2" will provide accessibility for the electrode that is necessary for obtaining penetration and uniform wall fusion. Also, this type of joint can be utilized in such a manner as to reduce deformation (wrapping) caused by shrinkage inherent in the single V joint design.

**TABLE 2-16. RELATION BETWEEN SHEET THICKNESS, WIRE DIA, CURRENT AND EDGE PREPARATION FOR METALIC ARC WELDING OF CORROSION RESISTING STEELS.**

THICKNESS OF SHEET	JOINT/GAP	BEADS	AMPS APPROX	ELECTRODE WIRE DIA INCHES	EDGE PREPARATION SEE NOTES
0.031	Tight	1	30	1/16-5/65	Square/sheared
0.0375	Tight	1	30-35	5/64-3/32	Square/sheared
0.0438	Tight	1	35-45	5/64-3/32	Square/sheared
0.050	Tight	1	35-50	3/32	Square/sheared
0.062	Tight	1	35-55	3/32	Square/sheared
0.080	1/2T" (040)	1	60-100	3/32-1/8	Square/sheared
0.093	1/16"	1	130	5/32	Sheared
		or 2 from both sides (1st in V) 2nd other sides	130	5/32	Single V Bevel
	100		100	1/8	30° on a side with 1/16" throat
0.187 (3/16")	1/16"	2	130	5/32	Bevel 30° on a side 1/16" throat
		1st in V	110	1/8	
		2nd other side			
0.250 1/4"	1/16"	2	170	3/16	Single V
		1st in V	130		Bevel 30° on a side 1/16" throat
		2nd other side			

NOTE: The edges should be cut straight and when setting up for welding they should be in tight contact or with a uniform gap throughout the length of weld joint.

**2-173.** For welding thin material less than 1/8" jiggging using copper chill bar for backing and steel hold down block bar are preferred to tacking, if practical. The use of chill block affords better control over the adverse effects of heat, i.e., warping and loss of corrosion resistance due to carbide precipitation. In sheet thickness, (up to 0.125") better results are usually obtained by welding from one side in a jig than are obtained by tacked assemblies welded the same way.

**2-174.** As with types welding material shall be clean before attempting to weld.

**2-175. TREATMENT OF WELD ZONES AFTER WELDING.** Recommended procedures for treatment of weld zones after welding has been completed are as follows:

1. All flux shall be removed after welding in the interest of obtaining maximum corrosion resistance. Flux remaining on the material can become molten and cause slagging attack and scaling when subjected to high temperature applications. Flux can be removed by striking with a sharp hammer, vigorous brushing with a stainless wire brush and abrasive blasting followed by passivation (acid treatment) for final removal of any residue including scale.

2. Weld spatters shall be completely removed. If the spatter remains in place (on the metal) it is a source for corrosion attack under normal service conditions. Such attack is usually crevice corrosion around edges or pitting underneath. Usually the majority of the spatter can be removed by striking a sharp blow followed by brushing with a stainless steel wire (0.008 to 0.010 diameter) brush. Abrasive blasting may be required in some instances to dislodge hard to remove spatter.

3. Removal of oxide film and discoloration. This is usually accomplished concurrently with removal of weld spatter by abrasive cleaning. However, if required, other methods such as chemical treating, grinding and polishing, etc., are used.

4. Warping of part and excess metal in weld zone. Warpage should be corrected immediately after welding and prior to heat treatment. In many instances, depending on the alloy, straightening of parts should be accomplished at pre-heat or postheat temperatures. Excess metal is removed by grinding or polishing or both. Good smooth surface finishes are necessary to prevent stress risers, etc., which are origination joints for concentrated stress and subsequent failure.

5. Heat treatments for restoration of corrosion resistance, stress relieving and softening is accomplished as necessary, depending on the alloy involved and intended in-service use. (See Table 2-18 for recommended treatment).

**2-176. ELECTRODES FOR ARC WELDING.** Electrodes shall be carefully selected in order to govern mechanical and corrosion resistant properties of welded joints. The analysis of the electrode core material are usually formulated to compensate for normal losses of certain alloying ingredients that pass through the arc. By controlling electrode analysis it is possible to obtain a deposit matching the alloy/ strength range of the material being welded. For example, a wire (electrode) with a 20%chromium content will normally produce a head with a 19% chromium content. In a like manner additional columbium/columbium plus tantalum compensates for a normal (30-35%) loss of that ingredient during combining (arc) of electrode with metal being welded.

**2-177.** The above is not true for all ingredients involved. Nickel and molybdenum are not subject to loss and conversely titanium is practically all lost through the arc and no compensation can be made. This is the basis for utilizing columbium bearing electrodes where stabilization against carbide precipitation is required. The carbon content of electrodes for welding corrosion steels is also held low and carbonaceous type material in the coating is controlled to prevent carbon pickup in the weld deposit.

**2-178.** For general data or selection of electrode to parent alloy and for other characteristics see Table 2-18.

**CAUTION**

**Electrode should be properly identified as to grade, type, etc., and stored in a clean dry area. Store in closed container (original package) when possible/practical to prevent moisture absorption. When necessary, moisture can be removed by heating to about 200°F. Also, electrode shall be handled with care to prevent shipping of coating.**

**2-179.** Electrodes shall also be selected in accordance with current (direct current, alternating current) direct current, etc., and position of welding. For example, electrode classification AWS-E308-16 (AWSASTM) is for use AC or DC in positions (F) flat, (V) vertical, (OH) overhead and (H) horizontal.

**2-180. INERT GAS SHEILDED ARC WELDING.** This is a method of arc welding in which the weld zone is protected by maintaining an inert atmosphere with helium, argon, or a mixture of both. The welding is accomplished using non-consumable electrodes. Weld deposits made by this method have good physical and corrosion resistant properties and are clean, smooth, free of flux (flux not normally required) and spatter.

**2-181.** The use of direct current is suitable for welding all thickness; however, for welding thicknesses less than 0.037" the use of alternating current will help prevent blow through. Alternating current produces less heat in the metal being welded because its rapidly changing polarity results in the hottest part of the arc being at the work end only 50% of the time. Also, because of reduced heating it produces a narrower line of fusion.

**2-182.** Observance of the following rules will aid in producing welds of desired quality.

- a. Grind tungsten electrode joint to approximately 65-70 degrees angle if not previously accomplished.
- b. Accomplish welding in still atmosphere, free of wind currents/drafts.
- c. Gas cap shall be of proper size and held as close as possible to the work.
- d. Do not attempt to strike an arc in molten weld pool.
- e. If electrode is accidentally struck or dipped in molten pool regrind to remove contaminants.
- f. When using filler rod, keep it away from the electrode to avoid touching and contaminating. Hold rod end in gas envelope at about a 20° angle with the plane of the work. The rod should point down toward the puddle from the opposite direction of the arc travel. The electrode is normally held at an angle of 65-75 degrees with the work, the slope being toward the direction of travel.
- g. Use gas welding flux, sparingly on underside of weld area when it cannot be protected by inert gas to control oxidation.
- h. Use correct filler rod as specified or as directed by process engineer.
- i. Control electrode length; maximum length of electrode protruding beyond end of gas cup should not exceed 1/2 inch.



j. Upon completion of welding, pass shut-off current before removing gas shield to avoid oxidation and tinting of lead.

k. Use appropriate amperage, voltage, electrode and gas flow. For general operating data see Table 2-17.

1. Have periodic tests made to determine if penetration, weld deposits, etc., are being accomplished in accordance with specified requirements and if changes are required/necessary to correct unsatisfactory condition.

**2-183.** Edges/joints for use with the inert gas shielded arc method are prepared essentially the same as those used with other methods except consideration is given to inerting back side of weld to prevent oxidation. In addition, particular emphasis is necessary to assure that joints are accurate, i.e., gap or butt joint shall be uniform, especially when no filler metal is used. Joints made without filler metal will generally develop a slight depression down the center line of the weld. The depression can be controlled to some extent by slightly bending mating edges of metal being welded. The bent edge provides a little additional metal to the joint. The joint is prepared by bending material 1/16 3/32 inch from each edge upward approximately 300 (toward welding side) and then butting together before welding. The above will slightly reduce overall dimensions and allowance for material lost must be made when fabricating precision or close tolerance parts.

**2-184. GAS WELDING OF CORROSION RESISTING STEELS AND NICKEL CHROMIUM IRON ALLOY.**

**2-185.** Typical characteristics/controls associated with gas welding are as follows:

a. Temperature (welding) is lower and less concentrated than the arc methods. Due to this factor the process should be limited to thickness (0.010" 0.125") that can be rapidly heated to fusion temperature. This is necessary so that time at heat can be minimized and adverse thermal effects, i.e., harmful carbide precipitation, warpage and grain growth can be held to a minimum.

b. Welding speeds are slower in comparison to other methods.

c. The tips used for welding should be one or two sizes smaller than those used for welding the low carbon steels of the same thickness, see Table 2-18. The flame should be slightly reducing with an excess acetylene feather not exceeding 1/16". The flow should be as near neutral as possible without the possibility of having either an oxidizing or carbonizing flame, both of which are detrimental to the ductility and corrosion resistance of the metal. A soft flame, although adjusted to have the appearance of being neutral, is actually oxidizing.

d. Joint designs are of the usual hand, i.e., straight butt, girth and upraised edge/flanged. On thin material, joining can be accomplished by forming a small flange equal to metal thickness, but not to exceed 1/16", on each edge and interfused together in lieu of using filler metal. Butt joints can also be used and thickness above 0.040" 0.080" should be gaped approximately 1/2" thickness of material to insure penetration. Thickness of 0.080 and larger should be prepared by beveling edges.

**TABLE 2-17. RELATION BETWEEN SHEET THICKNESS, CURRENT REQUIRED, WELDING SPEED FILLER ROD (WHERE REQUIRED) FOR WELDING OF CORROSION RESISTING STEELS AND NICKEL BASE ALLOYS.**

THICKNESS OF SHEET	ELECTRODE DIA INCH	CURRENT RANGE AMPS V/1 DE, STRAIGHT POLARITY AND A. C.	ARGON FLOW/2	WELDING SPEED INCH PER MINUTE
0.010	1/32	12-16	3 litres	20-40
0.015	1/32	14-20	3 litres	20-40
0.020	1/32	20-35	3 litres	20-40
0.025	1/32	20-40	3-4 litres	15-40
0.032	1/32	25-40	4 litres	15-40
0.040	1/16	50-130	4 litres	15-40
0.050	1/16	80-165	4 litres	15-40
0.0625	1/16	90-170	4-5 litres	15-40
0.080	3/32	125-200	5 litres	10-35
0.125	1/8	150-275	5 litres	10-30

1/ Welding voltage should be approximately 15.

2/ These figures are based on calibration for oxygen flow.

e. Weld joints shall be protected while at high temperature by use of flux such as Spec bML-F-7516 and by shield of properly adjusted (neutral as possible) welding flame. The flux protection shall be applied (sparingly) on all surfaces that may reach oxidizing temperatures (8000-15000F). The flux is applied by brushing on parts to be welded and by dipping end of filler rod. The flux is applied underneath the weld as well as on top and heat zone is kept covered for sufficient time to prevent oxidizing attack. When working with tacked assemblies, flux is applied before tacking, cleaned and complete area as cited above is fluxed before final welding. In no case shall parts be welded by the gas process without the use of flux of proper grade.

f. When possible, welding should be accomplished using carefully designed jigs. The jigs should be designed and arranged to serve dual purpose of absorbing excess heat and holding assembly in accurate alignment. When it is necessary to align parts by tacking, the tacks should be closely spaced approximately every 2" or closer. The tacks should be small enough to permit re-fusion into final weld. If buckling is encountered during the tacking operation, the part should be reshaped to specified dimensions before proceeding with welding operation. Prior to completing the welding operation, the tacks should be cleaned and prospective seam/heat affected area refluxed.

**NOTE**

**For additional information see Spec MIL-W-8611, MIL-E-8697, MIL-R-5031, MIL-R-5632, MIL-E-6843, MIL-E-6844, MIL-E-22200, and MIL-HDBK-5.**

**2-186. SPOT/SEAM WELDING - GENERAL.**

**2-187.** Spot/seam welding is a resistance welding process where two or more sheets of metal are clamped between two electrodes (copper/copper alloy) and a current is passed through the pieces to weld them together. The contact area of the electrode with the work pieces is the location of maximum temperature and therefore the weld is confined to a relatively small area (spot/seam).

**2-188.** Factors requiring consideration when spot/seam welding the corrosion resisting steels and iron alloys:

a. The corrosion resistant properties of the various alloys are sensitive to heat. The temperatures used and time at temperature must be accurately controlled to minimize adverse effect of heat and at the same time sufficient heat and pressure must be applied to attain required physical properties.

b. The amperage or duration of current flow (dwell time) should be decreased in comparison to those used for carbon steel.

c. The high room and elevated temperature strengths makes it necessary to employ higher pressure than used for other materials i.e., aluminum, lower carbon steels, etc.

d. Due to the higher co-efficient of expansion of the chromium-nickel grades, allowances must be made in setting up for welding and in welding sequence. The extent will depend upon the amount of heat generated in the specific assembly' and assemblies involved.

e. Some types of the corrosion resistant materials are chromium nickel steels (300 series).

**2-189.** The requirements for spot welding of non-hardening steels (by the welding process) austenitic steel, nickel alloys, and heat-resisting alloys for use on various weapons and components are cited in MIL-W-6858 (Group b). Welds in accordance with this specification are classified as follows:

a. Class A Used in joints, the single failure of which during any operating condition would cause loss of the weapons system or one of its major components, loss of control, unintentional release of, or inability to release any armament store, failure of gun installation components or which may cause significant injury to occupants of the manned weapons system.

b. Class B Used in joints, the failure of which would reduce the overall strength of the weapon system or preclude the intended functioning or use of equipment.

c. Class C - A weld which is considered non-critical and for which no stress analysis is requested/required.

**2-190. EQUIPMENT FOR SPOT WELDING.** The welding machine shall consists of a suitable source of electrical energy, electrodes and means of adequately cooling electrodes and a means of reliably controlling and indicating the magnitude of the current welding force/ pressure and time of current flow. The current and force controls shall operate so that no current flows until the welding force is applied at the welding electrodes. The current (welding) shall be cut off before the force is removed.

**2-191.** The welding machines shall be qualified to meet the weld requirements for the highest classification, i.e., Class A, B or C for which it is to be used in production. A machine qualified for a higher classification is automatically qualified for a lower weld classification.

**2-192.** The welding machines shall be requalified if machine is rebuilt or if significant operational changes are made. A change of location within a shop, not involving a change in power line, does not necessitate requalification.



Basically the welding characteristics and other associated data are related in the following table.

**TABLE 2-18. FUSION WELDING CHARACTERISTICS OF CORROSION RESISTING STEEL - GENERAL**

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
301 302	Austenitic	308	MILE-6844	MIL-R-5031 Class I, AMS 5681	None re- quired if above 60°E Material should be annealed.	Anneal after welding type 301 at 1950°- 20500F, 1 hour each inch of thick- ness, water quench, Cool- ing to 800°F should occur in 3 minutes.	Subject to intergranular corrosion (at 800°- 1550°F) in weld and heat affected zone, unless annealed after welding, therefore, strain hardened tem- pers i.e., 1/4H, 1/2H, 3/4 & hard are suitable for fusion welding and brazing. Welded material should be annealed.
303	Austenitic	310	MILE-6844 Class 3 AMS 5695	MIL-R-5031 Class 3, AMS 5695	None re- quired if above 60° F.	Anneal after welding. See Heat Treat Data para- graph.	Not recommended for welding however, can be fusion welded to a limited extent but post-weld annealing is required.
304	Austenitic	308		MIL-R-5031 Class 1, AMS 5681	None re- quired if above 600° F.	To restore corrosion re- sistance and to remove pre-welding sheet up to cipitated car- bides, heat treat 1850°- 2000°F, 1/2- 1 hour per inch of thick- ness, and then cool to below 800°F within 3 minutes maxi- mum by quenching in air. (Not re- quired for 304 L unless sub- jected to 1200°F for a prolonged period.)	Inert gas tungsten arc method is re- commended for welding sheet up to 1/8" thick. Shielded metal arc process is preferred for sheet over 1/8" thick. Some sensitization on welding may occur in type 304 especially if metal is over 1/8" thick. Type 304L is susceptible to inter- granular corrosion if heated at approxi- mately 1200°F for a long time, however, type 304 is susceptible to intergranular cor- rosion when heated in 800°- 1600°F range or welded. Type 304L due to low carbon con- tent (0.03% maximum) is the recommended grade for welding.

TABLE 2-18. FUSION WELDING CHARACTERISTICS OF CORROSION RESISTING STEEL - GENERAL(CONT'D)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
305	Austenitic	308		MIL-R-5031 Class 1,	None required if above 60° F.	To restore corrosion resistance and to remove precipitation carbide, heat treat to 1850°-2000°F), 1/2-1 hr per inch thick and then cool to below 800°F within 3 minutes maximum by quenching air.	Not generally recommended for welding reacts similar to 304 except due to higher nickel compared to chromium (18-12) it is more susceptible to cracking during cooling.
310	Austenitic	310	MIL-E-6844 Class 3, AMS 5075	MIL-R-5031 Class 3, AMS 5694	None required if above 60° F.	Post annealing required if welded joint is to be exposed to corrosive environment. See Heat Treat Data paragraph for temperature.	Weldable by gas/or electricity preferable by metal arc or inert gas arc methods. Oxyacetylene is not recommended because of carbon pick-up and resulting adverse effect on corrosion resistance.
316 317	Austenitic Austenitic	316	AMS 5691	MIL-R-5031 Class 4	None required if above 60° F.	Anneal after welding. See Remarks and General Heat Treat Data paragraph (2-74).	Subject to stress corrosion and embrittlement when heated at 800°- 1600°F for prolonged period. Low carbon type 316L is normally used for cross sections which cannot be annealed or low temperature stress relieved. Oxyacetylene welding is not advisable for casting because of carbon pickup and possible impairment of corrosion resistance. Metal arc process is recommended for welding, casting, using lime coated electrodes.
314	Austenitic	310	MIL-E-6844 Class 3, AMS 5695	MIL-R-5031 Class 3, AMS 5694	None required if above 60° F.	Anneal for maximum corrosion resistance. See Heat Treat Data paragraph.	Can be welded by gas or arc methods. Material should be annealed after welding to improve corrosion resistance.

TABLE 2-18. FUSION WELDING CHARACTERISTICS OF CORROSION RESISTING STEEL - GENERAL(CONT'D)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
321	Austenitic	347	MIL-E-6844 Class 5, AMS 5681	Class 5, Class 5A, AMS 5680	Same as above.	Postweld anneal not re- quired unless material is overheated to above 1900°F (See Remarks).	One of best grades for fabrication of parts by welding. Not subject to intergranular cor- rosion unless over heated to above 1900°F. Heating at this tem- perature followed by rapid cooling & re- heating at approxi- mately 800° - 1500°F will reduce resistance to intergranular at- tack due to carbide precipitation. For restoration of this sensitized condition, material should be stabilized or fully annealed.
347 348	Austenitic Austenitic	347	MIL-E-6844 Class 5 AMS 5681	MIL-R-5031 Class 5 Class 5A AMS 5680	Same as above.	Post weld an- neal not re- quired unless overheated to above 2150°F for prolonged periods, how- ever, after fabrication a stress relief is recommen- ded.	Primary use is for fabrication of parts by welding without postweld annealing, however, it is harder to fusion weld than 304L. Difficulty may be experienced in welding heavy sections due to cracking. For restoration of sen- sitized condition, material should be stabilized or fully annealed.
403 410 416	Martensitic	309 310 410	MIL-E-6844 Class 2/3 AMS 5777  See Remarks	MIL-R-5031 Class 2/3 AMS 5776	300°F	1350°F followed by cooling at rate of 100°F per hour maximum to 1100°F is necessary to prevent crack- ing. Type 416 should be an- nealed at 1450° F after weld- ing to improve ductility & corrosion re- sistance.	Fusion welding of type 403 and 410 can be accomplished us- ing electrode of same composition if mater- ial is to be heat treat- ed after welding. Type 309/310 ele- ctrodes can be used if material is to be used in a welded con- dition. 416 is not generally recommend- ed but can be fusion welded to a limited extent. 416 requires annealing after weld- ing to improve both ductility and corros- ion resistance.

TABLE 2-18. FUSION WELDING CHARACTERISTICS OF CORROSION RESISTING STEEL - GENERAL(CONT'D)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
420	Martensitic	420 309 310	MIL-E-6844 Class 2/3  See Remarks	MIL-R-5031 Class 2/3	4000 -6000F	1125°-1400° if possible before mater- ial has cooled to 300°F from preheat and welding.	Welding should be restricted to electrical method i.e., shielded metal arc & tungsten arc, etc. Oxyacetylene welding should be avoided to prevent carburizing and resulting loss in corrosion resistance. Type 309/310 electrodes can be used if high strength not required.
422	Martensitic	422	For inert gas method		350°-400°F	1200°-1300°F for 8 hours, air cool.	Can be welded by metal arc or inert tungsten-arc method.
440	A, B, C & F	440 309 310	See Remarks	MIL-R-5031 Class 2/3	450°F	1300°F for 4 hours and air cool.	Fusion welding should be accomplished using electrodes of same composition as parent metal when material is heat-treated after welding. If a softer weld will meet requirements, such as welding for mechanical bond only, type 309/310 electrodes can be used.
446	Ferritic	446			300°F	1400°-1450°F followed by air cooling/ water quench.	Fusion weld using same composition as parent metal. Welding of this type is not recommended for applications subject to high impact. For improvement of ductility in weld area, weld deposit should be preened while at elevated temperature.
PH 15-7 MO (AISI 632)		PH15-7MO PH15-7MO VM	17-4 AMS 5827 PH 7MO WPH15 7MO VM	AMS 5825 AMS 5813 AMS 5812	Not required.	Heat treat or anneal.	See 17-7PH except for the following. Inert gas tungsten or fusion welding of annealed and subsequently heat treated material yields a weld of 80-100%. Resistance flash butt welding is not recommended for joints to use in high strength application.

TABLE 2-18. FUSION WELDING CHARACTERISTICS OF CORROSION RESISTING STEEL - GENERAL(CONT'D)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
15-7 MO Cont'd							The molybdenum additive in this alloy causes larger amounts of delta ferrite or free ferrite to form in the weld deposit upon solidification. The amount of ferrite requires some control in order to maintain good ductility in the highest strength conditions. This control can be accomplished by the use of filler metal of appropriate chemical composition, through heat treatment or both.
17-4PH	Martensitic This alloy is Austenitic at elevated temperature but transforms to Martensitic upon cooling.		17-4PH AMS 5827	AMS 5825	Not required.	Heat treat or anneal.	Readily weldable using arc and resistance welding processes commonly used with Austenitic stainless steels. Sound welds with properties comparable to parent metal can be obtained using weld metal of same composition and post weld annealing or heat treating. Spot welding and seam welding readily accomplished using procedures similar to those used for austenitic stainless. Best results obtained by in partly or fully heated treated conditions. Resistance butt welding not currently recommended.
17-7PH	Austenitic in condition A. Heat treated condition are martensitic with some austenitic.		17-7PH AMS 5827 17-4PH	AMS 5825	Not required.	Heat treat or anneal. Fusion welded joints using 17-4PH electrode can be heat treated to 170 KSI ultimate tensile by austenitic conditioning at 1400° F followed by	Fusion welding and spot welding can be readily accomplished. Best results are obtained by spot welding partial or fully heat treated material. The surface to be welded should be cleaned by vapor or sand to avoid porous welds. Inert gas tungsten are of an-

TABLE 2-18. FUSION WELDING CHARACTERISTICS OF CORROSION RESISTING STEEL - GENERAL(CONT'D)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
17-7 PH (Cont'd)						age hardening at 950°F. Slightly higher strength may be obtained by austenitic conditioning 1600°F and age hardening at 900°F.	nealed and subsequently heated metal yields a weld of 95% efficiency welding of condition TH1050 yields a weld at 65% efficiency. Copper chill blocks with grooves should be used to inert back side of weld. In condition A 17-7PH alloy is primarily austenitic containing 5-20 ferritic.
19-9 DL 19-9 DX	Austenitic		19-9WX 19-9WMO MIL-E-6844 Class 19 AMS 5785	AMS 5782 MIL-R-5031 Class 6	None required.	Stress relieved at 1200°F minimum and preferably full annealed at 1800°F air cool.	Heating should be accomplished in a neutral or slightly oxidizing atmosphere.
AM350	AM350 AM355 308 309		AMS 5775 AMS 5781 MIL-E-22200/2 MIL-E-22200/2	AMS 5774 AMS 5780 MIL-R-5031 C11 MIL-R-5031 C12	Not required	To heat treat to condition SCT, use same full heat treatment as for unwelded material when age hardening to condition DA subsequent annealing to condition L is not required, if AM350 weld metal is used. If AM355 filler metal is used however, annealing to condition L should precede the condition DA aging treatment.	Weldable by using same procedures as those used for austenitic stainless steel, it is easier to weld than ferritic or martensite steel and preheating or post weld heating not required. This material remains ductile during cooling although structure changes from austenitic to 15% martensite. Welding can be accomplished in all conditions. The recommended techniques for welding the principal forms are electric resistance, tungsten electrode and consumable electrode inert gas welding. Where high strength is not required 308/309 electrode and filler wire may be used. Heat treated welds having 90-100% joint efficiency in light gage metal can be obtained

**TABLE 2-18. FUSION WELDING CHARACTERISTICS OF CORROSION RESISTING STEEL - GENERAL(CONT'D)**

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
AM350 (Cont'd)							without filler metal. AM350 or AM355 electrode/wire shall be used for heavier gages.
AM355		308 309 310 Remarks		Not required, Alloy is highly resistant to weld cracking.	Not required Alloy is highly resistant to weld cracking.	See remarks and heat treat data post heating not required.	Bar, plate and forgings are normally welded with filler metal in all conditions. Where joint strength is not important any austenitic (18-8) steel filler rod or electrode may be used. Welds heat treated to condition SCT/DA approaching 100% efficiency can be obtained with AM355, filler metal. Fusion welding of condition CRT and SCCRT destroys the effect of cold rolling as well as heating above 900°F.



TABLE 2-19. FUSION WELDING CHARACTERISTICS OF NICKEL-CHROMIUM-IRON AND NICKEL ALLOYS

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE	MAT'L	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
Inconel Alloy 600	-----	"62" Inconel  "42" Inconel		MIL-R-5031 CL8A AMS 5679  MIL-R-5301 CL 8 MIL-R-5683.	-----	-----	This alloy is readily weldable with high joint efficiency. Inconel "62" welding wire is recommended for inert gas method and tungsten arc. Inconel "42" is recommended where inert gas is not used. When gas welding a slight reducing flame should be used.
Inconel	-----	"69" Inconel	-----	MIL-R-5031 CL 14	Severely cold worked material should be stress relieved at 1500°F, 8 hours with part being rapidly brought up to heat.	After stress relieving welded assembly should be aged at 1300° F, 20 hours.	This alloy can be fusion welded by various methods and resistance welded. Fusion welding of Inconel X should be confined to annealed or cold worked material. The tungsten arc and inert gas shielded methods using Inconel X welding wire can be used to weld these conditions. Welding of aged material without cracking is only possible by the safe end method of adding Inconel edges to the Inconel X sections before heat treating and then welding the safe ends together with Inconel.
Hastelloy C	-----	Hastelloy C  Hastelloy W  310	-----	MIL-R-5031 CL 11 MIL-R-5031 CL 12 (See Remarks MIL-R-5031	Casting should be preheated to 1200°-1400°F.	See Remarks.	Alloy can be welded by all conventional methods. However, the oxy-acetylene method is not recommended for parts to be used in corrosive applications because of carbon pickup. Weldability of this

TABLE 2-19. FUSION WELDING CHARACTERISTICS OF NICKEL-CHROMIUM-IRON AND NICKEL ALLOYS. ( CONT'D)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE	MAT'L	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
					CL 3 (See Re-		alloy is similar to that of austenitic stainless steel. The following measures (marks) are required for fusion welding: a. Keep weld restraint at a minimum. b. Hold heat affected zone narrow and parent metal as cool as possible when welding wrought products. c. Maintain alignment. d. Use stringer beads. The same analysis filler metal should be used to join two pieces of the alloy. Type 310 stainless or hastelloy W (wire or electrode) are recommended for joining to other metals.
Hastelloy X		Hastelloy X	AMS5799	AMS 5798	Not required.		Alloy can be welded by most common welding methods. Fusion welding of cold worked material will result in a weld strength equal to that of annealed metal. Fusion welding may be accomplished by metallic arc, inert gas shielded arc, submerged melt and sigma methods. Welding should be done in a flat position as fluidity of the alloy makes position welding difficult. Welds in this alloy retain good ductility. Resistance welding requires special control; long dwell times with water cooling are recommended to

TABLE 2-19. FUSION WELDING CHARACTERISTICS OF NICKEL-CHROMIUM-IRON AND NICKEL ALLOYS. ( CONT'D)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
Monel	1K500	Nr44K Monel  Nr30K Monel				See Remarks.	avoid coring or crystal segregation and to develop a full nugget. For seam welding an intermittent drive is recommended to prevent cracking and excessive distortion. This alloy can be welded by oxy acetylene, inert gas tungsten arc, or metallic arc processes using proper filler rod. For oxyacetylene welding use NR44K monel gas welding wire with a paste flux. The oxyacetylene name should be reducing and heated end of Filler rod should be kept in the protecting atmosphere of the flame to avoid oxidizing the rod. For metallic arc welding, use NR- 34K monel. Welding should be performed on a nealed material and the welded assembly should be stress relieved before aging. Welded assembly should be taken through the age hardening range quickly.
Rene 41		REM 41 Hastelloy "W"		AMS  MIL-R CL 12	Not re- 5800	See Re- quired.	Alloy can be fusion Marks welded it copper and gee backing with a tight hold down is used. Start and finish should be made on metal tabs of the same thickness wing inert gas atmoa

TABLE 2-19. FUSION WELDING CHARACTERISTICS OF NICKEL-CHROMIUM-IRON AND NICKEL ALLOYS (CONT'D)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	ELECTRODE	ROD	PREHEAT	POSTHEAT TREAT	
							<p>phere of 2 parts helium to 1 part argon. This reduces the current input which should be held as low as possible. The use of the tab reduces heat input which should be held as low as possible to minimize the heat affected zone.</p> <p>Following the torch with a water spray reduces the hardness and produces maximum ductility in the weld and weld affected zones</p> <p>If possible solution heat treatment should follow welding. When solution heating high stress welds, heating and cooling rates through the aging range (1200°-1600° F) should be high.</p> <p>Hastelloy "W" filler material can be used when joining the alloy with it self or other age hardenable nickel-base alloys.</p>
				2-104			

**NOTE**

**Complete qualification and requalification requirements are cited in Specification MIL-W-6858.**

**2-193.** CLEANING/PREPARATION FOR SPOT WELDING. The surface of parts to be spot welded shall be free of paint, oxides, scale, ink, grease, dirt, or other contaminants detrimental to the welding process.

**2-194.** Cleaning of individual (separate) parts may be accomplished by one/combinations of the following methods: a. Immersion cleaning with Specification P-C436, prepared by dissolving 10-12 ounces of compound per gallon of water and heated to 2000 and 2120F.

a. Immersion will vary in accordance with type of contaminants to be removed. Ordinary soils, etc., require 6-10 minutes immersion.

b. Paint can be removed by immersion in paint and varnish remover Specification MIL-R-7751 (see T.O. 1-1-2 and 1-1-8 for preparation/application). Spot paint removal can be accomplished by application of MIL-R-25134.

c. Spray-wash with compound with Specification MIL-C-5543 or Specification P-S-751 (see T.O. 1-1-1 and 1-1-2 for preparation/application of solution).

d. Vapor degreasing with trichloroethylene, Specification MIL-T-7003 (aircraft parts) or Specification MIL-T-27602.

**WARNING**

**Trichloroethylene solvent produces dangerous and toxic fumes. Do not breathe fumes for prolonged periods. Use adequate ventilation. When using solvents, alkaline solutions acids, etc., wear approved clothing, acid/solvent resisting gloves, aprons/ coveralls, and face respirators. If solutions are splashed into eyes, flush thoroughly with water immediately and then report to the dispensary. For additional instructions contact local safety officer.**

**WARNING**

**If parts are to be used in areas of oxygen storage and transfer systems and on surfaces of missiles using liquid propellant, do not use dry cleaning solvent or solvent that is not compatible. In addition, such parts shall be cleaned as specified (see T.O. 42C-1-11 and T.O. 00-25-223). Failure to observe these precautions can result in serious or fatal injury to personnel.**

**2-195.** After grease, oils, dirt, etc., are removed by one of the above methods and parts are rinsed in hot water, material with heavy oxides and scale shall be cleaned by one of the following methods as applicable:

a. Parts (300 series chromium-nickel grades) in which acid solutions can not be trapped and are readily rinseable, may be cleaned by mixtures of nitric and hydrofluoric acid in water. The correct percentage content of the two acids for a given oxide/scale removal job shall be determined by testing. Make test panel (1" x 4") of the same material as that of part being cleaned and process through complete cleaning and descaling cycle. The part is then inspected to determine if it is clean and for etching, intergranular attack, or excessive metal loss which would cause component to be condemned. The acid concentration, immersion time or solution temperature is then adjusted until required results are obtained. The procedures controls, etc., must be established by competent operators trained in the handling of chemicals and metal inspection. Solutions acid content for the removal of heavy scale may be from 5 to 25% nitric acid and from 1/2 to 3% of hydrofluoric acid by volume. For light scale acid varies from 10 to 15% nitric acid and 3/4 to 1-1/4% hydrofluoric. For heavy oxides the percentage of hydrofluoric may have to be increased to 3% by volume. Bath temperatures are normally maintained at 120°-140°F.

**NOTE**

**The more nitric acid present in portion to hydrofluoric the less rapid the action will be. Conversely, the higher the percentage of hydrofluoric in proportion to the nitric acid, the more rapid the action will be. Table 2-18 shows the effect of the adjustable variables on the action (descaling) of the solutions. From this table, it can be readily determined that the nitric acid inhibits the action of the hydrofluoric.**

**TABLE 2-20. CONTROL OF PICKLING, DE-SCALING OR DISSOLVING ACTION OF NITRIC-HYDROFLUORIC ACID SOLUTIONS.**

Pickling or dissolving action is more severe  1. When the nitric acid content is decreased. When the hydrofluoric acid content is increased. 2. When the temperature is increased. 3. When immersion time is increased.	Pickling or dissolving action is less severe  1. When the nitric acid content is increased. When the hydrofluoric acid content is decreased. 2. When the temperature is decreased. /1 3. When immersion time is decreased.
<b>NOTE</b> <b>1. Holding bath below 120°F reduces the rapidity of intergranular attack in sensitized areas, such as would prevail in localized weld zones that has not been removed by overall annealing.</b>	

b. Descaling the Straight-Chromium (400 series) Grades. Scale removal from these grades is more difficult than removal of scale from nickel chromium grades. All of the straight chromium grades can be descaled in the nitric-hydrofluoric solutions. However, tests as previously described are required in addition to use of abrasives. Lightly adhering scales may be pre-cleaned by initially sand-blasting or vapor-blasting with silica sand (clean) and then following by normal nitric-hydrofluoric acid pickling treatment as cited in paragraph 2-195a.

**CAUTION**

**Immediately upon removal of parts from acid de-scaling solutions, thoroughly rinse in clean hot water (140° 180°F) and then completely dry with clean air blast, (free of oil, etc.,) or other approved method before starting/ the welding operation.**

**2-196.** The mechanical methods (grinding, wire brushing, abrasive blasting/sanding) of cleaning are recommended where chemical removal is impractical because of rinsing difficulties or structural complexities.

**CAUTION**

**Protect faying surfaces (lap joints), etc., against entry of dust particles, filing and other contaminants which may result in corrosion damage after parts are put into use. Do not use common steel wool, wire or brushes on corrosion resisting steel.**

**2-197.** Light scale/oxide may be removed by abrading weld area/zone with a stainless steel wire brush (0.005 inch diameter wire) No. 240 are finer emery cloth (polish if required to specified requirements) and stainless steel wool (medium/fine).

**2-198.** Heavy scale in some instances can be removed by sand, bead or vapor blasting, however, it shall be accomplished as specified by approved data or process engineer. Normally, sand blasting shall be followed by chemical cleaning unless otherwise specified to remove embedded particles of sand/scale.

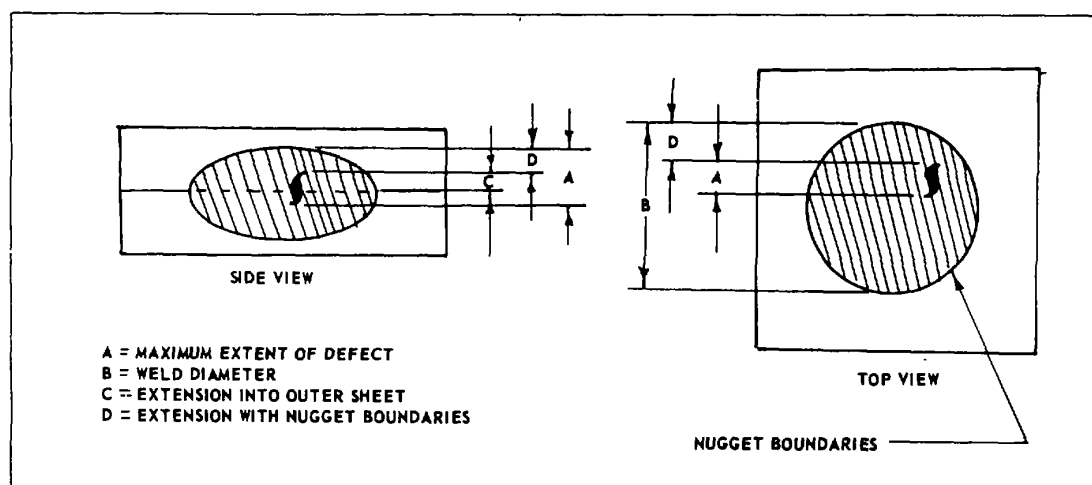
**CAUTION**

**Severe abrasive blasting/cleaning shall not be accomplished on materials thinner than 0.0625, especially if the material is to be used for skin surface of an aircraft or missile or other areas subject to high stress loads.**

**NOTE**

**After oxide removal, welding shall be accomplished immediately or within 36 hours.**

**2-199. WELD FORMATION/PRACTICES.** Table 2-21 and Table 2-22 are being provided as a guide in selecting machine settings for spot and seam welding corrosion steels. The values cited will vary with different welding machines, materials, tips, surface conditions, etc. Minimum electrode pressures are required to prevent cracks or porosity in the weld. The dwell time shall be long enough to obtain complete fusion in the weld area. Generally, if the weld penetration is less than 20%, it is below minimum requirements and if it is above 80% it exceeds maximum allowed. Welds with approximately 50% penetration though each sheet are the most satisfactory.



**Figure 2-3. INTERNAL DEFECT - SPOT WELD**

**2-200.** The best procedure to start the welding operation is by taking clean samples of the pile-up and testing and adjusting machine until optimum results are obtained. The tests are started by setting pressure and dwell time for the thinnest sheet in the pile-up and then adjusting the current and pressure to obtain a good spot/seam of the required strength. After the production is started, the welds shall be checked frequently to assure that proper conditions are maintained. The welds shall be inspected for proper spacing, correct size/diameter, surface appearance (welds should be smooth and free of cracks), tip pick-up (clean tips frequently), surface flashes, expulsion of weld between sheets, blown spots, surface indentation, porosity strength, sheet separation and edge distance. See Table 2-21, 2-22, 2-23, 2-24, and paragraph 2-201.

**2-201. SURFACE INDENTATIONS LIMITATIONS.** The surface (electrode) indentations for parts used in the airfoil (aerodynamic) areas of an aerospace craft shall not exceed 0.004 inch. In other areas, parts will not be acceptable if electrode indentations exceed the following depth limitations:

- a. For parts requiring Class A or B welds and thickness of the thinnest outside sheet in which the indentation will occur is 0.025 inch or greater, the indentations shall not exceed 0.005 inch or 10% whichever is greater.
- b. For parts requiring Class A or B welds and thickness of the thinnest outside sheet in which the indentation will occur, is less than 0.025 inch, the indentation shall not exceed 0.003 inch or 20%, whichever is greater.

**NOTE**

**If the indentation requirements cited in paragraph 2-201b cannot be attained, the strength of the weld will be the governing factor. However, the indentations shall not exceed those cited in paragraph 2-201a.**

- c. For parts requiring Class C welds, the electrode indentation shall not exceed 0.005 inch or 10%, whichever is greater of the thickness of the sheet in which the indentation occurs.

**2-202. PENETRATION AND INTERNAL DEFECTS LIMITATIONS.** Weld penetration and soundness shall be determined by examination of a metallurgical section through the center in test specimens/samples. The outline of the fusion zone shall be generally consistent in size and regular in shape.

**2-203.** Internal defects of production parts such as porosity, cracks, lack of fusion, or voids will be acceptable if the maximum extent of the defects does not exceed one of the following limits as indicated by metallographic examinations of section (see Figure 2-3).

- a. For Class A welds 10% and for Class B welds 15% of the weld diameter and 25% for Class C welds.
- b. Twenty-five percent of the respective sheet thickness extension into an outer sheet for Classes A and B and fifty percent for Class C.

**2-204. JIGS AND FIXTURES FOR SPOT/SEAM WELDING.** The jigs and fixtures for use in aligning and assisting in assembly of welded parts that must pass through the magnetic field during the welding



TABLE 2-21. TYPICAL MACHINE SETTINGS, MINIMUM SPACING AND NUGGET DIAMETER FOR SPOT WELDING CORROSION RESISTING STEEL

THICKNESS OF THINNEST SHEET (INCH) MS33528	PRESSURE /3 LBS ELECTRODE FORCE	CURRENT AMPERES FOR TENSILE STRENGTH		MIN WELD SPACING INCH /1 (CENTER TO CENTER)	TIME DWELL CYCLES (60 PER SEC)	NUGGET DIAMETER	
		BELOW 150,000 PSI	ABOVE			MINIMUM (INCH) (SPEC MIL-W-6858) /2	AVERAGE MIN (INCH)
0.006	180	2000	2000	1/4	2	0.06	0.07
0.008	200	2000	2000	1/4	3	0.07	0.08
0.010	230	2000	2000	1/4	3	0.08	0.09
0.012	260	2100	2000	5/16	3	0.09	0.10
0.016	330	3000	2500	5/16	4	0.10	0.12
0.018-0.020	380	3500	2800	3/8	4	0.11	0.13
0.021-0.022	400	4000	3200	7/16	4	0.12	0.14
0.025	520	5000	4100	1/2	5	0.13	0.15
0.031-0.032	650	6000	4800	9/16	6	0.14	0.17
0.035-0.036	750	7000	5500	5/8	6	0.15	0.18
0.040	900	7800	6300	11/16	6	0.16	0.19
0.044-0.045	1000	8700	7000	3/4	8	0.17	0.20
0.050-0.051	1200	9500	7500	13/16	8	0.18	0.21
0.056	1250	10300	8300	7/8	10	0.19	0.22
0.062	1500	11000	9000	1	10	0.20	0.24
0.071-0.072	1700	12300	10000	1 1/8	12	0.22	0.26
0.078-0.081	1900	14000	11000	1 1/4	14	0.23	0.27
0.090-0.091	2400	15700	12700	1 3/8	16	0.24	0.29
0.109	2800	17700	14000	1 1/2	18	0.26	0.31
0.125	3300	18000	15500	2	20	0.28	0.34

1/ Minimum spacing specified will prevent the necessity for precautions to compensate for shunting current effect of adjacent weld. Where pile-up contains three pieces, minimum spacing shall be increased 1/3 (33 1/3 %).

2/ Nugget diameter is based on minimum shear strength specified in accordance with MIL-W-6858. Nugget diameter is not applicable if shear strength values other than established therein are used or specified.

3/ See heat treat data for the particular alloy involved to determine tensile strength or use data supplied by print or other approved source.

TABLE 2-22. TYPICAL MACHINE SETTINGS, WELDING SPEED, SEAM WIDTH FOR SEAM WELDING CORROSION RESISTING STEELS.

THICKNESS OF THINNER SHEER (INCH) MS33528	PRESSURE LBS ELECTRODE FORCE	CURRENT AMPERES	ON TIME CYCLES (60 PER SEC)	OFF TIME DWELL CYCLES		WELD SPEED MAX.		WELDS PER IN.		SEAM WIDTH	
				1/	4T	INCH PER		2T	4T	MIN IN.	PRE-FERRED INCHES
						2T	4T				
0.006	300	4000	2	1	1	60	67	20	18	0.06	0.07
0.008	350	4600	2	1	2	67	56	18	16	0.07	0.08
0.010	400	5000	3	2	2	45	51	16	14	0.08	0.09
0.012	450	5600	3	2	2	48	55	15	13	0.09	0.10
0.016	600	6700	3	2	3	51	50	14	12	0.10	0.12
0.018-0.020	650	7300	3	2	3	55	50	13	12	0.11	0.13
0.021-0.022	700	7900	3	2	3	55	55	13	11	0.12	0.14
0.025	850	9200	3	3	4	50	47	12	11	0.13	0.15
0.031-0.032	1000	10600	3	3	4	50	47	12	11	0.14	0.17
0.040-0.042	1300	13000	3	4	5	47	45	11	10	0.16	0.19
0.044-0.045	1450	13500	3	4	5	46	45	11	10	0.17	0.20
0.050-0.051	1600	14200	4	4	5	45	44	10	9	0.18	0.21
0.056	1700	14600	4	5	7	43	42	10	8	0.19	0.22
0.062	1850	15100	4	5	7	40	41	10	8	0.20	0.24
0.071-0.072	2150	15900	4	5	7	40	41	9	8	0.22	0.26
0.078-0.081	2300	16500	4	6	7	40	41	9	8	0.23	0.27
0.090-0.091	2525	16600	5	6	7	36	38	9	8	0.24	0.29
0.109	2950	16800	5	7	9	38	37	9	7	0.26	0.31
0.125	3300	17000	6	6	8	38	37	9	7	0.28	0.34

1/ Used for maximum speed and pressure tight joints.

TABLE 2-23. MINIMUM SHEAR PER WELD AND AVERAGE SHEAR REQUIRED FOR SPOT WELDS IN FERROUS, NICKEL BASE AND HEAT RESISTING ALLOYS. 1/

THICKNESS OF THINNEST SHEET INCH MS33528	MATERIAL ULTIMATE STRENGTH PSI					
	ABOVE 150,000		ABOVE 90,000 to 150,000		BELOW 90,000 PSI	
	MINIMUM 1b/WELD	MINIMUM AVERAGE lb/WELD	MINIMUM lb/WELD	MINIMUM AVERAGE lb/WELD	MINIMUM lb/WELD	MINIMUM AVERAGE lb/WELD
0.006	90	115	70	90		
0.008	150	185	110	130	90	110
0.010	205	255	160	195	115	140
0.012	275	340	200	245	150	185

TABLE 2-23. MINIMUM SHEAR PER WELD AND AVERAGE SHEAR REQUIRED FOR SPOT WELDS IN FERROUS, NICKEL BASE AND HEAT RESISTING ALLOS. 1/ '(CONT'D)

THICKNESS OF THINNEST SHEET INCH MS33528	MATERIAL ULTIMATE STRENGTH PSI					
	ABOVE 150,000		ABOVE 90,000 to 150,000		BELOW 90,000 PSI	
	MINIMUM lb/WELD	MINIMUM AVERAGE lb/WELD	MINIMUM lb/WELD	MINIMUM AVERAGE lb/WELD	MINIMUM lb/WELD	MINIMUM AVERAGE lb/WELD
0.016	400	495	295	365	215	260
0.018	490	600	340	415	250	305
0.020	530	655	390	480	280	345
0.022	610	755	450	550	330	405
0.025	725	895	530	655	400	495
0.028	855	1055	635	785	465	575
0.032	1045	1280	775	955	565	695
0.036	1255	1545	920	1140	690	860
0.040	1460	1800	1065	1310	815	1000
0.045	1795	2210	1285	1585	1005	1240
0.050	2125	2620	1505	1855	1195	1475
0.056	2550	3145	1770	2185	1460	1800
0.063	3090	3815	2110	2595	1760	2170
0.071	3730	4595	2535	3125	2080	2560
0.080	4410	5440	3005	3705	2455	3025
0.090	5090	6275	3515	4335	2885	3560
0.100	5720	7050	4000	4935	3300	4070
0.112	6365	7855	4545	5610	3795	4675
0.125	7080	8730	5065	6250	4300	5310

1/ Test specimens shall be prepared/tested in accordance with MIL-W-6858.

2/ In accordance with MIL-HDBK-5, these factors should be reduced approximately 1/5 for spot weld maximum design shear strength.

TABLE 2-24. MINIMUM EDGE DISTANCES FOR SPOT WELDED JOINTS

NOMINAL THICKNESS OF THINNER SHEET INCH 1/	EDGE DISTANCE INCHES 2/
0.016	3/16
0.020	3/16
0.025	7/32
0.032	1/4

**TABLE 2-24. MINIMUM EDGE DISTANCES FOR SPOT WELDED JOINTS. (CONT'D)**

NOMINAL THICKNESS OF THINNER SHEET INCH 1/	EDGE DISTANCE INCHES 2/
0.036	1/4
0.040	9/32
0.045	5/16
0.050	5/16
0.063	3/8
0.071	3/8
0.080	13/32
0.090	7/16
0.100	7/16
0.125	9/16
0.160	5/8

1/ Intermediate gages will conform to the requirements for the next thinner gage shown.

2/ In some instance edge distance less than those cited may be used provided there is no explosion of weld metal, bulging of the edge of the sheet or damage to bend radius by the electrode.

operation shall be made of non-magnetic materials whenever possible. When it is required that magnetic material be used and the presence of the material requires a change in the welding current setting of more than 10% from the established setting without the jig, separate welding schedule shall be established by the responsible process engineer. In addition, jigs and fixtures shall be so designed that no current is shunted through them, rather than the work piece.

## **2-205. WELDING SAFETY PRECAUTIONS.**

**2-206.** The following information was extracted from AFM 127-101, dated 5 November 1963, Accident Prevention Handbook and is being included in this manual as a reference guide.

**2-207. WELDING SAFETY-GENERAL.** Welders during their daily work are exposed to many possible injury inducing environments such as follows:

- a. Harmful light rays from welding flames/arcs which can seriously injure the eyes and burn the skin.
- b. Burns to body from hot sparks, splashed metals, the welding flame and from objects being weld ed.
- c. Poisonous fumes and gases produced during the welding operation.
- d. Explosions and fire hazards when welding in done near flammable substances. In addition, explosions may occur as a result of mishandled oxygen (due to impact sensitivity with hydrocarbons such as oil, etc.) acetylene, etc. (due to escaped vapor, flammability, etc.).
- e. Material handling hazards such as cuts from sharp edges of metal, body injury resulting from dropping or moving of parts and equipment.
- f. Electrical shock from various types of arc and spot welding equipment.

### **WARNING**

**Because of the many possibilities of personnel injuries and property damage it is essential that safe welding practices be observed at all times. Only fully qualified personnel who are trained and are familiar with required safety practices will be authorized to perform welding operations.**

**2-208. PERSONNEL PROTECTION FOR WELDING.** Personnel will protect themselves with suitable protective clothing before starting any welding operation. Helmets, shields, aprons, gloves, gauntlets, goggles and other items of approved clothing will be worn depending upon the type of protection required.

**2-209.** To provide proper eye shielding, goggles, helmets and shields will be carefully selected and will have the proper shade lens as follows:

a. For electric and inert gas metal arc weldings, clear and filter lenses up to and including shade No. 2 will be used for resistance welding. These lens will also be used to protect eyes from stray light and from other nearby welding operations. For fusion arc welding, filter lens will be shade No. 6 for use up to 30 amperes, shade No. 8 for 30 to 75 amperes, shade No. 10 for 75 to 200 amperes, shade No. 12 for 200 to 400 amperes and shade No.14 for above 400 amperes.

b. For gas welding/cutting Shade No. 5 filter lens will be used for light cutting and welding, shade No. 6 for medium work and shade No. 8 for heavy work.

**2-210. VENTILATION.** Forced ventilation will be used in welding operations when natural ventilation is insufficient and will not prevent the accumulation of dangerous gases and fumes. In confined spaces, the use of exhaust fans/blowers is usually effective. When the concentration of hazardous (toxic) fumes cannot be kept within safe limits, all exposed personnel will wear appropriate breathing devices. Areas subject to accumulation of explosive gases/vapor will be brought within safe limits before and will be kept within safe limits during complete welding operations. Appropriate gas detecting devices, explosimeters, etc., will be utilized to determine condition of area atmosphere and that it is within safe limits.

#### **CAUTION**

**When in doubt about an operation, the Hygiene Officer or Fire Marshall will be contacted for directions before proceeding and all applicable data in AFM 127-101 will be reviewed.**

**2-211. FIRE/EXPLOSION HAZARDS.** Welding will not be permitted near flammable or explosive materials until all necessary safety precautions have been taken. Fire extinguishers with the correct charge for the type of fire that may be involved (Class A, B, or C), will be provided and readily available during all welding operations. In addition to the above, the following precautions shall be taken:

a. Flammable Materials. Before attempting any welding operation, all flammable materials will be removed from the immediate area. Wooden floors, and other combustible surfaces/materials will be protected against excessive heat. When it is impractical to remove flammable materials from the area, protect with a suitable fire resistant shield, i.e., asbestos blankets, metal shields, etc. Inspect area at regular intervals during and after completion of the welding operation to detect possible sources of potential fire.

b. Explosion Hazards. Welding will be prohibited where flammable gases or liquids may be ignited until the possibility of explosion or fire has been eliminated. In confined spaces, where ventilation is inadequate, welding itself may produce flammable and explosive vapors.

c. Fire Protection. When a fire hazard still exists after precautionary measures have been taken, no welding will be accomplished, until a decision to weld is made by the Fire Marshal and a fully equipped fire guard is standing by the welding operations.

**2-212. HANDLING AND CARE OF COMPRESSED GASES FOR WELDING.** The precautions given below shall be complied with in the handling of oxygen and other gases used in welding operations:

a. Gas cylinders shall be stored only in approved, assigned spaces where there is minimum danger of the cylinders being damaged or knocked over.

b. Compressed gas cylinders will be kept away from external sources of heat and highly combustible materials.

c. Oxygen cylinders will not be stored inside, in the same location with cylinders of fuel gases, i.e., propane, butane, acetylene, etc.), unless they are well separated. A fire -proof partition will be placed between oxygen and compressed fuel gases when it is necessary that they be stored in the same general location/compartment or room.

d. Cylinders stored in the open will be protected from ice, sleet, snow and the direct rays of the sun. Cylinders containing oxygen will be placed as far as possible from containers of combustible gases.

e. When cylinders are moved by crane or derrick, suitable cradles, boats or platforms will be used. Slings or electric magnets shall never be used to move cylinders of compressed gases.

f. Trucks and dollies suitably designed for such purposes will be used to transport and move compressed gas containers.

g. Oxygen cylinders and fittings will be kept free of oil and grease. Although oxygen will not burn, it will support combustion, causing oil and grease to burn with greater intensity. Oxygen under pressure can produce sufficient heat when released in the presence of oil or grease to cause explosion/fire.

- h. To prevent damage which can produce dangerous leaks, do not drop or handle compressed gas cylinder roughly.
- i. High pressure gas cylinders, especially oxygen shall not be used without the proper pressure reducing/control regulators.
- j. Pressurized oxygen shall not be used as a substitute for compressed air, artificial ventilation, or for other unauthorized purposes.
- k. Cylinders in use will be kept in an upright position and properly secured and protected to prevent them. from being accidentally knocked over or damaged.

**2-213. PREPARATION FOR AND WELDING CONTAINERS.** Before welding any tank, cylinder or other container, action shall be taken to make certain that they do not contain any flammable or explosive substance (i.e., liquid, gas, etc.). The containers which contain or have contained flammable substances will be adequately purged or inerted prior to welding. Sealed containers will not be welded until contents are investigated as cited above and provisions are made for venting during and after welding, until properly cooled. Adequate venting is necessary to prevent explosion or rupture of container because of increased/decreased pressure that will occur to a closed container from the heating and cooling process.

**2-214.** Gasoline tanks and other containers that have or had flammable liquids in them will be drained, flushed and steamed and if practicable filled with water before welding. Other approved process may be used when specified and approved by responsible engineering activity. For maximum safety, the containers will be welded/repared as soon as possible after draining and cleaning.

**2-215. OXYACETYLENE WELDING (SAFETY).** Careful handling of the gases and equipment used in oxyacetylene welding is essential to prevent serious injury to personnel and damage to equipment and material. The following precautions will be taken:

- a. Oil or grease will not be allowed to come in contact with welding equipment. If grease or oil is ignited accidentally the possibility exists of oxygen supported explosion.
- b. Acetylene (cylinders) will not be used at pressures exceeding 15 pounds per square inch The special (T) wrench used to open/close cylinders will be left in place during welding operations to permit shut down in emergencies. Control valves will be unobstructed and readily accessible to the welder throughout the operation. Special control and emergency cut-off valves will be checked at regular intervals for proper operation. Cylinders will be carefully handled to prevent damaging the regulators and valves. When cylinders are not in use, control valves will be covered by protective caps, specifically designed for that purpose.
- c. The flexible hoses used to supply gas to the welding torch will be of the proper type and color. The hose will be protected from damage caused by contact with hot metal, open flames or other destructive agents. Hoses will be inspected periodically for leaks by submerging in water. An open flame will not be used under any circumstances to test hoses for leaks. Only standard ferrules, clamps and other fittings will be used to secure hoses to cylinders, regulators, and torches. Makeshift tape or wire connections will not be permitted.
- d. After the welding torch is ignited, the flame will be kept within vision and control of the welder at all times. The welder shall not allow the torch to contact flammable materials, any part of the welding system and items that should not be heated. The welder will not point torch at concrete surfaces as a miniature explosion will occur resulting in flying fragments of concrete. When the torch is not in use, it will be extinguished and control valves will be turned OFF.
- e. When a flash-back occurs, both torch valves will be immediately closed. If a hose bursts, or escaping gas ignites at the tank, regulator controls will be turned OFF immediately.

**2-216. ELECTRIC ARC WELDING SAFETY.** Electrical shock is an added hazard of arc welding. Electrical fires caused by generating equipment and the arc itself add to the dangers of this operation. Fire resistant curtains or screens will be used during arc welding operations to protect personnel from eye injuries caused by intense arc flashes. The following additional precautions will be taken.

- a. The electrical and other components of the arc welding equipment will only be checked when the circuits are dead. The electrical circuits shall be checked only by a qualified electrician.
- b. Rotary and polarity switches will not be operated while the equipment is under an electrical load.
- c. Motor-generator and other electrical welding equipment will have effective grounds, which will be used when the equipment is in operation. Grounding of arc welding machinery will be done according to the provisions of the National Electrical Safety Code (Reference National Electrical Safety Code Article 250).
- d. Arc welding equipment will be inspected periodically to insure safe and efficient operation. Power cables, ground wire and electrode holders, will be carefully inspected for defects that could cause shock. Necessary repair to arc generators and equipment will be made immediately upon detection by qualified electricians.



**2-217. CADMIUM WELDING HAZARDS.** Fumes and dust accumulating in the air during welding of cadmium plated metals are major health hazards. Whenever it is necessary to weld cadmium plated parts adequate local exhaust ventilation will be provided. The minimum amount of air which must be removed from the point of fume origin is 250 cubic feet per minute. The Medical Service Sanitary and Industrial Hygiene Engineers shall approve the exhaust installation (reference AFP 161-2-2). In many instances it will be easier and safer to remove cadmium from the parts, accomplish welding, and re-cadmium plate to restore the original corrosion resistance to the part.

**2-218.** The exhaust load (when welding cadmium parts) will be kept as close to the point origin of cadmium fumes as possible and never more than 8 inches away.

If local ventilation cannot be supplied, and welding is being done in a small, confined space, the welder will wear an approved air line respirator.

**2-219.** Cadmium plated metals can be confused with other electroplated metals. When there is doubt about the composition of a metal to be welded (including the plating) a sample shall be submitted to a metallurgical or chemical laboratory for qualitative analysis. Welding will not be performed until the metal/plating is properly identified and appropriate safety precautions are taken accordingly.

**2-220.** The fumes (oxides) commonly generated in welding processes originate from several sources such as from the material being welded, from surface coating applied to the metal and from the electrodes used to weld. The metallic substance/elements encountered may include iron, zinc, lead, brass, bronze, copper, nickel, arsenic, cadmium, beryllium, chromium, aluminum, magnesium, manganese, phosphorus, selenium, mercury, etc. When these substances/elements are heated during the welding process, oxides are given off in the form of fumes. All of them present definite health hazards which shall be controlled by providing adequate ventilation. Cadmium oxide, for example, is extremely poisonous, particularly in the form of vapor. It has a marked effect on the human respiratory system. Heavy concentrations cause rawness of the throat, irritation of the mucous membrane and edema of the lungs. Death or permanent lung damage is the result of prolonged breathing cadmium oxides. Unless the welder is certain of the metal content, especially of those that are similar in appearance to those containing cadmium, he may become accidentally exposed to toxic concentrations of cadmium oxide from welding cadmium bearing on plated metals ((see paragraph 2-210 for ventilation requirements).

**2-221. WELDING ON AIRCRAFT.** As a general practice, welding in or on aircraft is strictly forbidden, except when specifically authorized as follows:

a. As specified in applicable technical data with joint concurrence of Fire Marshal, Ground Safety and Deputy Commander for Maintenance or his designated representative.

b. (Deleted)

**2-222.** Parts requiring repair by welding (other than as cited in paragraph 2-221 when practical, shall be removed from the aircraft, cleaned of all flammable or toxic deposits and then forwarded to the welding shop for required work.

**2-223. FABRICATION OF FERROUS ALLOYS.**

**2-224.** The information furnished in this section is provided as a guide to aid personnel engaged in the use and application of the ferrous alloys. Due to varied usage of steel products, details and rules related will not fit every application. In many, experimentation trial and further study will be required.

**2-225.** Personnel assigned to accomplish, application and fabrication must be well trained in fundamentals of metal forming practices, analysis, properties, corrosion control, machining, plating, welding, heat treat, riveting, painting, blue print reading, assembly, etc., in accordance with scope of relation to fabrication process. Also, these personnel must keep constantly abreast of advancing processes for maximum efficiency/proficiency.

**2-226.** The section of steel for design or application to equipment and component is usually based on the following:

- a. Strength and weight requirement of part/ equipment to be fabricated.
- b. Method to be used for fabrication, i.e., welding, forming, machining, heat treat, etc.
- c. Corrosion resistance to certain chemicals/ environments.
- d. Temperatures to which part will be subjected.
- e. Fatigue properties under cyclic loads, etc.

**2-227.** The following general rules should be employed in handling and forming:

a. Sheet, sheared/sawed strips and blank shall be handled with care to prevent cutting hands and other parts of the body.

b. Sheared or cut edges shall be sanded, filed or polished prior to forming. The removal of rough and sharp edges is also recommended prior to accomplishing other machining operations to reduce hazards in handling.



- c. Form material across the grain when possible using correct or specified bend radii. Also provide bend relief in corner when required.
- d. Observe load capacity of equipment such as brakes, presses, rolls, drills, lathes, shears, mills, etc.

**CAUTION**

**Machines rated for carbon steel shall not be used over 60% of rated capacity when cutting, forming or machining stainless steel unless approved by responsible engineering activity. When in doubt inquire.**

- e. Tool and equipment shall be maintained smooth, free of nicks, rust, burrs and foreign material. In addition to above, dies, ways, etc., shall be checked for alignment tolerances, etc., periodically/ each set-up.
- f. Surfaces of material, especially finished sheet, shall be protected from scratching, foreign particles, etc. These surfaces can be protected using non-corrosive paper, tape, other approved material and good cleaning procedures. Polished sheet material should be protected when forming to prevent die tool marking.
- g. After forming/machining is completed, remove all cutting lubrication, etc., by cleaning, degreasing, pickling, prior to any heat treat, plating or painting process.

**CAUTION**

**Avoid handling parts, especially corrosion resistant steel, with bare hands after cleaning and subsequent to heat treating/ passivation because finger prints will cause carburization and pitting of surface, when heated.**

**2-228. BENDING (SINGLE CURVATURE).** The bending of most steel sheet and thin bar stock can be readily accomplished provided that equipment with adequate bending and cutting capacity is available and if the materials are formed in the soft condition/lower temper range. The heat treatable alloys are usually formed in the annealed or normalized condition and heat treated if required/specified after forming. Some difficulty will be encountered from warping due to heat treating and precautions must be taken when forming the material to prevent sporadic or uneven stress in the work piece. Also, parts will require jigs or close control during the heating and cooling phase of heat treatment. The use of heat treated formed sheet metal parts on aerospace craft are usually an exception in part due to above and most materials are used in the normalized or annealed condition.

**2-229.** Springback allowance will vary according to the type and temper of material being formed. The use of sharp bend radii on parts for aeronautical application shall be avoided and other application where the parts will be subjected to flexing (cycle) or concentrated stresses, due to possible fatigue or stress corrosion failure. For recommended General Bend Radii for use on Aerospace weapon/equipment (see Table 2-25 for Low Carbon/low alloy steel and Table 2-26 for Corrosion Resistant Steel.)

**2-230.** In utilizing Table 2-25 and Table 2-26 it is recommended that in practice bend area be checked for strain, grain, or bend cracking. If parts show presence of above, increase radius by one thickness or more until difficulty does not exist. Other details, inspection requirements, etc., shall be used when specified.

**2-231. DRAW FORMING.** Control of die design, and material from which dies are made, are essential to successfully draw form steel. For long production runs, high carbon, high chromium steel is recommended to manufacture drawing dies because of wear resistance and hardness. For medium and short production runs, Kirksite/case zinc alloy can be used with drop hammer hydraulic press if the draw is not severe. Hardwood and phenolic can be used in some cases for piece production where draws are shallow.

**2-232.** Successful drawing of steel will depend on:

- a. Radii used for forming or bending Use moderate radii, usually equal to 3-6 times thickness of material depending on specific requirements, and the severity of draw.
- b. Finish of die-all scratches and surface roughness should be removed.
- c. Blank hold down pressure and drawing rings Hold down pressure should be sufficient to prevent wrinkling of material, but not to the extent that would prevent flow of the metal into the female portion of the die. Drawing rings radii should be 4-8 times metal thickness and smoothly polished.
- d. Clearance between punch and die - Generally punch clearance should be about 1 1/4 to 1 1/2 times thickness for the initial draws, and about 1 1/8 to 1 1/4 times for the following draws. If parts show signs of galling, clearance (drawing) should be increased when clearance is increased, size requirement must be considered.

e. Temper-drawing should be started with annealed/normalized material and intermediate annealing accomplished as required. The requirement for annealing (intermediate) usually is needed after reduction exceeds 30-35% for stainless/20-25% carbon steel on the initial draw, and when reduction exceeds 8-15% on each following draw. Parts should be cleaned removing all lubrication and other contaminants prior to annealing and desealed after annealing. In instances where draws exceed 22-25% annealing is recommended after completion of the drawing operation followed by descaling and passivation (stainless). Restriking on final stage die to remove distortion after final anneal is permissible without further heat treatment.

f. Drawing Speed - Generally a speed of 20-55 feet per minute is satisfactory. Drawing using a hydraulic powered press in lieu of a cam operated or toggle type press is usually the most satisfactory.

g. Lubricant Compounds - used should be of heavy consistency capable of withstanding high temperature and resisting pressure necessary to form material. One heavy bodied lubricant used is lard oil, sulfur (one pound of sulfur to 1 gallon of oil) to which lithopone is added in equal parts until consistency equals 600W engine grease, or as desired. Other compounds such as tallow, mixture of mineral oil and soft soap, powdered graphite mixed to thin paste with lightweight oil can be used.

h. Blank size and preparation - A good practice is to use minimum size required to meet dimensional size of parts and for hold down. When trimming, consideration must be given to the fact that on rectangular parts, the majority of drawings will occur on wider portions of the rectangle away from the corners. To overcome this problem, the radius of the vertical corner should be approximately 10% of the width. Trial, using a very ductile material to determine blank size and stress areas prior to starting the forming operation is recommended. After size is determined by trial, etc., the blank should be filed/polished to prevent cracking in wrinkle/stress areas, handling hazard and surface friction which hinders flow of metal into die.

**2-233.** The surface condition of the blank also has an effect on drawing. A slightly roughened surface, such as obtained by pickling (dull surface) improves control of metal under hold down pads and the holding lubricants. On the other hand, the roughened surface may be less desirable because of greater friction, especially where free flowing drawing methods are used (without hold down).

**2-234.** Where facilities are available, cold forming of some steels (primarily straight chromium stainless such as 410, 416, 430, 442, 446) can be improved by preheating dies and blanks. The preheating tends to reduce work hardening and the requirement for intermediate annealing during the drawing operation.

**2-235.** When forming involves more than one draw, the first operation should be a moderate draw with punch diameter equal to 60% of blank diameter and reduction of 15-25%. The second and subsequent draws should be made with punches about 20%. It is recommended that part be cleaned and annealed following each draw. Excessive distortion may result from final annealing after last draw. This problem can be overcome in most instances, by reducing the severity of the last draw or restriking after final annealing on last stage die for the purpose of removing distortion.

#### CAUTION

**Parts shall be cleaned of all contaminants, lubrication, filing, other foreign material, etc., before heating or annealing and upon completion of forming or drawing operation. Failure to clean the parts will result in pitting and carburization, which will damage the surface.**

**2-236. STRETCH FORMING.** Stretch forming is a process where material, sheet or strip, is stretched beyond the elastic limit until permanent set will take with a minimum amount of springback.

**2-237.** The stretch forming is usually accomplished by gripping ends of material (blank) and applying force by a separate ram carrying the forming die. The ram pressure sufficient to cause the material to stretch and wrap to contour of the die form blank is applied perpendicular to the blank (see Figure 2-4). This method of forming is usually limited to parts with large radii of curvature and shallow depth, such as shallow dishing, reverse curves, and curved pan shaped parts containing flat areas.

**2-238.** The trimming of edges and removal of nicks and scratches is important to prevent starting points for concentrated stress, which, under tension loads, would tear. The direction of major tension (stretch) and direction of grain is also important. It is recommended in forming that the major tension be transverse to the direction of grain. Lubrication aids in uniform distribution of stress and the lubricant shall be applied uniformly to work piece to avoid distortion which could result from unequal friction when material is sliding across the forming die during stretching.

**2-239.** Forming dies/blocks for general production are made from kirkite/zinc, alloy; for piece production from phenolic and hardwood. Some types and kinds of plastic with good hardness and high impact strengths are also used. The rubber pad hydraulic press is used to form relatively flat parts having flanges, beads, lightening holes, and for very light drawing of pan shaped parts having large radii.

**2-240.** Form blocks are usually manufactured from steel, phenolic (mechanical grades), kirksite/zinc cast alloy, and some types of hard molding plastic with high impact strength. The work is accomplished by setting the form block on the lower press plate or bed, and the blank is placed on the block. The blank is held in place on the block by locating pins (holes are drilled through the blank and into the form block for the insertion of the locating pins). These holes are referred to as "tooling holes" which prevent slippage of blank when pressure is applied. If tooling holes are not allowed, another method of alignment and holding of blank must be utilized. The sheet metal blank should be cut to size (allow sufficient material to form flange), deburred, and filed prior to pressing. After the block is prepared and placed on the plate, the rubber pad filled press head is lowered or closed over the block, and as the hydraulic pressure (applied by a ram to the head) increases, the rubber envelopes the form block forcing the blank to conform to the form block contour or shape. It is recommended that additional rubber be supplemented in the form of sheets (usually 1/2 1 inch, hardness of 70-80 durometers) over the form block :3rd blank to prevent damaging the rubber press pad. The design of form blocks for hydropress forming requires compensation for springback. The form for forming flanges on ribs, stiffeners, etc., should be undercut approximately 2-8 degrees depending on the alloy, hardness, and radius. In some cases, it will be necessary to use a combination of hand forming shrinking/stretching using supplemental machinery and pressing to complete forming by this method.

**2-241. DROP HAMMER FORMING.** Dies for drop hammer forming are usually made by casting metals such as kirksite. These dies can be rapidly produced; are more economical than permanent dies; can be melted and recast; and can be reinforced at selected points of wear by facing with harder material, such as tool steel for long production runs.

**2-242.** Normally, drop hammer forming is accomplished without benefit of hold down. The metal is slowly forced in shape by controlling the impact of blows. In many instances, it is necessary to use drawings, rings, 2 or 3 stage dies, supplemental equipment, and hard forming such as bumping hammer, wooden mallet to remove wrinkles, etc. To successfully complete forming operations, another aid that may be necessary is to anneal material between die stages and intermediately for single stage die forming.

#### CAUTION

**Parts should be cleaned prior to annealing to protect finish. Care should be taken to remove all traces of zinc that maybe picked up from kirksite forming dies, as failure to remove the zinc will result in penetration of the steel (stainless) when heated and will cause cracking.**

**2-243. SPINNING.** Those steels that have low yield strengths in the soft/annealed condition, and low rates of work hardening are the best grades for spinning. To overcome work hardening problems, intermediate annealing and 2-3 or more stage spinning blocks are used. Annealing of the part at intervals also aids the operator when manual spinning, because less pressure is required to form metal and springback is lower.

**2-244.** Form blocks for spinning are usually made of phenolic, hard wood, or carbon steel. Manual spinning is usually accomplished on a lathe specifically adapted and fitted for that purpose. The main requirements are that required speed be maintained without vibration; clamping pressure is sufficient to hold part; facilities are provided to apply pressure at a uniform rate; and tools are of proper design. Normally, spinning tools are the roller or round nose type designed in such a manner that high pressure can be applied without bending. Where local design of tools are required, raw material for manufacture is obtainable under QQ-T570, Type D2, hardened to Rockwell C40-50.

**2-245. SHEARING AND BLANKING.** To prevent damage to shear, and to assure clean, accurate cuts, clearance between shear blades should be approximately one-twentieth (5%) thickness of material to be cut. Also, blades or knives must be maintained in sharp condition, clean, and free of nicks. Where only one shear is available, a clearance of 0.005 to 0.006 could be used for general shearing of sheet stock up to 0.125 inches thick. Excessive blade clearance should be avoided to prevent work hardening of cut area which increases susceptibility to stress corrosion and burring. Lubrication such as lightweight engine oil or soap should be applied at regular intervals to prevent galling and to clean blades for prolonged shear blade life.

**2-246. BLANKING AND PUNCHING.** Blanking and punching requires close control of die clearance, shearing action of punch/blanking die. Clearance for blanking and punching should be 5% of thickness and closely controlled for all gauges. In designing dies and punches, it is important that shear action be incorporated to equalize and reduce load. Double shear should be used when possible to minimize off balance condition and load. Punches and dies should be maintained in clean sharp condition and lubricated by swabbing or spraying material to be punched with lightweight lube oil to prevent galling and to aid in keeping punch/die clean.

#### **2.247. GENERAL FABRICATING CHARACTERISTICS.**

#### **2-248. PLAIN CARBON AND ALLOY STEELS.**

**2-249.** Plain Carbon Steel 1006 through 1015. This group of steels is used where cold formability is the main requirement, and have good drawing qualities. This series is not used where great strength is required. The strength and hardness of these grades will vary according to carbon content and amount of cold work.

**2-250.** Plain Carbon Steels BSA 1016 through 1030. This group of steels is commonly known as the carburizing or case hardening grades. The addition of manganese improves machining qualities but reduces the cold formability characteristics. This group is widely used for forged stock.

**2-251.** Plain Carbon Steels 1030 through 1050. This group (medium carbon types) is used where higher mechanical properties are required. The lower carbon and manganese types are used for most cold formed parts. Alloys 1030 1035 are used for wire and rod for cold upsetting applications, such as bolts. The higher carbon groups, such as 1040 are often cold drawn to required physical properties for use without heat treatment.

**2-252.** Alloy Steels 1055 through 1095. Thin alloy group is used where wear resistance resulting from high carbon content is needed, and is heat treated before use in particularly every application..

**2-253.** 1100 Series Steel. Steels in this group are generally used where easy machining is the primary requirement. The main use of these steels is for screw stock.

**2-254.** 1300 Series Alloy Steel. The basic advantages of this group is high strength coupled with fair ductility and abrasion resistance. The major use is in the manufacture of forging.

**2-255.** 2300 Series Nickel Alloy Steels. The addition of nickel has very little effect on machinability and greatly increases elasticity and strength. This material is normally machined in the forged, annealed, and normalized condition, and heat treated after fabrication.

#### NOTE

**These grades not currently being produced. Listed for reference only.**

**2-256.** 2500 Series Nickel Steel. This series almost without exception, is a carburizing grade with extremely high strength core. However, the case is not as hard as obtained with other carburizing steels. This steel is used for parts requiring a high strength core and good wear resistance.

#### NOTE

**These grades not currently being produced.**

**2-257.** 3100, 3200, and 3300 Series Nickel Chromium steels. This series of steels is characterized by good wear resistance and tough core and surface. The 3300 series is used primarily in the form of forgings and bars which are required to meet rigid mechanical properties. This steel is more difficult to handle in fabrication and heat treatment than lower nickel chromium alloys.

**2-258.** 4000 Series Molybdenum Steels. This group of steels have good impact strength and require close control of heat treatment practices to obtain the required strength and ductility.

**2-259.** 4100 Series Chromium Molybdenum Steels. This series has good working properties, response to heat treatment, and high wear resistance. This group is easily fabricated by forging and rolling. After welding and cold forming, internal stresses produced should be relieved and loss in strength regained by normalizing.

**2-260.** 4130 Grade Steel. This grade is used extensively in aircraft construction in the form of sheet, bar, rod and tubing. This grade has very good cold forming characteristics. Forming and welding operations are accomplished utilizing annealed material, and heat treated or normalized after these operations are completed. 4130 sheet (MIL-8-18729 can be cold bent in the annealed condition to an angle of 180° with a radius equal to the thickness of the sheet. In the normalized condition, a radius equal to 3 times the thickness is recommended.

**2-261.** 4140 Series Steel. This steel is used for structural, machined and forged parts over 1/2 inch thick. It is usually obtained in the normalized condition. Forgings are always normalized or heat treated after fabrication.

**2-262.** 4300 Series Nickel-Chromium Molybdenum Steels. These steels are used to meet conditions in which other alloy steels have insufficient strength. Preparation for machining or forming must be by a suitable annealing cycle.

**2-263.** 8000 Series Molybdenum Steels. These steels are characterized by their high impact strength and resistance to fatigue. They are easy to forge and machine, and are stable at high temperatures.

**2-264.** 8600, 8700, 9300, 9700, 9800, and 0900 Series Steels. These steels have approximately the same characteristics as the 4300 series steels.

**2-265.** CORROSION RESISTANT (STAINLESS) AND HEAT RESISTANT STEEL.

**2-266.** The fabrication of stainless steel requires the use of modified procedures in comparison to those used for carbon steels.

**2-267.** Forming Sheet Stock. The corrosion resistant series, i.e., types 301, 302, 304, 305, 316, 321, 347, 410, 430, 431, etc., generally have good forming and drawing qualities. Some types (302, 304 and 305) have forming characteristics superior to plain carbon steel because of the wide spread between tensile and yield strength, and higher elongation. However, more power is required to form these types than is required for carbon steel because of higher tensile strength and the fact that yield strength increases rapidly during forming or bending.

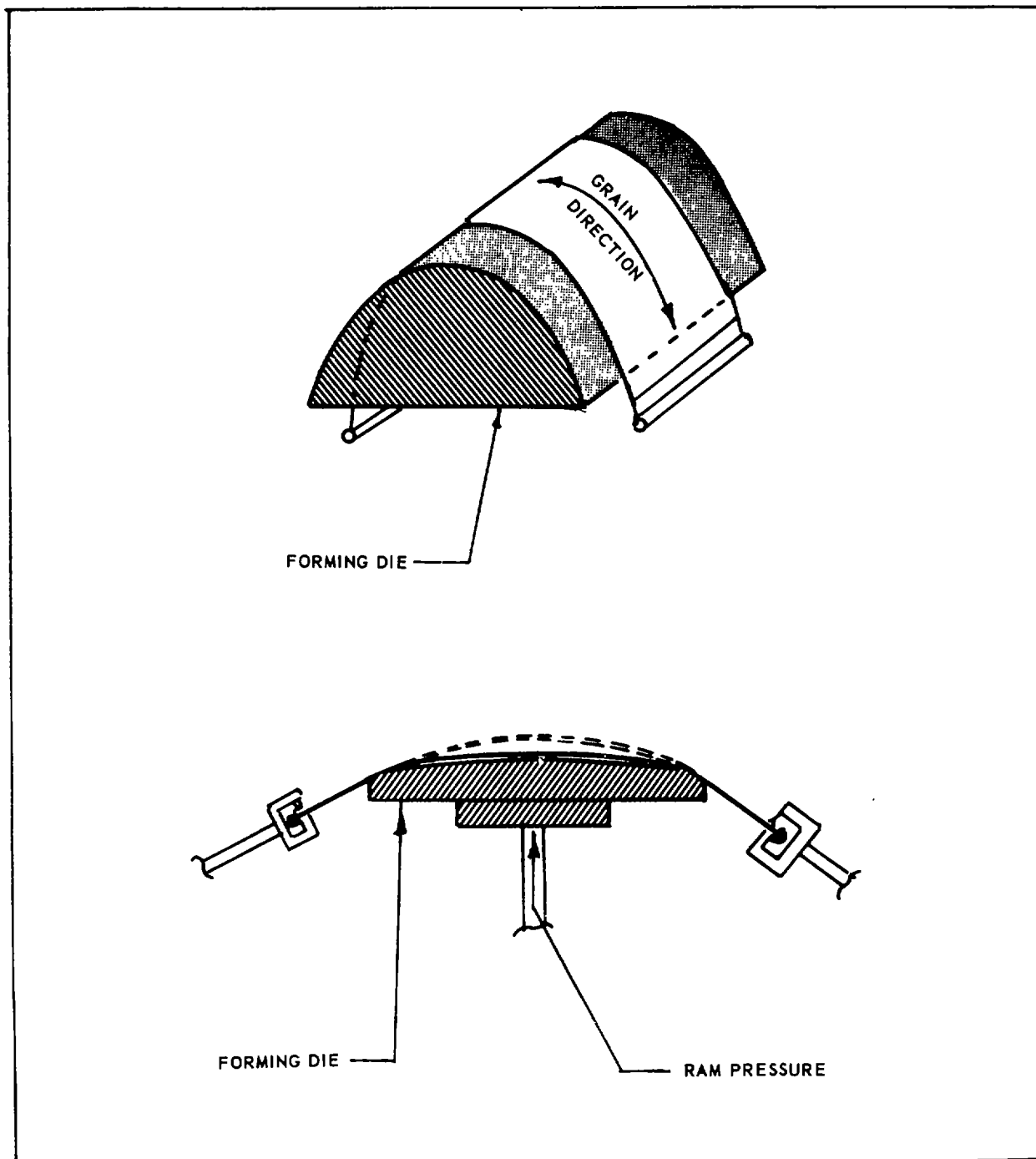


Figure 2-4. Stretch Forming

TABLE 2-25. COLD BEND RADH (INSIDE) CARBON/LOW ALLOY STEELS.

Temper, Sheet Thickness = T (Inches).									
Alloy Temper	0.016	0.020	0.025	0.032	0.040	0.050	0.063	0.125	0.187
1020/1025	2T	2T	2T	2T	2T	2T	2T	2T	2T
4130 Annealed	2T	3T	2 1/2T	2T	2 1/2T	2T	2T	2T	2T
4130 Normalized	2T	3T	2 1/2T	3T	3T	3T	3T	3T	3T
8630 Annealed	3T	3T	2 1/2T	3T	2 1/2T	2T	2T	2T	2T
8630 Normalized	3T	3T	2 1/2T	3T	3T	3T	3T	3T	3T

TABLE 2-26. COLD BEND RADII (INSIDE) CGRRCSICN RESISTANT STEEL ALLOYS.

Sheet Thickness = T (Inches)				
Alloy	Temper	0.012 - 0.051	0.051 - 0.090	0.190 - 0.250
201, 202	Annealed	1-2T	1T	1 1/2T
301, 302	1/4 Hard	1-2T	1 1/2T	2T
305, 304	1/2 Hard	2T	2T	2T
309, 310	3/4 Hard	2T	3T	--
316, 321, 347	Hard	3-4T	4-5T	--
405, 410, 430	Annealed	1T	1T	1 1/2T
17-7PH	Annealed	1T	1 1/2T	2T

TABLE 2-27. FCRGNG TEMPERATURE RANGES FOR CORRCSICN RESISTANT STEEL

TYPE/GRADE	PREHEAT °F	FORGING TEMPERATURE °F		HEAT TREATED
		STARTING	FINISHING	
301	1500-1600	2050-2200	1600-1700	SEE HEAT TREAT DATA FOR ANNEALING AND STRESS RELIEF, SEE TABLE 2-3.
302	1500-1600	2050-2200	1600-1700	
303	1500-1600	2050-2200	1700-1800	
304	1500-1600	2050-2200	1600-1700	
305	1500-1600	2100-2200	1600-1700	
308	1500-1600	2100-2200	1600-1700	
316	1500-1600	2150-2250	1600-1700	
321	1500-1600	2100-2200	1600-1700	
374	1500-1600	2100-2200	1650-1750	



TABLE 2-27. FORGING TEMPERATURE RANGES FOR CORROSION RESISTANT STEEL (CONT'D)

TYPE/GRADE	PREHEAT °F	FORGING TEMPERATURE °F		HEAT TREATED
		STARTING	FINISHING	
<b>AIR HARDENING</b>				
403	1400-1500	1900-2100	1600-1700	These grades shall be promptly annealed after forging because they air harden intentionally if allowed to cool from forging temperatures. See Heat Treat Data Table 2-3 for temperatures.
410	1400-1500	1900-2100	1600-1700	
414	1400-1500	2050-2200	1600-1700	
416	1400-1500	2100-2250	1600-1700	
420	1400-1500	2000-2100	1600-1700	
431	1400-1500	2050-2150	1600-1700	
440	1400-1500	1950-2100	1950-2100	
<b>NON-HARDENING</b>				
405	1400-1500	1900-2100	1750-1850	Post annealing required. See Heat Treat Data Table 2-3 for temperatures.
430	1400-1500	1900-2100	1350-1450	
442	1400-1500	1900-2000	1300-1400	
446	1400-1500	1800-2000	1300-1500	

**2-268.** The straight chromium grades such as 410, 416, 430, 442, and 446 react similar to carbon steel and are somewhat less ductile than the 300 series stainless. The tensile strength are higher than carbon steel and consequently will stand higher loads before rupture. Yield strengths are also higher which means that more power is required for bending and forming. Because of the ductility factor of this series drawing and forming should be limited to 20-25% reduction.

**2-269.** The 301, 302, 304, 305 and 316 types can be drawn based on a reduction of 35 to 50%, i.e., a shape 8 inches in diameter and 4 inches in depth could be drawn in one operation, based on a 50% reduction.

**2-270.** The strains set up by severe reductions (above 45% with chromium-nickel types and 20% with straight chromium types) should be relieved by annealing immediately after the operation is completed, especially if using type 301. If this material is not relieved in 2-4 hours, it may crack.

**2-271.** Springback allowance should be about 2 to 3 times the amount allowed for carbon steel, and naturally will vary according to the type of material being formed. The use of sharp radii shall be avoided where parts are subjected to flexing or concentrated stresses due to possible fatigue or stress corrosion failure.

**2-272.** Recommended bend radii for use with stainless is shown in Table 2-26.

**2-273.** Draw Forming. Stainless steels should be annealed for draw forming, and hardness should not exceed Rockwell B90. The best drawing grades are of the 18-8 series. In selecting the type for drawing, welding of the finished parts, if required, shall be considered.

**2-274.** Drop Hammer Forming. The most common types of corrosion resistant steel used for drop hammer forming are 301, 302, 304, 305, and stabilized grades 321 and 347. 301 work hardens more rapidly and is subject to strain cracking. The condition of material for best forming should be annealed. It is possible to form some type (301 and 302) in 1/4 and 1/2 hard condition. However, the severity of the forming operation must be reduced to compensate for the prehardened material.

**2-275.** Spinning. Spinning procedures for stainless are similar to those used for other metals. Difficulty and variations depend on individual characteristics of grade to be worked, i.e., yield strength, ultimate strength, ductility, hardness and reaction to cold working. The best grades for spinning are those that have low yield strength in soft/annealed condition and low rate of work hardening such as 304, 305, 403, 410 and 416. The straight chromium grades respond to spinning similar to carbon steel, however, more power is required. Mild warming above 200°F improves performance of the straight chromium grades.



**2-276. Shearing and Blanking.** Shearing and Blanking of corrosion resisting steels as with other fabrication processes requires more power in comparison to shearing carbon steel and most other metals. Shears and other equipment rated for carbon steel should not be used above 50 to 70% of rated capacity when cutting stainless.

**2-277. Hot Forming.** Hot forming is used to form shapes in stainless that cannot be accomplished by cold forming and for forging parts economically. In using heat for forming, it is important that temperature be closely controlled. Also, finished parts should be relieved of residual stress and carbide precipitation which affects corrosion resistance. In either case, this is accomplished by fully annealing.

#### **CAUTION**

**Difference in temper of raw material will result in variation of preheating, especially with the air hardening grades. The air hardening grades in tempers other than annealed may crack from thermal shock upon loading into a hot furnace.**

**2-278.** Hot forming by methods other than forging is accomplished at somewhat lower temperatures. The unstabilized chromium-nickel grades may be formed at temperatures up to 800°F and the extra low carbon grades up to 1000°F. The use of temperatures higher than those cited above should be avoided to prevent subsection of material to the carbide precipitation heat zone.

**2-279.** The straight chromium (type 400 series) are more responsive to hot forming than the chromium nickel grades. The reaction of these metals to hot forming is similar to carbon steels. Upon heating to 800°-900°F, their tensile strength is lowered considerably and at the same time ductility begins to increase.

**2-280.** Forming of the air hardening grades type 403, 410 is accomplished in two temperature ranges as follows:

a. Low temperature forming up to 1400°F. The advantage of forming at this temperature is that parts can be stress relieved at 1350°- 1450°F to restore strength uniformity, and scaling is held at a minimum.

b. High temperature forming at 1525° -1575° F. Forming at this temperature is somewhat easier because strength is low and ductility is higher. Upon completion of forming at this temperature, parts shall be fully annealed under controlled conditions by heating to 1550°F and holding, slowly cooling to 1100°F (at approximately 50°F per hour) and then cooling in air.

Grades 403, and 410 are not subject to loss of corrosion resistance due to the forming of intergranular carbides at grain boundaries.

**2-281.** When it is required that the non-hardening grades 430, 442, and 446 be hot formed, the recommended temperature for forming is 1400°-1500°F. This temperature is recommended in view of the following:

(a) Heating these grades above 1600°F promotes grain growth which can only be corrected by cold working.

(b) For types 442 and 446, the 1400° 1500°F temperature is below the scaling limit and very close to being below the scaling limit for type 430.

#### **2-282. STEEL SURFACE FINISHES.**

**2-283.** Metal plating is a process where an item is coated with one or more thin layers of some other metal. This is the type of finishes generally used on ferrous parts, other than organic finishes. It is usually specified when there is a need for surface characteristics that the basic metal does not possess. The most commonly used types of plating are: (1) Cadmium plate; (2) zinc plate; (3) nickel plate; (4) chromium plate; (5) copper plate; (6) tin plate; and (7) phosphate coatings. The thickness of the plated coating is important since its protective value is primarily dependent on its thickness. The type of plated coatings is generally dependent on the characteristics desired. For protection against corrosion when appearance is unimportant, either cadmium or zinc coatings is usually used. For appearance, nickel, chromium, and silver plating are the most commonly used. For hardness, wear resistance, and build up of worn parts, nickel and chromium plating are used. Effectiveness of most other metallic coatings depends on their ability to provide envelope or anodic protection. Porous coatings of the more noble metals such as silver, copper, platinum and gold, tend to accelerate the corrosion of steel. For proceeding instructions, refer to T.O. 42C2-1-7. The following galvanic series table and standard metal definition in accordance with M833586 are for use as a guide in the selection of the most suitable plating for parts subject to uses where galvanic corrosion would be a prime factor.

**2-284. DEFINITION OF DISSIMILAR METALS.** Dissimilar metals and alloys, for the purpose of aircraft and aircraft parts construction are separated into four groups in accordance with MB33586. Metals classified in the same group are considered similar to one another and materials classified in different

groups are considered dissimilar to one another. The metal/material referred to in the groups is the metal on the surface of the part; E.G., zinc includes all zinc parts such as castings as well as zinc coated parts, whether the zinc is electro deposited, applied by hot dipping, or by metal spraying over similar or dissimilar metal parts. The four groups are as follows:

- a. GROUP I Magnesium and its alloys. Aluminum alloys 5052, 5056, 5356, 6061 and 606q.
- b. GROUP II Cadmium, zinc, and aluminum and their alloys (Including the aluminum alloys in Group I).
- c. GROUP III Iron, lead, and tin and their alloys (except stainless steels).
- d. GROUP IV Copper, chromium, nickel, silver, gold, platinum, titanium, cobalt, rhodium and rhodium alloys; stainless steels; and graphite.

#### **NOTE**

**The above groups do not apply to standard attaching parts such as rivets, bolts, nuts and washers which are component parts of assemblies, which will be painted prior to being placed in service unless other wise specified by specifications MIL-F7179, or other approved data.**

#### **2-285. TYPES OF PLATING.**

**2-286. CADMIUM PLATING (QQ-P-416).** The primary purpose of cadmium plating is to retard or prevent surface corrosion of parts. Unless otherwise specified, the plating shall be applied after all machining, brazing, welding, forming and perforating of the item has been completed. Proper safety precautions should be observed in the event any welding or soldering operations are required on cadmium plated parts because of danger from toxic vapors during such operations. Cadmium coatings should not be used on parts subjected to temperatures of 450°F or higher. All steel parts having a hardness of Rockwell C40 (180,000 PSI) and higher shall be baked at 375° ± 25°F for 3 hours minimum after plating for hydrogen embrittlement relief. All steel parts having an ultimate tensile strength of 220,000 PSI or above shall not be plated, unless otherwise specified. When permission is granted, a low embrittlement cadmium plating bath shall be used. Federal Specifications QQ-P-416 should be used for cadmium plate requirements. Critical parts should be magnafluxed after plating.

**2-287. Zinc Plating (QQ-Z-325).** The primary purpose of zinc coatings is to retard or prevent the formation of corrosion products on exposed surfaces. Unless otherwise specified, the plating shall be applied after all machining, brazing, welding, forming and perforating have been completed. All parts having a hardness greater than Rockwell C40 and higher shall be baked at 375° ± 25°F for 3 hours after plating for hydrogen embrittlement relief. Zinc shall be deposited directly on the basic metal without a preliminary plating of other metal, except in the case of parts made from corrosion resisting steels on which a preliminary plating of nickel is permissible. Zinc plating (Type 1) should not be used in the following applications:

- a. Parts which in service are subjected to a temperature of 700°F or higher.
- b. Parts in contact with structural fabric structure.
- c. Parts in functional contact where gouging or binding may be a factor or where corrosion might interfere with normal functions.
- d. Grounding contacts where the increased electrical resistance of zinc plated surfaces would be objectionable.
- e. Surfaces where free circulation of air does not exist and condensation of moisture is likely to occur. For additional information, refer to QQ-Z-325.

#### **CAUTION**

**Chromium and nickel electro deposits severely reduce the fatigue strength of high strength steels. All steel parts having a tensile strength of 180,000 PSI or above should be shot-peened prior to electro plating. In addition high strength steels are susceptible to detrimental hydrogen embrittlement when electro plated. All steel having an ultimate strength of 220,000 PSI or above shall not be electro plated without specific approval of the procuring service or responsible engineering activity.**

**2-288. Nickel Plating (QQ-N-290).** This coating is divided into two classes. Class I, plating is intended for decorative plating, and Class II, plating is intended for wear and abrasion resistance. Unless otherwise specified, the plating shall be applied after all base metal heat treatments and mechanical operations such as machining, brazing, welding, forming and perforating on the article have been completed, all steel parts shall be given a stress relief at 375° ± 25°F (191° ± 14°C) for 3 hours or more prior to cleaning and plating, as required, to relieve residual tensile caused by machining, grinding or cold forming. Steel parts having a hardness of Rockwell C40 and higher shall be baked at 375° ± 25°F for 3 hours or more and within eight (8) hours after plating to provide embrittlement relief.

Parts shall not be reworked flexed or subjected to any form of stress loads after plating and prior to the hydrogen embrittlement relief treatment. The general requirements for nickel plating are specified in QQ-N-290. Nickel shall be used for the following application only in accordance with MIL-S5002:

- a. Where temperatures do not exceed 1,000°F and other coating would not be adequate or suitable.
- b. To minimize the effect of dissimilar metal contacts, such as mild steel with unplated corrosion resisting steel.
- c. As an undercoat for other functional coatings.
- d. To restore dimensions.

**2-289. Chromium Plating (QQ-C-320).** This coating is of two classes; Class I, intended for use as a decorative coating; and Class II, for wear resistance and corrosion protection. Heavy chromium electro deposits (0-1-10 MILS) are often used to salvage under machine parts. Unless otherwise specified, the plating shall be applied after all basic metal heat treatments and mechanical operations such as machining, brazing, welding, forming and perforating have been completed. Hydrogen embrittlement relief shall be in accordance with blue prints and /or applicable specifications. All plated parts which are designed for unlimited life under dynamic loads shall be shotpeened in accordance with military Specification MIL-S-13165 prior to plating. All parts with a hardness of Rockwell C40(180, 000 PSI), after shot peening and plating, shall be baked at  $375 \pm 25^\circ\text{F}$  for 3 hours for hydrogen embrittlement relief. It is extensively used as an undercoating for nickel and chromium plating.

**2-290. Tin Plating (QQ-T-425).** Tin plating is used where a neat appearance, protective coating and easy solderability are of prime importance. The base metal for tinplate shall be low carbon cold steel.

**2-291, Phosphate Coating (IL-P-16232).** The description of phosphate coatings herein is specified as "heavy" coatings. Light phosphate coatings used as a paint base are covered by specification TT-C-490. Type "M" (Manganese) coatings are resistant to alkaline environments and should not be exposed to temperatures in excess of 250°F. Except for special purpose applications, phosphate coatings should be used with a suitable supplementary treatment. Type "Z" (Zinc) coatings should not be used in contact with alkaline materials or temperature in excess of 200°F. For the different classes of coatings and required supplemental treatments, refer to MIL-P16232. This coating should be applied after all machining, forming, welding and heat treatment have been completed. Parts having a hardness of Rockwell C40 or higher shall be given a suitable heat treat stress relief prior to plating and shall be baked subsequent to coating as follows:

- a. Type "hM" shall be baked at  $210^\circ\text{--}225^\circ\text{F}$  for 1 hour.
- b. Type "Z" shall be baked at  $200^\circ\text{--}210^\circ\text{F}$  for 15 minutes (embrittlement relief).

**2-292. Silver Plating (QQ-S-635).** Silver plating (electro deposits) has high chemical and oxidation resistance, high electrical conductivity and good bearing properties. Silver is often used as an anti-seize and for preventing fretting corrosion at elevated temperatures. Silver plating shall be of the following types and grades:

- a. Type I, Matte. Deposits without luster, normally obtained from silver-cyanide plating solutions operated without the use of brighteners.
- b. Type II, Semi-Bright. Semi-lustrous deposits normally obtained from silver-cyanide plating solutions operated with brightener.
- c. Type m, Bright. Sometimes obtained by polishing or by use of "brighteners".
- d. Grade A. With supplementary tarnish resistant treatment (chromate treated).
- e. Grade B. Without supplementary tarnish resistant treatment.

**2-293. Intended Use.** The following applications of thickness are for information purposes only:

- a. 0.0005 for corrosion protection of nonferrous base metal.
- b. 0.0003 for articles such as terminals which are to be soldered.
- c. 0.0005 to 0.010 for electrical contacts, depending on pressure, friction and electrical load.
- d. 0.0005 for increasing the electrical conductivity of base metals.
- e. On ferrous surfaces, the total plated thickness shall not be less than 0.001 inch. After all base metal heat treatments and mechanical operations such as machining, brazing, welding, forming and perforating of the article have been completed, if the type is not specified, any type is acceptable. All steel parts subject to constant flexure or impact having a Rockwell hardness of RC40 or greater shall be heated at  $375 \pm 25^\circ\text{F}$  for 3 hours for stress relief prior to cleaning and plating.

**2-294.** Hardened parts which have been heat treated at less than 375°F shall not be heated as noted above, but shall be treated by any method approved by the contracting agency.

**2-295.** For complete information pertaining to silver plating, refer to Federal Specification QQ-S-365.

**2-296. SURFACE TREATMENTS FOR CORROSION AND HEAT-RESISTING STEELS AND ALLOYS** . Normally the corrosion-resisting and heat resisting alloys are unplated unless a coating is necessary to minimize the effect of dissimilar metal contacts. When a plating is required it shall be in accordance with specification MIL-S-5002A or other approved technical engineering data. Where a plating is required, steel parts plated with hard coating, such as nickel and chromium or combinations thereof, shall be processed as follows in accordance with MIL-S-5002A):

a. Plated parts below Rockwell C40 hardness and subject to static loads or designed for limited life under dynamic loads, or combinations thereof, need not be shot peened prior to plating or baked after plating.

b. Plated parts below Rockwell C40 hardness which are designed for unlimited life under dynamic loads shall be shot peened in accordance with specification MIL-S-13165 prior to plating. Unless otherwise specified, the shot peening shall be accomplished on all surfaces for which the coating is required and on all immediately adjacent surfaces when they contain notches, fillets or other abrupt changes of section size where stresses will be concentrated.

c. Plated parts which have a hardness of Rockwell C40, or above, and are subject to static loads or designed for limited life under dynamic loads or combination thereof, shall be baked at  $375^{\circ} \pm 25^{\circ}\text{F}$  for not less than three (3) hours after plating.

d. Plated parts which have a hardness of Rockwell C40, or above, and are designed for unlimited life under dynamic loads, shall be shot peened in accordance with specification MIL-S-13165 prior to plating. Unless otherwise specified, the shot peening shall be accomplished on all surfaces for which the coating is required and all immediately adjacent surfaces when they contain notches, fillets, or other abrupt changes of section size where stresses will be concentrated. After plating, the parts shall be baked at  $375^{\circ} \pm 25^{\circ}\text{F}$  for not less than three (3) hours.

**2-297. PASSIVATION OF STAINLESS STEELS**. The stainless steels are usually passivated after fabricating into parts to remove surface contaminants, which may cause discoloration or corrosive attack after the parts are placed in use. The process is primarily a cleaning operation which removes the contamination and speeds up the formation of the protective (invisible) oxide film which would occur naturally but slower in the presence of oxygen in abnormal atmosphere. The protective film formation is inherent with the stainless steels in normal air when they are clean.

**2-298.** The foreign materials are removed from stainless to provide for uniform surface contact with oxidizing agents (Air or Acid) which forms the protective film or passive surface. In this case after the film has formed the material is placed in a condition approaching that of maximum corrosion resistance. Any areas to which oxygen contact is prevented by contaminants or other means tends to remain activated and subject to corrosion attack.

**2-299.** Prior to accomplishing the passivation treatments the parts shall be cleaned, all grease, oil, wax, which might contaminate the passivation solution and be a detriment to the passivation treatment shall be removed. Surfaces will be considered sufficiently clean when a wetted surface is free of water breaks. After cleaning the parts will be passivated by immersing in a solution of 20-25% (Volume) nitric acid (Sp.gr 1.4A2) plus 1.5-2.5% (Weight) sodiumdichromate with process times and temperatures as follows: CAUTION Excessive time shall not be used, as damage to parts may occur. In addition the times and temperatures shall be selected according to the alloy involved.

TYPES OF PROCESS	TEMPERATURE	TIME (Minutes Minimum)
I	70-90	30
II	120-130	20
III	145-155	10

For parts made of ferritic or austenitic stainless use process Type I, II or III. For parts made of martensitic stainless steel, use process Type II or III. Within 15 minutes after above treatment, thoroughly rinse in hot water ( $140^{\circ}\text{F}$ - $160^{\circ}\text{F}$ ). Within 1 hour after hot water rinse, immerse in an aqueous solution containing 4-6% sodium dichromate (by weight) at  $140$ - $160^{\circ}\text{F}$  for 30 minutes, and rinse thoroughly with water and dry.

#### NOTE

**After the parts are passivated they shall be handled the minimum necessary consistent with packaging, assembly/installation. Parts for installations in high temperature areas shall not be handled with bare hands because finger prints will cause carburization and pitting of surface when heated.**

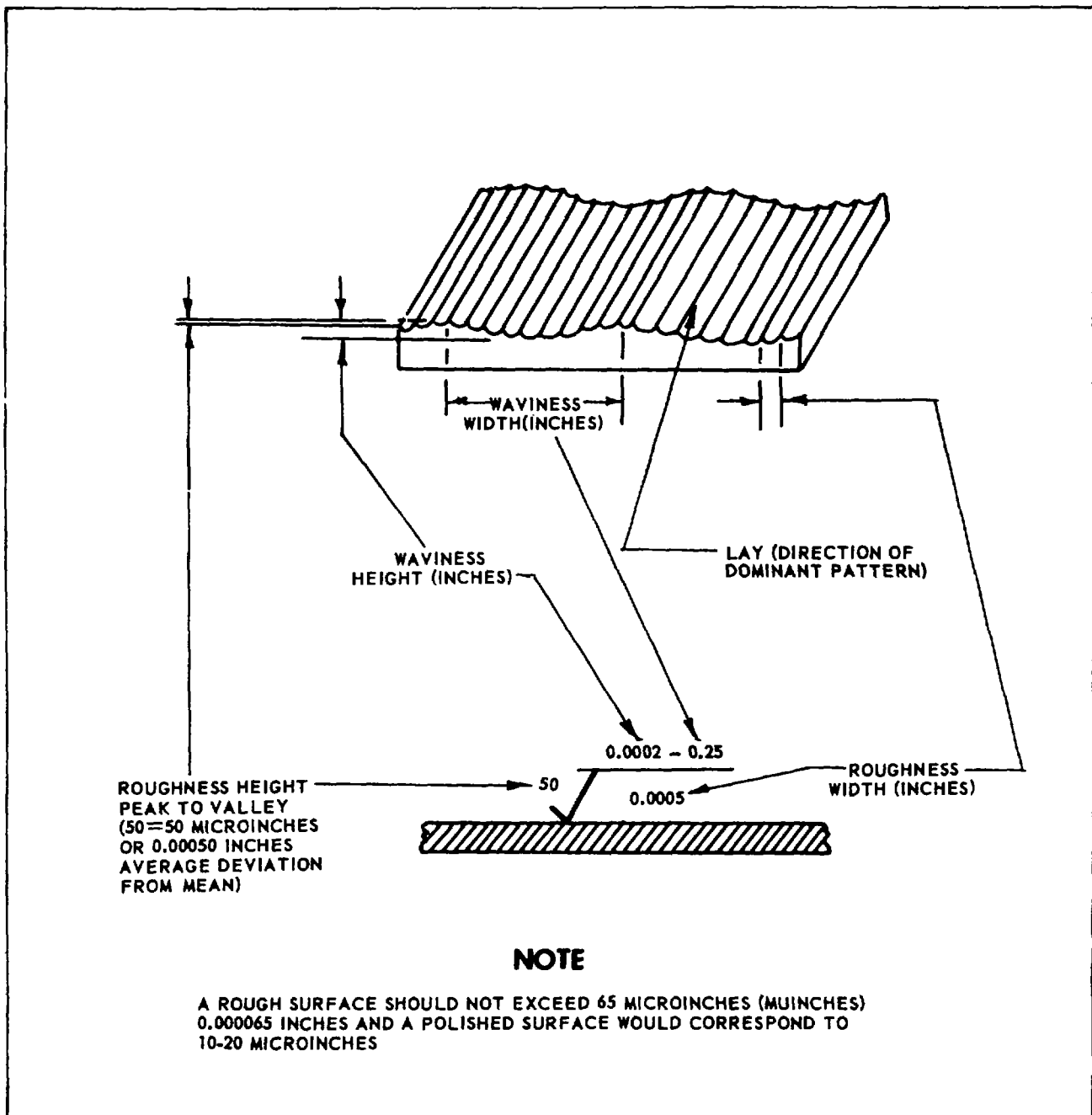


Figure 2-5. SURFACE ROUGHNESS.

**2-300. VAPOR DEPOSITED COATING.** Vapor deposited coating's are applied by exposing the base metal to a heated vaporized metallix coating such as cadmium and aluminum in a high vacuum. The metal coating forms by condensation of the vaporized coating metal on all exposed surfaces of the base metal. Vapor-deposited coatings can be obtained by processes in which a volatile compound of the coating is reduced or thermally decomposed upon the heated surface of the base metal. Vapor deposited coatings are used to provide good corrosion resistance for steel and eliminate sources of hydrogen embrittlement. Specific requirements for coating, aluminum vacuum deposited, are cited in specification MIL-C-23217A; and for coating, cadmium vacuum deposited, in specification MIL-C8837.

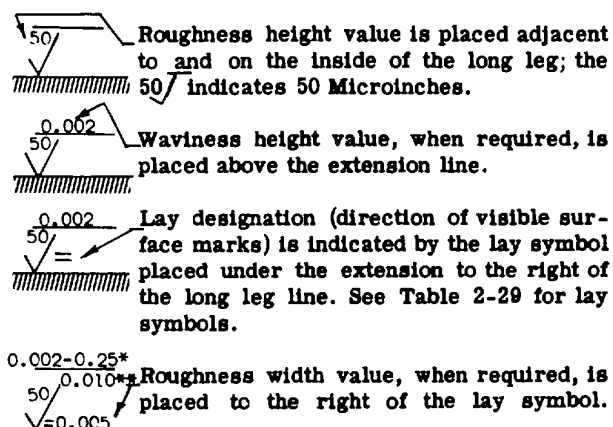
**2-301. MECHANICAL-SURFACE FINISH.** The following paragraphs are concerned with mechanical surface finish of the geometrical irregularities of surfaces of solid materials and established classification for various degrees of roughness and waviness. The surface roughness of a part is a measurement rating of the finely spaced irregularities, such as the surfaces produced by machining and abrading (abrasive honing, grinding, filing, sanding, etc.) The roughness height ratings are specified in micro inches as the arithmetic average of the absolute deviations from the mean surface. Profilometers and other instruments used to measure surface height if calibrated in RMS (Root Mean Square) average will read approximately 11% higher on a given surface than those calibrated for arithmetic average. Also associated with roughness high is roughness width, usually specified in inches and the maximum permissible spacing of surface irregularities. As the arithmetic average of the absolute deviations from the mean surface. Waviness height rating (when required) may be specified in inches as the vertical distance from peaks to valleys of the waves, whereas waviness width is the distance in inches from peak to peak of the waves. Figure 2-5 shows the meaning of each symbol defined.

**2-302.** The symbol used to designate surface irregularities is the check mark as shown below.

\*When waviness width value is required, the value may be placed to the right of the waviness height value.

\*\*Roughness width cutoff value, when required, is placed immediately below the right-hand extension.

**2-303.** Designation of Surface Finish. Surface finish should be specified for production parts only on those surfaces which must be under functional control. For all other surfaces the finish resulting from the machining method required to obtain dimensional accuracy is generally satisfactory. The surface chosen (unless already designated) for a specific application will be determined by its required function. Table 2-29 gives the typical normal ranges of surface roughness of functional parts. The values cited are micro inches, for example 63T= 63 Micro inches or 0.00063 inches average deviation from mean.



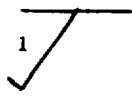
**TABLE 2-28. GALVANIC SERIES OF METALS AND ALLOYS.**

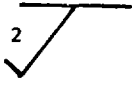
CORRODED END ANODIC (LEAST NOBLE)	
Magnesium	Tin
Magnesium Alloys	Nickel (active)
Zinc	Inconel (active)
Aluminum 7075 Clad	Brass
Aluminum 6061 Clad	Copper
Aluminum 5052	Bronze
Aluminum 2024 Clad	Titanium
Aluminum 3003	Monel
Aluminum 6061 T6	Silver Solder
Aluminum 7075 T6	Nickel (Passive)
Aluminum 7178	Inconel (Passive)
Cadium	Silver
Aluminum 2017 T4	Graphite
Aluminum 2024 T6	Gold
Aluminum 2014T6	Platinum
Steel or Iron	Protected End Cathodic
Lead	(Most Noble)

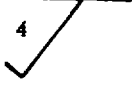


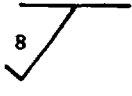
T.O. 1-1A-9

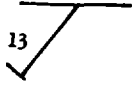
TABLE 2-29. SURFACE ROUGHNESS AND LAY SYMBOLS

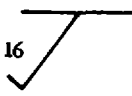
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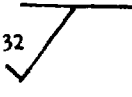
**1** MICROMETER ANVILS,  
MIRRORS, GAGES
- 

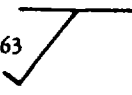
**2** SHOP GAGE FACES  
COMPARATOR ANVILS
- 

**4** VERNIES, CALIPERS FACES,  
WRIST PINS,  
HYDRAULIC PISTON RODS,  
PRECISION TOOLS,  
HONED ROLLER & BALL  
BEARINGS  
(SURFACE PRODUCED BY SPECIAL  
HONING, LAPPING, BUFFING, ETC)
- 

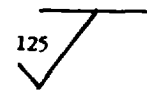
**8** CRANKSHAFT JOURNALS  
VALVE STEMS  
CAM FACES  
HYDRAULIC CYLINDER BORES  
(VERY FINE SURFACE FINISH  
PRODUCED BY LAPPING, HONING  
OR BUFFING)
- 

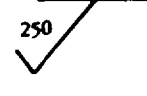
**13** PISTON OUTSIDE  
DIAMETERS, CYLINDER  
BORES
- 

**16** SPLINE SHAFTS  
MOTOR SHAFT BEARINGS
- 

**32** BRAKE DRUMS  
BROACHED HOLES  
PRECISION PARTS  
GEAR TEETH  
GROUND BALL & ROLLER  
BEARING
- 

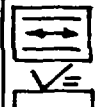


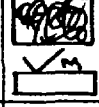




**63** GEAR LOCATING FACES  
GEAR SHAFTS & BORES  
CYLINDER HEAD FACES  
PISTON CROWNS

- 

**125** MATING SURFACES,  
NO MOTION
- 

**250** CLEARANCE SURFACES  
ROUGH MACHINE  
PARTS

LAY SYMBOLS

SYMBOL		EXAMPLE
=	LAY PARRALLED TO SURFACE TO WHICH SYMBOL APPLIES	 DIRECT. OF TOOL MARKS
⊥	LAY PERPENDICULAR TO SURFACE TO WHICH SYMBOL APPLIES	 DIRECT. OF TOOL MARKS
X	LAY IN BOTH DIRECTIONS TO SURFACE TO WHICH SYMBOL APPLIES	 DIRECT. OF TOOL MARKS
M	LAY MULTIDIRECTIONAL TO SURFACE TO WHICH SYMBOL APPLIES	
C	LAY CIRCULAR TO SURFACE TO WHICH SYMBOL APPLIES	 
R	LAY RADIAL RELATIVE TO SURFACE TO WHICH SYMBOL APPLIES	 



### SECTION III ALUMINUM ALLOYS

#### 3-1. CLASSIFICATION.

**3-2.** Aluminum alloys are produced and used in many shapes and forms. The common forms are casting, sheet, plate, bar, rod (round, hex, etc.), angles (extruded and rolled or drawn), channels and forgings. The inherent advantages of this material are lightweight, corrosion resistance to the atmosphere and many varieties of chemicals, thermal and electrical conductivity, reflectivity for radiant energy of all wave lengths and ease of fabrication.

**3-3.** The above factors plus the fact that some alloys of this material can be formed in a soft condition and heat treated to a temper comparable to structural steel make it very adaptable for fabricating various aircraft and missile parts.

**3-4. COMMERCIAL AND MILITARY DESIGNATIONS .** The present system utilized to identify aluminum alloys is the 4 digit designation system. The major alloy element for each type is indicated by the first digit (see Table 3-1) i.e., 1XXX indicates aluminum of 99.00% minimum, 2XXX indicates an aluminum alloy in which copper is the main alloying element, etc. Although most aluminum alloys contain several alloying elements only one group the 6XXX designate more than one alloying element. See Table 3-1 for complete listing.

**TABLE 3-1 DESIGNATIONS FOR ALLOY GROUPS**

<b>1XXX</b>	- - - Aluminum 99.00% of minimum and greater
<b>2XXX</b>	- - - Copper
<b>3XXX</b>	- - - Manganese
<b>4XXX</b>	- - - Silicon
<b>5XXX</b>	- - - Magnesium
<b>6XXX</b>	- - - Magnesium and Silicon
<b>7XXX</b>	- - - Zinc
<b>8XXX</b>	- - - Other element
<b>9XXX</b>	- - - Unused series

The second digit of the designation indicates modification in impurity limits. If the second digit is 0 it indicates that there is no special control on the impurities, while numbers 1-9 which are assigned consecutively as needed indicates special control of one individual impurity. Thus 1040 indicates 99.40% minimum aluminum without special control on individual impurities and 1140, 1240 etc. indicate same purity with special control on one or more impurities.

**3-5.** The last two of the four digits in alloy groups 2XXX through 8XXX have no special significance except that they serve to designate the alloy by its former number, i.e., 243, 525, 758, etc.

**3-6.** Experimental alloys are, also, designated by this system except that the 4 digit number is prefixed by an X.

**TABLE 3-2 ALUMINUM ALLOY DESIGNATION AND CONVERSIONS TO 4 DIGIT SYSTEM**

<u>OLD</u>	<u>NEW</u>	<u>MAJOR ALLOYING ELEMENT</u>
<b>2S</b>	<b>1100</b>	<b>None (Aluminum 99.00X)</b>
<b>3S</b>	<b>3003</b>	<b>Manganese</b>
<b>4S</b>	<b>3004</b>	<b>Manganese</b>
<b>11S</b>	<b>2011</b>	<b>Copper</b>
<b>14S R301 Core</b>	<b>2014</b>	<b>Copper</b>
<b>17S</b>	<b>2017</b>	<b>Copper</b>
<b>A17S</b>	<b>2117</b>	<b>Copper (Special control of impurities)</b>
<b>18S</b>	<b>2018</b>	<b>Copper</b>
<b>24S</b>	<b>2024</b>	<b>Copper</b>
<b>19S</b>	<b>2219</b>	<b>Copper</b>
<b>32S</b>	<b>4032</b>	<b>Silicon</b>
<b>50S</b>	<b>5050</b>	<b>Magnesium</b>
<b>52S</b>	<b>5052</b>	<b>Magnesium</b>
<b>56S</b>	<b>5056</b>	<b>Magnesium</b>
<b>61S</b>	<b>6061</b>	<b>Magnesium &amp; Silicon</b>
<b>62S</b>	<b>6062</b>	<b>Magnesium &amp; Silicon</b>
<b>63S</b>	<b>6063</b>	<b>Magnesium &amp; Silicon</b>
<b>72S</b>	<b>7072</b>	<b>Zinc</b>
<b>75S</b>	<b>7075</b>	<b>Zinc</b>
<b>78S</b>	<b>7178</b>	<b>Zinc</b>
<b>79S</b>	<b>7079</b>	<b>Zinc</b>

**NOTE**

**Cladding which is a sacrificial aluminum coating applied to an aluminum alloy core for the purpose of increasing corrosion resistance is designated as alclad 2024, alclad 2014, alclad 7075, etc.**

**3-7.** Aluminum alloys for military use are identified by military and federal specifications which are comparable to commercial specifications and designations.

The following table is a general list of the commonly used military and federal specifications according to the commercial designation and forms of material.

**3-8. MECHANICAL PROPERTIES.** Prior to presenting factual data on mechanical properties the tempers (hardness) and methods of designation should be explained. For nominal mechanical properties see Table 3-4.

**3-9.** The tempers of aluminum alloys are produced essentially by three methods. These methods are cold working (strain hardening), heat treatment and a combination of the two. The various alloys of aluminum are either classed as heat-treatable or non-heat-treatable. Alloys 1100, 3003, alclad 3003, 3004, alclad 3004, 5050 and 5052 are classed as nonheat-treatable.

The tempers of these alloys are designated by symbols H1, H2, H3, H4, F & O.

**3-10.** A second number added to the above indicates the degree of strain hardening-actual temper.

Example:        2=¼ hard (2/8) H12, H22, H32  
                   4=½ hard (4/8) H14, H24, H34  
                   6=¾ hard (6/8) H16, H26, H36  
                   8=Full Hard (8/8) H18, H28, H38

As previously pointed out the above tempers designation symbols are hyphen (-dash) suffixed to the 4 digit alloy designation.

Example: 1000-H12, 5052-H24, 3004-H34 etc. The general symbols used for the non-heat-treatable alloys are as follows:

- F As fabricated
- O Annealed
- H21 Strain hardened only
- H2 Strain hardened then partial annealed
- H3 Strain hardened then stabilized

**NOTE**

**Attempt should not be made to alter the temper characteristics of the "H" series of aluminum alloys other than in emergencies. This shall be limited to annealing operation only.**

**3-11.** Alloys alclad 2014, 2024, alclad 2024, 8061, 7075, alclad 7075 and 7178 are classed as heat treatable. The mechanical properties of these alloys is improved by heat treatment or by a combination of heat treatment and strain hardening. The tempers for these alloys is designated by symbols, W, T, T2, T3, T4, T5, T6, T7, T8, T9, T10, F & O. Following is a summary of these symbols.

- F As fabricated
- O Annealed
- W Solution heat treated unstable temper
- T Treated to produce stable tempers other than -F or -O
- T2 Annealed (cast products only)
- T3 Solution heat treated and then cold worked
- T4 Solution heat treated -T5 Artificially aged only
- T6 Solution heat treated and then artificially aged
- T7 Solution heat treated and stabilized
- T8 Solution heat treated, cold worked and then artificially aged
- T9 Solution heat treated, artificially aged, and then cold worked
- T10 Artificially aged and then cold worked

Added numbers to the above denotes a modification of standard tempers. Example: The numeral "6" following "T3" indicates a different amount of cold work than used in "T3" such as 2024-T36. The numbers added to indicate modification or significant alternation of the standard temper are arbitrarily assigned and specification for the alloy should be utilized to determine specific data.

**3-12.** The following standard modification digits have been assigned for wrought products in all alloys: TX-51 Stress-Relieved by Stretching: Applies to products which are stress-relieved by stretching the following amounts after solution heat treatment:

Plate	1 ½ to 3% permanent set
Rod, Bar and Shapes	1 to 3% permanent set

Applies directly to plate and rolled or cold finishes rod and bar. These products receive no further straightening after stretching.

Applies to extruded rod, bar and shapes which receive minor straightening after stretching to comply with standard tolerances.

- TX510 Applies to extruded rod, bar and shapes which receive no further straightening after stretching.
- TX511 Applies to extruded rod, bar and shapes which receive minor straightening after stretching to comply with standard tolerances.

TABLE 3-3 - FEDERAL AND MILITARY SPECIFICATIONS.

ALLOY	FORM (COMMODITY)	AMS	FEDERAL	MILITARY
1100	Bars Rolled Bar, rod, wire & shapes, rolled or drawn Sheet & Plate Tubing	4102  4001B, 4003B 4062C -	QQ-A-411, QQ-A-225/1  QQ-A-411, QQ-A-225/1 QQ-A-561, QQ-A-250/1 WW-T-783 (Old), WW-T-700/1 -	- - - - MIL-A-148
*	Extrusion (Impact)	-	-	MIL-A-12545
1360	Wrought Product	-	-	MIL-A-799
2011	Bar and Rod	-	QQ-A-365, QQ-A-225/3	-
2014	Bar, Rod & Shapes Extruded	4153A	QQ-A-261, QQ-A-200/2	
Alclad 2014	Bar, Rod & Shapes Rolled or Drawn	4121B	QQ-A-266, QQ-A-225/4	
	Forgings	4134A, 4135H	QQ-A-367	
	Extrusions (Impact)		(See QQ-A-367 & 367-1)	MIL-A-12545
	Plate & Sheet		QQ-A-255, QQ-A-250/3	
2017	Bar, Rod, Wire & Shapes, Rolled or Drawn	4118	QQ-A-351, QQ-A-225/5	
	WIRE - ROD		QQ-A-430	MIL-W-7986
	FORGINGS		QQ-A-367	
2018	Forgings	4140	QQ-A-367	
2020	Sheet & Plate		QQ-A-250/16	MIL-A-8882
2024	Bar, Rod & Shapes	4152	QQ-A-267, QQ-A-200/3	
	Extruded			
2024	Bar, Rod & Shapes Rolled or Drawn	4120	QQ-A-225/6, QQ-A-268	
	Plate & Sheet	4035 4037	QQ-A-355, QQ-A-250/4	
Alclad 2024	Sheet & Plate	4040 4041 4042	QQ-A-362, QQ-A-250/5	
2024	Tube Drawn	4086 4087 4088	WW-T-785 (Old), WW-T-700/3	
2025	Forgings	4130	QQ-A-367	
2218	Forgings	4142	QQ-A-367	
2219	Plate & Sheet			MIL-A-8720

TABLE 3-3 - FEDERAL AND MILITARY SPECIFICATIONS (CONT'D)

ALLOY	FORM (COMMODITY)	AMS	FEDERAL	MILITARY
3003	Bar, Rod, Shapes Extruded		QQ-A-200/1, New QQ-A-357, Old	
	Bar, Rod, Wire & Shapes Rolled or Drawn		QQ-A-225/2 (New) QQ-A-356 (Old)	
	Plate & Sheet	4006 4008	QQ-A-359, QQ-A-250/2	
	Tube Drawn	4065 4067	WW-T-786 (Old) WW-T-700/3	
4032	Forgings	4145	QQ-A-367	
5052	Bar, Rod, Wire & Shapes Drawn	4114	QQ-A-225/7 (New) QQ-A-315 (Old)	
5052	Plate & Sheet	4015 4016 4017	QQ-A-318 QQ-A-250/8	
	Tube, Drawn	4070 4071	WW-T-787 (Old), WW-T-700/4	
5056	Bar, Rod & Wire Rolled or Drawn	4182		MIL-C-915 (Ships)
	Bar, Rod, Shapes-Extruded		QQ-A-200/7	MIL-C-6136
	Plate Sheet		QQ-A-250/9	
	Wire Rod			MIL-W-7986
	Welding Rod		QQ-R-566 C1 FS-RA156	
5083	Bar, Rod & Shapes		QQ-A-200/4 (New)	MIL-A-19005
	Plate & Sheet		QQ-A-250/8 (New)	MIL-A-87001 MIL-A-17358
5086	Plate & Sheet		QQ-A-250/7 (New)	MIL-A-19070
5154	Plate & Sheet	4018 4019		MIL-A-17357
6061	Bar, Rod & Shapes Extruded	4150	QQ-A-270	
	Bar, Rod & Shapes Rolled or Drawn		QQ-A-225/8 (New) QQ-A-325 (Old)	
6081	Forgings	4127	QQ-A-367d-1	
	Plate & Sheet	4025 4026 4027	QQ-A-327 QQ-A-250/11 (New)	
	Tube, Drawn	4080 4082	WW-T-789/WW-T-700/6	
	Tube, Hydraulic	4081		MIL-T-7081

TABLE 3-3 - FEDERAL AND MILITARY SPECIFICATIONS (CONT'D)

ALLOY	FORM (COMMODITY)	AMS	FEDERAL	MILITARY
Alclad 6061	Sheet & Plate	4021 4022 4023		
6062	Bar, Rod & Shapes Extruded  Tube, Drawn  Tube, Hydraulic	4155  4091 4092 4093	QQ-A-270 (Old) QQ-A-200/8 (New)	MIL-T-7081
6063	Bar, Rod & Shapes Extruded	4156	QQ-A-200/9 (New) QQ-A-274 (Old)	
6066	Bar, Rod & Shapes Extruded			
6151	Forgings	4125	QQ-A-367	
7075      Alclad 7075	Bar, Rod & Shapes Extruded  Bar, Rod Shapes & Wire, Rolled or Drawn  Forgings Extrusions (Impact)  Plate & Sheet  Plate & Sheet  Plate & Sheet Alclad one side	4154  4122  4139 4170  4044 4045  4048 4049	QQ-A-225/11 QQ-A-277  QQ-A-225/9 QQ-A-282  QQ-A-367  QQ-A-283 QQ-A-250/12  QQ-A-287 QQ-A-250/13  QQ-A-250/13	MIL-A-12545      MIL-A-8902
7076	Forgings	4137	QQ-A-367	MIL-A-11352
7079	Forgings  Plate & Sheet  Plate and Sheet Alclad One side	4138	QQ-A-367  QQ-A-250/17  QQ-A-250/18	
7178	Bar & Shapes Extruded  Plate & Sheet	4158  4051 4052	QQ-A-250/14	MIL-A-9186  MIL-A-9180
8280	Sheet			MIL-A-11267 (ORD)

TABLE 3-3 - FEDERAL AND MILITARY SPECIFICATIONS (CONT'D)

ALLOY	FORM (COMMODITY)	AMS	FEDERAL	MILITARY
99.75% 99.5% 99.3% 99.0%	Ingot		QQ-A-451	
43 108 A108 113 122 A132	Foundry Ingot		QQ-A-371	
142 195 B195 214 220 319 355 356	Foundry Ingot		QQ-A-371	
<b>XB216</b>	Foundry Ingot			<b>MIL-A-10937 (ORD)</b>
43	Sand Castings		QQ-A-601	
108	Sand Castings		QQ-A-601	
113	Sand Castings		QQ-A-601	
122	Sand Castings		QQ-A-601	
142	Sand Castings	4222	QQ-A-601	
195	Sand Castings	4230 4231	QQ-A-601	
B214	Sand Castings		QQ-A-601	
<b>XB216</b>	Sand Castings			<b>MIL-A-10936 (ORD)</b>
220	Sand Castings		QQ-A-601	
319	Sand Castings	4240	QQ-A-601	
355	Sand Castings	4210 4212 4214	QQ-A-601	
356	Sand Castings	4217		
A612	Sand Castings			<b>MIL-A-10936 (ORD)</b>
ML	Sand Castings			<b>MIL-A-25450 USAF</b>
43	Permanent Mold Castings		QQ-A-596	
A108	Permanent Mold Castings		QQ-A-596	

TABLE 3-3 - FEDERAL AND MILITARY SPECIFICATIONS (CONT'D)

ALLOY	FORM (COMMODITY)	AMS	FEDERAL	MILITARY
113	Permanent Mold Castings		QQ-A-596	
122	Permanent Mold Castings		QQ-A-596	
A132	Permanent Mold Castings		QQ-A-596	
B195	Permanent Mold Castings	4282 4283	QQ-A-596	
XB216	Permanent Mold Castings			MIL-A-10935 (ORD)
319	Permanent Mold Castings		QQ-A-596	
355	Permanent Mold Castings	4280 4281	QQ-A-596	
356	Permanent Mold Castings	4284 4286	QQ-A-596	
750	Permanent Mold Castings	4275	QQ-A-596	
ML	Permanent Mold Castings			
13	Die Castings	4290	QQ-A-591	MIL-A-15153 Ships
43	Die Castings		QQ-A-591	MIL-A-15153 Ships
218	Die Castings		QQ-A-591	MIL-A-15153 Ships
360	Die Castings	4290	QQ-A-591	
A360	Die Castings		QQ-A-591	MIL-A-15153 Ships
380	Die Castings		QQ-A-591	
A380	Die Castings	4291	QQ-A-591	MIL-A-15153 Ships
Misc STANDARD/SPECIFICATIONS				



-TX52 Stress-Relieved by Compressing: Applies to products which are stress-relieved by compressing after solution heat treatment.

-TX53 Stress-Relieved by Thermal Treatment.

**3-13.** The following two digit T temper designations have been assigned for wrought products in all alloys:

-T42 Applies to products solution heat treated by the user which attain mechanical properties different from those of the -T4 temper.\*

-T62 Applies to products solution heat-treated and artificially aged by the user which attain mechanical properties different from those of the -T6 temper.\*

\* Exceptions not conforming to these definitions are 4032-T62, 6101-T62, 6062-T62, 6063-T42 and 6463T42.

**3-14.** For additional information on heat treating aluminum alloys, see paragraph 3-22.

**3-15.** Chemical composition nominal plus general use data are given in Table 3-4 and nominal mechanical properties at room temperature are given in Table 3-5. The values cited are general and intended for use as comparisons values. For specific values the specification for the alloy should be utilized.

TABLE 3-4 - CHEMICAL COMPOSITION NOMINAL AND GENERAL USE DATA 1/

ALLOY	1 NOMINAL COMPOSITION - %							FLAT AND COILED SHEET	PLATE	SHAPES RODS AND BARS	TUBE	PIPE	CHARACTERISTICS
	SI	CU	MN	MG	CR	ZN	AL						
EC	--	--	--	--	--	--	99.45		X				Electrical conductor
1060	0.25	0.05	0.03	0.03	--	0.05	99.60		X				Good corrosion resistance, electrical conductivity, formability and weldability.
1100	1.0	0.20	0.05	--	0.10	0.10	99.0	X	X	X	X		Excellent formability, readily welded and brazed, corrosion resistant.
1145	0.55	0.05	0.05	--	--	--	99.45	X					Excellent formability combined with high electrical and thermal conductivity and corrosion resistant.
2014	0.8	4.5	0.8	0.4	0.10	0.25	REM		X	X	X		High strength alloy. Electric resistance weldability excellent fusion weldability limited.
2024	0.5	4.5	0.6	1.5	0.10	0.25	REM		X	X	X		Popular sheet alloy for aircraft similar to 2014.
3003	0.6	0.20	1.2	--	--	0.10	REM	X	X	X	X	X	Stronger than 1100 with good weldability and formability, high resistance to corrosion.
3004	0.30	0.25	1.2	1.0	--	0.25	REM	X	X				Stronger than 1100 and 3003 with fair workability and good corrosion resistance.
5005	0.40	0.20	0.20	0.8	0.10	0.25	REM	X	X				Similar to 3003 in strength. Good anodizing characteristics, formability and resistance to corrosion.

TABLE 3-4 - CHEMICAL COMPOSITION NOMINAL AND GENERAL USE DATA 1/(CONT'D)

ALLOY	NOMINAL COMPOSITION - %							FLAT AND COILED SHEET	PLATE	SHAPE RODS AND BARS	TUBE	PIPE	CHARACTERISTICS
	SI	CU	MN	MG	CR	ZN	AL						
5050	0.40	0.20	0.10	1.4	0.10	0.25	REM	X	X				Good anodizing strength, formability, weldability, and corrosion resistance.
5052	0.45	0.10	0.10	2.5	0.25	0.10	REM	X	X				Highest strength of non-heat-treatable alloys. Good corrosion resistance and finishing characteristics.
5083	0.40	0.10	0.8	4.5	0.15	0.25	REM		X	X			High weld joint efficiency with basic good strength and resistance combined with good formability.
5154	0.45	0.10	0.10	3.5	0.25	0.20	REM		X	X			Good strength and excellent weldability.
5254	0.45	0.05	0.01	3.5	0.25	0.20	REM		X				Good strength, weldability and corrosion resistance.
5357	0.12	0.07	0.3	1.0	--	--	REM	X					Excellent bright finishing characteristics.
5454	0.40	0.10	0.8	2.7	0.2	0.25	REM		X	X	X		Excellent strength at elevated temperature (150°-300°F) plus weldability.
5456	0.40	0.20	0.8	5.3	--	--	REM		X	X			High strength and corrosion resistance, weldable.
5457	0.08	0.20	0.3	1.0	--	--	REM	X					Superior bright finish when anodized.
5557			0.25	0.6			REM	X					Good bright finishing characteristics. Good weldability and formability.

TABLE 3-4 - CHEMICAL COMPOSITION NOMINAL AND GENERAL USE DATA 1/(CONT'D)

ALLOY	1/ NOMINAL COMPOSITION - %							FLAT AND COILED SHEET	PLATE	SHAPES RODS AND BARS	TUBE	PIPE	CHARACTERISTICS
	SI	CU	MN	MG	CR	ZN	AL						
5652				2.5	0.25		REM		X				Excellent strength with good finishing characteristics and corrosion resistance.
6061	0.6	.25	0.15	1.0	.25	0.25	REM		X	X	X	X	Best weldability of heat treatable alloys, good formability and corrosion resistance.
6062	0.6	.25	0.15	1.0	.06	0.25	REM			X	X		Good weldability with formability better than 6061.
6063	0.4	0.10	0.10	0.7	0.10	0.25	REM			X	X	X	Good finishing characteristics and resistance to corrosion. Good workability with moderate strength.
7075	0.50	1.6	0.30	2.5	.3	5.6	REM		X	X	X		2/ Extra high strength and hardness. Electric resistance weldability but limited fusion weldability.
7079	0.30	.6	.2	3.3	.2	4.3	REM			X			Similar to 7075 but maximum strength in thick sections.
7178		2.0	0.30	2.7	.3	6.8	REM		X	X			High strength alloy for a/c applications, however it is notch sensitive.

SI = Silicon MN = Manganese CR = Chromium AL = Aluminum CU = Copper MG = Magnesium ZN = Zinc

1/ Nominal Composition Does Not Include All Alloying Elements That May Pertain, Specification Should Be Utilized When Specific Data Required.

2/ 7075 - T73 Is Completely Resistant To Stress Corrosion Cracking.

TABLE 3-5 - MECHANICAL PROPERTIES - TYPICAL

Alloy and Temper	Tensile Strength PSI	Yield Strength (Offset= 0.2%) PSI	Elongation, Per Cent in 2 in. Sheet Specimen (1/16 in. Thick)	Brinell Hardness 500-kg Load 10 MMM Ball	Shearing Strength PSI
1100-0	13,000	5,000	35	23	9,000
1100-H12	16,000	15,000	12	28	10,000
1100-H14	18,000	17,000	9	32	11,000
1100-H16	21,000	20,000	6	38	12,000
1100-H18	24,000	22,000	5	44	13,000
3003-0	16,000	6,000	30	28	11,000
3003-H12	19,000	18,000	10	35	12,000
3003-H14	22,000	21,000	8	40	14,000
3003-H16	26,000	25,000	5	47	15,000
3003-H18	29,000	27,000	4	55	16,000
Alclad 3003					
3004-0	26,000	10,000	20	45	16,000
3004-H32	31,000	25,000	10	52	17,000
3004-H34	35,000	29,000	9	63	18,000
3004-H36	38,000	33,000	5	70	20,000
3004-H38	41,000	36,000	5	77	21,000
Alclad 3004					
Alclad 2014-0	25,000	10,000	21	--	18,000
Alclad 2014-T3	63,000	40,000	20	--	37,000
Alclad 2014-T4	61,000	37,000	22	--	37,000
Alclad 2014-T6	68,000	60,000	10	--	41,000
2024-0	27,000	11,000	20	47	18,000
2024-T3	70,000	50,000	18	120	41,000
2024-T36	72,000	57,000	13	130	42,000
2024-T4	68,000	47,000	20	120	41,000
Alclad 2024-0	26,000	11,000	20	--	18,000
Alclad 2024-T3	65,000	45,000	18	--	40,000
Alclad 2024-T36	67,000	53,000	11	--	41,000
Alclad 2024-T4	64,000	42,000	19	--	40,000
Alclad 2024-T81	65,000	60,000	6	--	40,000
Alclad 2024-T86	70,000	66,000	6	--	42,000
5005-0	18,000	6,000	30	28	11,000
5005-H32	20,000	17,000	11	36	14,000
5005-H34	23,000	20,000	8	41	14,000
5005-H36	26,000	24,000	6	46	15,000
5005-H38	29,000	27,000	5	51	16,000

TABLE 3-5 - MECHANICAL PROPERTIES - TYPICAL

Alloy and Temper	Tensile strength psi	Yield strength (Offset=0.2%) psi	Elongation, per cent in 2 in. sheet specimen (1/16 in. thick	Brinell hardness 500-kg load 10 mm ball	Shearing strength psi
5050-0	21,000	8,000	24	36	15,000
5050-H32	25,000	21,000	9	46	17,000
5050-H34	28,000	24,000	8	53	18,000
5050-H36	30,000	26,000	7	58	19,000
5050-H38	32,000	29,000	6	63	20,000
5052-0	28,000	13,000	25	47	18,000
5052-H32	33,000	28,000	12	60	20,000
5052-H34	38,000	31,000	10	68	21,000
5052-H36	40,000	35,000	8	73	23,000
5052-H38	42,000	37,000	7	77	24,000
5154-0	35,000	17,000	27	58	22,000
5154-H112	35,000	17,000	25	63	- - -
5154-H32	39,000	30,000	15	67	22,000
5154-H34	42,000	33,000	13	78	24,000
5154-H36	45,000	36,000	12	83	26,000
5154-H38	48,000	39,000	10	87	28,000
5357-0	19,000	7,000	25	32	12,000
5357-H32	22,000	19,000	9	40	13,000
5357-H34	25,000	22,000	8	45	15,000
5357-H36	28,000	26,000	7	51	17,000
5357-H38	32,000	30,000	6	55	18,000
6061-0	18,000	8,000	25	30	12,000
6061-T4	35,000	21,000	22	65	24,000
6061-T6	45,000	35,000	12	95	30,000
7075-0	33,000	15,000	17	60	22,000
7075-T6	83,000	73,000	11	150	48,000
Alclad 7075-0	32,000	14,000	17	--	22,000
Alclad 7075-T6	76,000	67,000	11	--	46,000
Alclad 7079-T6	70,000	60,000			
7178-0	40,000	21,000	10		
7178-T6	83,000	72,000	6		
7079-T6	72,000	62,000			

TABLE 3-6 - PHYSICAL PROPERTIES

## STANDARD ALLOYS

ALLOY	SPECIFIC GRAVITY	WEIGHTS PER CU. IN.	APPROX MELTING RANGE DEGREES F	ELECTRICAL CONDUCTIVITY % COMPARE TO COPPER STANDARD
1100-0	2.71	0.098	1,190-1,215	59
1100-H18				57
3003-0				50
3003-H12	2.73	0.099	1,190-1,210	42
3003-H14				41
3003-H18				40
3004-0	2.72	0.098	1,165-1,205	42
3004-H38				42 50
2014-0	2.80	0.101	950-1,180	40 30
2024-0	2.77	0.100	935-1,810	50
2024-T3				30
5050-0	2.69	0.097	1,160-1,205	50
5050-H38				50
5052-0	2.68	0.097	1,100-1,200	35
5052-H38				35
5357-0	2.70	0.098	1,165-1,210	43
5357-H38				43
6061-0	2.70	0.098	1,080-1,200	45
6061-T4, T6				40
7075-0	2.80	0.101	890-1,180	--
7075-T6				30
BRASS	8.4-8.8	0.304-0.319	---	26-43
Copper	8.94	0.322	1981	100
Monel	8.8	0.318	---	4
Nickel	8.84	0.319	2645	16
Steel(low alloy)	7.6-7.8	0.276-0.282	2800	3-15
Steel(18.8 stainless)	7.92	0.283	2500-2650	2.4
Tin	7.3	0.265	449	15
Zinc	7.1	0.258	787	30



TABLE 3-7 - HEAT TREATING (SOAKING) TEMPERATURES

ALLOY DESIGNATION	SOLUTION HEAT TREAT TEMPERATURE (DEGREES F)	TEMPER
<b>WROUGHT ALLOYS</b> Except forgings alloys		
2014	925-945	2014-T4
2017	925-945	2017-T4
2117	925-950	2117-T4
2024	910-930	2024-T4
6061	960-1010	6061-T4
6062	960-1010	6062-T4
6066	960-980	6066-T4
7075 (rolled or drawn)	860-930	7075-W
7075 (Extruded)	860-880	7075-W
7075 (Sheet .051 in thickness or less)	910-930	7075-W
7178 (rolled or drawn)	860-930	7178-W
7178 (Extruded)	860-880	7178-W
*7079	820-840	7079-W
*7079 Other temperatures may be required for certain sections and conditions.		
<b>FORGINGS ALLOYS</b>		
2014	925-950	2014-T4
2017	925-950	2017-T4
2018	940-970	2018-T4
<b>FORGINGS</b>		
2025	950-970	2025-T4
4032	940-970	4032-T4
6151	950-980	6151-T4
6061	960-1010	6061-T4
7075	360-890	7075-W
7075 Other temperatures may be required for certain sections and conditions.		
7079	820-840	7079-W
7079 Other temperatures may be required for certain sections and conditions.		
<b>SAND CAST ALLOYS</b>		
122	930-960	T4
142	950-980	T4
195	940-970	T4
220	800-820	T4

TABLE 3-7 - HEAT TREATING (SOAKING) TEMPERATURES (CONT'D)

ALLOY DESIGNATION	SOLUTION HEAT TREAT TEMPERATURE (DEGREES F)	TEMPER
<b>SAND CAST ALLOYS</b>		
319	920-950	T <sub>1</sub>
355	960-990	T <sub>1</sub>
356	980-1010	T <sub>1</sub>
102 Solution heat treatment not required.		
<b>PERMANENT MOLD CAST ALLOYS</b>		
122	930-960	T <sub>1</sub>
A132	960-970	T <sub>1</sub>
142	950-980	T <sub>1</sub>
R195	935-965	T <sub>1</sub>
355	960-990	T <sub>1</sub>
356	980-1010	T <sub>1</sub>

**3-16. PHYSICAL PROPERTIES.** Commercially pure aluminum weighs 0.098 pounds per cubic inch, corresponding to specific gravity of 271. Data for standard alloys are shown in Table 3-6. The approximate weight for aluminum, including its alloys, is one tenth of a pound per cubic inch.

### 3-17. HEAT TREATMENT OF ALUMINUM ALLOYS .

#### NOTE

**MIL-H-6088, Heat Treatment of Aluminum Alloys, will be the control document for heat treatment of Aluminum Alloys used on aerospace equipment. For complete description of aluminum heat treat requirements, refer to latest issue of MIL-H-6088.**

**3-18. GENERAL.** There are two types of heat treatment applicable to aluminum alloys. They are known as solution and precipitation heat treatment. Some alloys such as 2017 and 2024 develop their full mechanical properties as a result of solution heat treatment followed by 96 hours (natural precipitation) aging at room temperature. Other alloys, such as 2014, 7075, and 7178 require solution heat treatment and aging (precipitation heat treatment) for specific length of time at a definite temperature (see Table 3-11).

**3-19.** Solution heat treatment is a process where the alloying elements enter into solid solution in the aluminum at critical temperatures. It has been found that those alloying elements which increase the strength and hardness are more soluble in solid aluminum at high temperature than at low. To complete the solution often the metal is held at high temperatures for sufficient time; it is then quenched rapidly in cold water to retain this condition. Immediately after quenching, the alloy is in an unstable condition, because it consists of a supersaturated solid solution of the hardening agent. Upon standing at room temperature the hardening constituent in excess of that which is soluble at room temperature precipitates. The precipitate is in the form of extremely fine particles which due to their "keying" action, greatly increase the strength. This is in effect a method where the molecules of the aluminum and alloying elements are realigned to increase the strength and hardness of some aluminum alloys.

**3-20. PRECIPITATION (AGE) HARDENING .** This phase of heat treatment consists of aging material previously subjected to solution heat treatments by natural (occurs at room temperature) or artificial aging. Artificial aging consists of heating aluminum alloy to a specific temperature and holding for a specified length of time. During this hardening and strengthening operation the alloying constituents in solid solution precipitate out. As precipitation progresses, the strength of the material increases until the maximum is reached. Further aging (overaging) causes the strength to decline until a stable condition is obtained. The strengthening of material is due to the uniform alignment or formation of the molecule structure of the aluminum and alloying element.

**3-21.** Artificial aged alloys are usually slightly "overaged" to increase their resistance to corrosion. Especially the high copper content alloys. This is done to reduce their susceptibility to intergranular corrosion caused by under-aging.

- 3-22.** Natural aging alloys can be artificially aged, however, It increases the susceptibility of the material to intergranular corrosion. If utilized it should be limited to clad sheet, extrusions and similar items. For aging treatment, temperature and times see Table 3-11.
- 3-23. SOLUTION HEAT TREATMENT .** As previously pointed out it is necessary that solution heat treatment of aluminum alloys be accomplished within close limits in reference to temperature control and quenching. The temperature for heat treating is usually chosen as high as possible without danger of exceeding the melting point of any element of the alloy. This is necessary to obtain the maximum improvement in mechanical properties.
- 3-24.** If the maximum specified temperature is exceeded eutectic melting will occur. The consequence will be inferior physical properties, and usually a severely blistered surface. If the temperature of heat treatment is low, maximum strength will not be obtained.
- 3-25. Heating Time.** The heating time commonly called the "soaking time" required to bring about solution increases with the thickness of the section or part to be heat treated. Solution heat treatment should be held to the minimum time required to obtain the desired physical properties. In many instances the above will require sample testing to determine the exact solution time. For the recommended approximate soaking time for various alloys see Table 3-7.
- 3-26.** The time at temperature (soaking time) is measured from the time the metal reaches the minimum limit of the temperature range. In the case of thick material the controlling factor would be when the center (core) reached the minimum temperature. The soaking period will vary from 10 minutes for thin sheet to approximately 12 hours for the thicker materials, such as heavy forgings. A general guide to use is approximately one hour for each inch of cross-sectional thickness. It is recommended that thermocouple be placed in the coldest part of the load to determine the period required to bring the load to the correct temperature (soaking temperature).
- 3-27.** The soaking temperature required is selected to put all of the soluble elements into solid solution. With clad materials, prolonged heating may defeat the purpose of the cladding by excessive diffusion of copper and other soluble elements into the cladding.
- 3-28. RE-SOLUTION HEAT TREATMENT .** The bare heat-treatable alloys can be solution heat treated repeatedly without harmful effects other than high temperature oxidation. The oxidation can be retarded by using either sodium or potassium fluoborate during the heating cycle.
- 3-29.** For clad sheet the number of solution heat treatment is limited due to the increased diffusion of the core and cladding. See Table 3-12 for the recommended reheat-treatment times.
- 3-30. QUENCHING.** The basic purpose for quenching is to prevent the immediate re-precipitation of the soluble constituents after heating to solid solution.
- 3-31.** To obtain optimum physical properties of aluminum alloys, rapid quenching is required. The recommended time interval between removal from the heat and immersion is 10 seconds or less. Allowing the metal to cool before quenching promotes intergranular corrosion and slightly affects the hardness. This is caused by re-precipitation along grain boundaries and in certain slip planes. For specific quench delay see Table 3-10.
- 3-32.** There are three methods employed for quenching. The one used depends upon the item, alloy and properties desired.
- 3-33. Cold Water Quenching.** Small articles Lade from sheet, extrusions, tubing and small fairing are normally quenched in cold water. The temperature before quenching should be 85°F or less. Sufficient cold water should be circulated within the quenching tanks to keep the temperature rise under 20°F. This type of quench will insure good resistance to corrosion and particularly important when heat-treating 2017 and 2024.
- 3-34. Hot Water Quenching.** Large forgings and heavy sections can be quenched in(150°-180°F)or boiling water. This type of quench is used to minimize distortion and cracking which are produced by the unequal temperatures obtained during the quenching operation. The hot water quench will also reduce residual stresses which improves resistance to stress corrosion cracking.
- 3-35. Spray Quenching.** Water sprays are used to quench parts formed from alclad sheet and large sections of most alloys. Principal reasons for using this method is to minimize distortion and to alleviate quench cracking. This system is not usually used to quench bare 2017 and 2024 due to the effect on their corrosion resistance. The parts quenched by this media should pass the corrosion test required for the item involved; (see specification MIL-H-6088).
- 3-36. STRAIGHTENING OF PARTS AFTER SOLUTION HEAT TREATMENTS .** It will be necessary to straighten some parts after heat treating due to warping produced by the process. These parts are usually straightened by restriking or forming. It is desirable to place these parts in refrigeration immediately after quenching to retard natural aging until such time straightening is accomplished. A temperature of 32°F or below will delay or retard natural aging for approximately 24 hours, lower temperatures will delay the aging longer.

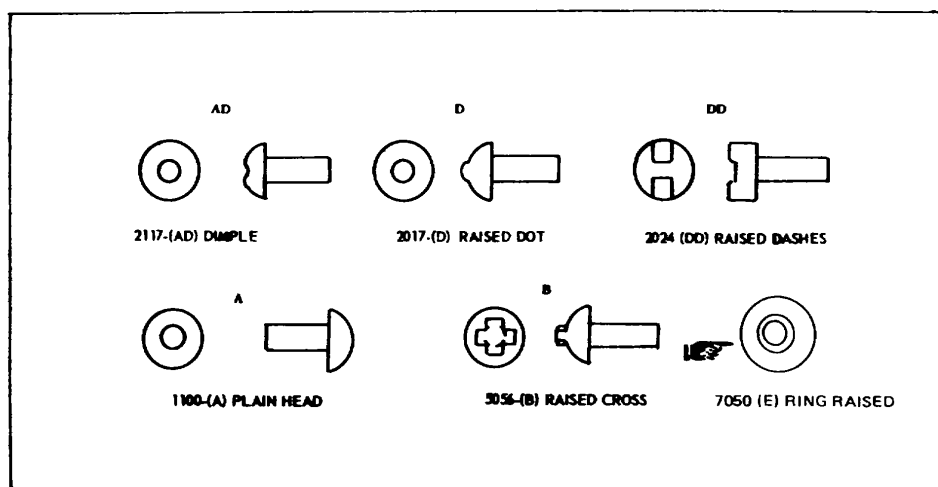


Figure 3-1. Head To Alloy Identification Method

**3-37. HEAT TREATMENT OF RIVETS.** The heat-treatable alloys commonly used for rivets are 2117, 2017, and 2024.

a. 2117 Rivets. If supplied in T-4 temper no further treatment is required. The rivet is identified by a dimple in the center of the head (see Figure 3-1-AD for head identification).

b. 2017 or 2017-T4 (D) Rivets. Heat treat prior to installation by heating to  $940^{\circ}\text{F} \pm 10^{\circ}\text{F}$  for 30 minutes in a circulating air furnace, 1 hour in still air furnace, or 30 minutes in a molten salt bath and quench in water. These rivets must be driven within 20 minutes after quenching or refrigerate at  $32^{\circ}\text{F}$  or lower which will delay the aging time 24 hours. If either time is exceeded re-heat treatment is required. See Figure 3-1-D for head identification.

c. 2024-0 or 2024-T4 (DD) Rivets. The same conditions apply for these rivets as for the 2017 (D) except heat treat at  $920^{\circ}\text{F} \pm 10^{\circ}\text{F}$ . See Figure 3-1-DD for head identification.

d. 1100 and 5056 Rivets. These do not require heat treatment, install as received. See Figure 3-1-A and 3-1-B for identification.

#### **CAUTION**

**Rivets which have been anodically oxide coated should not be reheat-treated in direct contact with molten salts more than 5 times.**

e. D/DD Rivets. These may be stored in refrigerators which ensure that the rivet temperature does not rise above minus  $10^{\circ}\text{F}$ . Rivets held at minus  $10^{\circ}\text{F}$  or below can be retained for use indefinitely. When the rivets are transported, their temperature will be maintained at minus  $10^{\circ}\text{F}$  or below by being carried in refrigerated boxes. MS20426E and MS20470E, do not require heat treatment, install as received. See fig. 3-1-E for head identification.

(1) Quality control shall be responsible for periodically checking the temperature of each refrigerator and for prohibiting the use of rivets in any box when the temperature becomes excessive.

(2) Each refrigerator shall have the rivets removed and be thoroughly cleaned at least once every six months. A tag or placard that denotes the next cleaning date shall be attached to each refrigerator.

(3) Rivets which remain out of refrigeration for 30 minutes or more shall be reheat treated. These rivets can be reheat treated a maximum of three times.

**3-38. ANNEALING.** Aluminum alloys are annealed to remove the effects of solution heat treatment and strain hardening. Annealing is utilized to help facilitate cold working. Parts work hardened during fabrication are annealed at various stages of the forming operation so that complicated shapes can be formed. During prolonged forming or stamping operations the metal becomes strain hardened (commonly called "work hardened") and upon the performance of additional work it will split or crack.

When the above is encountered it is usually necessary to anneal the part one or more times at progressive stages of the forming operation, if the part is to be successfully completed.

#### **CAUTION**

**Annealed aluminum parts shall not be used for parts or fittings on aircraft or missiles unless specified by drawings or other approved engineering data**

**3-39.** Time at temperature. This factor will vary depending upon the type of anneal (partial or full), metal, thickness, method of furnace charging and similar factors. Avoid excessive time at temperature to prevent growth, diffusion and discoloration, especially when annealing clad alloys.

**3-40.** When fully annealing, no attempt should be made to shorten the annealing cycle because the soluble constituents go into solution as the temperature is increased. If the material is then cooled rapidly the soluble constituents remain in solution and the material does not attain fully annealed mechanical properties.

**3-41.** Annealing and subsequent forming of material previously heat treated should be avoided if conditions and time permit. The recommended method is to repeat the solution heat treatment and immediately perform the forming or drawing operation.

**3-42.** Recommended times and temperatures for annealing various alloys are as follows:

a. Annealing of Work-Hardened Alloys. All of these alloys except 3003 are annealed by heating to 650° F and no higher than 775° F, holding at temperature until uniform temperature has been established throughout the furnace load, and cooling in air or in the furnace. Annealing temperature shall not exceed 775° F to prevent excess oxidation and grain growth. The 3003 alloy is annealed by heating to 775° F at a relatively rapid rate and holding at the minimum soaking period necessary to attain temperature uniformity and then cool as cited above.

b. Annealing of heat-treated alloys (wrought). These alloys (except 7075) are annealed by heating to 775° F for not less than 1 hour and most instances 2-3 hours. Material is then cooled at a rate of no greater than 50° F per hour until the temperature is 500° F or below. Rate of cooling below 500° F is not restricted; cool as desired. Alloy 7075 is fully annealed by heating to 775°F-850° F (higher temperature utilized for material having smaller amount of cold work), soaking for 2 hours at temperature, cooling in air, reheating to 450° F, holding at this temperature for 6 hours and then cooling to room temperature. Alternate 7075 annealing methods:

- (1) If forming is to be accomplished immediately after annealing, heat to 775° F, 2-3 hours; air cool.
- (2) If alloy is to be stored for an extended period before forming, heat to 670° -700° F, 2 hours; cool in air; reheat to 450° F; hold at this temperature for 4 hours and then cool in air.
- (3) Intermediate anneal during cold working of "O" condition material; heat to 670° -700° F, ½ hour maximum, or heat to 910°-930° F until uniform temperature is attained; cool in air. A part shall not be annealed using the 910°-930° F temperature more than 3 times.

c. Annealing of cast alloys. Castings are annealed by heating to 650° -750° F holding for approximately 2 hours, and cooling to room temperature. The purpose of such annealing are for the relief of stresses and attainment of dimensional stability.

d. Partial annealing of heat-treated material. When heat-treated materials are annealed as specified for annealing of the work-hardened alloys, the effect of heat-treatment is reduced considerably, but not completely. The partially annealed material is only to be utilized when moderate but not secure operations are to be performed. If difficulty is experienced with forming partially annealed material, recommend that "O" fully annealed material be utilized.

**3-43.** Heat treating temperatures and times. Aluminum alloy should be heat treated at the temperature given in Table 3-7. The load should be held within the heat-treatment range (after the coldest part has reached the minimum of the range) for a sufficient time to insure that specified properties will be developed. In some cases sample testing will be required to ascertain that specified properties are developed. Suggested soaking periods are given in Tables 3-8 and 3-9 for the common alloys. In instances where new alloys are involved it will be necessary to consult the specification for the alloys, Specification MIL-H6088 or the manufacturer for the appropriate heat treat data. In case of conflict the correct Military/ Federal specification will be the governing factor.

**3-44. QUENCHING.** To effectively obtain the desired qualities in aluminum alloys it is necessary that the interval between removing the charge from the furnace and immersion in the quenching water be maintained at the absolute minimum (See Table 3-10).

**3-45.** Wrought alloy products must be quenched by total immersion in water or by a drastic spray quench. Forgings of 2014, 2017, 2117 and 7075 are quenched in water at temperatures in excess of 100° F. 7079 forgings are generally quenched in water at temperatures less than 100° F to obtain optimum mechanical properties, however a hot water quench (180° F) should be used whenever possible providing the lower strength associated with the quench is satisfactory. The hot water quench lowers the residual stresses considerably. This is desirable from the point of view of reducing stress corrosion susceptibility.

**3-46.** Charging of furnace and baths. Individual pieces of materials or parts should be racked or supported to prevent distorting if possible and permit free access to the heating and quenching medium. The above is necessary to maintain the form of the material involved and to facilitate heating to the specified temperature and quenching rapidly. To prevent distortion it is necessary in some cases to provide jig and fixture support for complex contoured (formed) parts. However, the jig used shall be so constructed that it will not restrict the contact required with the heating medium of the part being treated.

#### NOTE

**Parts formed that are unavoidably distorted should be reformed immediately after quenching.**

**3-17.** When heat treating (clad sheet material, the size and spacing of the load will be arranged to permit raising to the heat treatment temperature range in the minimum time. The mixing of different thicknesses of clad material when charging heat-treatment furnaces will be avoided, in order to help prevent diffusion of the cladding, especially in the case where very thin to thick materials are involved.

**CAUTION**

**Heat-treating operations will be performed on the complete individual part or piece of material never on a portion only. This should be accomplished in such a manner that will produce the utmost uniformity. Maximum quench delay for immersion quenching is shown by Table 3-10.**

**3-48.** Wrought alloy products may be quenched using high velocity, high volume jets of cold water where the parts are effectively flushed in a specially constructed chamber, provided that the parts will pass the corrosion test set forth in Specification MII,-H6088, Metal Specification and the mechanical property requirements of the applicable material specification.

**3-49.** Castings and forgings quenching. Casting should be quenched by total immersion in water at 150° to 212° F. Forgings should be quenched by total immersion in water at no more than 180° F. Forgings and impact extrusion supplied in T41 or T61 should be quenched in boiling water. However, if conditions warrant castings or forgings may be quenched by complete immersion in cold water.

**3-50.** Small parts such as rivets, fasteners, washers, spacers, etc., should be quenched by dumping into cold water.

**CAUTION**

**Rivets, fasteners, washers and other small parts which have been anodically oxidecoated should not be heat treated in direct contact with molten salts or more than 5 times by this medium.**

**TABLE 3-8. SOAKING TIME FOR SOLUTION HEAT TREATMENT OF ALL WROUGHT PRODUCTS.**

THICKNESS (INCHES) (MIN. THICKNESS OF THE HEAVIEST SECTION)	SALT BATH		SOAKING TIME (MINUTES)	
	MIN	MAX (Alclad Only)	AIR MIN	FURNACE MAX (Alclad)
0.016 and under	10	15	20	25
0.017 - 0.020	10	20	20	30
0.021 - 0.032	15	25	25	35
0.033 - 0.063	20	30	30	40
0.064 - 0.090	25	45	35	45
0.091 - 0.125	30	40	40	50
0.126 - 0.250	35	45	50	60
0.251 - 0.500	45	55	60	70
0.501 - 1.000	60	70	90	100
1.001 - 1.50	90	100	120	130
1.501 - 2.000	105	115	150	160
2.001 - 2.500	120	130	180	190
2.501 - 3.000	150	160	210	220
3.001 - 3.500	165	175	240	250
3.501 - 4.000	180	190	270	280

**TABLE 3-9. SOAKING TIME FOR SOLUTION TREATMENT OF CAST ALLOYS.**

ALLOY	TIME (HOURS)
<b>SAND CAST ALLOYS</b>	
122	6-18
142	2-10
195	6-18
S195 (105)	6-24
220	12-24
319	6-18
355	6-18
356	6-18
<b>PERMANENT MOLD CAST ALLOYS</b>	
122	6-18
A132	6-18
142	2-10
B195	4-12
355	6-18
356	6-18

**TABLE 3-10. RECOMMENDED MAXIMUM QUENCH DELAY, WROUGHT ALLOYS (FOR IMMERSION TYPE QUENCHING).**

NOMINAL THICKNESS (INCHES)	MAXIMUM TIME (SECONDS)
up to 0.016	5
0.017 to 0.031	7
0.032 to 0.091	10
0.091 and over	15

**NOTE**

Quench delay time begins at the instant furnace door begins to open or at the instant any portion of a load emerges from a salt bath and when last portion of the load is immersed in the (water) quench tank. The maximum quench delay may be exceeded (usually confined to large sections or loads) if temperature will be above 775° F when quenched.

**3-51. HEAT TREATMENT.****3-52. PRECIPITATION (ARTIFICIAL AGE) HEAT TREATMENT.**

Precipitation heat treatment of many aluminum alloys is necessary to obtain the required properties. Heating of some aluminum alloys bare or clad at an elevated temperature, but well below the annealing temperature, after solution heat treatment will result in tensile and yield strength well above those obtained by room temperature aging. The above will also apply to alloy 2024. However, this process will reduce the elongation factor of the material and increase resistance to forming. Therefore, most forming operations should be performed prior to this stage of treatment.

**3-53.** Mechanical properties obtained from precipitation (aging) are dependent on the amount of cold work present in the material at the time of aging. The selection of materials for various uses will therefore be governed by the severity of the cold work to be performed, strength and condition of the material required.

**3-54.** Annealing or solution heat treating will remove any properties developed as a result of cold working the material. Subsequent heat treatment and aging of annealed material or aging of solution heat treated material will result in T-6 condition, provided the material is not cold worked prior to aging. The higher strength conditions can only be obtained by a controlled amount of cold work prior to aging. Conditions T-81 or T-86 would necessitate a cold work percentage of approximately 1% for T-81 and 6% for T-86 after solution heat treated and prior to aging.

**3-55.** Field accomplishment of the cold work required to produce the higher strength conditions is considered impractical. This is due to the amount and types of equipment necessary to stretch or roll the material in order to produce these conditions.

**3-56. HEAT TREATING EQUIPMENT.** Equipment and heating media used are divided into two distinct groups. They are liquid baths and controlled atmosphere. Either method has certain advantages over the other and it generally is advisable to weigh the advantages desired and consider environmental conditions.



**3-57.** The above are heated by gas, electricity and oil. Regardless of the method utilized it must be demonstrated that satisfactory results are obtained and the material is not injured.

**3-58. AIR FURNACES.** Air furnaces are ideal for precipitation (aging), thermal treatments and annealing. These furnaces are also used for solution heat treating. The initial cost of these type furnaces is higher than for the salt bath types, but they are usually more economical to operate, safer, cleaner and more flexible. Air furnaces used for heat treatment of aluminum alloy should be of the re-circulating air type. The heated air in this type furnace is recirculated at high velocities to obtain a rapid heating cycle and uniform temperatures. The products of combustion must be excluded from the furnace atmosphere to help avoid high temp oxidation and atmosphere contamination.

**3-59. SALT BATHS.** The salt baths method has certain advantages over the air furnace. However, the advantages are usually confined to solution heat treatment only. Associated advantages are uniform temperature without excess danger of high temperature oxidation and faster heating which reduces the time required to bring the load to temperature. This method is adaptable for solution heat treating small parts, large thin sections and mixed loads. The above advantages may be completely nullified by the slower quench caused by the necessary arrangement of equipment, fire and explosion hazards, and decomposition of the sodium nitrate which when dissolved in quenching water forms a compound that attacks aluminum alloys. The addition of potassium dichromate (approximately ½ ounce per hundred pounds of nitrate) tends to inhibit the attack.

**3-60.** Hollow core casting or parts where the salts are likely to be difficult or impossible to remove should not be treated by bath salt.

**TABLE 3-11. PRECIPITATION (AGING) TREATING TEMPERATURES, TIMES & CONDITIONS.**

ALLOY & TEMPER OR COND BEFORE AGING	AGING TIME (HOURS) 2/	AGING TEMP (DEGREES F) 2/	TEMPER AFTER AGING
<b>WROUGHT ALLOYS (EXCLUDING FORGINGS)</b>			
2017 - as quenched(w)	96	room	2017-T4
2117 - as quenched(w)	96	room	2117-T4
2024 - as quenched(w)	96	room	2024-T4
6061 - as quenched(w)	96	room	6061-T4
6061-T4	7½ - 8½	340-360	6061-T6
2020-W	18	310-360	2020-T6
2024-T4 1-T42	16	370-380	2024-T6 1-T62
2024-T4 (Alternate for sheet)	11-13	370-380	2024-T6
2024-T3	11-13	379-380	2024-T61
2024-T36	7 - 9	370-380	2024-T66
2014-T4 1-T42	8 - 12	305-330	2014-T6 1-T62
2014-T4 (Alternate for Plate)	17-20	305-330	2014-T6
6066-T4	7½ - 8½	340-360	6066-T6
6061-T4	7½ - 8½	340-360	6061-T6
7075-W 1/	22 Minimum	240-260	7075-T6
7178-W	22 minimum	240-260	7178-T6
6063-F	1-2	440-460	6063-T5
7079 - as quenched(w)	5 days at room temperature following 48 hours at 230-250 degrees F		7079-T6

TABLE 3-11. PRECIPITATION (AGING) TREATING TEMPERATURES, TIMES &amp; CONDITIONS (CONT'D).

ALLOY & TEMPER OR COND BEFORE AGING	AGING TIME (HOURS) 2/	AGING TEMP (DEGREES F) 2/	TEMPER AFTER AGING
<b>FORGING ALLOYS</b>			
2014-T4	5-14	340-360	2014-T6
2014 - as quenched	96 Minimum	room	2014-T4
2017 - as quenched	96 Minimum	room	2017-T6
2018-T4	4-12	330-350	2018-T6
2025-T4	6-14	330-350	2025-T6
4032-T4	4-12	330-350	4032-T6
6151-T4	4-12	330-350	6151-T6
7075-W	22 Minimum	230-260	7075-T6
X7079	5 days at room temperature followed by 48 hours at 230-250 degrees F		X7079-T6
<b>SAND CAST ALLOYS</b>			
142-T41	1-3	400-450	142-T61
195-T4	1-3	300-320	142-T6
S195-T4	1-4	300-320	S195-T6
220-W	96 Minimum	room	220-T4
319-T4	1-6	300-320	319-T6
335-T4	1-6	300-320	335-T6
356-T4	1-6	300-320	356-T6
356-F	6-12	430-450	356-T6
40	9-11	345-365	40-E
40-	21 days	room	40-E
<b>PERMANENT MOLD CAST ALLOYS</b>			
142-T41	1-3	400-450	142-T61
H195-T4	1-8	300-320	H195-T6
319-T4	1-6	300-330	319-T6
355-T4	1-6	300-320	355-T6
356-T4	1-6	300-320	356-T6
A132-T45	14-18	300-350	A132-T65

1/ Alternate aging treatment for 7075-W sheet only; in thicknesses less than 0.500 inch: Heat at 230<sup>0</sup>-250<sup>0</sup>F for 3-4 hours, then heat 315<sup>0</sup>-335<sup>0</sup>F for 3-4 hours. The temperature may be raised directly from the lower to the higher temperature, or load may be allowed to cool between the two steps of the treatment.

2/ Time is soak time after recorder is at temperature, for 0.500 inch thickness or less. Add 1/2 hour for each additional 1/2 inch of thickness.

TABLE 3-12. REHEAT TREATMENT OF ALCLAD ALLOYS.

THICKNESS (INCHES)	MAXIMUM NO. OF REHEAT TREAT- MENT PERMISSIBLE
0.125 and less	1
0.125 and less	1
over 0.125	2

**NOTE**

Heat treatment of a previously heat treated material is classified as a reheat treatment. Therefore, the first heat treatment of material purchased in the heat treated condition is a reheat treatment. Insofar as this chart is concerned annealing and precipitation treatments are not considered heat treatments.

**3-61.** Salt baths must be operated with caution to prevent explosions as any water on the material being treated is instantly transformed to steam upon immersion in the salt bath.

**3-62.** Nitrate charged salt baths should not be used to heat-treat minimum alloys types 5056 and 220 due to the fact that the bath compound will attack the alloy.

**3-63.** Temperature Control and Uniformity. Good temperature control is essential to produce the exacting temper requirements for superior quality material. Upon bringing a change to temperature, the furnace and the load should be controllable with  $\pm 5^\circ$  F of the required temperature range. The design and construction of the furnaces and baths should be such that during the recovery and soaking period, the air and metal (load) temperature at any point in the working or soaking area shall not exceed the minimum soaking temperature (see Table 3-7) for the specific alloy being heat treated.

**3-64.** Furnace temperature survey. Furnace equipment shall be installed with the necessary furnace control, temperature measuring, and recording instruments to assure and maintain accurate control.

**3-65.** Upon the initial installation and after each change is made in the furnace which might affect the operational characteristics a temperature survey should be made. The temperatures should be checked at the maximum and minimum required for solution and precipitation heat treatment for which the furnace is to be used. A minimum of 9 test locations within the furnace load area should be checked, one in each corner, one in the center and one for each 25 cubic feet of air furnace volume up to the maximum of 400 cubic feet. For salt bath the same as above except one test location for each 40 cubic feet of 3.24 air volume, 40 test locations are recommended. Other size furnaces should be checked with a ratio of test locations in accordance with those previously cited. A monthly survey should be made after the initial survey, unless separate load thermocouples are employed, to record actual metal temperatures. However, periodic surveys shall be made as outlined for the initial survey. The monthly survey should be made at one operating temperature for solution treatment and one for precipitation heat treatment. There should be a minimum of 9 test locations with at least one for each 40 cubic feet of heat treating volume. For all surveys, the furnaces should be allowed to heat to point of stabilization before commencing the survey. The temperature of all test locations should be determined at 5 to 10 minute intervals after insertion of the temperature sensing elements in the furnace. Temperature readings should be taken for a sufficient length of time after thermal equilibrium to determine the recurring temperature pattern. After all temperature sensing elements have reached equilibrium, the maximum temperature variation of all elements shall not exceed  $20^\circ$ F and at no time after equilibrium is reached should the temperature readings be outside the solution heat treating or precipitation range being surveyed.

**3-66.** Temperature measuring instruments used for furnace control shall not be used to read the temperature of the test temperature sensing elements.

**3-67.** Furnace thermocouple and sensing element should be replaced periodically. This is necessary due to oxidation and deterioration of the elements.

**3-68.** Salt Bath Testing Temperature uniformity in a salt bath may be determined by use of a temperature sensing element enclosed in a suitable protected tube. The temperature sensing element should be held in one position until thermal equilibrium has been substantially reached and reading made. The temperature sensing element should then be placed in a new location and the procedure repeated. These operations should be repeated until the temperature in all parts of the bath have been determined. The maximum variation indicated by reading from the various locations in the load zone shall not exceed  $20^\circ$  F and no reading shall be outside the heat treating range specified for the materials involved.

**3-69.** At this point it should be explained that a substantial amount of the difficulty encountered in heating aluminum alloy is due to improper or inadequate temperature control and circulation of heating medium. When difficulties arise the function of these units should be checked prior to performing other system test.

### 3-70. FABRICATION.

**3-71.** This portion is intended to provide some of the information required to fabricate the various aluminum product into part and assemblies. Aluminum is one of the most workable of all the common metals. It can be fabricated into a variety of shapes by conventional methods.

**3-72.** The formability varies considerably with alloy and temper. Specific application usually depends on the shape, strength and temper of the alloy. The preceding will necessitate that the mechanic be well trained to cope with the variables associated with this material especially when the end use of the item is an aircraft or a missile.

### 3-73. FORMING SHEET METAL.

**3-74. GENERAL.** The forming of aluminum (1100) is relatively easy, using approximately the same procedures as those used for common steel except that care must be taken to prevent scratching. Do not mark on any metal surface to be used as a structural component with a graphite pencil or any type of sharp pointed instrument. Use pencil, Aircraft Marking, Specification MIL-P-83953, NSN 7510-00-537-6928 (Black), 7510-00537-6930 (Yellow), and 7510-00-537-6935 (Red). All shop equipment, tools and work area should be kept smooth, clean and free of rust and other foreign matter.

**3-75.** Alloyed aluminums (2024, 7075, 7178, etc.) are more difficult to form, and extensive control is required to prevent scratching and radii cracking. Scratching will make forming more difficult plus it provides an easy path for corrosion attack, especially on clad materials. The clad coating referenced is usually a sacrificial corrosion resisting aluminum alloy coating sandwiched metalurgically to an alloyed core material. The thickness of the coating will depend on the thickness of the sheet or plate. The nominal cladding thickness is 4% of composite thickness for material under 0.063 inch; 2.5% for material in the range of 0.063 - 0.187 inch and 1.5% for material 0.188 inch and thicker.

**3-76.** The following general rules should be employed in the handling and forming operation:

- a. Provide clean area; free of chips, grit and dirt and other foreign material.
- b. Provide clean smooth (rust free) and adaptable forming equipment.
- c. Sheared or cut edges shall be banded and filed or polished, prior to bending or forming.
- d. Use only straight and smooth forming dies or brake leaves of the correct radius which are free of nicks, burrs and sharp edges.
- e. Form material across the direction of grain flow when possible.
- f. Material should be of the correct temper, thickness and alloy in the range of "formable" material.

**3-77.** For intricate forming operations it is necessary to use annealed (Con "O") material and final strength developed by heat treating after the forming has been accomplished. Heat-treated alloys can also be formed at room temperature immediately after quenching ("W" temper), which is much more formable than the fully heat-treated temper. The part is then aged to develop full strength. The forming operation should be performed as soon after quenching as possible, in view of the natural aging that occurs at room temperature on all the heat treatable alloys. The natural aging can be delayed to a certain extent by placing the part in a cold storage area of 320 or lower. The lower the temperature the longer the delay to a point where maximum delay is obtained.

**3-78. BENDING.** Bending is classified as single curvature forming. Upon bending metal sheet, bar or rod, the material at the bends flows or deforms, i.e., the material adjacent to the outer surface of the bend is under tension and the length is increased due to stretching and the material adjacent to and on the inner surface is under compression and the length is decreased.

**3-79.** The most common problems encountered in practice are springback and cracking within the bend area. Problems associated with bend cracking are usually a result of improper bend radii, rough edges of material being formed or forming equipment and bending parallel to direction of grain flow. For the approximate bend radius to use in bending various thicknesses and types of aluminum see Table 3-13. Actual practice may reveal that a larger or a smaller radius may be used in some instances. If tighter bend radii is required, then fabricators should proceed with additional caution and if needed, should seek assistance of engineering or laboratory metallurgists.

**3-80.** Difficulties encountered with springback are most commonly associated with bending of the stronger alloys, especially those having high yield strength. Springback problem associated with this material can be overcome to a certain degree by overforming. The amount of overforming utilized will depend on the temper and the alloy; the softer the material the less springback compensation required. Other means of reducing springback is to bend the material in the soft condition (Condition "O") or immediately after quenching and reducing the thickness of the radius if allowed. Avoid reducing radii to the point that grain separation or bad cracking results.

TABLE 3-13. COLD BEND RADII (INSIDE) FOR GENERAL APPLICATIONS.

Alloy & Temper	Sheet Thickness = T (Inches)						
	0.016	0.032	0.040	0.063	0.125	0.1875	0.250
1100-0	0.02	0.03	0.03	0.06	0.125	0.187	0.250
3003-0	0.03	0.03	0.06	0.06	0.160	0.187	0.250
5052-0	0.03	0.03	0.06	0.06	0.160	0.187	0.250
6061-0	0.03	0.03	0.06	0.06	0.16	0.1875	0.250
2014-0	0.03	0.06	0.09	0.09	0.19	0.312	0.44
7075-0	0.03	2T	2T	2T	2T	2½T	3T
7178-0	0.03	2T	2T	2T	2T	2½T	3T
1100-H12	0.02	0.03	0.03	1T	1T	1½T	1½T
3003-H12	0.03	0.03	0.03	1T	1T	1½T	1½T
5052-H32	0.03	0.06	0.06	1½T	2T	2½T	2T
1100-H16	0.03	0.06	2T	2T	2T	2½T	3T
3003-H16	0.03	0.06	2T	2T	2½T	4T	5T
5052-H36	0.03	0.06	2T	2T	2½T	4T	5T
	0.016	0.032	0.064	0.125	0.1875	0.250	
1100-H18	0.03	2T	2T	2½T	3T	3½T	
3003-H18	0.03	2T	2T	2½T	3T	4½T	
5052-H38	0.03	2T	3T	4T	5T	6T	
6061-T4	0.03	2T	2T	2T	3T	4T	
6061-T6	0.03	2T	2T	2T	3T	4T	
2024-T4	0.06	4T	4T	5T	6T	6T	
2024-T3	0.06	4T	4T	5T	6T	6T	
2014-T4	0.06	3T	4T	5T	6T	6T	
2014-T3	0.06	3T	4T	5T	6T	6T	
7075-T6	0.06	5T	6T	6T	6-8T	9-10T	
7178-T6	0.06	5T	6T	6T	6-8T	9-10T	

**3-81. DRAW FORMING.** Draw forming is defined as a method where a male die (punch) and a female die is used to form a sheet blank into a hollow shell. Draw forming is accomplished by forcing the male die and the metal blank into the female die. Generally mechanical press either single or double action and hydraulic presses are used to perform the drawing operation. Results will depend on die design, radii of die forming surfaces, finish of die, surface clearance between punch and female die, blank hold down pressure, shape of blank, material allowance on blank, elongation factor of material, temper, shape of part being formed, drawing speed, and lubricant. Optimum results usually requires experimentation and adjustment of one or more of these factors. Drawing of very deep shells require more experimentation and the utilization of a succession of limit draws. Because of the work hardening resulting from each draw, reduction in successive draws must be less. In severe conditions an intermediate anneal is sometimes used. Condition "O" material of the heat treatable alloys can be heat treated after drawing to obtain higher strength and to relieve the effect of work hardening. However, the non-heat treatable alloys can only be annealed to relieve the effect of work hardening. This material should not be annealed if high strength is the major requirement.

**3-82.** The recommended material to manufacture drawing dies is hardened tool steel for large scale production; kirksite and plastic for medium or short run production; and phenolic and hardwood for piece production.

**3-83. STRETCH FORMING.** This process involves stretching a sheet or strip to just beyond the elastic limit where permanent set will take place with a minimum amount of springback. Stretch forming is usually accomplished by gripping two opposite edges fixed vises and stretching by moving a ram carrying the form block against the sheet. The ram pressure being sufficient to cause the material to stretch and wrap to the contour of the form block.

**3-84.** Stretch forming is normally restricted to relatively large parts with large radii of curvature and shallow depth, such as contoured skin. The advantage is uniform contoured parts at faster speed than can be obtained by hand forming with a yoder hammer or other means. Also, the condition of the material is more uniform than that obtained by hand forming. The disadvantage is high cost of initial equipment, which is limited to AMA level repair facilities.

**3-85.** Material used for stretch forming should be limited to alloys with fairly high elongation and good spread between yield and tensile strength. Most of the common alloys are formed in the annealed condition. It is possible to stretch form the heat treatable alloys in tempers T4 or T6, where the shape is not too deep or where narrow width material is used. For the deeper curved shapes, the material is formed in the annealed "O" temper, heat treated and reformed, to eliminate distortion resulting from heat treatment. As previously stated the material should be reformed as fast as possible after heat treatment. In some instances the material is formed immediately after heat treating and quenching. Selection of a system or condition of material to be utilized will require experimentation and the subsequent utilization of the system that gives the best results.

**3-86. HYDRAULIC PRESS FORMING.** The rubber pad hydropress can be utilized to form many varieties of parts from aluminum and its alloys with relative ease. Phenolic, masonite, kirksite and some types of hard setting molding plastic have been used successfully as form blocks to press sheet metal parts such as ribs, spars, fans, etc. The press forming operations are usually accomplished by setting the form block (normally male) on the lower press platen and placing a prepared sheet metal blank on the block. The blank is located on the block with locating pins, to prevent shifting of blank when the pressure is applied (the sheet metal blank should be cut to size and edges deburred prior to pressing). The rubber pad filled press head is then lowered or closed over the form block and the rubber envelope, the form block forcing the blank to conform to the form blocks contour. This type forming is usually limited to relatively flat parts having flanges, beads and lightening holes. However, some types of large radii contoured parts can be formed with a combination of hand forming and pressing operations. It is recommended that additional rubber be supplemented in the form of sheets when performing the above to prevent damage to the rubber press pad. The rubber sheet used should have a shore hardness of 50-80 durometers. The design of foam block for hydropress forming require compensation for springback even through the material normally used is Condition "O" or annealed. Normal practice is to under cut the form block 2-7° depending on the alloy and radii of the form block.

**3-87. DROP HAMMER FORMING.** The drophammer can be used to form deep pan shaped and beaded type parts. Kirksite with a plastic surface insert is satisfactory for male and female dies. The surface of kirksite dies used without plastic insert should be smooth to prevent galling and scratching of the aluminum surface. When forming deep pans and complicated shaped parts it is often necessary to use drawings rings, pads or 2-3 stage dies. An intermediate anneal is sometimes used to relieve the hardened condition (cold work) resulting from the forming operation.

**3-88. JOGGLING.** A joggle is an offset formed to provide for an -overlap of a sheet or angle which is projecting in the same plain. The inside joggle radii should be approximately the same as used for straight bending.



Joggle run out or length as a normal rule should be three times the depth of the joggle for the medium strength alloys (2024, 2014, etc.) and approximately four times the depth for the higher strength alloys (7075, 7178, 7079 etc). Where deep and tight joggle are required, annealed material should be used with heat treatment to follow.

**3-89. HOT-FORMING.** Hot forming is not generally recommended, however, it is sometimes used where it is not possible to form an article by other methods. Accomplishment shall not be attempted unless adequate facilities are available to control temperature requirements. Actual formability will depend on the temperature that various alloys are heated. The higher the temperature the easier formed. Excessively high temperature shall not be used, as considerable loss in strength and corrosion resistance will occur. Frequent checks should be made using an accurate contact pyrometer. Table 3-14 cites the recommended times and temperature (accumulative) for the various alloys. The losses in strength as a result of re-heating at the temperature cited by this table will not exceed 5%. Equal formability will be obtained with shorter periods of heating in most cases and the minimum times should be used. It should be understood that this table cited the maximum accumulative times at cited temperature.

**3-90. SPINNING.** Spinning is an art and makes exacting demands upon the skill and experience of the mechanic performing the operation. For this reason mass production of parts is impractical. However, it can be used to advantages where only a few parts are required and to assist in the removal of buckles and wrinkles in drawn shell shaped objects.

**3-91.** Forming by spinning is a fairly simple process, an aluminum disc (circle) is placed in a lathe in conjunction with a form block usually made of hard wood; as the disc and form block are revolved, the disc is molded to the form block by applying pressure with a spinning stick or tool. Aluminum soap, tallow or ordinary soap can be used as a lubricant.

**3-92.** The best adapted materials for spinning are the softer alloys i.e., 1100, 3003, 5052, 8061, etc. Other alloys can be used where the shape to be spun is not excessively deep or where the spinning is done in stages and intermediate annealing is utilized to remove the effect of strain hardening (work hardening) resulting from the spinning operation. Hot forming is used in some instances when spinning the heavier gauge materials and harder alloys.

**3-93. BLANKING AND SHEARING.** Accurate shearing will be affected by the thickness of material, type of shear or knife blades, condition of material, adjustment and sharpness of blades, size of cut and the relationship of the width of the cut to sheet thickness.

**3-94.** Normally most aluminum alloys can be sheared ½ inch and less in thickness except for the harder alloys i.e., 7075-T6 and 7178-T6. These alloys have a tendency to crack in the vicinity of the cut especially if the shear blades are dull or nicked. The above will naturally require that tooling used be designed to handle the thickness of material to be cut. Correct clearance between shear blades is important for good shearing. Too little clearance will quickly dull or otherwise damage the blades or knives; too much will cause the material to be burred, or even to fold between blades. Normal clearance is from one-tenth to one-eighth the sheet thickness. Blade life will be prolonged by occasionally lubricating. When the capacity of shear is doubtful the shear manufacturer should be consulted.

**TABLE 3-14. MAXIMUM ACCUMULATIVE REHEAT TIMES FOR HOT FORMING HEAT TREATABLE ALLOYS AT DIFFERENT TEMPERATURES.**

ALLOY	450°F	425°F	400°F	375°F	350°F	325°F	300°F
2014-T6	To Temp	To Temp	5-15 Min	30-60 Min	2-4 Hrs	8-10 Hrs	20-50 H
2024-T81	5 Min	15 Min	30 Min	1 Hr	2-4 Hrs	- - -	20-40 H
2024-T86	5 Min	15 Min	30 Min	1 Hr	2-4 Hrs	- - -	10-20 H
6061-T6	5 Min	15 Min	30 Min	1-2 Hrs	8-10 Hrs	5-100 Hrs	100-200 H
7075-T6	No	No Temp	5-10 Min	30-60 Min	1-2 Hrs	2-4 Hrs	10-12 H
*2014-T4, 2014-T3	No	No	No	No	No	No	No
*2024-T4, 2024-T4	No	No	No	No	No	No	No

\* These materials should not be hot formed unless subsequently artificially aged.



**3-95. BLANKING.** Blanking is usually accomplished utilizing a blanking die in almost any type of punch press equipment. The essential factors requiring control are die clearance, shearing edge lead, and stripping action. The shearing principle is primarily the same as that encountered with the squaring shear. However, the method of grinding punch dies will vary according to the results required and in such manner that will reduce load on equipment. Commonly two or more high points are ground on die to keep side thrust on the punch at a minimum. Lubrication is essential in blanking operations. Suitable lubricants are engine oil, kerosene and lard oil which are normally used in mixed form.

### **3-96. JOINING ALUMINUM.**

**3-97. WELDING.** Aluminum and its alloys that are considered practical to weld, can be welded satisfactorily by using metal-arc, carbon arc, atomic-hydrogen, inert-gas shielded arc, and gas welding. Almost all alloys can be joined by resistance welding such as spot, seam welding, and flash welding.

#### **NOTE**

**For general welding procedures, see T.O. 34W415.**

**3-98.** Aluminum differs in welding characteristics from that of steel in that the melting point is much lower. For example, pure aluminum melts at 1216°F and the alloys melt at even lower temperatures as compared to approximately 2500° F for steel.

**3-99.** Aluminum oxidation is another factor that requires understanding and control. Aluminum oxides form a film or coating on all exposed surfaces. This must be removed before welding. Removal is frequently accomplished by use of flux which combines chemically with the oxide to form a fluid slag. Due to the apparent weakness of aluminum alloys to withstand high temperature and the high degrees of thermal conductivity, adequate support is necessary for all the areas of parts subjected to appreciable temperature rises. If the above precautions are not taken difficulty will be encountered with shrinkage warpage and reaction stresses. Aluminum does not change color at any temperature up to and including the melting point, therefore, it is necessary for the welder or operator to watch the "wet" appearance of the surface which indicates surface melting. This is contrary to ferrous metals where the color of the heated piece indicates the temperature.

**3-100.** There are basically two factors that determine whether an aluminum alloy can be welded by a particular process. They are percentage of copper content and magnesium content. High copper (3-4% or more) causes embrittlement of weld metal and considerable loss of mechanical properties of adjoining metal when fusion welded. Thus aluminum alloys with an appreciable content of copper are not recommended for fusion welding. A high magnesium content alloy tends to produce a heavier oxide coating and these alloys are not recommended for brazing or soldering operations where oxide formation is a critical factor.

#### **WARNING**

**When performing any welding operation safety precautions shall be taken to prevent injury to personnel, other equipment and to prevent fire. Wear eye, face, hand shields, consult local safety officer for specific instructions.**

**3-101. FUSION WELDING.** The common non-heat treatable alloys are the most easily fusion welded i.e., 1100, 3003, 3004, 5050, 5052, 5056, etc. An exception to the above is 6061 which is weldable, and heat-treatable. 6061 material is normally used where strength and weldability is a required factor. Due to the many methods employed for fusion welding aluminum and the many variables encountered this publication will be limited to the most common types which are gas welding and inert gas shielded arc (heliarc and argon arc). Gas welding was one of the earliest successful processes employed for welding aluminum and is generally used.

**3-102. WELDERS TRAINING AND QUALIFICATION .** Personnel assigned to accomplish aluminum welding should be trained in the handling of equipment fabrication procedures i.e. composition and identification of aluminum alloys, jigging, tacking, cleaning and treating, blue print reading, safety, use of tools (hand and machine) and to meet qualification requirements.

**3-103.** Tests for Aircraft and Missile Welding Operators qualifications are cited in Specification MIL-STD-1595 and T.O. 00-25-252. This specification and technical order are intended for use in ascertaining that welders to be engaged or that are engaged in welding aircraft, aircraft parts and accessories, missiles, missile parts, pressure systems, and accessories, possess and maintain a satisfactory level of proficiency. Periodic tests should be made to assure that welders qualifications are maintained in addition to test and inspection of parts as required by drawings, specifications, technical orders and other technical data. The primary factor involved in the fabrication of any part is that it will meet requirement set forth and this requirement shall not be waived because the work was accomplished by a qualified welder/ or person.

**3-104. GAS WELDING OF ALUMINUM.** Oxy-acetylene or oxy-hydrogen are the two common processes utilized as heating media. Other types may be used such as oxy-butane, oxy-propane and oxy-natural gas, etc., but they are more costly and welding speeds are slower.

**3-105.** Gas welding is normally but not specifically confined to material 0.032 to 0.087 inch thickness. The thickness of the material will also determine the method of edge preparation. The edges are prepared in the same manner as steel of the same thickness, with the exception to the thinner natural 0.040 inch and thinner which are formed to a 90° flange about the same height as the thickness of material or higher. The flange will help prevent warpage and buckling and serve as filler metal. The flange should be straight and square and if desired it may be used on material up to 1/8 inch in thickness provided the finished part will meet specification requirements.

**3-106. WELDING ROD.** Two types of welding rods will generally permit the gas welding of the various aluminum alloys. Commercially pure aluminum (1100) Federal Specification QQ-R-566 and 95% aluminum (4043) Federal Specification QQ-R-566 are the two standard filler rods most commonly used for welding. The 1100 rod is used when maximum resistance to corrosion and ductility are of prime importance. To minimize the tendency to crack and where greater strength is required, 4043 alloy is used. Other types of rods are used to provide resistance to specific chemicals and to meet special strength and specification requirements.

**3-107.** The diameter of filler rod for gas welding should be selected according to thickness of material to be welded. For material 0.064 inch thick use 3/32 inch diameter rod; 0.065 to 0.155 inch thick use 1/8 inch rod; 0.166 to 0.249 inch thick use 5/32 inch diameter rod; 0.250 to 0.374 inch thick use 3/16 inch diameter rod and 0.375 inch thick and up 3/16 inch or 1/4 inch diameter rod.

#### NOTE

**For additional information on welding see JAN-STD-19 Welding Symbols; MILSTD-22A, Welded Joint Designs; MILSTD-20, Welding Terms and Definitions; MIL-STD-272, Welding and Allied Processes; MIL-W-22248, Weldments, Aluminum and Aluminum Alloys and MIL-W8604 Welding of Aluminum Alloys.**

**3-108. CLEANING.** Proper cleaning is often an important factor that controls the final results of a welding operation. This is especially true when welding with oxy-acetylene, oxy-hydrogen or other types of gas and spot welding (resistance welding).

**3-109.** Heavily soiled parts can be pre-cleaned by vapor degreasing with trichloroethylene, Specification O-T-620, or immersing in dry cleaning solvent, I Specification P-D-680 Type II. The degreasing operation will remove the oil/grease and dirt but it has no effect on the oxide film. To remove the oxide film, the vapor degreasing should be followed by alkaline cleaning in a solution of 6 ounce Federal Specification P-S-751 to one gallon of water, heated to 180° - 200° F. Parts should be immersed for 20 minutes or until surface shows no water break and then rinse with tap water. The oxide can then be removed chemically by immersion for 4 - 6 minutes at room temperature in a solution of 9 oz/gal sulfuric acid; 1.0 - 2.0 oz/gal sodium dichromate and 0.02 oz/gal (by weight) hydrofluoric acid mixed with water. After removal of the parts from the solution rinse with tap water and air dry.

**3-110.** Welding should be accomplished immediately after deoxidizing and no later than 48 hours (preferably within 24 hours) after the deoxidize operation.

**3-111.** The chemical cleaning operation should be precisely timed, since over or under application time will increase the contact resistance and any chemical that will remove the oxide will also attack the aluminum.

#### WARNING

**Trichloroethylene Solvent, Specification O-T-620, produces dangerous and toxic fumes. Do not breathe fumes for prolonged periods. Use with adequate ventilation. When using solvents, alkaline solution and acids wear approved clothing, acid/solvent resisting gloves, aprons/coveralls, face shields and respirators. If solutions are splashed into eyes, flush thoroughly with water immediately, and then report to dispensary. For specific instructions contact local safety office.**

**3-112.** Mechanical Oxide Removal. Stainless brushes (hand or rotary), stainless steel wool and some abrasives can be used to mechanically remove oxides from unclad aluminum. The strand diameter of the wire brush utilized shall not be over 0.005 inch. Abrasives shall not be any coarser than 300 grit. Abrasive mats Specification MIL-A-9962, Type 1, Grade AAA1 (very fine) can also be used.

**3-113.** Mechanical removal of oxides shall be confined to the immediate weld area, application to other surfaces of the metal shall be avoided.

**3-114.** Do not over apply the mechanical cleaning, application should be controlled and only applied until the surface is clean of oxide.

**3-115.** Flux Removal from Aluminum Alloy. After each welding operation (complete) where flux has been used, the parts or material will be thoroughly cleaned to remove the flux. Most of all flux acts as a deoxidizing agent and if allowed to remain on the surface, corrosion attack of the area applied and adjacent area will occur.

**3-116.** Flux is removed by washing parts with water (preferably warm 140° F 180° F) or with steam (et) if available. If there is any possibility that all flux was not removed by washing with water, the part should be immersed in one of the following acid cleaning solutions:

**CAUTION**

**Acid solution shall not be used if assembly has any dissimilar metal or areas where acid solution may be entrapped and cannot be readily rinsed. On these type parts repeat washing of parts with water, agitate flux area with a non-metallic bristle brush.**

- a. NITRIC-HYDROFLUORIC ACID CLEANING The solution shall consist of:  
 1 gallon technical citric acid (58-62% HNO<sub>3</sub>) (39.5° Be)  
 ½ pint technical hydrofluoric acid (48° HF) (1.15 Sp)  
 9 gallons of water.

Parts shall be immersed for 3 to 5 minutes in cold acid.

- b. SULPHURIC ACID CLEANING The solution shall be mixed as follows:  
 1 gallon technical sulphuric acid (93% H<sub>2</sub>SO<sub>4</sub>) (66° Be)  
 19 gallons of water.

Parts shall be immersed for 10 to 15minutes in cold acid or 4 to 6 minutes in acid held at 150°F.

- c. NITRIC ACID CLEANING The solution shall be mixed as follows:  
 1 gallon technical nitric acid (58-62%HNO<sub>3</sub>) (39.5° Be)  
 14 Ounces Sodium dichromate (Na<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>)  
 1 gallon of water.

Immerse parts 5 to 10 minutes in hot acid.

**3-117.** After removing from acid, the parts shall be washed in fresh hot or cold running water for a sufficient length of time to thoroughly remove the acid. Dilute solutions of chromic acid or of sodium or potassium dichromate may be added to the rinse water as a corrosion inhibitor. The time for treatment with the above solution depends on the freshness of the solution and the amount of flux remaining on the part after washing. The rinsing time depends upon the size and design of the part and the amount of water circulated. One half hour or less should be sufficient. Parts shall then be completely dried by clean air blast or other approved method.

**3-118. INERT-GAS SHIELDED TUNGSTEN ARC WELDING (AC).** Inert atmosphere arc welding processes can be used to make clean and sound welds in aluminum without the use of corrosive fluxes. Two types of inert gas can be used to provide the shield for this type welding, which are argon and helium. Argon has certain advantages over helium for this use. Argon is a heavier gas and provides more protection and better arc characteristics than helium.

**3-119.** The power source for this type welding is electricity which may be ordinary 60 cycle alternating current. The alternating current provides the required combination of arc stability and oxide removal. Reverse polarity direct current provides adequate oxide removal but the arc is unstable and difficult to control.

**3-120.** Filler metal will present a problem in this type welding if the end of the rod is maintained at a position near the puddle, the rod will soften and melt outside the envelope of inert gas. This will produce oxidation of the rod surface and slow up welding as the operator must remove the oxide. Also, it may introduce oxide into the weld. To avoid this, apply the end of the rod intermittently to the molten pool, but do not withdraw from the protective envelope of gas as this will permit oxidation.

**3-121.** Composition of filler rods for tungsten arc welding is same as used for gas welding. Mechanical properties of weld deposits for 1100 rod are about 17,500 psi tensile and 25% elongation in 2 inches; and for 4043 rod about 22,000 psi tensile and 8% elongation in 2 inches.

**3-122.** Adequate precaution shall be taken to prevent contamination of the electrode. Contamination is indicated by the inability to produce a clean weld without a black deposit. When this begins to occur, correction can be made by grinding the contaminated part away. A black deposit at the edge of the weld does not necessarily indicate electrode contamination, if the weld surface is smooth and clean.

**3-123. INERT GAS SHIELDED TUNGSTEN ARC WELDING DIRECT CURRENT (STRAIGHT POLARITY).** The use of (DC) straight polarity current provides a "hotter" arc than that obtained with AC. Straight polarity DC puts the heat in the work rather than in the electrode. Another advantage over AC is the fact that the direct current straight polarity gives a more concentrated arc.

**3-124.** The hotter and more concentrated arc will achieve quicker melting of base metal, moreover, deeper-penetrated weld beads and requires less plate-edge preparation. Welding is faster, not only because the arc is hotter, but also because vees and grooves can be eliminated or reduced in size so consequently less filler metal is required.

**3-125.** Until the development of thoriated tungsten, high heat resistant electrodes the DC straight method was not suitable for welding aluminum. Using the improved thoriated tungsten electrodes, this method produces joints as good as those obtained with the AC method on flat and vertical butt joints, horizontal and vertical fillet joints and corner joints in the thicker material. AC is preferred for welding the thinner gauge materials.

**3-126.** The appearance of the finished DC weld will differ in appearance from the AC weld, i.e., AC welds are bright, shiny and clean and the DC welds will have a dull film caused by oxide. The oxide film is strictly a surface film and does not indicate lack of fusion, porosity, or inclusions in the weld. The film can be removed by light wire brushing to obtain a clear surface.

**3-127.** The mechanical properties of welds made by the DC method are equal to those obtained by the AC method. The distortion of the welded material is usually less with DC than with AC. The reason being that total heat input to accomplish the weld is required and the heat spread in the base metal is less.

**3-128.** Welding with the DC method is similar to the technique used for gas welding. The filler rod is held in contact with the joint and the arc is moved in straight steady progression longitudinally over the filler wire at a rate which fuses the filler metal into the desired shape of stringer heads. The filler wire is not moved, dipped or oscillated.

**3-129.** Generally using this method, one inch of filler rod should be used for each inch of weld to provide beads that are uniform. The bead size will be controlled by the size of the filler rod used. Large area welds, fillet and butt type, can be built up by multiple stringer heads. When welding with the DC (straight polarity) method care shall be taken to strike the arc within the weld area to prevent undesirable marking of material.

**3-130.** See Table 3-15 for Typical Metal Thickness Versus Filler Wire Diameter, Electrode, Welding Speed Machine Setting (current AMPS, ARC Voltage and Inert gas flow.)

**3-131. SPOT WELDING.** Spot welding is a process where two or more pieces of like metal are joined by the fusion of a concentrated area between the pieces. The material at the spot area is heated to its melting point which changes the material from a solid to liquid. The metals then combine while in the liquid state and upon cooling, solidify to form the spot weld.

**3-132.** This system of welding is classified as resistance welding. The heat for welding is developed as a result of imposing resistance to the flow of electric current. The current is supplied by the spot welding machine thru the electrode and the resistance is imposed by the metal being welded. Essentially this is a method of converting electrical energy to heat energy.

**3-133.** Aluminum is a low resistant metal and a high electric current flow thru the metal is required to produce enough heat to make the spot weld. This factor necessitates the use of high current capacity spot welding machines.

**3-134.** Precise control of energy (heat) input to weld area is required to obtain a good spot weld. The actual heat applied is determined by the electrical current input and the resistance of the metal. The spot welding is utilized to control the current, in addition it controls the application time and pressure.

**3-135.** Spot welding can be accomplished on all the aluminum alloys. The welding characteristics of the alloys will vary considerably. Generally the clad alloys are more difficult to spot weld than the bare alloys. The cause being that the low-resistance, high melting point surface (cladding material) at the contacting interfaces tend to decrease weld strength consistency.

**3-136.** The bare alloys classed as high strength, i.e. 2017, 2024, 7075, 7079, etc., are generally the easiest to spot weld because they have less tendency for sheet separation and they develop more uniform welds strength consistency. A disadvantage associated with these alloys is that welds develop more cracks and porosity (small cavities). The low strength alloys (1100, 3003, 5052, 5056, 6061, etc) have opposite tendencies; normally they are free from cracks and small cavities but are subject to more severe surface indentation and sheet separation with inconsistent welds.

**3-137.** Corrosion Resistance Spot Welding of unclad alloys 2017, 2024, 7075, 7079 and 7178 should be avoided if to be used in a corrosion environment. These alloys may be selective attacked under corrosive conditions. Spot welds have adequate corrosion resistance in the above alloys if clad coated; spot welds in the low strength alloys i.e., 1100, 5052, 3003, 5056, and 6061 have satisfactory corrosion resistance.

**3-138. WELD FORMATION.** Aluminum will expand when heated and will contract when cooled. This fact causes trouble in the formation of welds and also alignment of parts to which applied. When the metal expands a space larger than the cooled metal can occupy is created. The above is overcome to a certain degree by applying pressure (high) with the current. The pressure forces the sheets together preventing the metal from spitting or flashing. This pressure also reduces the areas as fast as the metal shrinks which counteracts the tendency of crack formation as a result of contraction.

**3-139.** Welder performing the welding operation should be properly trained. The above requires that he is trained to operate each specific spot welding machine involved in addition to other required spot welding techniques. Electrode (tip) maintenance is one of the major requirements of the system and controlled by the welder. Electrodes shall be kept clean and of the proper contour and shape.

**3-140.** The tip contour of welding electrode will depend upon (1) the thickness of the metal to be welded (2) the type of welding process being used (3) surface appearance required (4) distribution of weld indentations required (5) the rigidity of the welding arms (6) accuracy of alignment of top and bottom electrode. Optimum results usually are obtained with a spherical working face on the electrodes. The spherical surface provides for easier alignment, minimum sheet separation and easier maintenance of electrode tip for cleanliness/proper contour.

**3-141.** Electrode tip radius normally used in spot welding aluminum ranges from 2 inches on 0.020 inch thick to a 10 inch radius on 0.091 inch stock. Indentation can be minimized or entirely eliminated on one side by using a flat faced tip electrode on one side and a spherical faced tip on the other. The flat surface requirement is an important factor where supersonic aircraft is involved.

**3-142. WELD STRENGTH (SPOT).** The weld strength will be determined by the degree penetration and the area of the spot. Where penetration is less than 20% into one or both sheets weld strength will be below minimum requirements. If the weld penetration exceeds 80% the thickness of either sheet, cracked welds will usually result. Welds where the penetration is approximately half way (50%) through each sheet are considered the most satisfactory.

**3-143.** The most practical way to determine the condition, penetration and etc., of a spot weld is to make sample setups and testing the sample by peeling or pulling the sample apart. Then depending on the condition of the sample, change the machine setup until optimum results as obtained. The above should be accomplished frequently to determine that proper conditions are maintained.

**3-144.** Table 3-16 will be used only as a guide in selecting machine setting, since the values will vary with different welding machines, materials, tips, surface conditions, etc. Minimum pressures are required to prevent cracks or porosity in the weld, while excessive pressures deform the sheet. The dwells will be long enough to obtain complete fusion in the weld area. The best procedure is to set pressure and dwell for the thinnest sheet in the pile-up and then adjust the current to obtain a good spot of the desired strength. A good spot weld will be free from cracks or porosity to the extent permitted by Specification MIL-W-6858 will have a penetration of about  $\frac{1}{2}$  the sheet thickness, and a diameter of about three or four times the sheet thickness. A cross section of the spot, sanded smooth, may be given a coarse etch in hot caustic solution to determine the shape and size of the spot. Spot welds in alloys 1100 and 3003 are acceptable when meeting the above conditions. For alloys, 2017, 2024 and 5052, single spot shear specimen welds will be made in addition to determine the spot strength at that machine setting. This strength will be above the minimum value given in Specification MIL-W-6858.



TABLE 3-15. GENERAL PROCEDURE FOR MANUAL WELDING FLAT BUTT JOINTS WITH GAS SHIELDED TUNGSTEN ARC DC (STRAIGHT POLARITY) AND BALANCED ALTERNATING CURRENT, USING ARGON/HELIUM (GAS) AND THORIATED TUNGSTEN ELECTRODES.

METAL THICKNESS INCH	JOINT	FILLER WIRE DIAMETER INCH	ELECTRODE DIAMETER INCH	JOINT SPEED IN/INCHES	CURRENT AMPS	AVE VOLT	HELIUM FLOW CU FT.
0.030	Square 1 pass	3/64	0.040	17	20	21	10
0.040	Square Butt 1 pass	1/16	0.040	16	26	20	10
0.062	Square Butt 1 pass	1/16	0.040	20	44	20	10
0.090	Square Butt 1 pass	3/32	1/16	14	80	17	10
1/8	Square Butt 1 pass	1/8	1/16	16	118	15	10
1/4	Square Butt 1 pass	5/32	1/8	7	250	14	15
1/2	90° Incl Angle Bevel 1/4" Nose 2 passes	5/32	1/8	5 1/2	310	14	20
3/4	90° Double Bevel 3/16" Nose 2 passes	5/32	1/8	4	300	17	25
1	90° Double Bevel 1/4" Nose 5 passes	1/4	1/8	1 1/2	360	19	25

TABLE 3-16. TYPICAL MACHINE SETTINGS FOR SPOT WELDING ALUMINUM ALLOYS.

THICKNESS OF THINNEST SHEET	ALLOYS NO 1100 AND 3003			ALLOYS NO 2017 2024 AND 5052		2017 - 2024	5052
	PRESSURE LBS	DWELL CYCLES	CURRENT AMPERES	PRESSURE LBS	DWELL CYCLES	CURRENT AMPERES	CURRENT AMPERES
0.010	60	3	15,000	135	5	10,000	10,000
0.020	100	3	16,000	265	5	13,000	12,000
0.030	150	4	19,000	400	7	16,000	15,000
0.040	200	5	21,000	530	9	18,000	17,000
0.050	250	6	24,000	670	11	22,000	20,000
0.060	300	6	26,000	800	13	25,000	22,000
0.070	350	7	28,000	930	14	28,000	24,000
0.080	400	8	31,000	1,070	15	31,000	26,111
0.090	450	8	33,000	1,200	16	34,000	28,000

**NOTE**

For further information concerning the process for welding of aluminum and aluminum alloys, refer to Military Specification MIL-W-8604 and MIL-W-6858. Specification MIL-W-6858 established requirements for equipment, classification of welds shear strengths, surface preparation, testing, etc. This specification also limits the joint thickness to not more than four times the thickness of the thinnest outer layer of material and maximum ratio between two thickness in the pile to 3-1.

**3-145. BRAZING ALUMINUM.** Aluminum can be brazed although it is not commonly practiced. Utilization of brazing is limited and confined to certain specific applications.

**3-146.** Aluminum is brazed by using filler metal (brazing alloy) which melts at about 100° F below the melting point of aluminum. Thus the joining action is accomplished by the adhesion and diffusion of the brazing alloy to the base aluminum. Brazing differs from welding in that the parent metal is not melted, however, since the brazing material is an aluminum alloy the finished joint will have a metallurgical structure similar to that obtained by welding. The strength and corrosion resistance is also approximately the same as that by welding.

**3-147.** Brazing of aluminum alloys is normally confined to the none-heat-treatable alloys 11003003-3004-5050, 5052 and heat treatable alloys 6061 and 6062.

**3-148.** To properly perform the brazing operation surfaces of metal must be free of grease, oil, dirt and other foreign matter as with welding. The oxide coating of the aluminum shall be removed to the extent that brazing flux will effectively complete the oxide removal and clean the surface for good adhesion of the filler metal. This is especially necessary where magnesium and silicon alloyed aluminum (5050, 5052, 6053, 6062 and 6063) are involved. The natural oxide coating of these alloys is heavy and difficult to remove by the use of brazing flux alone.

**3-149.** The cleaning and oxide removal can be accomplished as previously cited in paragraphs 3-108, 3-112 and 3-115. The requirement for flux removal is reemphasized. All traces of flux shall be removed from the finished part/product to prevent chemical attack and corrosion. Flux removal may be aided by agitating with a non-metallic bristle brush when washing and rinsing. The parts should then be (bright dipped) chemically cleaned by immersing in a solution of sodium hydroxide (6 oz per gallon) for 45 to 60 seconds; followed by rinsing in hot water (150°-180° F); dipping in a 10% solution of nitric acid (HN03); completing with another hot water rinse and drying. Final rinsing in clean water is absolutely necessary to remove the cleaning materials. The chemical cleaning process shall be accomplished in the plating shop area or other facility specifically designed for that purpose. Personnel utilized shall be trained to handle the chemicals involved and the particular process. Procedure cited in paragraph 3-115 may also be used.

**3-150.** Flux for Aluminum Brazing. Brazing fluxes consist of fluorides and chlorides which are corrosive in nature. They will seriously attack aluminum and must be used with care and in small quantities. Flux is normally received in powder form in air-tight containers of glass or earthen ware. The powder shall be mixed in a glass container or earthen ware (never steel) container by adding distilled water to form a paste (1 part water to 3 parts powder for brushing). Mix only enough flux to last for 4-8 hrs. The unused powder should be tightly sealed after the quantity required is removed to prevent contamination.

**3-151.** Aluminum Brazing Method. Aluminum may be brazed by three common methods. These methods are furnace, dip (salt bath flux) and torch. The difference in the methods primarily is the manner in which heat is applied.

a. Furnace Brazing. The parts to be joined (brazed) are assembled, fluxed and then heated in a furnace with accurately controlled temperature. This method is normally used for mass production brazing operations.

b. Dip Brazing. The joining of the parts is accomplished by immersing the parts into a molten flux bath. The temperature of the bath is held slightly above the melting point of the filler metal (brazing alloy) but below the melting point of the base metal, which permits the brazing alloy to flow into the joint. Normally unless the parts are self-supporting they must be supported with jigs. Large parts require preheating prior to dipping to prevent reduction of flux bath temperature.

c. Torch Brazing. This method of brazing is similar to torch welding. The difference being that the special brazing metal and flux permits the joining action to be accomplished without meeting the base metal.

**3-152.** The flow of the brazing alloy through closely fitted parts results from capillary attraction and gravity.

**3-153.** Filler metal used for aluminum brazing is normally in aluminum silicon alloy. The three common alloys contain (1) 7½% silicon melting point 1180° F, alloy 4043(713) (2) 10% silicon melting point 1110° F, alloy 4343 (3) 12 ½% silicon melting point 1060° F, alloy 4047, See Federal Specification QQ-B-655.



**3-154. SOLDERING.** Soldering of aluminum is limited in methods and application. Difficulty encountered in soldering is due to the mutual attraction of aluminum for oxygen in which the atoms combine and instantaneously form an oxide surface coating. Solder will not bond to the smooth oxide coating and therefore must be removed.

**3-155.** Another factor requiring consideration in reference to soldering aluminum is corrosion caused by electrogalvanic action. Galvanic action occurs where two or more dissimilar metals are in contact in a solution that conducts electricity. Aluminum solder contains at least two other metals, thus all the elements required to produce galvanic action in presence of moisture. The moisture present in the atmosphere is sufficient to complete the electrogalvanic circuit.

#### **CAUTION**

**Solder shall not be used on aerospace craft unless specifically authorized by approved engineering data, etc. due to the above factor.**

**3-156.** Soldering Procedure. The requirements for performing the soldering operation on aluminum are approximately the same as with any other metal except as previously stated. Surfaces must be free from foreign matter. Surfaces can be cleaned by the methods previously cited in para 3-108 thru 3-117.

**3-157.** Soldering aluminums require good control of heat application due to the inherent high conductivity. Generally a torch is required because of higher heat output and the flame should be non-oxidizing.

**3-158.** The best soldering results are obtained in conjunction with high purity aluminum and the wrought alloys which contain 1% or less manganese or magnesium.

**3-159.** Soldering alloys used for aluminum normally contain 50 to 75% tin and the remainder zinc. (See Specification MIL-S-12204). Preferred alloy is 60% tin and 40% zinc which may be obtained in accordance with Specification MIL-S-12204, Comp B.

**3-160.** Care should be taken to prevent overheating the solder and flux. This can be overcome to a certain degree by applying the heat to the material being soldered and by letting the material heat the solder flux. When the flux begins to fume or smoke apply the solder which will flow freely (Always use the correct flux and never overheat). The use of temperature in excess of 750° F will break the flux down and contaminate the solder.

**3-161.** If difficulty is encountered because of poor adhesion, puddle the solder and while still molten rub through the solder and abrade the underlying surface. This may be done with a sharp tool such as a stiff wire brush, hacksaw blade, or other type of clean material with a high melting point.

**3-162. RIVETING.** Riveting is the most common method of assembling components fabricated from aluminum. Typical advantages of this method of mechanical fastening are (1) simplicity of application, (2) consistent joint uniformity, (3) easily inspected (X Ray and other type equipment not required.) (4) low cost, (5) in many cases lighter weight.

**3-163.** The rivets used in USAF Weapon System structures require that the alloys and shapes be closely controlled by specification/standards, to assure structural integrity and uniformity. These rivets are presently classified as solid shank, hi-shear, blind (structural-non-structural) explosive/chemical expanded. They are available in a variety of shapes, alloys, sizes, lengths and types. The most common alloys utilized are aluminum because the structure alloys are normally aluminum. In addition some of the aluminum rivet characteristics can be changed by heat treating which facilitates application (see paragraph 3-37).










**3-164.** All of the aluminum alloys could be used to manufacture rivets; however, due to some alloys having superior properties they have been selected as standard. See Table 3-17 for alloys head, identification, MS/AN standard cross references, etc., for general rivets used on AF weapons systems.

**3-165.** Rivets in aluminum alloys 1100(A), 5056(B), 2117(AD) are used in the condition received. Alloys 2017(D) and 2024(DD) often referred to as "Ice Box Rivets" require heat treatment prior to use (see paragraph 3-43). Rivets in alloy 2017 and 2024 should be driven immediately after quenching with a maximum delay of 20 minutes or refrigerated to delay aging. The customary procedure (unless only a few rivets are involved) is to place the rivets under refrigeration immediately after heat treatment. The time the rivets may be used will depend on refrigeration equipment available. Cooling to 32° F will retard natural aging to the extent that the rivets may be driven up to 24 hours. Cooling rivets +0-10°F and below will retard natural aging to the extent that the rivets may be retained for use indefinitely.

**3-166.** Rivets utilized with extended driving time should be closely inspected after upsetting for cracks. If inspection reveals that rivets are cracked, discontinue use, remove defective rivets and obtain reheat treated rivets prior to continuing the assembly operation.

**3-167.** If for some reason it is necessary to determine if a rivet has been heat treated this may be done by Rockwell Hardness testing. Test by supporting rivets in a vee block and hardness reading taken with a 1/16 inch ball 60 kilogram load. A hardness of over 75 will indicate a heat treated rivet.

TABLE 3-17. GENERAL RIVET (ALUM) IDENTIFICATION CHART.

HEAD SHAPE IDENTIFICATION				RIVET MARKING TO ALLOY IDENTIFICATION		
						
ROUND	UNIVERSAL	BRAZIER	COUNTERSUNK	PLAIN HEAD 1100 (A)	RAISED CROSS 5056B	DIMPLE 2117 (AD)
NOTE: RIVETS MARKED X SUPERSEDED BY UNIVERSAL HEAD.						
NOTE: HEAD SHAPES APPLY TO SOLID SHANK ALUM RIVETS ONLY.						
						
				RAISED DOT 2017 (D)	RAISED DASHES 2024 (DD)	

**CAUTION**

Heat treatment and most other operations requiring use of heat will be accomplished prior to installing rivets, since heating after rivets are installed will cause warping and possible corrosion if salt bath is used. The salt from the bath will contaminate cracks and crevices of the assembly and complete removal cannot be assured.

**3-168.** Shear strength (ultimate) of a driven rivet can be determined by the formula  $P_s = S_s A N$ .  $P_s$  = ultimate shear strength (pounds),  $S_s$  = specified shear strength of the driven rivet (psi),  $A$  = cross sectional (area of the driven rivet, normally equal to hole cross section (square inch) and  $N$  = number of shear planes. For shear strength of protruding and flush head rivets see Table 3-19.

**3-170.** Rivet Selection. Unless otherwise specified, rivets should be selected that have comparable strength and alloy as material being assembled. This is an important factor in preventing corrosion from dissimilar metal contact and to assure structurally sound assemblies. The following tables are provided as a general guide for selection of rivet alloy vs. assembly alloy.

**3-171.** The formula  $P_s = S_b A C$  can be used to determine failure in bearing strength.  $P_s$  = ultimate bearing strength of the joints (lbs),  $S_b$  = specified ultimate bearing strength of the plate (psi) and  $A_c$  = projected crushing area (bearing area) of rivet, or

diameter (sq in) see Table 3-20 for typical bearing properties of aluminum alloy plates and shapes.

**3-172.** Rivet hole preparation is one of the key factors in controlling (1) successful upsetting of rivet head (2) material separation and buckling which weakens the structural strength of the rivet joint (3) corrosion attack of rivets and material after equipment is placed in service/use. The rivet hole should be drilled, punched/reamed to size that allows the minimum clearance (approximately 0.003 for thin sheet and up to about 0.020 for 0.750 - 1.000 inch thick material) required to insert rivet without forcing. Theoretical rivet holes should be completed i.e., drilled, reamed to size, deburred, chips removed that may lodge or be trapped in between surface of metal and treated (anodized, etc.) before starting to rivet assembly. The above cannot always be accomplished, especially where the assembly is large and requires the application of a large amount of rivets due to hole tolerance and variations in holding clamping/pressures. To overcome these problems requires that holes be pilot drilled and reamed to size at time rivet is to be installed. This method has a twofold purpose (1) allows easy insertion of rivets, (2) prevents elongation of rivet holes and resulting weakening of rivet joint.

**3-173.** Rivet holes drilled/reamed after assembly is started should be treated by coating with zinc chromate primer or other approved material. Two methods for coating rivets and improving protection of hole surfaces from corrosion are:

TABLE 3-17. GENERAL RIVET (ALUM) IDENTIFICATION CHART.

OLD AN/STD	SUPERSEDING MS STD	FROM	MATERIAL	HEAD AND NUMERICAL IDENT CODE	CONDITION	HEAT TREAT
AN456	MS20470	Brazier Head Solid Modified	See AN470			
USAF460	See MS20601	1000 Flush Head Blind type II Class 2	See MS20601			
USAF461	See MS20600	Protruding Head Type II Class I Blind	See MS20601			
USAF463	See MS20600	Same	Same			
NAF1195	See MS20600	Same	Same			
AN470	MS20470	Universal Head Solid	1100	A-Plain	F	No
			5056	B-Raised Cross	F	No
			2117	AD-Dimple	T-4	No
			2017	D-Raised Dot	T-4	Yes
			2024	DD-Raised Dash	T-4	Yes
	MS20600	Protruding Head-Blind Type II, Class I	5056	B	F	No
			2117	AD	T-4	No
			Monel	M		No
	MS20601	100° Flash Head Blind Type II, Class 2	5056	B	F	No
			2117	AD	T-4	No
	MS20602	Protruding Head Blind Chemically Expanded Type I, Class I, Styles A & B	Monel	M		No
			5056	B	F	No
			2017	D	T-4	No

TABLE 3-17. GENERAL RIVET (ALLUM) IDENTIFICATION CHART (CONT'D)

OLD AN STD	SUPERS EDING MS STD	FORM	MATERIAL	HEAD AND NUMERICAL IDENT CODE	CONDITION	HEAT TREAT
	MS20604	Universal Head Blind Class I Non Struct	5056	B	F	No
			2117	AD	T-4	No
			Monel M or MP (MP = Monel Plated)			No
	MS20605	100 ° Flash Head Blind Class 2, non struct	5056	B	F	No
			2117	AD	T-4	No
			Monel M or MP (MP= Monel Plated)			No
	MS20606	Modified Trusshead Blind Class 3 Non Struct	5056	B	F	No
			2117	AD	T-3	No
			Monel M or MP (MP= Monel Plated)			No
	MS20613	Universal Head Solid	1010	Recessed Triangle annealed		No
			302	C-None	Annealed	No
	MS20615	Universal Head Solid	Copper	CW Annealed		No
			Monel	Raised Dots	Class A	No

Note: Copper, steel, and Monel listed for information purposes. For special rivets see manufacturing drawing, data, specification, etc. For other information on rivets see T.O. 1-1A-8/1-1A-1.

TABLE 3-17. GENERAL RIVET (ALUM) IDENTIFICATION CHART (CONT'D)

OLD AN STD	SUPERSEDING MS STD	FORM	MATERIAL	HEAD AND NUMERICAL IDENT CODE	CONDITION	HEAT TREAT
AN426	MS20426	Countersunk 100 °	1100	A-Plain	F	No
			5056	B-Raised Cross	F	No
			2117	AD-Dimple	T-4	No
			2017	D-Raised Dot	T-4	Yes
			2024	DD-Raised Dashes	T-4	Yes
Note: See Paragraph 3-44 for heat treat data.						
AN427	MS20427	Countersunk 100 °	1006/ 1010	Recessed Triangle	A	No
			Copper 302/304	C-None F-Recessed	A A	No No
			Monel M	Dash M-None		
AN430	MS20470	Round Head Replaced by universal See AN470 + MS20470				
AN435	MS20435	Round Head Solid	1006	Head Ident Recessed Triangle	A	No
			Copper 302/304	C-None F-Head Ident None	A A	No No
			Monel	M-None		
Note: Listed for Reference only.						
AN441	Use MS20435	See AN435				
AN442	Use MS20470	See AN70+ MS20470				
AN450	MS20450	Countersunk & oval tubular	1006/ 1010/ 1015	Blank/ None	A	No
			Copper	C-None	A	No
			2117	AD-None	T-4	No
			Brass	B-None	Grade B	No
			MONEL	M-None	A	No
Note Listed for Reference only.						
AN455	MS20471	Brazier Head Solid Superseded by Universal	See AN470			

**TABLE 3-18. GENERAL ALUMINUM RIVET SELECTION CART (RIVET ALLOY VS ASSEMBLY ALLOY)**

Rivet Alloy	Assembly Alloy
1100	1100, 3003, 3004, 5052
2117-T4 (AD)	3003. H16 and H-18, 5052. H16 and H18, 2014, 2017 2021, 6061 7075, and 7178.
2017-T4(D), 2024TL (DD)	2014, 2017, 202h, 5052, 6061 7075 and 7178
5056-1132(B)	5052 and magnesium alloys, AZ31B, etc.

- a. Spraying holes with primer after drilling and immediately preceding installation of rivet.
- b. Dipping rivet in zinc chromate primer and installing while still wet.

**3-174.** For additional information on rivets (strengths, factors, etc.) see MIL-HDBK-5, T.O.'s 1-1A-8 and 1-1A-1.

**3-175. MACHINING.** The resistance encountered in cutting aluminum alloys is low in comparison to other metals. In fact most of the aluminum alloys will machine approximately 10 times faster than steel. This factor combined with other properties, i.e., strength, heat treatability, weight, corrosion resistance, etc. makes aluminum a preferred material in many instances for fabrication of parts by machining. Brass (free machining) is the only other material with comparable machining properties.

**3-176.** Personnel accomplishing the work should be properly trained in machining aluminum as with other types of metals. Due to various circumstances personnel familiar with machining steel products are required to machine aluminum without proper training/information on speeds, feeds, tools etc., required to effectively accomplish a specific task. The purpose of this section is to provide a general guide for selection of tools, machining, speeds, etc.

**3-177.** The tools used for machining aluminum will normally require more rake side-top and operation at higher/feeds than used for steel. The amount of rake required will depend on composition, physical form (cast or wrought) and temper. The more ductile or softer the alloy the more rake required. The following general practices are recommended for shafing, grinding and maintaining tools for cutting aluminum:

1. Allow more space for chips to be formed and expelled from tool than allowed for steel.
2. Design tools (grind tool) so that chips and cuttings are expelled away from the work piece.
3. Keep cutting edges of tools sharp, smooth, free of burrs, wire edges and scratches.
4. Use high machining speeds, moderate feeds and depths of cut.
5. Apply lubricant/coolant in large quantities to tool when cutting.

**3-178.** The higher speeds utilized for machining aluminum requires:

1. Machines be free of vibration and lost motion.
2. Rigid support of tool near cutting edge to minimize clatter and vibration.
3. Secure clamping of work to machine to avoid distortion or slippage.

4. Use of proper lubricant, cutting compound or coolants to prevent overheating, warpage/distortion and to provide adequate lubrication to cutting tool.

**3-179. CUTTING TOOLS FOR MACHINING ALUMINUM .** There are four general types of tool steel material that can be used to machine aluminum. They should be selected in accordance with availability and scope of job to be accomplished. The following is a suggested guide for selection of tools:

- a. High carbon tool steel is adequate for machining a small number of parts or where cutting speed required is relatively low.

This material will exceed the performance of some of the other types of tools when used for fragile tools such as drills, taps, etc., because it does not break as easily as the other types. Stock material is obtainable in accordance with Federal Specification QQ-T-580 where required for local fabrication of high carbon tools etc.

b. High speed tool steel is the most common type used for machining except on the higher silicon alloys.

(1) Availability, reasonable cost.

(2) Heat resistance (will retain cutting edge up to about 950°F dull red).

(3) Permits use of large rake angle required. Federal Specification QQ-T-590 applies to stock material. All the various classes (T1, T2, T3, etc.) may be used for machining aluminum. Class T1 (18-4-1) general purpose type is the most widely used.

c. Where long production runs are involved cemented carbide (solid or tipped) tools give better service. The carbide tools have been known to last thirty times longer than high speed tool steel. The carbide tools are also recommended for cutting high silicon content alloys. Because of the brittleness of the cemented carbide tool the cutting angle should be greater than those recommended for high carbon/high speed steels.

d. Diamond tipped tools should only be used for light finishing cuts or special finishing operations. Normal cutting of 750 900 are used with top rake angles of 6 to 10°. Tool projection (or set) should be slightly above center line (CL) of the work.

**3-180. TURNING.** To properly perform the turning operation firmly attach the work to the machine (lathe) chuck, collet or faceplate. The work should be held in the best manner to minimize distortion from chuck or centrifugal force action during the turning operation. Long rods/stock should be supported by ball or roller bearing tailstock centers which are more satisfactory than solid or fixed centers in resisting thrusts from centrifugal force and thermal expansion. Soft liners may be used between work and machine jaw faces to prevent jaw teeth from damaging/marring work piece. When it is necessary that work be held by clamping from inside diameter outward the tightness of jaws should be checked frequently to be sure that work is not being released as a result of thermal expansion.

**3-181.** The recommended cutting fluids are the soluble oil emulsion which combine the functions of cooling and lubricating for general purpose use. For heavy cutting especially when speeds are low, lard oil such as Specification C-0-376 or mineral oil, Specification W-0-241 is recommended. In practice it will be found that some machining operations can be performed dry.

**3-182.** Tables 3-22 and 3-23 cite suggested turning speeds, tool angles and feeds. Tool projection in relation to work should be set at or slightly above work piece center line. Sturdy construction of tools and holders is essential to minimize vibration/chatter at the high speeds aluminum alloys are machined.

#### NOTE

**Parting tools should have less top rake than turning tools. Recommend top rake angles of 12 to 20° and front clearances of 4 to 8° grind face concave (slightly) and so that corner adjacent to work will lead opposite corner by 4 to 12° or as required for best results.**

**3-183. MILLING-ALUMINUM.** Milling of aluminum alloys should be accomplished at high cutter speeds. The limitations will usually depend on the machine and type cutters used. The reason for the higher cutter speeds is that at low speeds the cutters will have a tendency to load and gum. This will normally clear as the speed is increased.

**3-184.** The tooling for milling should be selected according to the operation and duration/size of job to be performed. The cutters should have fewer teeth and should be ground with more top and side rake than those used for milling steels. Most operations can be accomplished with spiral cutters. Nick tooth cutters are used when reduction in size of chips is required. Solid-tooth cutters with large helix angles are used where free-cutting tools are required. When cutters with large helix angles are used it is often necessary that two interlocking cutters of opposite helixes be employed to alleviate axial thrust.

**3-185.** Tool alloys should be selected for milling aluminum as follows:

a. For short runs high carbon steel is normally satisfactory.

b. For production runs of extended duration high speed steel is recommended.

c. Where climb milling/high speeds are utilized, carbide tipped tools are recommended for extended runs.



**TABLE 3-19. SHEAR STRENGTH OF PROTRUDING AND FLUSH HEAD ALUMINUM ALLOY RIVETS, INCH POUNDS.**

Size of Rivet(In Dia)	1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8
Alloy + driven temper 5056 FSU = 28 KSI	99	203	363	556	802	1,450	2,290	3,280
2117-T321, FSU=30 KSI	106	217	388	596	862	1,550	2,460	3,510
2017-T31, FSU = 34 KSI	120	297	442	675	977	1,760	2,970	3,970
2017-T3, FSU = 38 KSI	135	275	494	755	1,090	1,970	3,110	4,450
2024-T31, FSU = 41 KSI	145	296	531	815	1,180	2,120	3,360	4,800

FSU = Average Shear strength of alloy in specified temper.

KSI = 1000 lbs square inch example: 34 KSI = 34,000 lbs per square inch.

Single shear rivet strength correction factor (resulting from use in thin plates and shapes).

Sheet thickness (in)

0.016	0.0964							
0.018	0.0984							
0.020	0.0996							
0.025	1.000	0.972						
0.032		1.000	0.964					
0.036			0.980					
0.040			0.996	0.964				
0.045			1.000	0.980				
0.050				0.996	0.972			
0.063				1.000	1.000	0.964		
0.071						0.980	0.964	
0.080						0.996	0.974	
0.090						1.000	0.984	
0.100							0.996	0.972
0.125							1.000	1.000
0.160								
0.190								
0.250								

TABLE 3-19. SHEAR STRENGTH OF PROTRUDING AND FLUSH HEAD ALUMINUM ALLOY RIVETS, INCH POUNDS (CONT'D).

Double shear rivet strength correction factor (resulting from use in thin plates and shapes)								
SIZE OF RIVETS								
Sheet Thick Inch	1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8
0.016	0.688							
0.018	0.753							
0.020	0.792							
0.025	0.870	0.714						
0.032	0.935	0.818	0.688					
0.036	0.974	0.857	0.740					
0.040	0.987	0.896	0.792	0.688				
0.045	1.000	0.922	0.831	0.740				
0.050		0.961	0.870	0.792	0.714			
0.063		1.000	0.935	0.883	0.818	0.688		
0.071			0.974	0.919	0.857	0.740		
0.080			1.000	0.948	0.896	0.792	0.688	
0.090				0.974	0.922	0.831	0.753	
0.100				1.000	0.961	0.870	0.792	0.714
0.125					1.000	0.935	0.883	0.818
0.160						0.987	0.835	0.883
0.190						1.000	0.974	0.935
0.250							1.000	1.000

Note: Values (lbs) of shear strength should be multiplied by the correction factor whenever the D/T = rivet diameter/plates sheet or shape thickness ratio is large enough to require correction. Example: Rivet diameter 1/8 (alloy 2117 - T3) installed in 0.040 sheet, shear factor is 388 lbs correction factor 0.996 =

388
<u>0.996</u>
2328
3492
<u>3492</u>
386.448 corrected shear pounds

TABLE 3-20. BEARING PROPERTIES, TYPICAL, OF ALUMINUM ALLOY PLATES AND SHAPES.

Edge Distance = 1.5 X Rivet Diameter			Edge Distance = 2.0X Rivet Diameter	
Alloy	Yield Strength	Ultimate Strength	Yield Strength	Ultimate Strength
1100 - 0	10,000	21,000	12,000	27,000
1100 - H12	18,000	23,000	21,000	29,000
1100 - H14	22,000	24,000	23,000	31,000
1100 - H16	23,000	16,000	26,000	34,000
1100 - H18	27,000	19,000	32,000	38,000
3003 - 0	12,000	22,000	15,000	34,000
3003 - H12	21,000	27,000	24,000	36,000
3003 - H16	28,000	34,000	33,000	42,000
3003 - H18	32,000	38,000	38,000	46,000
2014 - T4	56,000	93,000	64,000	118,000
2014 - T6	84,000	105,000	96,000	133,000
2024-T3	64,000	102,000	74,000	129,000
Alclad 2024-T3	60,000	96,000	69,000	122,000
2024-T36	80,000	110,000	91,000	139,000
Alclad 2024-T36	74,000	100,000	85,000	127,000
5052 - 0	25,000	46,000	30,000	61,000
5052 - H32	37,000	54,000	42,000	71,000
5052 - H34	41,000	59,000	47,000	78,000
5052 - H36	47,000	62,000	54,000	82,000
5052 - H38	50,000	66,000	58,000	86,000
6061 - T4	29,000	56,000	34,000	73,000
6061 - T6	56,000	72,000	64,000	94,000
7075 - T6	101,000	123,000	115,000	156,000
Alclad 7075-T6	94,000	114,000	107,000	144,000

**3-186.** Milling cutters should be inclined to work and beveled on leading corner (least bevel for finish cuts) to minimize chatter.

**3-187.** The cutting fluids for milling aluminum should combine cooling and lubrication properties. Coolant lubrication should be applied under pressure (atomized spray if available) in large quantities to tool and work. The recommended cutting fluids are water base cutting fluids such as soluble oils and emulsions, mixed 1 part to 15 for high speeds and 1 part to 30 for low speed cutting.

**3-188.** Tables 3-24 and 3-25 cite suggested speeds, contour and tool angles, for milling aluminum. The best combination of cutting speeds, feed and cut for a given job will depend on design of tool/cutter, kind of tool material, condition of machine, machine power, size, clamping method and type material being worked.

**3-189. SHAPING AND PLANING.** The speed at which aluminum alloys can be cut by planing and shaping is somewhat slower in comparison to other machining methods, due to equipment design and limitations.

**TABLE 3-21. STANDARD RIVET HOLE SIZES WITH CORRESPONDING SHEAR AND BEARING AREAS FOR COLD DRIVEN ALUMINUM ALLOY RIVETS.**

Rivet Size, In.	1/16	3/32	1/8	3/32	3/16	1/4	5/16	3/8
Drill Size, No.	51	41	30	21	11	F	P	W
Nom hole dia, In.	0.067	0.096	0.1285	0.159	0.191	0.257	0.323	0.386
Single Shear area sq in.			0.01296	0.01986	0.02865	0.05187	0.08194	0.1170
Bearing Area Sq. in for various Shear Sheet and Plate Thicknesses	0.032		0.00411	0.00509				
	0.040		0.00514	0.00636	0.00764			
	0.051		0.00655	0.00811	0.00974	0.01311		
	0.064		0.00822	0.0108	0.01222	0.01645	0.0207	
	0.081		0.01041	0.01288	0.01547	0.02082	0.0262	0.0313
	0.102		0.01311	0.01622	0.01948	0.02621	0.0369	0.0394
	0.125		0.01606	0.01988	0.02388	0.03213	0.0404	0.0483
	0.156		0.02480	0.02980	0.04016	0.0505	0.0603	
	0.187			0.3581	0.04819	0.0606	0.0724	
	0.2187				0.04178	0.05622	0.0707	0.0844
	0.250					0.06425	0.0808	0.0965
	0.3125						0.1009	0.1206
	0.3750							0.1448
	0.500							

The slower cutting speeds can be overcome to some extent by securely anchoring the work to the machine and using heavy rough cutting feeds. The tools used for rough cut should be (round nose) of heavy construction and properly ground to operate efficiently. Rough cut tools should be ground with moderate amount of rake to provide maximum cutting edge support. Finish tool should have more top rake and an extra large amount of side rake. Finishing tool shall be used with fine feeds only due to the additional side and top rake (finish cut should not exceed 0.018 inch).

**3-190.** Most cutting operations by shaping and planing can be accomplished without cutting fluids, however fine finishing can be improved by lubrication.. Recommended cutting compounds are kerosene, mixture of 50-50 lard-oil and soluble oil.

**3-191.** Tables 3-26 and 3-27 cite suggested turning speeds, tool angles and feeds. Secure clamping of work is re-emphasized especially when heavy cutting feeds are to be used.

**3-192. DRILLING ALUMINUM ALLOY.** Standard type twist drills may be used satisfactorily for many drilling

operations in aluminum alloys. However, better results can be obtained with improved designed drills where soft material and drilling of thick material or deep holes are involved. These drills are usually designed having more spiral twists per inch (see Figure 3-2). The additional spiral twist gives more worm action or force to drill causing the drill to cut/feed faster and is helpful in removing chips, especially in deep hole drilling operations.

**3-193.** Generally a drill for a given job should be selected according to the thickness, type alloy and machine/drill motor to be utilized. The following is a general guide for the selection of drills and recommended speeds:

(a) Drill press.

Point Angle: 118°-140° for general work and 90°-120° for high silicon.

Spiral Angle: 24°-28° for thin stock and medium depth holes up to 6 times drill diameters, 24°-48° for deep holes over 6 times drill diameter.

TABLE 3-22. TURNING SPEEDS AND FEEDS.

ALLOY TYPE AND TEMPER	CUT INCHES	CUTTING SPEED FPM	FEED, IN./REV	OPER	TOOL MATERIAL
Soft Series, 1100 All temp	0.250 Maximum	700 - 1600	0.050 Maximum	Rough	Plain high carbon/high speed
5052-H12, H14	0.040 Maximum	1500 - 3500	0.004 - 0.015	Finish	"
2011 - 2024 - 0	0.250 Maximum	4000 - 7000	0.012 Maximum	Rough	Carbide
5056-0-6061-0	0.020 Maximum	6000 - 8000	0.010 Maximum	Finish	"
7075-0, 113	0.010 Maximum	At Minimum vibration	0.002 - 0.005	Finish only	Diamond
138, 214, 212					
750, 220 122					
HARD SERIES	0.200 Maximum	400 - 650	0.007 - 0.020	Rough	Plain high carbon/high speed
108, 319, 43	0.020 Maximum	600 Maximum	0.002 - 0.004	Finish	Plain high carbon/high speed
5052 - H34, H36, H38	0.200 Maximum	500 - 1300	0.010 Maximum	Rough	Carbide
T4, 2024-T3	0.020 Maximum	700 - 2500	0.010 Maximum	Finish	Carbide
7075-T6, 7178-T6	Not recommended			Rough	Diamond tipped
6061-T4, T6, etc.	0.006 Maximum	At minimum vibration	0.002 - 0.004	Finish	Diamond tipped
HIGH SILICON SERIES	0.120 Maximum	600 Maximum	0.007 - 0.020	Rough	Plain high carbon/high speed
	0.020	600 Maximum	0.002 - 0.004	Finish	Plain high carbon/high speed
4032, 333,	0.120 Maximum	500 - 1000	0.008 Maximum	Rough	Carbide
A132, 132, 356	0.020 Maximum	500 - 1500	0.004 Maximum	Finish	Carbide
etc		NOT RECOMMENDED		Rough	Diamond tipped
	0.006	At minimum vibration	0.001 - 0.003	Finish	Diamond tipped

TABLE 3-23. TOOL ANGLES - TURNING.

TOOL ANGLES	PLAIN HIGH CARBON/HIGH SPEED	CARBIDE	DIAMOND
Cutting Angles	30° - 50°	52° - 80°	74° - 88°
Top Rake	30° - 53°	0° - 32°	10° - 0°
Side Rake	10° - 20°	5° - 10°	0° - 6°
Front Clear	7° - 10°	6° - 10°	Nose Radii 0.06 - 0.10
Side Clear	7° - 10°	6° - 10°	--

TABLE 3-24. MILLING - SPEEDS AND FEEDS.

ALLOY	CUT	CUTTER SPEED	FEED		OPER	TOOL MATERIAL
			Ft/minutes	Inches per tooth		
Temper	Inches	Ft/minutes	Ft/minutes	Inches per tooth		
Soft	0.250 Maximum	700 - 2000	10 Maximum	0.005 - 0.025	Rough	High car- High bon Speed
Soft	0.020 Maximum	5000 Maximum	10 Maximum	0.005 - 0.025	Finish	" "
Hard	0.200 Maximum	500 - 1500	10 Maximum	0.005 - 0.025	Rough	" "
Hard	0.020 Maximum	4000 Maximum	10 Maximum	0.005 - 0.025	Finish	" "
Soft	0.300 Maximum	3000 - 15000	20 Maximum	0.004 - 0.020	Rough	Carbide Tipped
Soft	0.020 Maximum	3000 - 15000	20 Maximum	0.004 - 0.020	Finish	" "
Hard	0.250 Maximum	3000 - 15000	20 Maximum	0.004 - 0.020	Rough	" "
Hard	0.020 Maximum	4000 - 15000	20 Maximum	0.004 - 0.020	Finish	" "

Lip Clearance (lip relief): 17° for soft alloys 15° for medium and hard alloys, 12° for silicon alloys Speed: 600 ft/min with high speed drills and up to 2000 ft/min with carbide tipped drills,

Feed: 0.004-0.012 inch per revolution for drills 3/8 inch diameter, 0.006-0.020 in/rev for 3/8 1 ¼ inch diameter and 0.016 to 0.035 in/rev for drills over 1 ¼ inch diameter. When using carbide tipped drill, feed should be slightly less. Feed also may be determined by the formula: square root of drill diameter (inches) divided by 60 feet: Drill diameter (IN) + 0.002.

b. Lathe/screw-machine.

Point Angle: 118° 1400

Spiral Angle: 0°-28°

Lip Clearance (lip relief): 15° 20°

Speed ft/min up to 1500

Feed inches/revolution 0.004-0.016.

(c) Portable Drills Electric/Air Driven. Due to variables involved no set factors can be given. However, factors given for drill press should be used as a guide. Feed should be adjusted in accordance with speed of motor to prevent tip heating and also to satisfy operation/operator.

**WARNING**

When operating any machinery all safety precautions must be observed, i.e., safety goggles shall be worn when grinding/ drilling. Machinery shall be inspected to insure that safety guards are in place/ for safe operation etc. prior to operating. Work shall be securely clamped to prevent slippage. Consult safety officer when in doubt about the safety of an operation.

3-194. The drilling of thin material normally does not require coolant/lubrication however adequate lubrication is essential to drill life and hole quality when drilling holes of ¼ inch depth or more. Soluble oil emulsions and lard oil mixtures are satisfactory for general drilling. The lubrication should be applied by forced feed spray/flow where possible and the drill should be withdrawn at intervals to be sure lubricant flows to the drill tip (fill holes completely) when drill is withdrawn.

TABLE 3-25. TOOL ANGLES - MILLING.

TOOL ANGLES	HIGH CARBON/HIGH SPEED	CARBIDE
Cutting Angle	48° - 67°	68° - 97°
Top Rake	20° - 35°	10° - 15°
Clearance	3° - 7° Primary	3° - 7° Primary
Helix	7° - 12° Secondary	7° - 12° Secondary
	10° - 50°	10° - 20°
Tooth Spacing	Course - Sufficient for chip Clearance	Approximately 1 tooth per inch of diameter.

TABLE 3-26. SHAPING AND PLANING-SPEEDS AND FEEDS.

METHOD	CUT INCHES	CUTTING SPEED	FEED (INCHES)	OPER	TOOL MATERIAL
Shaping	1/4 Maximum	Maximum speed of RAM	0.008 - 0.031	Rough	High Carbon/ High Speed
Shaping	0.005 - 0.014	Maximum speed of RAM	0.094 - 0.156	Finish	High Carbon/ High Speed
Planing	3/8 Maximum	Maximum speed of Table	0.020 - 0.100	Rough	High Carbon/ High Speed
Planing	0.005 - 0.018	" " " "	0.050 - 0.375	Finish	High Carbon/ High Speed

TABLE 3-27. SHAPING TOOL ANGLES.

	OPERATION		TOOL MATERIAL
	ROUGH	FINISH	HIGH CARBON/HIGH SPEED
Top rake	19°-10°	43° -52°	"
Bottom Clear	7°- 9°	8° -10°	"
Side Rake	30° -40°	50° -60°	"
Side Clear	7° - 9°	0° -0°	"
Cutting Angle	64° -71°	30° -37°	HIGH CARBON/HIGH SPEED



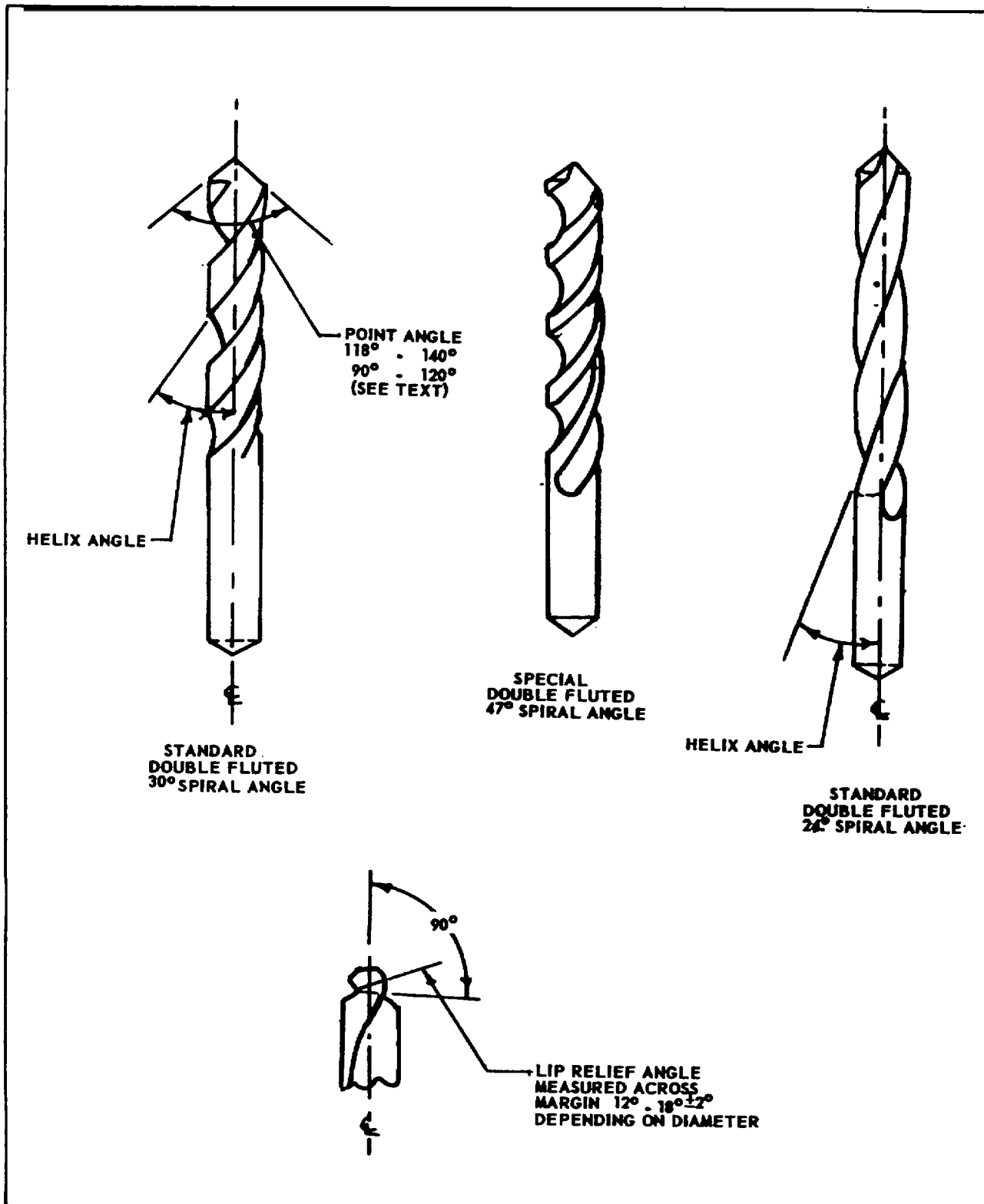


Figure 3-2. Drill Designs and Recommended Cutting Angles.

**TABLE 3-28. THREAD CONSTANT FOR VARIOUS STANDARD THREAD FORMS.**

THREAD FORM	PERCENT OF FULL THREAD DESIRED			
	75%	80%	85%	90%
American Std Course Series C =	0.9743	1.0392	1.1042	1.1691
Whitworth C=	0.9605	1.0245	1.0886	1.1526
British Ass'n Std C=	0.9000	0.9600	1.0200	1.0800
Amer Std 60° Stub C=	0.6525	0.6960	0.7395	0.7830
Amer Std Sq C=	0.7500	0.8000	0.8500	0.9000
Amer Std 10° modified Sq Sq C=	0.7500	0.8000	0.8500	0.9000

**3-195. TAPPING.** The taps used for threading aluminum alloys should be of the spiral fluted type for best results. Straight fluted taps can be used but have a tendency to clog and tear the threads during the tapping operation. Spiral fluted taps for cutting right-handed threads should have a right-hand spiral of about 40° angle with a generous back off taper and highly polished flutes.

**3-196.** Spiral Pointed or "Gun Taps" (straight fluted except they have a short spiral on the starting end) cut aluminum more freely than the other types. With this type tap the major portion of cutting occurs at the spiral end and curls ahead of the tap. The use of the "Gun Tap" is therefore limited to tapping holes which have room for the cuttings ahead of the tool. This spiral pointed tap should not be used for cutting tapered thread or for bottoming taps.

**3-197.** The following procedures and tools are recommended for tapping aluminum alloys:

- a. Cutting Speed: 40 to 130 feet/minute use lower speed for hard alloys and higher speed for soft alloys.
- b. Tap Type Selection: For blind holes and bottoming use spiral fluted; for semi-blind use spiral pointed (gun taps); and for hole through work use spiral pointed (gun taps).
- c. Thread Type: Rounded or flattened (turn coated) thread contour for general use.
- d. Tool Angles: Spiral flute-grind a lead spiral extending one full thread beyond chamfer on straight fluted tap. To make gun tap and spiral flute tap should be 28° to 40°; cutting angle 40° to 45°; top rake 45° to 50°; back rake 4-8°; cutter area (included angles); 2 flute 36° to 72° and 3 flutes 24° to 48°.
- e. Tapping Allowance: Drill diameter for general tapping should be from 0.005 to 0.006 inches per inch larger than standard for the same thread in steel or in accordance with the following.

$$\text{Drill diameter (1.005 X tap diameter)} - \frac{C}{\text{thread per inch}}$$

C = Thread constant for various thread forms and percentages of thread depth required as given in Table 3-28.

- f. Lubrication: For high speed tapping use lard oil/mineral oil and for hand tapping a more viscous lubricant is recommended such as heavy grease/oil, white lead, etc.

### **3-198. FILING.**

**3-199.** Hand files of the single cut type having milled teeth usually give the best results for filing aluminum. The main consideration in file design/ selection for aluminum is to provide ample chip space clearance. The cuttings generated are large and have a tendency to powder, pack and clog between file teeth. To overcome clogging problem chip space is increased, grooves are cut deeper and teeth are cut with generous side and top rake.

**3-200.** For finish filing a long angle millfile (single) (cut) with tooth spacing of 14-24 teeth per inch with side rake angle of 45° to 55° is recommended. In absence of the preferred file the same effect can be obtained using standard mill cut files by adjusting angle of filing incidence to the metal worked. The file is often adjusted until force or motion applied is parallel to the work piece for best results. A good general purpose file is the curved tooth type (often called "vixen") having about ten deeply cut teeth per inch. It can be used for heavy and finish cuts. Lightly double cut files having tooth spacing of 14 20 per inch can be used for light duty rough cutting and finishing when working the harder alloys.

User should be careful not to drag file across work on back stroke as with any filing operation. Files shall be kept clean and free of rust. Clogged files can be cleaned by wire brushing. The use of chalk or talc on file will help prevent clogging.

**3-201.** Machine filing using rotary files (miniature milling cutters having spiralled sharp teeth with smooth deeply cut flutes) are operated at high speed. The rotary files are operated up to 10,000 RPM for small diameter and to 2,000 m2Yimum peripheral feet/min for the larger diameter. The teeth should be coarse (about 14 teeth per inch) with deep polished flute and spiral notched design.

#### **CAUTION**

**Wear goggles or face shield when filing with rotary files to protect eyes.**

**3-202. REAMING.** Generally most of the different type reamers may be used for aluminum, but for best results the spiral fluted reamers are recommended solid, expansion or adjustable. The spiral should be opposite to the rotation to prevent reamer from feeding and hogging into the hole. Holes to be finished by reaming should be drilled sufficiently wider-size to assure positive cutting rather than scraping and swedging (indication of oversize drilled holes and improper feed is the projection of a lip around hole diameter after the reaming operation is accomplished). Finish reamers should be maintained with exceptionally keen cutting edges and highly polished flutes for smooth work.

**3-203.** The following procedures and tools are recommended for reaming aluminum alloys:

a. Tool material: High carbon steel for general use; high speed steel/or carbide tipped for durability and continued production jobs.

b. Tool type: Straight/spiral with 100 spiral flute and solid teeth.

c. Clearance and rake angles: Top rake 5 to 8; clearance angle primary 4° to 7, secondary angle 15° to 20°; cutting angle 84° to 90°.

d. Machine speed and hole reaming allowance: Cutting speeds up to 400 it/min for straightholes, tapered hole should be somewhat slower about 300 350. The desired feed in inches/revolution is 0.003 to 0.010. Hole to be reamed should be undersize 0.005 0.015 inch diameter (reaming allowance).

e. Cutting fluids: Soluble oil/mixture of kerosene and lard oil, light weight machine oil.

**3-204. SAWING.** It should be emphasized that the same principles which govern the shape of cutting tools for aluminum should be applied, as far as practicable to saws for aluminum.

**3-205. Band Saws.** Band saw blades of spring temper steel having a tooth spacing of from 4 to 11 teeth per inch and with amply radiused gullets are recommended for 21lminum alloys. Curved or copying cuts are made with band saws. In any type of work, high blade speeds are desirable with a speed range from 1,500 to 5,000 feet per minute. For heavy sections the saw teeth should be fairly coarse with a slight set and a slight amount of front rake, the restricted chip space requires the use of coarser tooth spacing of about four teeth per inch to avoid clogging and binding. Also the flexible back type of saw with teeth hardened to the bottom of the gullet is used for heavy work. Blades having as many as 14 teeth per inch are satisfactory for thin materials. A good and simple general rule to follow when sawing aluminum is that the spacing of the teeth on band saws for 2hllminum should be as coarse as is consistent with the thickness of the material being sawed. The softer alloys require appreciably more blade set than do the harder, heat treated alloys. Usually an alternate side rake of about 15° and a top rake or "hook" of 10° to 20° proves quite satisfactory. This amount of hook, however, requires a power feed and securely clamped work. For hand feeds the top rake must be reduced considerably to avoid overfeeding.

**3-206.** The band saw blades must be well supported by side rollers and back support both immediately below the saw table and about 2 or 3 inches above the work. The top blade supports are placed slightly in advance of those below the tables and the blade should be allowed to vibrate freely to elimin9te excessive saw breakage. As a general rule, a noisy band saw is cutting more efficiently than the saw that cuts quietly. Quiet smooth cutting band saws usually produce smooth burnished surfaces accompanied by excessive heat and consequently decreased blade life.

**3-207. Hack Saws.** Hack saw blades of the wavy-set type are well suited for cutting aluminum by hand. The wavy set type of blade having 5 to 15 teeth per inch has sufficient chip space to avoid clogging and binding on aluminum alloys. For extremely fine work a jewelers blade may be used.

**3-208.** Special routing machines are available which cut varied profiles from aluminum sheet or plate rapidly and efficiently.

**3-209.** Lubricants and coolants. Power hacksaws and hand saws require a cutting lubricant for most operations involving thick sections. Soluble oil cutting compounds and neutral mineral-base lubricating oil applied to the sides of the blade aid in minimizing friction and gullet clogging. Light applications of heavy grease or paraffin wax will provide ample lubrication for some work. A wide selection of lubricants exists, ranging from tallow or grease stick to kerosene-thinned mineral base lubricating oil. Stick type lubricants should be applied very frequently.

Experience has revealed in most cases it is more convenient and adaptable to use the fluid type lubricant applied freely through a recycling system directly to the blade and work stock.

**3-210. GRINDING.** The grinding characteristics of the various aluminum alloys vary in many instances. The harder free-cutting aluminum alloys may be ground satisfactorily with free cutting commercial silicon carbide grinding wheels, such as crystalon, carborundum and natalon. Rough grinding operations are usually performed by use of resin bonded wheels of medium hardeners and grit sizes of 24 to 30. Also the aluminum abrasives from No. 14 to No. 36 have been found to be satisfactory for rough grindings.

**3-211.** Common alloys, particularly in their softer tempers have a tendency to clog the wheels and do not finish to as bright and smooth a surface as the harder materials.

**3-212.** Caution should be taken in selecting the proper grade of each commercial make of wheel. Once the grinding wheel has been selected there are three variables that affect the quality of a finish; these are the wheel speed, work speed and grinding compound. Experienced operators have proven that their own good judgment is a determining factor as to the correct wheel and work speeds, however, wheel speeds of about 6,000 feet per minute have given good results.

**3-213.** For finish work, a soft silicon carbide wheel of 30 to 40 grit in a vitrified bond have proven to be very satisfactory. A grinding compound of soluble cutting oil and water works well. However, the fine grindings of aluminum must be strained from the compound before reusing in order to prevent deep scratches on the finished surface.

**3-214.** Special care should be exercised when grinding castings and wrought alloy products that have been heat treated, since their greater resistance to cutting or grinding generates a considerable amount of heat which may cause warping and damage to the material.

**3-215. Lubricants and Coolants.** Generous applications of stick grease are recommended to prevent clogging of the grinding wheels during rough grinding, while copious quantities of a low viscosity coolant type grinding compound are essential and recommended for finish grinding. Soluble oil emulsions of the proportions of 30 or 40 to 1 are most suitable.

**3-216. POLISHING.** Polishing or finishing aluminum and most of its alloys, by the application of proper machining procedures, gives it a smooth lustrous finish. Aluminum and its alloys are polished in the same manner as other metals, but a lower wheel-to-metal pressure is used for aluminum.

**3-217.** Polishing is the act of removing marks, scratches or abrasion on the metal resulting from previous handling and operations; it must be understood that a more gentle cutting action or finer abrasives are used for polishing aluminum than used for steel. The various operations covered under the polishing category include roughing greasing or oiling, buffing and coloring. These operations are briefly described in the following paragraph.

**3-218. ROUGHING.** This is a term used to describe the preliminary finishing operation or process, used to prepare aluminum surfaces having deep scratches gouges or unusually rough surfaces, for subsequent polishing procedures. Roughing is not required on smooth undented or unscratched surfaces. The preliminary finishing or roughing process usually employs a flexible aluminum oxide paper disc, a semi flexible bonded muslin or canvass wheel, faced with suitable abrasives. Usually 50 100 grit abrasives are for this process and are set in an adhesive in accordance with standard practice. The peripheral speed of these discs runs around 6,000 feet per minute; faster wheel speeds would cause heating or ridging of the soft metal surface. Heating is also reduced by small applications of tallow or a tallow oil mixture.

**3-219. GREASING OR OILING.** This is a refined or gentle roughing procedure for finishing aluminum surfaces. Application is visually employed by a soft wheel faced with 100 to 200 grit aluminum oxide emery, plus a light coat of tallow or beeswax lubricant to prevent excessive heating. Here again, peripheral speeds of about 6,000 FPM are used.

**3-220.** Greasing or oiling is a necessary operation in finishing coatings and other fabricated work which has been marred by previous operations. Excess aluminum pick-up on the wheels as results from overheating will cause deep scratches in the metal.

**3-221. BUFFING.** This is a term used to describe a finishing procedure employed to obtain a smooth high luster on an aluminum surface. This high luster finish is obtained by use of a fine abrasive, such as tripole powder mired with a grease binder, which is applied to the face of the wheel. These wheels usually consist of muslin discs sewed together, turned at a peripheral speed of 7,000 FPM.

**3-222.** Many factors, such as, the thread count of the buff, the pressure applied to the buff against the work, the buffing compound used, the speed of the buff or wheel and the skill and experience of the operator must be considered in obtaining a satisfactory and quality type finish.

**3-223. HARDNESS TESTING.**

**3-224.** Hardness is the resistance of a metal to deformation by scratching penetration or indentation, and is usually a good indication of strength. Metal hardness can be measured accurately by the Brinell, Rockwell or Vickers Process.

**3-225. BRINELL HARDNESS.** The Brinell technique is usually used to obtain the hardness of aluminum and aluminum alloys. This hardness value is obtained by applying a load through a ball indenter and measuring the permanent impression in the material. To obtain the hardness value of a material, divide the applied load in kilograms by the spherical area of the impression in square millimeters. Hardness value of aluminum alloy is tested by applying a load of 500 kilograms to a ball ten millimeters in diameter for 30 seconds.

**3-226. NON-DESTRUCTIVE TESTING/INSPECTION.**

**3-227.** Aluminum and aluminum alloys are susceptible to stress risers resulting from notching, nicking or scratching. A very close visual inspection is required of all raw material prior to any forming or machining operations. Before any fabrication commences it is necessary that all scratches, nicks and notches be removed by sanding, polishing and filing.

**3-228 thru 3-238.** Deleted.

**3-239. ANODIZING PROCESS FOR INSPECTION OF ALUMINUM ALLOY PARTS** . Parts for which anodic coating is applicable in accordance with MIL-A-8625 Type I, can be anodized for the inspection of defects as cited in Specification MIL-I-8474.

**3-240.** The parts are examined visually for indications of cracks, forging laps or other defects. Parts inspected by this method shall be limited to sheet stock and surface defect of forgings. This method of inspection is not acceptable for inspection of parts subject to internal defects, i.e. inclusion in castings and forging or any part subject to internal stress, etc.

**3-241.** Defects are indicated by darkening of cracked or void areas after the anodic treatment. Insufficient rinsing in cold water after anodizing produces stains which may be confused with defects. In case of doubt strip film from part and reanodize. If the indications do not reappear the defects shall be considered absent and part should not be rejected for that reason.

#### **NOTE**

**For additional general information on inspection and testing see Section VI of this technical order.**

**3-242. ALUMINUM ALLOY EFFECTS ON SCRATCHES ON CLAD ALUMINUM ALLOY** . The purpose of the following information on the effects of scratches on aluminum alloys is to assist in eliminating controversy in depots and field inspection, regarding serviceability of aluminum alloy, sheet, skin and aircraft structural parts which have been scratched, abraded or discolored from the stand point of corrosion resistance and fatigue strength.

**3-243.** In some instances, serviceable aluminum alloy parts and sheets, have been disposed of due to lack of knowledge by inspection personnel as to the effect of various depth scratches on the strength and corrosion resistance of the clad alloy. Also, attempts have been made to remove scratches from aircraft skin by sanding, buffing, or polishing resulting in removal of much of the cladding material and causing decrease in strength and corrosion resistance.

#### **3-244. ALLOWABLE DEFECTS.**

a. The following surface defects are those which do not affect the strength or corrosion resistance.

(1) Scratches which penetrate the surface layer of clad aluminum alloy sheets or parts but do not extend beneath the cladding are not serious or detrimental.

(2) The presence of small corroded areas will not materially affect the strength of clad unless the corroded pitted area extends through the cladding down to or into the bare metal. Clean corroded areas thoroughly by authorized methods (See Par 3-253).

(3) Stains are not grounds for rejection since they affect neither the strength nor the corrosion resistance.

#### **CAUTION**

**No attempt will be made to remove scratches or other surface defects by sanding or buffing since the protective layer of cladding will be removed by such operations.**

**3-245. HARMFUL SCRATCHES.** Scratches which extend through the cladding and penetrate the core material act as notches and create stress concentrations which will cause fatigue failure if the part is highly stressed or subjected to repeated small stress reversals. However, sheets so scratched may be utilized for non-stressed applications.

**3-246. INSPECTION.** Assemblies fabricated from clad aluminum-alloy sheets will not be rejected by inspection personnel, unless the defect is of sufficient depth to adversely affect the mechanical properties or cover sufficient area to impair the corrosion resistance of the assembly. Scratches or abrasions which penetrate the cladding will not affect corrosion resistance. Scratches resulting from the normal handling and processing of clad aluminum-alloy sheet rarely extend through the cladding and penetrate the core.

**3-247. TEST FOR DEPTH OF SCRATCHES.** Since it is very difficult to measure the depth of a scratch on a sheet without cross sectioning the sheet, it has been found convenient (on clad material) to use a "spot" test to determine whether or not a scratch extends through the cladding.

**3-248.** On alloys except 7075 and 7178 the "spot" test is made by placing a drop of caustic solution (10% by weight of sodium hydroxide, NaOH, in water) on a portion of the scratch, and allowing it to react for 5 minutes. The caustic solution will then be rinsed off the sheet with water, and the spot allowed to dry. If a black residue remains in the base of the scratch at the spot tested, it indicates that the scratch extends to the core. If no black color is visible and only a white residue remains in the base of the scratch, it indicates that the scratch does not penetrate through the cladding.



For alloys 7075 and 7178 a drop of 10% cadmium chloride solution will produce a dark discoloration within two minutes if the scratch penetrates the clad. The cadmium chloride applied as above will not cause 2024 to discolor within two minutes.

**3-249.** When making the "spot" test to determine whether a scratch extends to the core, it is advisable for comparison purposes to spot test an adjacent area in which there are no scratches. It is then easier to determine whether the residue which remains is black or white.

**3-250.** Before making the "spot" test, the sheet area will be cleaned and degreased with solvent Federal Specification P-D-680, Type I, or other suitable solvent, so that the caustic solution will react properly.

**3-251.** Caution will be exercised to make sure that all of the caustic solution is removed from the sheet by thorough rinsing, since the caustic solution is very corrosive to aluminum and aluminum alloys. Care will be taken not to use excessive amounts of the caustic solution for the same reason and it is preferable that only one drop be used for each test. The caustic solution will be prepared fresh for each series of tests to be made.

**3-252. DISPOSITION OF SCRATCHED SHEETS/ PARTS.**

a. All scratched clad aluminum-alloy sheets will be utilized to the fullest extent. Serviceable portions of damaged sheets will be used in the manufacture of smaller parts and assemblies. Only that portion of sheet that is scratched and otherwise damaged beyond serviceability will be administratively condemned.

b. Parts (air weapon) shall be closely inspected as cited and if they do not meet specified requirement shall be condemned and replaced as directed.

**3-253. CLEANING OF ALUMINUM ALLOY SHEET (STOCK).**

**3-254.** Solvent Cleaning. Stubborn or exceptionally oily sheets may be cleaned by using solvent, Federal Specification P-D-680, Type I, before cleaning with alkali solution. The cleaning will be accomplished by brushing, soaking, scrubbing and wiping. Material or equipment that would scratch or abrade the surface shall not be used. Also material shall not be stored after solvent cleaning and prior to alkaline cleaning, unless solvent is completely removed from the surfaces of the metal.

**3-255.** Alkali Cleaning Solution. Composition of solution is 4 to 6 oz of cleaner Specification MIL-C5543 to one gallon of water. The material is cleaned by immersing in the solution (as prepared by instructions cited in paragraph 3-289) for 4-6 minutes, thoroughly rinsing in water (fresh tap) and then completely drying. Never pile/store material while damp, wet or moist. Refer to T.O. 00-85A23-1 for packaging and storage.

**CAUTION**

**Do not use strong alkali solution because it will etch the aluminum.**

**3-256.** Preparation. Use water heated to a temperature of 170°F (77°C). Add not more than one pound of cleaner at a time. Prepare the solution in the following manner:

- a. Fill the tank ½ to 2/3 full of water.
- b. Carefully dissolve the alkaline cleaner.
- c. Add water to operating level and stir thoroughly with a wooden paddle or other means.

**3-257.** Maintain solution in the following manner:

- a. Add tap water to balance-up solution loss.
- b. Make addition as required to maintain the active alkali concentration between 4 and 6 oz alkaline cleaner for each gallon of water added and stir thoroughly.
- c. Prepare a new solution when contamination impairs the cleaning ability of the solution.
- d. Clean the tank thoroughly before preparing a new solution.

**3-258.** Corrosion removal from Aluminum Alloy Sheets. Corrosion is removed by immersing the sheet in the following acid cleaning solution:

**CAUTION**

**When using acid solution wear approved clothing, acid resisting gloves, aprons/ coveralls, face shields or respirator. If solution is splashed into eyes, flush thoroughly with water immediately, and then report to dispensary. For special instructions, contact local safety officer.**

- a. Nitric-Hydrofluoric Acid Cleaning. The solution shall consist of 1 gallon technical nitric acid (58-62% HNO<sub>3</sub>) (39.5° Be).



½ pint technical hydrofluoric acid (48°HF) (1.15 Sp).

9 gallons of water.

b. Parts shall be immersed for 3 to 5 minutes in cold acid (50° 105°F).

**3-259.** After removing from the acid, the parts shall be washed in fresh hot or cold running water for a sufficient length of time to thoroughly remove the acid. Diluted solution of sodium dichromate (Na<sub>2</sub> Cr<sub>2</sub> O<sub>7</sub>) 12 to 14 ounces per gallon of water, shall be added to the rinse water as a corrosion inhibitor. The rinsing time depends upon the freshness of the solution, size of the part and the amount of solution circulated. One half hour or less should be sufficient. Parts shall then be completely dried by blasting with compressed air or other approved method.

#### **NOTE**

**The sheet will stain when rinsed with sodium dichromate. The stronger the solution the darker the stain. A light detectable stain is desired on corroded areas. If the stain is dark reduce the amount of sodium dichromate added to rinse water.**

**3-260.** Corrosion Removal and Treatment of Aluminum Sheets When Immersion Is Not Practical.

**3-261.** The surface shall be cleaned with water base cleaner, Specification MIL-C-25769, Type I.

a. Heavily soiled areas. Dissolve the contents of two 5-pound packages in 10 gallons of water. Stir with a wooden paddle until fully dissolved.

b. Lightly soiled areas. Dissolve four 5-pound packages in 50 gallons of water (a 55 gallon drums suitable for this purpose). Agitate thoroughly with wooden paddle to insure proper mixture.

c. Application. Apply the solution by spraying, or with a mop, sponge, or brush. Allow to remain on the surface for several minutes while agitating with a brush. Rinse thoroughly with a spray or stream of water. Do not allow solution to dry before rinsing as less effective cleaning will result.

**3-262.** Corrosion Removal. To remove corrosion products use a metal conditioner and brightener, Specification MIL-C-38334.

#### **CAUTION**

**Metal conditioner and brightener is for use only on aluminum alloys, and it shall not be used just for the sake of improving the appearance of material. Material in storage shall not be treated with this material more than one time.**

#### **WARNING**

**When using acid solution wear approved clothing, acid resistant gloves, aprons/ coveralls, face shields or respirator. If solution is splashed into eyes, flush thoroughly with water immediately, and then report to dispensary. For special instructions contact local safety officer.**

a. Prepare the brightening solution by mixing Specification MIL-C-38334 compound with an equal amount of water, in a rubber pail.

b. Apply enough diluted brightener to completely cover the area being treated with a non-metallic bristle brush.

c. Agitate the brightener by scrubbing with a non-metallic bristle brush. Depending on the ambient temperature and amount of corrosion deposits pre sent, allow approximately 5 to 10 minutes from application of brightener before rinsing. When using brightener at high ambient temperature (above 80°F) leave brightener on for shorter periods of time. Do not leave brightener on the surface longer than necessary to dissolve the corrosion.

d. Rinse the brightener from the surface (using approximately 50 gallons of water per minute. Insure that all traces of brightener has been removed (shown by no foaming or bubbles while rinsing).

**3-263.** Chromate Conversion Coating Specification MIL-C-5541, for aluminum alloys. Aluminum alloys which are treated with Specification MIL-C-38334 shall be treated with Specification MIL-C-5541. Most solutions conforming to Specification MIL-C-5541 leave a stain. A clear Specification MIL-C-5541 coating is available (reference QPL 5541) and should be used when a bright metal finish is desired.

**WARNING**

Conversion coating is a toxic chemical and requires use of rubber gloves by personnel during its application. If acid, accidentally contacts the skin or eyes, flush immediately with plenty of clear water. Consult a physician if eyes are affected or if skin is burned.

**WARNING**

Do not permit Specification MIL-C-5541 material to contact paint thinner, acetone or other combustible materials. Fire may result.

1. Mix the solution in a stainless steel, rubber or plastic container; not in lead, copper alloy or glass.
2. Mix in accordance with manufacturers instructions.
3. Apply the conversion coating (light) by using a fiber bristle brush or a clean, soft cloth. Keep the surface wet with the solution until a coating is formed which may take from 1 to 5minutes depending on the surface condition of the metal.

**NOTE**

Do not permit excess conversion coating to dry on the metal surface because the residue is difficult to flush off with water.

4. Rinse with clear water, or sponge the area with a clean, moist cloth, frequently rinsing the cloth in clear water. Thorough rinsing is required.
5. Allow the surface to air dry. To speed drying the surface may be blown dry with warm clean air (140F maximum).

**CAUTION**

Avoid brushing or rubbing the newly applied chemical conversion coating, since it is soft and can be easily rubbed off the surface before completely drying.

**WARNING**

Any absorbent material used in applying or wiping up MIL-C-5541 material shall be rinsed in water before discarding. They are extreme fire hazards if allowed to dry otherwise.

**NOTE**

A light Oust visible to the naked eye) evenly dispersed conversion coating is all that is required. It is recommended that a test panel be prepared and subjected to complete cleaning/treating procedure before applying material to a sheet. The test panel shall be used to determine the dwell time of MIL-C-5541 material. When clear material is being used, no control of discoloration is necessary.

**NOTE**

After the procedures cited in paragraphs 3-252 through 3-263 have been complied with, an AF Form 50A will be attached to each sheet with a statement that, "This material has been cleaned and treated for corrosion IAW T.O. 1-1A-9 Section III, date..." If original markings are removed as a result of the cleaning and treatment process, the material shall be remarked (staggered) at each end and in the middle with the Specification, size/thickness, temper and type or grade. The marking may be applied with Black paint Specification TT-L-50, MIL-B-7729 or "Magic Marker" manufactured by Speeddry Products Inc., Richmond Hill, N.Y. or "Equal". A felt tip pen may also be used.

**3-264.** For Packaging, Packing, and Storage of Aluminum Alloy Sheets and Plates Refer to T.O. 00-85A-23-1.

**3-265. ANODIC COATINGS FOR ALUMINUM .** Anodizing is the anodic process of treating aluminum alloys; a thin film of artificially produced oxide is formed on the surface of the metal by electrochemical reaction. Military Specification MIL-A-8625 lists the requirements of aluminum anodizing, and Technical Order 42C2-1-7 gives the anodizing process.

**3-266.** Military Specification MIL-C-5541 lists the requirements for corrosion protection and paint base of aluminum by the use of chemical film. These chemical films are substitutes that may be used in lieu of anodic films, and may be applied by spray, brush, or immersion as specified by QPL-5541. The anodizing method is preferable to chemical films on aluminum parts where facilities are available. For process procedures applying to chemical films, refer to Technical Orders 1-1-8 and 1-1-2.

**3-59/(3-60 Blank)**

## SECTION IV

## MAGNESIUM ALLOYS

**4-1. CLASSIFICATION.**

**4-2.** Magnesium alloys are produced and used in many shapes and forms, i.e., castings, extruded bars, rods, tubing, sheets and plate and forgings. They are suitable for varied stress and non-stress aerospace applications. Their inherent strength, lightweight, shock and vibration resistance are factors which make their use advantageous. The weight for an equal volume of magnesium is approximately two-thirds of that for aluminum and one-fifth of that for steel.

**4-3.** The current system used to identify magnesium alloys, is a two letter, two or three digit number designation in that order. The letters designate the major alloying elements, (arranged in decreasing percentage order, or in alphabetical order if the elements are of equal amounts), followed by the respective digital percentages of these elements. The percentage is rounded off to the nearest whole number or if a tolerance range of the alloy is specified, the mean of the range (rounded off to nearest whole number) is used. A suffix letter following the percentage digits, denotes the latest qualified revision of the alloy. For example: Alloy Designation AZ92A would consist of 9% (mean value) aluminum and 2% (mean value) zinc as the major alloying elements. The suffix 'A' indicates this is the first qualified alloy of this type. One exception to the use of the suffix letter is that an 'X' denotes that impurity content is controlled to a low limit. Some of the letters used to designate various alloying elements are:

A	Aluminum,	E	Rare Earth,
H	Thorium,	K	Zirconium,
M	Manganese,	Z	Zinc.

**4-4. DEFINITIONS.**

**4-5. HARDNESS.** Hardness is the resistance of a metal to plastic deformation from penetration, indentation, or scratching. The degree of hardness is usually a good indication of the metals strength. The hardness of a metal can be accurately measured using the Brinell or Rockwell process of testing. Tables 4-4, 4-5 and 4-6 list the nominal hardness of various magnesium alloys. Brinell hardness testing is explained in Section VIII of this manual.

**4-6. TENSILE STRENGTH.** The useful tensile strength of a metal is the maximum stress it can sustain in tension or compression without permanent deformation. The yield strength is that point of stress, measured in pounds per square inch, at which permanent deformation results from material failure. The data in Tables 4-4, 4-5 and 4-6 lists the nominal yield strengths of various alloys. The yield point in magnesium is not reached abruptly, but rather a gradual yielding when the metal is stressed above the proportional limit. Tensile and yield strengths decrease at elevated temperatures.

**4-7. TEMPER** is the condition produced in the alloy by mechanically or thermally treating it to alter its mechanical properties. Mechanical includes cold rolling, cold working, etc.; thermal includes annealing, solution and precipitation heat treat and stabilization treating. See paragraph 4-12 for temper designations.

**4-8. SHEAR STRENGTH** is the maximum amount (in pounds per square inch) in cross sectional stress that a material will sustain before permanent deformation or rupture occurs.

**4-9. ELONGATION** is the linear stretch of a material during tensile loading measured before and after rupture. In magnesium it is the increase in distance which occurs when stretch is applied between two gage marks placed 2 inches apart on the test specimen. After rupture the two pieces are fitted together and remeasured. The elongation is the percentile difference of the amount of stretch in ratio to the original 2 inches.

**4-10. PHYSICAL PROPERTIES.** Magnesium, in its pure state, has a specific gravity of 1.74, weighing .063 pounds per cubic inch. Similar data for magnesium alloys are included in Table 4-6 as well as other physical property information.

**4-11. CHEMICAL PROPERTIES.** Chemically pure magnesium is resistant to attack by alkalis, chromic and hydrofluoric acids and many organic chemicals including hydrocarbons, aldehydes, alcohols, phenols, amines, esters and most oils. It is susceptible to attack by salts and by galvanic corrosion from contact with dissimilar metals and other materials. Adequate protection of the metal against unfavorable conditions can be maintained generally, by using proper surface finish (See paragraph 4-93) and assembly protection. The chemical property constituents of the various alloys are listed in Table 4-3.

**4-12. TEMPER DESIGNATION SYSTEM.** The hyphenated suffix symbol which follows an alloy designation denotes the condition of temper, (heat treat or strain hardening), to which the alloy has been processed. These symbols and their meanings are listed below: (Heat treating itself is discussed in subsequent paragraphs of this section of the manual).

-AC	As-Cast
-F	As-fabricated
-O	Annealed
-W	Solution heat treated - unstable temper
-T	Treated to produce stable tempers other than for -O
-T2	Annealed (cast products only)
-T3	Solution heat treated and then cold worked
-T4	Solution heat treated
-T5	Artificially aged only
-T6	Solution heat treated and then artificially aged

- T7 Solution heat treated and stabilized
- TB Solution heat treated, cold worked and then artificially aged
- T9 Solution heat treated, artificially aged and then cold worked
- T10 Artificially aged and then cold worked
- H1 Strain hardened only
- H2 Strain hardened and partially annealed
- H3 Strain hardened and stabilized

Added suffix digits 2, 4, 6, B, to the H1, H2, H3 symbols indicate the degree of strain hardening ,i.e., 2=1/4 hard, 4=1/2 hard, 6r 3/4 hard, and 8= full hard.

#### **4-13. SAFETY REQUIREMENTS FOR HANDLING AND FABRICATION OF MAGNESIUM ALLOYS.**

**4-14.** There are two special major areas of safety precautions to observe in processing of magnesium alloys other than general shop safety practices. One is the fact some alloys contain thorium, a radioactive element (e.g., HK31A, HM21A, HM31A) and the other is the low melting point/rapid oxidation (fire hazard) characteristics of the metal. Where the application of heat is to be made to a thorium alloy, both of these areas must be considered.

#### **WARNING**

**Magnesium thorium alloys shall be handled, stored and disposed of in accordance with T.O. 00-110N-4.**

**4-15. MAGNESIUM-THORIUM ALLOYS (HK31, HM21, HM31, HZ32, ZH42, ZH62)** are mildly radioactive but are within the safe limits set by the Atomic Energy Commission (AEC) and represent no hazard to personnel under normal conditions. A standard of 0.1 milligram per cubic meter (mg/m<sup>3</sup>) of thorium in air is a safe limit for continuous atmospheric exposure and is readily met in processing magnesium alloys containing up to 10% thorium. For Example: Stirring alloy melt of 5% thorium content resulted in 0.002 mg/m<sup>3</sup> atmospheric contamination and grinding air alloy of 3% thorium content gave thorium contamination in the breathing zone ranging from 0.008 to 0.035 mg/m<sup>3</sup>. Only long exposure to fine dust or fumes need cause concern as to radioactive toxicity of magnesium thorium. Normal dust control precautions, followed to avoid fire hazards, can be expected to control any health hazards that might result from fine dust in grinding the low thorium content alloys. In welding these alloys without local exhaust, concentrations of thorium above the tentative limit of 0.1 mg/m<sup>3</sup> of air were found in the breathing zone. Use of local exhaust reduced thorium concentrations to well within acceptable limits. If ventilation is such that the visible fumes flow away from the welder, it is adequate, providing such fumes are not permitted to accumulate in the immediate vicinity. An alternate practice involves use of a ventilated welder's hood, if there is not sufficient room ventilation to control contamination of the general atmosphere. Thorium containing scrap and wet grinding sludge may be disposed of by burning providing an ABC amendment is secured for the basic AEC license. If burned, the ashes which will then contain the thorium, must be disposed of in accordance with AEC Standards for Protection Against Radiation 10 CFR Part 20. As an alternative the ashes or scrap may be turned over to an AEC licensed scrap dealer, through applicable disposal procedures. See T.O. 00-110N-4.

**4-16.** For indoor storage of thorium alloy sheets and plates, the size of stacks should be limited to 1000 cubic feet with an aisle width not less than one-half the stack's height. Such storage is within the normal recommendations for fire safety.

**4-17.** Radiation surveys have shown that exposure of workers handling the referenced thorium alloys is well within the safe limits set by the AEC. Assuming hand contact, the body one foot away from the alloy for an entire 40 hour work week, the exposure would be 168 millirems (mr) to the hands and 72 mr to the whole body. These are maximum values which probably would not be approached in actual practice. The corresponding AEC permissible safe limits are 1500 mr/week for the hands and 300 mr/week for the whole body.

**4-18.** Despite the relative safety present in the handling, storage and processing of thorium containing alloys, it is mandatory that all such actions be made according to the requirements and restrictions of the 00-100 series technical orders, as applicable, and ABC regulations. As previously stated, the normal precautions taken in the shop processing of magnesium will suffice for safe handling of thorium alloys. These precautions are noted in the following paragraphs on safety precautions.

#### **4-19. SAFETY PRECAUTIONS FOR ALL ALLOYS (INCLUDING FIRE HAZARDS).**

**4-20.** Since magnesium will ignite and burn fiercely when heated to a point near its melting temperature, certain precautions should be taken during working of it.

**4-21.** Machining Safety Rules. During machining operations, observance of the following rules will control any potential fire hazard:

- a. Keep all cutting tools sharp and ground with adequate relief and clearance angles.
- b. Use heavy feeds to produce thick chips.

TABLE 4-1. CROSS-REFERENCE, ALLOY DESIGNATION TO SPECIFICATIONS.

<u>ALLOY</u>	<u>FED SPEC</u>	<u>MIL SPEC</u>	<u>HNBK</u>	<u>SAE AMS</u>	<u>ASTM (ASME)</u>	<u>USE</u>
AM100A	QQ-M-56 QQ-M-55	-- --	502	4483	B80 B199	Sand Casting Permanent Mold Casting
AZ31B	QQ-M-31 QQ-M-40 WW-T-825 QQ-M-44 QQ-M-44 QQ-M-44	-- -- -- -- -- --	52 510 52 510 510 510	4375 4376 4377	B107 B91 B217 B90 B90 B90	Extruded Bars, Rods, Shapes Forgings Extruded Tubes Sheet & Plate Sheet & Plate Sheet & Plate
AZ31C	-----	MIL-R-6944 -- -- --	-- -- --	-- -- --	B107 B217 B90	Extruded Bars, Rods, Shapes Extruded Tubes Sheet & Plate
AZ61A	QQ-M-31 QQ-M-40 WW-T-825	-- -- --	520 530 520	4350 4358 4350	B107 B91 B217 B260	Extruded Bars, Rods, Shapes Forgings Extruded Tubes Welding Rod
AZ63A	QQ-M-56 QQ-M-56 QQ-M-55 -----	MIL-C-19163 MIL-C-19163 MIL-C-19163 MIL-R-6944	50 50 -- --	4420, 4422 4424	B80 B80 B199 B260	Sand Castings Sand Castings Permanent Mold Castings Welding Rod
AZ80A	QQ-M-31 QQ-M-40	--- ---	523 532	-- 4360	B107 B91	Extruded Bars, Rods, Shapes Forgings
AZ81A	QQ-M-56 QQ-M-55	--- ---	505 505	-- --	B80 B199	Sand Castings Permanent Mold Castings
AZ91A AZ91B AZ91C	QQ-M-55 QQ-M-38 QQ-M-38 QQ-M-56 QQ-M-55	--- --- --- --- ---	-- 501 501 504 --	-- 4490 -- 4437 --	B199 B94 B94 B80 B199	Permanent Mold Castings Die Castings Die Castings Sand Castings Permanent Mold Castings
AZ92A	QQ-M-56 QQ-M-55 -----	MIL-C-19163 MIL-C-19163 MIL-R-6944	500 503 --	4434 4484 --	B80 B199 B260	Sand Castings Permanent Mold Castings Welding Rod

TABLE 4-1. CROSS-REFERENCE, ALLOY DESIGNATION TO SPECIFICATIONS (CONT'D).

<u>ALLOY</u>	<u>FED SPEC</u>	<u>MIL SPEC</u>	<u>HNBK</u>	<u>SAE AMS</u>	<u>ASTM (ASME)</u>	<u>USE</u>
EK30A	QQ-M-56	---	--	--	B80	Sand Castings
EK41A	QQ-M-56	---	--	4440, 4441	B80	Sand Castings
	QQ-M-55	---	--	--	B199	Permanent Mold Castings
EZ33A	QQ-M-56	---	506	4442	B80	Sand Castings
	QQ-M-55	---	506	--	B199	Permanent Mold Castings
	-----	MIL-R- 6944	--	--	B260	Welding Rod
HK31A*	QQ-M-56	---	507	4445	B80	Sand Castings
	-----	MIL-M- 26075	507	4384	B90	Sheet & Plate
	*	-----	MIL-M- 26075	4385		
	-----	MIL-R- 6944	--	--	B260	Welding Rod
HM21A*	QQ-M-40	---	--	--	--	Forgings
	-----	MIL-M- 8917	--	4390	B90	Sheet & Plate
HM31A*	-----	MIL-H- 8916	--	4388	B107	Extruded Bars, Rods, Shapes
	-----	MIL-H- 8916	--	4389	--	Extruded Bars, Rods, Shapes
HZ32A*	QQ-M-56	---	--	4447	B80	Sand Castings
KIA	QQ-M-56	MIL-M- 45207	--	--	B80	Sand Castings
MIA	QQ-M-31	---	522	--	B107	Extruded Bars, Rods, Shapes
	QQ-M-40	---	533	--	--	Forgings
	WW-T-825	---	522	--	B217	Extruded Tubes
	QQ-M-44	---	51	--	B90	Sheet & Plate
	-----	MIL-R- 6944	--	--	B260	Welding Rod
QE22A	QQ-M-56	---	--	--	--	Sand Castings
	QQ-M-55	---	--	--	--	Permanent Mold Castings
TA54A	QQ-M-40	---	53	--	B91	Forgings
ZE10A	-----	---	534	--	B90	Sheet & Plate
ZE41A	QQ-M-56	---	--	--	--	Sand Castings



TABLE 4-1. CROSS-REFERENCE, ALLOY DESIGNATION TO SPECIFICATIONS (CONT'D).

<u>ALLOY</u>	<u>FED SPEC</u>	<u>MIL SPEC</u>	<u>HNBK</u>	<u>SAE AMS</u>	<u>ASTM (ASME)</u>	<u>USE</u>
ZH42*	- - - -	- - - -	- -	- -	- -	Sand Castings
ZH62*	QQ-M-56	- - -	508	4438	B80	Sand Castings
ZK21A	- - - -	MIL-M- 46039	- -	4387	- -	Extrusions
ZK51A	QQ-M-56	- - -	509	4443	B80	Sand Castings
ZK60A	QQ-M-31	- - -	524	4352	B107	Extruded Bars, Rods, Shapes
	QQ-M-40	- - -	- -	4362	B91	Forgings
	WW-T-825	- - -	524	4352	B217	Extruded Tubes
ZK60B	- - - -	MIL-M- 26696	- -	- -	- -	Extruded Bars, Rods, Shapes
ZK61A	QQ-M-56	- - -	513	4444	B80	Sand Castings

\*These alloys contain radioactive thorium element. See paragraph 4-15 for precautionary instructions.

#### MISC SPECIFICATION

MIL-M-3171 Magnesium alloy, processes for corrosion protection of MIL-M-6857 Magnesium alloy castings, heat treatment of.

TABLE 4-2. ALLOY DESIGNATION CROSS-REFERENCE.

<u>NEW DESIGNATOR</u>	<u>FORMER DOW REVERE</u>	<u>FORMER AMERICAN MAGNESIUM</u>	<u>FORMER * MILITARY</u>	<u>NEW FEDERAL</u>	<u>USE</u>
AZ63A	H	AM265	- - - -	QQ-M-56	Castings, Sand
MIA	M	AM3S	AN-M-26	QQ-M-31	Extruded Bars, Rods, Shapes
MIB	M	AM403	AN-M-30	QQ-M-56	Castings, Sand
MIA	M	AM3S	AN-T-73	WW-T-825	Extruded Tube
MIA	M	AM3S	AN-M-22	QQ-M-40	Forgings
MIA	M	AM3S	AN-M-30	QQ-M-44	Sheet
AZ92A	C	AM260	- - - -	QQ-M-56	Castings, Sand
AZ92A	C	AM260	- - - -	QQ-M-55	Castings, Perm Mold
AM100A	G	AM240	- - - -	QQ-M-55	Castings, Perm Mold
AZ91A	R	AM263	AN-M-16	QQ-M-38	Castings, Die
AZ31B	FS-1	AM52S	AN-M-27	QQ-M-31	Extruded Bar, Rod, Shape
AZ31B	FS-1	AM52S	AN-T-72	WW-T-825	Extruded Tube
AZ31B	FS-1	AM52S	- - - -	- - - -	Forgings
AZ31B	FS-1	AM52S	AN-M-29	QQ-M-44	Sheet
AZ61A	J-1	AM57S	AN-M-24	QQ-M-31	Extruded Bar, Rod, Shape
AZ61A	J-1	AM57S	AN-T-71	WW-T-825	Extruded Tubes
AZ61A	J-1	AM57S	AN-M-20	QQ-M-40	Forgings
AZ80A	O-1	AM58S	AN-M-25	QQ-M-31	Extruded Bar, Rod, Shape
AZ80A	O-1	AM58S	AN-M-21	QQ-M-40	Forgings
ZK60A	- -	AMA76S	- - - -	QQ-M-31	Extruded Bar, Rod, Shape
EZ11A	- -	AMA130	- - - -	- - - -	Castings, Perm Mold
EZ33A	- -	AMA131	- - - -	- - - -	Castings, Perm Mold
TA54A	- -	AM65S	- - - -	QQ-M-40	Forgings

NOTES: \*These "AN" Specifications have been superseded by the listed Federal Specifications.

TABLE 4-3. CHEMICAL PROPERTIES OF MAGNESIUM ALLOYS.

ALLOY	AL	MN	ZINC	ZIRCONIUM	RARE EARTH	THORIUM	SI	CU	NICKEL	MG	FORMS
AM100A	9.3-10.7	0.10	0.30max	----	----	----	0.30	0.10	0.01	Bal	Castings, sand, perm mold
AZ31B(1)(2)	2.5-3.5	0.20	0.6-1.4	----	----	----	0.10	0.05	0.005	Bal	Extruded Bars, rods, shapes tubes = sheets
AZ91C	2.4-3.6	0.15	0.5-1.5	----	----	----	0.10	0.10	0.03	Bal	Same
AZ63A(2)	5.3-6.7	0.15	2.5-3.5	----	----	----	0.10	0.05	0.005	Bal	Castings, sand & perm mold
AZ80A	7.8-9.2	0.12	0.2-0.8	----	----	----	0.30	0.25	0.01	Bal	Extruded bars, rods, shapes, forgings
AZ81A	7.0-8.1	0.13	0.40-1.0	----	----	----	0.30	0.10	0.01	Bal	Castings, sands & perm mold
AZ91A	8.1-9.3	0.13	0.4-1.0	----	----	----	0.30	0.10	0.01	Bal	Castings, perm mold
AZ91A	8.3-9.7	0.13	0.4-1.0	----	----	----	0.50	0.10	0.03	Bal	Castings, Die
AZ91B	8.3-9.7	0.13	0.4-1.0	----	----	----	0.50	0.30	0.03	Bal	Castings, Die
AZ91C	8.1-9.3	0.13	0.4-1.0	----	----	----	0.30	0.10	0.01	Bal	Castings, sand & perm mold
AZ92A	8.3-9.7	0.10	1.6-2.4	----	----	----	0.30	0.25	0.01	Bal	Same
EK30A	----	----	0.3 max	0.20 min	2-3.0	----	----	0.10	0.01	Bal	Castings, sand only
EK41A	----	----	0.3	0.4-1.0	3.0-5.0	----	----	0.10	0.01	Bal	Castings, sand & perm mold
EZ33A	----	----	2.0-3.1	0.5-1.0	2.5-4.0	----	----	0.10	0.01	Bal	Castings, Sand & Sheet/Plate
HK31A*	----	0.15mx	0.3mx	0.4-1.0	----	2.5-4.0	----	0.10	0.01	Bal	Castings, Sand/Sheet/Plate
HM21A*	----	0.45-1.1	----	----	----	1.5-2.5	----	----	----	Bal	Forgings, Sheet/Plate
HM31A*	----	1.2mn	----	----	----	2.5-3.5	----	----	----	Bal	Extruded Bars/Rods/Shapes
HZ32A*	----	----	1.7-2.5	0.5-1.0	0.1mx	2.5-4.0	----	0.10	0.01	Bal	Castings, sand
K1A	----	----	----	0.4-1.0	----	----	----	----	----	Bal	Castings, Sand
M1A(1)	----	1.2	----	----	----	----	0.10	0.05	0.01	Bal	Extruded Bars, rods, shapes tube-sheets-forgings
QE22A(3)	----	----	----	0.4-1.0	1.8-2.5	----	----	0.10	0.01	Bal	Castings, sand
TA54A(4)	3.0-4.0	0.20	0.3mx	----	----	----	0.30	0.05	0.01	Bal	Forgings
ZE10A	----	----	1.0-1.5	----	0.12-0.22	----	----	----	----	Bal	Sheet & Plate
ZE41A	----	----	4.25-	0.5	1.25	----	----	----	----	Bal	Castings, Sand
ZH42*	----	----	3.0-4.5	0.5	----	1.5-2.5	----	----	----	Bal	Castings, Sand
ZH62A*	----	----	5.2-6.2	0.5-1.0	----	1.4-2.2	----	0.10	0.01	Bal	Castings, Sand
ZK20A	----	----	2.0-2.6	0.45mn	----	----	----	----	----	Bal	Extrusions
ZK51A	----	----	3.6-5.5	0.5-1.0	----	----	----	0.10	0.01	Bal	Castings, Sand
ZK60A	----	----	4.8-6.2	0.45	----	----	----	----	----	Bal	Extruded Bars/Rods/Shapes Tube-Forgings
ZK60B	----	----	4.8-6.8	0.45	----	----	----	0.10	0.01	Bal	Same

\*NOTE: These alloys contain radioactive thorium. See paragraph 4-15.

- (1) Calcium, AX31B, 0.04---M1A, 0.4.0.14
- (2) Iron, AZ31B, 0.005---AZ61A, 0.005---AZ63A, 0.005.
- (3) Silver, QE22A, 2.5-3.0
- (4) Tin, TA54A, 4.6-6.0

TABLE 4-4. MECHANICAL PROPERTIES MAGNESIUM EXTRUSIONS AND FORGINGS  
AT ROOM TEMPERATURE - TYPICAL

ALLOY & COND	FORM	DIEMN (DIA THICKNESS; WALL THKNESS - IN's)	CROSS SECTIONAL AREA (INCHES)	MIN TEN-SILE STR (1000PSI)	MIN TEN YLD STR (1000PSI)	MIN ELONGATION (2" %)	MIN SHEAR STR (1000PSI)	HARDNESS (BRINELL)
AZ31B-F & AZ31C-F	Bars, Rods, shapes	0.249 & under	All areas	35	21	7	17	--
		0.250-1.499	All areas	35	22	7	17	49
		0.500-2.499	All areas	34	22	7	17	--
		2.500-4.999	All areas	32	20	7	--	--
	Hollow shapes	All dimensions	All areas	32	16	8	17	49
AZ61A-F	Bars, rods, shapes	0.249 & under	All areas	38	21	8	--	--
		0.250-1.499	All areas	39	24	9	18	60
		0.250-4.999	All areas	40	22	7	--	--
	Hollow shapes	All dimensions	All areas	36	16	7	18	60
AZ80A-F	Bars, Rods, shapes	0.249 & under	All areas	43	28	9	19	60
		0.250-1.499	All areas	43	28	8	19	60
		1.500-2.499	All areas	43	28	6	19	60
		2.500-4.999	All areas	42	27	4	--	60
	T-5 Same	0.249 & under	All areas	47	30	4	--	82
		0.250-2.499	All areas	48	33	4	21	82
		2.500-4.999	All areas	45	30	2	--	82
HM31A-T5	Bars, rods, shapes	Not applicable	Under 4.000	37	26	4		
MIA-F	Bars, rods, shapes	0.249 & under	All areas	30	not req	2	--	44
		0.250-1.499	All areas	32	" "	3	15	44
		1.500-2.499	All areas	32	" "	2	15	44
		2.500-4.999	All areas	29	" "	2	--	44
	Hollow shapes	All dimensions	All areas	28	" "	2	15	44
ZK60A-F	Bars, rods, shapes	All dimensions	4.999 & under	43	31	5	22	75
			5.000-29.999	43	31	4	22	75

**TABLE 4-4 MECHANICAL PROPERTIES MAGNESIUM EXTRUSIONS AND FORGINGS  
AT ROOM TEMPERATURE - TYPICAL (CONT'D)**

ALLOY & COND	FORM	DIAMN (DIA THICKNESS; WALL THKNESS - IN's)	CROSS SECTIONAL AREA (INCHES)	MIN TENSILE STR (1000PSI)	MIN TENSILE STR (1000PSI)	MIN ELONGATION (2" %)	MIN SHEAR STR (1000PSI)	HARDNESS (BRINELL)
T5	Hollow shapes	All dimensions	All areas	40	28	5	--	--
	Bars, rods, shapes	All dimensions	4,999 & under	45	36	4	22	82
	Hollow shapes	All dimensions	All areas	46	38	4	22	82
<b>EXTRUDED TUBES</b>								
AZ31B -F & AZ31C -F		0.050-0.500	Not applicable	32	16	8	--	46
AZ61A -F		0.050-0.500	Not applicable	28	--	2	--	42
MIA -F		0.050-0.500	Not applicable	40	28	5	--	75
ZK60A -F ZK60A -T5		0.050-0.250 0.050-0.250	Not applicable Not applicable	46 46	38 38	5 4	-- --	75 82
<b>DIE FORGINGS</b>								
AZ31B -F				34	19	6	17	55
AZ61A -F				38	22	6	19	55
AZ80A -F				42	26	5	20	69
AZ80A -T5				42	28	2	20	72
T6				50 (typ)	34 (typ)	5 (typ)	--	72
MIA IA54A -F ZK60A -T5				30 36 42	18 22 26	3 7 7	14 -- --	47 -- --

NOTES: This alloy contains radioactive elements. See paragraph 4-15 for precautions.

**TABLE 4-5 MECHANICAL PROPERTIES MAGNESIUM ALLOW SHEET AND PLATE  
AT ROOM TEMPERATURE - TYPICAL**

ALLOY & COND	DIMENSION THICKNESS (INCHES)	MINIMUM** TENSILE STRENGTH (1000PSI)	MINIMUM** TENSILE YIELD STR (1000PSI)	MIN ELON-GATION (2" $\rightarrow$ %)	MINIMUM SHEAR STRENGTH (1000PSI)	HARDNESS (BRINELL)	USE	
AZ31B-F	All gauges	35 (typical)	19 (typical)	12 (typical)	---	---	Tooling Plate	
AZ31B-H10	0.251-2.000	30	12	10	---	---	Standard plate	
-H11	0.016-0.250	32	12	12	---	---	Standard plate & sheet	
-H23	0.016-0.064	39	25	4	---	---	Standard Sheet	
-H24	0.065-0.064	39	25	4	---	---	& Plate	
	0.016-0.063	39	29	4	18	73	Spec Sheet & Plate	
-H26	0.065-0.250	39	29	4	18	73	Same	
	0.251-0.500	37	24	10	---	---	Same	
-H26	0.501-1.000	37	22	10	---	---	Same	
	0.501-0.750	37	25	8	---	---	Spec Sheet & Plate	
-O	0.751-1.000	37	23	8	---	---		
	1.001-1.500	35	22	8	---	---		
	0.016-0.060	32	18	12	17	56	Spec Sheet & Plate	
-O	0.061-0.250	32	15	12	17	56	Same	
	0.251-0.500	32	15	12	---	---	Same	
	0.501-2.000	30	15	10	---	---	Same	
AZ31C-F	All gauges	32	15	8	---	52	Tread Plate	
HK31A-O*	0.016-0.250	30	16	12	---	---	Sheet	
	0.251-0.500	30	16	12	---	---	Sheet	
	0.501-1.000	30	15	12	---	---	Sheet	
	1.001-3.000	29	14	12	---	---	Sheet	
	-H24*	0.016-0.125	34	26	4	21(typ)	57	Sheet
		0.126-0.250	31	22	4	21(typ)	57	Sheet
		0.251-1.000	34	25	4	20(typ)	---	Sheet
		1.001-3.000	33	25	4	20(typ)	---	Sheet
HM21A-T8	0.016-0.250	31	18	4			Sheet & Plate	
	0.251-0.500	32	21	6			Sheet & Plate	
	0.501-1.000	30	19	6			Sheet & Plate	
	1.001-2.000	29	18	6			Sheet & Plate	
MIA-O	All Gauges	33 (typ)	18 (typ)	17 (typ)	17 (typ)	48	Sheet & Plate	
H	All gauges	35 (typ)	26 (typ)	7 (typ)	17 (typ)	54		

TABLE 4-5. MECHANICAL PROPERTIES MAGNESIUM ALLOY AND PLATE  
AT ROOM TEMPERATURE - TYPICAL (CONT'D)

ALLOY & COND	DIMENSION THICKNESS (INCHES)	MINIMUM** TENSILE STRENGTH (1000PSI)	MINIMUM** TENSILE YIELD STR (1000PSI)	MIN ELON- GATION (2"-%)	MINIMUM SHEAR STRENGTH (1000PSI)	HARDNESS (BRINELL)	USE
ZE10-0	0.016-0.060	30	18	15			Sheet & Plate
	0.061-0.250	30	15	15			
	0.251-0.500	29	12	12			
H24	0.016-0.125	36	25	4			Sheet & Plate
	0.126-0.188	34	22	4			
	0.189-0.250	31	20	4			



TABLE 4-6 MECHANICAL PROPERTIES OF MAGNESIUM ALLOY CASTINGS AT ROOM TEMPERATURES

ALLOY & COND	TENSILE STRENGTH (1000 PSI)		TENSILE STRENGTH YIELD (1000 PSI)		TYPICAL ELONGATION IN 2" _____%		SHEAR STRENGTH (1000 PSI)	HARDNESS (Brinell)
	TYPE	MIN	TYPE	MIN	TYPE	MIN		
AM100A-F	22	20	12	10	2	--	18	54
-T4	40	34	13	10	10	6	20	52
-T6	40	34	16	15	4	2	21	69
-T61	40	34	22	17	1	--	21	69
AZ63A-F	29	24	14	10	6	4	16	50
-T4	40	34	14	10	12	7	17	55
-T5	30	24	16	10	4	2	17	55
-T6	40	34	19	16	5	3	19	73
AZ81A-T4	40	34	14	10	12	7	17	55
AZ91C-F	24	18	14	10	2.5	--	16	52
-T4	40	34	14	10	11	7	17	55
-T5	23	23	12	12	2	--	--	--
-T6	40	34	19	16	5	3	19	73
AZ92A-F	24	20	14	10	2	1	16	65
-T4	40	34	14	10	10	6	17	63
-T5	26	20	17	11	1	--	16	80
-T6	40	34	21	18	2	1	20	84
EK30A-T6	23	20	16	14	3	2	18	45
EK41A-T5	23	20	16	14	1	--	18.7	45
-T6	25	22	18	16	3	1	19.4	50
EZ33A-T5	23	20	15	14	3	2	19.8	50
HK31A-T6*	30	27	15	13	8	4	21	55
HZ32A-T5*	29	27	14	13	7	4	20	57
K1A-F	24	24	6	6	14	14	--	--
QE22A-T6	35	35	25	25	2	2	--	--
ZE41A-T5	28	28	19	19	2.5	2.5	23	62
ZH42-T51*	32.5	--	21.6	--	4.5	--	--	--
ZH42-T4*	33.6	35	--	--	12	--	--	--
ZH62A-T5	35.0	35	22	22	4	5	24	70
ZK51A-T5	40	34	24	20	8	5	22	65
ZK61A-T6	39	39	26	26	5	5	26	68
			DIE CASTINGS					
AZ91A-F	33	--	22	--	3	--	20	67
AZ91B-F	33	--	22	--	3	--	20	67

NOTE: \*This alloy contains radioactive thorium element. See paragraph 4-19 precautionary instructions.

TABLE 4-7. PHYSICAL PROPERTIES MAGNESIUM ALLOY @68°F.

ALLOY & COND	SPECIFIC GRAVITY	DENSITY LBS/CUin	MELTING RANGE °F	ELECTRICAL CONDUCTIVITY (IACS)
AM100A-F	1.81	0.065	867-1101	11.5
-T4	1.81	0.065	867-1101	9.9
-T6	1.81	0.065	867-1101	12.3
AZ31B & AZ31C	1.77	0.064	1116-1169	18.5
AZ61A	1.80	0.065	977-1145	11.6
AZ63A-F	1.82	0.066	850-1130	15.0
-T4	1.82	0.066	850-1130	12.3
-T6	1.82	0.066	850-1130	13.8
AZ80A	1.80	0.065	914-1130	10.6
AZ81A	1.81	0.065	914-1132	12.0
AZ91A-AZ91B	1.81	0.065	875-1105	10.1
AZ91C-F	1.81	0.065	875-1105	11.5
-T4	1.81	0.065	875-1105	9.9
-T6	1.81	0.065	875-1105	11.2
AZ92A-AC	1.83	0.066	830-1100	12.3
-T4	1.83	0.066	830-1100	10.5
-T6	1.83	0.066	830-1100	12.3
EK30A	1.79	0.065	1100-1184	27.0
EK41A-T5	1.81	0.065	1193	24.0
-T6	1.81	0.065	1193	26.0
EZ33A	1.83	0.066	1010-1189	25.0
HK31A-T6	1.79	0.065	1092-1204	22.0
HM21A	1.77	0.064	1100-1195	
HM-31A-F	1.80	0.065	1121-1202	26.0
HM32A	1.83	0.066	1026-1198	26.5
MI-A	1.76	0.064	1200	34.5
TA54A	1.87	0.067	---	--
ZE10A	1.76	0.063	1100-1200	--
ZH42	1.86	0.067	1180	23.9
ZH62A	1.86	0.067	1180	26.5
ZK21A	1.80	0.645	--	--
ZK51A	1.81	0.066	1020-1185	28.0
ZK60A-F	1.83	0.066	968-1175	29.0
-T5	1.83	0.066	968-1175	30.0
ZK60B	1.83	0.066	968-1175	31.0
ZK61A	1.80	0.065	1145	--

NOTE: \*Percentage conductivity of annealed copper at 68°F (international annealed copper standard).

- c. Machine the metal dry whenever possible, avoiding fine feeds and keeping speeds below 500-700 surface feet per minute during turning and boring. If a coolant is definitely required use a mineral oil.
- d. Keep work areas clean.
- e. Store magnesium chips in clean, plainly labeled covered, non-combustible containers where they will remain dry. Do not allow chips to accumulate on machines or operator's clothing. Machinists should not wear texture or fuzzy clothing and chips and sawdust not be allowed to accumulate in cuffs or pockets.
- f. Do not permit tools to rub on the work after a cut has been made.
- g. Keep an adequate supply of a recommended magnesium fire extinguisher within reach of the operators. If chips should become ignited, extinguish them as follow:

**WARNING**

**Water or any of the common liquid or foam type extinguishers will intensify magnesium chip fire and may cause an explosion and shall not be used.**

- (1) Cover with a layer of G-1 or Met-L-X powder. Clean, dry unruined cast iron chips, graphite powder clean dry sand, talc and pitch may also be use
- (2) Actively burning fires on combustible surfaces should be covered with a 1/2 inch layer or more of extinguishing powder; then the entire mass shoveled into a iron container or onto a piece of iron plate. Alternately a one or two inch layer of powder can be spread o the floor or surface nearby and the burning metal transferred to it, then add more powder as required.
- (3) High cutting speeds, extremely fine feeds, dull chipped or improperly designed tools, tool dwell on work after feed is stopped, tool rub, or tool hitting a steel or iron insert increase the chances of chip ignition. Keeping the cutting speed below 700 feet per minute will greatly reduce the fire possibilities even with dull or poorly designed tool and fine feeds.

**4-22. GRINDING AND POLISHING SAFETY PRACTICES** . During grinding and polishing operations a proper dust collection system must be used. Figure 4-1 illustrates acceptable type collectors. The dust produced during grinding and polishing of magnesium must be removed immediately from the working area with a properly designed wet type dust collection system. Proper systems precipitate the magnesium dust by a heavy spray of water and must be so designed that dust or sludge cannot accumulate and dry out to a flammable state . Small collectors as shown in Figure 1A, serving one or two grinders are the best. The grinder to collector ducts should be short and straight. The self opening vents illustrated prevent hydrogen collection during shutdown. The grinder's power supply air exhaust blower and liquid level controller should be electrically water connected so cessation or failure of the dust collector operation will shut the grinder off. In addition a suitable device should be installed in the system that will insure the collector system is in full operation and has changed the air in the duct, etc., several times before the grinder begins running. Dry type filter collectors or central collector system which carry the dust through long dry ducts should not be used for magnesium. The collector portrayed in Figure 4-1B is used with booth type portable grinding and polishing where the dust passes through the grate with the air being circulated into a liquid spray which removes the dust. Design the booth to catch all the dust possible. On individual grinders for small scale work, as shown in Figure 4-1C, the hood design and the oil pan combine to afford a satisfactory dust collection. Any dust escaping the hood should be kept swept up and properly disposed of.

**4-23.** The following specific safety rules pertain to the grinding and polishing of magnesium:

- a. Magnesium grinding should be done on equipment set aside and labeled for that purpose. Do not grind sparking material on these grinders unless the magnesium dust has been completely removed from the equipment system. In addition, the grinding wheel or belt must be replaced prior to grinding of any other metal.
- b. If chrome pickled magnesium is to be ground, sparks may result. Therefore, dust and air-dust mixtures must not be allowed to accumulate within spark range.
- c. Maintain adequate supplies of plainly labeled approved fire extinguishing powder and suitable dispensing tools readily available to operators. Fire control is the same as detailed in paragraph 4-21 for machine chips.
- d. Keep dust from accumulating on surrounding floors, benches, windows, etc. If such accumulation is evident the collector system is not operating properly and must be checked and repaired. Periodically and no less than once a month, completely clean the entire collector systems. Inspect and clean the grinder to collector ducts daily or move frequently if the volume of collection is high.

**T.O. 1-1A-9**

e. Dispose of grinding sludge as soon as it is removed from the equipment. Do not store or allow to even partially dry since it is extremely flammable. This may be done by spreading it on a layer of fire brick or hard burned paving brick to a maximum depth of 3" to 4", then placing a combustible material on top of it and burning the entire lot. The sludge will burn with intense heat, therefore, a safe location must be used. A method of rendering magnesium sludge chemically inactive and non-combustible by reacting it with a 5% solution of ferrous chloride ( $\text{FeCl}_2 \cdot 2\text{H}_2\text{O}$ ) is detailed in the National Fire Protection Association's Bulletin No. 48, Standards for Magnesium.

f. The clothing of operators should be smooth and fire retardant without pockets and cuffs. Caps should be worn. All clothing should be easy to remove and kept free of dust accumulations.

**4-24. WELDING, BRAZING AND SOLDERING SAFETY PRACTICES**. Other than the precautions for thorium alloy welding previously discussed, no special safety practices are necessary for welding, brazing or soldering magnesium than for other metals so long as the metal's characteristics of a low melting point and rapid oxidation are borne in mind and allowed for. Partial melting of the metal must occur before it will burn and continued burning will occur only as long as the melting temperature is maintained. If the remote possibility of fire does occur it can be controlled and extinguished by the same means as detailed for machine chip fire in paragraph 4-21.

**WARNING**

**Welding operations produce heat, highly toxic fumes, injurious radiation, metal slag and airborne particles. Protection equipment, consisting of welding goggles with proper tinted lenses, apron or jacket, and welder's boots is required. Good general ventilation is normally adequate.**

**4-25. HEAT TREATING SAFETY PRACTICES**. Heat treating of magnesium alloys requires the exercising of certain definite rules, if safe and good quality workmanship is to result. The following rules should be closely followed:

- a. Use furnace equipment having two sets of temperature controls, operating independently of each other.
- b. Standardize checking procedures and adjustments of all equipment and of operating cycles.
- c. Load the furnace with castings of one identical alloy only. Insure the castings are clean.
- d. Use  $\text{SO}_2$  (Sulfur Dioxide) atmosphere to control oxidation.
- e. Use the recommended time and temperature operating ranges at all times.
- f. Provide approved fire extinguishing equipment.

**WARNING**

**Water and other extinguishers for Class A, B, AND C fires shall not be used.**

**4-26.** If a fire should occur for any reason, as evidenced by excessive furnace temperature and omission of a light colored smoke, proceed as follows:

- a. Shut off all power, fuel and  $\text{SO}_2$  feed lines to the furnace.
- b. Notify fire marshal control crew at once.
- c. Begin fire extinguishing procedures using one of the following methods:

(1) G-1 Powder Method.

Where it can be safely done, a small fire should be removed from the furnace, dumped into an iron container and then extinguished by covering with G-1 powder which is a graphite base powder of the Pyrene Co Company. Metal Fyr Powder of the Fyr Fyter Company is the same material. In large furnaces or with fires of high intensity, the powder can be applied to the burning parts with a shovel (assuming the furnace door can be opened safely). Paper bags filled with the powder can be used if the fire is so located that such bags can be thrown in effectively. Remove parts not burning with long handled hooks. After all burning parts have been covered with the powder, the furnace load should be allowed to cool with the door open. For the handling of large quantities of G-1 powder, pumps have been constructed which can throw 75-100 lbs/minute onto the fire through a 30 foot hose and nozzle.

(2) Boron Trifluoride ( $\text{BF}_3$ ) Gas Method.

**WARNING**

**Boron trifluoride vapor or gas is toxic in the proportion of more than 1 part per million by volume of air when exposures are prolonged or frequently repeated. Five parts per million by volume of air or more are usually present in visible clouds of material resulting from the release of the gas to atmosphere. Therefore, personnel must not enter such clouds or any area where there is reason to believe the safe level is exceeded unless wearing a gas mask with an acid gas canister containing a dust filler. Analysis of atmosphere in the worker's breathing zone will be accomplished to assure personnel safety.**

This is an effective gaseous means of extinguishing magnesium fires in heat treating furnaces. The gas is introduced into the furnace from a storage cylinder through an entry port preferably located near floor level. Connect the gas feed line to this port, open the feed line valve to provide about 2 lbs/minute (depending on furnace size and number of gas cylinders) and maintain gas flow until furnace temperature drops to 700F indicating the fire is out. The furnace door should be kept closed during this action and until a definite temperature drop below 700°F is evident. Running the furnace circulating fans for about 1 minute after the gas is first introduced will assist in gas dispersal, then but the fan off. The gas cylinder used should be fitted with a Monel needle valve and a "tee" for attaching a 0-160 psi pressure gauge. A suitable gas transfer system uses a 5/16" flexible bronze hose to carry the gas to the furnace where it enters through a 1/4" steel pipe entry port. Using 10 feet of hose and feed of pipe, a gauge pressure of 15-30 psi will deliver 1-2 lbs of BF<sub>3</sub> per minute. The cylinders may be permanently connected or brought to the furnace, when needed, on a suitable dolly. This gas does not require heating in order to flow. The cylinders should be weight checked for contents every 6 months.

(3) Boron Trichloride (BCL<sub>3</sub>) Gaseous Method. This material has been successfully used to extinguish magnesium heat treat furnace fires. However, there are several factors involved with its use which makes it less preferred than boron trifluoride. These include: ten times more concentration than the 0.04% of boron trifluoride, the gas must be heated to flow freely; it is more expensive than trifluoride; the liquid is corrosive and the fumes irritating with a health hazard similar to hydrochloric acid fumes. Workmen should not occupy areas where noticeable vapors are present unless wearing a gas mask with an acid gas canister containing a dust filter. If this agent must be used, the liquid containing cylinders should be heated with infrared lights to provide the heat necessary to insure adequate gas flow. The cylinder outlet should be fitted with a special valve and gauge to control gas flow. Flexible 5/8" ID neoprene hose may be used to connect the cylinder to a steel pipe for insertion into the furnace port. Otherwise its use in extinguishing a furnace fire is similar to the procedures for boron trifluoride.

#### 4-27. IDENTIFICATION OF ALLOY.

**4-28.** Positive identification of an alloy, from a constituency standpoint, can only be determined by laboratory analysis. However, whether a light metal is magnesium or not can be generally determined by a simple test consisting of placing the test metal in contact with an 0.5% solution of silver nitrate, and observing the reaction for 1 minute. The solution is made by dissolving 0.5g. of silver nitrate in 100 ml. of water. Formation of a black deposit of metallic silver on the metal indicates magnesium or high-magnesium alloy. Then immerse the metal in a chrome pickle chemical solution, Type I Specification MIL-M-3171 (Commercially known as DOW No. 1). The solution should be freshly prepared and the test operator familiar with the colors of chemical treatment. If the metal assumes a very bright brassy coating, it indicates it is aluminum free alloy. If a greyish iridescent coating forms the alloy contains aluminum. The solution is made in the proportions of 24 ounces sodium dichromate and 24 fluid ounces concentrated nitric acid to enough water to make one gallon. Prior to the test the metal should be thoroughly cleaned down to the base metal, if necessary, by grinding or filing a clean area on the surface.

#### 4-29. HEAT TREATING MAGNESIUM ALLOYS - GENERAL.

##### NOTE

**MIL-M-6857, Heat Treatment of Magnesium Alloy Castings, will be the control for heat treatment of magnesium alloy castings used on aerospace equipment. For complete description of magnesium alloy castings heat treat requirements, refer to latest issue of MIL-M-6857.**

**4-30. PRECAUTIONS DURING HEATING.** Of first importance in the heat processing of these alloys is a clear understanding of the characteristics of the metal relative to heat. Pure magnesium will melt at approximately 1202F. The alloys melting points range from 830°F to 1204°F, approximately, according to their element constituency. Therefore, during any heating of alloy items, specified temperature maximums must be closely adhered to, particularly during solution heat treating. The metal is easily burned and overheating will also cause formation of molten pools within it, either condition resulting in ruining of the metal. Certain alloys such as AZ63A Type 1, or AZ92A Type 1, are subject to eutectic melting of some of its elements if heated too rapidly. They must be brought up to heat treating temperature slowly enough to prevent this. In the case of these two examples, no less than two hour should be consumed in bringing them from 640°F to treating temperature.

**4-31.** An additional and no less important characteristic of the metal relative to heat treatment, is that it is subject to excessive surface oxidation at 750°F and higher temperatures. In an oxidizing atmosphere, this characteristic can result in ignition and fierce burning. To prevent such occurrences, a protective atmosphere containing sufficient sulphur dioxide, carbon dioxide or other satisfactory oxidation inhibitor shall be used when heating to 750°F and over. When oxidation inhibitors are used, their concentration percentages in the furnace atmosphere should be periodically checked for correct amounts. The particular requirements for various alloys are detailed in paragraph 4-46 in this section. These requirements and those of other pertinent specifications and instructions should be consulted and strictly adhered to in processing the metal. The safety measures defined in paragraph 4-1 must be rigidly practiced.

#### 4-32. HEAT TREATING EQUIPMENT.

**4-33.** Furnaces used for solution heat treatment shall be of the air chamber type with forced air circulation. Heating provisions can be gas, electricity or oil. Their design must be such as to make impossible, direct heating element radiation or flame impingement on the articles being treated. The furnaces shall be installed with the necessary control, temperature measuring and recording instrument equipment to assure complete and accurate control.



The temperature control shall be capable of maintaining a given temperature to within  $\pm 10^{\circ}\text{F}$  at any point in the working zone, after the charge has been brought up to this temperature. Each furnace used shall be equipped with a separate manual reset safety cut-out which will turn off the heat source in the event of any malfunction or failure of the regular automatic controls. The safety cut-outs shall be set as close as practicable above the maximum solution heat treating temperature for the alloy being treated. This will be above the variation expected but shall not be more than  $10^{\circ}\text{F}$  above the maximum heat treat temperature of the alloy being processed. There shall also be protective devices to shut off the heat source in case of circulation air stoppage. These devices shall be interconnected with a manual reset control.

**4-34.** Upon initial furnace installation and after any maintenance on the furnace or its equipment which might affect its operational characteristics, a temperature survey shall be made to test its capability of maintaining the minimum and maximum temperatures required for the various treatments it will be used for. A minimum of 9 test locations within the furnace load area should be checked. One in each corner, one in the center and one for each 25 cubic feet of furnace volume up to the maximum of 400 cubic feet. A monthly survey should be made after the initial survey, unless separate load thermocouples are employed, to record actual metal temperatures. The monthly survey should consist of one test for a solution heat treat temperature and one test for a precipitation heat treat temperature, one for each 40 cubic feet of heat treating volume with a minimum of 9 test locations required regardless of the volume. In addition, a periodic survey should be made, using the test criteria of the initial survey. For all surveys, the furnaces should be allowed to heat to a point stabilization before taking any readings. The temperature of all test locations should be determined at 5 to 10 minute intervals after insertion of the temperature sensing elements in the furnace. The maximum temperature variation of all elements shall not exceed  $20^{\circ}\text{F}$  and shall not exceed the solution or precipitation heat treating range at any time after equilibrium is reached.

**4-35.** Furnace control temperature measuring instruments shall not be used as test instruments during any survey. The thermocouple and sensing elements should be replaced periodically because of the in-service incurred effects of oxidation and deterioration.

**4-36.** Pyrometers used with the automatic control system to indicate, maintain and record the furnace temperatures, should preferably be of the potentiometer type.

**4-37.** Suitable jigs, fixtures, trays, hangers, racks, ventilators and other equipment shall be used in processing the articles.

**4-38. HEAT TREATMENT SOLUTION.** Solution for heat treating of magnesium alloyed articles is accomplished by heating at an elevated temperature in an air furnace for a specific length of time (holding period); during which certain alloying elements enter into uniform solid solution, since the alloys tend to become plastic at high heat treat temperatures, it is mandatory that suitable support be provided for articles being processed to prevent warping. Table 4-8 below lists the recommended soaking and holding time for solution heat treating alloys. The holding periods given are for castings up to 2 inches thick. Items thicker than 2 inches will require longer periods.

**4-39.** AZ92A (Type 2), AZ91C and QE22A sand castings, and AM100A permanent mold castings may be charged into the furnace which is at the heat treating temperature. Since magnesium castings are subject to excessive surface oxidation at temperatures of  $750^{\circ}\text{F}$  and over, a protective atmosphere containing sufficient sulphur dioxide, carbon dioxide or other satisfactory oxidation inhibitor shall be used when solution heat treating at  $750^{\circ}\text{F}$  and over. The whole casting must be heat treated, not just part of it.

**4-40.** Precipitation heat treatment or artificial aging of alloys is accomplished at temperature lower than those of the solution treatment. Suggested aging treatments for various alloys are as cited in Table 4-9.

**4-41.** Stabilization heat treating an alloy increases its creep strength and retards growth at service encountered elevated temperatures. The same general procedure of heating to temperature, holding for a time and cooling to room temperature is used as in the other two types, only the temperature and time elements are different. When applied to a solution heat treated alloy, it increases the alloy's yield strength. Actually stabilization treatment is a high temperature aging treatment accomplished quickly rather than allowing an alloy to age naturally over a period of time.

TABLE 4-8. SOLUTION HEAT TREATING TEMPERATURES AND HOLDING TIMES.

<u>ALLOY</u>	<u>TEMPERATURE RANGE</u>	<u>TIME PERIOD(HRS)</u>	<u>MAX TEMP °F</u>
AM100A	790-800	16-24	810
AZ63A (Type 1)	720-730 (F to T4)	10-14	734
AZ63A (Type 2)*	720-740 (F to T4)	10-14	745
AZ81A	770-785	16-24	785
AZ91C	770-785	16-24	785
AZ92A (Type 1)	760-770	16-24	775
AZ92A (Type 2)	775-785	14-22	785
HK31A	1045-1055	2	1060
QE22A**	970-990	4-8	1000
ZK61A	925-935 or 895-905	2  10	935  935
* Contains calcium.			
** Quench in 150°F water bath within 30 seconds after opening of furnace.			

4-42. Annealing of magnesium alloys is accomplished to relieve internal stresses, generally resulting from forming operations; soften the material for forming; improve the ductility; and/or refine the grain structure. The alloy is heated to the proper temperature, soaked or held at that temperature for a specified time and cooled to room temperature. The desired effects are gained by controlling the temperature, hold time and cooling medium exposure. Avoid excessive time at temperature to prevent unwanted grain growth. Conversely, no attempt should be made to shorten the time at temperature and overall annealing time by increasing the temperature, since elements of the alloy subject to melting points lower than the alloy itself can go into solution.

4-43. **HEAT TREATING PROCEDURES.** Placing of articles to be treated in the furnace, (generally referred to as charging the furnace), should not be done in a haphazard fashion. Individual pieces should be racked or supported to prevent distorting without interfering with the free flow of the heated atmosphere around the article. Distortion or warping can occur due to the semi-plastic qualities of the alloy at the furnace elevated temperatures during solution heat treat. Distortion is not a particular problem during precipitation or stabilization treatment or annealing. However, it is good practice to handle magnesium alloy articles with care at all times under elevated heat conditions. In the case of complicated formed parts, it may be necessary to utilize a specially contoured jig or fixture to adequately protect the design contour of the item at high temperature.

4-44. Cooling after treating is accomplished in either still or blast air, depending upon the alloy. The one exception is alloy QE22A which is water quenched. The water should be at 150F temperature.

#### 4-45. ALLOY GENERAL CHARACTERISTIC INFORMATION.

4-46. In the following paragraphs are brief summaries of the general characteristics of the various alloys.

a. AM100-A Used in pressure tight sand and permanent mold castings with good combination of tensile strength, yield strength and elongation. Solution heat treat in 0.5% SQ atmosphere 20 hours at 790°F; cool in a strong air blast. Partially artificial aging -12 hours at 325°F; cool in still air. Completely artificial age 5 hours at 450°F; cool in still air or oven. Aging increases basic yield strength and hardness and decreases toughness and elongation.



TABLE 4-9. ARTIFICIAL AGING (PRECIPITATION TREATMENT)0

<u>ALLOY &amp; TEMPER</u>	<u>AGING TREATMENT</u>
AM100A-T6	5 hrs at 450°F or 24 hrs at 400°F
AM100A-T5*	5 hrs at 450°F
AZ63A-T6	5 hrs at 425°F or 5 hrs at 450°F
AZ63A-T5*	4 hrs at 500°F or 5 hrs at 450°F
AZ91C-T6	16 hrs at 335°F or 4 hrs at 420°F
AZ92A-T6 (Type 1)	4 hrs at 500°F or 5 hrs at 425°F
AZ92A-T6 (Type 2)	5 hrs at 450°F or 16 hrs at 400°F or 20 hrs at 350°F
AZ92A-T5* (Type 2)	5 hrs at 450°F
ZZ33A-T5*	2 hrs at 650°F / 5 hrs at 420°F or 5 hrs at 420°F
HK31A-T6	16 hrs at 400°F
HZ32A-T5*	16 hrs at 600°F
QE22A-T6	8 hrs at 400°F
ZH62A-T5*	2 hrs at 625°F / 16 hrs at 350°F
ZK51A-T5*	8 hrs at 424°F or 12 hrs at 350°F
ZK61A-T5*	48 hrs at 300°F
ZK61A-T6	48 hrs at 265°F
*T5 is aged from as-cast condition. Others are aged from T4 condition.	

b. AZ31B and C - Used in low cost extruded bars, rods, shapes, structural sections and tubing with moderate mechanical properties and high elongation sheet and plate; good formability and strength, high resistance to corrosion, good weldability. Liquid temperature 1170°F; solid 1120°F. Hot working temperature is 450° - 800°F. Annealing temperature 650°F. Stress relief of extrusions and annealed sheet :500°F for 15 minutes; hard rolled sheet = 300°F for 60 minutes. Welding done with helium argon arc using AZ61A or AZ92A rod. Gas welding is not in general use but resistance welding is. Stress relieve after welding. Foreign equivalents are: British DTD 120A Sheet, 1351350 forgings; German and Italian, Electron AZ31; French SOC Gen Air Magnesium, F3 and T8.

c. AZ61A - Use in general purpose extrusions with good properties, intermediate cost; press forgings with good mechanical properties. Rarely used in sheet form. Hot working temperature 350-750°F; shortness temperature above 780°F. Anneal 650°F. Heat treat annealed sheet extrusions and forgings 15 minutes at 500°F rolled sheet 400°F for 15 minutes. Weld with helium or argon gas using AZ61A or AZ92A. Resistance welding in satisfactory. Stress relieve after welding. Foreign equivalents are British BS 1351 (forgings) BS 1354 (extrusions); German AZM.

d. AZ63A - Used in sand castings for good strength properties with best ductility and toughness. Solution heat treat at 740°F in a 0.5%-SO<sub>2</sub> atmosphere for 10 hours then cool in air. Aging is done at 450°F for 5 hours and cooled in air or furnace. Stabilize at 300°F at 4 hours and cool in air. Foreign equivalents are Elektron AZG, British DTD59A (as cast) and DTD289 (heat. treated). Good salt water anti-corrosion properties.

e. AZ80A - Used for extruded and press forged products. Heat treatable. Hot working temperature 600-750°F. Shortness temperature above 775°F, annealing temperature 725 F. Stress relief: as extruded, 500°F for 15 minutes; extruded and artificially aged 400°F for 60 minutes; forgings 500°F for 15 minutes. Foreign equivalents are British 1351 (forgings); German AZ855 Helium or Argon-arc weldable using AZ92A welding rod or may be resistance welded. Stress relieve after welding.

TABLE 4-10. PHYSICAL PROPERTIES OF MAGNESIUM ALLOYS IMPORTANT TO WELDING.

FORM	ALLOY & TEMPER	DENSITY LBS/CU IN	MELTING RANGE °F	THERMAL CONDUCTIVITY AT 68°F CGS UNITS	ELECTRICAL RESIS AT 68°F MICROHIM CENTI METERS
Sand Cast	AZ63A-T4	0.0656	850-1135	0.12	14.0
	AZ81A-T4	0.0649	900-1115	0.12	15.0
	AZ91C-T6	0.0652	875-1105	0.13	12.9
	AZ92A-T6	0.0659	830-1110	0.14	12.4
	EZ33A-T5	0.0659	1010-1189	0.24	7.0
	HK31A-T6	0.0647	1092-1195	0.22	7.7
	HZ32A-T5	0.0659	1026-1198	0.26	6.5
	KIA-F	0.0628	1200-1202	0.30	5.6
	QE22A-T6	0.0654	- - - - -	0.24	6.8
Extrusions	AZ31B-F	0.0639	1050-1160	0.18	9.2
	AZ61A-F	0.0647	950-1140	0.14	12.4
	AZ80A-T5	0.0649	900-1115	0.12	14.5
	HM31A-T5	0.0651	1121-1202	0.25	6.6
	ZK21A-F	0.0645	- - - - -	0.30	5.4
	ZK60A-T5	0.0659	970-1175	0.29	5.7
SHEET & PLATE	AZ31B-H24	0.0639	1050-1160	0.18	9.2
	-0	0.0639	1050-1160	0.18	9.2
	HK31A-H24	0.0647	1092-1195	0.25	6.1
	-0	0.0647	1092-1195	0.27	6.6
	HM21A-T8	0.0640	1121-1202	0.33	5.0

TABLE 4-11. RELATIVE WELDABILITY OF MAGNESIUM ALLOYS.

WROUGHT ALLOY	WELD ARC	RATING SPOT	CAST ALLOY	WELD RATING ARC	CAST ALLOY	WELD RATING ARC
AZ31B, C	A	A	AZ63A	C	HK31A	B/
AZ61A	B	A	AZ81A	B/	HK32A	C
AZ80A	B	A	AZ91C	B/	KIA	A
HK31A	A	A	AZ92A	B	QE22A	B
HM21A	A	A-	EK30A	B	ZE41A	C
HM31A	A	A	EK41A	B	ZH62A	D
ZK21A	B	A	EZ33A	A	ZK51A	D
ZK60A	D	A				

A = Excellent

B = Good

C = Fair

D = Welding not recommended

**T.O. 1-1A-9**

f. AZ81A - Used in sand or permanent mold castings for good strength, excellent ductility, pressure tightness and toughness. Readily castable with low micro-shrinkage tendency. Solution heat treat 775°F for 18 hours, cool in air or by fan. Stabilizing treatment 500°F, 4 hours and air cool. To prevent germination (grain growth) an alternate heat treat of 775° F for 6 hours, 2 hours at 665°F and 10 hours at 775°F may be used. Weld with helium or argon-arc method using AZ92A rod or base metal rod. Preheat is not necessary in structural welding. Emergency repair with oxyacetylene neutral flame, AZ92A rod and flux may be done. Stress relieve after welding.

g. AZ91A, AZ91B AZ91A - Used for die castings generally.

h. AZ91C - AZ91B is also die cast alloy but has higher impurity content. AZ91C is used for pressure tight sand and permanent mold castings having high tensile and weld strength. Shortness temperatures are above 7500°F. Heat treat: T-4 condition, 16 hours at 780° F, cool in air blast and then age at 400°F for 4 hours; T-7 condition, 5 hours at 450°F. Foreign equivalents are Elektron AZ91 and British DTD136A. Good impact resistance in T-4 temper. T-6 has good yield strength and ductility.

j. AZ92A - Used in pressure tight sand and permanent mold castings. Has high tensile and yield strengths. Solution heat treat 20 hours at 760°F in an atmosphere of 0.5% SO<sub>2</sub>. Cool in strong air blast. Artificial aging is done at 420°F for 14 hours. Cool in air or oven. Stabilize for 4 hours at 500°F, then cool in air. Equal to AX63A in salt water corrosion resistance.

k. EK30A - Used in sand casting for elevated temperature applications. Has good strength properties in temperature range 300°500°F. Solution heat treat at 1060°F maximum 16 hours then cool in air by fan. Age at 400°F then air cool. Weld by helium or argon arc method using EZ33A or base metal rod. May be preheated if desired. Stress relieve after welding. Castings are pressure tight.

l. EK41A - Used as pressure tight sand casting alloy. Good strength at 300° 500°F. Solution heat treat at 1060°F maximum 16 hours then cool in air or with fan. Age at 400°F 16 hours, air cool. Helium or argon arc weld using EZ33A or base metal rod. May be preheated as desired. Stress relieve after welding.

m. EZ33A - Used for pressure tight, good strength sand and permanent mold castings where temperatures may reach 500°F in use. Age at 420°F for 5 hours. Weld with helium or argon gas arc method using EZ33A rod. Stress relieve after welding. Foreign equivalent British ZRE1.

n. HK31A - Used in sand castings for elevated temperature use up to 650°F and sheet and plate applications. Has excellent weld and forming characteristics in sheet/plate form and retains good strength up to 650°F. Hot working temperature is 800° to 1050°F. Anneal at 750°F. Solution heat treat sand castings by loading into a 1050°F furnace and holding for 2 hours, then fan or air cool. Age for 16 hours at 400°F. H23 sheet may be stress relieved after welding at 650°F for 1 hour or 675°F for 20 minutes. Weld using helium or argon gas arc weld and EZ33A or HK31A rod. Stress relieve sand castings. Sheet maybe resistance welded.

p. HM21A - Used sheet, plate and forgings, usable at 650F and above. Hot work at 850°F 1100°F Anneal at 850°F. Heat treat forgings (T5) 450°F for 16 hours. Weld with helium or argon gas arc method using HM31A rod when service temperature will be above 600°F or EZ33A rod for lower temperatures. Resistance welding is also satisfactory.

q. HM31A - Used in extruded bars, rods, shapes and tubing for elevated temperature service. Exposure to temperatures through 600°F for periods of 1000 hours caused practically no change in short time room and elevated temperature properties. Superior modulus of elasticity particularly at elevated temperatures. Hot work at 700F 1000°F. Weld by resistance method or helium argon gas arc methods. Use HM31A rod for temperature application in excess 600°F or EZ33A rod where temperature will be below 600°F . No stress relief after welding is necessary.

r. HZ32A - Used for sand castings. It is of properties for medium and long range exposure at temperatures above 500°F and is pressure tight.

s. KIQA - Casting alloy with comparatively low strength has excellent damping characteristics.

t. MIA - Used for wrought products and provides for moderate mechanical properties with excellent weldability, corrosion resistance and hot formability. Hot work at 560° 100°F. Anneal at 700°F. Stress relieve annealed sheet at 500°0F, in 15 minutes; hard rolled sheet at 400°F in 60 minutes; and extrusions at 500°F in 15 minutes. Shielded arc, oxyacetylene gas and resistance welding are used for joining. Use MIA rod where applicable and a neutral flame and magnesium flux for gas welds. Stress relief is not required, but maybe used. Foreign equivalents are British BS1352 (forgings) and German AM503.

u. QE22A - Castings have high yield strength at elevated temperatures. Solution heat treat at 970-990°F 4 to 8 hours. Quench in 150°F water bath.

v. TA54A - Best hammer forging alloy.

w. ZE10A - Used for low cost, moderate strength sheet and plate. No stress relief required after welding. Hot work at 500°-900°F. Anneal 400°F. Weld by shielded arc or resistance methods. AZ61A or EX33A rod is preferred for welding.

x. ZE41A - A good strength, pressure tight, weldable alloy, where temperatures are below 200°F. Age 2 hours at 625°F, air cool; 16 hours at 350°F air cool. Shield arc weld with EZ33A rod, then stress relieve. Foreign equivalent British RZ5.

y. ZH42A - Used in sand castings for aircraft engines and airframe structures where high strength at room temperatures and moderate long-time creep resistance at temperatures up to 480°F are required. The alloy is a precipitation hardening one from the as-cast condition and requires no solution heat treatment. Minimum hardness is developed at 480°F in 24 hours. More ductility and better shock resistance may be obtained by overaging at temperatures such as 750°F. For T51 condition treat at 480°F for 24 hours; T4 condition 750°F for 24 hours. Weld by shield arc method using ZH42A, ZH62A or EZ33A rod in that order.

z. ZH62A - Used as a high strength good ductility structural alloy at normal temperatures and has the highest yield strength of any alloy except ZK61A-T6. Heat treat at 480°F for 12 hours. Weld with shielded arc using ZH62A or EZ33A rod then stress relieve. Foreign equivalent is British T26.

aa. ZK21A - An alloy of moderate strength for extrusion fabrication. Good weldability using shielded arc and AZ61A or AZ92A, rod. Resistance welding also satisfactory. ZK51A - Used for high yield strength, good ductility, sand castings. Heat treat for 12 hours at 350°F. Weldable to a limited degree using shielded arc and EZ33A or base metal rod. Stress relieve after welding. Foreign equivalent is British Z52.

ab. ZK60A - Used as a wrought alloy for extruded shapes and press forgings. Has high strength and good ductility characteristics. Hot work at 600°-750°F. Shortness temperature is 950°F. Age at 300°F for 24 hours, air cool. Use resistance or shielded arc welds for joining although arc welding is somewhat difficult since the alloy is susceptible to hot short crack ring. Use AZ92A welding rod. Crack force welds exhibit high efficiency. Foreign equivalent is German ZW6.

ac. ZK61A - Casting Alloy. Solution heat treat at 925°-935°F for 2 hours or 895°-905° F for 10 hours.

#### **4-47. WELDING OF VARIOUS ALLOYS.**

**4-48.** Tables 4-10 and 4-11 provide information relative to the welding of various alloys. Successful welding of the varied alloys can be accomplished by one or more methods such as inert-gas welding, gas welding and resistance welding which includes spot, seam and flash methods. In any of these methods fusion of the metal is done at comparatively low temperatures because of the metals' low melting point, low fusion heat and specific heat per unit volume. Distortion should be guarded against since the high thermal-conductivity and high thermal expansion coefficient of the metal will lead to this condition unless precaution is exercised. Another factor that requires special attention to prevent detrimental effects while welding with arc or gas methods, is the characteristic of the metal to oxidize very fast when heated to its melting point in normal atmosphere. This characteristic can be successfully overcome by shielding the metal with an inert gas during arc welding and a suitable flux when the gas type is used.

**4-49. WELDERS TRAINING AND QUALIFICATION .** Personnel assigned to accomplish magnesium welding must meet the qualification requirements of MIL-T5021, Tests, Aircraft and Missile Welding Operators qualification. In addition, they should be trained in fabrication procedures, identifying magnesium alloys and their composition, blue print reading, cleaning and treating methods, safety rules and procedures and use of applicable hand and machine tools. Personnel proficiency should be maintained at a high level by periodic testing in accordance with MIL-T-5021 and inspection of the workmanship of the individual. All parts produced must meet the requirements of their applicable specifications, i.e., blueprints, drawings technical orders, etc.

**4-50.** As the alloy element content is increased the solidification temperature range increases proportionally, and the melting point and shrinkage decreases. Alloys with up to 10% aluminum content are most weldable. Hot shortness or cracking tendencies under heat is increased by the zinc content.

**4-51.** Failure in material in the area of welds can be a result of base metal grain growth caused by the weld heating cycle or from the annealing overaging effects of the weld temperatures on the metal. Cracking in the weld or weld area some time after welding may be from the effects of stress corrosion caused by the failure to properly relieve stress built up by heat during welding. Stress relieving is discussed in paragraph 4-76 and under discussions on welding methods.

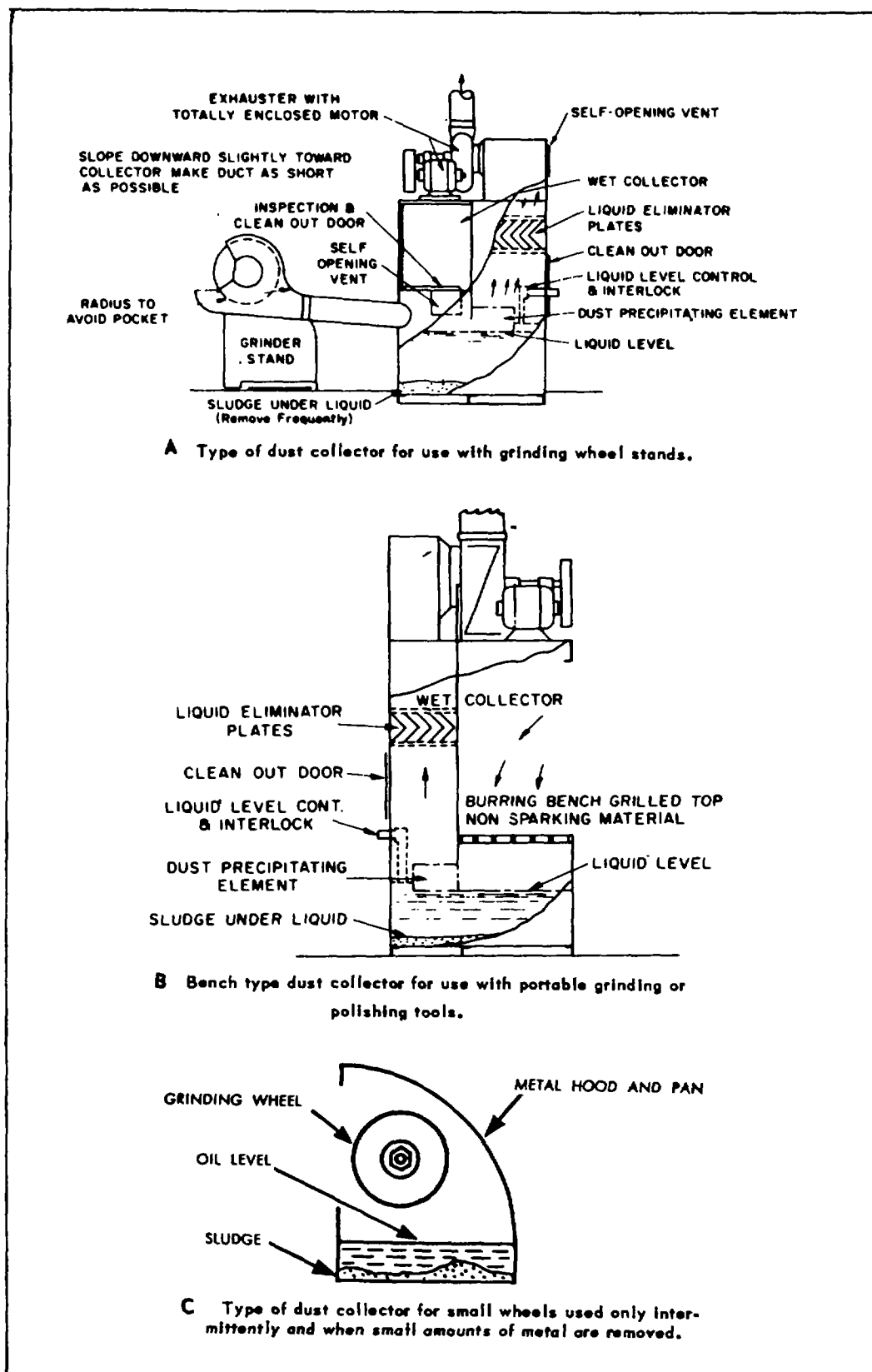


Figure 4-1. Typical Dust Collectors for Magnesium.

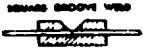
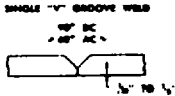
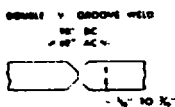
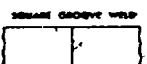


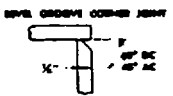
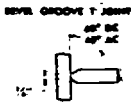
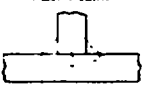
Gas Tungsten-Arc				
	Direct Current Reverse Polarity	Direct Current Straight Polarity	Alternating Current	Gas Metal- Arc
 SQUARE GROOVE WELD	$\frac{3}{8}$ " max.	$\frac{1}{4}$ " max.	$\frac{1}{4}$ " max.	$\frac{3}{8}$ "
 SINGLE V GROOVE WELD 90° BC 90° AC	$\frac{3}{8}$ " max.	$\frac{3}{8}$ " max.	$\frac{3}{8}$ " max.	$\frac{3}{8}$ " min.
 DOUBLE V GROOVE WELD 90° BC 90° AC	$\frac{3}{8}$ " min.	—	$\frac{3}{8}$ " min.	$\frac{1}{2}$ " min.
 SQUARE GROOVE WELD	—	$\frac{3}{8}$ " max.	$\frac{3}{8}$ " max.	$\frac{1}{2}$ " max.
 CORNER JOINT	$\frac{1}{8}$ "	$\frac{1}{8}$ "	$\frac{1}{8}$ "	—
 FLARE T JOINT	$\frac{1}{8}$ " max.	$\frac{1}{8}$ " max.	$\frac{3}{8}$ " max.	—
 BEVEL GROOVE CORNER JOINT 90° BC 90° AC	$\frac{1}{8}$ " min.	$\frac{1}{8}$ " min.	$\frac{1}{8}$ " min.	$\frac{3}{8}$ " min.
 BEVEL GROOVE T JOINT 90° BC 90° AC	$\frac{1}{8}$ " min.	$\frac{1}{8}$ " min.	$\frac{1}{8}$ " min.	$\frac{1}{2}$ " min.
 FLARE T JOINT	—	—	$\frac{3}{8}$ " max.	—

Figure 4-2. Typical Joints For Arc For Magnesium.

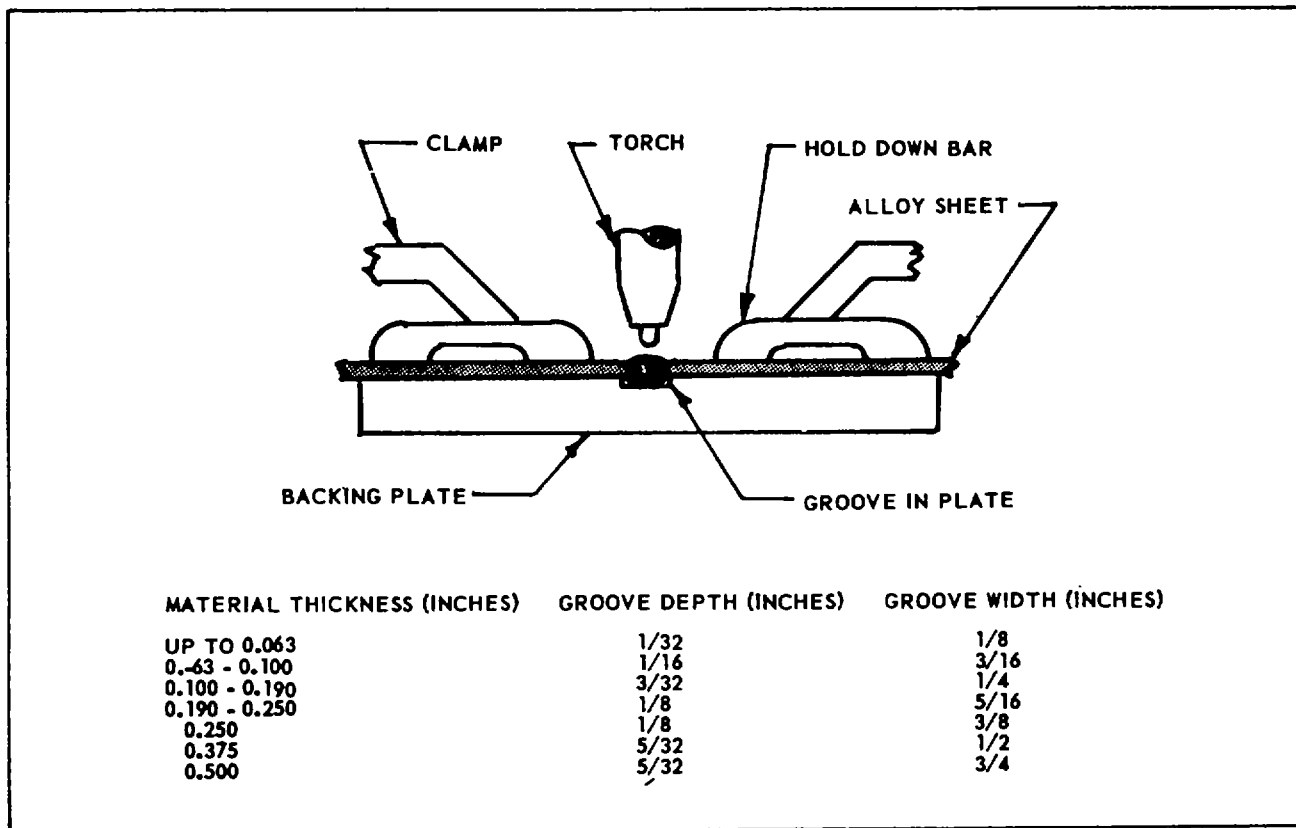


Figure 4-3. Backing Plate.

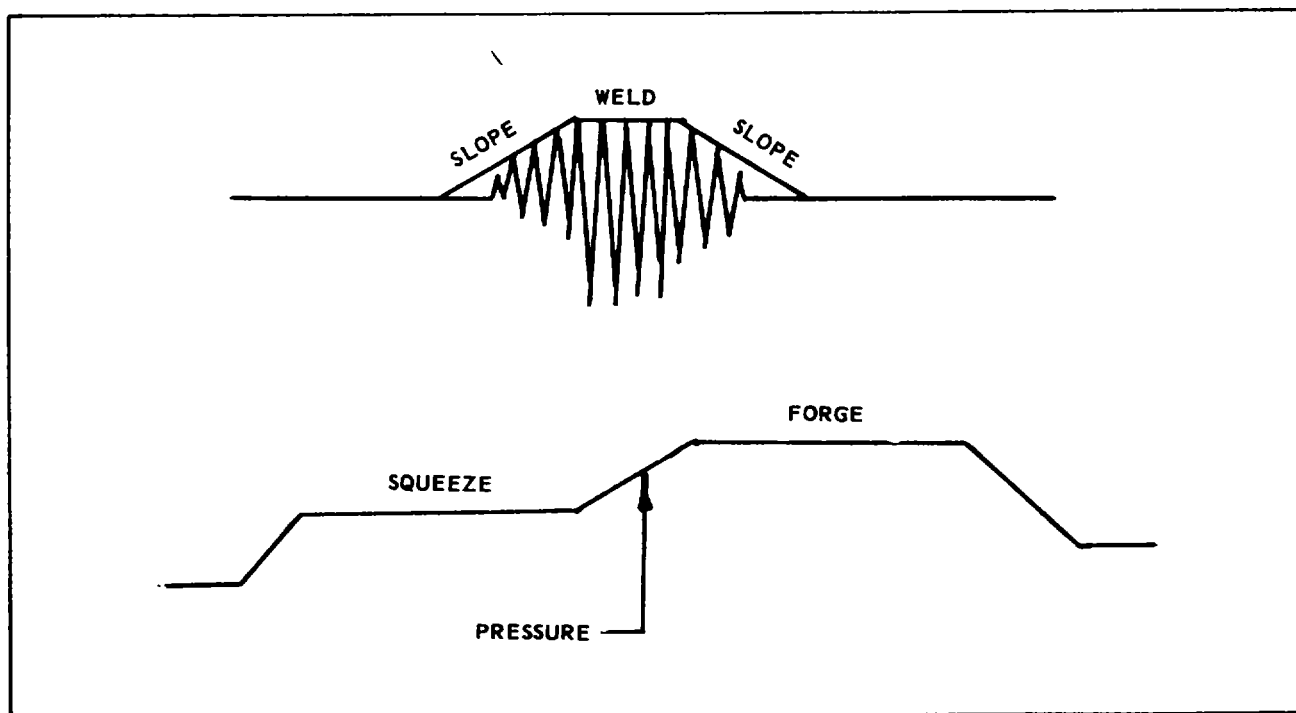


Figure 4-4. Slope Control Schematic.



**TABLE 4-12. SPECIFICATIONS APPLICABLE TO WELDING MAGNESIUM ALLOYS.**

MIL-W-18326	Arc Welding - Gas Welding
MIL-H-6857	Heat Treatment of Castings
MIL-T-5021	Qualification of Welds
MIL-1-6866	Fluorescent Penetrant Inspection
MIL- 1-6865	Radiographic Inspection
MIL-F-6943	Welding Flux
MIL-R-6944	Welding Rod
MIL-W-6858	Welding Resistance Aluminum, Magnesium, Non-Hardening Steel or Alloys, etc.(Spot and Seam).
AFLCR-74-1	Welding Repair of Castings

**4-52.** Safety precautions in welding are set forth in separate paragraphs herein. These precautions should be reviewed and adhered to at all times. Of prime importance is the proper technique for the welding of thorium containing alloys (see paragraph 4-14).

**4-53. GAS WELDING.** This type welding, although once the predominant method for fusion joining magnesium, has been generally replaced by other methods. One of the main reasons is its inherent weakness for corrosion from the flux used with welding. For this reason only butt type joints are recommended in gas welding. In a lap type joint, flux deposits would be trapped in the lap, leading to destructive corrosion of the joint. After welding of a joint all traces of flux must be removed. Procedures for this are contained in later paragraphs. Welds should be made in one pass, therefore, only material up to ¼" can be welded. The general present practice is to use gas welding as an emergency repair procedure of magnesium assemblies. Thin sheet may continue to be welded using butt joints.

**4-54.** Equipment. Torches used have tip sizes of 0.035" to 0.081" or 0 to 1 for 0.032" thick material and size 3 or 4 for 0.128" stock. The gases are oxygen, acetylene and oxy carbohydrogen (80% hydrogen 20% methane). The last gas is particularly satisfactory for welding stock up to 0.064" thick due to its soft flame. Acetylene is used with oxygen for thicker gauges. See Table 4-13 (or a general guide to regulation of welding equipment).

**4-55.** Welding Rods. Welding rods recommend for use in welding alloys ire listed in Table 4-14, for joining wrought alloy, Table 4-15 for joining cast to wrought alloy, and Table 4-16 for joining cast to cast alloys. If a rod is not specified for an alloy, use one of the same composition as alloy involved.

**4-56.** Flux. Fluxes for use in welding magnesium are cited in Table 4-17. The flux is usually supplied in powder form and shall be kept dry until mixed for use. Flux should be mixed in approximately the quantity required for the job on hand by mixing 2 parts of water to 1 part powder by volume. Keep paste covered when not in use.

**4-57. WELDING PROCEDURES.** Surface preparation is the first step required if a good welded joint is to be expected. The surface to be fused should be cleaned of all material down to the base metal. Chemical cleaning is preferred over mechanical methods, if possible, as its action provides uniform longer life cleanliness. Parts should be degreased if their condition requires it, washed thoroughly in a hot alkaline cleaner and then immersed for about 3 minutes in a 70-90°F bath of 24 oz Chromic Acid (CrO<sub>3</sub>), 4 oz Sodium Nitrate (NaNO<sub>3</sub>) and enough water to make one gallon of solution (Type I in accordance with MIL-M-3171). Any amount of solution may be used in these proportions. Rinse thoroughly in hot water and air dry. If chemical cleaning is not possible, the surface should be degreased with a solvent such as trichloroethylene, solvent specification P-D-680, Type II or alkaline cleaner Specification MIL-C-25769 and then cleaned with steel wool, 2luminum oxide cloth or stainless wire brushes. Insure the surface is free of all loose and imbedded abrasive material. If the work is a repair, the edges of the defect must be dressed down to clean sound metal to a 450 slope. Leave a land or root face of about 1/18" at the bottom of defects which penetrate through the surface. For joining of sheets, etc., the surface must be cleaned as above and a suitable gap may be left between the sheet edges to allow for shrinkage and warpage. A gap 1/16 " for thinner materials 0.040" and below, gradually increasing through gauge ranges to 3/8" gap for 14" material is satisfactory.

TABLE 4-13. GUIDE TO REGULATION OF GAS WELDING EQUIPMENT.

METAL THICK- NESS INCHES	ROD DIA INCHES	OXYGEN PRES- SURE lbs/sq in	ACETYLENE		CARBON HYDROGEN	
			ORIFICE DIA INCHES	PRESSURE lbs/sq in	ORIFICE DIA INCHES	PRESSURE lbs/sq in
0.020	1/16-3/32	1-4	0.035	1-3	0.040	1-4
0.032	1/16-3/32	3-5	0.035	1-3	0.046	3-5
0.040	3/32-1/8	3-5	0.035	1-3	0.059	3-5
0.051	3/32-1/8	3-5	0.035	1-3	0.059	3-5
0.064	3/32-1/8	3-5	0.040	3-5	0.059	3-5
0.072	3/32-1/8	3-5	0.040	3-5	0.059	3-5
0.081	3/32-1/8	3-5	0.046	3-5	0.059	3-5
0.091	1/8-5/32	3-5	0.046	3-5	0.067	3-5
0.128	1/8-5/32	3-5	0.059	3-5	0.081	3-5

**4-58.** The second step is to join the edges using a suitable rod and flux, (See Table 4-14 and 4-17.) Adjust the torch flame to a neutral or slightly reducing (carburizing) flame with a ¼" tip or slightly feathered tip when the oxygen pressure is reduced. If the part is a casting or other large item, it may require preheating in an oven or by torch application to about 650°F. Temperature indication may be determined by use of a hand pyrometer, temperature indicating crayon or by observing the color change in mark made on the part with blue carpenter chalk. When the chalk becomes white, a temperature of 600°F is indicated. Thin wrought material requires no preheating. Fan the flame over a small area of the surface to slowly heat it, then as the metal begins to melt, dip the rod into the puddle until sufficient molten metal is obtained. Keep the rod in the outer flame, dipping it into the puddle as more metal is needed. Continue the process, moving the flame ahead as rapidly as possible in a straight line, keeping the torch inclined at a 45 angle to the surface. Magnesium, aluminum, zinc alloy castings, should be stress relieved, after welding, in a 5000° oven for 1 hour or by torch heating the entire part to about 650° then still air cooling, Welding of castings is covered in more detail in paragraph 4-60.

**4-59.** The final step to complete a gas weld is to properly clean it. Immediately after welding clean the seams with a stiff bristle brush and plenty hot water. Follow this by a 1 minute bath in a chrome pickle solution of 24 ounce nitric acid, 24 fluid ounce sodium dichromate and enough water to make a gallon (Type I, MIL-M-3171). Any amount of the solution maybe pre-pared in these proportions. Wash in running cold water then boil for two hours in a solution of 8 ounces sodium dichromate to one gallon of water. Rinse, dry and apply appropriate finish.

**4-60.** Castings are welded for two reasons; (1) to join them to wrought metal during assembly work and (2), to repair broken or cracked sections or parts providing the damage is not in highly stressed area and that government specifications permit the particular repair. Gas tungsten-arc welding is preferred for such welding although emergency field repair of a casting may be done by gas methods. There are several important factors to know before casting welding is attempted, i.e., alloy composition, heat treatment, section size and complexity and weld location relative to expansion and contraction effects. If alloy designation or type is not known, a chemical or spectrographic analysis of composition should be made so proper welding technique and material can be used. For the same purpose, the basic heat treat condition of the part is required.

**4-61. GAS TUNGSTEN-ARC REPAIR WELDING IS ACCOMPLISHED AS FOLLOWS:**

1. Strip casting of paint, remove any pickle treatment from broken edges with steel wool or power stainless wire brush.
2. Clamp broken pieces in place and bevel the fractured edges (or the crack edges if only cracked) as shown for wrought welds in Figure 4-2. Preheat in accordance with Table 4-20 using furnace or local torch heat.
3. Weld immediately after preheating. Reheat when casting temperature drops below 650F.
4. Use medium size weld beads.

TABLE 4-14. WELDING RODS FOR JOINING WROUGHT TO WROUGHT ALLOY.

BASE ALLOY	A3A	AZ31B	AZ61A	AX80A	HK31A	HM31A	ZK21A	ZK60A&B
A3A	1							
AZ31B	1	1						
AZ61A	1	1	1					
AZ80A	1	1	1	1				
HK31A	1	1	1	1	2			
HM21A	1	1	1	1	2	2		
HM31A	1	1	1	1	2	2	2	
ZK21A	1	1	1	1	1	1	1	1
ZK60A, B	X	X	X	X	X	X	X	X X

CODE 1 = Use AZ92A or AZ61A rod - AZ92A preferred. AZ61A cheaper, generally satisfactory, but subject to weld cracking.

2 = Use EZ33A rod, particularly when two alloys for elevated temperature use are to be welded. Use AZ92A or AZ61A when an elevated and room temperature alloy are welded together.

X = Welding not recommended.

TABLE 4-15. WELDING RODS FOR JOINING CAST TO WROUGHT ALLOYS.

CAST ALLOY	A3A	AZ31B	AZ61A	AZ80A	HK31A	HM21A	HM31A	ZK21A	ZK60A&B
AZ63A	X	X	X	X	X	X	X	X	X
AZ81A	1	1	1	1	1	1	1	1	X
AZ91C	1	1	1	1	1	1	1	1	X
AZ92A	1	1	1	1	1	1	1	1	X
EZ33A	1	1	1	1	2	2	2	1	X
HK31A	1	1	1	1	2	2	2	1	X
HZ32A	1	1	1	1	2	2	2	1	X
KIA	1	1	1	1	1	1	1	1	X
QE22A	1	1	1	1	2	2	2	1	X
ZE41A	1	1	1	1	1	1	1	1	X
ZH62A	X	X	X	X	X	X	X	X	X
ZK51A	X	X	X	X	X	X	X	X	X

CODE 1 = Same as for Table 4-14

2 = Same as for Table 4-14

X = Same as for Table 4-14

TABLE 4-16. WELDING RODS FOR JOINING CAST TO CAST ALLOYS.

CAST ALLOYS	AZ63A	AZ81A	AZ91C	AZ92A	EZ33A	HK31A	HZ32A	KIA	QE22A	ZE41A	ZH62A ZK51A
AZ63A	1										
AZ81A	X	1									
AZ91C	X	1	1								
AZ92A	X	1	1	1							
EZ33A	X	1	1	1	2						
HK31A	X	1	1	1	2	2					
HZ32A	X	1	1	1	2	2	2				
KIA	X	1	1	1	1	1	1	2			
QE22A	X	1	1	1	2	2	2	1	2		
ZE41A	X	1	1	1	1	1	1	1	1	2	
ZH62A	X	X	X	X	X	X	X	X	X	X	X
ZK51A	X	X	X	X	X	X	X	X	X	X	X

**TABLE 4-16. WELDING RODS FOR JOINING CAST TO CAST ALLOYS (CONT'D).**

CODE = 1=Same as for Table 4-14  
 2=Same as for Table 4-14  
 X=Same as for Table 4-14

**TABLE 4-17. WELDING FLUXES FOR MAGNESIUM.**

DOW NO.	TYPICAL COMPCOSITION	USE
450	KC1-45 NAC1-26 LIC1-23 NAF-6	Oxyacetylene welding
460	KC1-53 CAC1 <sub>2</sub> -29 NAC1-12 NAF-6	All gas welding

Dow 450 has excellent characteristics with acetylene gas but may cause more pitting of the head than Dow 460. If the beak is not to be ground flush or if bead appearance is important, Dow 460 with its lessened ease of welding should be used with acetylene gas.

**TABLE 4-18. STRESS RELIEVING ARC WELDED MAGNESIUM.**

ALLOY	SHEET TIME (MIN)	TEMP <sup>o</sup> F	EXTRUSIONS			CASTINGS		TEMP <sup>o</sup> F
			ALLOY	TIME	TEMP <sup>o</sup> F	ALLOY	TIME (HRS)	
AZ31B-0(1)	15	500	AZ31B-F(1)	15	500	AZ63A(1)	1	500
AZ31B-H24(1)	60	300	AZ61A-F(1)	15	500	AZ81A(1)	1	500
HK31A-H24(2)	30	550	AZ80A-T5(1)	60	400	AZ91C(1)	1	500
HM21A-T8(3)	30	700	HM31A-T5	30	500	AZ92A(1)	1	500
			(3)	(2)		EZ33A(2)	2	650
							plus	
						HK31A(2)	5	420
							16	400

CODE (1) = Requires these alloys to prevent stress corrosion cracking.

(2) = Requires these alloys to obtain stress free assembly.

(3) = 80-95% stress relief obtained in all alloys except HM21A-T8 and HM31A-T5 where about 50% stress relief is obtained.

5. Weld broken pieces from the center of the break to the outside edges. Do not let the arc dwell too long in one area as weld cracking can result.

6. Use a foot control to fade out the arc gradually to prevent cracking which can occur with sudden arc stops.

7. Reheat treat or stress relieve as applicable in accordance with Table 4-8 or Table 4-18.

4-62. Arc weld joining of wrought parts to castings is done using the appropriate welding rods (See Table 4-15) and the following method:

a. Taper the edges of heavy casting sections to the thickness of the wrought sheet or extrusion. Use Figure 4-2 as a guide for edge preparation.

b. Preheat the casting if desired but it is not required.

c. Direct heat principally upon casting during welding.

d. For maximum properties the castings should already be in the heat treat condition desired since further heat treat of the joined assembly will decrease the wrought material's properties. Stress relieve per Table 4-18 if desired, using the lower of the temperatures recommended for relieving the two different components.

**4-63.** Gas Weld Repair Of Castings. The procedures of paragraph 4-60 generally apply to this work. Parts so welded should be stress relieved per Table 4-18 or heat treated according to Table 4-20. All excess flux must be removed as soon as the part is cool enough to handle.

**4-64. ARC WELDING.** The advantages of arc welding over gas welding of magnesium are many. Included are: high strength efficiency, porosity free welds, elimination of flux requirement, no restrictions on type joints possible, detrimental heat side effects virtually eliminated, any thickness of commonly used alloys can be welded, rapid and accurate welds and less after weld clean up and finishing required. Inert gas, concentrated at the point of fusion, shields the metal from the atmosphere, preventing the rapid oxidation which would be present otherwise. Methods utilizing AC or DC current are used and either tungsten electrodes or consumable electrodes are employed. The method used depends upon the alloy, design or part, thickness of alloy and equipment available. Joining of dissimilar magnesium alloys can be done with the resultant joint retaining the approximate strength of the alloy with the lower weld strength. Use of welding rod with higher alloy content than that of the material being joined, improves the weld strength. Peening of the weld at 300° - 400°F heated condition also improves the weld strength. Overpeening must be guarded against to prevent weld cracking. Stress relieving of weldments is necessary in some alloys listed in Table 4-18 and discussed in paragraph 4-95. Table 4-25 lists some common faults in arc welding and the causes.

**4-65.** Equipment. Welding machines are of the stable arc DC continuous amperage control type, the AC type; having a high frequency current superimposed on the normal current and a constant potential (reverse polarity of electrode positive, work negative) DC type. Material under 3/16" thick may be welded with any machine; thicker material requires an AC machine which has better penetrating power. Machines should be of 100-200 ampere capacity. Direct current machines should have continuous amperage control in low ranges. They can be utilized in place of AC types when smooth welds are desired or when a weld is made on material without back up support.

**4-66.** Electrodes begin at 3/32" diameter for 0.030" thickness material and range to 1/2" for thicker stock and are of tungsten for the non-consumable electrode welding with the stable arc DC and AC machines. The DC constant potential type welder uses consumable electrode wire of 1/16" to 3/32" diameter.

**4-67.** Welding rods serve as filler metal, coming in 36" long pieces for manual welding and in wire reels for automatic machines. Refer to paragraph 4-55 for rod information.

**4-68.** The inert gas used is either argon or helium and must be of high purity. Normally one-third the volume of argon is required for any given amount of welding, compared to helium. Helium is better for use with DC reverse polarity welding, argon for AC. The gas control should be such that it starts to flow a fraction of a second before striking an arc and continues to flow several seconds, after stopping the arc.

**4-69.** Operators should be equipped with the necessary goggles, helmets, and fire resistant clothing. The gases used are considered non-toxic and no special precautions are necessary for their use.

**4-70.** Suitable fixtures and jigs should be used to properly support and securely hold the part being welded to prevent distortion and warping.

**4-71.** Arc Welding Procedures for Joining Sheet, Plate and Extrusions. As in gas welding, the first important procedural step in successful arc welding is surface preparation. Cleaning of the surface is the same as for gas welding. Joining edges should be clean and smooth. Sheared edge of sheet stock above 0.080" thickness should be double sheared, thinner stock than this may be single sheared. Preparation of the abutting edges or surfaces of the alloy material for typical joints are as shown in Figure 4-2. Clean welding rods should be used. If cleaning is necessary, straight rods may be cleaned with steel wool or in a chromic acid sodium nitrate dip; coiled rod by using the dip. All surface and rod cleaning should be done just before welding.

**4-72.** In addition to cleaning and proper surface and edge conditioning, the material to be welded should be properly supported in rigid jigs or fixtures to prevent any movement in any way during the actual welding. In magnesium with its high thermal expansion and conductivity properties, parts being welded will move if not securely restrained. One particular fixture of primary importance in welding flat material seams is the backing plate. The plate may be of magnesium, steel or aluminum. A groove machined in the plate to the approximate size of the bead to be made serves to prevent concavity of the weld when it cools. The material being welded should be securely clamped to the backing plate with the proposed seam line centered over the groove. A seam gap no greater than 1/16" is generally used. Clamps or hold down devices should be placed as close to the weld area as possible to prevent metal distortion and bead lift-up. All fixtures used must be clean and rust free, especially in the weld areas to prevent weld porosity. If materials of different thicknesses are being welded and the thickness difference is 1/4" or more, heat the heavier section with a gas torch to 350°F. A typical backing plate is shown in Figure 4-3.

TABLE 4-19. PREHEAT TEMPERATURES FOR WELDING CASTINGS.

ALLOY	PREHEATING REQUIRED - °F	
	HEAVY OR UNRESTRAINED SECTIONS	THIN AND /OR RESTRAINED SECTIONS
AZ63A*	Local or none	650 - 720
AZ81A	Local or none	650 - 750
AZ91C	Local or none	650 - 750
AZ92A	Local or none	650 - 750
EZ33A	None to 500°F	1 1/2 hrs max at 500
HK31A	None to 500°F	None to 500
HZ32A	None to 500°F	None to 500
KIA	None	None

\* Preheat at rate not exceeding 150°F/hr from 500°F to treating temperature if casting is in -F temper.

ALLOY	ROD	PREWELD TEMPER	DESIRED PCST WELD TEMPER	HEAT TREATMENT AFTER WELDING
AZ63A	AZ92A*	-F*	-T4	12 hrs @ 725 + 5°F
		-F**	-T6	12 hrs @ 725 + 5°F plus 5 hrs @ 425°F
		-T4	-T4	1/2 hr @ 725 + 5°F
		-T4 or T6	-T6	1/2 hr @ 725 + 5°F plus hrs at 425°F
AZ81A	AZ92A	-T4	-T4	1/2 hr @ 725 + 5°F (Use CO <sub>2</sub> or SO <sub>2</sub> atmosphere)
		-T4	-T4	1/2 hr @ 725 + 5°F (Use CO <sub>2</sub> or SO <sub>2</sub> atmosphere)
		-T4	-T6	Same
AZ91C	AZ92A	-T6 or T4	-T6	1/2 hr @ 775 ± 10°F plus 4 hrs @ 420°F or
				16 hrs @ 335°F (Use CO <sub>2</sub> or SO <sub>2</sub> atmosphere)
		-T4	-T4	1/2 hr @ 775 ± 10°F (Use CO <sub>2</sub> or SO <sub>2</sub> atmosphere)
AZ92A	AZ92A	-T4 or T6	-T6	Same plus--
				4 hrs @ 500°F or 5 hrs @ 425°F
EZ233A	EZ33A	-T5	-T5	2 hrs @ 650°F plus 5 hrs @ 420°F or 5 hrs @ 425°F
HK31A	EZ33A	-T6	-T6	16 hrs @ 400°F
HZ32A	EZ33A	-T5	-T5	16 hrs @ 600°F
KIA	EZ33A	-F	-F	None

TABLE 4-20. HEAT TREATMENT CASTINGS AFTER WELDING.

\* Use AZ63A rod if required.

\*\* Preheat not exceeding 150°F/hr from 500°F - Use AZ63A rod with -F since 12 hrs @ 725°F causes germination in AZ92A welds.

**4-73. Welding Methods and Procedures.** The following paragraphs will explain the general guidance for manual arc welding, machine welding and consumable electrode welding. Specific data on alloys should be derived from the use of applicable specifications for the alloy and for the type welding to be done.

**4-74. Prevention of Cracks, Warpage and Stress Corrosion.** Cracks sometime occur during welding of some alloys and can be prevented by one of two methods:

a. Butt scrap pieces of stock of the dimension and alloy of the material being welded against each end of the joint. Start the weld in the joint of one scrap piece and continue across onto the opposite scrap piece, welding both scrap and basic material together for later separation.

b. Start the weld in the middle of the joint of the material and weld to each edge. No scrap use is necessary here. Some crack minimization can be gained also if both material and holding fixtures are preheated to 200-400°F or by increasing the speed of the welding.

**4-75. Warpage** can often be prevented by proper use of jigs or holding fixtures and/or tack welding prior to complete welding. Tack welds on 0.064" material are 1/16" tacks spaced 1-2 inches apart. On thicker material such as 1/4" the tacks are 1/4" 4-5 inches apart. Start the tacks a short distance from the end of the seam. Any straightening of the metal required from tacking may be done with a soft leather or wood mallet. If work hardening has occurred in a part it may be corrected by heating the parts at stress relief temperatures and then lightly hammering or pressing it into shape with a leather or wooden mallet, or by placing the part in the fixture it was welded in and oven heating it to stress relief heat.



TABLE 4-21. INFORMATION FOR MANUAL GAS TUNGSTEN - ARC WELDING MAGNESIUM.

MATERIAL THICKNESS (INCHES)	NR OF PASSES	WELDING CURRENT* IN AMPERES		ELECTRODE DIAMETER (INCHES)			WELD ROD DIAMETER (INCHES)	GAS FLOW ARGON	(CU FT/HR)	
		AZ31B	HK31A-HM21A	AC	DCRP	DCSP			ARGON	HELIUM
0.040	1	35	40	1/16	5/32	.040	3/32	12	24	
0.063	1	50	55	1/16	3/16	.040	3/32	12	24	
0.080	1	65	70	1/16	3/16	1/16	3/32	12	14	
0.100	1	85	95	3/32	1/4	1/16	1/8	18	30	
0.125	1	100	110	1/8	1/4	1/16	1/8	18	36	
0.190	1	140	155	1/8	---	3/32	5/32	18	36	
0.190	2	100	110	1/8	1/4	1/16	1/8	18	36	
0.250	1	180	200	5/32	---	3/32	5/32	18	48	
0.250	2	115	125	1/8	1/4	1/16	1/8	18	36	
0.375	1	250	275	3/16	---	1/8	3/16	24	48	
0.375	2	140	155	1/8	---	3/32	5/32	24	48	
0.500	2	310	340	1/4	---	1/8	3/16	24	48	
0.750 and over	2	350	385	1/4	---	5/32	3/16	36	48	

\* Current values given are for welding with backing plate and fillet welds. Slightly lower current values are used for welding without plate and for making corner or edge joints.

TABLE 4-22. INFORMATION FOR MACHINE GAS TUNGSTEN - ARC WELDING \*.

MATERIAL THICKNESS (INCHES)	WELDING** CURRENT (AMPERES)	WELDING** SPEED (IN/MIN)	ELECTRODE DIAMETERS (INCHES)			WELDING ROD DIA (INCHES)	WELDING ROD SPD (IN/MIN)	GAS FLOW CU/FT/HR	
			AC	DCRP	DCSP			ARGON	HELIUM
0.040	55	20	1/16	3/16	.040	3/32	12	18	
0.063	75	18	3/32	3/16	1/16	3/32	20	18	
0.080	95	17	3/32	1/4	1/16	3/32	24	18	
0.100	115	16	3/32	1/4	1/16	1/8	14	18	
0.125	150	14	1/8	---	3/32	1/8	17	18	
0.190	250	12	3/16	---	1/8	1/8	24	18	
0.250	350	10	1/4	---	1/8	1/8	28	18	

\* Information based on use of backing plates, hold down bars and square butt joints.

\* Approximate current values and welding speeds only. Lower welding currents and slower speeds possible when welding with DC.

\*\* Maximum thickness recommended for DCRP welding.



**4-76.** Stress corrosion occurs in welding some alloys, especially those of the magnesium, aluminum zinc types, from heat induced residual stresses in the weld area. If not relieved the stresses will nearly always result in cracking of the weld. To properly eliminate this condition the part should be placed in its welding jig or fixture and heated at the temperatures reflected in Tables 4-19 and 4-20 for the particular alloy. Cool in still air after relieving. Jigs or fixtures should be used to prevent possible warpage during relieving.

#### **4-77. WELDING METHODS.**

**4-78. MANUAL WELDING, ARC TYPE.** Table 4-22 lists manual welding data. In both AC and DC welding, gas flow should start prior to starting the arc. Continue this flow for a few seconds after the arc is stopped to prevent excessive oxidation of the tungsten electrodes. Start the DC arc by brushing the electrode over the material surface and maintain it to about 1/8" length. Starting and stopping the arc in AC welding should be done by an operator controlled switch. The electrode should be held nearly flush or a little below the surface of the work. In both types hold the torch almost perpendicular to the work and the welding rod nearly parallel to the work. Move the torch and rod along the seam at an even speed in a straight line, using a fanning or rotary motion only if large corner or fillet welding is being done. Control the rate of movement to give an even secure bead. Work from one edge of the material to the opposite edge with as few stops as possible. Whenever a stop is made in a bead, resume the weld by starting back in the bead about 1/2" from the stopping place. Welds in material thicker than 3/8" should be made with multiple beads. The material should be V-grooved in accordance with the pattern of Figure 4-2. Run a small bead at the base of the groove, the length of the joint. Wire brush this bead then fill the groove with additional beading. When possible, use a double V-groove (one on each side) will reduce warping and improve weld soundness. The beads should be flat or concave, not convex. Maintain medium size beads, which give maximum strength and less finishing work.

**4-79. CONSUMABLE ELECTRODE ARC WELDING.** This type welding is accomplished using one of three constant potential power sources:

- (1) A motor generator with a rising volt-ampere characteristic.
- (2) A motor generator with a flat or slightly rising characteristic.

(3) Rectified direct current with a drooping characteristic. Argon gas provides the shield. High welding speeds and deposition rates are available with this method resulting in a weld as strong as tungsten arc welds. Table 4-23 lists service data for this type welding. The use of this process produces three types of metal transfer. Higher density current results in a forceful spray effect, which is especially effective when welding material over 3/16" thick. The metal from the rod actually sprays to form a bead. Decreasing the current density and voltage results in the metal dripping from the rod in the form of small globules. Welding of material less than 1/8" can be effectively done with this type.

**4-80.** Finishing of material after it is arc welded is a fairly simple process since no flux is used. Usually only a wire brushing or cleaning as described for preweld surface treatment is required. If arc weld "smoke" is present, the material can be cleaned in a 180° 212°F bath composed of 16 ounces tetrasodium pyrophosphate ( $\text{Na}_4\text{P}_2\text{O}_7$ ); 12 ounces sodium metaborate ( $\text{NaBO}_2$ ) with enough water to make one gallon of solution. Qualities required may be less or greater but proportions should not vary. One half to 2 minutes immersion is sufficient. Excess bead may be removed by filing, grinding, routing or some similar method.

**4-81.** Inspection of joints. Visual, radiographic, ultrasonic or fluorescent oil penetrant types of inspection are used on magnesium welds to check for cracks, porosity, and other detrimental defects. A separate section of this technical manual details inspection and test criteria and procedures. General inspection specifications are:

Radiographic	- MIL-I-6865, MIL-R-11471, MIL-X-6141
Penetrant	- MIL-I-6866
Testing	- MIL-T-5021

**4-82. SPOT WELDING.** This type of resistance welding is the most widely used, and provides the means for rapidly obtaining statically strong seams in properly prepared metal. A minimum of finishing of the seams is required after welding. Usually some stress relieving and possibly joint sealing or painting is sufficient to complete the job. Spot welds are not as strong as riveted or adhesive bonded joints. Parts with spot weld type of joints are generally used in lower stress applications although past use in high vibration free high stress locations have been successful. The quality of the weld is dependent on properly prepared metal surfaces and closely controlled welding techniques. The exactness of machine control is mandatory since the conduction properties of magnesium are such, that high current and short dwell or weld time must be used to effect a good joint without damaging the metal.

In addition to the current and time requirements, correct pressure must be applied to the metal while it is plastic from the electrical heating. Pressure can be divided into two steps. The first is the application of initial squeeze to press the surfaces together; the second is the forge force which is applied to force the plasticized metals together. The best control of pressure is available in pneumatic operated mechanisms since they are capable of both rapid and accurate pressure follow up. Closer edge spacing and smaller flanges are made possible because magnesium spot welding generally requires less pressure than aluminum. Also because of this fact, smaller off-set electrodes may be used in confined areas. Table 4-25 lists some spot weld machines and Table 4-26 lists recommended spacing data for spot welding.

**4-83.** There are some conditions to be avoided if functionally sound joints are to result.

- a. Dissimilar alloys should not be spot welded together, especially those that have very different properties.
- b. Avoid use of spot welded assemblies in areas where very high vibration is encountered.
- c. In welding together material of different thicknesses, when high strength joints are desired, avoid exceeding a thickness ratio of 2.5 to 1. (If such welding is necessary use DC equipment and place the thicker piece against the positive electrode).
- d. Do not join three pieces together unless the thicknesses are within 25% of each other and the thickest piece is in the middle. Table 4-27 reflects typical shear strengths of spot welds in some alloys.

**4-84.** Spot Welding Equipment Requirements. Machines used in this type welding may be AC single and 3-phase, DC stored energy and dry disk rectifier. They should incorporate high current capacity, accurate welding time control and positive pressure control if quality strong welds are expected. The design of the electrodes used with the welding machine is particularly important. Both dome shaped and flat tipped over are used. The tip radius may vary from 2 to 8 inches in the dome shaped. The flat type tips range from 3/8" to 1-1/4" in diameter and are used when mark free surfaces are a requirement. Electrodes are made of high conductivity copper alloy, R.W.M.A. Group A, Class 1 or 2. Water cooling of these to within 3/8" of the tip is necessary and intermittent cooling occurring only when the weld is made is the better means of maintaining constant tip temperature control. Keep the electrode contact surfaces clean and smooth.

**4-85.** Spot welding Procedures. As in arc and gas welding the initial step of surface preparation is important if a good weld is expected. The surface should be clean with an even and low resistance (50 microhms or less). Use water cooled high conductivity tips and keep them clean, smooth and free of condensation.

**4-86.** In surface preparation (prior to welding) the material may be cleaned with stainless steel, aluminum oxide pads, cloth, or stainless steel rotary wire brushes. Do not use steel wonder brushes Other, than these in mechanical cleaning since the electrically charged tip will attract metal particles. Chemical cleaning is recommended if possible and especially if a large production is contemplated. A low even surface resistance, half as much tip cleaning and a longer allowable period between cleaning and actual welding will result if material is chemically rather than mechanically cleaned. Mechanically cleaned material should be welded at once; chemically cleaned material can go as long as 24 hours before being welded. Chemical cleaning is accomplished in the following manner:

- a. Vapor degrease or alkali clean the surface.
- b. Dip the material in a 30 second bath proportioned to 0.67-1.3 fluid ounce of sulfuric acid (nitric or hydrochloric are substituted) to each gallon of water to remove oxide deposits. Rinse in cold water.
- c. Finally immerse the material in a 30 second room temperature bath in 1/3 ounce chromic acid per one gallon of water; or a 3-minute bath in 24 ounce chromic acid and 1/16 fluid ounce of concentrated sulfuric acid to each gallon of water.

#### **CAUTION**

**Alloys containing thorium will be immersed for 3-8 minutes; Tanks for these baths are of ceramic, rubber lined, stainless steel or 1100 aluminum.**

- d. Rinse material in cold running water then in hot water.

**4-87.** Only material with an oiled or acid pickled surface finish should be used for spot welding due to the surface etch imparted to magnesium by a chrome pickle finish. It is difficult to remove this etch.

**4-88.** Welding with single phase AC machines is accomplished using electronic current and timing control and slope control of wave must be maintained. If the electricity supply line is used to power other equipment and therefore subject to voltage drop, the welding machine should be equipped with either a signal device to show a poor weld has been made or a nonfiring device to prevent welding, when a detrimental voltage drop occurs. Prevention of cracks in spot welds can be avoided by post heat application to the welds. About 2 or 3 cycles of heat is effective in preventing such cracks. Slope control, as illustrated by Figure 4-4 will also assist in controlling weld cracking. Precise timing other heat and pressure application with variable control of heat and pressure intensity results in welding with minimum possibility of cracking and spitting. Slope control enables single phase machines to weld alloys normally welded by stored energy machines.

TABLE 4-23. CONSUMABLE ARC WELDING DATA.

SHEET OR PLATE THICKNESS(INCHES)	TYPE WELD	WIRE DIA INCHES	ARC		WIRE SPEED IN/MIN	ARGON FLOW CU FT/MIN	TYPE OF TRANSFER
			VOLTS	AMPS			
0.025-0.050	Butt	0.027	13-18	16-40	205-510	40-60	Low Voltage Drip
0.040-0.093	Butt	0.050	13-18	32-80	125-290	40-60	" "
0.040-0.093	Butt	0.064	13-18	40-130	100-205	40-60	" "
0.064-0.125	Butt	0.092	13-18	50-130	70-144	40-60	" "
0.250	Vertical Down Fillet	0.050	22-24	220-230	890-913	60-80	Spray
0.500	" "	0.050	24-26	220-230	913	60-80	Spray
0.1875-0.375	Butt & Fillet	0.050	24-30	222-280	788-960	60-80	Spray
0.250	" "	0.064	24-30	240-290	550-660	60-80	Spray
0.375	" "	0.064	24-30	260-350	560-745	60-80	Spray
0.500	" "	0.064	24-30	320-390	740-820	60-80	Spray
0.375	" "	0.092	24-30	330-350	350-385	60-80	Spray
0.500	" "	0.092	24-30	350-380	360-402	60-80	Spray
0.625	" "	0.092	26-30	370-420	375-417	60-80	Spray
1.000	" "	0.092	26-30	370-420	375-417	60-80	Spray

TABLE 4-24. ARC WELD FAULTS.

WELD FAULT	CAUSE	CORRECTION
Crater Cracks	Improper manipulation torch and welding rod.  Wrong rod alloy.	Break arc slowly while continuing to add rod. Use runout tabs. Decrease current at end of weld while adding rod. Use recommended alloy.
Longitudinal Cracks	Wrong rod alloy Improper joint spacing Improper edge preparation. Low weld current Overstressed Weld.	Use recommended alloy. Use proper joint design. Use proper preparation. Use correct current. Preheat 200°F to 400°F. Increase weld size of section thickness. Place weld in compression. Use more ductile alloy.
Underhead Cracks (Mostly Common) on Automatic type.	Arc travel speed too high Wrong type joint, fillet size of parent alloy.	Reduce travel for better control and penetration. Adjust as required. Use proper joint design.
Incomplete Fusion	Improper joint preparation oil, dirt, etc on joint. Low welding current.	Use proper design. Clean joint thoroughly before welding. Use proper weld current.
Undercutting	Improper torch or rod manipulation. High weld current. Fast weld speed.	Practice welding to replace melted parent metal with rod Use proper current. Decrease speed.
Porosity	Dirty welding wire or parent metal. Wrong arc length and technique. Inadequate coverage.	Clean materials thoroughly. Use recommended arc length, hold close arc to get proper gas shielding. Use proper amount of gas.
Incomplete Penetration.	Low Weld current Wrong joint spacing. Improper edge preparation. Long Arc.	Use proper current. Use Proper joint design. Use correct preparation. Hold shorter arc.

TABLE 4-25. SPOT WELDING MACHINES FOR MAGNESIUM.

TYPE MACHINE	CHARACTERISTICS	REMARKS
AC 3 Phase	Greater gauge capacity at a given line demand.	Preferred Equipment.
AC Single Phase	Line demand as high as 500KVA in welding 0.125" sheet.	Best with electronic control of weld-timing plus slope control.
AC Dry Disk Rectifier	Similar to 3 Phase.	Converts 3 Phase AC to DC.
DC Stored Energy Electrostatic	Low line demand. Capacitance required varies from 240 to about 2300 mfd for sheet up to about 0.125".	Most widely used stored energy machine. Best results with high turn ratio/peak current 10-20 milliseconds.
Electro-Magnetic	Low line demand.	-----

TABLE 4-26. RECOMMENDED SPOT SPACING AND EDGE DISTANCE FOR SPOT WELDS.

SHEET THICKNESS (INCHES)	SPOT SPACING		EDGE DISTANCE	
	MIN IN	NOM IN	MIN IN	NOM IN
0.020	0.25	0.50	0.15	0.25
0.025	0.25	0.50	0.16	0.25
0.032	0.31	0.62	0.18	0.25
0.040	0.38	0.75	0.20	0.25
0.050	0.41	0.75	0.23	0.31
0.063	0.50	1.00	0.27	0.38
0.080	0.62	1.25	0.31	0.41
0.100	0.62	1.25	0.37	0.50
0.125	0.75	1.50	0.44	0.62

TABLE 4-27. TYPICAL SHEAR STRENGTH OF SPOT WELDS.

SHEET ALLOY	THICKNESS (INCHES) DIA	AVERAGE SPOT DIA (INCHES)	SINGLE SPOT SHEAR STRENGTH (POUNDS)
AZ31B	0.020	0.14	220
	0.025	0.16	270
	0.032	0.18	330
	0.040	0.20	410
	0.050	0.23	530
	0.063	0.27	750
	0.080	0.31	890
	0.100	0.34	1180
HK31A	0.025	0.38	1530
	0.032	0.18	300
	0.040	0.20	375
	0.050	0.23	550
	0.063	0.27	720
	0.090	0.35	1200
HM21A	0.125	0.38	1490
	0.040	0.20	360
	0.063	0.27	660
	0.125	0.38	1220

TABLE 4-28. SPOT WELDING AX31B SINGLE PHASE AC SINGLE WELD FORCE.

MATERIAL THICKNESS INCHES	TIME (CYCLES)	ELECTRODE WELD FORCE (LBS)	WELDING CURRENT AMPERES	DOME TIP RADIUS (INCHES)
0.020	4-3	200-400		
0.040	5-4	400-600		
0.063	7-5	500-700		
0.080	9-7	600		
0.100	12-9			
0.125	14-10			

**4-89.** The second type of AC spot welding is done using a three phase frequency converter operation. This also is referred to as pulsation welding. Line voltage and frequencies are transformed into single direction current pulses by transformers and controls. Standard machines produce from 1 to 5 pulses. Table 4-29 gives reference data for welding with these machines. Although this table only presents single weld force data, dual force operation with both weld and force pressure applied makes welding of the alloys possible at lower current and electrode forces. Best general weld-to-force force is about 1-1 to ½-2.

**4-90.** Electrostatic spot welding is accomplished using DC transformer-condenser machines operated on the principal of electrical current from step-up transformer being stored by condensers and then discharged through the electrodes and the alloy metals. The resulting heat, when used with correct pressure and under proper timing and intensity control, will effectively weld the metal together. The intensity of available current is governed by the transformer; turn ratio 480:1 is the best for magnesium.

**4-91.** A means of reversing current flow direction or polarity should be provided since electrode tip life can be greatly extended if the polarity is reversed for each successive weld. An example for this type welding is given in Table 4-30. Using this method with automatic operation, however, requires speed control reduction to insure full charging of the condenser before discharge, otherwise inconsistent welding may occur.

**4-92.** Beam welding is done in a manner similar to spot welding with the added advantage that a continuous fluid and gas tight seam can be made by overlapping the welds. Shear strength compares very favorably to those of conventional spot welds; e.g., 10752250 lbs/linear inch for 0.040 0.0125" thick AZ31B alloy.

#### **4-93. MAGNESIUM ALLOY SURFACE TREATMENT.**

**4-94.** Some magnesium surface treatments outlined in, Military Spec MIL-M-3171 for corrosion protection and producing suitable paint surfaces are as follows:

a. Type I - Chrome-Pickle Treatment used for temporary storage, domestic shipment, electrical bonding and touch-up of previously treated work. Applicable to all alloys when close dimensional tolerance is not required (commercially known as DOW No. 1).

b. Type II - Dichromate Treatment For general long time protection of all alloys except magnesium cerium and magnesium-manganese alloys (commercially known as DOW No. 7).

c. Type IV - Galvanic Anodizing Treatment For general long time protection of all alloys when close dimensional tolerances are required (commercially known as DOW No. 9).

d. Type VI - Chromic Acid Brush -Or Treatment For temporary storage, protective touch-up of previously treated work, and brush application where parts and assemblies are too large to be immersed. Applicable to alloys when close dimensional tolerances are not required (commercially known as DOW No. 19).

e. Type VII - Fluoride Anodizing Treatment For cleaning of magnesium alloys as a substitute for shot or grit blasting, by providing a relatively inert film when close dimensional tolerances are required and a good base favorable to paint adhesion (commercially known as magnesium elektron fluoride anodize).

**4-95.** T.O. 42C2-1-7 provides instructions covering the procedures to be used in the processing of magnesium base alloys for the coatings listed above. Additional types of treatments (anodic) are specified by "IL Specification MIL-M-45202. Application of some methods also cited in T.O. 1-1-2 and T.O. 1-1-8.

**TABLE 4-29. SPOT WELDING WITH 3-PHASE FREQ CONVERTER MACHINES - SINGLE WELD FORCE \***

ALLOY	SHEET THICKNESS (IN.)	LOW FREQ PULSE	CYCLES WELD	ELECTRODE WELD FORCE (LBS)	APPROX RMS CURRENT AMPS	ELECTDE DOME RADIUS
AZ31B	0.063	3	½	1750-3400	35200-67900	4"
HK31A	0.040	1	½	1000-1800	19600-27900	3"
	0.063	3	½	2400-3600	39400-53800	4"
	0.125	5	3	5000 (min)	65900 (min)	6"
HM21A	0.040	1	1	800-1600	21600-30300	3"
	0.083	3	1	1600-2800	40600-53800	4"
	0.125	5	1	3800 (min)	66700 (min)	6"

**TABLE 4-30. SPOT WELDING AZ31B, ELECTROSTATIC STORED ENERGY MACHINES  
1/ - SINGLE WELD FORCE.**

SINGLE SHEET THICKNESS (INCHES)	ELECTRODE WELD FORCE (LBS)	CONDENSER CAPA (MICROFARADS)	CONDENSER VOLTAGE	DOME TIP RADIUS (INCHES)
0.020	600-800	240	1400-1800	2-4
0.040	900-1100	600	2200-2600	2-4
0.063	1300-1600	1080	2000-2400	2-6
0.080	2000-2400	1400	2000-2400	4-6
0.100	2600-3000	1800	2000-2400	4-6
0.125	3500-4000	2280	2000-2400	4-6

1/ Time to peak 10-20 milliseconds; turns Ratio 480:1.

**TABLE 4-31. SPOT WELD FAULTS.**

FAULT	CAUSE	CORRECTION
Explosion	Insufficient weld pressure. Welding current too high partially cleaned surface. Electrode radius too small.	Increase pressure. Decrease current. Clean material thoroughly. Use proper electrode.
Cracking and Porosity	Dirty Surfaces Wrong pressure & hold time	Make trial welds to determine - proper settings. Penetrate should not be less than 20% nor more than 80% into each of the parts welded
Indentation	Electrode tip contour.	Use flat tip on outside surfaces - or gauges up to 0.063". On heavier gauges use flat tips on both surfaces.
Pick-Up	Inadequate surface cleaning Electrode tips not cleaned frequently enough. Improper cooling and condensation  Polarity effect of IC equipment.	Clean thoroughly. Clean frequently. Intermittent cooling during welding only.



## SECTION V TITANIUM AND TITANIUM ALLOYS.

### 5-1. CLASSIFICATION.

**5-2.** Titanium is produced in pure form as well as in various alloys. Pure titanium is commonly known as unalloyed. It can be cast, formed, joined, and machined with relative ease as compared to the various alloy grades. Unalloyed titanium cannot be heat treated. Therefore, its uses are limited to end items not requiring the higher strengths obtained from the heat treatable alloys.

**5-3.** Titanium is a very active metal, and readily dissolves carbon, oxygen, and nitrogen. The most pronounced effects are obtained from oxygen and nitrogen. For this reason, any heating process must be performed in a closely controlled atmosphere to prevent the absorption of oxygen and nitrogen to a point of brittleness.

### 5-4. GENERAL

**5-5. MILITARY AND COMMERCIAL DESIGNATIONS .** There are presently two military specifications in existence (See Table 5-1) covering alloyed and unalloyed titanium in classes established to designate various chemical compositions. For the selection of the proper class and form of stock required for a particular purpose, reference will be made to Table 5-1.

**5-6. PHYSICAL PROPERTIES.** Limited physical properties are available on the titanium compositions covered by existing military specifications. Compared to other materials, the melting point of titanium is higher than that of any of the other construction materials currently in use. The density of titanium is intermediate to aluminum and steel. Electrical resistivities of titanium are similar to those of corrosion resistant steel. The modulus of elasticity is somewhat more than half that of the alloy steels and the coefficient of expansion is less than half that of austenitic stainless steels.

**5-7. MECHANICAL PROPERTIES .** As previously pointed out, titanium is a very active metal and readily dissolves carbon, oxygen and nitrogen. All three elements tend to harden the metal; oxygen and nitrogen having the most pronounced effect.

**5-8.** The control of these elements causes considerable difficulty in obtaining correct mechanical properties during the fabrication of titanium. This variation in mechanical properties is the cause of difficulties encountered in the fabrication of parts, since the absorption of small amounts of oxygen or nitrogen makes vast changes in the characteristics of this metal during welding, heat treatment, or any application of heat in excess of 800°F.

**5-9.** Operations involving titanium requiring the application of heat in excess of 800°F must be performed in a closely controlled atmosphere by methods explained in future paragraphs. The nominal mechanical properties are listed in Table 5-2.

**5-10. METHODS OF IDENTIFICATION .** Methods of distinguishing titanium alloys from other metals are simple and definite. One quick method is to contact the titanium with a grinding wheel. This results in a pure white trace ending in a brilliant white burst.

Also, identification can be accomplished by moistening the titanium and marking the surface with a piece of glass. This leaves a dark line similar in appearance to a pencil mark. Titanium is non-magnetic. To positively identify the various alloys, a chemical or spectrographic analysis is necessary.

**5-11. HARDNESS TESTING .** Hardness is the resistance of a metal to plastic deformation by penetration, indentation, or scratching, and is usually a good indication of strength. This property can be measured accurately by the Brinell, Rockwell or Vickers Technique. The hardness to be expected from the various alloys and unalloyed titanium is listed in Table 5-2.

**5-12. TENSILE TESTING .** The useful strength of a metal is the maximum load which can be applied without permanent deformation. This factor is commonly called yield strength. The tensile strength of a metal is that load, in pounds per square inch, at which complete failure occurs. In the case of titanium the yield strength is the most important factor and is therefore used by industry to designate the various types of unalloyed titanium.

**5-13. NON-DESTRUCTIVE TESTING .** Titanium and titanium alloys are highly susceptible to stress risers resulting from scratching, nicking, and notching. For this reason, close visual inspection is required of all raw stock prior to any forming or machining operations. All scratches, nicks and notches must be removed, before fabrication, by sanding and polishing.

**5-14. and 5-15.** Deleted.

TABLE 5-1. SPECIFICATION CROSS REFERENCE TITANIUM ALLOYS.

Designation		AMS	military	Other (Z)
<b>COMMERCIALLY PURE (UNALLOYED)</b>				
40KS1 (A-40 55A) YIELD	SHEET, STRIP PLATE	4902	MIL-T-9046 Type I, COMP. A	A-40; HA1940; MST-40; RS-40; T1-55A
	Tubing Welded	4941		A40; 55A
	Tubing Seamless	4942		
55KS1 (A55; 65A) Yield	Sheet, Strip Plate	4900	MIL-T-9046 Type I, COMP. C	A55; HA-1950; MST 55 RS55; T1-65A; NA2-7123B
	Forgings		MIL-F-83142 Comp 1	
70KS1 (A70; 75A) Yield	Sheet Strip Plate	4901	MIL-T-9046 Type I, COMP. B	A70; HA-1970; MST70 RS70; T1-75A; NA2-7126G
70KS1 (A70; 100A)	Bars, Forgings and Forging Stock	4921	MIL-T-9046 Type I, COMP. A	A70; HA-1970; MST70 RS70; T1-75A
	Welding Wire	4951		
<b>ALPHA TITANIUM ALLOY</b>				
5AL-2.5Sn (A110AT)	Sheet Strip, Plate	4910	MIL-T-9046 Type II, COMP. A	A-110AT; HA5137; 0.01 014; MST 5AL-2.5Sn; RS110C; T1-5AL-2.5Sn; NA2-71269
	Bars and Forgings	4926 4966	MIL-T-9047 Comp 2	A-110AT; HA5137; MST 5AL-2.5Sn; RS110C; T1-5AL-2.5Sn; NA2-7149A
	Wire Welding	4953		
5AL-2.5SnEL1	Sheet Strip Plate	4909	MIL-T-9046 Type II, COMP. B	
	Bars and Forgings	4924	MIL-T-9047 Comp 3	
5AL-SZr-5Sn	Sheet, Strip Plate		MIL-T-9046 Type II, COMP. C	
7AL-12Zr	Sheet, Strip Plate		MIL-T-9046 Type II, COMP. D	
7AL-2Cb-1Ta	Sheet, Strip Plate		MIL-T-9046 Type II, COMP. E	
8AL-1MO-1V	Sheet, Strip, Plate	4915 (Single ann'1)	MIL-T-9046 Type II, COMP. F	
	Bars and Forgings		MIL-T-9047 Comp 5	
	Bars, Rings	4972		





TABLE 5-1. SPECIFICATION CROSS REFERENCE TITANIUM ALLOYS (Cont).

8AL-1M0-1V (Continued)	Forgings (Solution heat treated and stabilized)	4973		
	Wire, Welding	4955		
13V-11Cr-3AL	<u>BETA TITANIUM ALLOYS</u>			
	Forgings		MIL-F-83142 Comp 14	
	Bars and Forgings		MIL-T-9047 Comp 12	
13.5V-11Cr-3AL (B120VCA)	Plate, Sheet and Strips Solution Heat Treated	4917		B-120VCA; MST 13V-11Cr-3AL; R120B; Ti-13V-11C4-3AL
11.5 Mo-6Zr-	Bars and Forgings		MIL-T-9047 Comp 13	
	Bars and Wire (Solution Heat Treated)	4977		
8Mn (C110M)	Sheet, Strip, Plate	4908	MIL-T-9046 Type III, COMP. A	C110M, MST 8Mn; RS110A; Ti-8Mn; 0.01002
	Forgings		MIL-T-83142 Comp 12	
4AL-3Mo-IV	Sheet, Strip, Plate	4912	MIL-T-9046 Type III COMP. B	MST 4AL-3MO-IV; RS115; Ti-3AL- 3MO-IV; LB-0170-104
	Sheet, Strip, Plate (Solution and Pre- treated)	4913		
6AL-4V (C120AV)	Sheet, Strip, Plate	4911	MIL-T-9046 Type III, COMP. C	C-120AV; HA6510; MST 6AL-4V; RS120A; Ti-6AL-4V; LB0170-110
	Bars and Forgoings	4928	MIL-T-9047 Comp 6	C120AV; HA6510; MST-6AL-4V; RS120A; Ti-6AL-4V; LB0170-110; 0.01037
	Bars and Forgings (Solution & Precipita- tion Heat Treated)	4965		
	Extrusions	4935		C120AV; HA6510; MST-6AL-4V; RS120A; Ti-6AL-4V; LB0170-147
	Wire, Welding	4954		C120AV
	Forgings		MIL-F-83142 Comp. 6	

TABLE 5-1. SPECIFICATION CROSS REFERENCE TITANIUM ALLOYS (Cont).

6AL-4VEL1	Sheet, Strip, Plate		MIL-T-9046 Type III, COMP. D	
	Bars and Forgings	4930	MIL-T-9047 Comp 7	
	Forgings		MIL-F-83142 Comp F	
	Wire, Welding (Extra low interstitial environment controll- ed)	4956		
6AL-6V-2Sn	Forgings		MIL-F-83142 Comp. 8	
	Sheet, Strip, Plate	4918	MIL-T-9046 Type III, COMP. E	
	Bars and Forgings	4973 Ann'1) 4979 (H. T.)	MIL-T-9046 COMP. B	
	Forgings		MIL-T-83142 Comp. 9	
7AL-4Mo (C135MO)	Sheet, Strip, Plate		MIL-T-9046 Type III, COMP. F	C135MO; HA-7148; MST 7AL-4MO; RS 135; T1-7AL-4MO; LB0170-122
	Bars and Forgings	4970 (H. T.)	MIL-T-9047 Comp. 9	
	Forgings		MIL-F-83142 Comp 13	
6AL-2SN-4Zr- 2Mo	Sheet, Strip, Plate		MIL-T-9046 Type III, COMP. G	
	Bars and Forgings	4979 (H. T.) 4976 (Ann'1)	MIL-T-9047 Comp II	
6AL-2Sn-4Zr- 6Mo	Bars and Forgings		MIL-T-9047 Comp 14	
Heat Treatment of Titanium and Titanium Alloys	<u>MISCELLANEOUS SPECIFICATIONS</u>			
			MIL-H-81200	

TABLE 5-1. SPECIFICATION CROSS REFERENCE TITANIUM ALLOYS (Cont).

Comp/Alloy Designation	Form/Commodity	Specification Data 		Other 
		AMS	Military	
Commercially Pure and various alloys	Wire, Weld, Filler (Fusion Welding)		MIL-W-83138	
<p> There may be controlled requirements applicable to some specifications listed in the same alloy type or series. Validate any difference and assure that selected specification material(s) will comply with end item specification requirements before specifying or using.</p> <p> The following manufactures names apply to designations listed under other:</p> <ul style="list-style-type: none"> <li>a. For designation beginning with A, B, C (example A-40) CRUCIBLE STEEL CO.</li> <li>b. For designation beginning with HA (example HA-1940) HARVEY ALUMINUM CO.</li> <li>c. For designation beginning with MST (example MST-70) REACTIVE METAL CORP.</li> <li>d. For designation beginning with RS (example RS-40) REPUBLIC STEEL CO.</li> <li>e. For designation beginning with T1 (example T1-8Mn) TITANIUM METAL CORP.</li> <li>f. For designation beginning with LB or NA (example LB0170-110 or NA2-7123B) NORTH AMERICAN AVIATION INC.</li> <li>g. For designation beginning with 0.0 (example 0.01015) CONVAIR OR GENERAL DYNAMICS CORP.</li> </ul>				

**5-16. FIRE DAMAGE.** Fire damage to titanium and alloys becomes critical above 100°F due to the absorption of oxygen and nitrogen from the air which causes surface hardening to a point of brittleness. However, an overtemperated condition is indicated by the formation of an oxide coating and can be easily detected by a light green to white color. If titanium aircraft parts, the affected parts will be removed and replaced with serviceable parts.

#### 5-17. HEAT TREATMENT-GENERAL

##### NOTE

MIL-H-81200, Heat Treatment of CAUTION Titanium and Titanium Alloys, will be the control document for heat treatment of titanium and titanium alloys used on aerospace equipment. For complete description of titanium heat treat requirements, refer to latest issue of MIL-H-81200.

**5-18.** A majority of the titanium alloys can be effectively heat treated to strengthen, anneal and stress relieve. The heating media for accomplishing the heat treatment can be air, inert atmosphere or vacuum shall be used as necessary to protect all parts (titanium or titanium alloy), etc, which comprise the furnace load to prevent reaction with the elements hydrogen, carbon, nitrogen and oxygen.

##### CAUTION

Cracked ammonia or hydrogen shall not be used as a protective atmosphere for titanium and titanium alloys in any heat treating operation.

TABLE 5-2. NOMINAL MECHANICAL PROPERTIES AT ROOM TEMPERATURE.

MATERIAL TYPE	ANNEALED CONDITION				SOLUTION TREATED CONDITION				SOLUTION TREATED AND		
	Yield Str (0.2% Off set) 1000 psi Min	Tensile Str (Ultimate min) 1000 psi	Elong % in 2 in	Rock well Hard ness	Yield Str (0.2% Off set) 1000 psi Min	Tensile Str (Ultimate min) 1000 psi	Elong % in 2 in	Rock well Hard ness	AGED Yield Str	Tensile	Elong % in 2 in
MIL-T-9046 1/											
TYPE I, Comp A (Unalloyed 40 ksi)	40-65	50	20	B88							
Comp B (Unalloyed 70 ksi)	70-95	80	15	C23							
Comp C (Unalloyed 65 ksi)	55-80	65	18	B95							
TYPE II, Comp A (5AL-2, 5Sn)	110	120	10	C35							
Comp B (5AL-2, 5SnE11)	95	100	8-10								
Comp C (5AL-5Zr- 5Sn)	110	120	10	C35	Not recommended						
Comp D (7AL-23Zr)	120	130	10								
Comp E (7AL-2Cb 1Ta)	110	115	10	C35							
Comp F (8AL-1Mo- IV)	135	145	8-10	C38							
TYPE III, Comp A (8Mn)	110	120	10		Not recommended						
Comp B (4AL-3Mo- IV)	115	125	10		130		8		155	170	5.0
Comp C (6AL-4C)	120	130	8	C36	150	160	5		145	160	5.0
Comp D (6AL-4V- EL1)	120	130	10	C36							
Comp E (6AL-6V- 2Sn)	140	150	10		160	170	10		160	170	8.0
Comp F (7AL-4Mo)	135	145	10	C38	160		10		160	170	8.0
TYPE IV, Comp A (13V-11Cr -3Al)	120	125	10		120	125	10		160	170	10.0
MIL-T-9047, Class 1 (Un- alloyed)	70	80	15	C23							
Class 2 (5AL, 2.5 Sn)	110	115-120	10	C36							
Class 3 (3AL, 5Cr)	130	140	10								
Class 4 (2Fe, 2Cr, 2Mo)	120	130	15	C36							
Class 5 (6Al, 4V)	120	130	8	C36	145	160	5		150	160	5.0
Class 6 (6AL, 4V)	130	140	10	C40	150	160	5		160	175	5.0
Class 7 (5AL, 1.5Fe, 15Cr, 1.5Mo)	135	145	10	C39	NOTE 1/ Comp A, B and C are classified as commercially pure.						

**T.O. 1-1A-9**

**5-19.** Air-chamber furnaces are more flexible and economical for large volumes of work and for low temperature heat treatments; but at high temperatures where surface oxidation (above 1000°F) is significant, a muffle furnace utilizing external heating gives more protection, especially if gas heated. For general use, electric furnaces are preferred since heating can be accomplished internally or externally with a minimum of contamination. Furnaces which have given satisfactory results are vacuum furnaces capable of supplying pressures of one micron or less; and inert gas furnaces which control the atmosphere to 1% or less of oxygen and nitrogen combined.

**NOTE**

**Avoid direct flame impingement to prevent severe localized oxidation and contamination. Also avoid contact with scale or dirt.**

**5-20.** Alternately direct resistance heating may be used where extremely short heat up cycle on nearly finished parts is required to minimize surface oxidation.

**5-21.** The commercially pure, or unalloyed titanium, can only be hardened/strengthened by cold work. Stress relief and annealing are the only heat treatments applicable to these alloys. These processes of heat treatment are employed to remove residual stress resulting from grinding, work hardening, welding, etc. For recommended temperatures and times see Table 5-3.

**5-22.** The soaking period for heat treatment of titanium alloys shall be the minimum necessary to develop the required mechanical properties. The minimum soaking period (when unknown) shall be determined by test samples run prior to heat treating the finished material or part. Excessive heat treat soaking periods shall be avoided to prevent diffusion of oxygen hydrogen and nitrogen. Oxygen and nitrogen diffusion will take the form of a hard brittle surface layer which is difficult to distinguish from the base metal. The brittle layer must be removed by mechanical or chemical means prior to forming or application in stressed components. For the recommended soaking periods and temperatures see Table 5-3.

**5-23.** Scaling (oxidation) of titanium and titanium alloys starts at about 900°F. Light scaling which forms from exposure to temperatures up to 1000°F has little or no detrimental effect on mechanical properties. Heating to temperatures above 1000°F under oxidizing conditions results in severe surface scaling as well as diffusion of oxygen.

**5-24. HYDROGEN EMBRITTLEMENT.** Hydrogen embrittlement is a major problem with titanium and titanium alloys. Hydrogen is readily absorbed from pickling, cleaning and scale removal solution at room temperature and from the atmosphere at elevated temperatures. Hydrogen embrittlement in the basically pure and alpha alloys is evident by a reduction in ductility and a slight increase in strength. This is associated with a decrease in impact strength at temperatures below 200°F and a shift in the temperature range where the change from ductile to brittle occurs. With alpha-beta alloys, embrittlement is found at slow speeds of testing and under constant or "sustained" loads as demonstrated by tests on notched specimens. This type of embrittlement, which is similar to the embrittlement of steel, only becomes evident above a certain strength level. Solution heat treating and aging the alpha-beta alloys to high strength levels increases sensitivity to hydrogen embrittlement.

**5-25.** Quenching from solution heat treating for temperature wrought titanium alloys, except for alloy 3AL-13V-IICr less than 2 inches thick, which maybe air cooled, shall be by total immersion in water. The water shall be of sufficient volume or circulation or both so that the water temperature upon completion of the quenching operation will not be more than 100°F. The quenching baths shall be located and arranged to permit rapid transfer of the load from the furnace to the bath. Maximum quench delay for immersion type quenching shall be 4 seconds for wrought alloys up to 0.091 nominal thickness and 7 seconds for 0.091 and over. Quench delay time begins when furnace doors begin to open and ends when the last corner of the load is immersed. With extremely large loads or long lengths quench delay may be exceeded if performance test indicates that all parts comply with specification requirements.

**5-26. AGING AND STRESS RELIEVING.** For aging, the material shall be held within temperature range for sufficient time, depending on section size, for the necessary aging to take place and to insure that specified properties are developed. Wrought alloys should be fully quenched by air cooling from the aging temperature. The same applies for stress relieving except the time at temperature will depend on section size plus amount of cold work hardening present in the material. The material is also quenched by air cooling from the stress relieving temperature.

**NOTE**

**All heat treating operations shall be performed uniformly on the whole part, etc., never on a portion thereof.**



TABLE 5-3. HEAT TREAT, STRESS RELIEF AND ANNEALING TEMPERATURES AND TIMES.

MATERIAL	STRESS RELIEF TEMP °F	STRESS RELIEF TIME HOURS	ANNEALING TEMP °F	ANNEALING TIME HOURS	HEAT TREATING TEMP °F	H. T. SOAKING TIME MINUTES <u>1h/</u>	AGING TEMP °F	AGING SOAKING TIME HOURS
Unalloyed Commercially Pure Comp A, B and C	1000-1100 900 800	1/2-1 2-4 8	1000-1300	1 1/2-2	Hardened only by cold work			
Alpha Alloys								
5Al-2.5Sn	1080-1125	1-2	1335-1550	1/4-4	Hardened only by cold work			
5Al-5Zr-5Sn	1100-1300	1/2-3/4	1335-1550	1/4-1				
7Al-12Zr	1275-1325	1/2-3/4	1630-1670	1/4-1				
7Al-2Cb-1Ta <u>2/</u>	1000-1200	1/3-3/4	1630-1670	1/4-1				
8Al-1Mo-1V <u>1/</u>	1285-1315	1/2	1430-1470	8				
Alpha-Beta Alloys								
8Mn <u>3/</u>	950-1000	1/2-2	1250-1300	1	Not recommended			
2Fe-2Cr-2Mo <u>4/</u>	800-1000	1/2-15	1175-1200	1/2	1650-1750	5-25	900-950	4-6
2.5Al-16V <u>5/</u>	960-990	3-5	1360-1400	1/16-1/2	1360-1400	10-30	960-990	3-5
3Al-2.5V	---	---	1250-1350	1/2-1 1/2	Not recommended			
4Al-4Mn <u>6/</u>	1250-1350	1/2-2 1/2	1250-1300	2-24	1420-1480	60-120	875-925	6-10
4Al-3Mo-1V <u>7/</u>	900-1100	1/2-8	1225-1250	2-4	1620-1660	10-20	910-940	6-12
5Al-1.25Fe-2.75Cr <u>7/8/</u>	1000-1100	1/2-2	1425-1450	1/3-2	1350-1550	10-60	900-1000	6-10
5Al-1.5Fe-4Cr-1.2Mo <u>9/</u>	1100-1200	1/2-2	1180-1200	4-24	1650-1700	30-120	950-1050	4-8
6Al-4V <u>7/ 10/ 5/</u>	900-1200	1/2-50	1275-1550	1/2-8	1670-1730	5-25	960-990	4-6
6Al-6V-2Sn <u>9/ 15/</u>	1000-1100	1/2-3	1300-1500	2-3	1575-1675	30-60	875-1175	4-8

TABLE 5-3. HEAT TREAT, STRESS RELIEF AND ANNEALING TEMPERATURES AND TIMES(CONTD).

MATERIAL	STRESS RELIEF TEMP °F	STRESS RELIEF TIME HOURS	ANNEALING TEMP °F	ANNEALING TIME HOURS	HEAT TREATING TEMP °F	H. T. SOAKING TIME MINUTES <u>1h/</u>	AGING TEMP °F	AGING SOAKING TIME HOURS
7Al-4Mo <u>11/</u>	900-1300	1/2-8	1425-1450	1-8	1675-1275	30-90	975-1175	4-8
6Al-4V (low o) <u>10/ 5/</u>	900-1200	1/2-50	1275-1550	1/2-8	Not recommended			
Beta Alloy								
3Al-13V-11Cr <u>12/</u>	900-1000	1/4-60	1430-1470	1/4-1	1375-1425	30-90	880-920	2-60
1Al-8V-5Fe <u>13/</u>	1000-1100	1/4-60	1200-1300	1/2-1 1/2	1375-1470	15-60	925-1000	1-3

T.O. 1-1A-9

- 1/ Sheet: Regular anneal furnace cool  
 Duplex anneal. Mill anneal + 1435°F, 15 minutes air cool.  
 Triplex anneal. Mill anneal + 1850°F, 5 minutes air cool, + 1375, 15 minutes air cool.  
 Bar and Forgings:  
 Duplex anneal  
 1650-1850, 1 hour air cool + 1000°-1100°F, 8-24 hours air cool.
- 2/ Bar Duplex anneal: Mill anneal + 1000°-1200°F, 1/2-6 hours air cool.
- 3/ Anneal furnace cool at 300°F per hour maximum to 1000°F to 1050°F.
- 4/ Stress relief may be accomplished at 800°F - 15 hours, 850°F - 5 hours, at 900°F - 1 hour and 950°F - 1/2 hour.
- 5/ For 100 % stress relief, 1000°F - 50 hours or 1200°F - 5 hours.  
 For 50 % relief, 1000°F - 5 hours or 1100°F - 1/2 hour.
- 6/ Furnace cool at 300°F maximum from anneal temperature for maximum formability, also, formability may be improved by holding at annealing temperature 24 hours.
- 7/ Slow cool to 1000°-1050°F maximum from upper annealing temperature.
- 8/ Anneal sheet at temperature for 20 minutes. For bar hold at anneal temperature 2 hours.

- 9/ Air cool from annealing temperature.
- 10/ For sheet anneal, heat 1300°-1350°F, 1 hour, furnace cool at a rate of 50°F per hour maximum to 800°F. Air cool may be used for lower ductility requirements. For bar and forging anneal, heat at 1275°-1325°F for 2 hours, air cool. For hydrogen removal by vacuum annealing, heat at 1300°F-1500°F for 1/2-2 hours, then furnace cool to 1100°F maximum.
- 11/ Furnace cool from annealing temp (1425°-1450°F) to 1000°-1050°F maximum at 300°F per hour (maximum) for maximum formability. For maximum creep properties (after lowering from upper annealing) temperature hold at 1050° for 2 1/2 hours.
- 12/ Solution heat treatment recommended for annealing. Stress relieve at temperature cited during aging. If aging not employed, heat treat at 1000°F for 15 minutes. Aging time will depend on strength level required/desired.
- 13/ Furnace cool from upper annealing temperature at 300°F per hour maximum to 900°F.
- 14/ Longer soaking times may be necessary for specific forgings. Shorter times are satisfactory when soak time is accurately determined by thermocouples attached to the load. Soaking time shall be measured from the time all furnace control instruments indicate recovery to the required (minimum) process range.
- 15/ Age at 1050°-1150°F air cool for best combination of mechanical properties and thermal stability.

**5-27. FABRICATION.**

**5-28. FORMING SHEET METAL-GENERAL.** The forming of the unalloyed titanium can be accomplished at room temperature using approximately the same procedures as those established for 18-8 stainless steel. The basic difficulties encountered are sheet thickness, property variations, direction of grain flow and flatness. The above factors combined with high yield strength, high tensile strength and low uniform elongation of commercial titanium alloys makes forming difficult. The current equipment available was designed for material of uniform quality and considerable work is required for adaptation to form titanium.

**5-29. BENDING.** Straight-Edge Bending of titanium using power brake on hand forming equipment can be accomplished to a limited degree using the methods developed for stainless steel. The factors which require control are the compensation for spring back and the bend radii. Springback is comparable to that of hard stainless steel when formed at room temperature. The bend radii will depend on the type of material or alloy and whether forming is accomplished hot or cold. The forming of material requiring tight bends or small radii necessitates the application of heat in the range of 500°F. The heat should be applied for only short periods of time to avoid excessive oxygen and nitrogen contamination which causes embrittlement. For approximate cold bend radii of sheet titanium see Table 5-4. Actual practice may reveal that smaller bend radii can be used.

**5-30. DRAW FORMING.** Deep draw forming should not be attempted unless adequate equipment and facilities are available. This will require that facilities be maintained for heating and controlling temperatures of the blanks to be formed and the dies used in the forming operation.

**5-31. HYDRAULIC PRESS FORMING.** Rubber pad hydropress forming can be accomplished either hot or cold depending on the type tooling employed and the press pressures used. This type of forming is used on parts that are predominately flat and have flanges, beads, and lightening holes. A male form block is set on the lower press platen and the blank held in place on the block by locating pins. A press-contained rubber pad (45 to 55 Shore Durometer hardness and about 8 inches thick) is located over the form block and blank. The press is then closed. As the ram is lowered, the rubber pad envelops the form block forcing the sheet metal blank to conform to its contour.

**5-32.** Many parts can be formed at room temperature on the hydropress if flange clips, wedges and hinge-type dies are used. When cold forming is employed, it is usually desirable to partially form the parts, stress-relieve at 1000°F for 20 minutes, then finish form. Hot forming for severely contoured parts or when only low-forming pressures are available is accomplished between 600°F and 800°F. For this procedure, the form block is heated to the required temperature, the blank positioned and covered with powdered or shredded asbestos; then a rubber pad 70 to 80 Durometer hardness is placed on top. This extra pad of rubber serves two purposes: First, it provides additional rigidity for forming; and second, it protects the press-contained rubber from the hot form block.

**5-33.** Tooling for hydropress form blocks, if elevated temperature forming is to be used, requires that pressure plates and dies be made somewhat thicker than in normal practice. If long runs are anticipated, it is recommended that form blocks be made from a good grade of hot-work tool steel due to the galling action of titanium at elevated temperatures.

**5-34. STRETCH FORMING.** Stretch forming has been used on titanium primarily to bend angles, hat sections, Z-sections and channels and to stretch form skins so that they will fit the contour of the airplane fuselage. This type of forming is accomplished by gripping the section to be formed in knurled jaws, loading until plastic deformation begins, then wrapping the part around a female die. This operation is performed at room temperature and should be done at a very slow rate. Spring back is equivalent to that of ¼ hard 18-8 stainless steel. All blanks for stretch-forming should have the edges polished to remove any notch effects. Approximately 0.025 inch of sheared edges should be removed.

**5-35. DROP-HAMMER FORMING.** Drop-hammer forming of titanium has been very successful and has been accomplished both at room and at elevated temperatures. Kirksite is satisfactory for male and female dies where only a few parts are required. If long runs are to be made, ductile iron or laminated steel dies are usually necessary. In drop-hammer forming, the best results have been obtained by warming the female die to a temperature of 2000 to 300SF to remove the chill and heating the blank to a temperature of 800°-1000°F for 10 to 15 minutes. The part is then struck and set in the die. Usually a stress relief operation at 1000°F for 20 minutes is necessary, then a re-strike operation. In most instances, a finished part requiring no hand work is obtained.

TABLE 5-4. RECOMMENDED MINIMUM COLD BEND RADII.

TYPE/COMP	MINIMUM BEND RADIUS (90 DEGREE BEND) <sup>1/</sup>	
	0.070 & under thickness	over 0.070 to 0.187
<b>Type I - Commercially Pure</b>		
Comp A (unalloyed 40,000 psi)	2T	2.5T
Comp B (unalloyed 70,000 psi)	2.5T	3T
Comp C (unalloyed 55,000 psi)	2T	2.5T
<b>Type II - Alpha Titanium Alloy</b>		
Comp A (5AL02.5Sn)	4T	4.5T
Comp B (5AL-2.5Sn EL1)	4T	4.5T
Comp C (5AL-5Zr-5Sn)	4.5T	5T
Comp D (7AL-12Zr)	5T	5T
Comp E (7AL-2Cb-1T:)	--	--
Comp F (8AL-1Mo-1V)	4.5T	5T
<b>Type III Alpha-Beta</b>		
Comp A (8Mn)	3T	3.5T
Comp B (4AL-3Mo-1V)	3.5T	4T
Comp C (6AL-4V)	4.5T	5T
Comp D (6AL-4V)	4.5T	5T
Comp E (6AL-6V-2Sn)	--	--
Comp F (7AL-4Mo)	--	--
<b>Type IV - Beta</b>		
Comp A (13V-11Cr-3AL)	3T	3-5T

<sup>1/</sup> T = Thickness of material. Example: A piece of 0.040 MIL-T-9046, Type II, Composition A, would require a bend radii of  $4 \times 0.040 = 0.160$  bend radii (minimum).

**5-36. JOGGLING.** Jogging of titanium can be accomplished without any particular difficulty provided the following rules are adhered to:

- a. The joggle die corner radius should not be less than 3T-8T.
- b. Joggle run-out should be the determining factors whether joggles are formed hot or cold. Joggles should be formed hot where a ratio of joggle run-out to joggle depth is less than 8.1.
- c. Minimum joggle run-outs should be as follows:

Hot joggling four times the joggle depth.

Cold joggling eight times the joggle depth.

**5-37. BLANKING AND SHEARING.** These operations compare to those of 18-8 stainless steel in the  $\frac{1}{4}$  hard condition for commercially pure, and the alloys compare to  $\frac{1}{2}$  hard 18-8 stainless steel. The force required for titanium and its alloys is greater and the dies wear faster. Materials up to 0.125 inch in thickness have been sheared on  $\frac{1}{2}$  inch capacity flat bed shears designed for steel. If this capacity is to be exceeded, the shear designer should be consulted.

**5-38.** Before any forming or other operations are performed 0.025 inch of the sheared, blanked, sawed, or nibbed edges should be removed to prevent stress risers that will cause a tear in the part during forming operations.

#### **5-39. JOINING.**

**5-40. WELDING.** Commercially pure titanium can be welded satisfactorily by fusion, seam and resistance spot welding method; however, because of its affinity for oxygen, nitrogen, and hydrogen at welding temperatures, titanium becomes embrittled and unworkable. To prevent this embrittlement and consequent loss in ductility, special precautions must be taken, such as inert gas protection of the weld areas.

**5-41. FUSION WELDING.** Welding by the open fusion method can be accomplished provided that any air contact with surface heated to 180°0F or above can be prevented. Welding can be effected by utilization of a sufficient quantity of helium or argon or preferably a 50/50 mixture of both to shield weld zone. Alternatively an inert gas chamber which can be constructed of ordinary sheet steel and fitted with observation windows and shoulder length rubber access gloves, permits the fusion welding of titanium under ideal conditions. This chamber can be of any convenient size, should have double seal gaslock doors, and can be mounted on a conventional welding table. The chamber should also be equipped with a hose connection for the entrance of the inert gas and an escape valve to permit a constant flow of gas through the chamber during the welding operation. It is suggested that the weld area be purged with the gas for approximately 30 seconds before the arc is struck and that a flow of 10 to 30 liters be maintained during welding. This flow of gas should continue after the arc is broken until the color has disappeared from the weld. In selecting the inert gas to be used one must keep in mind that helium permits a hotter arc and better penetration, whereas argon provides better control. A satisfactorily protected weld has a bright silver color with no more than a slight straw to blue tint. Any sign of brown or powdery white scale indicates insufficient shielding and must be corrected immediately upon detection. Uniformity of the weld is best if direct current reverse polarity current supply is used, however, penetration and strength are equally good with either alternating current or direct current.

## 5-42. WELDING CHARACTERISTICS.

MATERIAL	FILLER METAL	REMARKS
Unalloyed Commercially Pure Spec Comp A, Band C	Commercially Pure AMS 4951	Stress Relieve after welding; resistance (spot and seam) may be accomplished without protective atmosphere.
4A1-4Mn	Not recommended for welding.	
4A1-3Mo-IV	6A1-4V (AMS4954 3A1 or AMS4951	For resistance welding use technique similar to those used for austenitic stain- less steels.
5Al-1.5Cr-1.5Fe-IMo	Not currently recommended for welding, however, procedures under development.	
5A1-2.7SCr-1.25Fe	Fusion welding not recommended.	Spot welding can be satisfactory accomplished.
5A1-2.5Sn	5A1-2.5Sn AMS 4953, 3A1, or commercially pure AMS4951.	Fusion welding by the heli- arc method is recommended for welding Also readily weldable by spot and seam methods. Welds have good ductility and mechanical properties comparable to base metal. Difficulty may be experienced from porosity after welding.
5Al-5Sn-5Zr		Alloy has good properties in welded condition. Improvement - in properties can be achieved by post weld stress relief annealing. Readily weldable by resistance methods. Under most conditions of exposure to elevated temperature, lost of strength of spot welds is lower than parent metal.
7A1-12 Zr		Only limited data available. Present data indicates fusion and resistance welding is readily accomplished by use of technique common to other titanium alloys. Fusion welds are somewhat more notch sensitive than parent metal. Stress relieving at 1300, ¾ hr recommended to minimize stress corrosion cracking; avoid stress relieving at 1200°F or below.
8Al-2Cb-IT2		Current data indicates alloy readily weldable with same techniques used for unalloyed titanium.



## 5-42. WELDING CHARACTERISTICS (CONT'D).

MATERIAL	FILLER METAL	REMARKS
2Cr-2Fe-2Mo  8Mn	Not recommended for welding, because brittle when cooled. Not recommended for welding.	
3A1-13V-11Cr	3A1-13V-11Cr	Can be satisfactorily welded using inert-gas-shielded tungsten arc without filler or with consumable filler electrode. Also, it can be seam and spot welded.
6A1-4V	6A1-4V AMS4954, 3A1, or commercially pure AMS4951	Weldments have lower ductility than parent metal, however, useful fusion and resistant welds can be made with proper precautions. Complete inert gas shielded required for either tungsten arc or consumable electrode fusion welds. Resistance welding is accomplished by technique similar to those used for austenitic stainless
7A1-4Mo	See 6A1-4Mo.	
8A1-1Mo-1V		Only limited data available. Fusion and resistance welding of sheet accomplished using technique common to other titanium alloys. Stress relief recommended after welding.

**5-43.** Non-consumable tungsten electrodes, 1/32 inch to 1/8 inch diameter, may be used with or without filler metal as desired. When filler metal is desired, the use of AMS4951 rod is recommended.

**5-44. CLEANING.** As in the welding of other metals, the surface of titanium must be clean prior to welding operations. Grease oil, dirt, and scale must be removed by solvent degreasing, chemical pickling, grit blasting, grinding, wire brushing or a combination of these treatments. Solvent degreasing may be accomplished using hot trichloroethylene (180°F). Either wet or dry grit blasting may be used. The pickling solution most recommended is a mixture of 20 to 307% nitric acid and hydrofluoric acid mixed in water. The ratio of nitric to hydrofluoric acid should be at least 15 to 1 to minimize hydrogen pick up. Precautions will be taken to keep the nitric acid content from dropping below its normal range, since a nitric content below 10% will result in hydrogen embrittlement.

**5-45. SPOT AND SEAM WELDING.** Effective joining of titanium with this method of welding can be accomplished without the difficulty experienced with other types of welding. Excessive penetration is the only characteristic requiring control, since the welds are less ductile than the base metal. Trial is advised by obtaining set-up pieces from the same lot of material as the parts to be welded so that penetration may be limited.

**5-46.** Protective atmosphere control, which is usually required with other types of welding, of titanium is not necessary and for most practical purposes the welding conditions, electrode pressures, current settings and times are essentially the same as those used for stainless steel, except for seam welding. The electrode force should be reduced slightly for seam welding as compared to stainless steel. See paragraph 2-170 through 2-193 for general requirements regarding spot/seam welding and Table 5-5 for minimum required shear strength per weld for spot weld shear specimens and minimum average strength and titanium and titanium base alloys. This data was obtained from Specification YIL-W-6858.

**5-47. BRAZING.** To braze titanium and its alloys, special atmospheres and fluxes are required; however, ordinary furnace, torch induction, or resistance procedures can be utilized. Furnace and induction brazing can be done without fluxes in a vacuum of an inert atmosphere. Without atmospheric protection, special fluxes developed especially for titanium are required. Generally these fluxes are composed of a mixture of fluoride and chlorine in various percentages.

**5-48.** To prevent alloying between the titanium and the brazing alloy, rapid heating cycles should be employed. Excess mixing (alloying) will cause the formation of brittle phases at the joints. Since induction brazing is faster than furnace brazing, this is the method recommended. The most satisfactory filler metal is fine silver. Joints brazed with fine silver have better strength and ductility than those prepared with silver-base alloys. The brazing method can be used to join titanium to other metals, but precoating is required to obtain a satisfactory joint. The strength of the joints is lower than those that are obtained by brazing titanium to titanium.

**5-49. SOLDERING.** Limited information is available on soldering. It is possible to successfully solder titanium where little strength is required, by precoating with a thin film of silver, copper or tin from their chloride salts. This can be accomplished by heating the chloride salts-coated titanium in an atmosphere controlled furnace as previously mentioned in paragraph 5-18. The resultant film should be made wet with either a 60W tin-40% lead or a 50%-50%tinandlead solder. Since the deposited film may dissolve in the liquid solder and dewet the surface, it is important that the time and temperature be held to a minimum.

**5-50. RIVETING.** Riveting of titanium can be accomplished using conventional equipment with rivets manufactured from commercially pure material; however, the rivet holes require close tolerances to insure good gripping. The driving time is increased about 65% over that required for high strength aluminum rivets. Better results can be obtained by using the squeeze method rather than the rivet gun and bucking bar. When it is necessary to have flush-head rivets, dimpling can be accomplished at temperatures of 500°F to 700°F. Other types of rivets such as high strength aluminum, stainless steel and monel are also used to join titanium.

**5-51.** Due to difficulties involved, the above mentioned method will probably be replaced in most cases with rivets of the high shear series, i.e., pin rivets such as NAS1806 through NAS1816, tension rivet NAS2006 through NAS-2010, and shear rivet NAS-2406 through NA8-2412.

**5-52.** As with other metals, it is necessary to take precautions to avoid galvanic corrosion when titanium is riveted to other metals. This can be accomplished by coating the titanium with zinc chromate primer Specification MIL-P-8585.

TABLE 5-5. MINIMUM REQUIRED SHEAR STRENGTH PER WELD FOR SPOT WELD SHEAR SPECIMEN AND MINIMUM AVERAGE STRENGTH, TITANIUM AND TITANIUM BASE ALLOYS 1/

Nominal thickness of thinner sheet (inch)	Material Ultimate Strength PSI			
	Ultimate strength above 100,000 PSI	Ultimate strength 100,000 PSI or below		
Thickness, see Std MS33528 <u>2/</u>	Minimum lb/weld	Minimum average lb/weld	Minimum lb/weld	Minimum average lb/weld
0.010-----	205	265	160	210
0.012-----	275	360	200	260
0.016-----	400	520	295	385
0.018-----	490	635	340	445
0.020-----	530	690	390	510
0.022-----	610	795	450	585
0.025-----	725	945	530	690
0.028-----	855	1,110	635	825
0.032-----	1,045	1,360	775	1,000
0.036-----	1,255	1,630	920	1,200
0.040-----	1,460	1,900	1,065	1,385
0.045-----	1,795	2,340	1,285	1,670
0.050-----	2,125	2,760	1,505	1,910
0.056-----	2,550	3,320	1,770	2,300
0.063-----	3,000	3,900	2,110	2,730
0.071-----	3,380	4,400	2,395	3,115
0.080-----	3,810	4,960	2,700	3,510
0.090-----	4,290	5,570	3,040	3,955
0.100-----	4,760	6,170	3,380	4,395
0.112-----	5,320	6,800	3,785	4,925
0.125-----	5,950	7,700	4,220	5,490

1/ Strength of material shall be based on its guaranteed minimum ultimate strength.

2/ Standard MIL-STD-204 may be used as an alternate. Interpolation can be used to establish strength values.

**5-53. MACHINING AND GRINDING.**

5-54. MACHINING. Commercially pure, unalloyed titanium machines similarly to 18-8 stainless steel, but the alloy grades are somewhat harder. Variations in actual practice will depend on the type of work, equipment, and finish, so the following information is only intended as a guide.

5-55. The basic requirements are: rigid machine setups, use of a good cutting fluid that emphasizes cooling rather than lubrication, sharp and proper tools, slow speeds and heavy feeds. Since titanium has a tendency to gall and seize on other metals, the use of sharp tools is very important. Sliding contact, and riding of the tool on the work must be avoided.

5-56. TURNING. Commercially pure and alloy titanium is not difficult to turn. Carbide tools such as metal carbides C91 and Carboloy 44A and other similar types give the best results for turning titanium. Cobalt-type high speed steels give the best results of the many types available. Cast alloy tools such as Stellite, Lantung, Rexalloy, etc., may be used when carbide is not available, or when the high speed steels, are not satisfactory.

5-57. The recommended cutting fluids are water base cutting fluids such as soluble oils or chemical type fluids.

5-58. Tables 5-6 and 5-7 show suggested turning speeds, tool angles and feeds. All work should be accomplished with live centers since galling or seizing will occur on dead centers. Tool sharpness is again emphasized because a nick or a seized chip on a tool increases temperature and will cause rapid tool failures.

5-59. MILLING. Considering the type of tool which is required in milling operations, it can be readily seen that this type of machining is more difficult than turning. The difficulty encountered is that chips remain tightly welded to the cutter's edge at the end of cut or during the portion of the revolution that it does not cut. As the cutter starts the next machining portion the chips are knocked off. This damages the cutting edge and the tool fails rapidly.

5-60. One method that can be utilized to relieve this difficulty to a great extent is climb milling. The cutter machines the thinnest portion of the chip as it leaves the cut. Thus, the area of contact between chip and tool is at a minimum when the chip is removed at the start of the next cutting portion of the revolution. This will reduce the danger of chipping the tool. The machine used for climb milling should be in good condition because if there is any lost motion in the feed mechanism of the table, the piece being cut will be pulled into the cutter. This may damage the cutter or the work piece.

5-61. For effective milling, the work feed should move in the same direction as the cutting teeth, and for face milling the teeth should emerge from the cut in the same direction that the work is fed.

5-62. To select the appropriate tool material it is advisable to try both cast alloy and carbide tools to determine the better of the two for large milling jobs. This should be done since the cutter usually fails because of chipping, and the results are not as satisfactory with carbide as they are with cast-alloy tools. The increase in cutting speeds (20 to 30%) possible by using carbide rather than cast (all alloy tools) does not always compensate for the additional tool grinding cost.

5-63. The same water-base cutting fluids used for turning are recommended for milling; however, carbide tools may give better results when dry.

5-64. See Table 5-8 for recommended speed and feeds. For tool grinding information see Table 5-9.

5-65. DRILLING. Drilling of titanium can be accomplished successfully with ordinary high speed steel drills. Low speeds and heavy positive feeds are required. The unsupported portion of the drill should be as short as possible to provide maximum rigidity and to prevent drill running. All holes should be drilled without pilot holes if possible. As with other materials, chip removal is one of the principal problems and the appearance of the chip is an indication of the sharpness and correct grinding of the drill. In drilling deep holes, intermittent drilling is recommended. That is, the drill is removed from the hole at intervals to remove the chips.

5-66. The cutting fluids recommended are sulfurized and chlorinated coolants for drills with diameters of less than 1/4 inch and mixtures of mineral oil or soluble oil with water for hole sizes larger than 1/4 inch diameter.

5-67. The cutting speed should be 50 to 60 FPM for the pure grade of titanium and 30 to 50 FPM for alloy grades. Feeds should be 0.005 to 0.009 inch for 1/4 to 1/2 inch diameter drills; 0.002 to 0.005 inch for smaller drills. Point angle, 90° for drills 1/4 inch diameter and larger and 140° for drills 1/8 inch diameter or less; but 90°, 118° and 140° should be tried on large jobs to determine the angle that will give the best result. Helix angle 28° to 35° and lip relief 10L. Additional information on drills may be obtained from NAS907.

TABLE 5-6. TURNING SPEEDS FOR TITANIUM ALLOYS

TYPE	MILITARY MIL-T-9047C	CUTTING SPEED FPM	FEED, in/rev	TOOL MATERIAL
Unalloyed 70,000 PSI	Class 1	250-300 150-170 170-200	0.010-0.020 0.004-0.007 0.005-0.010	Carbide Hi-Speed Steel Cast Alloy
5Al, 2.5 Sn 3Al, 5Cr 2Fe, Cr 2 Mo 6Al, 4V 4Al, 4Mn	Classes 2, 3, 4, 5, and 6	120-160 30-60 50-80	0.008-0.015 0.004-0.007 0.005-0.010	Carbide Hi-Speed Steel Cast Alloy
5Al, 1.5 Fe 1.5 Cr, 1.5 Mo	Class 7	110-150 20-40 40-70	0.005-0.012 0.003-0.006 0.004-0.008	Carbide Hi-Speed Steel Cast Alloy

TABLE 5-7. TOOL ANGLES FOR ALLOYS

TOOL ANGLES	CARBIDE	HIGH SPEED STEEL	CAST ALLOY
Back Rake	0°	5° Pos	5° Pos
Side Rake	6°	5° - 15°	5° - 15°
Side Cutting Edge Angle	6°	5° - 15°	5° - 15°
End Cutting Edge Angle	6°	5°	5°
Relief	6°	5°	5°
Nose Radius	0.040 inch	0.010 inch	0.005 inch to 0.010 inch

TABLE 5-8. SPEEDS AND FEEDS FOR MILLING

TYPE	MILITARY	MILLING SPEED FPM	FEED, IPT -IN INCHES	TOOL MATERIAL
Unalloyed 70,000 PSI	MIL-T-9047C Class 1	160-180 120-140	0.004-0.008 0.004-0.008	Carbide Cast Alloy
5Al, 2.5Sn 3Al, 5Cr 2Fe, 2Cr, 2Mo, 6Al, 4V 4Al, 4Mn	Class 2, 3, 4, 5, 6	80-120 80-100	0.004-0.008 0.004-0.008	Carbide Cast Alloy
5Al, 1.5Fe, 1.5Cr 1.5Mo	Class 7	70-110 70-90	0.004-0.008 0.004-0.008	Carbide Cast Alloy

TABLE 5-9. ANGLES FOR TOOL GRINDING

ANGLES	CAST ALLOY TOOL	CARBIDE TOOL
Axial Rake	0°	0°
Radial Rake	0°	0°
Corner Angle	30°	60°
End Cutting		
Edge Angle	6°	6°
Relief	12° <sup>1</sup>	6-10° <sup>1</sup>

5-68. TAPPING. Due to the galling and seizing that are characteristic of titanium, tapping is one of the more difficult machining operations. Chip removal is one of the problems that will require considerable attention in an effort to tap titanium. Another problem will be the smear of titanium. Build up from smear will cause the tap to freeze or bind in the hole. These problems can be alleviated to some extent by the use of an active cutting fluid such as sulphurized and chlorinated oil.

5-69. Power equipment should be used when possible and a hole to be tapped should be drilled with a sharp drill to prevent excessive hardening of the hole wall. In the attempt to tap titanium, difficulties involved can be minimized by reducing the thread to 55 or 65% from the standard 78%.

5-70. The following are procedures and material recommended for tapping titanium.

- a. Cutting speed: 40 to 50 FPM for unalloyed and 20 to 30 FPM for the alloy grades.
- b. Type of Tap: Gun or spiral point, 2 fluted in sizes 1/4-20 or less; 3 fluted in sizes greater than 1/4-20.
- c. Cutting fluid; Active cutting oil such as oil, cutting, sulfurized mineral, 8peciilcation VV-0-283, Grade 1.

5-71. REAMING. Preparation of the hole to be reamed and the type of reamer used is the key-note to successful reaming operations. As with tapping operations, the hole to be reamed should be drilled with a sharp drill. A straight-fluted reamer can be used, but spiral-fluted reamers with carbide tips usually produce the best results. Speeds of 40-200 FPM and feeds of 0.005 to 0.008 inch are satisfactory; however, these factors depend on the size of the hole. Feeds should increase in proportion to the size of the hole. The removal of larger amounts lessens the degree of concentricity. If the degree of concentricity is an important factor, smaller amounts should be removed.

5-72. GRINDING. The essential requirements for grinding are the selection and use of grinding fluids and abrasive wheels. Grinding of titanium is different from grinding steel in that the abrasive grain of the wheel wears or is dissolved by a surface reaction, rather than wheel wear which is caused by breakage. To overcome this problem, lower wheel speeds and the use of aluminum oxide or soft bonded silicone carbide wheels employing wet grinding methods are recommended. Recommended wheel speeds are: 1500-2000 SFPM and table feeds of 400 to 500 inches per minute with down feed of 0.001 inch maximum per pass and using 0.05 inch cross feed for highest grinding ratios.

5-17/(5-18 Blank)

## SECTION VI

### COPPER AND COPPER BASE ALLOYS.

#### 6-1. COPPER AND COPPER BASE ALLOYS.

6-2. Most of the commercial coppers are refined to a purity of 99.90%, minimum copper plus silver. The two principal copper base alloys are brass and bronze, containing zinc and tin respectively, as the major alloying element. Alloy designations for wrought copper and copper alloys are listed in table 6-1, with the corresponding specification and common trade names.

#### 6-3. COPPER ALLOYING ELEMENTS.

ZINC - Added to copper to form a series of alloys known as brasses. They are ductile, malleable, corrosion resistant and have colors ranging from pink to yellow.

TIN - Added to copper to form a series of alloys known as bronzes. Bronzes are a quality spring material, and are strong, ductile and corrosion resistant.

LEAD - Added to copper in amounts up to 1% to form a machinable, high-conductivity copper rod. It is added to brasses or bronzes in amounts of 0.5 to 4% to improve machinability and in the range of 2 to 4% to improve bearing properties.

ALUMINUM - Added to copper as a predominating alloy element to form a series known as aluminum bronzes. These alloys are of high strength and corrosion resistance.

IRON - Added to copper along with aluminum in some aluminum bronzes and with manganese in some manganese bronzes.

PHOSPHOROUS - Added to copper principally as a deoxidizer and in some bronzes to improve spring properties.

NICKEL - Added to copper for higher strength without loss of ductility. They have excellent corrosion resistance.

SILICON - Added to copper to form the copper silicon series having high corrosion resistance combined with strength and superior welding qualities. Small amounts are used as deoxidizers.

BERYLLIUM - Added to copper to form a series of age hardenable alloys. In the fully treated condition, it is the strongest of the copper base alloys and has an electrical conductivity of 20%. Beryllium-coppers are widely used for tools where non-sparking qualities are desired.

MANGANESE - Added primarily as a desulfurizing and de-gassing element for alloys containing nickel.

6-4. CHEMICAL COMPOSITION The chemical composition of the copper alloys (listed by commercial trade name) is listed in table 6-1.

#### 6-5. HEAT TREATMENT AND NOT WORKING TEMPERATURE OF COPPER ALLOYS.

6-6. During production and fabrication, copper alloys may be heated for homogenizing, hot working, stress relief for solution treatment, and precipitation hardening. The temperatures commonly used for heating, hot working and annealing after cold working are given in table 6-2.

#### 6-7. STRESS RELIEF OF COPPER ALLOYS.

6-8. Table 6-3 below gives a list of typical stress relief treatments commonly used in industry. This table is listed in terms of chemical composition percents, and should be used as representing average stress relieving temperatures.

6-9. MACHINING COPPER AND COPPER ALLOYS. Free cutting brass is one of the most easily machined metals and serves as a standard for machinability ratings of copper alloys. The following table gives the machinability ratings and recommended speeds and feeds for use with high speed steel tools.

6-10. WROUGHT-COPPER-BERYLLIUM ALLOYS. The beryllium copper alloys are frequently used due to their ability to respond to precipitation or age hardening treatments and other beneficial characteristics. Some of the characteristics are; good electrical and thermal conductivity, high strength hardness, corrosion resistance, good wear resistance, non-magnetic qualities and very good fatigue strength.



TABLE 6-1. CHEMICAL COMPOSITION BY TRADE NAME

COPPER ALLOY NO	SPECIFICATION		TRADE NAME
	FEDERAL	MILITARY	
101	QQ-A-673, type II QQ-C-502 QQ-C-576 QQ-W-343 WW-P-377	MIL-W-85C	Oxygen free certified copper.
102	QQ-A-673 Type II QQ-C-502 QQ-C-825 QQ-C-576 QQ-R-571, Class FS-RCu-1 QQ-W-343 WW-T-799	MIL-W-85C MIL-W-6712A	Oxygen free copper.
104	QQ-C-502 QQ-C-825		Oxygen Free with silver
105	QQ-C-502 QQ-C-825		Oxygen free with silver
110	QQ-A-673, Type I QQ-C-502 QQ-C-825 QQ-C-576	MIL-W-3318 MIL-W-6712	Electrolyte Tough pitch copper.
128	QQ-C-502 QQ-C-576		Fire refined tough pitch with silver
130	QQ-C-502 QQ-C-576		Fire refined tough pitch with silver
170 172	QQ-C-530 QQ-C-533		Beryllium Copper
210	QQ-W-321, comp 1		Gilding, 95%
220	QQ-W-321, comp 2	MIL-W-85C MIL-W-6712	Commercial bronze, 90%
230	QQ-B-613, comp 4 QQ-B-626, comp 4 QQ-W-321 comp 3 WW-P-351 grade A WW-T-791 Grade 1		Red Brass, 85%
240	QQ-B-591 QQ-B-613 comp 3 QQ-B-626 comp 3 QQ-B-650 comp D QQ-W-321 comp 4	JAN-W-472	Low Brass, 80%

TABLE 6-1. CHEMICAL COMPOSITION BY TRADE NAME (CONTD)

COPPER ALLOY NO	SPECIFICATION		TRADE NAME
	FEDERAL	MILITARY	
260	QQ-B-613 comp 2 & 11 QQ-B-626 comp 2 & 11 QQ-B-650 comp C QQ-W-321 comp 6	*MIL-S-22499  MIL-T-6945 comp II MIL-T-20219  *Laminated Shim Stock	Cartridge brass, 70%
261	Same as 260		
262	QQ-B-613 comp 11 QQ-B-626 comp 11		
268	QQ-B-613 comp I & 11 QQ-B-626 comp 1 & 11		Yellow brass, 66% (Sheet)
270	QQ-B-613 comp 11 QQ-B-626 comp 11 QQ-W-321 comp 7		Yellow brass 65% (rod and wire)
274	QQ-B-613 comp 11 QQ-B-626 comp 11 QQ-W-321 comp 8		Yellow brass 63%
280	QQ-B-613 comp 11 QQ-B-626 comp 11 WW-P-351 Grade C WW-T-791 Grade 3		Muntz metal, 60%
298	QQ-B-650 comp A		Brazing Alloy
330	QQ-B-613 comp 11 QQ-B-626 Comp 11 WW-P-351 Grade B WW-T-791 Grade 2	MIL-T-6945 comp III	Low leaded brass
331	QQ-B-613 comp 11 QQ-B-626 comp 11		

TABLE 6-1. CHEMICAL COMPOSITION BY TRADE NAME (CONTD)

COPPER ALLOY NO	SPECIFICATION		TRADE NAME
	FEDERAL	MILITARY	
110	QQ-R-571, Class FS-RW-1 QQ-W-343 WW-P-377		
111	QQ-C-502 QQ-C-825 QQ-C-576 QQ-W-343		Electrolytic Tough pitch anneal resist copper
114	QQ-C-502 QQ-C-825 QQ-C-576		Tough pitch with silver
116	QQ-C-502 QQ-C-825 QQ-C-576		Tough pitch with silver
120	QQ-C-502 QQ-C-576 WW-P-377 WW-T-797 WW-T-799	MIL-W-85C	Phosphorous deoxidized low residual phosphorus copper.
121	QQ-C-502 QQ-C-576		
122	QQ-A-674, Type III QQ-C-502		Phosphorus deoxidized high residual phosphorus copper.
122	QQ-C-576 WW-P-377 WW-T-797		
123	QQ-C-502 QQ-C-576		
125	QQ-C-502 QQ-C-576		Fire Refined tough pitch copper
127	QQ-C-502 QQ-C-576		Fire refined tough pitch with silver
332	QQ-B-613 comp 11 QQ-B-626 comp 11		High leaded brass
340	QQ-B-613 comp 11 QQ-B-626 comp 11		Medium leaded brass 61½%
335	QQ-B-613 comp 11 QQ-B-626 comp 11		Low leaded brass
342	QQ-B-613 comp 11 & 24 QQ-B-626 comp 11 & 24		High leaded brass 64½%
344	QQ-B-613 comp 11 QQ-B-626 comp 11		

TABLE 6-1. CHEMICAL COMPOSITION BY TRADE NAME (CONTD)

COPPER ALLOY NO	SPECIFICATION		TRADE NAME
	FEDERAL	MILITARY	
347	QQ-B 613 comp 11 QQ-B-626 comp 11		
348	QQ-B-613 comp 11 QQ-B-626 comp 11		
350	QQ-B-613 comp 11 QQ-B-626 comp 11		Medium leaded brass 62%
353	QQ-B-613 comp 11 QQ-B-626 comp 11		Extra High leaded brass
356	QQ-B-613 comp 11 QQ-B-626 comp 11 & 22		Extra High Leaded brass
370	QQ-B-613 comp 11 QQ-B-626 comp 11		Free cutting muntz metal
360	QQ-B-613 comp 11 QQ-B-626 comp 11 & 22		Free cutting brass
377	QQ-B-626 comp 21		Forging brass
443	WW-T-756		Admiralty, Arsenical
444	WW-T-756		Admiralty, Antimonial
445	WW-T-756		Admiralty, Phosphorized
462	QQ-B-626 comp 11 QQ-B-637 comp 4		Naval Brass, 63½%
464	QQ-B-613 comp 11 QQ-B-626 comp 11 QQ-B-637 comp 1	MIL-W-6712  MIL-T-6945 comp 1	Naval Brass
465	QQ-B-613 comp 11 QQ-B-626 comp 11 QQ-B-637 comp 1	MIL-W-6712  MIL-T-6945  comp 1	Naval brass, arsenical
466	QQ-B-613 comp 11 QQ-B-626 comp 11 QQ-B-637 comp 1	MIL-W-6712  MIL-T-6945  comp 1	Naval Brass, antimonial

TABLE 6-1. CHEMICAL COMPOSITION BY TRADE NAME (CONTD)

COPPER ALLOY NO	SPECIFICATION		TRADE NAME
	FEDERAL	MILITARY	
467	QQ-B-613 comp 11 QQ-B-626 comp 11 QQ-B-637 comp 1	MIL-W-6712 MIL-T-6945	Naval Brass, phosphorized
470	QQ-R-571 Class FS-RWZn-1		Naval brass, welding and brazing rod
472	QQ-B-650 comp B		Brazing Alloy
482	QQ-B-626 comp 11 QQ-B-637 comp 2	MIL-W-6712 MIL-T-6945 comp 1	Naval Brass, medium leaded
485	QQ-B-626 comp 1 QQ-B-637 comp 3	MIL-W-6712 MIL-T-6945 comp 1	Naval Brass, High Leaded
510	QQ-B-750 comp A QQ-W-401 QQ-R-571, class FS-RCuSm -2		Phosphor Bronze A
518	QQ-R-571 Class FS-RCu Sm-2		Phosphor bronze
521	QQ-R-571 Class FS-Rcu Sm-2		Phosphor Bronze C
524	QQ-B-750 Comp D		Phosphor Bronze D
544	QQ-B-750	MIL-B-13501	Phosphor Bronze B-2
606	QQ-C-450 comp 3		
612	QQ-C-450 comp 4		
614	QQ-C-450 comp 5		Aluminum Bronze D
618		MIL-W-6712 MIL-R-18818 MIL-RUA1-2	
622		MIL-R-18818 class MIL-RCA-B	
651	QQ-C-591 comp B		Low silicon bronze B
655	QQ-C-591 comp A	MIL-T-8231	High Silicon Bronze A
656	QQ-R-571 Class FS-RCuSi	MIL-E13191 class MIL-EcuSi-A	

TABLE 6-1. CHEMICAL COMPOSITION BY TRADE NAME (CONTD)

COPPER ALLOY NO	SPECIFICATION		TRADE NAME
	FEDERAL	MILITARY	
658		MIL-E-13191 class MIL-ECuSi-A	
661	QQ-C-591 comp D		
670	QQ-B-728 Class B		Manganese Bronze B
675	QQ-B-728 Class A		Manganese Bronze A
680	QQ-R-571 Class FS-RCu-Zn-3		Bronze Low Fuming (Nickel)
681	QQ-R-571 class FS-RCuZn-2		Bronze, Low Fuming
692	QQ-C-591 Comp E		Silicon Brass
715	QQ-R-571 Class FS-RcuNi		Copper Nickel 30%
735	QQ-C-585 comp 6		
745	QQ-C-585 comp 5 QQ-C-586 comp 5 QQ-W-340 comp 5		Nickel Silver 65-10
752	QQ-C-585 comp 1 QQ-C-586 comp 1 QQ-W-340 comp 1		Nickel Silver 65-18
764	QQ-C-586 comp 3 QQ-W-340 comp 3		
766	QQ-C-585 comp 7		
770	QQ-C-585 comp 2 QQ-C-586 comp 2 QQ-W-340 comp 2		Nickel Silver 55-18
794	QQ-C-586 comp 4 QQ-W-340 comp 4		

TABLE 6-1. CHEMICAL COMPOSITION BY TRADE NAME (CONTD)

COMMERCIAL DESIGNATION	CHEMICAL COMPOSITION	HOT WORKING TEMP °F	ANNEALING TEMP °F
Copper, commercially pure	99.93 Cu	1300 to 1650	700 to 1200
Gilding Metal	95 Cu, 5 Zn	1300 to 1650	800 to 1450
Commercial Bronze	90 Cu, 10 Zn	1400 to 1600	800 to 1450
Red Brass	85 Cu, 15 Zn	1450 to 1650	800 to 1350
Low Brass	80 Cu, 20 Zn	1450 to 1650	800 to 1300
Cartridge Brass	70 Cu, 30 Zn	1350 to 1550	800 to 1300
Yellow Brass	65 Cu, 35 Zn	(a)	800 to 1300
Muntz Metal	60 Cu, 40 Zn	1150 to 1450	800 to 1100
Leaded Commercial Bronze	89 Cu, 9.25 Zn, 1.75 Pb	(a)	800 to 1200
Low Leaded Brass	64.5 Cu, 35 Zn, 0.5 Pb	(a)	800 to 1300
Medium Leaded Brass	64.5 Cu, 34.5 Zn, 1 Pb	(a)	800 to 1200
High Leaded Brass	62.5 Cu, 35.75 Zn, 1.75 Pb	(a)	800 to 1100
Extra High Leaded Brass	62.5 Cu, 35 Zn, 2.5 Pb	(a)	800 to 1100
Free cutting Brass	61.5 Cu, 35.5 Zn, 3 Pb	1300 to 1450	800 to 1100
Leaded Muntz Metal	60 Cu, 39.5 Zn, 5 Pb	1150 to 1450	800 to 1100
Free Cutting Muntz Metal	60.5 Cu, 38.4 Zn, 1.1 Pb	1150 to 1450	800 to 1100
Forging Brass	60 Cu, 38 Zn, 2 Pb	1200 to 1500	800 to 1100
Architectural Bronze	57 Cu, 40 Zn, 3 Pb	1200 to 1400	800 to 1100
Admiralty	71 Cu, 28 Zn, 1 Sn	1200 to 1500	800 to 1100
Naval Brass	60 Cu, 39.25 Zn, 0.75 Sn	1200 to 1400	800 to 1100
Leaded Naval Brass	60 Cu, 37.5 Zn, 1.75 Sn	1200 to 1450	800 to 1100
Manganese Bronze	58.5 Cu, 39.2 Zn, 1 Sn, 3Mn, 1Fe	1250 to 1450	800 to 1100
Aluminum Brass	76. Cu, 22Zn, Z al	1450 to 1550	800 to 1100



TABLE 6-2. HOT WORKING AND ANNEALING TEMPERATURES FOR COPPER AND WROUGHT COPPER ALLOYS. (CONTD)

COMMERCIAL DESIGNATION	CHEMICAL COMPOSITION	HOT WORKING TEMP °F	ANNEALING TEMP °F
Phosphor Bronze "A"	95 Cu, 5 Sn	(a)	900 to 1250
Phosphor Bronze "C"	92 Cu, 8 Sn	(a)	900 to 1250
Phosphor Bronze "D"	90 Cu, 10 Sn	(a)	900 to 1250
Phosphor Bronze "E"	98.75 Cu, 1.25 Sn	1450 to 1600	900 to 1200
Cupro-Nickel 30%	70 Cu, 30 Ni	1700 to 2000	1200 to 1600
Nickel Silver 18% (A)	65 Cu, 17 Zn, 18 Ni	(a)	1100 to 1500
Nickel Silver 18% (B)	55 Cu, 27 Zn, 18 Ni	(a)	1100 to 1400
High-Silicon Bronze (A)	94.8 Cu, 3 Si, 1.5 Mn, 0.7 Zn	1300 to 1650	900 to 1300
Low Silicon Bronze (b)	96. Cu, 2 Si, 1.5 Zn, 0.5 Mn	1300 to 1650	900 to 1250
(a) These alloys are usually hot extruded after casting, further hot working is uncommon.			

6-11. Typical Engineering properties of alloys 170, Specification QQ-C-530 and 172, Specification QQ-C-533 are cited in Table 6-5.

#### 6-12. HEAT TREATING PROCEDURES AND EQUIPMENT REQUIREMENTS.

##### NOTE

MIL-H-7199, Heat Treatment of Wrought Copper-Beryllium Alloys, Process for (Copper Alloy #'s 170, 172 and 175), will be the control document for heat treatment of wrought copper-beryllium alloy, #'s 170, 172 and 175. For complete description of heat treat requirements for these alloys, refer to the latest issue of MIL-H-7199.

6-13. Furnaces for solution heat treating of copper beryllium items/parts may be heated by electricity, gas or oil, with either controlled gas atmosphere or air (static or forced), used in the chamber, continuous or induction types. Molten salt baths shall not be used because of corrosive attack of beryllium alloys by the molten salts at solution heat treatment temperatures. Air atmosphere furnaces shall not be used when the loss of material due to excessive scaling is detrimental to the finished part.

6-14. The furnace alloy shall be capable of maintaining a temperature in working zone with a normal load, of  $\pm 20^{\circ}\text{F}$  for solution heat treatment, or  $\pm 5^{\circ}\text{F}$  for aging, or precipitation heat treatment. In addition, the temperature in working zone shall not vary above the maximum or below the minimum specified for the alloy being treated, during the holding portion of the treatment cycles (See Table 6-6).

6-15. SOLUTION HEAT TREATMENT COPPER BERYLLIUM. Normally solution heat treatment is not required because the material is furnished in a condition suitable for accomplishing forming operations and then precipitation heat treating. An exception is when the material has been rendered unsuitable for precipitation or age hardening as result of (i) welding, brazing or other fabrication operations or when (b) cold working requirements demand intermediate softening (annealing) treatment.

6-16. The solution heat treatment temperatures for alloys 170 and 172 shall be  $1425^{\circ}$  to  $1460^{\circ}\text{F}$ . The time the material is held at the temperature will determine the potential properties of the material. Insufficient time will make it impossible to achieve maximum strength after precipitation hardening, while excessive time may cause grain growth with attendant harmful possibilities. Once the parts are brought up to temperature it is recommended that material be held at temperature for 1 hour per inch of thickness. For parts less than 1/2 inch in thickness, 1/6-1/2 hour may be sufficient. Test sample should be used to determine specific time or if laboratory facilities are available an examination of microstructure will confirm the adequacy of the time selected. The part/material should be rapidly (10 seconds or under) quenched in water from the annealing temperature. An agitated quench should be used. Some oxidation will occur as a result of the annealing temperatures and it should be removed by pickling or other suitable cleaning process.

6-17. PRECIPITATION OR AGE HARDENING. Appreciable changes can be produced in both mechanical and physical by this treatment. The actual changes can be controlled by the time and temperature of hardening. Table 6-6 gives times and temperatures for obtaining various tempers.

TABLE 6-3. TYPICAL STRESS-RELIEF TREATMENTS FOR CERTAIN COPPER ALLOYS)

ALLOY COMPOSITION	TEMP °F	TIME, HOURS
Copper, commercially pure	300	1/2
90 Cu - 10 Zn	400	1
80 Cu - 20 ZN	500	1
70 Cu - 30 ZN	500	1
63 CU - 37 ZN	475	1
60 CU - 40 ZN	375	1/2
70 Cu - 29 ZN - 1 SN	575	1
85 Cu - 15 Ni	475	1
70 Cu - 30 Ni	475	1
64 Cu - 18 ZN - 18 Ni	475	1
95 Cu - 5 Sn	375	1
90 Cu - 10 Sn	375	1

TABLE 6-4. STANDARD MACHINABILITY RATING OF COPPER ALLOYS

ALLOY DESIGNATION	MACHINABILITY RATING	SURFACE SPEED FEET PER MINUTE	ROUGHING FEED, INCH	FINISHING FEED, INCH
Leaded Copper	80	300 to 700	0.006 to 0.020	0.003 to 0.015
Leaded Commercial Bronze	80	↑	↑	↑
Low Leaded Brass	80	↑	↑	↑
Medium Leaded Brass	70	↑	↑	↑
High Leaded Brass	90	↑	↑	↑
Free Cutting Brass*	100	↑	↑	↑
Forging Brass	80	↓	↓	↓
Leaded Naval Brass	70	↓	↓	↓
Architectural Bronze	90	300 to 700	0.006 to 0.020	0.003 to 0.015
Red Brass, 85%	30	150 to 300	0.015 to 0.035	0.005 to 0.015
Low Brass, 80%	30	↑	↑	↑
Muntz Metal	40	↑	↑	↑
Naval Brass	30	↑	↑	↑
Manganese Bronze (A)	30	↑	↑	↑
Leaded Nickel Silver, 12%	50	↑	↑	↑
Leaded Nickel Silver 18%	50	↑	↑	↑
High Silicon Bronze (A)	30	↑	↑	↑
Leaded Silicon Bronze (d)	60	↓	↓	↓
Aluminum Silicon Bronze	60	150 to 300	0.015 to 0.035	0.005 to 0.015
Electrolytic Tough-pitch copper	20	75 to 150	0.015 to 0.040	0.005 to 0.020
Commercial Bronze	20	↑	↑	↑
Phosphor Bronze	20	↑	↑	↑
Nickel Silver	20	↑	↑	↑
Cupro-Nickel	20	↑	↑	↑
Aluminum Bronze	20	↑	↑	↑
Beryllium Copper	20	↓	↓	↓
Chromium Copper	20	75 to 150	0.015 to 0.040	0.005 to 0.020

\* Table based on machining characteristics in comparison to this alloy.

TABLE 6-5. TYPICAL ENGINEERING PROPERTIES

	TENSILE STRENGTH KSI	YIELD STRENGTH 0.2% OFFSET	% ELONGATION IN 2 INCHES	FATIGUE(1) STRENGTH KSI	ROCKWELL HARDNESS	ELECTRICAL CONDUCTIVITY % OF 1 ACS
A- Annealed	60-78	28-36,000	35-60	30-35	B45-78	17-19
1/4 Hard	75-88	60-80,000	10-35	31-36	B68-90	16-18
1/2 Hard	85-100	55-70,000	5-25	32-38	B88-96	15-17
Hard	100-120	90-112,000	2-8	35-39	B96-102	15-17
AT	165-190	100-125,000	4-10	34-38	C36-MIN	22-25
1/4 HT	175-200	110-135,000	3-6	35-39	C38-MIN	22-25
1/2 HT	785-210	160-195,000	2-5	39-43	C39-MIN	22-25
HT	190-215	165-205,000	1-4	41-46	C40-MIN	22-25

(1) Based on 100,000,000 load cycles.

TABLE 6-6. AGE HARDENING TIME-TEMPERATURE CONDITIONS AND MATERIAL TEMPER-DESIGNATIONS

MATERIAL FORM	TEMPER DESIGNATION BEFORE AGE HARDENING	AGE HARDENING		TEMPER DESIGNATION AFTER AGE HARDENING
		TIME HRS.	TEMP (°F)	
Plate, Sheet or Strip	A	3	600 ± 5	AT
	1/4 H	2-1/2	600 ± 5	1/4 HT
	1/2 H	2	600 ± 5	1/2 HT
	H	2	600 ± 5	HT
Forgings Rod and Bar 3/4 Inch or Less Over 3/4 Inch	A	3	600 ± 5	AT
	H	2	600 ± 5	HT
	H	3	600 ± 5	HT
Wire	A	3	600 ± 5	AT
	1/4 H	2	600 ± 5	1/4 HT
	1/2 H	1-1/2	600 ± 5	1/2 HT
	3/4 H	1	600 ± 5	3/4 HT

NOTE: For additional data see Specification MIL-H-7199.

## SECTION VII

### TOOL STEELS

#### 7-1. GENERAL

7-2. Tool steels are essential to the fabrication of aircraft parts. It is therefore necessary to provide guidance in the handling of these important metals.

7-3. Tool steels are produced and used in a variety of forms. The more common forms are bars, (round, square, hexagonal, or octagonal), drill rods, (round, square, or rectangular), flats, and forged shapes.

7-4. ALLOYING ELEMENTS IN TOOL STEELS. (See Table 7-2, chemical composition table.)

a. CARBON - Carbon is the most important single element in tool steel. Changing the carbon content a specific amount will change the physical properties a greater degree than the same amount of any other element. Degree of hardness of tool steel quenched from a suitable temperature is a function of carbon content alone.

b. CHROMIUM - In amounts up to 1.80% the addition of chromium produced a marked increase in the hardenability (depth of hardness) of steels. Small amounts of chromium toughens the steel (greater impact strength), and increases its strength. Machinability decreases as chromium increases. The addition of 5 to 15% chromium imparts hardening qualities to the steel. A degree of red hardness and resistance to wear and abrasion results from the addition of chromium to steel.

c. COBALT - Cobalt is sometimes used in high speed tools. Addition of 5 to 8% increase the red hardness of these steels.

d. MANGANESE - This element is present in all steels. In amounts of less than 1/2%, it acts as a deoxidizer and desulfurizer. In amounts greater than 15% it gives steel air hardening tendencies. In intermediate amounts it is necessary to have other alloying agents present with manganese because of its tendency to make the steel brittle.

e. MOLYBDENUM - Always used in conjunction with other alloying elements, molybdenum acts as an intensifier. It improves the deep hardening and elevated temperature properties of steel.

f. NICKEL - Nickel makes the steel more ductile. It is used in only a few applications and only in small amounts.

g. SILICON - This element is present in all steels. In amounts of 1/4 to 1% it acts as a deoxidizer. Silicon is added to shock resisting and hotwork steels to improve their impact characteristics and hardenability. It has a graphitizing influence and usually requires the addition of carbide stabilizing elements such as molybdenum and chromium.

h. TUNGSTEN - One of the most important features of tungsten steels is their high redhardness. Tungsten steels are fine grained and high strength, which means they hold good cutting edges. Tungsten content is usually 5 - 12% in heat resisting tool steels, 4 - 9% in tungsten molybdenum high speed steels, and 14 - 20% in straight tungsten high speed steel.

j. VANADIUM - This element forms stable carbides and has considerable effect on the hardenability of steels. Undissolved vanadium carbides inhibit grain growth and reduce hardenability. Dissolved carbides increase hardenability. Vanadium is also used as a deoxidizer. It is added to plain carbon tool steels to make them fine grained and tough. It is added to high speed and hot working steels to resist grain growth and help maintain their hardness at elevated temperatures.

7-5. SPECIFICATIONS. The armed services procure tool steels under three different Federal Specifications, dependent upon its intended use. Table 7-1 lists these specifications, and present and past classification of the tool steels. Army Specification 57-108A was superseded by three Army Ordnance Specification's QQ-8-778, QQ-8-779, and QQ-S-780. which were then superseded by Federal Specification's QQ-T-570, QQ-T-580 and QQ-T-590 respectively.

D - High carbon-high chromium types  
 H - Hot work tool steels  
 T - High speed tool steels  
 n - Molybdenum Base types  
 L - Special purpose, low alloy types  
 F - Carbon tungsten tool steels

TABLE 7-1. TOOL STEEL SPECIFICATIONS

SAS DESIGNATION	FEDERAL SPECIFICATION		SUPERCEDED SPECIFICATION	
	NUMBER	CLASS	NUMBER	CLASSIFICATION
W1-.80 Carbon	QQ-T-580	W1-08	57-108A	A1
W1-.90 Carbon	QQ-T-580	W1-09	57-108A	A2
W1-1.0 Carbon	QQ-T-580	W1-10	57-108A	A3
W1-1.2 Carbon	QQ-T-580	W1-12	57-108A	A4/A5
W2-.9 Carbon V	QQ-T-580	W2-09	57-108A	B1
W2-1.0 Carbon V	QQ-T-580	W2-10	57-108A	B1
W3-1.0 Carbon VV	QQ-T-580	W3-10	QQ-S-00779 (Army)	FS-W3-10
A2	QQ-T-570	A2	57-108A	C1
A6	QQ-T-570	A6	-----	-----
D2	QQ-T-570	D2	57-108A	C2
D3	QQ-T-570	D3	57-108A	C3
D5	QQ-T-570	D5	QQ-S-00778 (Army)	FS-D5
D7	QQ-T-570	D7	-----	-----
F3	QQ-T-570	F3	57-108A	D1
H11	QQ-T-570	H11	-----	-----
H12	QQ-T-570	H12	QQ-S-00778 (Army)	FS-H12
H13	QQ-T-570	H13	-----	-----
H21	QQ-T-570	H21	QQ-S-00778 (Army)	FS-H21
T1	QQ-T-590	T1	QQ-S-00780 (Army)	FS-T1
T2	QQ-T-590	T2	QQ-S-00780 (Army)	FS-T2
T3	QQ-T-590	T3	-----	-----
T4	QQ-T-590	T4	QQ-S-00780 (Army)	FS-T4
T5	QQ-T-590	T5	QQ-S-00780 (Army)	FS-T5
T6	QQ-T-590	T6	MIL-S-15046 (Ships)	T6
T7	QQ-T-590	T7	QQ-S-00780 (Army)	FS-T7
T8	QQ-T-590	T8	QQ-S-00780 (Army)	FS-T8
M1	QQ-T-590	M1	QQ-S-00780 (Army)	FS-M1
M2	QQ-T-590	M2	QQ-S-00780 (Army)	FS-M2
M3	QQ-T-590	M3	QQ-S-00780 (Army)	FS-M3
M4	QQ-T-590	M4	-----	-----
M10	QQ-T-590	M-10	57-108A	F1
M15	QQ-T-590	M15	-----	-----
M30	QQ-T-590	M30	57-108A	F3
M34	QQ-T-590	M34	QQ-S-00780 (Army)	FS-M34
O1	QQ-T-570	O1	57-108A, QQ-T-778	B4
O2	QQ-T-570	O2	57-108A	B3
O6	QQ-T-570	O6	-----	-----
L6	QQ-T-570	L6	-----	-----
L7	QQ-T-570	L7	QQ-S-00778 (Army)	FS-L7
T15	QQ-T-590	T15	-----	-----
S1	QQ-T-570	S1	QQ-S-00778 (Army)	FS-S1
S2	QQ-T-570	S2	QQ-S-00778 (Army)	FS-S2
S5	QQ-T-570	S5	QQ-S-00778 (Army)	FS-S5
W5	QQ-T-570	W5	QQ-S-00778 (Army)	FS-W5

TABLE 7-2. CHEMICAL COMPOSITION, TOOL STEEL

SAE DESIGNATION	CHEMICAL COMPOSITION, PERCENT (TABLE II)										
	C	MN	SI	CR	V	MO	W	CO	NI	CU	P
W1-.80 Carbon	0.70-0.85	0.15-0.35	0.10-0.35	0.15	0.10	0.10	0.15		0.20	0.20	0.025
W1-.90 Carbon	0.85-0.95	0.15-0.35	0.10-0.35	0.15	0.10	0.10	0.15		0.20	0.20	0.025
W1-1.00 Carbon	0.95-1.10	0.15-0.35	0.10-0.35	0.15	0.10	0.10	0.15		0.20	0.20	0.025
W1-1.20 Carbon	1.10-1.30	0.15-0.35	0.10-0.35	0.15	0.10	0.10	0.15		0.20	0.20	0.025
W2-.90 Carbon -V	0.85-0.95	0.15-0.35	0.10-0.35	0.15	0.15-0.35				0.20	0.20	0.030
W2-1.00 Carbon -V	0.95-1.10	0.15-0.35	0.10-0.35	0.15	0.15-0.35	0.10	0.15		0.20	0.20	0.030
W3-1.00 Carbon VV	0.95-1.10	0.15-0.35	0.10-0.35	0.15	0.35-0.50	0.10	0.15		0.20	0.20	0.030
A2-5% Chromium	0.95-1.05	0.45-0.75	0.20-0.40	4.75- 5.50	.40	0.90-1.40					
A6-Manganese	0.65-0.75	1.80-2.20	0.20-0.40	0.90- 1.20		0.90-1.40					
D2	1.40-1.60	0.30-0.50	0.30-0.50	11.0- 13.0	0.80	0.70-1.20		0.60			
D3	2.00-2.35	0.24-0.45	0.25-0.45	11.0 13.0	0.80	0.80	0.15				
D5	1.40-1.60	0.30-0.50	0.30-0.50	11.0 13.0	0.80	0.70-1.20		2.5-3.5			
D7	2.15-2.50	0.30-0.50	0.30-0.50	11.5- 13.5	2.8-4.4	0.70-1.20					
F3	1.25-1.40	0.20-0.50	0.60-0.90		0.25 max		3.00 4.50				
H11	0.30-0.40	0.20-0.40	0.80-1.20	4.75 5.50	0.30-0.50	1.25-1.75					
H12	0.30-0.40	0.20-0.40	0.80-1.20	4.75- 5.50	0.50 max	1.25-1.75	1.0-1.7				
H-13	0.30-0.40	0.20-0.40	0.80-1.20	4.75- 5.50	0.80-1.20	1.25-1.75					
H21	0.30-0.40	0.20-0.40	0.15-0.30	3.0 3.75	0.30-0.50		8.75 10.00				

TABLE 7-2. CHEMICAL COMPOSITION, TOOL STEEL (CONTD)

SAE DESIGNATION	CHEMICAL COMPOSITION, PERCENT (TABLE II)										
	C	MN	SI	CR	V	MO	W	CO	NI	CU	P
T1	0.65-0.75	0.20-0.40	0.20-0.40	3.75-4.50	0.90-1.30		17.25-18.75				
T2	0.75-0.85	0.20-0.40	0.20-0.40	3.75-4.50	1.80-2.40	0.70-1.00	17.50-19.00				
T3	1.00-1.10	0.20-0.40	0.20-0.40	3.75-4.50	2.90-3.50	0.70-1.00	17.50-19.00				
T4	0.70-0.80	0.20-0.40	0.20-0.40	3.75-4.50	0.80-1.20	0.10-1.00	17.25-18.75	4.25 5.75			
T5	0.75-0.85	0.20-0.40	0.20-0.40	3.75-4.75	1.80-2.40	0.70-1.00	17.50-19.00	7.00 9.50			
T6	0.75-0.85	0.20-0.40	0.20-0.40	4.00-4.75	1.50-2.10	0.70-1.00	18.50-21.25	10.25 13.75			
T7	0.70-0.76	0.20-0.40	0.20-0.40	3.75-4.25	1.80-2.20	0.70-1.00	13.50-14.50				
T8	0.75-0.85	0.20-0.40	0.20-0.40	3.75-4.50	1.80-2.40	0.70-1.00	13.25-14.75	4.25- 5.75			
M1	0.75-0.85	0.20-0.40	0.20-0.40	3.75-4.50	0.90-1.30	7.75-9.25	1.15-1.85				
M2	0.78-0.88	0.20-0.40	0.20-0.40	3.75-4.50	1.60-2.20	4.50-5.50	5.50-6.75				
M3	1.00-1.25	0.20-0.40	0.20-0.40	3.75-4.50	2.35-3.25	4.75-6.25	5.50-6.75				
M4	1.25-1.40	0.20-0.40	0.20-0.40	4.00-4.75	3.90-4.50	4.50-5.50	5.25-6.50				
M10	0.85-0.95	0.20-0.40	0.20-0.40	3.75-4.50	1.80-2.20	7.75-9.00					
M15	1.50-1.60	0.20-0.40	0.20-0.40	4.00-5.00	4.50-5.25	2.75-3.50	6.00-6.75	4.75- 5.25			
M30	0.77-0.85	0.20-0.40	0.20-0.40	3.50-4.25	1.00-1.40	7.75-9.00	1.30-2.30	4.50- 5.50			
M34	0.85-0.92	0.20-0.30	0.20-0.30	3.50-4.25	1.90-2.30	8.00-9.20	1.30-2.30	7.75 8.75			
O1	0.85-0.95	1.00-1.30	0.20-0.40	0.40-0.60	0.30 max		0.40-0.60				
O2	0.85-0.95	1.40-1.80	0.20-0.40	0.35	0.20	0.30					
O6	1.35-1.55	0.30-1.00	0.80-1.20			0.20-0.30					
L6	0.65-0.75	0.30-0.80	0.20-0.40	0.65-0.85	0.20-0.35	0.20-0.35			1.25 1.75		
L7 T15	0.95-1.05 1.50-1.60	0.25-0.45	0.20-0.40	1.25-1.75 3.75-4.50		0.30-0.50 4.75-5.25					
							12.00-13.00	4.75-5.25			
S1	0.45-0.55	0.20-0.40	0.25-0.45	1.25-1.75	0.15-0.30	0.40	1.0-3.0				
S2	0.45-0.55	0.30-0.50	0.80-1.20		0.25	0.40-0.60					
S5	0.50-0.60	0.60-0.90	1.80-2.20	0.30	0.25	0.30-0.50					
W5	1.05-1.25	0.15-0.35	0.10-0.40	0.40-0.60	0.25 max	0.30-0.50					



TABLE 7-3. TOOL STEEL SELECTION

MATERIAL TO BE CUT	TOTAL QUANTITY OF PARTS TO BE MADE		
	1,000	10,000	100,000
Aluminum, copper and magnesium alloys	W1, AIS14140	W1, 01, A2	01, A2
Carbon & alloy steels, ferritic stainless	W1, AIS14140	W1, 01, A2	01, A2
Stainless steel, austenitic	W1, A2	W1, A2, D2	A2, D2
Spring steel, hardened, Rockwell C52max	A2	A2, D2	D2
Electrical sheet, transformer grade	A2	A2, D2	A2, D2
Paper, gaskets, & similar soft mat'l	W1	W1	W1, A2
Plastic sheet, not reinforced	01	01	01, A2

Table 7-3 is listed for use as a guide reference in the selection of tool steel types for specific applications.

TABLE 7-4. Tool steel Hardening And Tempering Temperatures

STEEL	HARDENING TREATMENT	TEMPERING TREATMENT	SIZE CHANGE, IN/IN
W	1450°F, Water	300°F	0.0017 - 0.0025
O	1450°F, Oil	300°F	0.0014 - 0.0021
L	1550°F, Oil	300°F	0.0014 - 0.0024
F	1600°F, Oil	300°F	0.0011 - 0.0021
S	1750°F, Oil	500°F	0.0010 - 0.0025
A	1775°F, Air	500°F	0.0005 - 0.0015
D	1875°F, Air	500°F	0.0005 - $\neq$ 0.0005
T	2350°F, Oil	1050°F	0.0006 - 0.0014
M	2225°F, Oil	1025°F	0.0016 - 0.0024

#### 7-6. CLASS DESIGNATIONS.

W - Water hardening tool steels

S - Shock resisting tool steels

O - Cold work tool steels, oil hardening types

A - Cold work tool steels, air hardening types

#### 7-7. APPLICATIONS OF TOOL STEELS

7-8. The majority of tool steel applications can be divided into a small number of groups: cutting, shearing, forming, drawing, extrusion, rolling and battering. Cutting tools include drills, taps, broaches, hobs, lathe tools, etc. Shearing tools include shears, blanking and trimming dies, punches, etc. Forming tools include draw, forging, cold heading and die casting dies. Battering tools include chisels and all forms of shock tools. Most cutting tools require high hardness, high resistance to the softening effect of heat, and high wear resistance. Shearing tools require high wear resistance and fair toughness. Forming tools must possess high wear resistance or high toughness and strength. In battering tools, high toughness is most important.

7-9. SELECTION OF MATERIAL FOR A CUTTING TOOL. The selection of material for a cutting tool depends on several factors: the metal being machined, nature of cutting operation, condition of the machine tool, machining practice, size and design of tool, coolant to be used, and cost of tool material. Selection is usually based more on previous experience or applications than on an engineering or metallurgical analysis.

**T.O. 1-1A-9**

7-10. High speed cutting tools are usually manufactured from the class "T" or class "M" alloys. Four classes, T1, M1, M2 and M10 make up nearly 90% of the general purpose high speed steels. Certain special purpose steels in each class, such as T6, T7, T8 and T15 are advantageous for operations like milling cutters and pre-hardened forging die blocks.

7-11. High speed drills should possess high strength and toughness, notably M1, M2, M10 and T1. Classes T1 and M1 are used for tools subject to shock, while M2 and M10 are generally used where tools require less toughness and more abrasion resistance.

7-12. Material for reamers should be of high hardness and abrasion resistance, such as M1, M2, M10 and T1. The M3 and M15 and T15 classes possess greater abrasion resistance than the lower-vanadium grades.

7-13. Material for taps is generally of the M1, M2 or M10 types. In tapping heat-resisting alloys or steels harder than Rockwell C35, M15 or T15 may be justified.

7-14. Milling cutters are usually made from the high speed steels. As the hardness of the work piece increases beyond Rockwell C35, the cobalt high speed steels should be used.

7-15. Recommended punch and die material for blanking parts from 0.050 inch sheet materials are shown in following table. This table does not cover all operations, and is a sample table intended for use as a guide only:

**7-16. HEAT TREAT DATA**

7-17. The thermal treatments listed in table 7-5 cover the generally used treatments for the forgings, normalizing, and annealing of tool and die steels. The thermal treatments listed in table 7-7 cover the usual ranges of temperatures for hardening and tempering tool and die steels. These tables are listed for use as a guide only, and test samples should be checked prior to use.

7-18. **DISTORTION IN TOOL STEELS** Distortion is a general term encompassing all dimensional changes; the two main types being volume change or change in geometrical form. Volume change is defined as expansion or contraction and geometric change is defined as changes in curvature or angular relations. Table 7-4 shows an approximate range of size changes depending upon the type of tool steel, and also dependent on specific tempering and heat treatments. If a very close tolerance is required for a finished tool, specific data covering this item should be obtained from a detailed source.

**7-19. WELDING OF TOOL STEELS**

7-20. Compared to other carbon steels, tool steels are relatively difficult to weld.

7-21. **GAS WELDING.** In the lower carbon ranges, gas welding of tool steels presents no great welding difficulties. Welding rods should contain a carbon content at least equal the base metal and when hardened and tempered should have approximately the same physical characteristics.

7-22. **SHIELDED METAL - ARC WELDING.** Because of the heat effects of arc welding, this process is seldom used for tool steels. If welding is required one of the following procedures is recommended:

- a. After annealing, preheat the parts and weld with a suitable shielded arc-electrode; then heat treat to restore the desired properties.
- b. Preheat the parts and use an austenitic electrode.

7-23. **PRESSURE GAS WELDING -** Drills and other machining tools are frequently welded to less expensive steels. Use of pressure welds are made at relatively low temperatures in order that no harm may occur to the tool steel that cannot be removed by subsequent heat treatment. In welds of this nature heat treatment is usually required. Pressure cycles used on steels vary with the materials, tool steels requiring much high pressure cycles than low carbon steels.

**NOTE**

**See paragraph 2-117, welding STEEL (General).**

TABLE 7-5. FORGING, NORMALIZING AND ANNEALING TREATMENTS OF TOOL AND DIE STEELS

SAE DESIGNATION	FORGING <sup>a</sup>			NORMALIZING <sup>b</sup>		TEMPERATURE	MAX RATE OF COOLING F/HR	ANNEALING <sup>c</sup> BRINELL HARDNESS APPROX.	ROCKWELL B, APPROX.
	HEAT SLOWLY TO	START FORGING AT	DO NOT FORGE BELOW	HEAT SLOWLY TO	HOLD AT				
W1 (0.8C)	1450	1800 1950	1500	1450	1500	1400-1450	75	159-202	84-94
W1 (0.9C)	1450	1800 1950	1500	1450	1500	1375-1425	75	159-202	84-94
W1 (1.0C)	1450	1800 1900	1500	1450	1550	1400-1450	75	159-202	84-94
W1 (1.2C)	1450	1800 1900	1500	1450	1625	1400-1450	75	159-202	84-94
W2 (0.9C)	1450	1800 1900	1500	1450	1500	1375-1425	75	159-202	84-94
W2 (1.0C)	1450	1800 1900	1500	1450	1550	1400-1450	75	159-202	84-94
W3 (1.0C)	1450	1800 1900	1500	1450	1550	1400-1450	75	159-202	84-94
A2	1600	1850 2000	1650	DO NOT NORMALIZE		1550-1600	40	202-229	94-98
A6	1200-1300			DO NOT NORMALIZE				248	102
D2	1650	1850 2000	1650	DO NOT NORMALIZE		1600-1650	40	207-255	95-102
D3	1650	1850 2000	1650	DO NOT NORMALIZE		1600-1650	50	212-255	96-102
D5	1650	1850 2000	1650	DO NOT NORMALIZE		1600-1650	40	207-255	95-102
D7	1650	2050 2125	1800	DO NOT NORMALIZE		1600-1650	50	235-262	99-103
F3	1550	1800 2000	1600	DO NOT NORMALIZE		1475	50	235	99
H11	1650	1950 2100	1650	DO NOT NORMALIZE		1550-1600	50	192-229	92-98
H12	1650	1950 2100	1650	DO NOT NORMALIZE		1600-1650	50	192-229	92-98
H13	1650	1950 2100	1650	DO NOT NORMALIZE		1550-1600	50	192-229	92-98
h21	1600	2000 2150	1650	DO NOT NORMALIZE		1600-1650	50	202-235	94-99
T1	1600	1950 2100	1750	DO NOT NORMALIZE		1600-1650	50	217-255	96-102
T2	1600	2000 2150	1750	DO NOT NORMALIZE		1600-1650	50	223-255	97-102
T3	1925	2025	1750	DO NOT NORMALIZE		1650	50		
T4	1600	2000 2150	1750	DO NOT NORMALIZE		1600-1650	50	229-255	98-102

TABLE 7-5. FORGING, NORMALIZING AND ANNEALING TREATMENTS OF TOOL AND DIE STEELS (CONT)

SAE DESIGNATION	HEAT SLOWLY TO	FORGING <sup>a</sup> START FORGING AT	DO NOT FORGE BELOW	NORMALIZING <sup>b</sup> HOLD AT		TEMPERATURE	MAX RATE OF COOLING F/HR	ANNEALING <sup>c</sup> BRINELL HARDNESS APPROX.	ROCKWELL B, APPROX.
				HEAT SLOWLY TO					
T5	1600	2000 2150	1800	DO NOT NORMALIZE		1600-1650	50	248-293	102-106
T6	1600	1950 2150	1700	DO NOT NORMALIZE		1600-1650	50	248-293	102-106
T7	1600	1950 2150	1700	DO NOT NORMALIZE		1550-1625	50	217-250	96-102
T8	1600	2000 2150	1750	DO NOT NORMALIZE		1600-1650	50	229-255	98-102
M1	1500	1900 2050	1700	DO NOT NORMALIZE		1525-1600	50	207-248	95-102
M2	1500	1950 2100	1700	DO NOT NORMALIZE		1550-1625	50	217-248	96-102
M3	1500	2000 2150	1700	DO NOT NORMALIZE		1550-1625	50	223-255	97-102
M4	1500	2000 2150	1700	DO NOT NORMALIZE		1550-1625	50	229-255	98-102
M10	1400	1900 2100	1700	DO NOT NORMALIZE		1600-1650	50	235-262	99-103
M15	1400	1900 2100	1700	DO NOT NORMALIZE		1600-1650	50	235-262	99-103
M30	1400	1900 2100	1600	DO NOT NORMALIZE		1600-1650	50	235-262	99-103
M34	1400	1900 2100	1600	DO NOT NORMALIZE		1600-1650	50	235-262	99-103
O1	1500	1750 1900	1550	1500	1600	1425-1475	50	183-212	90-96
O2	1500	1750 1900	1550	1500	1550	1375-1425	50	183-212	90-96
O6	1500	1750 1900	1500	1500	1625	1425-1275	50	183-212	90-96
L6	1500	1800 2000	1600	1550	1650	1400-1450	50	183-212	90-96
L7	1500	1800 2000	1550	1550	1650	1450-1500	50	174-212	88-96
T15	1500	2000 2100	1600	DO NOT NORMALIZE		1600-1650	35	241-269	100-104
S1	1500	1800 2000	1600	DO NOT NORMALIZE		1450-1500	50	192-235	92-99
S2	1500	1900 2100	1600	1500-	1650	1400-1450	50	192-229	92-98
S5	1500	1900 2050	1600	1500	1600	1400-1450	50	192-229	92-98
W5	1200	1700 1900	1500	DO NOT NORMALIZE		1400-1425	50	192-212	92-96

**TABLE 7-5. FORGING., NORMALIZING AND ANNEALING TREATMENTS OF TOOL AND DIE STEELS (CONTD)**

- a. The temperature at which to start forging is given as a range, the higher aide of which should be used for large sections and heavy or rapid reductions, and the lower aide for smaller sections and lighter reductions,, as the alloy content of the steel ,, the time of soaking at forging temperature increases proportionately.. Likewise, as the alloy content increases, it becomes more necessary to cool slowly from the forging temperature.. With the very high alloy steels,, such as high speed or air hardening steels,, this slow cooling is imperative in order to prevent cracking and to leave the steel in a semi-soft condition. Either furnace cooling or burying in an insulating medium such as lime, mica, or silocel la satisfactory.
- b. The length of time the steel is held after being uniformly heated through at the normalizing temperature,, varies from about 15 minutes for a small section to about 1 hour for larger sizes,, Cooling from the normalizing temperatures is done in still air. The purpose of normalizing after forging is to refine the grain structure and to produce a uniform structure throughout the forging. Normalizing should not be confused with low temperature(about 1200F)) annealing used for the relief of residual stresses resulting from heavy -machining, bonding and forming.
- c. The annealing temperature is given as a range,, the upper limit of which should be used for cargo sections,, and the lower limit for smaller sections., The temperature varies from about 1 hour for light sections and small furnace charges of carbon or low alloy steel, to about 4 hours for heavy sections and large furnace charges of high alloy steel.

TABLE 7-6. THERMAL; TREATMENT FOR HARDENING AND TEMPERING TOOL STEEL - GENERAL

CLASS	QUENCH MEDIUM	PREHEAT TEMPERATURE F	HARDENING TEMPERATURE RANGE F	HARDNESS AFTER QUENCHING ROCKWELL C	TEMPERING TEMPERATURE RANGE F	HARDNESS AFTER TEMPERING ROCKWELL C	DECARBURIZATION (PREVENTION OF DURING HEAT TREATMENT)
W1-08	Water	-a	1120-1150	65-67	350-525	65-56	-b
W1-09	Water	-a	1120-1150	65-67	350-525	65-56	-b
W1-10	Water	-a	1120-1150	65-67	350-525	65-56	-b
W1-12	Water	-a	1120-1500	65-67	350-525	65-56	-b
W2-09	Water	-a	1120-1500	65-67	350-525	65-56	-b
W2-10	Water	-a	1120-1500	65-67	350-525	65-56	-b
W3-10	Water	-a	1120-1500	65-67	350-525	65-56	-b
A2	Air	1200-1300	1725-1775	61-63	400-700	60-57	-c
A6	Air	1200-1300	1525-1600	60			
D2	Air	1200-1300	1800-1875	61-63	400-700	60-58	-c
D3	Oil	1200-1300	1750-1800	62-64	400-700	62-58	-c
D5	Air	1200-1300	1800-1875	60-62	400-700	59-57	-c
D7	Air	1200-1300	1850-1950	63-65	300-500	65-63	-c
F3	Water	-a	1550	62-66	850-1000	62-58	
H-11	Air	1150-1500	1825-1875	53-55	300-500	66-62	-c
H12	Oil-Air	1150-1500	1800-1900	53-55	1000-1100	51-43	-c
H13	Air	1100-1150	1825-1875	53-55	1000-1100	51-43	-c
H21	Oil-Air	1500-1550	2100-2150	50-52	950-1150	50-47	-c
T1	Oil-Air-Salt	1500-1550	2300-2375	63-65	1025-1100	65-63	-c
T2	Oil-Air-Salt	1500-1550	2300-2375	63-65	1025-1100	63-65	-c
T3	Oil-Air	1500-1550	2275-2325		1000-1050	67-60	-c
T4	Oil-Air-Salt	1500-1550	2300-2375	63-65	1025-1100	65-63	-c
T5	Oil-Air-Salt	1500-1550	2300-2400	63-65	1050-1100	65-63	-c
T6	Oil	1600	2350	60-65	1000-1100	65-60	-c
T7	Oil	1600	2325	60-65	1000-1100	65-60	-c
T8	Oil-Air-Salt	1500-1550	2300-2375	63-65	1025-1100	65-63	-c
M1	Oil-Air-Salt	1100-1500	2150-2250	63-65	1025-1100	65-63	-c
M2	Oil-Air-Salt	1150-1500	2175-2250	63-65	1025-1075	65-63	-c
M3	Oil-Air-Salt	1150-1500	2150-2225	63-65	1025-1075	65-63	-c
M4	Oil-Air-Salt	1150-1500	2150-2225	63-65	1025-1075	65-63	-c
MIC	Oil	1100	2220	60-65	1000-1100	65-60	-c

TABLE 7-6. THERMAL; TREATMENT FOR HARDENING AND TEMPERING TOOL STEEL - GENERAL (CONT)

CLASS	QUENCH MEDIUM	PREHEAT TEMPERATURE F	HARDENING TEMPERATURE RANGE F	HARDNESS AFTER QUENCHING ROCKWELL C	TEMPERING TEMPERATURE RANGE F	HARDNESS AFTER TEMPERING ROCKWELL C	DECARBURIZATION (PREVENTION OF DURING HEAT TREATMENT)
M5	Oil	1100	2220	60-65	1000-1100	65-60	-c
M30	Oil	1100	2220	60-65	1000-1100	65-60	-c
M34	Oil	1100	2220	60-65	1000-1100	65-60	-c
O1	Oil	-a	1150-1500	63-65	300-800	62-50	-b
O2	Oil	-a	1120-1150	63-65	375-500	62-57	-b
O6	Oil	-a	1150-1500	63-65	300-800	63-50	-b
L6	Oil	-a	1500-1600	62-64	400-800	62-48	-b
L7	Oil	-a	1525-1550	63-65	350-500	62-60	-b
E15	Oil-Air	1500-1600	2250-2300	65-66	1025-1100	66-68	-c
S1	Oil	1200-1300	1650-1800	57-59	300-1000	57-45	-c
S2	Water-oil	-A	1550-1575	60-62	300-500	60-54	-b
			1660-1625	58-60	300-500	58-54	-b
S5	Water		1550-1600	60-62	300-650	60-54	-b
	Oil		1600-1675	58-60	300-650	58-54	-b
W5	Water	1100-1200	1100-1550	65-66	300-400	62-65	-b

- a. For large tools and tools having intricate sections, preheating at 1050 to 1200° is recommended.
- b. Use moderately oxidizing atmosphere in furnace or a suitable neutral salt bath.
- c. Use protective pack, from which volatile matter has been removed, carefully balanced neutral salt bath or atmosphere controlled furnaces. In the latter case, the furnace atmosphere should be in equilibrium with the carbon content of the steel being treated. Furnace atmosphere dew point is considered a reliable method of measuring and controlling this equilibrium.



TABLE 7-7. COMPARISON OF TOOL STEEL PROPERTIES

CLASS	NON DEFORMING PROPERTIES	TOUGHNESS	RESISTANCE TO SOFTENING EFFECT OF HEAT	WEAR RESISTANCE	MACHINE ABILITY
W1-08	Poor	Good	Poor	Fair	Best
W1-09	Poor	Good	Poor	Fair	Best
W1-10	Poor	Good	Poor	Good	Best
W1-12	Poor	Good	Poor	Good	Best
W2-09	Poor	Good	Poor	Fair	Best
W2-10	Poor	Good	Poor	Good	Best
W3-10	Poor	Good	Poor	Good	Best
A2	Best	Fair	Fair	Good	Fair
A6	Good	Fair	Poor	Good	Fair
D2	Best	Fair	Fair	Best	Poor
D3	Good	Poor	Fair	Best	Poor
D5	Best	Fair	Fair	Best	Poor
D7	Best	Poor	Fair	Best	Poor
F3	Poor	Poor	Poor	Best	Fair
H11	Good	Good	Good	Fair	Fair
H12	Good	Good	Good	Fair	Fair
H13	Good	Good	Good	Fair	Fair
H21	Good	Good	Good	Fair	Fair
T1	ood	Poor	Good	Good	Fair
T2	Good	Poor	Good	Good	Fair
T3	Good	Poor	Good	Good	Fair
T4	Good	Poor	Best	Good	Fair
T5	Good	Poor	Best	Good	Fair
T6	Good	Fair	Good	Best	Fair
T7	Good	Poor	Good	Best	Fair
T8	Good	Poor	Best	Good	Fair
M1	Good	Poor	Good	Good	Fair
M2	Good	Poor	Good	Good	Fair
M3	Good	Poor	Good	Best	Fair
M4	Good	Poor	Good	Best	Fair
M10	Good	Poor	Good	Best	Fair
M15	Good	Poor	Good	Best	Fair
M30	Good	Poor	Good	Best	Fair

TABLE 7-7. COMPARISON OF TOOL STEEL PROPERTIES (CONTD)

CLASS	NON DEFORMING PROPERTIES	TOUGHNESS	RESISTANCE TO SOFTENING EFFECT OF HEAT	WEAR RESISTANCE	MACHINE ABILITY
M34	Good	Poor	Good	Best	Fair
O1	Good	Fair	Poor	Good	Good
O2	Good	Fair	Poor	Good	Good
O6	Fair	Fair	Poor	Good	Best
L6	Fair	Fair	Poor	Fair	Fair
L7	Fair	Fair	Poor	Good	Fair
T15	Good	Poor	Best	Best	Fair
S1	Fair	Good	Fair	Fair	Fair
S2	W-Poor O-Fair	Best	Fair	Fair	Good
S5	W-Poor O-Fair	Good	Poor	Fair	Best
W5	Poor	Good	Poor	Fair	Best

7-13/(7-14 Blank))

## SECTION VIII TESTING AND INSPECTION HARDNESS TESTING

### 8-1. GENERAL.

8-2. Hardness testing is used to determine the results of heat treatment as well as the state of the metal prior to heat treatment. Its application in determining the approximate tensile strength of the material by use of a hardness-tensile strength table is very limited and should only be used in the case of ferrous (steel) alloys. Table 8-1 should be used only as a conversion table for converting the various hardness values from one type of test to another, and should not be used as an indication of tensile strength for alloys other than ferrous. In addition, it should be realized that values given in Table 8-1 are only approximate. Whenever a specific type of hardness test is given in a drawing, specification, etc., necessary hardness readings should be made by that test whenever possible, rather than by other means, and a conversion made. In obtaining hardness value, precaution must be taken to assure removal of eloding and decarburized surface layers from area to be tested.

### 8-3. METHODS OF HARDNESS TESTING.

8-4. The methods of hardness testing in general use are: Brinell, Rockwell, Vickers (British), Tukon and Shore scleroscope.

8-5. **BRINELL HARDNESS TEST.** This test consists of pressing a hardened steel ball into a flat surface of the metal being tested by the application of a known pressure. The impression made by the ball is measured by means of a microscope with a micrometer eyepiece. The Brinell "number" is obtained by dividing the load in kilograms by the area of the spherical impression made by the ball, measured in square millimeters. The thickness of all samples used for testing must be sufficient to prevent bulging on the under side.

8-6. **Brinell Tester.** The Brinell tester (Figure 8-1) consists of the following major parts:

- a. An elevating screw and anvil for bringing the sample into contact with the ball.
- b. A manually operated hydraulic pump for applying the pressure to the hardened steel ball, which is mounted on its actuating member.
- c. A pressure gage for determining the applied pressure.
- d. A release mechanism with micrometer eyepiece for calculating the area of the impression.

8-7. **Making The Brinell Test.** The test is performed as follows:

1. Prepare the sample by filing, grinding, and polishing to remove all scratches and variations that may affect the reading.
2. Place the sample on the anvil of the machine and elevate until the hardened ball contacts the surface to be tested.
3. Apply the load by pumping handle.

#### NOTE

**A load of 3,000 kilograms is required for steel, while 500 kilograms is used when testing the softer metals, such as aluminum alloy, brass, and bronze. Normally, the load should be applied for 30 seconds. although this period may be increased to 1 minute for extremely hard steels, in order to produce equilibrium.**

4. Release the pressure and measure the area of impression with the calibrated microscope.
5. Calculate the Brinell number, completing the test.

8-8. **ROCKWELL HARDNESS TEST.** The Rockwell hardness test is based on the degree of penetration of a specifically designed indenter into a material under a given static load. The indenter/penetrator used may be either a diamond or hardened steel ball. The diamond indenter called a "brale" is precision ground and polished and the shape is spheroconical. The steel ball for normal use is 1/16 inch diameter, however, other larger diameter steel ball such as 1/8, 1/4 or 1/2 inch may be used for testing soft metal. The selection of the ball is based on the hardness range of the type of material to be tested.

8-9. The Rockwell machine/tester for accomplishing the hardness test applies two loads to obtain the controlled penetration and indicates results on a graduated dial (see Figure 8-2). A minor load of 10 kilograms is first applied to seat the penetrator in the surface of the test specimen. The actual penetration is then produced by applying a major load, subsequently, releasing and then reading hardness number from the dial. The dial reading is related to the depth of penetration, load and the penetrator used. The shallower the penetration, the higher the hardness value number for given indenter and load. The normal major load is 150 kilograms ("C" Scale) when using the diamond penetrator and 100 kilograms ("B" Scale)

TABLE 8-1 - HARDNESS CONVERSION CHART

FOR HARDENED STEEL AND HARD ALLOYS												FOR UNHARDENED STEEL, STEEL OF SOFT TEMPER, GREY AND MALLEABLE CAST IRON AND MOST NON-FERROUS METAL																								
SCALE												SCALE																								
C	A	D	15-N	30-N	45-N							B	F	G	15-T	30-T	45-T	E	K	A	Brinell	SHORE	B	F	15-T	30-T	45-T	E	H	K	A	Brinell				
Rockwell Hardness Tester						Rockwell Superficial <sup>1</sup>						VICKERS <sup>2</sup>	Brinell <sup>3</sup>	Rockwell Test: 1/16 Ball	SHORE	Rockwell Hardness Tester						Rockwell Superficial <sup>1</sup>						Rockwell Hardness Tester						Brinell		
Penetrator						Penetrator						10 mm Ball	1/16 Ball			Ball Penetrator						Ball Penetrator						10 mm								
"Brale"						"N Brale"										1/16						1/16						10 mm								
Load (kg.)												Load (kg.)																								
150	60	100	15	30	45	10	3000	150				100	60	150	15	30	45	100	150	60	500	3000		100	60	15	30	45	100	60	150	60	500	3000		
80	92.0	86.5	96.5	92.0	87.0	1865						100	82.5	93.0	82.0	72.0				61.5	201	240	33	100	85.5	77.0	49.5	23.0	87.0			64.5	35.0	83		
79	91.5	85.5		91.5	86.5	1787						99	81.0	92.5	81.5	71.0				61.0	195	234	32	49	85.0	76.5	49.0	22.0	86.5			63.5	34.5	81		
78	91.0	84.5	96.0	91.0	85.5	1710						98	79.0		81.0	70.0				60.0	189	228	32	48	84.5		48.5	20.5	85.5			62.5	34.5	81		
77	90.5	84.0		90.5	84.5	1633						97	77.5	92.0	80.5	69.0				59.5	184	222	31	47	84.0	76.0	47.5	19.5	85.0			61.5	34.0	80		
76	90.0	83.0	95.5	90.0	83.5	1556						96	76.0		80.0	68.0				59.0	179	216	30	46	83.0	75.5	47.0	18.5	84.5			61.0	33.5			
75	89.5	82.5		89.0	82.5	1478						95	74.0	91.5	79.0	67.0				58.0	175	210	30	45	82.5		46.0	17.5	84.0			60.0	33.0	79		
74	89.0	81.5	95.0	88.5	81.5	1400						94	72.5		78.5	66.0				57.5	171	205	29	44	82.0	75.0	45.5	16.5	83.5			59.0	32.5	78		
73	88.5	81.0		88.0	80.5	1323						93	71.0	91.0	78.0	65.5				57.0	167	200	28	43	81.5	74.5	45.0	15.5	82.5			58.0	32.0	77		
72	88.0	80.0	94.5	87.0	79.5	1245						92	69.0	90.5	77.5	64.5				100	56.5	163	197	28	42	81.0	74.0	44.0	14.5	82.0			57.5	31.5	76	
71	87.0	79.5		86.5	78.5	1160						91	67.5		77.0	63.5				99.5	56.0	160	190	27	41	80.5	74.0	43.5	13.5	81.5			56.5	31.0	75	
70	86.5	78.5	94.0	86.0	77.5	1076						90	66.0	90.0	76.0	62.5				98.5	55.5	157	185	27	40	79.5	73.5	43.0	12.5	81.0			54.5	30.5	74	
69	86.0	78.0	93.5	85.0	76.5	1004						89	64.0	89.5	75.5	61.5				98.0	55.0	154	180	25	39	79.0		42.0	11.0	80.0			54.0	30.0	73	
68	85.5	77.0		84.5	75.5	942					96	88	62.5		75.0	60.5				97.0	54.0	151	176	25	38	78.5	73.0	41.5	10.0	79.5			53.0	29.5	72	
67	85.0	76.0	93.0	83.5	74.5	894					94	87	61.0	89.0	74.5	59.5				96.5	53.5	148	172	24	37	78.0	72.5	40.5	9.0	79.0			53.0	29.0	72	
66	84.5	75.5	92.5	83.0	73.0	854					92	86	59.0	88.5	74.0	58.5				95.5	53.0	145	169	24	36	77.5		40.0	8.0	78.5	100	52.0	29.0			
65	84.0	74.5	92.0	82.0	72.0	820					90	85	57.5		73.5	58.0				94.5	52.5	142	165	23	35	77.0	72.0	39.5	7.0	78.0	99.5	51.5	28.5	71		
64	83.5	74.0		81.0	71.0	789					88	84	56.0	88.0	73.0	57.0				94.0	52.0	140	162	23	34	76.5	71.5	38.5	6.0	77.0	99.0	50.5	28.0	70		
63	83.0	73.0	91.5	80.0	70.0	763					86	83	54.0	87.5	72.0	56.0				93.0	51.0	137	159	23	33	76.0	71.0	38.0	5.0	76.0	98.5	49.5	27.5	69		
62	82.5	72.5	91.0	79.0	69.0	739					84	82	52.5		71.5	55.0				92.0	50.5	135	156	23	32	75.5	71.0	37.5	4.0	76.0	98.0	48.5	27.0	68		
61	81.5	71.5	90.5	78.5	67.5	716					82	81	51.0	87.0	71.0	54.0				91.0	50.0	133	153	22	31	74.5		36.5	3.0	75.5	98.0	48.0	26.5	67		
60	81.0	71.0	90.0	77.5	66.5	695	614				80	80	49.0	86.5	70.0	53.0				90.5	49.5	130	150	22	30	74.0	70.5	36.0	2.0	75.0	97.5	47.0	26.0	66		
59	80.5	70.0	89.5	76.5	65.5	675	600				78	79	47.5		69.5	52.0				89.5	49.0	128	147	21	29	73.5	70.0	35.5	1.0	74.0	97.5	46.0	25.5	66		
58	80.0	69.0		75.5	64.0	655	587				76	78	46.0	86.0		51.0				88.5	48.5	126	144	21	28	73.0		34.5		73.0	97.0	45.0	25.0	66		
57	79.5	68.5	89.0	75.0	63.0	636	573				74	77	44.0	85.5	68.0	50.0				88.0	48.0	124	141	20	27	72.5	69.5	34.0		73.0	96.5	44.5	25.0	65		
56	79.0	67.5	88.5	74.0	62.0	617	560				72	76	42.5		67.5	49.0				87.0	47.0	122	139		26	72.0	69.0	33.0		72.5	96.0	43.5	24.5	65		
55	78.5	67.0	88.0	73.0	61.0	598	547				70	75	41.0	85.0	67.0	48.5				86.0	46.5	120	137		25	71.5		32.5		72.0	96.0	42.5	24.0	64		
54	78.0	66.0	87.5	72.0	59.5	580	534				68	74	39.0	84.5	66.0	47.5				85.0	46.0	118	135		24	71.0	68.5	32.0		71.5	95.5	41.5	24.0	63		
53	77.5	65.5	87.0	71.0	58.5	562	522				66	73	37.5	84.5	65.5	46.5				84.5	45.5	116	132		23	70.5	68.0	31.0		71.0	95.0	41.0	23.5	63		
52	77.0	64.5	86.5	70.5	57.5	545	509				64	72	36.0	84.0	65.0	45.5				83.5	45.0	114	130		22	69.5		30.5		70.5	95.0	40.0	23.0	62		
51	76.5	64.0	86.0	69.5	56.0	528	496				62	71	34.5		64.0	44.5	100			82.5	44.5	112	127		21	69.0	67.5	29.5		69.5	94.5	39.0	22.5	62		
50	76.0	63.0	85.5	68.5	55.0	513	484				60	70	32.5	83.5	63.5	43.5	99.5			81.5	44.0	110	125		20	68.5		29.0		68.5	94.0	38.0	22.0	61		
49	75.5	62.0	85.0	67.5	54.0	498	472				58	69	31.0	83.0	62.5	42.5	99.0	81.0		80.5	43.5	109	123		19	68.0	67.0	28.5		68.0	94.0	37.5	21.5	61		
48	74.5	61.5	84.5	66.5	52.5	485	460				56	68	29.5	82.5	62.0	41.5	98.0	80.0		80.0	43.0	107	121		18	67.0	66.5	27.5		67.5	93.5	36.5	21.0	60		
47	74.0	60.5	84.0	66.0	51.5	471	448				54	67	28.0	82.0	61.5	40.5	97.5	79.0		80.0	42.5	106	119		17	66.5		27.0		67.0	93.0	35.5	21.0	60		
46	73.5	60.0	83.5	65.0	50.0	458	437				52	66	26.5	82.0	60.5	39.5	97.0	78.0		80.0	42.0	104	117		16	66.0	66.0	26.0		66.5	93.0	35.0	20.5	60		
45	73.0	59.0	83.0	64.0	49.0	446	426				50	65	25.0		60.0	38.5	96.0	77.5		80.0	41.5	102	116		15	65.5	65.5	25.5		66.0	92.5	34.5	20.5	59		
44	72.5	58.5	82.5	63.0	48.0	435	415				48	64	23.5	81.5	59.5	37.5	95.5	76.5		80.0	41.0	101	114		14	65.0		25.0		65.5	92.0	33.0	20.0	59		
43	72.0	57.5	82.0	62.0	46.5	424	404				46	63	22.0	81.0	58.5	36.5	95.0	75.5		80.0	40.5	99	112		13	64.5	65.0	24.0		64.5	91.5	32.0	20.0	58		
42	71.5	57.0	81.5	61.5	45.5	413	393				44	62	20.5		58.0	35.5	94.5	74.5		80.0	40.0	98	110		12	64.0	64.5	23.5		64.0	91.5	31.5	20.0	58		
41	71.0	56.0	81.0	60.5	44.5	403	382				42	61	19.0	80.5	57.0	34.5	93.5	74.0		80.0	39.5	96	108		11	63.5		23.0		63.5	91.0	30.5	20.0	57		
40	70.5	55.5	80.5	59.5	43.0	393	372				40	60	17.5		56.0	32.0	92.5	72.0		80.0	39.0	94	106		10	63.0	64.0	22.0		62.5	90.5	29.5	20.0	57		
39	70.0																																			

**T.O. 1-1A-9**

a material start with the diamond penetrator and switch to the steel ball if the material is below C20-C22.

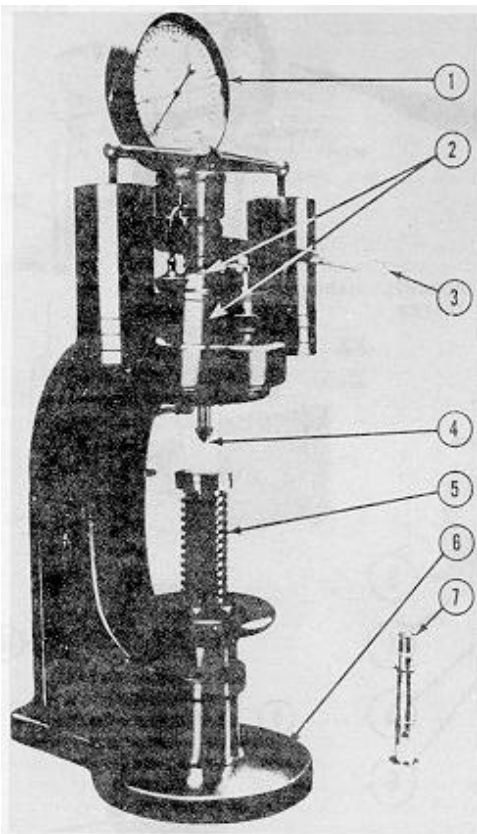
8-11. Rockwell Test Procedure: The procedure for making the Rockwell test is outlined as follows: (See Figure 8-2 for machine illustrations.)

1. Prepare the sample by removing (file, grind and polish) scale, oxide films, pits, variations and foreign material that may affect the reading. The surface should be flat, of one thickness and no bulge should be opposite the indentation.

**NOTE**

**Do not perform test closer than 1/8" from edge of specimen to assure accurate reading.**

2. Select the proper anvil and penetrator and place proper weight on the weight pan.
3. Check trip lever for proper location. Lever should be located in the OFF LOAD position.
4. Place the test specimen on the anvil and by turning the hand wheel, raise it slowly (do not crash) until contact is made with the penetrator. On the older model continue turning until pointer of the indicator has made three revolutions and is within five divisions (plus or minus) of the upright position. On the newer model after contact, continue turning hand-wheel until the small pointer is nearly vertical and slightly to right of the dot. Then watching the long pointer, raise specimen until long pointer is approximately upright within three degrees (plus or minus) of C-O. If the C= +3 degrees position is overshoot, lower the specimen and start over. When the pointer is within three divisions of C-O, set dial to zero. After this step is complete, the minor load has been applied.
5. Apply the major load by tripping the trip lever. Trip the lever, do not push.
6. When the trip lever comes to rest and there is no further movement of pointer, return lever to the original position and read the hardness number indicated by the dial. When dial pointer indicates a fraction, use next lower whole number for the reading.



- 1...Gage indicating applied pressure
2. Hydraulic actuating unit
3. Lever for applying pressure
4. Hardened steel ball
5. Elevating screw
6. Base
7. Calibrated microscope

**Figure 8-1. Brinell Hardness Tester**

when using a 1/16 inch steel ball. A hardness value indicated by a number alone is incomplete. The number must be prefixed with a letter to indicate the load and indenter used to obtain the number. There is a variety of combinations of indentors and loads used to obtain a hardness value in accordance with hardness range of various material. The combinations are listed in Table 8-2 which is based on Specification ASTM E-18.

8-10. Review of Table 8-2 will reveal that the Red Dial Numerals "B" scale are used for steel ball indentors regardless of size of ball or load and Black Figure "C" scales are used for the diamond penetrator. When the readings fall below the hardness value, C20 (B98) the material is considered too soft for the diamond cone and 1/16 inch or larger hardened ball should be used. The diamond cone must be used for all hard materials (those above 100 on the "B" scale) as the steel ball may be deformed by the test. If in doubt about the hardness of

8-12. All hardness tests should be made on a single thickness to obtain accurate results. In testing curved specimens, the concave side should face the indenter; if reversed, an inaccurate reading will result due to flattening of the piece on the anvil. Specimens that do not balance on the anvil because of overhang should be properly supported to obtain accurate readings and to prevent damaging the penetrator. Also to obtain a true



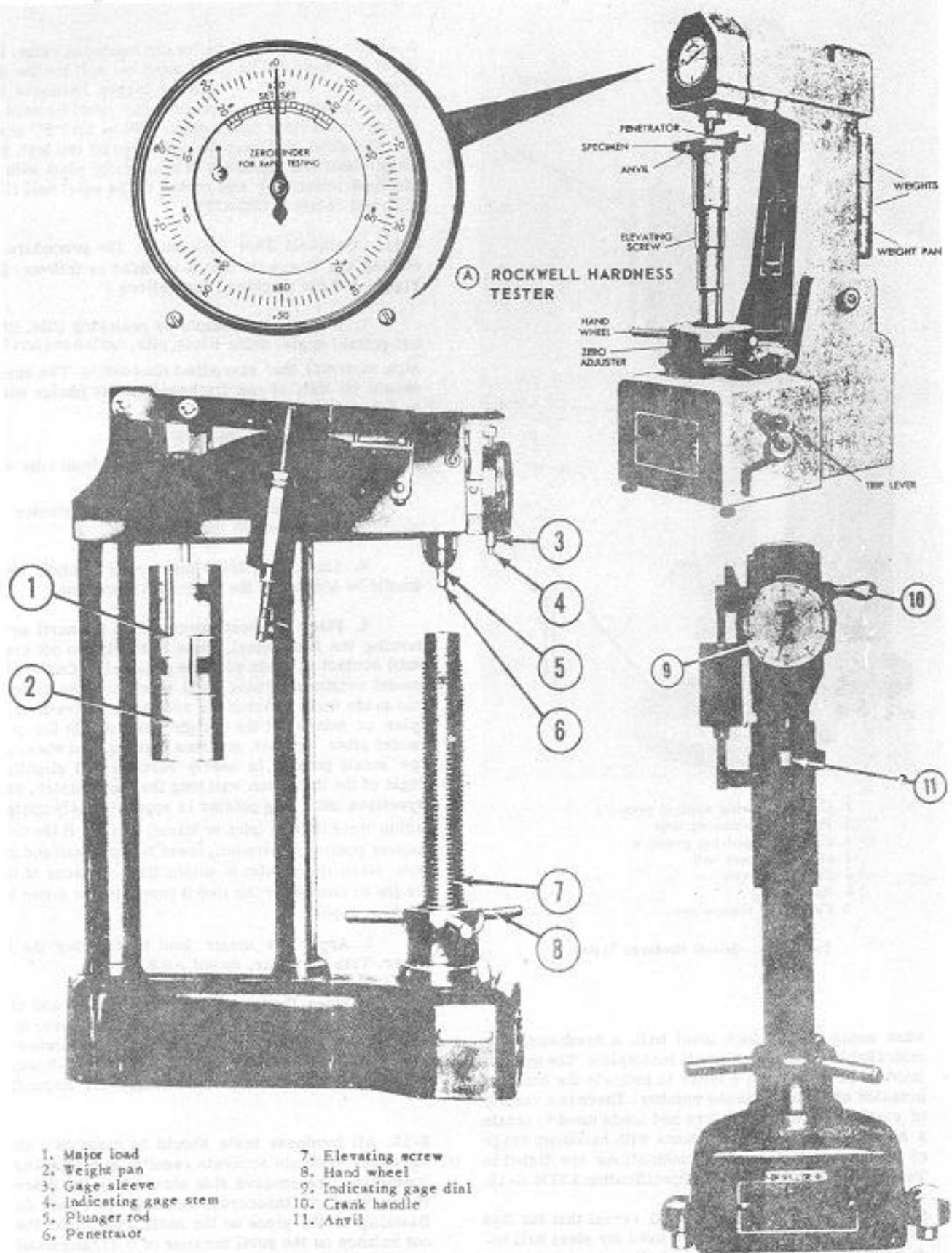
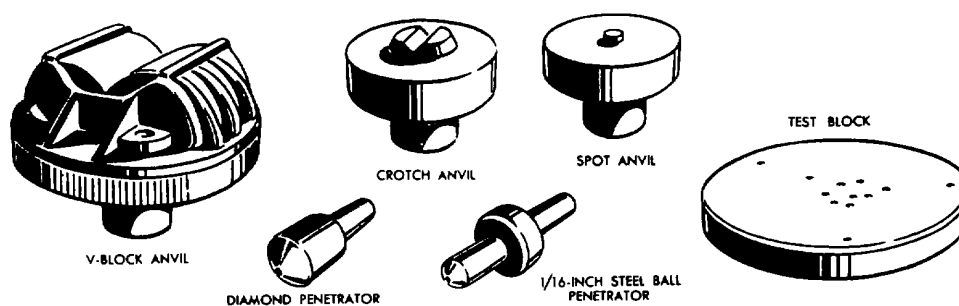


Figure 8-2. Rockwell Hardness Tester



**Figure 8-3. Attachments for Rockwell Tester**

indication of hardness of a given part, several readings (3-6 is usually sufficient) at different points should be taken and averaged. If it is necessary to determine the condition of the interior, parts should be cut by some method that does not appreciably change the temper/ condition, such as using a water-cooled saw-off-wheel. When testing clad material; the clad coat shall be removed. Specimen samples of clad and other materials should be provided when possible. It is not desirable to accomplish the test on the finished part.

8-13. The Rockwell testers are equipped with various anvils and indentors. Typical anvils and attachments are shown in Figure 8-3. The anvil (a) should be properly selected to accomplish the job. The tester should also be properly set and in good working order before making any test. The table on which the Rockwell tester is mounted must be rigid and not subject to any vibration if accurate results are to be obtained.

8-14. The accuracy of the Rockwell hardness tester should be checked regularly. Test blocks are available for testing all ranges of hardness. If the error in the tester is more than  $\pm 2$  hardness numbers, it should be re-calibrated. The dash-pot should be checked for oil and properly adjusted for completion of travel. The bell indenter and diameter should also be checked regularly for bluntness and chipping and replaced as required.

8-15. VICKERS PYRAMID HARDNESS TEST. The Vickers pyramid hardness test (Figure 8-4) covers a normal range of loading from 2.5 to 127.5 kilograms. However, for special applications, such as the hardness testing of thin, soft materials, loads as low as 50 to 100 grams may be used. This test is made by pressing a square base diamond indenter into a flat surface of the metal being tested by the application of known pressure. The indentation left by the indenter is a square, the diagonal of which remains the hardness of the metal. The diagonal of the square impression is measured by a microscope which reads directly to 0.001 millimeters on a large micrometer drum. With the standard pyramidal diamond indenter (Figure 8-5) having an angle of 136° between opposite faces of the pyramid, the pyramidal hardness number is determined by dividing the applied load in kilograms by the pyramidal area of the impression in square millimeters by the formula,

$$\text{Hardness} = \frac{1.854 \text{ applied load in kilograms}}{\text{square of the diagonal of impression}}$$

or from correlation tables accompanying the tester.

Rapid readings may be taken by means of three knife edges in the field of the eye-piece. The first knife edge is fixed; the second knife is movable through a micrometric screw connected to a counter. The third knife edge, moved by means of a special screw, may be used if rapid reading of values to specified limits is desired. This method of testing is highly flexible and permits testing for very high hardness values. In the Amsler-Vickers variation of this hardness tester the surface of the material to be tested, at which the indenter contacts may be thrown on a ground-glass screen directly in front of the operator, allowing the length of the diagonals to be read directly.

8-16. Vickers Tester. The Vickers tester consists of the following major parts:

- a. Table for supporting the metal to be tested.
- b. A lever with a 20 to 1 ratio through which a load is applied through a rod to an indenter at the end of a tube moving up and down in a vertical position.
- c. A frame containing a control in which a plunger moves up and down vertically under the influence of a cam which applies and releases the test load. The cam is mounted on a drum and when the starting handle is depressed, the whole is rotated by a weight attached to a flexible cable, the speed of rotation being controlled by a piston and dashpot of oil. The mechanism provides for a slow and diminishing rate of application for the last portion of the load.



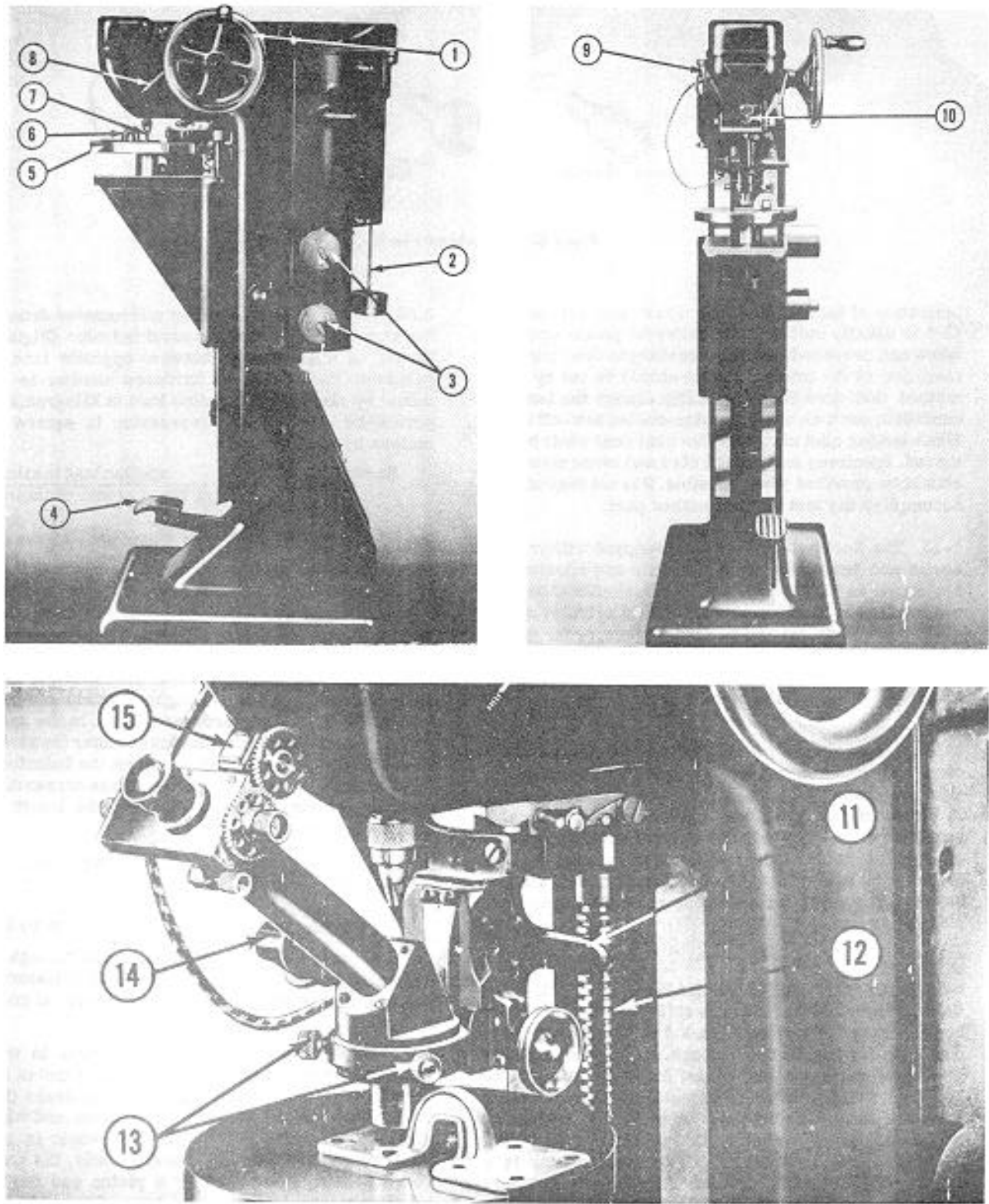


Figure 8-4. Vickers Pyramid hardness Tester

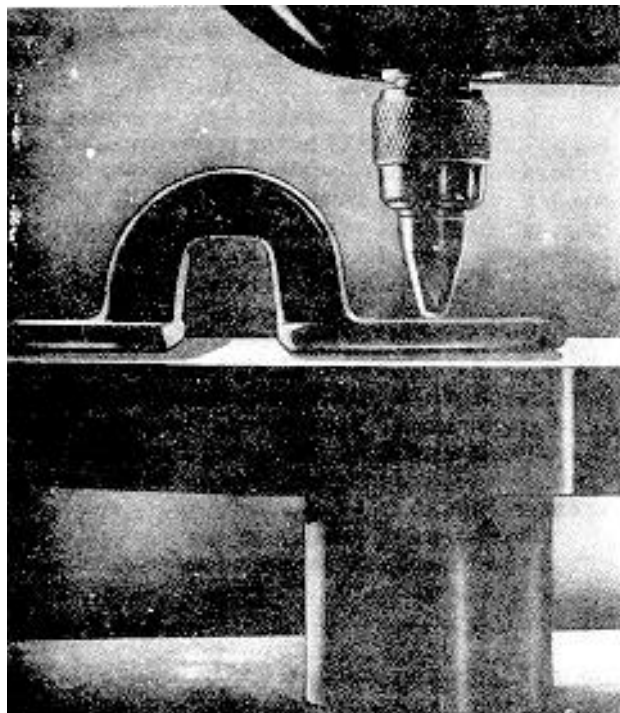


Figure 8-5. Standard Pyramid Diamond Indentor

d. A foot pedal, which when depressed, returns the cam, drum and weight to their original positions, thus cocking the mechanism and preparing the instrument for another test.

e. A tripper, which supports the beam during the return of the cam, weight and drum. The tripper also released the lever for load applications.

f. A medium-power compound microscope for measuring the indentation across the diagonal of a square.

8-17. Making The Vickers Test. The test is applied as follows (See figure 8-4):

1. Prepare the sample by smooth grinding or polishing to remove all scratches and variations that may affect the readability of the indentation.

2. Place the test piece (6) on the testing table (5) and turn the table elevating wheel (1) until the indenter (7) fails to contact the metal being tested.

#### CAUTION

**Sudden contact of the indenter and the material under test should be avoided to prevent possible injury to the diamond point.**

3. Depress the load trip level (8) applying the load. The duration of the load application is fixed by the manufacturers at from 10 to 30 seconds, the time being determined by the rate at which oil is allowed to bleed out of the dashpot. The load is fully applied, the indenter is automatically released.

4. Elevate the indenter by turning the wheel. Lower the testing table by reversing the table elevating wheel.

5. Swing the microscope (10) into place until locked.

6. View the impression of the indentation in the form of a square in the field shown by the eyepiece.

7. Bring the left corner of the impression, by means of the centering screws (13) to a point where it touches the left hand fixed knife edge. Adjust the right hand movable knife edge by means of the micrometric screw connected to the counter until it touches the right hand corner of the impression. The counter (15) will then show an ocular reading which is transposed to the Vickers pyramid numeral by use of correlation tables accompanying the tester.

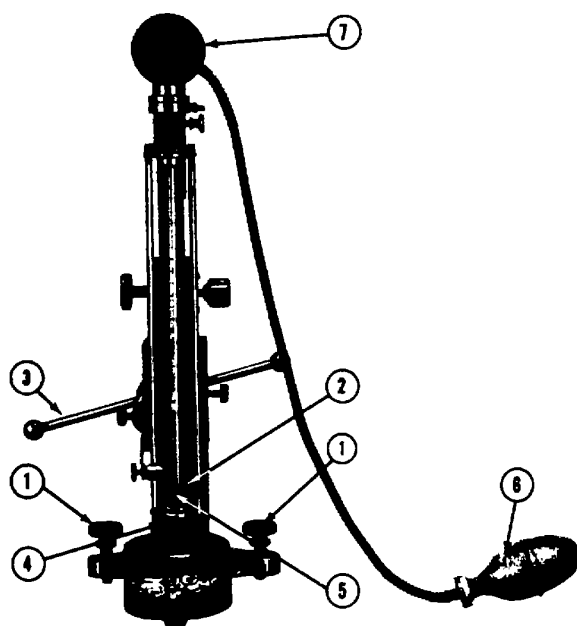
8. Where specified hardness limits are desired the third knife edge is used. This is moved by means of special screws to correspond to the smaller dimension or maximum hardness, while the micrometer-controlled knife edge is adjusted to correspond to the minimum hardness or larger dimension. When the settings of the second and third knife edges are made, it is only necessary when taking readings to set the fixed knife edge to the left hand corner of the impression in the usual way. If the right hand corner of the impression appears between the second and third knife edges, the material has the proper hardness for the range desired.

#### 8-18. SHORE SCLEROSCOPE HARDNESS TEST.

The Shore scleroscope is not a precision instrument as the others discussed in preceding paragraphs. It is used to give approximate values for comparative hardness readings. Testing hardness with the scleroscope consists of dropping a diamond tipped hammer upon the test specimen from a definite height and measuring the rebound produced. In one type of tester, the height of the rebound must be measured directly on the scale of the machine, while on another the amount is indicated on a dial.

8-19. The Scleroscope Tester. The tester (Figure 8-6) consists of the following major parts:

- a. A base, provided with leveling screws, and a clamping arrangement to hold the sample to be tested.



- |                   |                          |
|-------------------|--------------------------|
| 1. Tripod screws  | 5. Diamond-tipped hammer |
| 2. Plumb rod      | 6. Release bulb          |
| 3. Clamping lever | 7. Head                  |
| 4. Clamping shoe  |                          |

**Figure 8-6. Shore Scleroscope**

b. A vertical glass tube, mounted to the base and containing the cylindrical diamond point hammer.

c. A suction heat and bulb for lifting and releasing the hammer.

d. A scale, visible through the glass tube, for determining the height of the rebound.

e. A magnifier hammer with a larger contact area is supplied for use with extremely soft metals.

8-20. TESTING WITH THE SCLEROSCOPE. The test is made as follows:

1. Level the instrument by means of the adjusting screws (1). (See figure 8-6). The level position is determined by means of the plumb rod (2).

2. Prepare the test specimen as described for the Brinell and Rockwell tests in preceding paragraphs and clamp it on the base. This is done by raising the lever (3) inserting the sample and exerting the pressure on the clamping shoe (4).

3. Raise the hammer (5) by squeezing and releasing the bulb (6).

4. Release the hammer by again squeezing the bulb and observing its rebound.

5. Several tests should be made at different points of a specimen, and an average reading taken to reduce visual error.

8-21. TENSILE TESTING. The terms tension test and compression test are usually taken to refer to tests in which a prepared specimen is subjected to a gradually increasing load applied axially until failure occurs. For the purpose of tensile testing implied by this technical order this type of setting would apply to determining the mechanical properties desired in a material. For this test, the following test specimens are listed. (See Figure 8-7.) This does not exclude the use of other test specimens for special materials or forms of material. The tensile strength shall be determined by dividing the maximum load on the specimen during a tension test by the original cross-sectional area of the specimen.

1. Diameter of the reduced section may be smaller at center than at ends. Difference shall not exceed 1% of diameter at ends.

2. When an extensometer is required to determine elastic properties, dimensions C and L may be modified. In all cases the percentage of elongation shall be based on dimension G.

3. The type  $R_1$  test specimen is circular in cross section and is used for bars, rods, forgings, plates, shapes, heavy-walled tubing, and castings. Types  $R_2$ ,  $R_3$ ,  $R_4$ , &  $R_5$  are circular in cross-section and are used for material of dimensions insufficient for type  $R_1$ .

1. The ends of the reduced section shall not differ in width by more than 0.004 inch.

2. The ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 inch.

3. When material is over 2 inches thick, machine to 3/4 inch or use type  $R_1$  test specimen. For more detailed information, refer to Federal Test Method Standard No. 151.

## 8-22. DECARIURIZATION MEASUREMENT.

8-23. Decarburization is the loss of carbon at the surface of ferrous materials which have been heated for fabricating, welding, etc., or when heated to modify mechanical properties. Effective decarburization is any measurable loss of carbon content which results in mechanical properties below the minimum acceptable specifications for hardened materials. The most common methods used to measure decarburization are microscopic, hardness and chemical. The microscopic method is sufficiently accurate for most annealed and hot rolled material for small amounts of decarburization in high carbon (over 0.60%), high hardness steels.

TABLE 8-2. ROCKWELL SCALES, LOADS AND PREFIX LETTERS

SCALE PREFIX LETTERS	INDENTOR/PENETRATOR	MAJOR LOAD KILOGRAMS	DIAL NUMBERS
A	Diamond	60	Black
B*	1/16 in Steel Ball	100	Red
C*	Diamond	150	Black
D	Diamond	100	Black
E	1/8 in Ball	100	Red
F	1/16 in Ball	60	Red
G	1/16 in Ball	150	Red
H	1/8 in Ball	60	Red
K	1/8 in Ball	150	Red
L	1/4 in Ball	60	Red
M	1/4 in Ball	100	Red
P	1/4 in Ball	150	Red
R	1/2 in Ball	60	Red
S	1/2 in Ball	100	Red
V	1/2 in Ball	150	Red

\* Most Commonly Used Scales.

The hardness method is insensitive in this case, and recourse must be taken to chemical analysis. In this technical order, only the hardness method is covered. When precise measurements are required, publications giving detailed measurements must be consulted.

#### 8-24. HARDNESS METHOD.

8-25. Taper or Step Grind The specimen containing the surface on which decarburization is to be measured is prepared so that it can be manipulated on a Rockwell superficial or Vickers hardness tester. If the specimen is not in the hardened condition, it is recommended that it be hardened by quenching from heating equipment under conditions which avoid further change in carbon distribution. For the taper grind procedure, a shallow taper is ground through the case, and hardness measurements are made along the surface. The angle is chosen so that readings spaced equal distances apart will represent the hardness at the desired increments below the surface of the case. The step grind procedure is essentially the same as the taper grind, except that hardness readings are made on steps which are known distances below the surface. These steps should be ground at pre-determined depths below the surfaces, and of sufficient areas to allow several hardness readings on each flat.

8-26. The file method is often suitable for detecting decarburization of hardened materials during shop processing, but not for accurate measurement. Base metals expected to harden above RC60 and found to be file soft are probably decarburized. Decarburization of base metal that will not harden to RC60 can not be detected by this method unless specially prepared files are used. The extent and severity of any decarburization detected by this method should be verified by either of the other methods.



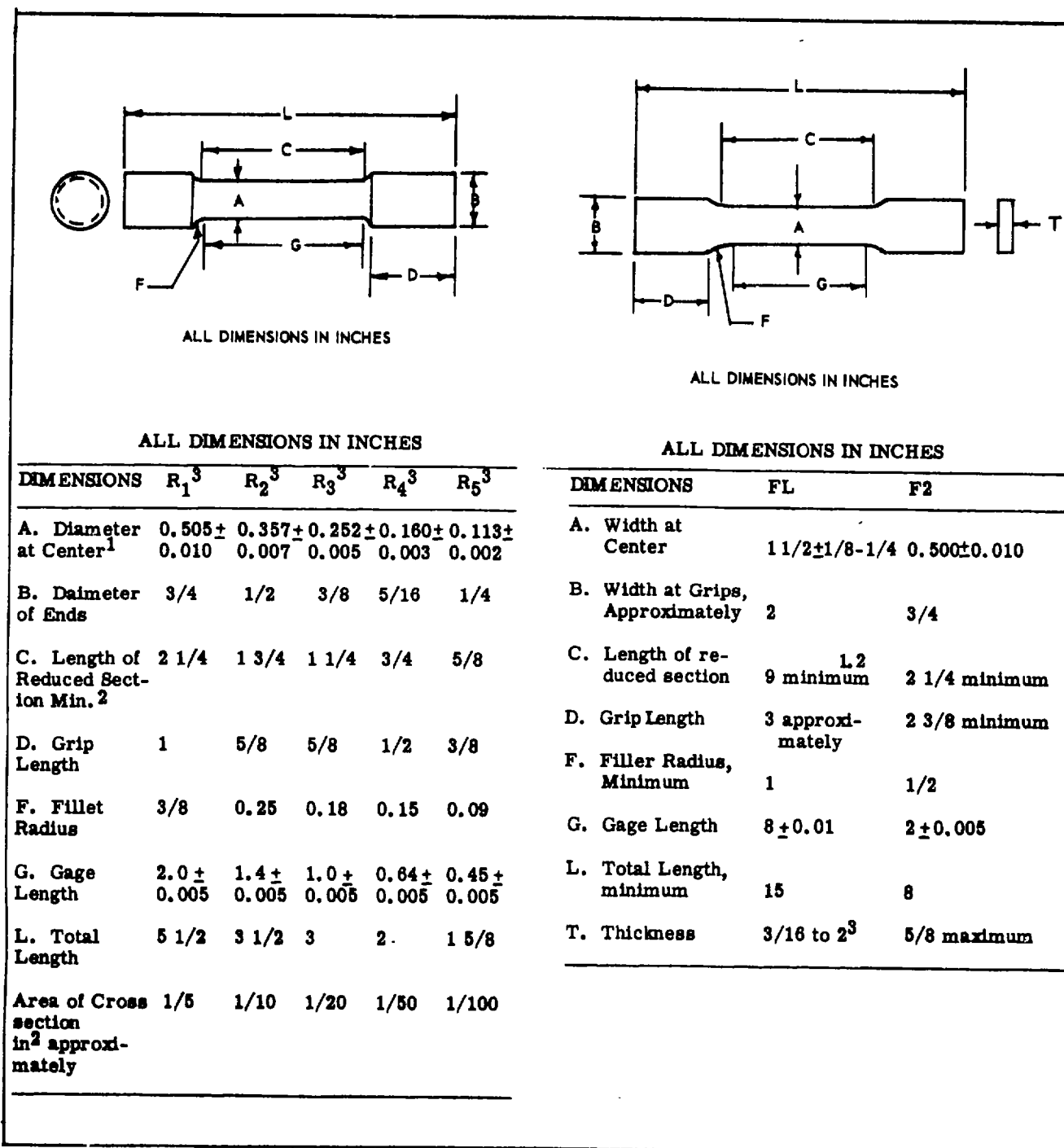


Figure 8-7. Test Specimens

TABLE 8-3. APPROXIMATE HARDNESS - TENSILE STRENGTH RELATIONSHIP OF CARBON AND LOW ALLOY STEELS

Rockwell		Vickers Diamond Pyramid 50 Kg Load	Brinell <sup>3</sup> 300 Kg Load - 10mm Ball		Tensile Strength 1000 lb per sq in.
C 150 Kg Load	B 100 Kg Load 1/16 Ball		Tungsten Carbide Ball	Steel Ball	
67		918	820	717	
66		884	796	701	
65		852	774	686	
64		822	753	671	
63		793	732	656	
62		765	711	642	
61		740	693	628	
60		717	675	613	
59		694	657	600	
58		672	639	584	
57		650	621	574	
56	121.3	630	604	561	
55	120.8	611	588	548	
54	120.2	592	571	536	
53	119.6	573	554	524	283
52	119.1	556	538	512	273
51	118.5	539	523	500	264
50	117.9	523	508	488	256
49	117.4	508	494	476	246
48	116.8	493	479	464	237
47	116.2	479	465	453	231
46	115.6	465	452	442	221
45	115.0	452	440	430	215
44	114.4	440	427	419	208
43	113.8	428	415	408	201
42	113.3	417	405	398	194
41	112.7	406	394	387	188
40	112.1	396	385	377	181
39	111.5	386	375	367	176
38	110.9	376	365	357	170
37	110.4	367	356	347	165
36	109.7	357	346	337	160
35	109.1	348	337	327	155
34	108.5	339	329	318	150
33	107.8	330	319	309	147
32	107.1	321	310	301	142
31	106.4	312	302	294	139
30	105.7	304	293	286	136
29	105.0	296	286	279	132
28	104.3	288	278	272	129
27	130.7	281	271	265	126
26	102.9	274	264	259	123
25	102.2	267	258	253	120
24	101.5	261	252	247	118
23	100.8	255	246	241	115

TABLE 8-3. APPROXIMATE HARDNESS - TENSILE STRENGTH RELATIONSHIP OF CARBON AND LOW ALLOY STEELS (CONT'D)

Rockwell		Vickers Diamond Pyramid 50 Kg Load	Brinell <sup>3</sup> 300 Kg Load - 10mm Ball		Tensile Strength 1000 lb per sq in.
C 150 Kg Load	B 100 Kg Load 1/16 Ball		Tungsten Carbide Ball	Steel Ball	
22	100.2	250	241	235	112
21	99.5	245	236	230	110
20	98.9	240	231	225	107
19	98.1	235	226	220	104
18	97.5	231	222	215	103
17	96.9	227	218	210	102
16	96.2	223	214	206	100
15	95.5	219	210	201	99
14	94.9	215	206	197	97
13	94.1	211	202	193	95
12	93.4	207	199	190	93
11	92.6	203	195	186	91
10	91.8	199	191	183	90
9	91.2	196	187	180	89
8	90.3	192	184	177	88
7	89.7	189	180	174	87
6	89	186	177	171	85
5	88.3	183	174	168	84
4	87.5	179	171	165	83
3	87	177	169	162	82
2	86	173	165	160	81
1	85.5	171	163	158	80
0	84.5	167	159	154	78
	83.2	162	153	150	76
	82	157	148	145	74
	80.5	153	144	140	72
	79	149	140	136	70
	77.5	143	134	131	68
	76	139	130	127	66
	74	135	126	122	64
	72	129	120	117	62
	70	125	116	113	60
	68	120	111	108	58
	66	116	107	104	56
	64	112	104	100	54
	61	108	100	96	52
	58	104	95	92	50
	55	99	91	87	48
	51	95	86	83	46
	47	91	83	79	44
	44	88	80	76	42
	39	84	76	72	40
	35	80	72	68	38
	30	76	67	64	36
	24	72	64	60	34
	20	69	61	57	32
	11	65	57	53	30
	0	62	54	50	28



**8-27. NONDESTRUCTIVE INSPECTION METHODS.**

8-28. Radiographic inspection will show internal and external structural details of all types of parts and materials. It is accomplished by passing penetrating radiation (usually X or gamma rays) through the part or assembly being inspected to expose a film. After developing, interpretation of the radiograph will indicate defects or damage. All radiographic inspections shall be accomplished in accordance with T.O. 33B-1-1, MIL-STD-453, and MIL-STD-410.

8-29. Penetrant inspection is a nondestructive inspection method that is used to detect discontinuities open to the surface of nonporous material.

It is accomplished by treating the inspection area with a fluid (penetrant) that penetrates the surface discontinuity. Surplus penetrant remaining on the surface is removed and an absorbent material (developer) is applied to the surface. The developer acts as a blotter and draws some of the penetrant from the discontinuity to the surface. Discontinuities are visible due to color contrast between the penetrant drawn out and the background surface.

Only fluorescent penetrants are approved for Air Force use. All penetrant inspection materials shall conform to MIL-I-25135. All penetrant inspections shall be accomplished in accordance with T.O. 33B-1-1 and MIL-STD-410.

8-30. Ultrasonic inspection uses a high frequency sound wave to detect discontinuities in materials. The pulser in the ultrasonic instrument sends an electrical impulse to a piezoelectric material in the search unit (transducer). The transducer changes the electrical impulse into mechanical vibrations (sound) and transmits them into the material being inspected. Any marked change in acoustic properties, such as a flaw or interface in the material, reflects the sound back to the transducer. Examination of the reflections on a cathode ray tube will reveal discontinuities in the material. All ultrasonic inspections shall be accomplished in accordance with T.O. 33B-1-1, MIL-I-8950, and MIL-STD-410.

8-31. Magnetic particle inspection is used to detect discontinuities in ferromagnetic materials, principally iron and steel. Magnetic particle inspection is accomplished by inducing a magnetic field into the material being inspected. A discontinuity will interrupt this field, creating north and south poles which will attract magnetic particles applied to the material. Discontinuities are visible due to color contrast between the magnetic particles and the background surface. All magnetic particle inspections shall be accomplished in accordance with T.O. 33B-1-1 and MIL-STD-410.

8-32. Eddy current inspection is used to detect discontinuities in materials that are conductors of electricity. An eddy current is the circulating electrical current induced in a conductor by an alternating magnetic field, which is produced by a small test coil in contact with or close to the material being inspected. Discontinuities in the material being tested cause variations in the induced eddy current. The test coil measures the variations which reveal discontinuities in the material. All eddy current inspections shall be in accordance with T.O. 33B-1-1 and MIL-STD-410.

8-33 thru 8-39. Deleted.

8-40. CHEMICAL ANALYSIS. Chemical analysis methods are those in which the elements present in metals are determined by the use of reagents in solution, by combustion methods, or by other none-mission methods. Sample metal from any piece shall be such that it represents as nearly as possible the metal of the entire piece. Drilling, milling and other machining operations for sample metal shall be performed without the use of water, oil, or other lubricants, and cutting speeds shall be such that no burning takes place to cause alteration of the chemical composition of the test metal. Method III.I of Federal Method Standard 151A is the controlling document for chemical analysis.

8-41. SPECTROCHEMICAL ANALYSIS. Spectrochemical analysis includes all methods in which measurements of electromagnetic radiations produced by a sample metal are employed to determine the chemical composition. Samples shall be so selected as to be representative of the entire quantity of metal under inspection. Cutting speeds in all machining operations shall be such that no burning takes place to cause alteration of the chemical composition of the test metal. Method 112.1 of Federal Test Method Standard 151A governs this type of analysis. The result of spectrochemical analysis shall be determined to the number of decimal places shown in the chemical requirements for the material.

APPENDIX I  
SUPPLEMENTAL DATA

TABLE A-1. CHEMICAL SYMBOLS

<u>ELEMENT</u>	<u>SYMBOL</u>	<u>ATOMIC NO.</u>	<u>ELEMENT</u>	<u>SYMBOL</u>	<u>ATOMIC NO.</u>
Aluminum	Al	13	Neodymium	Nd	60
Antimony	Sb	51	Neon	Ne	10
Argon	A	18	Nickel	Ni	28
Arsenic	As	33	Nitrogen	N	7
Barium	Ba	56	Osmium	Os	76
Beryllium	Be	4	Oxygen	O	8
Bismuth	Bi	83	Palladium	Pd	46
Boron	B	5	Phosphorus	P	15
Bromine	Br	35	Platinum	Pt	78
Cadmium	Cd	48	Polonium	Po	84
Cesium	Cs	55	Potassium	K	19
Calcium	Ca	20	Praseodymium	Pr	59
Carbon	C	6	Protactinium	Pa	91
Cerium	Ce	58	Radium	Ra	8
Chlorine	Cl	17	Radon(radium emanation) Rn		86
Chromium	Cr	24	Rhenium	Re	75
Cobalt	Co	27	Rhodium	Rh	45
Columbium(Niobium)	Cb(Nb)	--	Rubidium	Rb	37
Copper	Cu	29	Ruthenium	Ru	44
Dysprosium	Dy	66	Samarium	Sm	62
Erbium	Er	68	Scandium	Sc	21
Europium	Eu	63	Selenium	Se	34
Fluorine	F	9	Silicon	Si	14
Gadolinium	Gd	64	Silver	Ag	47
Gallium	Ga	31	Sodium	Na	11
Germanium	Ge	32	Strontium	Sr	38
Gold	Au	79	Sulphur	S	16
Hafnium	Hf	72	Tantalum	Ta	73
Helium	He	2	Tellurium	Te	52
Holmium	Ho	67	Terbium	Tb	65
Hydrogen	H	1	Thallium	Tl	81
Indium	In	49	Thorium	Th	90
Iodine	I	53	Thulium	Tm	69
Iridium	Ir	77	Tin	Sn	50
Iron	Fe	26	Titanium	Ti	22
Krypton	Kr	36	Tungsten	W	74
Lanthanum	La	57	Uranium	U	92
Lead	Pb	82	Vanadium	V	23
Lithium	Li	3	Xenon	Xe	54
Lutecium	Lu	71	Ytterbium	Yb	70
Magnesium	Mg	12	Yttrium	Y	39
Manganese	Mn	25	Zinc	Zn	30
Mercury	Hg	80	Zirconium	Zr	40
Molybdenum	Mo	42			

TABLE A-2. DECIMAL EQUIVALENTS

<u>INCH</u>	<u>Mm.</u>	<u>DRILL SIZE NO. OR LTR</u>	<u>DECIMALS OF AN INCH</u>	<u>INCH</u>	<u>Mm.</u>	<u>DRILL SIZE NO. OR LTR</u>	<u>DECIMALS OF AN INCH</u>
		80	0.0135		1.7		0.066929
		79	0.0145			51	0.067
1/64			0.015625		1.75		0.068897
	0.4		0.015748			50	0.07
		78	0.016		1.8		0.070866
		77	0.018		1.85		0.072834
	0.5		0.019685			49	0.073
		76	0.02		1.9		0.074803
		75	0.021			48	0.076
	0.55		0.021653		1.95		0.076771
		74	0.0225	5/64			0.07825
	0.6		0.023622			47	0.0785
		73	0.024		2.0		0.07874
		72	0.025		2.05		0.080708
	0.65		0.02559			46	0.081
		71	0.026			45	0.082
	0.7		0.027559		2.1		0.082877
		70	0.028		2.15		0.084645
		69	0.02925			44	0.086
	0.75		0.029527		2.2		0.086614
		68	0.031		2.25		0.088582
1/32			0.03125			43	0.089
	0.8		0.031496		2.3		0.090551
		67	0.032		2.35		0.092519
		66	0.033			42	0.0935
	0.85		0.033464	3/32			0.09375
		65	0.035		2.4		0.094488
	0.9		0.035433			41	0.096
		64	0.036		2.45		0.096456
		63	0.037			40	0.098
	0.95		0.037401		2.5		0.098425
		62	0.038			39	0.0995
		61	0.039			38	0.1015
	1.0		0.03937		2.6		0.102362
		60	0.04			37	0.104
	1.05		0.041		2.7		0.106299
		59	0.041338			36	0.1065
		58	0.042		2.75		0.108267
		57	0.043	7/64			0.109375
	1.1		0.043307			35	0.11
	1.15		0.045275		2.8		0.110236
		56	0.0465			34	0.111
3/64			0.046875			33	0.113
	1.2		0.047244		2.9		0.114173
	1.25		0.049212			32	0.116
	1.3		0.051181		3.0		0.1181
		55	0.052			31	0.12
	1.35		0.053149		3.1		0.122047
		54	0.055	1/8			0.125
	1.4		0.055118		3.2		0.125984
	1.45		0.057086		3.25		0.127952
	1.5		0.059055			30	0.1285
		53	0.0595		3.3		0.129921
	1.55		0.061023		3.4		0.133858
1/16			0.0625			29	0.136
	1.6		0.062992		3.5		0.137795
		52	0.0635			28	0.1405
	1.65		0.06496	9/64			0.140625

TABLE A-2. DECIMAL EQUIVALENTS (CONT'D)

<u>INCH</u>	<u>Mm.</u>	<u>DRILL SIZE NO. OR LTR</u>	<u>DECIMALS OF AN INCH</u>	<u>INCH</u>	<u>Mm.</u>	<u>DRILL SIZE NO. OR LTR</u>	<u>DECIMALS OF AN INCH</u>
	3.6		0.141732			A	0.234
		27	0.144	15/64			0.234375
	3.7		0.145669		6.0	B	0.23622
		26	0.147				0.238
	3.75		0.147637		6.1	C	0.240157
		25	0.1495				0.242
	3.8		0.149606		6.2	D	0.244094
		24	0.152				0.246
	3.9		0.153543		6.25		0.246062
5/32		23	0.154	1/4	6.3	E	0.248031
			0.15625				0.25
		22	0.157		6.4		0.251968
	4.0		0.15748		6.5	F	0.255905
		21	0.159				0.257
		20	0.161		6.6	G	0.259842
	4.1		0.161417				0.261
	4.2		0.165354		6.7		0.263779
		19	0.166	17/64			0.265625
	4.25		0.167322		6.75		0.265747
	4.3		0.169291			H	0.266
11/64		18	0.1695		6.8		0.267716
			0.171875		6.9		0.271653
		17	0.173			I	0.272
	4.4		0.173228		7.0	J	0.27559
		16	0.177				0.277
	4.5		0.177165		7.1	K	0.279527
		15	0.18				0.281
	4.6		0.181102	9/32			0.28125
		14	0.182		7.2		0.283464
		13	0.185		7.25		0.285432
	4.7		0.185039		7.3		0.287401
3/16	4.75		0.187007			L	0.29
			0.1875		7.4		0.291338
	4.8		0.188976			M	0.295
		12	0.189		7.5		0.295275
		11	0.191	19/64			0.296875
	4.9		0.192913		7.6		0.299212
		10	0.1935			N	0.302
		9	0.196		7.7		0.303149
	5.0		0.19685		7.75		0.305117
		8	0.199		7.8		0.307086
	5.1		0.200787		7.9		0.311023
13/64		7	0.201	5/16			0.3125
			0.203125		8.0		0.31496
		6	0.204			O	0.316
	5.2		0.204724		8.1		0.318897
		5	0.2055		8.2		0.322834
	5.25		0.206692			P	0.323
	5.3		0.208661		8.25		0.324802
		4	0.209		8.3		0.326771
	5.4		0.212598	21/64			0.328125
		3	0.213		8.4		0.330708
	5.5		0.216535			Q	0.332
7/32			0.21875		8.5		0.334645
	5.6		0.220472		8.6		0.338582
		2	0.221			R	0.339
	5.7		0.224409		8.7		0.342519
	5.75		0.226377	11/32			0.34375
		1	0.228		8.75		0.344487
	5.8		0.228346		8.8		0.346456
	5.9		0.232283			S	0.348

TABLE A-2. DECIMAL EQUIVALENTS (CONT'D)

<u>INCH</u>	<u>Mm.</u>	<u>DRILL SIZE NO. OR LTR</u>	<u>DECIMALS OF AN INCH</u>	<u>INCH</u>	<u>Mm.</u>	<u>DRILL SIZE NO. OR LTR</u>	<u>DECIMALS OF AN INCH</u>
	8.9		0.350393	23/32			0.71875
	9.0		0.35433		18.5		0.728345
		T	0.358	47/64			0.734375
23/64	9.1		0.358267		19.0		0.74803
			0.359375	3/4			0.75
	9.2		0.362204	49/64			0.765625
	9.25		0.364172		19.5		0.767715
	9.3		0.366141	25/32			0.78125
		U	0.368		20.0		0.7874
	9.4		0.370078	51/64			0.796875
3/8	9.5		0.374015		20.5		0.807085
			0.375	13/16			0.8125
		V	0.377		21.0		0.82677
	9.6		0.377952	53/64			0.828125
	9.7		0.381889	27/32			0.84375
	9.75		0.383857		21.5		0.846455
	9.8		0.385826	55/64			0.859375
		W	0.386		22.0		0.86614
25/64	9.9		0.389763	7/8			0.875
			0.390625		22.5		0.885825
	10.0		0.3937	57/64			0.890625
		X	0.397		23.0		0.90551
		Y	0.404	29/32			0.90625
13/32			0.40625	59/64			0.921875
		Z	0.413		23.5		0.925195
	10.5		0.413385	15/16			0.9375
27/64			0.421875		24.0		0.94488
	11.0		0.43307	61/64			0.953125
7/16			0.4375		24.5		0.964565
	11.5		0.452755	31/32			0.96875
29/64			0.453125		25.0		0.98425
15/32			0.46875	63/64			0.984375
	12.0		0.47244	1			1.0
31/64			0.484375				
	12.5		0.492125				
1/2			0.5				
	13.0		0.51181				
33/64			0.515625				
17/32			0.53125				
	13.5		0.531495				
35/64			0.546875				
	14.0		0.55118				
9/16			0.5625				
	14.5		0.570865				
37/64			0.578125				
	15.0		0.59055				
19/32			0.59375				
39/64			0.609375				
	15.5		0.610235				
5/8			0.625				
	16.0		0.62992				
41/64			0.640625				
	16.5		0.649605				
21/32			0.65625				
	17.0		0.66929				
43/64			0.671875				
11/16			0.6875				
	17.5		0.688975				
45/64			0.703125				
	18.0		0.70866				

TABLE A-3. ENGINEERING CONVERSION FACTORS

## LENGTH

1 inch = 2.54 Centimeters = 0.0833 Foot = 0.0278 Yard  
 1 foot = 0.305 Meter = 0.333 Yard  
 1 yard = 0.914 Meter = 3 Feet  
 1 Rod = 16 1/2 Feet = 5 1/2 Yards  
 1 Mile = 1.609 Kilometers = 5280 Feet = 1760 Yards  
 1 Centimeter = 0.3937 Inch = 0.0328 Foot  
 1 Meter = 39.37 Inches = 3.281 Feet = 1.094 Yards  
 1 Kilometer = 1000 Meters = 3280.83 Feet = 1093.61 Yards = 0.62137 Mile

## AREA

1 Sq. Inch = 6.452 Sq. Centimeters  
 1 Sq. Foot = 144 Sq. Inches = 929.032 Sq. Centimeters  
 1 Sq. Yard = 1296 Sq. Inches = 9 Sq. Feet = 0.836 Sq. Meter  
 1 Sq. Rod = 272 1/4 Sq. Feet = 30 1/4 Sq. Yards  
 1 Acre = 43,560 Sq. Feet = 160 Sq. Rods  
 1 Sq. Mile = 640 Acres  
 1 Sq. Centimeter = 0.155 Sq. Inch  
 1 Sq. Meter = 1550 Sq. Inches = 10.764 Sq. Feet = 1.196 Sq. Yards  
 1 Sq. Kilometer = 0.3861 Sq. Miles = 247.104 Acres

## VOLUME

1 Cu. Inch = 16.39 Cu. Centimeters = 0.00433 Gallons\*  
 1 Cu. Foot = 1728 Cu. Inches = 7.48 Gallons\* = 28.317 Liters = 0.037 Cu. Yards  
 1 Cu. Yard = 27 Cu. Feet = 0.7646 Cu. Meter = 202 Gallons\*  
 1 Cu. Centimeter = 0.001 Liter = 0.061 Cu. Inch  
 1 Cu. Meter = 35.31 Cu. Feet = 1.308 Cu. Yards = 264.2 Gallons\*  
 1 Quart\* = 0.25 Gallons\* = 57.75 Cu. Inches = 0.946 Liter = 2 Pints\*  
 1 Gallon\* = 0.832702 Imperial Gallon = 231 Cu. Inches = 0.1377 Cu. Feet = 3.785 Liters = 3785 Cu. Centimeters  
 1 Gallon, Imperial = 1.20091 U. S. Gallons  
 1 Barrel (Std.) = 31 1/2 Gallons  
 1 Barrel (Oil) = 42 Gallons  
 \*U. S. Measure

## WEIGHT

1 Ounce = 16 Drams = 437.5 Grains = 0.0625 Pound = 28.35 Grams = 0.9155 Ounce (Troy)  
 1 Pound = 16 Ounces = 453.593 Grams = 0.453593 Kilogram  
 1 Ton (Short) = 2000 Pounds = 907.185 Kilograms = 0.892857 Long Ton = 0.907185 Metric Ton  
 1 Ton (Metric) = 2204.62 Pounds = 0.98421 Long Ton = 1.10231 Short Tons  
 1 Ton (Long) = 2240 Pounds = 1016.05 Kilograms = 1.120 Short Tons = 1.01605 Metric Tons  
 1 Gram = 15.43235 Grains = 0.001 Kilogram  
 1 Kilogram = 2.20462 Pounds

## COMPOUND UNITS

1 gram per square millimeter = 1.422 pounds per square inch  
 1 kilogram per square millimeter = 1.422, 32 pounds per square inch  
 1 kilogram per square centimeter = 14.2232 pounds per square inch  
 1 kilogram per square meter = 0.2048 pound per square foot  
 = 1.8433 pounds per square yard  
 1 Kilogram meter = 7.2330 foot pounds  
 1 kilogram per meter = 0.6720 pound per foot  
 1 pound per square inch = 0.07031 kilogram per square centimeter  
 1 pound per square foot = 0.0004882 kilogram per square centimeter

TABLE A-3. ENGINEERING CONVERSION FACTORS (CONT'D)

COMPOUND UNITS ( CONT )	
1 pound per square foot	= 0.006944 pound per square inch
1 pound per cubic inch	= 27679.7 kilograms per cubic meter
1 pound per cubic foot	= 16.0184 kilograms per cubic meter
1 kilogram per cubic meter	= 0.06243 pound per cubic foot
1 foot per second	= 0.30480 meter per second
1 meter per second	= 3.28083 feet per second
1 meter per second	= 2.23693 miles per hour
MULTIPLES	
Circumference of Circle	= Diameter X 3.1416
Area of Circle	= Square of Diameter X 0.7854, or Square of Radius X 3.1416, or Square of Circumference X 0.07958
Area of Triangle	= Base X one-half altitude
Surface of Sphere	= Circumference X diameter, or Square of diameter X 3.1416
Volume of Sphere	= Surface X one-sixth diameter, or Cube of diameter X 0.5236
Area of Hexagon	= Square of Diameter of Inscribed Circle X 0.866
Area of Octagon	= Square of Diameter of Inscribed Circle X 0.828
ENGINEERING UNITS	
1 Horsepower =	1 Killowatt Hour =
33,000 foot pounds per minute	1,000 watt hours
550 foot pounds per second	1.34 horsepower hours
746 watts	2,655,220 foot pounds
0.746 kilowatts	3,412 heat units (B. T. U.) -
1 Horsepower Hour =	1 British Thermal Unit =
0.746 Killowatt hours	1,055 watt seconds
1,980,000 foot pounds	778 foot pounds
2,545 heat units (B. T. U.)	0.000293 kilowatt hour
	0.000393 horsepower hour
1 Killowatt =	1 Watt =
1,000 watts	1 joule per second
1.34 horsepower	0.00134 horsepower
737.3 foot pounds per second	3.3412 heat units (B. T. U.) per hour
44.240 foot pounds per minute	0.7373 foot pounds per second
56.9 heat units (B. T. U.) per minute	44.24 foot pounds per minute







TABLE A-5. TABLE OF WEIGHTS - BRASS (CONT.)

Tubing—Round (Cont.)		Size	Lbs Per Linear Ft	Size	Lbs Per Linear Ft
Size	Lbs Per Linear Ft	2 1/4 x .065	1.831	.0285	.002336
1 1/4 x .032	.451	2 1/4 x .1875	5.875	.032	.002946
1 1/4 x .049	.681	3 x .032	1.200	.0359	.003715
1 1/4 x .058	.800			.0403	.004684
1 1/4 x .065	.891			.0453	.005907
1 1/4 x .072	.951			.0508	.007449
1 3/8 x .035	.543			.0571	.009393
1 3/8 x .049	.752			.0641	.01184
1 3/8 x .065	.935			.072	.01493
1 1/2 x .032	.544			.0800	.01883
1 1/2 x .049	.823			.0907	.02375
1 1/2 x .065	1.08			.1019	.02994
1 3/4 x .032	.590			.1144	.03776
1 3/4 x .049	.893			.1285	.04761
1 3/4 x .065	1.173			.1443	.06004
1 3/8 x .032	.636			.162	.07571
1 3/8 x .049	.964			.1819	.09547
1 3/8 x .065	1.267			.2043	.1204
1 1/2 x .049	1.035			.2294	.1518
2 x .032	.729			.2576	.1914
2 x .035	.796			.2893	.2414
2 x .065	1.455			.3249	.3044
2 1/4 x .049	1.248			.3648	.3838
2 1/4 x .065	1.643			.4096	.4839
2 3/8 x .035	.9275			.460	.6102
2 1/2 x .035	.988				

Wire		Size	Lbs Per Linear Ft
		.0010	.00002884
		.0031	.00002852
		.0035	.00003596
		.004	.00004535
		.0045	.00005718
		.005	.00007210
		.0056	.00009092
		.0063	.0001146
		.0071	.0001446
		.008	.0001823
		.0089	.0002299
		.010	.0002898
		.0113	.0003655
		.0126	.0004609
		.0142	.0005812
		.0159	.0007328
		.0179	.0009241
		.0201	.001165
		.0226	.001499
		.0254	.001853

TABLE A-6. TABLE OF WEIGHTS - BRONZE

Bars—Hexagon		Size	Lbs Per Linear Ft	Size	Lbs Per Linear Ft
Size	Lbs Per Linear Ft	1 1/8	.9054	3 1/2	35.05
1/8	.3081	1 1/4	1.118	4	45.78
1/4	.4437	1 1/2	1.353		
3/8	.6039	1 3/4	1.610		
1/2	.7888	2	1.889		
5/8	.9983	2 1/4	2.191		
3/4	1.232	2 1/2	2.862		
7/8	1.775	3	3.622		
1	3.155	3 1/4	4.035		
		3 1/2	4.471		
		4	5.410		
		4 1/4	5.913		
		4 1/2	6.438		
		4 3/4	8.763		
		5	11.45		
		5 1/4	12.92		
		5 1/2	17.88		
		6	25.75		

Rods—Round		Thickness	Lbs Per Sq Ft
Size	Lbs Per Linear Ft	.010	.4406
1/8	.04471	.012	.5552
1/4	.1006	.0159	.7006
3/8	.1788	.0201	.8857
1/2	.2794	.0253	1.115
5/8	.4024	.032	1.410
3/4	.7154	.0359	1.58*
		.0403	1.776
		.050	2.238
		.0641	2.825
		.0808	3.567
		.0907	3.997
		.1285	5.662

TABLE A-7. TABLE OF WEIGHTS - COPPER

Bars—Flat		Size	Lbs Per Linear Ft	Size	Lbs Per Sq Ft
Size	Lbs Per Linear Ft	1/8	1.184	.0159	.7353
1/8 x 1/4	.1809	3/8	1.705	.0201	.9296
1/8 x 1	.4823	1/2	2.320	.0226	1.0452
1/8 x 2	.9646	1	3.030	.0253	1.170
1/4 x 1	.9646	1 1/8	3.835	.032	1.4799
1/4 x 2	1.929	1 1/4	4.735	.0359	1.6602
1/4 x 3	3.894	1 1/2	6.818	.0403	1.8637
1/4 x 4	3.858	1 3/4	9.281	.0453	2.0950
3/8 x 1	1.447	2	12.12	.0508	2.3493
3/8 x 2	2.894	2 1/2	18.94	.0571	2.6407
1/2 x 1/4	1.425	3	27.27	.0641	2.9644
1/2 x 1	1.929			.0808	3.7367
3/4 x 1 1/2	3.675			.0907	4.1946

Rods—Round		Sheet	
Size	Lbs Per Linear Ft	Thickness	Lbs Per Sq Ft
1/8	.1894	.002	.125
1/4	.2959	.003	.1434
3/8	.4261	.005	.2312
1/2	.580	.006	.2914
5/8	.7576	.010	.4625
		.0126	.5827
		.0142	.6567

Tubing—Round	
Size	Lbs Per Linear Ft
1/8 x .020	.026
1/8 x .025	.030
1/8 x .028	.033
1/8 x .032	.036

TABLE A-7. TABLE OF WEIGHTS - COPPER (CONT.)

Tubing—Round (Cont.)		Size	Lbs Per Linear Ft	Size	Lbs Per Linear Ft
Size	Lbs Per Linear Ft				
1/8 x .049	.045	3/8 x .042	.298	1 1/2 x .049	.790
1/8 x .022	.044	3/8 x .049	.343	1 1/2 x .065	1.036
1/8 x .028	.055	3/8 x .065	.443	1 1/2 x .148	2.209
1/8 x .032	.061	3/8 x .083	.547	1 1/2 x .035	.597
1/8 x .035	.065	3/8 x .120	.737	1 1/2 x .032	.571
1/8 x .042	.075	1/2 x .120	.812	1 1/2 x .042	.745
1/8 x .049	.083	1/2 x .025	.220	1 1/2 x .049	.865
1/8 x .065	.132	1/2 x .028	.246	1 1/2 x .058	1.017
1/4 x .028	.076	1/2 x .032	.280	1 1/2 x .065	1.135
1/4 x .032	.085	1/2 x .035	.304	1 1/2 x .148	2.434
1/4 x .035	.092	1/2 x .042	.362	1 1/2 x .032	.620
1/4 x .042	.106	1/2 x .049	.418	1 1/2 x .042	.809
1/4 x .049	.120	1/2 x .058	.488	1 1/2 x .049	.939
1/4 x .065	.146	1/2 x .065	.542	1 1/2 x .058	1.108
3/8 x .042	.122	1/2 x .083	.673	1 1/2 x .065	1.238
3/8 x .025	.088	1/2 x .120	.920	1 1/2 x .148	2.659
3/8 x .028	.097	1/2 x .134	1.00	1 1/2 x .032	.669
3/8 x .032	.110	1/2 x .042	.396	1 1/2 x .042	.873
3/8 x .035	.119	1/2 x .049	.452	1 1/2 x .049	1.014
3/8 x .042	.139	1/2 x .028	.289	1 1/2 x .065	1.332
3/8 x .049	.158	1/2 x .032	.328	1 1/2 x .148	2.884
3/8 x .058	.180	1/2 x .035	.358	1 1/2 x .032	.717
3/8 x .065	.196	1/2 x .049	.492	1 1/2 x .042	.937
3/8 x .025	.106	1/2 x .058	.576	1 1/2 x .049	1.088
3/8 x .028	.118	1/2 x .095	.901	1 1/2 x .065	1.431
3/8 x .032	.134	1/2 x .109	1.02	1 1/2 x .148	3.109
3/8 x .035	.145	1/2 x .120	1.10	2 x .032	.766
3/8 x .042	.170	1 x .025	.297	2 x .035	.837
3/8 x .049	.194	1 x .028	.331	2 x .042	1.00
3/8 x .065	.245	1 x .032	.377	2 x .049	1.163
3/8 x .083	.295	1 x .035	.411	2 x .065	1.530
3/8 x .095	.325	1 x .042	.489	2 x .083	1.936
1/2 x .032	.158	1 x .049	.567	2 x .095	2.202
1/2 x .035	.171	1 x .065	.739	2 1/2 x .049	1.31
1/2 x .042	.202	1 x .120	1.29	2 1/2 x .065	1.73
1/2 x .049	.232	1 1/4 x .032	.403	2 1/2 x .065	1.93
1/2 x .065	.295	1 1/4 x .035	.438	2 1/2 x .095	3.07
1/2 x .028	.161	1 1/4 x .032	.425	3 x .120	4.20
1/2 x .032	.182	1 1/4 x .042	.553		
1/2 x .035	.198	1 1/4 x .049	.641		
1/2 x .042	.234	1 1/4 x .065	.838		
1/2 x .049	.269	1 1/4 x .148	1.759		
1/2 x .058	.312	1 1/2 x .032	.453		
1/2 x .065	.344	1 1/2 x .032	.474		
1/2 x .120	.554	1 1/2 x .035	.517		
1/2 x .134	.596	1 1/2 x .049	.718		
1/2 x .032	.207	1 1/2 x .065	.937		
1/2 x .035	.225	1 1/2 x .072	1.03		
1/2 x .042	.266	1 1/2 x .148	1.98		
1/2 x .049	.306	1 1/2 x .032	.498		
1/2 x .120	.645	1 1/2 x .042	.648		
3/4 x .134	.704	1 1/2 x .049	.758		
3/4 x .032	.231	1 1/2 x .028	.459		
3/4 x .035	.251	1 1/2 x .032	.523		
		1 1/2 x .035	.570		
		1 1/2 x .042	.681		

Size	Lbs Per Linear Ft	Size	Lbs Per Linear Ft
1 1/2 x .049	.790	1 1/2 x .049	.790
1 1/2 x .065	1.036	1 1/2 x .065	1.036
1 1/2 x .148	2.209	1 1/2 x .148	2.209
1 1/2 x .035	.597	1 1/2 x .035	.597
1 1/2 x .032	.571	1 1/2 x .032	.571
1 1/2 x .042	.745	1 1/2 x .042	.745
1 1/2 x .049	.865	1 1/2 x .049	.865
1 1/2 x .058	1.017	1 1/2 x .058	1.017
1 1/2 x .065	1.135	1 1/2 x .065	1.135
1 1/2 x .148	2.434	1 1/2 x .148	2.434
1 1/2 x .032	.620	1 1/2 x .032	.620
1 1/2 x .042	.809	1 1/2 x .042	.809
1 1/2 x .049	.939	1 1/2 x .049	.939
1 1/2 x .058	1.108	1 1/2 x .058	1.108
1 1/2 x .065	1.238	1 1/2 x .065	1.238
1 1/2 x .148	2.659	1 1/2 x .148	2.659
1 1/2 x .032	.669	1 1/2 x .032	.669
1 1/2 x .042	.873	1 1/2 x .042	.873
1 1/2 x .049	1.014	1 1/2 x .049	1.014
1 1/2 x .065	1.332	1 1/2 x .065	1.332
1 1/2 x .148	2.884	1 1/2 x .148	2.884
1 1/2 x .032	.717	1 1/2 x .032	.717
1 1/2 x .042	.937	1 1/2 x .042	.937
1 1/2 x .049	1.088	1 1/2 x .049	1.088
1 1/2 x .065	1.431	1 1/2 x .065	1.431
1 1/2 x .148	3.109	1 1/2 x .148	3.109
2 x .032	.766	2 x .032	.766
2 x .035	.837	2 x .035	.837
2 x .042	1.00	2 x .042	1.00
2 x .049	1.163	2 x .049	1.163
2 x .065	1.530	2 x .065	1.530
2 x .083	1.936	2 x .083	1.936
2 x .095	2.202	2 x .095	2.202
2 1/2 x .049	1.31	2 1/2 x .049	1.31
2 1/2 x .065	1.73	2 1/2 x .065	1.73
2 1/2 x .065	1.93	2 1/2 x .065	1.93
2 1/2 x .095	3.07	2 1/2 x .095	3.07
3 x .120	4.20	3 x .120	4.20

Size	No. of Ft Per Lb
.020	826.9
.0253	516.7
.032	323.0
.0359	256.6
.0403	203.7
.0508	128.2
.0625	84.67
.064	80.75
.072	63.80
.0808	50.66
.0907	40.21
.1019	31.85
.1285	20.03
.2576	4.984

TABLE A-8. TABLE OF WEIGHTS - IRON

Angle	Size	Lbs Per Linear Ft	Thickness	Lbs Per Sq Ft
Size	Lbs Per Linear Ft			
1 x 1 x 1	1/4 x 1 1/2 x 1 1/2	2.34	.0188	.75
1/2 x 1/4 x 1/4	1/4 x 2 x 2	3.19	.025	1.00
1/2 x 1 x 1	1/4 x 2 1/2 x 2 1/2	4.10	.032	1.25
1/2 x 1 1/2 x 1 1/2	1/4 x 3 x 3	4.9	.0375	1.50
1/2 x 1 3/4 x 1 3/4	1/4 x 4 x 4	6.6	.0438	1.723
1/2 x 2 x 2	1/4 x 2 1/2 x 3	5.6	.050	2.00
1/2 x 1 x 1	1/4 x 3 x 3	6.1	.0625	2.55
1/2 x 1 1/4 x 1 1/4	1/4 x 1 1/2 x 1 1/2	3.35	.0781	3.2
1/2 x 1 1/2 x 1 1/2	1/4 x 2 1/2 x 2 1/2	5.90	.093	3.757
1/2 x 1 3/4 x 1 3/4	1/4 x 6 x 6	24.2	.125	5.1
1/2 x 2 x 2			.156	6.4
1/2 x 2 1/2 x 2 1/2			.1875	7.56
1/2 x 1 1/4 x 1 1/4			.250	10.2
			.375	15.178

Thickness	Lbs Per Sq Ft
.0156	.625

TABLE A-8. TABLE OF WEIGHTS - IRON (CONT.)

Sheet—Black (Cont.)		Thickness	Lbs Per Sq Ft	Sheet—Terne Plate	
Thickness	Lbs Per Sq Ft			Thickness	Lbs Per Sq Ft
.500	20.4	.032	1.406	.0156	.6377
<b>Sheet—Galvanized</b>		.0375	1.658	.0186	.7685
		.0438	1.9064	.025	1.022
Thickness	Lbs Per Sq Ft				
.0156	.781	.050	2.156	.0313	1.2795
.0188	.906	.0625	2.62	.037	1.5329
.025	1.156	.0938	3.9603	.050	2.044
		.125	6.1563		

TABLE A-9. TABLE OF WEIGHTS - LEAD

Sheet		Thickness	Lbs Per Sq Ft	Thickness	Lbs Per Sq Ft
Thickness	Lbs Per Sq Ft				
$\frac{1}{16}$	2.10	$\frac{1}{16}$	4.25	$\frac{1}{8}$	7.812
		$\frac{1}{8}$	6.031	$\frac{1}{4}$	11.720

TABLE A-10. TABLE OF WEIGHTS - MAGNESIUM AND MAGNESIUM ALLOY

Bars—Flat		Rods—Round		Size	Lbs Per Linear Ft
Size	Lbs Per Linear Ft	Size	Lbs Per Linear Ft		
$\frac{1}{2}$ x 1	.372	$\frac{1}{16}$	.021	$3\frac{1}{2}$	7.450
$\frac{1}{2}$ x 2	.756	$\frac{1}{8}$	.037	4	9.800
$\frac{3}{4}$ x 2	1.135	$\frac{3}{16}$	.068	<b>Sheets</b>	
$\frac{3}{4}$ x 3	1.700	$\frac{1}{4}$	.083	Thickness	Lbs Per Sq Ft
1 x 2	1.513	$\frac{5}{16}$	.114	.0126	.1158
1 x 3	2.270	$\frac{3}{8}$	.148	.020	.1814
$1\frac{1}{2}$ x 2	2.290	$\frac{1}{2}$	.188	.016	.1451
$1\frac{3}{4}$ x $3\frac{1}{2}$	4.630	$\frac{5}{8}$	.232	.0253	.230
2 x 3	4.535	$\frac{3}{4}$	.280	.032	.290
$2\frac{1}{4}$ x 4	8.320	$\frac{7}{8}$	.334	.0359	.3258
3 x 4	9.240	1	.392	.0403	.366
<b>Bars—Hexagon</b>		$1\frac{1}{8}$	.454	.0508	.462
Size	Lbs Per Linear Ft	1	.522	.0641	.582
$\frac{3}{8}$	.095	$1\frac{1}{4}$	.593	.0808	.733
$\frac{1}{2}$	.129	1	.927	.128	1.167
$\frac{3}{4}$	.169	$1\frac{1}{2}$	1.122	.0907	1.823
$\frac{1}{2}$	.213	$1\frac{3}{4}$	1.348	.156	1.418
$\frac{3}{8}$	.263	2	1.818	.1875	1.708
$\frac{1}{4}$	.412	$2\frac{1}{2}$	2.385	.250	2.270
1	.674	$2\frac{3}{4}$	3.710	.375	3.405
$1\frac{1}{4}$	1.043	3	4.480	.500	4.650
$1\frac{1}{2}$	1.510		5.340		

TABLE A-11. TABLE OF WEIGHTS - NICKEL CHROMIUM IRON ALLOY (Inconel)

Rods—Round		Tubing		Size	Lbs Per Linear Ft
Size	Lbs Per Linear Ft	Size	Lbs Per Linear Ft		
$\frac{1}{4}$	.182	$\frac{1}{4}$ x .028	.071	$\frac{1}{8}$ x .049	.472
$\frac{3}{8}$	.285	$\frac{1}{4}$ x .035	.088	$\frac{1}{8}$ x .058	.552
$\frac{1}{2}$	.409	$\frac{1}{4}$ x .049	.113	$\frac{1}{8}$ x .065	.613
$\frac{3}{4}$	.728	$\frac{1}{4}$ x .065	.139	1 x .035	.393
$\frac{1}{2}$	1.638	$\frac{3}{8}$ x .028	.091	1 x .049	.543
1	2.912	$\frac{1}{2}$ x .035	.113	1 x .058	.636
$1\frac{1}{4}$	4.55	$\frac{1}{2}$ x .049	.150	1 x .065	.708
$1\frac{1}{2}$	6.553	$\frac{3}{8}$ x .065	.188	$1\frac{1}{4}$ x .049	.686
2	11.651	$\frac{1}{2}$ x .028	.113	$1\frac{1}{4}$ x .065	.897
$2\frac{1}{2}$	18.203	$\frac{3}{8}$ x .035	.139	$1\frac{1}{8}$ x .049	.757
<b>Sheets</b>		$\frac{3}{8}$ x .049	.188	$1\frac{1}{8}$ x .065	.988
Thickness	Lbs Per Sq Ft	$\frac{3}{8}$ x .058	.217	$1\frac{1}{2}$ x .035	.597
.018	.84	$\frac{3}{8}$ x .065	.236	$1\frac{1}{2}$ x .049	.828
.025	1.11	$\frac{1}{2}$ x .035	.191	$1\frac{1}{2}$ x .065	1.09
.032	1.39	$\frac{1}{2}$ x .049	.257	$1\frac{3}{4}$ x .049	.969
.037	1.65	$\frac{1}{2}$ x .058	.299	$1\frac{3}{4}$ x .065	1.28
.043	1.91	$\frac{1}{2}$ x .065	.329	2 x .049	1.11
.050	2.22	$\frac{5}{8}$ x .049	.329	2 x .065	1.46
.0625	2.78	$\frac{5}{8}$ x .065	.424	$2\frac{1}{4}$ x .049	1.26
.093	4.14	$\frac{3}{4}$ x .035	.292	$2\frac{1}{4}$ x .065	1.65
.125	5.56	$\frac{3}{4}$ x .049	.400	$2\frac{1}{2}$ x .049	1.40
.156	6.94	$\frac{3}{4}$ x .058	.468	$2\frac{1}{2}$ x .065	1.84
.1875	8.32	$\frac{3}{4}$ x .065	.519	$3\frac{1}{4}$ x .120	4.38
.250	11.12	$\frac{7}{8}$ x .035	.343		

TABLE A-12. TABLE OF WEIGHTS - NICKEL COPPER ALLOY  
(Monel Metal)

Rods—Round		Size	Lbs Per Linear Ft	Thickness	Sheets	Lbs Per Sq Ft
Size	Lbs Per Linear Ft					
1/4	.190	1/4	1.172	.018		.86
5/16	.309	1/2	3.044	.025		1.15
3/8	.428	3/4	4.756	.032		1.44
1/2	.761	1	6.849	.037		1.72
		1 1/2	12.178	.125		5.75
		2	19.027			

TABLE A-13. TABLE OF WEIGHTS - STEEL

Bars—Flat		Size	Lbs Per Linear Ft	Size	Lbs Per Linear Ft	Size	Lbs Per Linear Ft
Size	Lbs Per Linear Ft						
1/8 x 1/8	.106	5/8 x 2 1/2	5.31	5/8	1.328		
1/8 x 3/8	.1594	5/8 x 3	6.38	3/4	1.913		
1/8 x 1	.212	5/8 x 3 1/2	7.44	7/8	2.603		
1/8 x 1 1/2	.319	5/8 x 4	8.50	1	3.40		
1/8 x 2	.425	5/8 x 6	12.75	1 1/8	4.303		
1/8 x 2 1/2	.531	5/8 x 1	2.55	1 1/4	5.313		
1/8 x 3	.638	5/8 x 1 1/2	3.85	1 1/2	5.857		
1/8 x 3 1/2	.744	5/8 x 2	5.10	1 3/4	6.428		
1/8 x 4	.850	5/8 x 2 1/2	6.38	1 7/8	7.050		
1/8 x 4 1/2	.956	5/8 x 3	7.65	2	7.650		
1/8 x 5	1.062	5/8 x 4	8.90	2 1/4	10.41		
1/8 x 5 1/2	1.168	5/8 x 5	10.20	2 1/2	13.60		
1/8 x 6	1.274	5/8 x 6	11.50	2 3/4	17.21		
1/8 x 6 1/2	1.380	5/8 x 1 x 2	6.80	2 7/8	21.25		
1/8 x 7	1.486	1 x 2	8.50	3	30.60		
1/8 x 7 1/2	1.592	1 x 2 1/2	10.20				
1/8 x 8	1.698	1 x 3	13.60				
1/8 x 8 1/2	1.804	1 x 4	17.00				
1/8 x 9	1.910	1 x 5	20.40				
1/8 x 9 1/2	2.016	1 x 6	24.80				
1/8 x 10	2.122	1 1/4 x 2	8.50				
1/8 x 10 1/2	2.228	1 1/4 x 3	12.75				
1/8 x 11	2.334	1 1/4 x 4	17.00				
1/8 x 11 1/2	2.440	1 1/4 x 5	21.25				
1/8 x 12	2.546	1 1/4 x 6	25.50				
1/8 x 12 1/2	2.652	1 1/2 x 2	10.20				
1/8 x 13	2.758	1 1/2 x 3	15.30				
1/8 x 13 1/2	2.864	1 1/2 x 4	20.40				
1/8 x 14	2.970	1 1/2 x 5	25.50				
1/8 x 14 1/2	3.076	1 1/2 x 6	30.60				
1/8 x 15	3.182	2 x 2 1/2	17.00				
1/8 x 15 1/2	3.288	2 x 3	20.40				
1/8 x 16	3.394	2 x 4	27.20				
1/8 x 16 1/2	3.500	2 1/2 x 3	25.50				
1/8 x 17	3.606	3 x 4	40.80				
1/8 x 17 1/2	3.712						
1/8 x 18	3.818						
1/8 x 18 1/2	3.924						
1/8 x 19	4.030						
1/8 x 19 1/2	4.136						
1/8 x 20	4.242						
1/8 x 20 1/2	4.348						
1/8 x 21	4.454						
1/8 x 21 1/2	4.560						
1/8 x 22	4.666						
1/8 x 22 1/2	4.772						
1/8 x 23	4.878						
1/8 x 23 1/2	4.984						
1/8 x 24	5.090						
1/8 x 24 1/2	5.196						
1/8 x 25	5.302						
1/8 x 25 1/2	5.408						
1/8 x 26	5.514						
1/8 x 26 1/2	5.620						
1/8 x 27	5.726						
1/8 x 27 1/2	5.832						
1/8 x 28	5.938						
1/8 x 28 1/2	6.044						
1/8 x 29	6.150						
1/8 x 29 1/2	6.256						
1/8 x 30	6.362						
1/8 x 30 1/2	6.468						
1/8 x 31	6.574						
1/8 x 31 1/2	6.680						
1/8 x 32	6.786						
1/8 x 32 1/2	6.892						
1/8 x 33	6.998						
1/8 x 33 1/2	7.104						
1/8 x 34	7.210						
1/8 x 34 1/2	7.316						
1/8 x 35	7.422						
1/8 x 35 1/2	7.528						
1/8 x 36	7.634						
1/8 x 36 1/2	7.740						
1/8 x 37	7.846						
1/8 x 37 1/2	7.952						
1/8 x 38	8.058						
1/8 x 38 1/2	8.164						
1/8 x 39	8.270						
1/8 x 39 1/2	8.376						
1/8 x 40	8.482						
1/8 x 40 1/2	8.588						
1/8 x 41	8.694						
1/8 x 41 1/2	8.800						
1/8 x 42	8.906						
1/8 x 42 1/2	9.012						
1/8 x 43	9.118						
1/8 x 43 1/2	9.224						
1/8 x 44	9.330						
1/8 x 44 1/2	9.436						
1/8 x 45	9.542						
1/8 x 45 1/2	9.648						
1/8 x 46	9.754						
1/8 x 46 1/2	9.860						
1/8 x 47	9.966						
1/8 x 47 1/2	10.072						
1/8 x 48	10.178						
1/8 x 48 1/2	10.284						
1/8 x 49	10.390						
1/8 x 49 1/2	10.496						
1/8 x 50	10.602						
1/8 x 50 1/2	10.708						
1/8 x 51	10.814						
1/8 x 51 1/2	10.920						
1/8 x 52	11.026						
1/8 x 52 1/2	11.132						
1/8 x 53	11.238						
1/8 x 53 1/2	11.344						
1/8 x 54	11.450						
1/8 x 54 1/2	11.556						
1/8 x 55	11.662						
1/8 x 55 1/2	11.768						
1/8 x 56	11.874						
1/8 x 56 1/2	11.980						
1/8 x 57	12.086						
1/8 x 57 1/2	12.192						
1/8 x 58	12.298						
1/8 x 58 1/2	12.404						
1/8 x 59	12.510						
1/8 x 59 1/2	12.616						
1/8 x 60	12.722						
1/8 x 60 1/2	12.828						
1/8 x 61	12.934						
1/8 x 61 1/2	13.040						
1/8 x 62	13.146						
1/8 x 62 1/2	13.252						
1/8 x 63	13.358						
1/8 x 63 1/2	13.464						
1/8 x 64	13.570						
1/8 x 64 1/2	13.676						
1/8 x 65	13.782						
1/8 x 65 1/2	13.888						
1/8 x 66	13.994						
1/8 x 66 1/2	14.100						
1/8 x 67	14.206						
1/8 x 67 1/2	14.312						
1/8 x 68	14.418						
1/8 x 68 1/2	14.524						
1/8 x 69	14.630						
1/8 x 69 1/2	14.736						
1/8 x 70	14.842						
1/8 x 70 1/2	14.948						
1/8 x 71	15.054						
1/8 x 71 1/2	15.160						
1/8 x 72	15.266						
1/8 x 72 1/2	15.372						
1/8 x 73	15.478						
1/8 x 73 1/2	15.584						
1/8 x 74	15.690						
1/8 x 74 1/2	15.796						
1/8 x 75	15.902						
1/8 x 75 1/2	16.008						
1/8 x 76	16.114						
1/8 x 76 1/2	16.220						
1/8 x 77	16.326						
1/8 x 77 1/2	16.432						
1/8 x 78	16.538						
1/8 x 78 1/2	16.644						
1/8 x 79	16.750						
1/8 x 79 1/2	16.856						
1/8 x 80	16.962						
1/8 x 80 1/2	17.068						
1/8 x 81	17.174						
1/8 x 81 1/2	17.280						
1/8 x 82	17.386						
1/8 x 82 1/2	17.492						
1/8 x 83	17.598						
1/8 x 83 1/2	17.704						
1/8 x 84	17.810						
1/8 x 84 1/2	17.916						
1/8 x 85	18.022						
1/8 x 85 1/2							







TABLE A-13. TABLE OF WEIGHTS - STEEL (CONT.)

Tubing—Streamline (Cont.)		Thickness	No of Ft Per Lb	Thickness	No. of Ft Per Lb
Size	Lbs Per Linear Ft	.011	2936.	.045	182.7
2.386 x .994 x .049	.8892	.012	2604.	.047	166.2
2.386 x .994 x .058	1.047	.013	2218.	.049	156.2
2.386 x .994 x .065	1.169	.014	1913.	.0508	145.3
2.726 x 1.136 x .035	.7338	.016	1465.	.054	128.6
3.00 x .375 x .035	.7338	.018	1157.	.056	119.6
3.067 x 1.278 x .049	1.151	.020	937.3	.058	111.5
3.067 x 1.278 x .065	1.515	.024	650.9	.0625	95.98
3.748 x 1.563 x .083	2.362	.025	599.9	.0641	91.25
		.028	478.2	.071	72.32
		.031	383.9	.080	58.58
		.032	366.1	.0907	45.58
		.035	308.1	.101	36.11
		.036	289.3	.118	26.04
		.040	234.3	.1285	22.71
		.041	223.	.162	14.29

Wire		Thickness	No. of Ft Per Lb
.006	10415.		
.008	5858.		
.009	4629.		
.010	3749.		

TABLE A-14. TABLE OF WEIGHTS - ZINC

Sheet		Thickness	Lbs Per Sq Ft	Thickness	Lbs Per Sq Ft	Thickness	Lbs Per Sq Ft
.018	.67	.045	1.68	.0508	1.87		
.032	1.20	.049	1.87	.109	3.98		

TABLE A-15. TEMPERATURE CONVERSION CHART

-459.4 to -220			-210 to 0			1 to 25			26 to 50			51 to 75			76 to 100			101 to 340			341 to 490			491 to 750		
C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F
-273	-459.4		-134	-210	-346	-17.2	1	33.8	-3.33	26	78.8	10.6	51	123.8	24.4	76	168.8	43	110	230	177	350	662	280	500	932
-268	-450		-129	-200	-328	-16.7	2	35.6	-2.78	27	80.6	11.1	52	125.6	25.0	77	170.6	49	120	248	182	360	680	286	510	950
-262	-440		-123	-190	-310	-16.1	3	37.4	-2.22	28	82.4	11.7	53	127.4	25.6	78	172.4	54	130	266	188	370	698	271	520	968
-257	-430		-118	-180	-292	-15.6	4	39.2	-1.67	29	84.2	12.2	54	129.2	26.1	79	174.2	60	140	284	193	380	716	277	530	986
-251	-420		-112	-170	-274	-15.0	5	41.0	-1.11	30	86.0	12.8	55	131.0	26.7	80	176.0	66	150	302	199	390	734	282	540	1004
-246	-410		-107	-160	-256	-14.4	6	42.8	-0.56	31	87.8	13.3	56	132.8	27.2	81	177.8	71	160	320	204	400	752	288	550	1022
-240	-400		-101	-150	-238	-13.9	7	44.6	0	32	89.6	13.9	57	134.6	27.8	82	179.6	77	170	338	210	410	770	293	560	1040
-234	-390		-95.6	-140	-220	-13.3	8	46.4	0.56	33	91.4	14.4	58	136.4	28.3	83	181.4	82	180	356	216	420	788	299	570	1058
-229	-380		-90.0	-130	-202	-12.8	9	48.2	1.11	34	93.2	15.0	59	138.2	28.9	84	183.2	88	190	374	221	430	806	304	580	1076
-223	-370		-84.4	-120	-184	-12.2	10	50.0	1.67	35	95.0	15.6	60	140.0	29.4	85	185.0	93	200	392	227	440	824	310	590	1094
-218	-360		-78.9	-110	-166	-11.7	11	51.8	2.22	36	96.8	16.1	61	141.8	30.0	86	186.8	99	210	410	232	450	842	316	600	1112
-212	-350		-73.3	-100	-148	-11.1	12	53.6	2.78	37	98.6	16.7	62	143.6	30.6	87	188.6	100	212	413	238	460	860	321	610	1130
-207	-340		-67.8	-90	-130	-10.6	13	55.4	3.33	38	100.4	17.2	63	145.4	31.1	88	190.4	104	220	428	243	470	878	327	620	1148
-201	-330		-62.2	-80	-112	-10.0	14	57.2	3.89	39	102.2	17.8	64	147.2	31.7	89	192.2	110	230	446	249	480	896	332	630	1166
-196	-320		-56.7	-70	-94	-9.44	15	59.0	4.44	40	104.0	18.3	65	149.0	32.2	90	194.0	116	240	464	254	490	914	338	640	1184
-190	-310		-51.1	-60	-76	-8.89	16	60.8	5.00	41	105.8	18.9	66	150.8	32.8	91	195.8	121	250	482				343	650	1202
-184	-300		-45.6	-50	-58	-8.33	17	62.6	5.56	42	107.6	19.4	67	152.6	33.3	92	197.6	127	260	500				349	660	1220
-179	-290		-40.0	-40	-40	-7.78	18	64.4	6.11	43	109.4	20.0	68	154.4	33.9	93	199.4	132	270	518				354	670	1238
-173	-280		-34.4	-30	-22	-7.22	19	66.2	6.67	44	111.2	20.6	69	156.2	34.4	94	201.2	138	280	536				360	680	1256
-169	-273	-459.4	-28.9	-20	-4	-6.67	20	68.0	7.22	45	113.0	21.1	70	158.0	35.0	95	203.0	143	290	554				366	690	1274
-168	-270	-454	-23.3	-10	14	-6.11	21	69.8	7.78	46	114.8	21.7	71	159.8	35.6	96	204.8	149	300	572				371	700	1292
-162	-260	-436	-17.8	0	32	-5.56	22	71.6	8.33	47	116.6	22.2	72	161.6	36.1	97	206.6	154	310	590				377	710	1310
-157	-250	-418				-5.00	23	73.4	8.89	48	118.4	22.8	73	163.4	36.7	98	208.4	160	320	608				382	720	1328
-151	-240	-400				-4.44	24	75.2	9.44	49	120.2	23.3	74	165.2	37.2	99	210.2	166	330	626				388	730	1346
-146	-230	-382				-3.89	25	77.0	10.0	50	122.0	23.9	75	167.0	37.8	100	212.0	171	340	644				393	740	1364
-140	-220	-364																						399	750	1382

751 to 1000			1001 to 1250			1251 to 1490			1491 to 1750			1751 to 2000			2001 to 2250			2251 to 2490			2491 to 2750			2751 to 3000		
C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F	C	C or F	F
404	760	1400	543	1010	1850	682	1260	2300	816	1500	2732	960	1760	3200	1099	2010	3650	1238	2260	4100	1371	2500	4532	1616	2760	5000
410	770	1418	549	1020	1868	688	1270	2318	821	1510	2750	966	1770	3218	1104	2020	3668	1243	2270	4118	1377	2510	4550	1621	2770	5018
416	780	1436	554	1030	1886	693	1280	2336	827	1520	2768	971	1780	3236	1110	2030	3686	1249	2280	4136	1382	2520	4568	1627	2780	5036
421	790	1454	560	1040	1904	699	1290	2354	832	1530	2786	977	1790	3254	1116	2040	3704	1254	2290	4154	1388	2530	4586	1632	2790	5054
427	800	1472	566	1050	1922	704	1300	2372	838	1540	2804	982	1800	3272	1121	2050	3722	1260	2300	4172	1393	2540	4604	1638	2800	5072
432	810	1490	571	1060	1940	710	1310	2390	843	1550	2822	988	1810	3290	1127	2060	3740	1266	2310	4190	1399	2550	4622	1643	2810	5090
438	820	1508	577	1070	1958	716	1320	2408	849	1560	2840	993	1820	3308	1132	2070	3758	1271	2320	4208	1404	2560	4640	1649	2820	5108
443	830	1526	582	1080	1976	721	1330	2426	854	1570	2858	999	1830	3326	1138	2080	3776	1277	2330	4226	1410	2570	4658	1654	2830	5126
449	840	1544	588	1090	1994	727	1340	2444	860	1580	2876	1004	1840	3344	1143	2090	3794	1282	2340	4244	1416	2580	4676	1660	2840	5144
454	850	1562	593	1100	2012	732	1350	2462	866	1590	2894	1010	1850	3362	1149	2100	3812	1288	2350	4262	1421	2590	4694	1666	2850	5162
460	860	1580	599	1110	2030	738	1360	2480	871	1600	2912	1016	1860	3380	1154	2110	3830	1293	2360	4280	1427	2600	4712	1671	2860	5180
466	870	1598	604	1120	2048	743	1370	2498	877	1610	2930	1021	1870	3398	1160	2120	3848	1299	2370	4298	1432	2610	4730	1677	2870	5198
471	880	1616	610	1130	2066	749	1380	2516	882	1620	2948	1027	1880	3416	1166	2130	3866	1304	2380	4316	1438	2620	4748	1682	2880	5216
477	890	1634	616	1140	2084	754	1390	2534	888	1630	2966	1032	1890	3434	1171	2140	3884	1310	2390	4334	1443	2630	4766	1688	2890	5234
482	900	1652	621	1150	2102	760	1400	2552	893	1640	2984	1038	1900	3452	1177	2150	3902	1316	2400	4352	1449	2640	4784	1693	2900	5252
488	910	1670	627	1160	2120	766	1410	2570	899	1650	3002	1043	1910	3470	1182	2160	3920	1321	2410	4370	1454	2650	4802	1699	2910	5270
493	920	1688	632	1170	2138	771	1420	2588	904	1660	3020	1049	1920	3488	1188	2170	3938	1327	2420	4388	1460	2660	4820	1704	2920	5288
499	930	1706	638	1180	2156	777	1430	2606	910	1670	3038	1054	1930	3506	1193	2180	3956	1332	2430	4406	1466	2670	4838	1710	2930	5306
504	940	1724	643	1190	2174	782	1440	2624	916	1680	3056	1060	1940	3524	1199	2190	3974	1338	2440	4424	1471	2680	4856	1716	2940	5324
510	950	1742	649	1200	2192	788	1450	2642	921	1690	3074	1066	1950	3542	1204	2200	3992	1343	2450	4442	1477	2690	4874	1721	2950	5342
516	960	1760	654	1210	2210	793	1460	2660	927	1700	3092	1071	1960	3560	1210	2210	4010	1349	2460	4460	1482	2700	4892	1727	2960	5360
521	970	1778	660	1220	2228	799	1470	2678	932	1710	3110	1077	1970	3578	1216	2220	4028	1354	2470	4478	1488	2710	4910	1732	2970	5378
527	980	1796	666	1230	2246	804	1480	2696	938	1720	3128	1082	1980	3596	1221	2230	4046	1360	2480	4496	1493	2720	4928	1738	2980	5396
532	990	1814	671	1240	2264	810	1490	2714	943	1730	3146	1088	1990	3614	1227	2240	4064	1366	2490	4514	1499	2730	4946	1743	2990	5414
538	1000	1832	677	1250	2282				949	1740	3															



TABLE A-16. STANDARD BEND RADII FOR 90 ° COLD FORMING FLAT SHEET (CONTD)

MATERIAL	MATERIAL CONDITION	FORMING TEMP	GUAGE																	
			0.008	0.012	0.016	0.020	0.025	0.032	0.036	0.040	0.050	0.063	0.080	0.090	0.112	0.125	0.160	0.190	0.250	
Corrosion Resistant	ANNEALED	ROOM	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.06	0.06	0.09	0.12	0.12	0.16	0.16	0.19	0.25
Corrosion Resistant	1/4 HARD	ROOM	0.03	0.03	0.03	0.03	0.06	0.06	0.06	0.06	0.06	0.09	0.09	0.12	0.16	0.19	0.22	0.25	0.31	0.38
Corrosion Resistant	1/2 HARD	ROOM	0.03	0.03	0.06	0.06	0.09	0.09	0.12	0.12	0.16	0.16	0.19	0.25	0.31	0.38	0.50	0.62	0.75	
Corrosion Resistant	FULL HARD	ROOM	0.06	0.09	0.09	0.12	0.16	0.16	0.16	0.19	0.19	0.25	0.31	0.38	0.44	0.50	0.62	0.75	1.00	
Commercially Pure AMS 4901	ANNEALED	ROOM	0.03	0.03	0.06	0.06	0.09	0.09	0.12	0.12	0.16	0.19	0.25	0.31	0.38	0.38	0.44	0.56	0.75	
Alloy AMS 4908	ANNEALED	ROOM	0.03	0.03	0.06	0.06	0.09	0.09	0.12	0.12	0.16	0.19	0.25	0.31	0.38	0.38	0.44	0.56	0.75	
Alloy Convaiv Spec 0-01014	ANNEALED	ROOM			0.09	0.09	0.12	0.15	0.19	0.19	0.25	0.31	0.38	0.44	0.56	0.62	0.78	0.94	1.25	

TABLE A-17. METAL BENDING AND BEND RADII BEND ALLOWANCES SHEET METAL BEND ALLOWANCES PER DEGREE OF BEND ALUMINUM ALLOYS

BEND RADIUS	Stock Thickness							
	0.022	0.032	0.040	0.051	0.064	0.091	0.128	0.187
	Bend Allowance per One Degree							
1/32	0.00072	0.00079	0.00086	0.00094	0.00104	0.00125	0.00154	0.00200
1/16	0.00126	0.00135	0.00140	0.00149	0.00159	0.00180	0.00209	0.00255
3/32	0.00180	0.00188	0.00195	0.00203	0.00213	0.00234	0.00263	0.00309
1/8	0.00235	0.00243	0.00249	0.00258	0.00268	0.00289	0.00317	0.00364
5/32	0.00290	0.00297	0.00304	0.00312	0.00322	0.00343	0.00372	0.00418
3/16	0.00344	0.00352	0.00358	0.00367	0.00377	0.00398	0.00426	0.00473
7/32	0.00398	0.00406	0.00412	0.00421	0.00431	0.00452	0.00481	0.00527
1/4	0.00454	0.00461	0.00467	0.00476	0.00486	0.00507	0.00535	0.00582
9/32	0.00507	0.00515	0.00521	0.00530	0.00540	0.00561	0.00590	0.00636
5/16	0.00562	0.00570	0.00576	0.00584	0.00595	0.00616	0.00644	0.00691
11/32	0.00616	0.00624	0.00630	0.00639	0.00649	0.00670	0.00699	0.00745
3/8	0.00671	0.00679	0.00685	0.00693	0.00704	0.00725	0.00753	0.00800
13/32	0.00725	0.00733	0.00739	0.00748	0.00758	0.00779	0.00808	0.00854
7/16	0.00780	0.00787	0.00794	0.00802	0.00812	0.00834	0.00862	0.00908
15/32	0.00834	0.00842	0.00848	0.00857	0.00867	0.00888	0.00917	0.00963
1/2	0.00889	0.00896	0.00903	0.00911	0.00921	0.00943	0.00971	0.01017
17/32	0.00943	0.00951	0.00957	0.00966	0.00976	0.00997	0.01025	0.01072
9/16	0.00998	0.01005	0.01012	0.01020	0.01030	0.01051	0.01080	0.01126
19/32	0.01051	0.01058	0.01065	0.01073	0.01083	0.01105	0.01133	0.01179
5/8	0.01107	0.01114	0.01121	0.01129	0.01139	0.01160	0.01189	0.01235
21/32	0.01161	0.01170	0.01175	0.01183	0.01193	0.01214	0.01245	0.01289
11/16	0.01216	0.01223	0.01230	0.01238	0.01248	0.01268	0.01298	0.01344
23/32	0.01269	0.01276	0.01283	0.01291	0.01301	0.01322	0.01351	0.01397
3/4	0.01324	0.01332	0.01338	0.01347	0.01357	0.01378	0.01407	0.01453

Example: To determine bend allowance

Given: Stock = 0.064 aluminum alloy. Bend Radius = 1/8, Bend Angle = 50°

Find bend allowance for 1° in column for 0.064 Aluminum opposite 1/8 in column "Bend Radius".

Multiply this bend allowance (0.00268 in this case) by the number of degrees of the desired bend angle:

$0.00268 \times 50 = 0.1340 =$  total bend allowance to be added to the length of the straight sides of the part to determine the total length of the material needed.

TABLE A-18. BEND SET BACK CHART

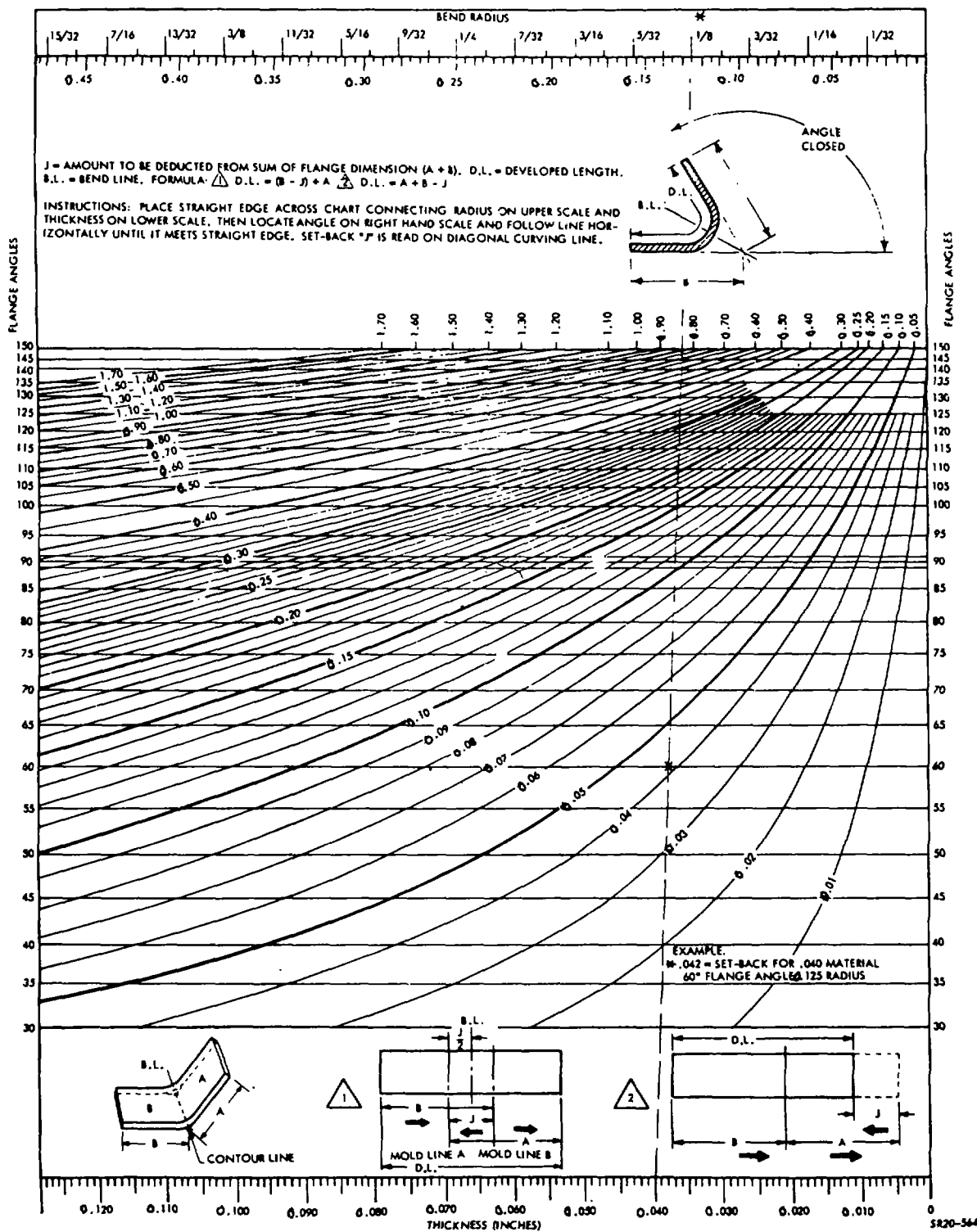


TABLE A-19. COMPARATIVE TABLE OF STANDARD GAGES

1. **United States Steel Wire Gage (STL.W.G.)**  
 Also known as: National Wire, Standard Steel Wire, Steel Wire, American Steel and Wire Company, Roeb-ling, Washburn and Moen Gages.  
 Used for bare wire of galvanized, black annealed, bright basic tinned or copper coated, iron or steel, spring steel wire. Not used for telephone and tele-graph wire.
  2. **British Imperial Standard Wire Gage (I.S.W.G.) or (N.B.S.)**  
 Also known as British Imperial Wire or English Legal Standard Gages.  
 Used for bare copper telephone wires in the U. S. and for all wires and aluminum sheets in England.
  3. **Browne & Sharpe Gage (B.&S.G.)**  
 Also known as American or American Wire Gages.  
 Used for bare wire of brass, phosphor bronze, German silver, aluminum, zinc and copper (not for copper tele- phone or telegraph wire).  
 Also resistance wire of German silver and other alloys, and for insulated wire of aluminum and copper.  
 Also for rods of brass, copper, phosphor bronze and aluminum; sheets of copper, brass, phosphor bronze, aluminum and German silver; brazed brass and brazed copper tubing.
  4. **Birmingham Wire Gage (B.W.G.)**
  5. **Standard Birmingham Sheet and Hoop Gage (B.G.)**  
 Used in England for iron and steel sheets and hoops.
  6. **United States Standard (Revised) (U.S.S.G.)**  
 Also known as U. S. Standard Sheet Metal or U. S. Standard for Steel and Iron Sheets and Plates Gages.  
 This is a gage based on the weight per square foot of sheets rather than on thickness. It is used for com- mercial iron and steel sheets and plates including plished, galvanized, tinned and terne plates, black sheet iron, blue annealed soft steel, steel plate, hor- rolled sheet steel, cold-rolled sheet steel, hot-rolled monel metal, cold-rolled monel metal.
- Other gages in use:**  
 Trenton Iron Company Gage.  
 Zinc gage for sheet zinc only.  
 Birmingham Metal Gage—in England for brass sheets.  
 American Steel and Wire Company's music wire gage.  
 Twist Drill and Steel Wire Gage for twist drill and steel drill rods.

Gage Number	THICKNESS IN DECIMALS OF AN INCH						United States Standard (Revised) U. S. S. G.	
	United States Steel Wire (STL.W.G.)	British Imperial Standard Wire (I.S.W.G.)	Browne & Sharpe (B. & S. G.)	Birmingham Wire (B. W. G.)	Standard Birmingham Sheet and Hoop (B. G.)	Thickness Approx.	Weight Oz./Sq. Ft.	
0000000	.4900	.500			.6666			
000000	.4615	.464	.580000		.6250			
00000	.4305	.432	.516500	.500	.5883			
0000	.3938	.400	.460000	.454	.5416			
000	.3623	.372	.409642	.425	.5000			
00	.3310	.348	.364796	.380	.4452			
0	.3065	.324	.324861	.340	.3964			
1	.2830	.300	.289297	.300	.3532			
2	.2625	.276	.257627	.284	.3147			
3	.2437	.252	.229423	.259	.2804	.2391	160	
4	.2255	.232	.204307	.238	.2500	.2242	150	
5	.2070	.212	.181940	.220	.2225	.2092	140	
6	.1920	.192	.162023	.205	.1981	.1943	130	
7	.1770	.176	.144285	.180	.1764	.1793	120	
8	.1620	.160	.128490	.165	.1570	.1644	110	
9	.1483	.144	.114423	.148	.1398	.1494	100	
10	.1350	.128	.101897	.134	.1250	.1345	90	
11	.1205	.116	.090742	.120	.1113	.1196	80	
12	.1055	.104	.080808	.109	.0991	.1046	70	
13	.0915	.092	.071962	.095	.0882	.0897	60	
14	.0800	.080	.064084	.083	.0785	.0749	50	
15	.0720	.072	.057068	.072	.0699	.0673	45	
16	.0625	.064	.050821	.065	.0625	.0598	40	
17	.0540	.056	.045257	.058	.0556	.0538	36	
18	.0475	.048	.040303	.049	.0495	.0478	32	
19	.0410	.040	.035890	.042	.0440	.0418	28	
20	.0348	.036	.031961	.035	.0392	.0359	24	
21	.03175	.032	.028462	.032	.0349	.0329	22	
22	.0286	.028	.025346	.028	.03125	.0299	20	
23	.0258	.024	.022572	.025	.02782	.0269	18	
24	.0230	.022	.020101	.022	.02476	.0239	16	
25	.0204	.020	.017900	.020	.02204	.0209	14	
26	.0181	.018	.015941	.018	.01961	.0179	12	
27	.0173	.0164	.014195	.016	.01745	.0164	11	
28	.0162	.0148	.012641	.014	.015625	.0149	10	
29	.0150	.0136	.011257	.013	.0139	.0135	9	
30	.0140	.0124	.010025	.012	.0123	.0120	8	
31	.0132	.0116	.008928	.010	.0110	.0105	7	
32	.0128	.0108	.007950	.009	.0098	.0097	6.5	
33	.0118	.0100	.007080	.008	.0087	.0087	6	
34	.0104	.0092	.006305	.007	.0077	.0077	5.5	
35	.0095	.0084	.005615	.005	.0069	.0069	5	
36	.0090	.0076	.005000	.004	.0061	.0061	4.5	
37	.0085	.0068	.004453		.0054	.0064	4.25	
38	.0080	.0060	.003965		.0048	.0060	4	
39	.0075	.0052	.003531		.0043			
40	.0070	.0048	.003144		.0038			



TABLE A-20. MELTING POINTS APPROXIMATE

ELEMENTS	DEGREES	
	C	F
ALUMINUM	660	1220
ANTIMONY	631	1167
BARIUM	850	1562
BERYLIUM	1350	2462
BISMUTH	271	520
CADMIUM	321	610
CALCIUM	810	1490
CARBON	3500	6332
CHROMIUM	1765	3209
COBALT	1480	2696
COPPER	1083	1981
GOLD	1063	1945
IRON	1535	2795
LEAD	327	621
LITHIUM	186	367
MAGNESIUM	651	1204
MANGANESE	1260	2300
MERCURY	-39	-38
MOLYBDENUM	2620	4748
NICKEL	1446	2635
PHOSPHOROUS (YELLOW)	44	111
PLATINUM	1773	3223
SILICON	1420	2588
SILVER	961	1761
TIN	232	449
TUNGSTEN	3400	6152
VANADIUM	1710	3110
ZINC	420	787

**By Order of the Secretary of the Army:**

**CARL E. VUONO**  
*General, United States Army*  
*Chief of Staff*

**Official:**

**R. L. DILWORTH**  
*Brigadier General, United States Army*  
*The Adjutant General*

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