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MILITARY HANDBOOK

MANUFACTURE OF PROJECTILES, PROJECTILE COMPONENTS, AND CARTRIDGE CASES FOR ARTILLERY, TANK MAIN ARMAMENT, AND MORTARS

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FOREWORD

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3. This handbook was developed under the auspices of the US Army Materiel Command's Engineering Design Handbook Program, which is under the direction of the US Army Management Engineering College.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAP = Army Ammunition Plants
AI = automated inspection
AIS = automated inspection systems
AISI = American Iron and Steel Institute
AP = armor-piercing
APC = armored personnel carrier
APDS = armor-piercing discarding sabot
APFSDS = armor-piercing, fin-stabilized discarding sabot
APT = ammonium paratungstate
AQL = acceptance quality level
ASTM = American Society for Testing and Materials
BHN = Brinell hardness number
CAD = computer-aided design
CAIS = computer-aided inspection systems l
CAM = computer-aided manufacture
CE = cold extrusion
CLGP = cannon-launched guided projectile
CMM = coordinate measuring machines
CNC = computer numerical control
COCO = contractor-owned contractor-operated
DU = depleted uranium
ECM = electrochemical machining
EFP = explosively formed penetrator
GFM = Government-furnished material
GOCO = Government-owned contractor-operated
GOGO = Government-owned Government-operated
HC-CC = hot cup-cold coin
HC-CD = hot cup-cold draw
HE = high explosive
HEAT = high-explosive antitank
HEAT-T-MP = high-explosive antitank-tracer-multipurpose
HERA = high-explosive rocket-assisted
H F = high fragmentation
HF-HT = hot forge-heat treat
HT = hydrostatic testing
ICM = improved conventional munitions
ID = inner diameter
JRTV = joint room temperature vulcanizing
KE = kinetic energy
LT = leak testing
MPI = magnetic particle inspection
NC = numerical control
NDT = nondestructive testing
OD = outer diameter
RAP = rocket-assisted projectile
R&D = research and development
RP = red phosphorus
SAE = Society of Automotive Engineers
TDP = technical data package
TNT = trinitrotoluene
UNS = Unified Numbering Standard
UUT = unit under test
W = tungsten alloy
WC-CD = warm cup-cold draw
WP = white phosphorus

CHAPTER 1
INTRODUCTION

This chapter describes the purpose, background, and scope of this handbook and gives a chapter-by-chapter summary of the contents, which outline the processes involved in the manufacture of projectiles, projectile components, and cartridge cases for artillery, tank main armament, and mortars.

1-1 PURPOSE

This revision of Engineering Design Handbook, AMCP 706-249, *Ammunition Series, Section 6, Manufacture of Metallic Components of Artillery Ammunition,* updates and broadens the coverage of the July 1964 edition. Both title and contents have been changed to include metallic and nonmetallic components for tank main armament, mortars, and artillery ammunition.

During the last two decades new munitions have been developed to meet a variety of threats. Increased capabilities include the engagement of new and more difficult targets through increased range and improved accuracy as well as improvements in terminal effectiveness, k., increased armor penetration and improved fragmentation. New tactical concepts have evolved that increase the demand for carrier rounds to deliver smoke, submunitions, and pyrotechnics. As a result, munitions and component designs have become more sophisticated, and emphasis on cost, effectiveness, and producibility is introduced early in the life cycle.

Thus the introduction of new materials, manufacturing methods, and inspection technology has kept pace with these new developments, which result in the availability of new manufacturing technology and facilities capable of producing reliable metal parts at a reasonable cost.

This handbook has been written to give the munitions designer insight into the manufacturing processes that have been used. Because these are "tried and proven", they should be considered during the design of a new munition. If a new design is adaptable to the available manufacturing processes and facilities, it can be produced faster and probably at a lower cost once released for production. In particular, cost savings are most significant when existing production facilities can be modified to produce new items.

The existence of a production processor facility should not be interpreted as a mandatory restriction on the designer if a specific design represents a quantum improvement in munitions efficiency and effectiveness. However, the availability of production facilities can be a major asset in promoting a new munition.

1-2 BACKGROUND

The compatibility of manufacturing processes and product design has rarely received sufficient consideration during the early stages of the life cycle of ammunition hard ware. Such consideration, however, is important in establishing realistic and achievable cost estimates as early as possible because the mass production phase represents the greatest part of life cycle cost.

The metal parts fabricating facilities for large caliber munitions are unique in many aspects. They do not have the advantage that many other military items such as aircraft, trucks, and even small arms ammunition do, i.e., an existing and operable production facility that is active during peacetime and turns out a similar or compatible civilian product. During a national emergency these facilities that are producing civilian products can readily be converted to production of a military product with existing technology and work force in place. Large caliber munitions must be produced in large quantity during wartime, and because no civilian counterpart production exists, the facilities must be designed, built, and dedicated to single or similar items of production. Furthermore, these large caliber munitions manufacturing facilities are for the most part idle during peacetime and thus present an economic burden that cannot be borne by industry. Yet, because they are essential during an emergency and must be kept in a satisfactory state of readiness, they result in a major cost to the Government.

Government planning for a war emergency includes a mobilization plan for munitions production facilities with proposed production schedules based on state of readiness, i.e., operating, laid away in place, or in storage as a package.

Just as the cost of maintaining such munition production facilities is too great for industry to absorb, so is the cost of their initial establishment because they are single- or similar-item dedicated, integrated production lines. As a result, the majority of the production equipment is purchased and owned by the Government. Therefore, the greatest portion of the production base consists of Government-owned equipment placed in contractor-owned plants. These plants are designated as contractor-owned/contractor-operated (COCO) facilities. and the equipment is maintained by the contractor under a mobilization agreement with the Government.

Another type of facility is owned by the Government and operated by a contractor and designated as Government-owned/contractor-operated (GOCO). This type of facility may be shut down during peacetime with everything kept in place so the facility can be rapidly reactivated for production of its dedicated items during an emergency.

The third type of facility is Government-owned/ Government-operated (GOGO). This type of plant is operated by Government employees and as such can be activated by reassigning qualified personnel. Normal practice was to maintain small orders in peacetime to keep the GOGO assembly lines in a high state of readiness. GOGO facilities are now rare and are not likely to be a significant factor in view of the current trend toward out-of-house procurement. Consequently, present practice is to maintain as many COCO or GOCO facilities in a low production state of readiness as is economically practical during peacetime.

Cost is a major consideration in adopting a new development program and production of large quantities of munitions is the normal course of action; therefore, the designer should keep end-item cost as low as possible without compromising performance of the item. Cost factors can be minimized by achieving a design that is compatible with minor modfications to existing production facilities and by avoidance of overly restrictive tolerances or expensive and critical materials without strong justification.

Overly restrictive tolerances must be avoided because of the high cost associated with the need for special manufacturing and inspection equipment as well as an increased rejection rate. The cost of rejects is especially high when an item is at the final inspection station because all material costs and prior machining costs have been incurred.

It cannot be emphasized enough that the designer's final product is the technical data package (TDP). The designer may have demonstrated that the developed item is far superior to anything currently available, but the whole effort is meaningless unless it has been thoroughly documented and controlled by proper drawings with realistic tolerances and specifications that will control the design within practical imitations.

Whenever new munition designs dictate radical departures from the conventional, use of new manufacturing processes may be necessary, and when necessary, development of the production process must be accomplished concurrently with component design. Such a coordinated approach will insure that the item can be produced economically and can minimize time delay in process development. Furthermore, if no major design changes are required for producibility, further test and evaluation programs to prove safety, reliability, and performance will not be required, and time as well as COSTS will be saved.

1-3 SCOPE

This expanded revision of AMCP 706-249 covers aspects relating to production of munitions that the design engineer must consider early in the development stage of the life cycle. Each munition type cited represents different disciplines with regard to design, materials, manufacturing methodology, and end use. The descriptions of acceptable manufacturing processes for manufacturing the current generation of projectiles and cartridge cases are based on state of the art and recognize current trends aimed at reducing production costs and meeting higher standards of product reliability.

Even as early as the concept expiration phase, emphasis is-placed on the need to create realistic munitions designs. Thus an inordinate amount of time and project funds will not be wasted in pursuing an approach that is impractical from a production point of view. The full-scale development phase, during which requirements for materials, dimensions, and physical properties are established, has the greatest influence on the production cost of the item. For this reason, this handbook addresses the impact of overly restrictive dimensional and mechanical properties on the manufacturing process.

Examples of various munitions are given because they represent not only a basic process or a specific material but also because they exemplify the reasons a particular sequence of operations was selected. Also explanations are provided as to why an alternate procedure may have been considered and then eliminated.

Materials and manufacturing methods not covered in the previous edition of this handbook are included for production of artillery projectiles. A summary of this new information is in the paragraphs that follow.

The manufacture of kinetic energy (KE) armor-defeating munitions represents a major departure from the forming and machining procedures used in manufacture of artillery munitions, and therefore it is treated in this handbook. The use of heavy metal alloys as penetrators and the more severe firing environment of KE munitions mandate the need for a coordinated approach among design, development, and manufacturing controls.

The use of nonferrous materials, such as heavy metals, copper and aluminum alloys, and plastics, has increased in recent years. The processing of these materials into munitions components is also discussed. These components may interface with other metallic components, and knowledge of the various constraints and advantages in their use should be beneficial to the munitions designer.

Mortar ammunition metal parts production is included because it combines much of the deep cavity projectile manufacturing process and also includes nonferrous metal components.

Training ammunition production has become increasingly more important because of its potential to reduce costs and increase safety. Here the use of alternate, lower cost materials and methods of manufacture are possible because terminal effectiveness is not a prerequisite. If no negative training results are experienced with the use of this type of ammunition, the trainer can shoot more rounds at a lower cost than if he used service rounds.

Overall new and more sophisticated inspection methods have been introduced to keep pace with the use of new materials and the requirement for greater reliability and maintainability of modern munitions. Quality assurance measures have always been an integral part of munitions production and play an important role in product qualifications. New studies in nondestructive testing developments have reduced the number of firing tests required in acceptance and stockpile surveillance and have increased the assurance of failure-free materiel.

1-4 OVERVIEW

In addition to Chapter 1, this handbook contains thirteen chapters, which discuss the various types of projectiles and weapons used against various targets, the materials used, and the manufacturing processes employed. Steel cartridge cases, qualilty and inspection system requirements, the evaluation of the properties of ammunition components, and a detailed discussion of dimensional inspection and nondestructive testing of artillery metal parts are included.

Chapter 2, "Types of Projectiles", is a description of the various types of projectiles available for different mission assignments. Their use in different roles, such as against hard or soft targets or special-purpose missions of obscuration and spotting, is discussed.

Chapter 3, "Materials", presents the basic qualitative and quantitative data on ferrous and nonferrous metals and nonmetallic materials used in the manufacture of projectiles, cartridge cases, and related components.

Chapter 4, "Manufacturing Methods", discusses the evolution of manufacturing processes used to produce large caliber munitions and associated metal parts.

Chapter 5, "Manufacture of Conventional High-Explosive (HE) and Other Deep Cavity Projectiles"; Chapter 6, "Manufacture of Carrier Projectiles": Chapter 7, "Manufacture of Shaped Charge Projectiles": Chapter 8, "Manufacture of Kinetic Energy projectiles"; Chapter 9, "Mortar Ammunition"; and Chapter 10, "Manufacture of Steel Cartridge Cases", describe the various manufacturing processes and materials used in production of these munition components.

Chapter 11, "Product Assurance", discusses the basic regulations and definitions an ordnance engineer should know and be guided by when he is involved specifically in the design and production of projectiles. Inspection system requirements of the Government and contractor(s) are detailed as are control and review of quality during the life of the components.

Chapter 12, "Evaluation of Properties", explains the purpose of evaluating or controlling properties of ammunition components and discusses methods and/or types of testing involved, such as tensile and hardness testing, chemical analysis, and environmental tests such as salt spray. Other mechanical property or functional tests, such as compression testing bend testing, and impact testing that are performed less frequently are discussed.

Chapter 13, "Dimensional Inspection", explains the purpose of dimensional inspection and describes the equipment used. Manual gaging equipment presently used, e.g., snap, ring, depth, and mechanical types, are described, as are in-process air gages and electronic controls used in current automation methods. Included in this chapter is a discussion of future computer manufacturing processes encompassing computer-driven machining and acceptance processes, built-in machine compensation, and control from automatic measuring devices—mechanical, optical, and electronic.

Chapter 14, "Nondestructive Testing", describes the theory and techniques currently available to industry to assure acceptability of items. Also covered in this chapter are specific examples of how these tests and procedures, i.c., leak testing, magnetic particle testing, the magnaflux method, the rnagnaglo method, hydrostatic testing, eddy current testing, and ultrasonic testing, are applied to artillery metal parts. Description of the equipment used, applications, and case histories are included.

TABLE 1-2. ADVANTAGES AND DISADVATAGES OF FIBER REINFORCEMENTS

FIBER	ADVANTAGE	DISADVANTAGE
Fiberglass	Resistance to mildew and rot, resistance to chemicals, high tensile strength, perfect elasticity, good electrical insulation, low cost, good processibility	Glass friable and brittle, surface treatment and lubrication required, subject to static fatigue, lowest modulus of elasticity
Carbon-Graphite	High modulus, low thermal expansion, high electrical conductivity, low density, low coefficient of friction, resistance to chemicals, resistance to creep, good vibration damping, high temperature resistance, zero or very low thermal linear expansion	High cost, poor impact resistance
Aramid	Lightweight, high flexural and compressive modulus, good electrical and thermal insulation properties, radar and sonar transparency; good processibility, low creep, low notch sensitivity, chemical resistance, good impact resistance	Lower interlaminar shear strength, lower flexural and compressive strength, attacked by UV light, lower high-temperature service, poor citability, requires surface treatment
Boron	High strength very high modules, very high compressive strength, high hardness, low thermal conductivity and expansion, high-temperature resistance	Very high cost, limited number of suppliers, limited materials forms (epoxy/ boron tape)

1-6 SUMMARY

Most plastic resins are not suitable for structural applications. Although many resins are extremely tough, most lack strength, stiffness, and deform under load with time. By mixing strong, stiff, fibrous materials into the plastic matrix, a variety of structural composite materials can be formed. The properties of these composites can be tailored by fiber selection, orientation, and other factors to suit specific applications.

Table 1-2 briefly summarizes the advantages and disadvantages of fiberglass, carbon-graptite, aramid (Kevlar® 49), and boron fibers.

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CHAPTER 2
TYPES OF PROJECTILES

Projectile types are described in terms of the weapons from which they are fired and in terms of terminal effects. The mission of each weapon type and its family of ammunition are discussed to illustrate that despite the differences in terminal effects, there are design similarities that lead to ballistic similitude and application of common manufacturing processes.

2-1 INTRODUCTION

Fire support on the battlefield is provided by artillery, mortars, and tank main armament. Weapon systems have become more sophisticated along with the increased complexity of the battlefield and improved countermeasures.

Munitions designs, therefore, have undergone significant changes to improve terminal effectiveness and reliability. Manufacturing facilities and processes are updated continuously and consistently with the introduction of new and higher strength materials, closer tolerances, and more stringent product acceptance tests.

2-2 WEAPON TYPE

The projectiles covered in this handbook are delivered by artillery, tank main armament, or mortar fire. Each type of weapon fires a family of ammunition, which consists of a variety of projectiles governed by the mission of the weapon.

2-2.1 ARTILLERY

Field artillery doctrine (Ref. 1) demands the timely and accurate delivery of fire to meet the requirements of supported units. Field artillery weapons in the US Army vary in caliber from 105 mm to 8 in. and are classified as howitzers. These weapons deliver projectiles at medium velocity and medium curvature of trajectory. Artillery cannons are normally placed in defilade to conceal them from the enemy. This placement precludes sighting the weapon directly at the target; consequently, indirect fire must be employed. Indirect fire is the primary problem of the gunnery team, which consists of observers and all target acquisition devices, the fire direction center, and the firing battery.

The range of an artillery projectile depends upon its muzzle velocity and the angle of fire. Adjustments in projectile muzzle velocity are made by removing one or more of the bagged increments that makeup the propelling charge. The incremented charge corresponds to a range zone in the weapon firing tables. The upper and lower limits of each range zone are based on maximum and minimum weapon elevations, respectively, for a given propelling charge.

Artillery ammunition is either semifixed or separately loaded. Semifixed ammunition, as shown in Fig. 2-1, allows field assembly of the projectile and cartridge case. The propelling charge can be modified by removing one or more of the bagged increments. After the charge is adjusted, the projectile and cartridge case are chambered in the weapon as a unit. Semifixed ammunition is used in 105-mm howitzers.

Separate loading ammunition, shown in Fig. 2-2, is used in 155-mm and larger caliber weapons. Projectile weight and length of the weapon chamber preclude handloading of these weapons. Ram loading the projectile

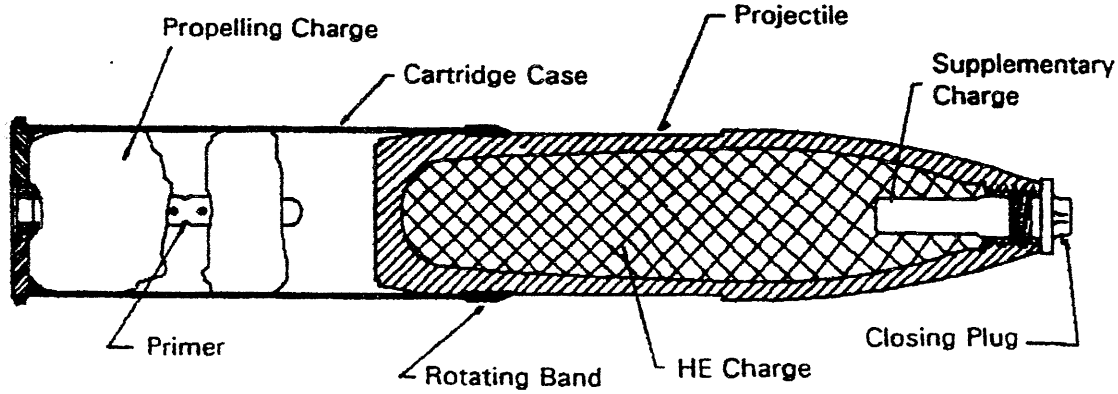
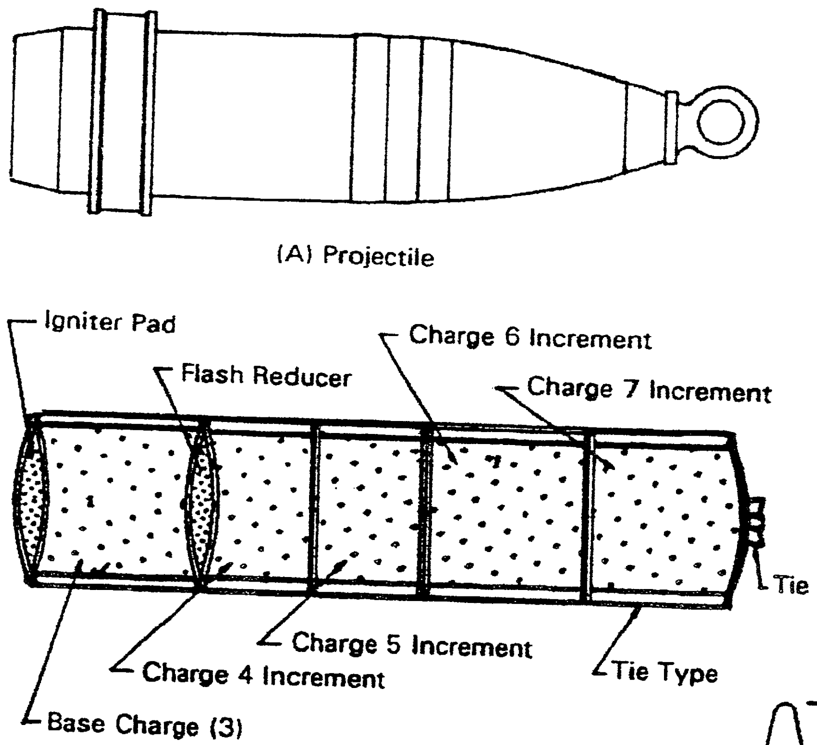


Figure 2-1. Typical 105-mm Semifixed Ammunition



(B) Propelling Charge

Figure 2-2. Typical Separate Loading Ammuniotion

assures that the rotating band is fully seated in the forcing cone at the origin of tube rifling. The propelling charge can be unitary or adjustable and is placed in the chamber behind the projectiole. Examples of 155-mm projectile types are shown in Fig. 2-3.

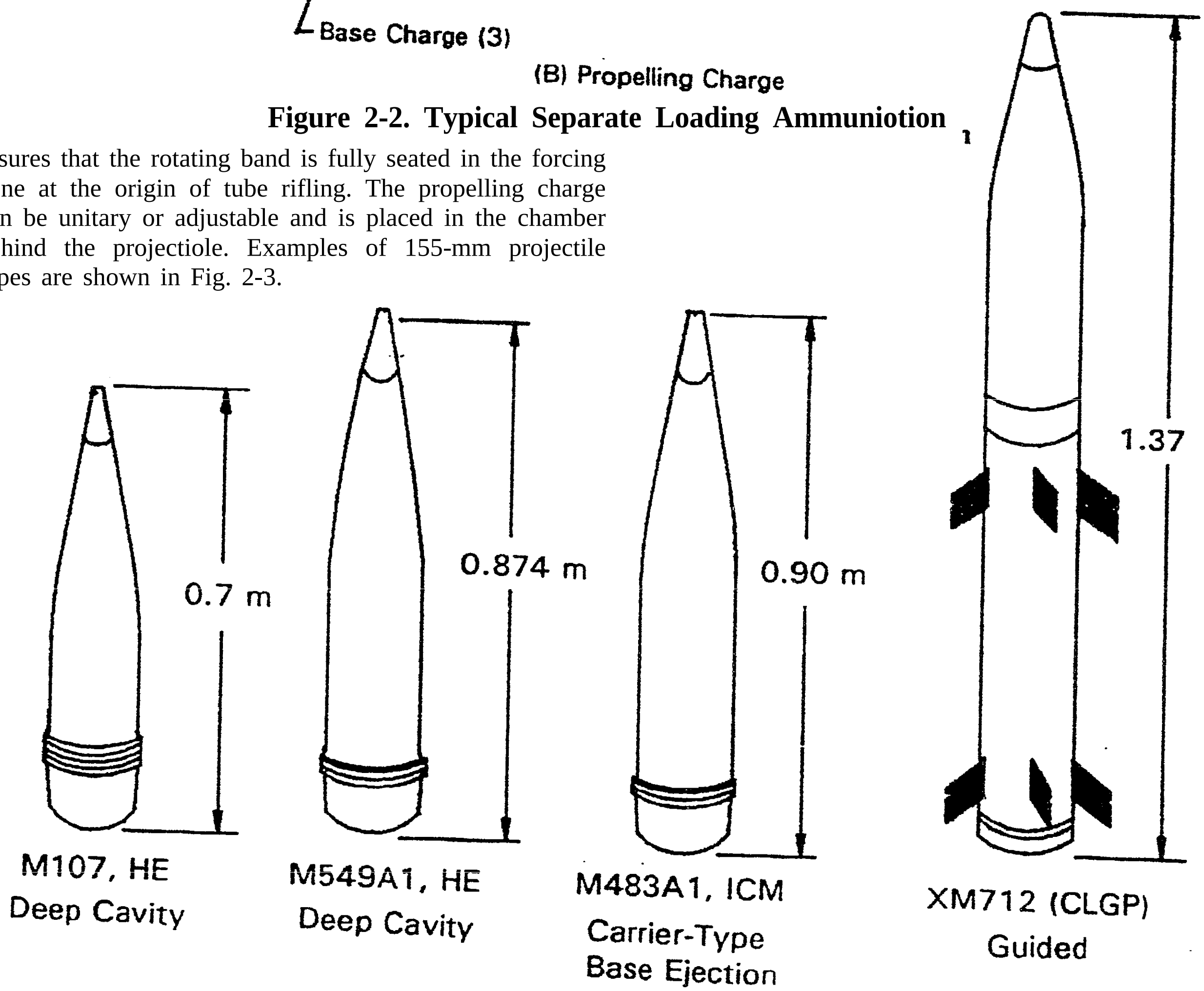


Figure 2-3. 155-mm Projectile

Spin-stabilized projectiles are equipped with a rotating band that centers the projectile in the chamber, provides a seal to prevent blowby of propellant gases, precludes backward movement of the projectile upon elevation of the howitzer tube, and imparts spin to the projectile when it engages and is engraved by the helical rifling in the bore of the weapon.

Artillery projectiles can be categorized as shown in Table 2-1.

TABLE 2-1. TYPES OF ARTILLERY PROJECTILES

Type	Payload	Purpose
Deep Cavity	Inert filler or empty	Training
	High-explosive (HE)	Antipersonnel and antimateriel
	White phosphorus (WP)	obscuration
	Chemical agents	Antipersonnel
Base Ejection	Submunitions	Antiarmor and antipersonnel
	Mines	Area denial
	WP	Obscuration
	Illuminating canister and parachute	Battlefield illumination
Guided	Shaped charge	Antitank

2-2.2 TANK MAIN ARMANMENT

The mission of tanks is to spearhead infantry advances, defeat enemy tanks and armored vehicles, breach enemy lines, disrupt supply lines, and hold positions until friendly forces can secure them. Tactics vary with specific targets and terrain, but the main concept is to use the speed, protection, and fire power of tanks to assist the infantry in defeating enemy positions.

Tank weapons are sighted directly at the target and deliver projectiles at high velocities and flat trajectories. Direct fire precludes the need for propelling charge adjustment; therefore, the propelling charge and projectile are fixed and chambered in the weapon as a unit or cartridge. in the example of fixed ammunition shown in Fig. 2-4, the cartridge ease is joined with the projectile by crimping to the sabot at the leading edge of the rotating band. Tank guns may be rifled or smooth bore. Rifled tubes such as the 105-mm M68 tank gun can fire both fin- and spin-stabilized projectiles, whereas smooth bore weapons can fire only fin-stabilized projectiles. Fin-stabilized projectiles have no rotating band but do have an obturating band to prevent blowby of propellant gases, which is a function performed by the rotating band on spin-stabilized projectiles.

Two types of armor defeating projectiles are fired from tank weapons: kinetic energy (KE) and shaped charge or high-explosive antitank (HEAT). KE projectiles can be either spin- or fin-stabilized, whereas HEAT projectiles are fin-stabilized because spinning of the shaped charge results in degradation of performance.

As shown in Fig. 2-4, KE projectiles consist of sub-caliber, high-density penetrators encased in a sabot that discards upon exit from the gun muzzle. This design concept is applied to both spin- and fin-stabilized KE projectiles and represents the most practical way of developing the high muzzle velocity of the penetrator required to defeat armor targets.

HEAT projectiles develop the energy to penetrate armor plate through the detonation of a high-explosive charge, which collapses a funnel-shaped copper liner upon target impact. The detonation creates a very high-velocity-focused shock wave and a jet of metal particles that penetrate the armor. HEAT projectiles are sometimes referred to as shaped charge ammunition because the HE filler conforms with the shape of the copper liner, as

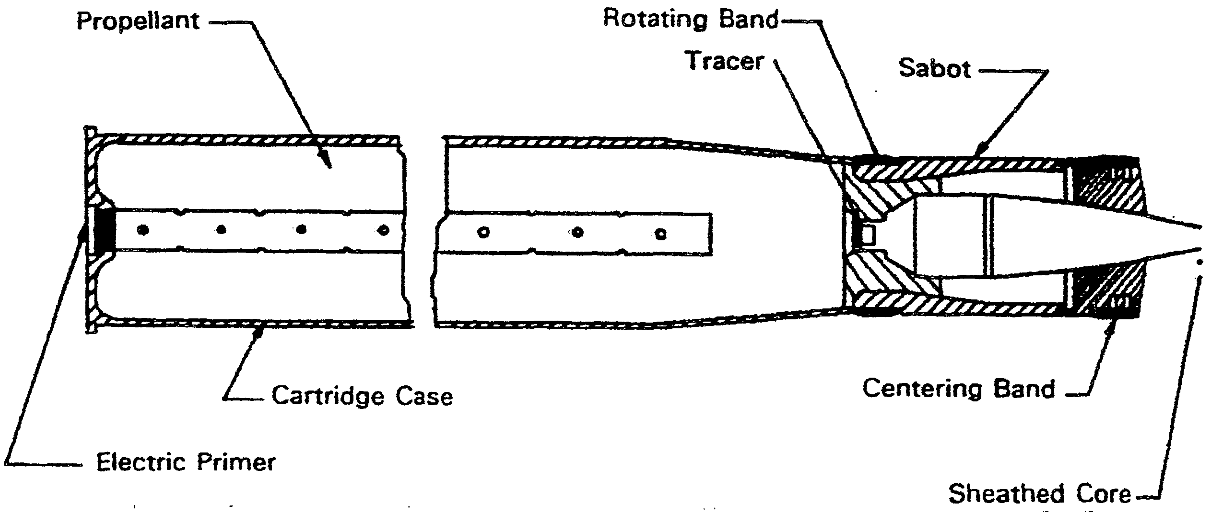


Figure 2-4. 105-mm M392 Armor-Piercing Discarding Sabot

shown in Fig. 2-5. This round is also effective against personnel and materiel as a result of fragmentation of the projectile body.

2-2-3 MORTARS

Mortars are close support weapons that provide the combat elements with their "own artillery". Current inventory of US mortars includes 60-mm, 8l-mm (smooth bore), and 4.2-in. (rifled). Procurement of the 120-mm mortar is planned to replace the 4.2-in.

US mortars are muzzle loaded and fire projectiles at low velocity and high curvature of trajectory to the target. Mortar firing procedures are similar to those used in firing artillery weapons in that adjustments in range are made through adjustments in the propelling charge and tube elevation. Indirect fire is generally employed because mortars are placed in defilade to conceal them from counterfire. Forward observers provide information to the mortar battery regarding location of targets and effectiveness of fire.

Light (60-mm) and medium (81-mm) mortars are man-transportable and can be quickly emplaced, fired, and moved to another site. The heavier 4.2-in. and 120-mm mortars are usually mounted in armored personnel carriers (APCs) but are also equipped with separate base plates for ground mounting.

Smooth bore mortars fire fin-stabilized projectiles similar in design to those shown in Figs. 2-6 through 2-9.

Each mortar cartridge contains a fuzed projectile with its stabilizing fin assembly including primer, ignition cartridge, and propelling charge increments. After adjusting the propelling charge and setting the fuze, the cartridge is muzzle loaded in the mortar. It descends in the tube until the primer at the base of the fin strikes the fixed firing pin located in the base cap. This action causes the propellant in the ignition cartridge to burn and flash through the holes in the fin housing or cartridge container, and in turn ignite the main propelling charge. Gases formed by the burning propellant are sealed by the expanding split-ring obturator, and pressure buildup behind the projectile causes it to accelerate up the tube. Note that this obturator must be flush or below the projectile body surface to assure free fall in the tube.

The 4.2-in mortars fire spin-stabilized projectiles like those shown in Figs. 2-10 through 2-12. Cartridges are muzzle loaded, and ignition of the main propelling charge is the same as that described for fin-stabilized ammunition. The cartridges are fitted with rotating devices that engage the rifling and prevent escape of propellant gases.

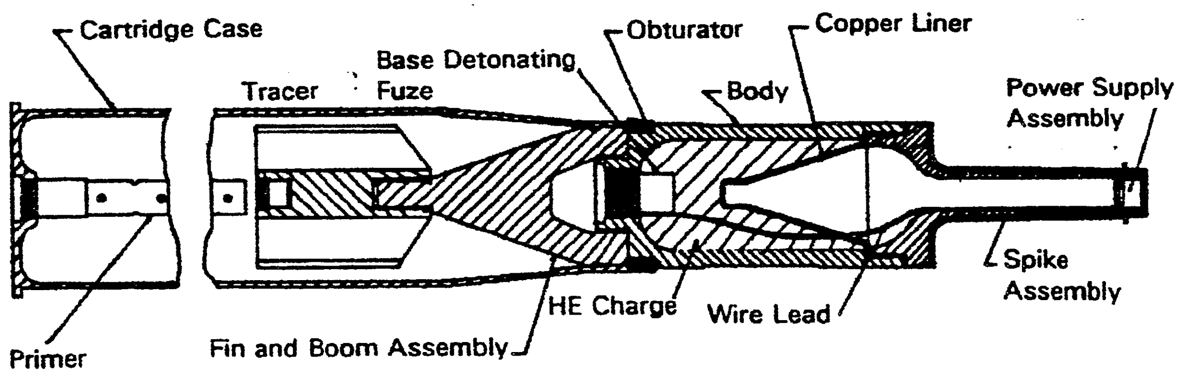


Figure 2-5. 105-mm M456 HEAT Cartridge

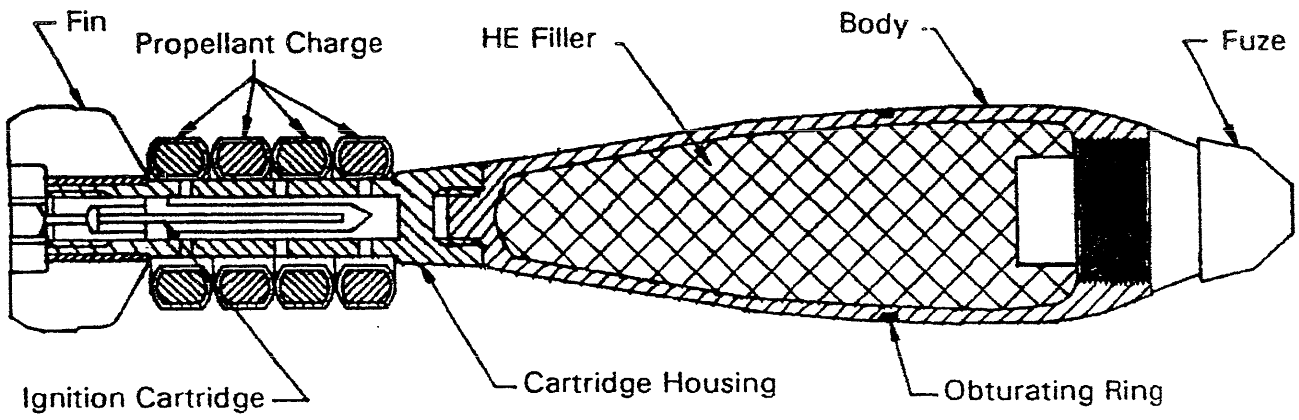


Figure 2-6. 81-mm M374A3 HE Cartridge

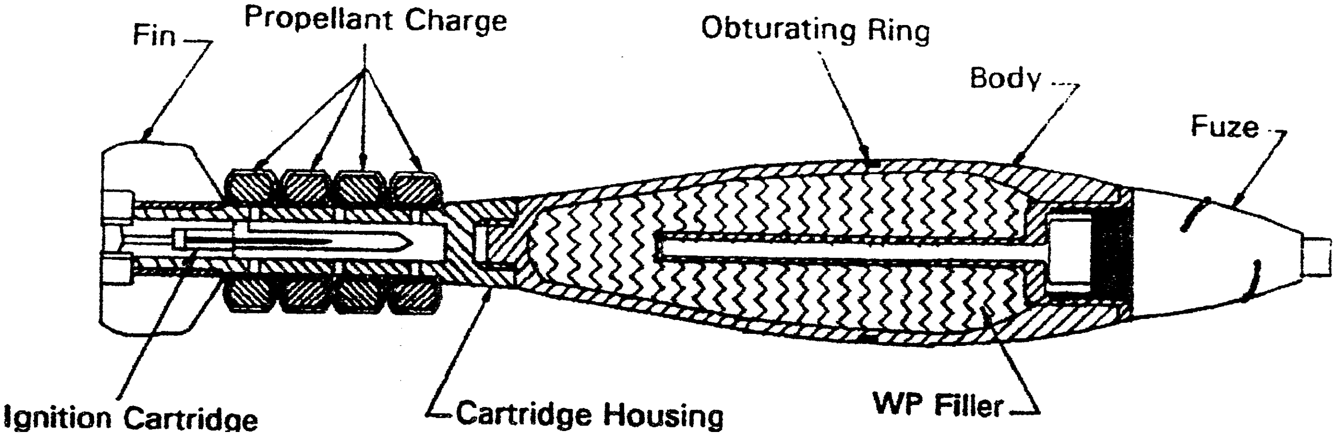


Figure 2-7. M375 Smoke Cartridge (Central Burster)

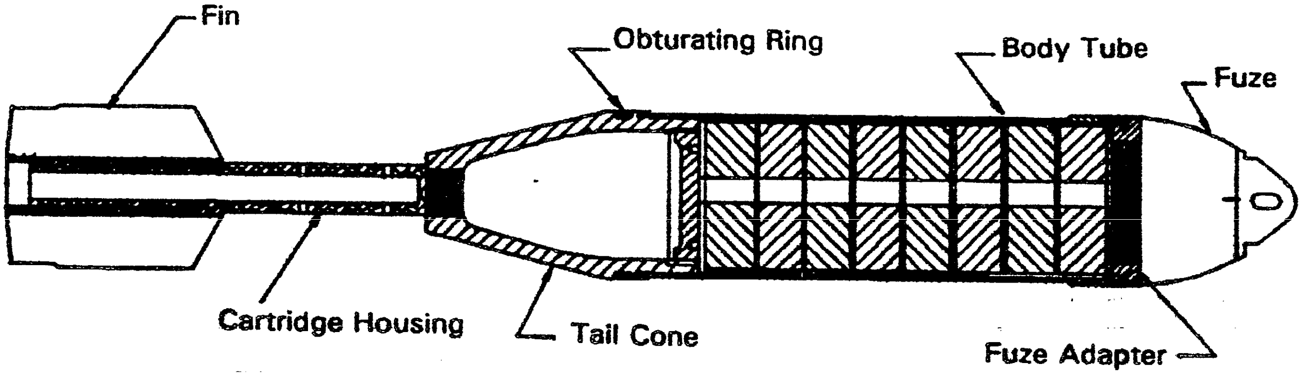


Figure 2-8. 81-mm M819 Smoke Cartridge (Base Ejection)

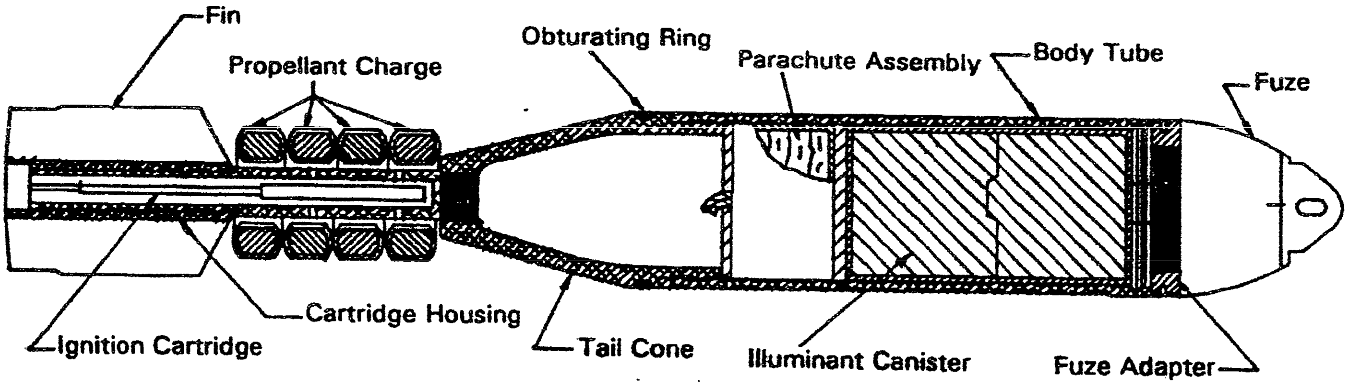


Figure 2-9. 81-mm M853 Illuminating Cartiridge

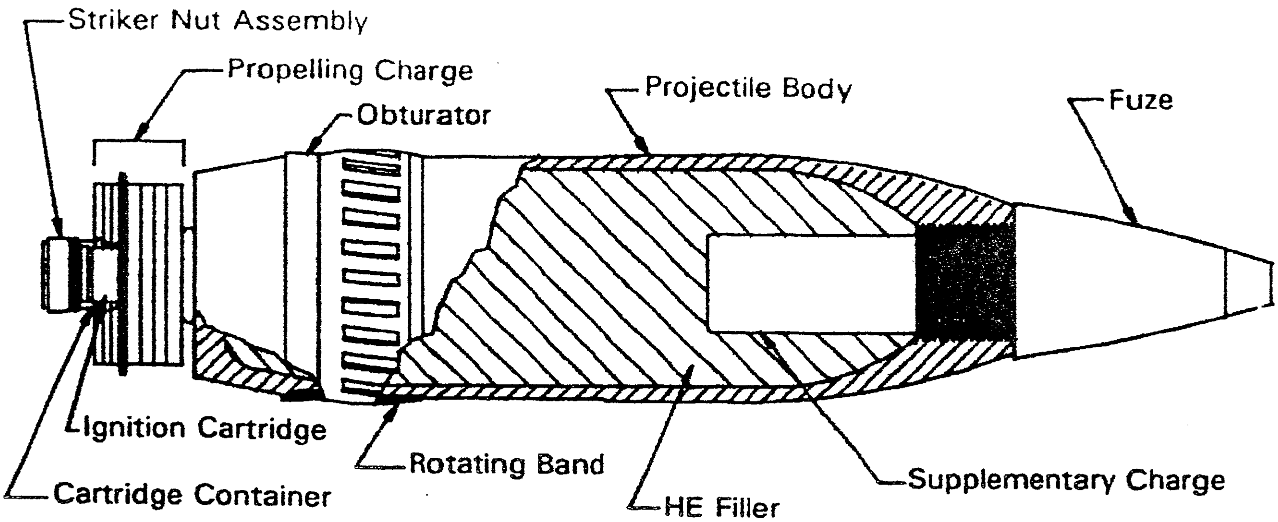


Figure 2-10. 4.2-in. HE M329A2 Cartridge

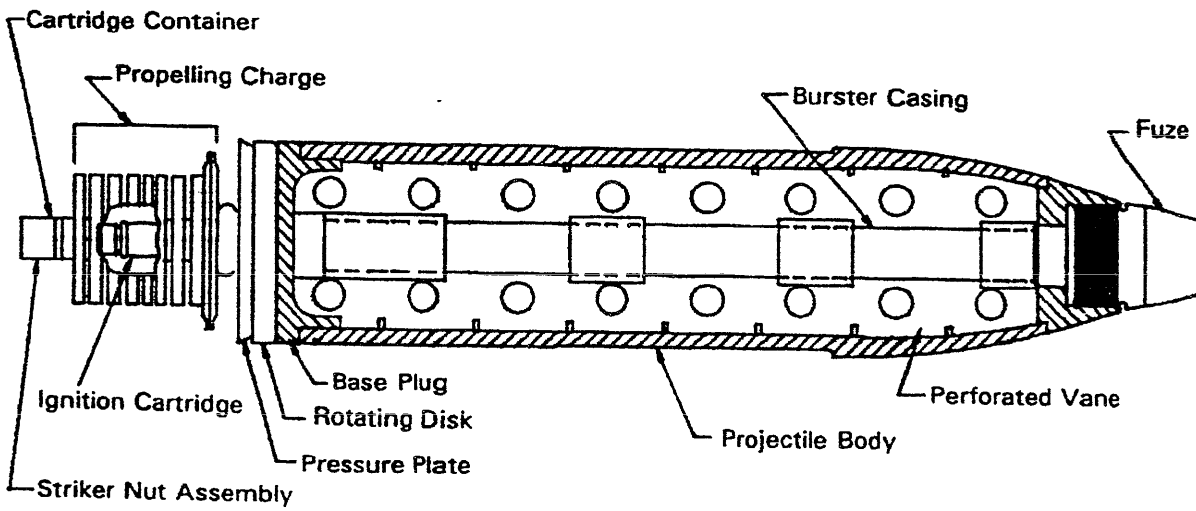


Figure 2-11. 4.2-in. Smoke WP M328A1 Cartridge

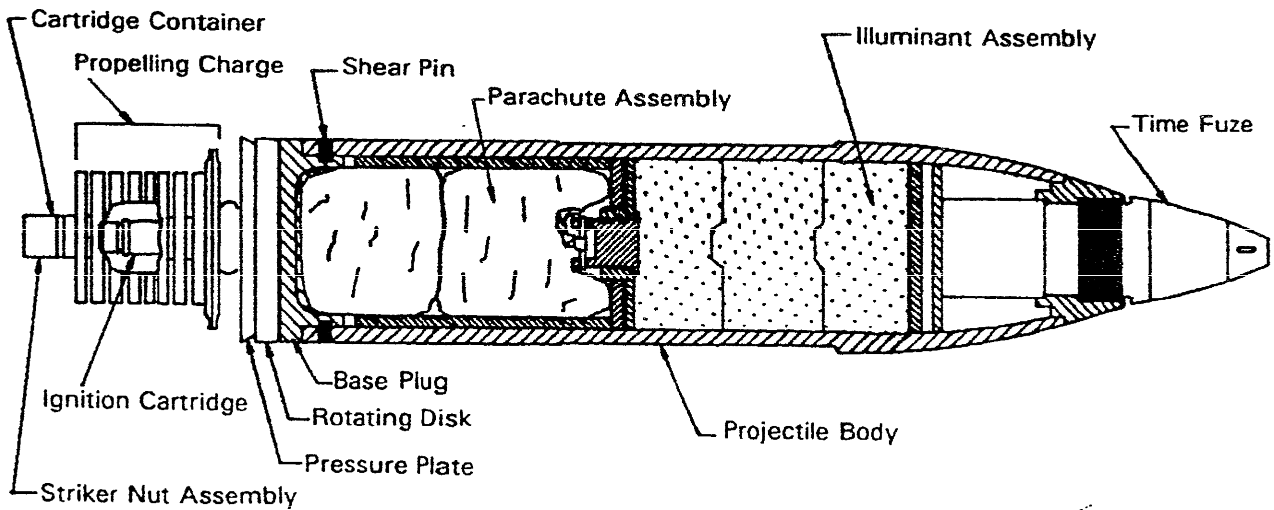


Figure 2-12. 4.2-in. Illuminating M335A2 Cartridge

2-3 PROJECTILE TYPES BY TERMINAL EFFECTS

Artillery and mortars fire high-explosive projectiles designed for blast and fragmentation effects on personnel and light targets. Tank main armament and some artillery projectiles such as the cannon-launched guided projectiles (CLGP) are designed to defeat armored and other bard targets.

2-3.1 ANTIPERSONNEL

There are several types of projectiles available for use in the antipersonnel role. The unitary charge HE projectile with a fragmenting body initiated by a nose fuze fills the major portion of the stockpile. These projectiles may be initiated upon impact or by airburst over enemy personnel. When using the point-detonating impact-fuzing mode, the user has the option of instantaneous or delayed functioning. If personnel targets are sheltered, the delay mode allows penetration before detonation. Proximity or time fuzing causes projectile detonation at an optimum height above ground to produce maximum fragmentation effect. With the advent of the improved conventional munitions (ICM), which are submunition carriers, a major portion of the present production requirements have been converted to this type of round. Submunition payloads for the carrier projectile consist of' either dual-purpose grenades or antipersonnel mines. The grenades are ejected through the base end of the projectile and dispersed in the air through the action of a preset time fuze and expelling charge. The grenades detonate on impact and cover a large area. Antipersonnel mines are dispensed in the same manner but do not become armed until they are at rest on the ground; thus they provide an area denial function. Later they self-destruct to allow use of the territory by friendly troops if desired. Representative 155mm antipersonnel projectiles are shown in Fig. 2-13. The 8 l-mm round M374A3, shown in Fig. 2-6, is a typical mortar antipersonnel round.

2-3.2 ANTIMATERIEL

Materiel targets are divided into hard targets (tanks, armored personnel carriers, bunkers, and reinforced shelters) and soft targets (lightly armored personnel carriers, vehicles, command and control vans, and radars).

2-3.2.1 Hard Targets

The projectiles used in the defeat of tanks by tanks are kinetic energy and high=explosive antitank rounds. When artillery is used to combat tanks, the primary rounds are the cannon-launched guided HEAT projectile shown in Fig. 2-3 or explosively formed penetrators (EFP). The EFP rounds employ seekers that can detect the target and defeat it by the use of EFPs. ICM projectiles carrying antitank mines can provide an area denial function for a predetermined period of time; then they self-destruct or self-sterilize.

High-explosive artillery rounds require a direct hit to accomplish mobility or firepower kills on tanks, and the ICM dual-purpose grenades have a limited probability of causing severe damage to this target. Because mortar HE rounds have a smaller charge than similar artillery projectiles, at best they will accomplish a mobility kill on a tank.

Although the antitank rounds rarely are used to defeat bunkers or reinforced shelters, they do have the capability in direct fire of penetrating most of these buildings, but usually they have only limited effect. Thus the standard artillery HE round—set in the delay mode-is the primary projectile used to defeat bunkers and shelters. HE mortar rounds have limited penetrating capabilities in this role.

2-3.2.2 Soft Targets

There is no ammunition specifically designed for soft targets; however, all of the rounds effective against hard targets have an increased probability of rendering severe damage to soft targets. The antipersonnel fragmenting characteristics of the HE rounds and ICM grenades are especially effective against trucks and unarmored vehicles, frame buildings, and enemy weapons. The larger caliber HE artillery rounds are very effective against conventionally constructed brick and masonry buildings and lightly armored vehicles.

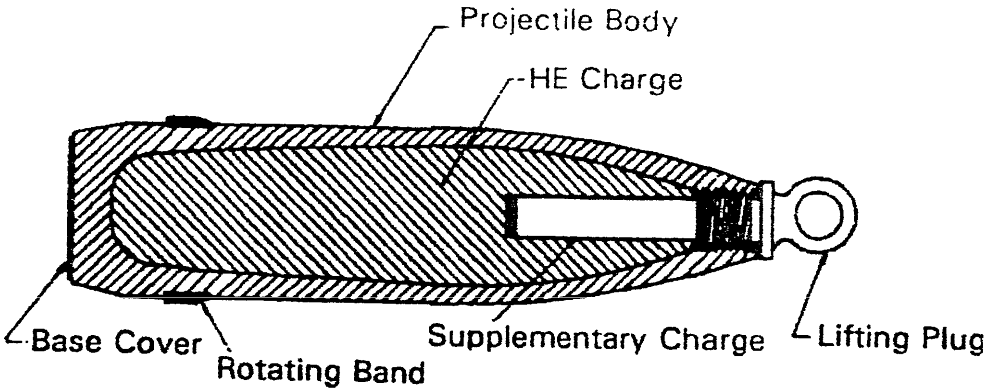
2-3.3 BATTLEFIELD ILLUMINATION

The 105-mm and the 155-mm artillery and all mortar systems have illuminating projectiles to provide illumination to the battlefield. The 8 l-mm M853 illuminating projectile is depicted in Fig. 2-9, and the 155-mm M485 illuminating projectile is shown in Fig. 2-14. There are no such projectiles for tanks. Because tanks employ only direct fire, infrared sighting devices provide night vision.

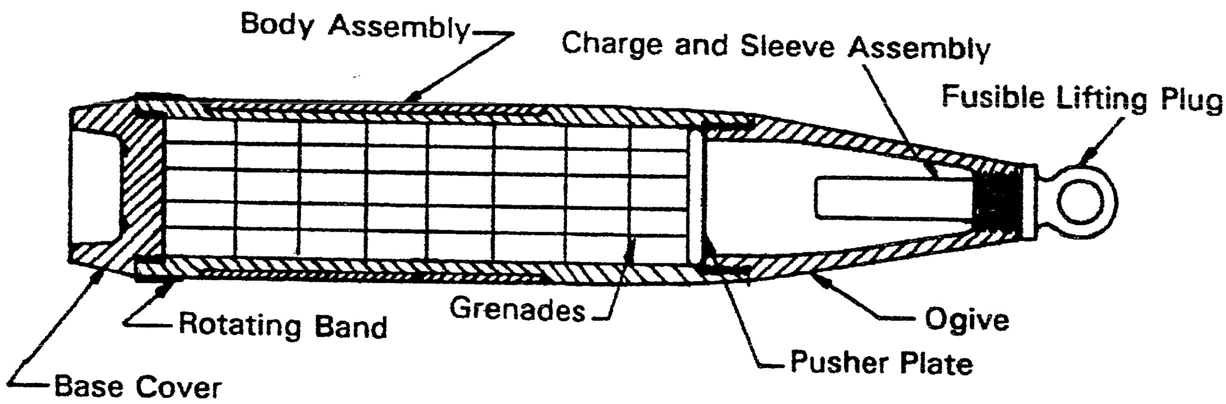
2-3.4 BATTLEFIELD OBSCURATION AND MARKING

There has been an increasing demand for improved smoke-producing projectiles to form a smokescreen to obscure friendly troop movements or positions from the enemy. The white phosphorus (WP) projectile is the basic obscuration round in use. There are two types of WP projectile, the solid fill type with a central burster charge and a submissiled type containing felt wedges. Both types are illustrated in Fig. 2-15. Tanks do not have smoke projectiles; they rely on small grenade launchers integral with the vehicle to provide smoke or markers of their own.

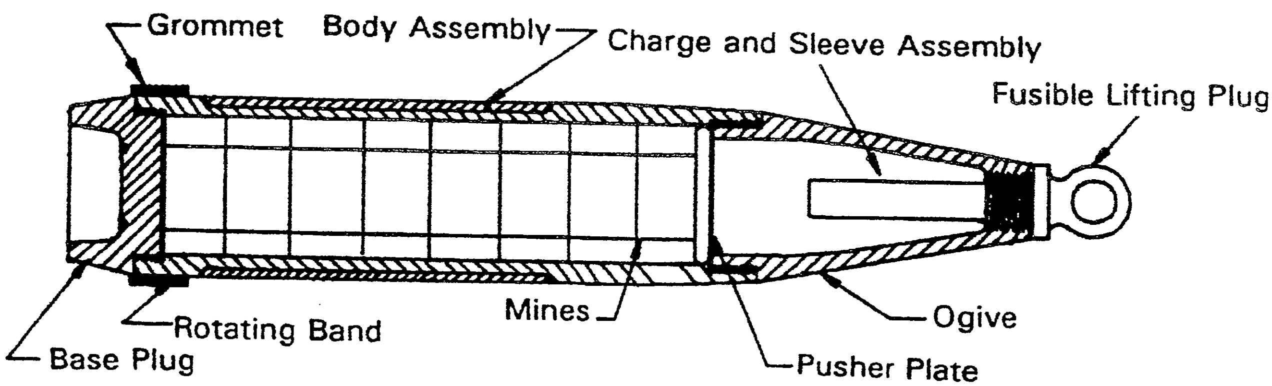
All the mortars have WP smoke projectiles to obscure, set fires, or mark and spot. The WP projectile for the 81-mm mortar is shown in Figs. 2-7 and 2-8.



(A) 155-mm M107 HE Projectile



(B) 155-mm M483A1 HE (ICM) Projectile



(C) 155-mm M692 HE Projectile

Figure 2-13. 155-mm Antipersonnel Projectiles

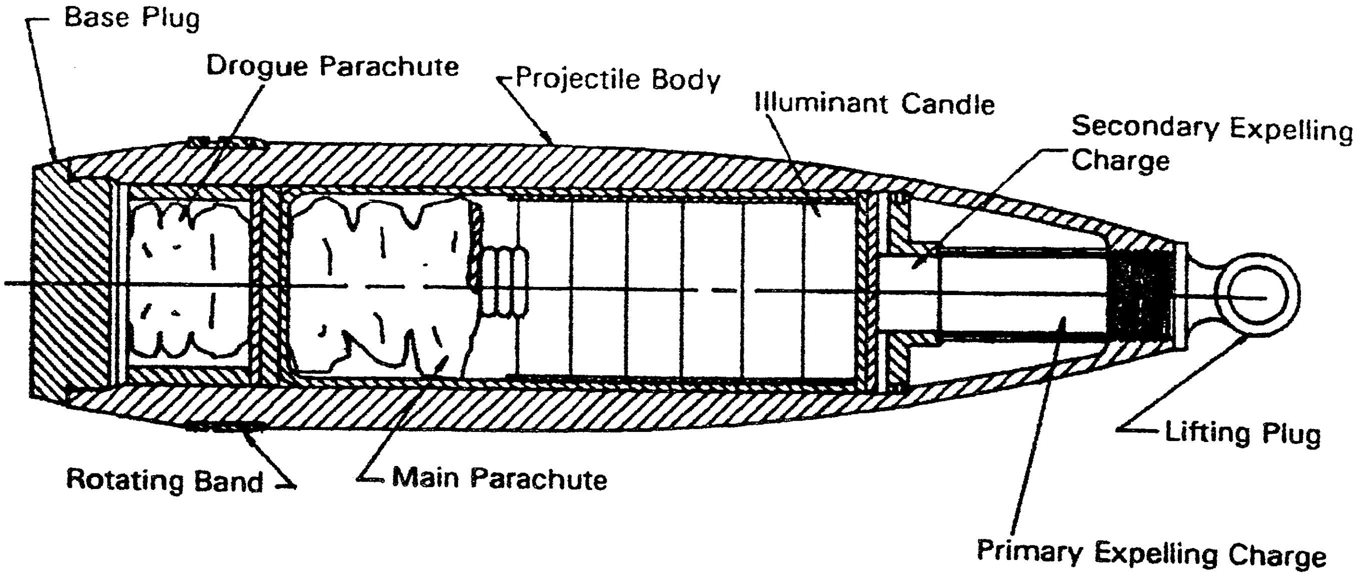
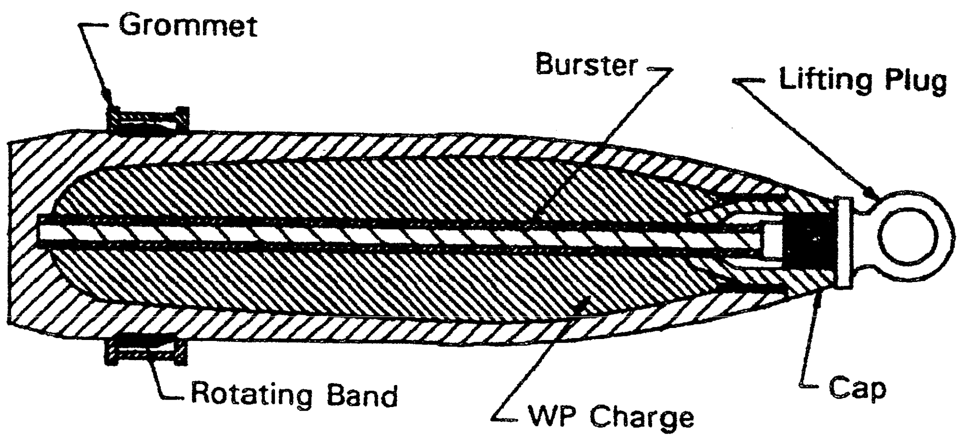
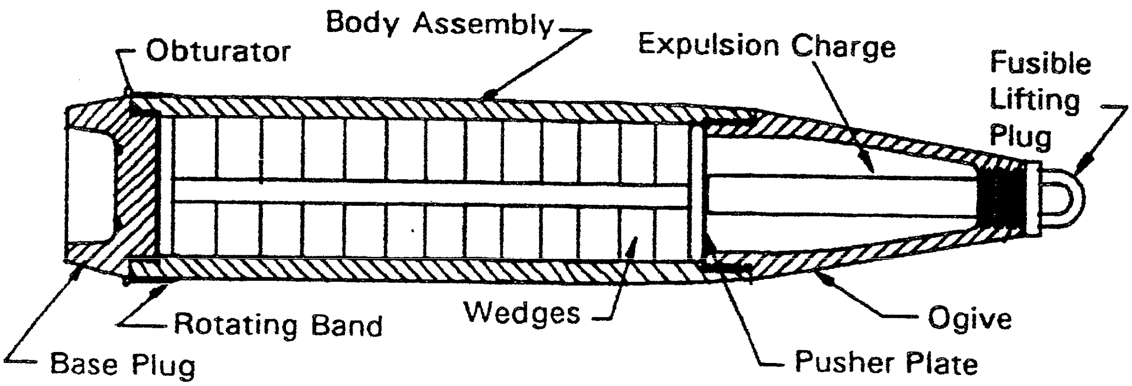


figure 2-14. 155-mm M485A2 Illuminating Projectile



(A) 155-mm M110A2 WP Projectile



(B) 155-mm M825 Felt Wedge WP Projectile

Figure 2-15. Types of WP Projectiles

2-3.5 TRAINING AMMUNITION

During peacetime a large amount of ammunition is expended during troop training exercises. In the past, most of the training was with standard ammunition. Due to the cost, limited availability of suitable ranges, and environmental considerations, however, more and more of the training is performed with ammunition specifically designed for this purpose.

Standard practice followed to provide ballistically matched HE-type training ammunition has been to load the empty HE projectile with an inert filler that is approximately the density of HE and to provide a spotting charge (flash or smoke) to indicate detonation upon impact.. Newer training items are designed to be a ballistic match by increasing wall thickness to compensate for the weight of a filler. Fuzes are assembled at the training site. Considerable savings are accrued through such a design- Modifications at the projectile manufacturing facility consist of minor tooling changes and additional raw material to make the heavier projectile. Kinetic energy tank projectiles require a lengthy safety zone due to their high velocity and thereby limit the number of ranges on which they can be used. The design solution for training projectiles is to match the KE projectile trajectory to a specified, limited distance and then to have it erode, disintegrate, or otherwise fall to the ground in order to reduce the safety zone.

REFERENCES

1. FM 6-40, Field Artillery Cannon Gunnery, Department of the Army, 7 December 1984.

CHAPTER 3
MATERIALS

This chapter introduces the design engineer to the various types of materials used in the manufacture Of projectile components. These materials include steels, light metals, copper, cast irons, and heavy metals. Some comments are made on the nonmetallic components that can be purchased from commercial vendors.

3-1 INTRODUCTION

The selection of proper materials is the first significant step in the manufacture of projectiles, cartridge cases, and related components. This chapter presents qualitative and quantitative data on ferrous metals, nonferrous metals, and nonmetallic materials to provide users of this handbook with sufficient information to assist in material selection. The ferrous metals include carbon, alloy, and high-fragmentation steels, in addition to cast irons, and the nonferrous metals include aluminum, magnesium, tungsten, depleted uranium, and copper alloys. The nonmetallic materials presented are confined to polymers and composites.

3-2 DESIGN TRENDS

Recently improved weapon systerns--eharacterized by longer range requirements, increased payloads, and greater mobility-have required the design of lighter weight metal parts. This requirement has resulted in thin-walled projectiles that require higher strengths. Thus alloy steels are specified. Also the incorporation of aluminum alloys has become a basic method by which to reduce the weight of various parts. New fragmentation steels have been introduced to improve the terminal ballistic effects of a number of projectiles.

Thus alloy steels are specified for those structural components, such as projectile bodies or cannon-fired rooket motor bodies, that are exposed to large forces during launching. New alloy steels made especially for better fragmenting properties are also specified for the high-explosive (HE) fragmentation projectiles. In order to reduce the parasitic weight of inert components on carrier projectiles and conversely allow an increase in the weight of the effective payload, aluminum alloys are required for components such as bases and ogives.

3-3 FERROUS METALS

Ferrous metals normally contain at least 50% iron and range from the almost pure irons, characterized by ingot iron or wrought iron, to alloys of iron, carbon, and a number of other elements.

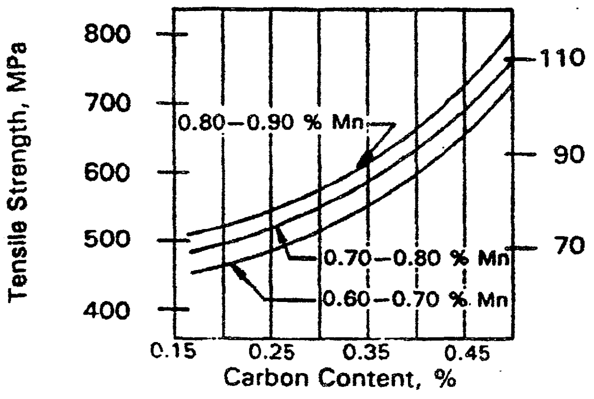
3-3.1 CARBON STEELS

3-3.1.1 Definition

Carbon steel, as defined by the American Iron and Steel Institute (AISI), is steel that owes its properties chiefly to various percentages of carbon without substantial amounts of other alloying elements (Ref. 1). Commercially, steel is classed as carbon steel when it contains carbon up to about 2% and only residual amounts of other elements except deoxidizing agents.

Carbon is the principal hardening element in steel and increases the as-rolled hardness and tensile strength of the steel. Above 0.83% carbon, which is the eutectoid composition of carbon steels, the effect on the as-rolled hardness and tensile strength lessens. The as-quenched hardness also increases with increased carbon, but above O.60% carbon the increase is very small.

Manganese increases hardness and tensile strength in the as-rolled product but to a lesser degree than carbon. Manganese combines with sulfur to improve hot-rolling characteristics and contributes to better surface quality. It also results in greater depth of hardening with increases in manganese content. This increase in hardening is especially effective when the upper limit of manganese (1.65%) for carbon steels is approached. Fig 3-1 shows the positive



From Metals *Handbook, Volume I, 8th Edition, Properties and Selection of Metals,* Published by American Society for Metals, 1977.

Figure 3-1. Effect of Manganese and Carbon on Tensile Strength of Hot-Rolled Carbon Steels (Ref. 2)

effect of manganese and carbon on the tensile strength of hot-rolled steels with low to medium manganese content.

Most applications for projectiles require a "killed" steel, which is made by adding silicon (usually 0.15 to 0.30%.) to carbon steels as a deoxidizer. Sulfur and phosphorus are normally considered undesirable impurities in steel, and carbon steels usually are specified with maximums of 0.040% phosphorus and 0.050% sulfur to minimize their adverse effects on ductility and impact strength. In summary, the principal elements normally specified in carbon steels for large caliber metal parts are carbon, manganese, and silicon. However, sulfur or sulfur and phosphorus are sometimes added to steels when machinability emerges as the prime factor.

The AISI and Society of Automotive Engineers (SAE) method of designating carbon steels is shown in Table 3-1.

Carbon steel has been the most widely used material in huge caliber munitions metal parts over the years because the needed mechanical properties are achieved in many instances through cold-working or heat treatment. Also carbon steel is comparatively easy to process, its cost is relatively low, and its performance is excellent in most operations on a sustained production basis. See Chapter 4 for more information on these processes.

3-3.1.2 Low-Carbon Steels

Low-carbon steels are normally compositions that contain less than 0.25% carbon Mild steel is another term sometimes applied to this family of steels. The as-rolled mechanical properties of low-carbon steels are in the area of 172 to 241 MPa (25 to 35 ksi) yield strength and 310 to 421 MPa (45 to 61 ksi) tensile strength. These materials, however, are extremely well suited to cold-working applications, such as bending, blanking, drawing and extrusion, because of their malleability. The forging characteristics are also excellent.

TABLE 3-1.
CARBON STEEL DESIGNATIONS

Numerals	Type of Steel Nominal Alloy Content
10XX	Plain carbon (Mn, 1.00% maximum)
l1XX	Resulfurized
12XX	Resulfurized and rephosphorized
l5XX	Plain carbon (Maximum Mn range 1.00 to 1.65%)

Note: XX in the last two digits of the designations indicates the carbon content in hundredths of a percent.

Low-carbon steels have been used principality as projectile bodies and related components in the metal parts manufacturing process. When used in projectile bodies, low-carbon steels are furnished as billets or bars for the cold extrusion (CE) process or the hot cup-cold draw (HC-CD) process. In these applications the desired mechanical properties are obtained by cold-working of the steel. Deoxidized or killed steels are specified in these methods with the amount of silicon under 0.20%, whereas generous amounts of aluminum are used in the deoxidation processes to produce consistently fine grain material. Although the standard maximum percentages of 0.40% phosphorous and 0.050% sulfur are allowable for these steels, material for these applications is usually delivered with much lower percentages of these impurities.

The mechanical properties given in Table 3-2 are guides to the minimum properties that maybe expected in the various grades of steel in the hot-rolled condition. However, these properties may vary based on the size of the rolled product, variations in residual elements, and compositions of individual heats of the same grade (Ref. 2).

In the cold extrusion method of manufacture, low mechanical properties in the raw material are desirable because the initial metalworking operations are performed at room temperature. The extrusion operations become very difficult if the yield and tensile strengths are high. Therefore, the process pieces arc annealed immediately after some of the major codd-working operations to permit additional deformation by odd-work. The final extrusion, or draw, operations, which determine final physical properties, are followed by a single stress relief treatment to attain mechanical properties and to relieve

TABLE 3-2. PROPERTIES OF SELECTED LOW-CARBON STEELS, HOT-ROLLED CONDITION, MINIMUM VALUES

AISI No.	Yield Strength		Tensile Strength		Elongation	Reduction	Hardness
	MPa	ksi	MPa	ksi	%	%	*BHN
1010	179	26	324	47	l 28	50	95
1015	186	27	345	50	28	50	101
1016	207	30	379	55	25	50	111
1018	221	32	400	58	25	50	116
1020	207	30	379	55	25	20	111
1022	234	34	427	62	23	47	121

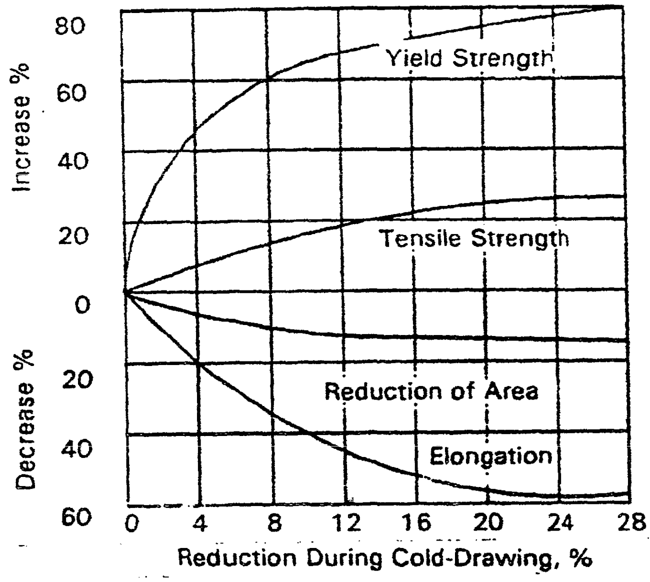
* Brinell Hardness Number

internal stresses resulting from the previous cold deformation. Projectiles manufactured by cold extrusion usually have requirements in the range of 414 to 552 MPa (60 to 80 ksi) minimum yield strength and 12 to 15% minimum elongation.

Little or no machining of the surface of the item takes place in this process; therefore, the surface of the raw material must be smooth and defect free to produce an acceptable finished projectile surface.

The hot cup-cold draw method of manufacture usually employs billets or bars, the composition of which is in the area of AISI 1018 or AISI 1020. These steels are purchased as special-quality carbon steel bars under American Society for Testing and Materials (ASTM) A576 (Ref. 3) or under military specification MIL-S-10520 (Ref. 4). The steels are silicon killed with enough aluminum added to assure a fine grain steel Adding aluminum is desirable for projectiles because it improves the notch toughness of the steel. Mechanical properties in the as-supplied raw material are not critical because the steel is heated to forge the cup. The cup is control cooled to maintain the proper pearlitic structure for subsequent extrusion or cold-drawing. The exterior of the cup is completely machined to provide art excellent surface to withstand the forthcoming cold metalworking operations. Process anneals are applied as appropriate in later operations. Projectiles made by the hot cup-cold draw process range from approximately 448 to 552 MPa(65 to 80 ksi) and have 15% elongation. Table 3-3 displays usage data for low-carbon steel and applicable specifications.

The effect of cold-working steel raises yield and tensile strengths; however, the percentage increase in yield strength is greater than that for tensile strength. Also the reduction of area and elongation decrease at the same time. See Fig. 3-2 for the effect of cold-drawing on the tensile properties of steel bars.



From *Metals Handbook, Volume I 8th Edition, Properties and Selection of Metals,* Published by American Society for Metals, 1977.

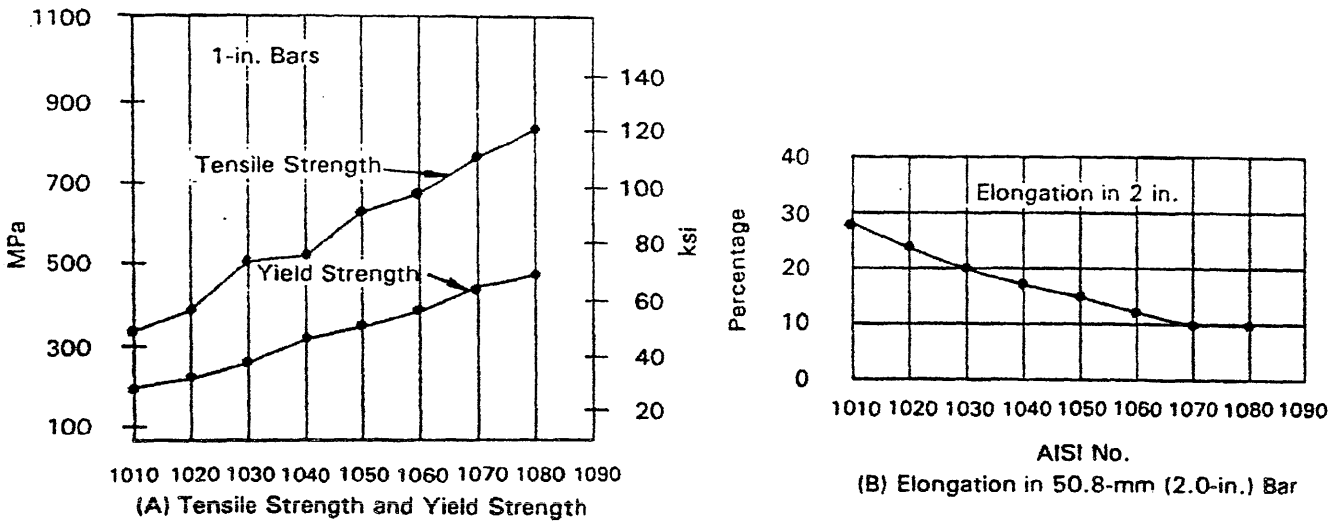
Figure 3-2. Effect of Cold-Work on Tensile Properties of Steel (Ref. 2)

3-3.1.3 Medium- and High-Carbon Steels

Medium-carbon steels are normally compositions that contain 0.25 to 0.55% carbon. These steels are suitable for applications in the as-roiled or the quenched and tempered condition. The as-rolled mechanical properties are in the range of 241 to 414 MPa (35 to 60 ksi) yield strength and 414 to 689 MPa (60 to 100 ksi) tensile strength. These steels are excellent for forging applications. Minimum tensile properties to be expected in hot-rolled steel bars are shown in Fig. 3-3. The ability to cold-work and form these steels becomes increasingly marginal as the carbon content increases. At the lower carbon levels and with the proper thermal treatments, cold-work can be ac-

TABLE 3-3. USAGE DATA FOR LOW-CARBON STEELS

Specification	Title	Uses
ASTM A108	Steel Bars, Carbon, Cold-Finished, Standard Quality	Components machined from bar stock
ASTM A109	Steel Strip, Carbon, Cold-Rolled, Standard Specification	Deep drawn cartridge cases
ASTM A576	Steel Bars, Carbon, Hot-Wrought, Special-Quality	Special-quality bar for forging, heat treating, cold-drawing and machining
MIL-S-10520	Steel, Forging for Projectile Stock	Projectiles made by hot cup-cold draw process
MIL-S-11310	Steel Bars, Carbon, Hot-Rolled for Cold Shaping Including Cold Extrusion	projectiles made by cold extrusion process



From *Metals Handbook, Volume I 8th Edition, Properties and Selection of Metals,* Published by American Society for Metals, 1977.

Figure 3-3. Minimum Mechanical Properties of Hot-Rolled Carbon Steel Bars (Ref. 2)

complished. One notable application has been deep-drawn steel cartridge cases.

High-carbon steels are usually identified as steels with a carbon content over 0.55%. Although material with any amount of carbon up to approximately 1.70% falls within the definition of steel, the compositions used for ammunition metal parts normally contain well below l% carbon. The hot-forging characteristics of these steels are excellent, but the machining properties start to diminish as the carbon increases. Therefore, the cooling rate of the forging should be retarded to produce a softer microstructure and improve machinability. The response of these steels to hardening and tempering is very good although they harden throughout their cross sections only in thin sections. The structures provided by oil quenching and tempering are completely satisfactory to meet mechanical property requirements up to approximately 621 MPa (90 ksi) yield strength. The chemistry of both medium- and high-carbon steels requires specified carbon rind manganese ranges and maximum limits of 0.040% phosphorus and 0.050% sulfur. Fine grain killed steels are specified for ammunition applications, usually with 0.15 to 0.30% silicon content. The steels are very uniform in chemical composition, which makes them ideal for forging, machining, and heat treating applications, but they always contain surface imperfections to some degree. Steels ordered for ammunition use are conditioned at the steel mills sometime during the rolling process to remove surface defects such as laps or seams. The conditioning methods employed usually consist of hot scarfing, chipping, or grinding, but small amounts of surface defects invariably remain. To insure complete removal of all surface defects on a machined item a machining allowance should be considered during process planning. If machined parts are produced from high-carbon round bar stock, annealing is often specified to improve machinability.

Medium- and high-carbon steels are the raw material primarily used for projectile bodies. The steel is purchased as round-cornered square stock, usually in billet or bloom sizes. The applicable specification is ASTM A711 (Ref. 5).

The steel is ordered in multiples of a specified length equivalent to the amount of steel used to make one forging and up to a maximum length. For example, a producer may order 102-mm (4-in.) round-cornered square in multiples of 305-mm (12-in.) in 7.0-m (20-ft) lengths. In this instance, 20 mults for forging would be obtained from each specified 7.0-m (20-ft) length. For more information see Chapter 4 under billet separation. Table 3-4 displays use data for medium- and high-carbon steels and applicable specifications.

TABLE 3-4. USAGE DATA FOR MEDIUM- AND HIGH-CARBON STEELS

Specification	Title	Uses
ASTM A576	*Steel Bars, Carbon, Hot-Wrought, Special-Quality*	Forgings for projectile sizes less than 105 mm
ASTM A711	*Steel Blooms, Carbon and Alloy Billets, and Slabs for Forging*	Forgings for projectiles over 105 mm
MIL-S-3289	*Steel, Plate, and Disc, Carbon, Forging Quality*	Spheroidized plate and disc for deepdrawn cartridge cases

3-3.2 ALLOY STEELS

3-3.2.1 Definition

Alloy steel, as specified by the AISI, is defined as follows:

"Steel is considered to be alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: manganese, 1.65%; silicon, 0.60%; copper, 0.60%; or in which a definite range or a definite minimum quantity of any of the following elements is specified or required within the limits of the recognized field of constructional alloy steels aluminum, boron, or chromium Up to 3.99%; cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium, or any other alloying element added to obtain a desired alloying effect." (Ref. 6).

Although the AISI definition is most widely accepted, less formal definitions are sometimes expressed. One such definition states that an alloy steel is a type of steel to which one or more alloying elements have been added to give it special properties that cannot be obtained in carbon steel.

3-3.2.2 Alloying Elements

Alloy steels are used when more strength, ductility, and/or toughness are required for an application than carbon steel can provide. The alloying elements most universally used for projectiles and projectile components are manganese (Mn), chromium (Cr), nickel (Ni), silicon (Si), molybdenum (Mo), and vanadiun(V). The functions of these alloying elements are

1. *Manganese*. In addition to the advantages of adding manganese to carbon steel noted previously, manganese considerably decreases the critical cooling rate. Therefore, when quenching manganese alloy steels in the heat treat cycle, it substantially contributes to deep hardening of the steel. It also lowers the eutectoid percentage of carbon and the critical temperatures upon heating and cooling. Thus it reduces the temperatures required for hardening. Manganese is soluble in ferrite and austenite, in addition to forming a carbide. It qualifies as an alloy addition only when the amount Specified exceeds 1.65%.

2. *Chromium*. Chromium is a strong former of carbides. With carbon and iron it forms a complex series of carbides and compounds of chromium and iron. It raises the upper critical temperature at which transformation to austenite (face-centered cubic iron) is complete. Complex chromium-iron carbides go into solution in austenite slowly. Usually a longer heating time is required before hardening. If the carbides are properly dissolved, greater depth of hardening on quenching is obtained because the critical cooling rate is decreased. Chromium additives lower the eutectoid carbon content. It also forms a solid solution with ferrite and austenite. Two of the most important properties of chromium steels are wear resistance and cutting ability, which can be traced to the high hardness of chromium carbides. It also contributes to maintaining strength in steels at elevated temperatures.

3. *Nickel.* When nickel is added to steel, it is effective as a ferrite strengthener and is completely soluble in ferrite and austenite. However, because nickel forms no carbides in steel, no problems result in getting the element into solution when heating. It lowers the critical temperatures for heating and cooling and extends the temperature range for effective heat treatment. Nickel also lowers the critical cooling rate for quenching to provide effective and easy heat treatment. It increases the strength and toughness properties as well as the low-temperature impact properties of steel.

4. *Molybdenum*. Molybdenum, like manganese and chromium, significantly increases the hardening properties of steel. It raises the upper critical temperature on heating for austenite formation and contributes to close control of hardening when required. Molybdenum substantially increases the high-temperature tensile and creep strength of steels. Also it prevents temper embrittlement, especially when added in amounts above 0.15%.

5. *Silicon.* Silicon is soluble in ferrite and increases the strength of the ferrite without resulting in a significant loss in ductility. It does not form carbides in steel. Silicon additions raise the critical temperature to form austenite, increase hardening rates, and strengthen low-alloy steels. If it is added in amounts of approximately 2% (a spring steel composition), machinability becomes poor and resistance to decarburization is low. Silicon is considered an alloy in percentages above 0.60%. The use of silicon as a deoxidizing agent is covered in par. 3-3.1.1.

6. *Vanadium.* Vanadium additions to steel refine the grain and inhibit grain growth in heat treatment. The strength and toughness improve after quenching and tempering. It is soluble in ferrite and moderately hardens the ferrite. Vanadium is a very strong former of carbides and higher hardening temperatures are often used to dissolve these carbides. This results in an increase in hardening (Ref. 7).

3-3.2.3 Properties

Alloy steels are customarily ordered to specified ranges for carbon and one or more alloying elements. Phosphorus is limited to 0.035% maximum and sulfur to 0.04096 maximum in steels made by the basic oxygen process, whereas the limit is 0.025% for each of these impurities in electric furnace grades. Manganese and silicon are ordered to ranges even when their percentages fall below alloy steel minimums. Most of these steels are made to fine grain practice with a 0.15 to 0.30% silicon content.

Examples of AISI-SAE methods used in designating some of the types of alloy steels are shown in Table 3-5.

TABLE 3-5. ALLOY STEEL DESIGNATI0NS

Type of Alloy Steel	AISI-SAE Numerals
Manganese	13XX
Molybdenum	40XX, 44XX
Chromium-Molybdenum	41XX
Nickel-0Chromium-Molybdenum	43XX, 47XX, 81XX, 86XX, 87XX, 88XX, 93XX, 94XX
Chromium	50XX, 51XX, 52XX
Chromium-Vanadium	61XX
Silicon-Maganese	92XX

The steels in Table 3-5 are among the most commonly specified types of alloy stee. The first two digits of the numerical designation identify the major alloying elements in the stee, and the remaining digits indicate the carbon content in humndredthes of a percent. Specified ranges are given for each alloying element in each composition listed.

Alloy steels are specified when mechanical property requirements of 689 MPa (100 ksi) minimum yield strength and above are required. They are specified principally as shell bodies on various types of projectiles and spikes for high-explosive antitank (HEAT) rounds. When used as projectile bodies, alloy steel blooms, billets, and bars are the raw materials for forging. Spikes for HEAT rounds are usually forged or extruded from alloy steel bar stock. Table 3-6 covers the predominant use data for alloy steal and the most widely used specifications for projectile metal parts. When heat treated, alloy steels are required to be oil quenched and tempered for projectile metal parts applications. The mechanical properties obtained are usually in the range of 689 to 1103 MPa (100 ksi to 160 ksi) yield strength depending on individual requirements and the specific steel composition employed. The forging characteristics of these steels are excellent.

3-3.3 IllGH-FRAGMENTATION STEELS

3-3.3.1 Definition

High-fragmentation steels are steels that, by structure and properties and when exposed to explosive forces, provide the proper fragmentation to do maximum damage against a given target. The applications may be antimateriel or antipersonnel.

3-3.3.2 Types of High-Fragmentation Steels

Numerous carbon and alloy steels, mostly those of medium- to high-carbon levels, were investigated. Such types as tool steels, bearing steels, standard carbon steels, high-phosphorus standard alloy steels, and special alloys were tested. Parameters including standard heat treatments, intercritical heat treatments, cold-working with and without stress relief anneals, warm-working, and hot-working were investigated. The initial work was accomplished with thin-walled cylinders and was pit tested by filling them with explosive, initiating them in a pit filled with sand, and sizing and counting the fragments. The most promising candidates were them manufactured into projectile configurations and pit tested. Comparisons were made with the results achieved with pearlitic malleable iron, the original high-fragmentation material. The few successful candidates were panel tested so velocity and distribution patterns could be determined for a lethality evaluation. Those approved after evaluation over a period of years were AISI 52100 (a bearing steel), AISI 1340 (a manganese alloy steel), and HF-1 (a special high-carbon, manganese-silicon alloy steel). These three steels have been used to manufacture projectiles on production lines and were approved in the chronological order given.

3-3.3.3 Properties

The chemical compositions of these steels are given in Table 3-7.

The bearing steel, 52100, was used in the manufacture of 152-mm M409 multipurpose projectiles. A number of problems, which include critical temperature controls too restrictive for production, occurred in this application, therefore, 52100 is no longer considered a choice for projectiles.

The manganese alloy steel, 1340, is perhaps the most versatile of the high-fragmentation steels. It has been used in warm-working, hot cup-cold draw, and hot forge-heat treat applications. Also it has been used with mechanical properties of 552 MPa (80 ksi) to over 965 MPa(140 ksi).

TABLE 3-6. USAGE DATA FOR ALLOY STEEL

Specification	Title	Uses
ASTM A322	Steel Bars, Alloy, Standard Grades	Forgings for mortar shell; spikes for HEAT projectiles
ASTM A711	Steel Alloy and Carbon Blooms, Billets, and Slabs for Forging	Forgings for large projectiles with high mechanical properties
MIL-S-50783 (MU)	Steel, Alloy, Special Purpose for Ammunition Components (HF-1)	Forgings for high-fragmenting projectiles

TABLE 3-7. COMPOSITION OF HIGH-FRAGMENTATION STEELS

Steels	C, %	Mn, %	P, %	S, %	Si, %	Cr, %
52100	0.95-1.10	0.25-0.45	0.025	0.025	0.15-0.30	1.30-1.60
1340	0.38-0.43	1.60-1.90	0.035	0.040	0.15-0.30	—
HF-1	1.00-1.15	1.60-1.90	0.035	0.040	0.70-1.00	—

The applicable specifications are ASTM A711 for billets and bloom and ASTM A322 for bars.

HF-1 steel is currently used to produce the 155-mm M549, rocket-assisted projectile (RAP); 155-mm HE M795; and 8-in. M650, RAP, projectiles, and it is being considered for other fragmentation requirements. It is a nonstandard steel and is the only high-fragmentation material with an individual specification: a limited co-ordination military specification, MIL-S-50783, entitled Steel Alloy, Special-Purpose for Ammunition Components (HF-l). The mechanical properties required are 965 MPa (140 ksi) yield strength and 5% minimum elongation. The M549 RAP and its peculiarities are discussed in Chapter 5.

3-3.4 CAST IRONS

Cast irons are manufactured by melting pig iron in a cupola. This melting refines the pig iron by reducing the carbon content and some of the impurities. White cast iron—the result of rapid cooling of the casting—is very hard and brittle and produces white crystalline fractures. White east iron is formed when the cooling rate allows the carbon to be combined with iron in the form of massive carbides and no flake graphite is formed.

Gray cast iron is the result of cooling the casting slowly to allow some of the carbon to separate out of the solid solution to form flakes of graphite. When this product is fractured, the graphite flakes are exposed and the surface has a gray appearance. Neither white nor gray iron, because of a brittle nature, are used in ammunition metal parts.

3-3.4.1 Pearlitic Mallable Iron

Pearlitic malleable iron is an iron-silicon-carbon alloy. Because it is cast as white iron and heat treated under controlled conditions, part of the carbon is present as nodules of graphite and the remainder is intentionally retained in the combined form. The combined carbon appears as spheroids, pearlitic lamellae, or tempered martensitic products. Pearlitic malleable iron with a typical yield strength of 372 MPa (54 ksi) and an elongation of 7% was used primarily as shell bodies in the manufacture of mortar ammunition. The material was used because of its good mechanical properties and its superior fragmentation characteristics. The manufacture of pearlitic malleable iron is the most closely controlled casting process in the industry and as such produces a quality product consistent with the requirements of mortar ammunition. However, currently no mortar ammunition is being made from pearlitic malleable iron because there are severe limitations on production capacity and because this method of manufacture is not economically competitive with other methods.

3-3.4.2 Ductile or Nodular iron

Ductile or nodular iron is produced by a process that transforms the graphite flakes usually found in gray iron to a nodular or spheroidal form of graphite. The ductile iron is obtained by adding small amounts of magnesium to the molten cast iron. The nodules are formed during the solidification process; therefore, ductile iron does not require the extensive heat treatment of malleable iron. This product is much more ductile than gray iron, and it has increased impact properties and is superior in mechanical properties to pearlitic malleable iron. It has been used for 2.75-in. rocket bodies because the material is not subjected to high setback forces.

3-4 NONFERROUS METALS

3-4.1 DEFINITION

Nonferrous metals are those that contain iron only as a minor alloying element.

3-4.2 LIGHT METAL ALLOYS

The light metal alloys presently used in the components addressed in this handbook are either aluminum alloys or magnesium alloys.

3-4.2.1 Methods of Manufacture

3-4.2.1.1 Aluminum

Aluminum—one of the most abundant metals on earth-is produced from bauxite ore, which contains from 32 to 55% aluminum (aluminum oxide).

The most popular production method is to crush the bauxite to a fine powder and mix it with lime, soda ash, and hot water. This slurry is then fed to a digester where it is mixed with caustic soda, which dissolves the alumina and leaves the impurities as solids. Processing through a series of filters and dryers captures pure alumina powder.

The pure alumina is dissolved in a bath of molten cryolite solution, which forms the electrolyte for a powerful electrolytic cell. The molten pure aluminum is drawn off the cathode base of the cell and cast into molded shapes or ingots.

The molds or ingots are then heated and rolled or extruded into plate, sheet, strips, foil, tubing, rods, bars, or extruded shapes.

3-4.2.1.2 Magnesium

Like aluminum, magnesium is also produced by an electrolytic process, but a much simpler one than that for aluminum because magnesium is extracted from seawater. Lime is mixed with seawater, and the magnesium forms magnesium hydroxide. Subsequent additions of hydrochloric acid convert it to magnesium chloride, which, when added to a molten mixture of sodium and calcium chloride in an electrolytic cell, forms pure magnesium. The molten magnesium is poured into ingots or molds in a manner similar to that for aluminum, and subsequent processing makes magnesium available as castings, forgings, extruded shapes, tubing, bar, wire, and rod.

3-42.2 Properties

3-4.2.2.1 Aluminum

Aluminum is available as rolled or extruded plate, sheet, strips, foil, tubing, rods, bars, or other shapes. A multitude of aluminum and aluminum alloys containing Mg, Zn, Cu, Mn, Si, Ni, or Cr are available commercially and are included in ASTM B211 (rolled products) or ASTM B221 (extruded products) (Refs. 8 and 9). Wrought aluminum alloys are designated by a four-digit numbering system, the first digit of which indicates the main alloying element. 1XXX represents pure aluminum (99.00% or greater); 2XXX, copper, 3XXX, manganese: 4XXX, silicon; 5XXX, magnesium; 6XXX, magnesium and silicon; and 7XXX, zinc (Ref. 10). These alloys are available in various temper designations as shown in Table 3-8 and give the designer a wide range of choice. Table 3-9 shows a considerable range of mechanical properties available for typical alloys used for projectile metal parts (Ref-11).

3-4.2.2.2 Magnesium

In its metallic state magnesium is one of the lightest commercial metals available. Additions of aluminum or zinc give added strength to pure magnesium; manganese improves corrosion resistance, and tin or zirconium imparts fine grain (Ref. 12).

TABLE 3-8
ALUMINUM TEMPER DESIGNATIONS

Symbol	Condition
F	As fabricated
O	Annealed
H	Strain hardened
W	Solution heat treated (unstable)
T	Heat treated to produce stable tempers other than F, O, or H

The symbols are representative of the basic tempers. Where required, they are followed by one or more digits designating specific sequences of treatments, i.e., 7075-T6 reflects heat-treated and artifically aged solution.

3-4.2.3 Applications and Constraints

3-4.2.3.1 Aluminum

The principal applications for aluminum in the projectile metal parts area are as fins and booms for mortar rounds, as fins and sabots on fin-stabilized tank rounds, and as ogives and bases for carrier projectiles.

Aluminum has been selected for these applications mainly because of its light weight, high strength-to-weight ratio, and corrosion resistance properties. Thus the designer has greater latitude in concentrating on payloads and maintaining proper ballistic properties.

Alloy selection varies with the item design. For example, the 81-mm fin requires an alloy that can be selected from ASTM B221 (Ref. 9). This specification stipulates a minimum yield strength of 241 MPa (35 ksi) and 8% elongation, which give the manufacturer some latitude in the alloy he chooses.

In most cases, however, especially when the higher mechanical properties are essential for satisfactory performance, the actual alloy, temper, and minimum mechanical properties are specified by the designer. Deviation from these requirements cannot be made without a thorough retest of the performance and safety aspects of the item. An example of alloy designation for an item would be Aluminum Alloy 7075-T651, ASTM B221, with a minimum yield strength of 558MPa(81 ksi) for the sabot material used for the 120-mm M833 projectile.

TABLE 3-9. MECHANICAL PROPERTIES OF TYPICAL ALUMINUM ALLOYS USED IN PROJECTILE METAL PARTS (Ref. 11)

Alloy	Composition	Tensile Strength		Yield Strength		Elongation
(All Tempers)		MPa	ksi	MPa	ksi	%
1100	99.0 Al, 0.12 Cu	90-165	13-24	34-152	5-22	45-15
2014	93.5 Al, 0.8 Si, 4.4 Cu. 0.8 Mn, 0.5 Mg	186-483	27-70	97-414	14-60	18-13
6061	97.9 Al, 0.6 Si, 0.30 Cu, 1.0 Mg, 0.2 Cr	124-310	18-45	55-276	840	30-17
7075	90.0 Al, 1.6 Cu, 2.5 Mg, 0.23 Cr, 5.6 Zn	262-572	38-83	103-503	15-73	17-11

When specifying forgings, recognition should be given to the difference in mechanical properties in a longitudinal or transverse direction as well as the effect of the amount of deformation on the material with the longitudinal properties being directly improved with the amount of work.

In some applications the standard procedure of specifying strength and ductility requirements may not be adequate to assure acceptable items. It may also be necessary to institute process or metallurgical controls. The amount of deformation involved in wrought or forged items can be critical to the structural strength or corrosion resistance properties of the higher strength alloys, which have high percentages of alloying elements (Refs. 11 and 13). A recent problem with structural strength that developed in the ogives of the 155-mm M483 projectile was resolved by requiring the forgings to be made from extrusions reduced from 0.36-m (14-in.), rather than from 0.18-m (7-in.) diameter castings. The effect of the additional work done by increasing the reduction and breaking up semicontinuous interdendritic brittle constituents at grain boundaries is evident in the microstructures shown in Fig. 3-4. Note the considerable amount of semicontinuous insoluble constituents in the failed part shown in Fig. 3-4(A); these constituents are indicative of the extrusions made with limited reduction The microstructure of the more worked extrusion shown in Fig. 3-4(B) shows only scattered longitudinal stringers and a considerable amount of recrystallization.

Special treatment may be required for aluminum items to prevent deterioration in spite of the excellent corrosion resistance of aluminum to acidic conditions. Most items are specified with an anodized finish, which gives further protection from environmental exposure.

Anodizing is the conversion of the aluminum surface to aluminum oxide while the part is the anode in an electrolytic cell. The process consists of vapor decreasing, alkaline cleaning, and anodizing in sulfuric acid with water rinses between operations. An optional water seal may be applied at the conclusion of the process. Aluminum fins for tank rounds are given a special hard coat, anodized finish to prevent their ablating due to the high temperatures imparted by the burning propellant and the air friction caused by the high-velocity launch.

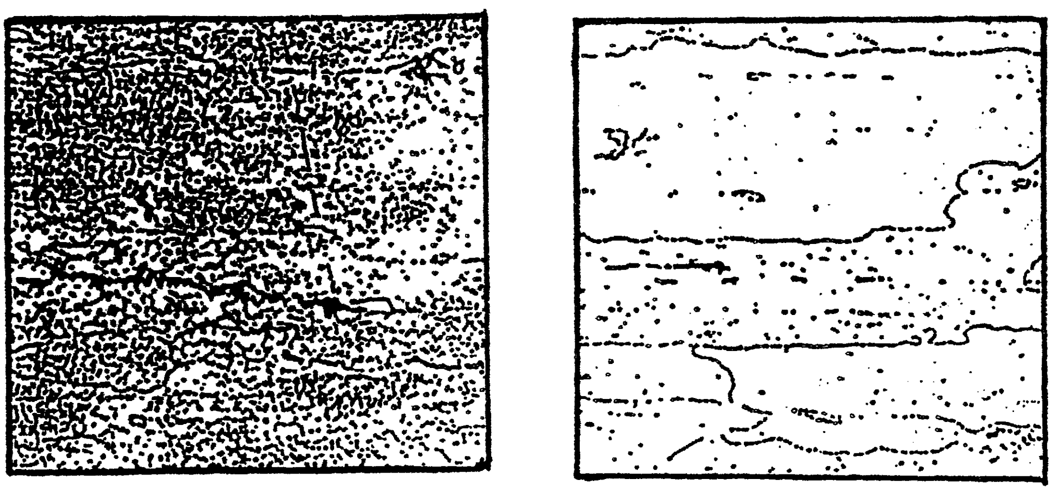
3-4.2.3.2 Magnesium

Applications for magnesium in projectiles have been limited to a sabot structure for the 105-mm M392 family of armor-piercing discarding sabot (APDS) rounds. The main attribute of magnesium for use as the sabot is its light weight. Extruded magnesium bars or rods have limited mechanical properties with a range of 200-331 MPa (29-48 ksi) tensile strength and yield strengths of 110-262 MPa (16-38 ksi.

A limiting factor of its use is that it is pyrophoric and requires extreme precautions during machining operations and the handling of chips.

3-4.3 HEAVY METAL ALLOYS

Heavy metal alloys are used in ammunition manufacture as penetrator components to defeat armor. In addition to a high density as a prerequisite, these alloys must have additional mechanical properties to survive gun launch at very high velocities and remain intact during the initial phases of penetration. The two alloy systems in use are tungsten and uranium. They are unique to metal parts manufacture in that, unlike other materials that are purchased as alloys in a billet, bar, or rod form,



(A) Extruded With Limited Reduction (35%)

(B) Extruded With Proper Reduction (95%)

Figure 3-4. Comparative Microstructure of Aluminum Ogives (Ref. 10)

the heavy metal alloys are purchased in a purified chemical form and processed into a finished product completely within the metal parts facility.

3-4.3.1 Methods of Manufacture and Properties

3-4.3.1.1 Tungsten Alloys

Tungsten metal has a melting point of approximately 33 16°C (6000° F), which is far in excess of the approximately 1927° C (3500°F) capabilities of conventional melting techniques. Powder metallurgy techniques therefore must be used wherein powders of tungsten and alloying elements are blended and compacted to an approximate final shape and heated to 1482°C (2700°F) (sintered). The powder particles are consolidated by solid-state diffusion to achieve a usable solid component.

To obtain tungsten powder, the purified chemical ammonium paratungstate (APT) is heated in air at about 371°C (700°F), at which time the ammonia is driven off and the oxide remains. Hydrogen gas is used to reduce the oxide to elemental powder. Particle size and distribution, which are important in subsequent processing and in achieving a find density approaching theoretical, are primarily controlled during this operation by the flow rate of hydrogen. Trays of APT are stoked into a tube-type furnace through which hydrogen gas flows in a counter direction. Furnace temperature is approximately 1093°C (2000°F).

Once in the powder form, the tungsten is blended with other elemental powders such as nickel, copper, iron, and cobalt. After blending, the powders are compacted by pouring them into rubber molds of the approximate shape of the finished parts and putting the molds into a chamber filled with water and pressurizing the chamber to approximately 69 MPa (10 ksi). This operation provides a shape that can be handled and even subjected to machining operations prior to sintering.

For sintering to achieve density, final configuration, and mechanical properties, parts are loaded on trays and stoked through a tube-type furnace having a hydrogen atmosphere. The hydrogen atmosphere is important because it reduces any oxides that may remain on the individual powder grains from processing and storage. The sintering operation deviates from a conventional powder metal process in that the sintering operation occurs above the melting point of the alloying powders and is called liquid phase sintering. To retain the shape of the compact, the furnace is zoned into different temperatures to allow solid-state consolidation of the tungsten powders and then the temperature is elevated to melt the alloy phase. After sintering, the result is a composite of tungsten grains surrounded by a matrix of alloy metal.

To achieve a final shape, the part is conventionally machined. Typical mechanical properties are 552 MPa (80 ksi) yield strength and 8% elongation.

3-4.3.1.2 Depleted Uranium

Depleted uranium is a by-product of the uranium enrichment process that separates the fissionable U235 isotope from the nonfissionable U238 isotope. The two isotopes occur in nature in a ratio of 99.3% U238 and 0.7% U235. Because of its high density, approximately 19 g/cm^3 compared to 7.87 g/cm^3 for steel, U238 is of little value as a structural material. It is however suitable for penetrator applications.

Depleted uranium (DU) is received from the Department of Energy as uranium hexafluoride, UF_6, and must be converted to uranium tetrafluoride, UF_4, by reaction with hydrogen gas. Penetrator production facilities have the capability to start with UF_4. To convert UF_4 to uranium metal, it is blended with magnesium metal machining chips, enclosed in a reaction bomb, and heated to a temperature of approximately 816°C (1500°F). Once the entire charge has reached this temperature, an exothermic reaction occurs that elevates the temperature to 1649°C (3000°F) and the magnesium reacts with the UF_4 to produce magnesium fluoride and uranium metal.

For penetrator applications uranium is alloyed with 0.75% titanium; this alloying permits the uranium to be hardened through heat treatment. Due to its chemical reactivity, it is alloyed in a vacuum furnace by melting the uranium metal at approximately 1316°C (2400°F). A plug in the bottom of the crucible holding the molten metal is knocked out, and the metal flows into ingot molds directly underneath the crucible within the furnace. Once the furnace has been cooled and the ingots have been solidified, they are reheated to 649°C (1200°F) and either rolled or extruded into rods of 29.2 mm (1.15 in.) in diameter. The rod is then cut into penetrator blank lengths and subjected to heat treatment (solutionize, quench, and age) to achieve final mechanical properties of 758 MPa(110 ksi) yield strength, 15% elongation, and a Rockwell hardness of C40-45. The part is then machined to final configuration.

3-4.3.2 Applications and Constraints

The high densities of DU and tungsten make these materials unique for penetrators but render them objectionable for most other applications. In the manufacture of penetrators a ballistic plate penetration requirement exists that the projectile manufacturer must meet. Chemical composition requirements for tungsten alloys are not rigid, so the inclusion of one or more additional elements can be tolerated. The ballistic requirement overrides tight chemical composition requirements.

3-4.4 COPPER ALLOYS

3-4.4.1 Methods of Manufacture

Copper, like aluminum, is produced by using an electrolytic process for the final refinement; however, prior steps differ from the aluminum process. Flotation tables sort copper ore from other material; the aluminum process uses a chemical dissolving process.

The ore, crushed by ball milling in a water solution, forms a slurry, which is then passed to a flotation cell where the copper powder becomes suspended in the oil and water froth. The suspended copper is floated out of the cell while the other materials, called tailings, settle to the bottom and are discarded. At this stage the concentrated copper ore is approximately 25% pure.

The copper concentrate is then placed in a reverberating furnace in which the mass becomes molten and inclusions such as silicon, iron, and lime are floated above the copper as a slag and are drawn off and discarded. The copper is now known as copper matte and consists of a CuS/FeS mixture containing approximately 50% copper.

The copper matte is then placed in a converter that converts the FeS to iron oxide. The iron oxide combines with the limestone and forms a slag, the CuS is reduced to copper. This is called blister copper because during cooling, escaping gases form blisters on the surface. Blister copper anodes are approximately 98.5% pure copper.

The copper anodes are then placed in an electrolytic cell and are plated onto thin sheet, pure copper cathodes. The resultant heavy cathodes contain approximately 99.95% copper.

This pure copper is remelted, alloying elements are added if desired, and it is cast into slabs or ingots for further processing by milling or extrusion into plate, sheet, strips, foil, rod, tubing, or extruded shapes.

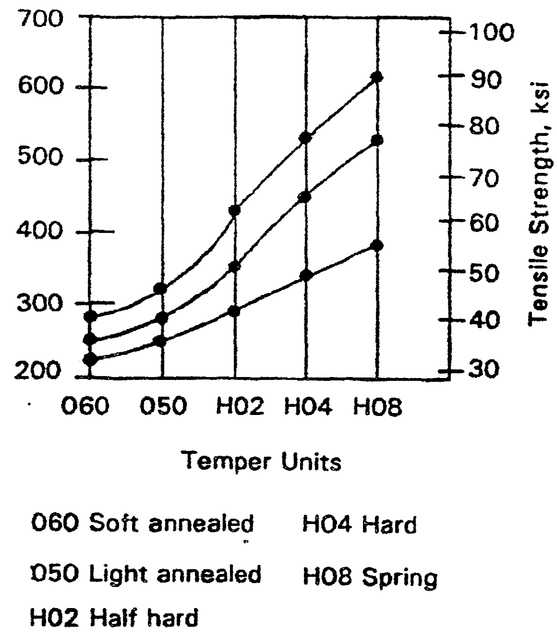
3-4.4.2 Properties

The most common copper alloys are those that incorporate compatible elements to form solid solutions. These include the brasses (Zn), bronzes (Sri), aluminum bronzes (Al), silicon bronzes (Si), and copper nickels or nickel silvers (Ni). These alloys all form alpha phase alloys and as such are readily workable and hardenable by cold-working. The brittleness usually associated with second phases or compounds is not encountered. The effects of cold-working are shown in Fig. 3-5 for representative commercial copper and copper zinc alloys. The bulk of copper products are of this nature and cannot be hardened by heat treatments. Special alloys containing iron (Fe), beryllium (Be), zirconium (Zr), or chromium (Cr) are heat treatable, but none are specified for the projectile components covered in this handbook.

A wide range of mechanical properties are available to the designer in his selection of copper and copper alloys as shown in Table 3-10.

3-4.4.3 Application and Constraints

Copper and copper alloys are used in the projectile manufacturing process principally as rotating bands or



From *Metals Handbook, Volume II, 9th Edition, Properties and Selection: Nonferrous Alloys and Pure Meals,* Published by American Society for Metals, 1977.

Figure 3-5. Effect of Cold-Work on Copper and Copper-Zinc Alloys (Ref. 11)

cones for HEAT rounds. When used as applied bands, they are furnished as band blanks made from extruded tubing or are centrifically cast. When used as welded overlay bands, the material is supplied in wire form and deposited on the projectile by a welding machine. Cones ‘ for HEAT rounds are manufactured from circular blanks made from rolled sheet.

ASTM B152 (Ref. 14) is the specification for material purchased for the manufacture of cones. Details on manufacture are described in Chapter 7.

Welding wire to specification MIL-E-45829 (Ref. 15) is used to apply the welded overlay rotating bands to thin-walled projectiles. One application described in this handbook is for the 155-mm M483 projectile. Details are given in Chapters 4 and 6.

Rotating bands on heavy-walled shells are assembled to the projectile body by pressing rings made from tubing to specification MIL-B-20292 (Ref.16) into precut grooves in the projectile body. Application of pressed on bands to the 155-mm M107 projectile is explained in Chapter 5.

3-5 Nonmetallic Materials

Some of the latest projectile designs incorporate nonmetallic components in the form of seals, obturators, slip and rotating bands, and as weight-saving devices.

Materials used to make these forms are commercially available and described in the chapters on representative

TABLE 3-10. REPRESENTATIVE MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (Ref. 11)

Alloy		Tensile Strength		Yieid Strength		Elongation
		MPa	ksi	M Pa	k s i	%
C10100	annealed	221	32	69	10	45
(Copper)	H04	345	50	310	45	6
C21000	annealed	234	34	69	10	45
(Gilding Metal)	H04	386	56	345	50	5
C24000	annealed	331	48	117	17	47
(Low Brass)	H04	510	74	407	59	7
C26000	annealed	338	49	117	17	57
(Cartridge Brass)	H04	524	76	434	63	8
C40500	annealed	283	41	83	12	49
(Penny Bronze)	H04	441	64	379	55	10
C41900	annealed	338	49	131	19	42
(Tin-Brass)	H04	565	82	510	74	4
C50500	annealed	276	40	76	11	47
(Phosphor-Bronze)	H04	421	61	414	60	5
C61400	annealed	552	80	276	40	40
(Aluminum-Bronze)	H04	586	85	400	58	35
C65500	annealed	414	60	172	25	60
(Silicon-Bronze)	H04	648	94	400	58	8

From *Metals Handbook, Volume II 9th Edition, Properties and Selection: Nonferrous Alloys and Pure Metals,* Published by American Society for Metals, 1979.

items. Some examples are

1. Some carrier projectiles use glass-filled epoxy wraps to fill an undercut on the body to develop the required hoop strength and yet reduce body weight for proper ballistic flight. This is described in Chapter 6.

2. The high-explosive antitank rounds use nylon slip bands to provide a gas seal; they reduce the rate of spin of the projectile in a rifled tube. This is described in Chapter 7.

3. The kinetic energy (KE) tank rounds also employ slip bands and have a molded rubber seal vulcanized to the base end to prevent propellant gas leakage into the projectile assembly. This is described in Chapter 8.

4. Some mortar rounds employ plastic obturators to seal the tube during propulsion. This is described in Chapter 9.

5. The cartridge case base for the 120-mm tank ammunition combustible cartridge case has a rubber sealing lip vulcanized to the top edge of the case base to act as an obturator. This is described in Chapter 10.

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CHAPTER 4
MANUFACTURING METHODS

This chapter explains the predominant manufacturing processes that form the production base for mortar, artillery, and tank projectiles. Also discussed are the rationale for selecting each process and the major operations.

4-1 INTRODUCTION

The means employed to cause metals to assume the desired form include casting, squeezing, forging, drawing, extruding, anti machining. Selection of one or more of these techniques, in an appropriate sequence, is governed by both cost and adaptability. The proper application of forming techniques to the manufacture of munitions hardware is the key to efficient manufacture of projectiles, and it is incumbent upon the design engineer to know the sequence of operations presented in this chapter.

4-1.1 BACKGROUND

During World War II deep cavity projectiles were made by the hot forge-heat treat (HF-HT) and machine process. Forgings were either supplied to prime contractors as Government-furnished material (GFM) or purchased from the forge plant under subcontract. The prime contractor was responsible for projectile manufacturing operations such as rough turning, nosing, heat treating, finish machining, surface preparation, painting, and packaging. At that time forging practice was not uniform throughout the industry; additional billet weight was required to compensate for poor forging practice. This lack of uniformity increased scrap losses and machining costs because material was later removed during rough machining. Production of forgings under separate contract was later phased out when the Government required prime contractors to produce forgings in-house. This change eliminated procurement problems related to split responsibility between forging and machining contractors and allowed the prime contractor to control forging dimensions to insure compatibility with machining operations and vice versa. Postwar studies proved that commercial grade-semifinished-forging-quality steel would produce satisfactory forgings if the forming operations were preceded by a cabbaging operation, which assured that the round or square mult was compressed and deformed to fill the cylindrical die pot and provided an initial centered piercing of the cavity. Also the use of semifinished, forging quality steel resulted in a significant cost reduction through the elimination of the extra charges associated with military specifications. (See Chapter 3 for a discussion of materials.)

Cold extrusion (CE) of deep cavity projectiles and other metal components gained in popularity as a result of technology developed by Germany prior to and during World War II. Some of the heavy German presses were removed and installed in the United States, and after a period during which the process was further refined, several facilities were established to manufacture a variety of projectiles from 3 in. to 155 mm. Projectiles produced by the CE process were expected to cost less than HF-HT projectiles because fewer machining operations were required, heat energy requirements and scrap losses were reduced, and the as-formed dimensional controls and surface finishes were significantly improved. On the other hand, capital investment for this type of facility was higher than for a HF-HT line because cold-forming operations required many expensive high-tonnage presses.

Combining the best features of HF-HT and CE manufacturing methods resulted in the adoption of the hot cup-cold.draw (HC-CD) process during the 1950s. In this process the cup is hot forged and machined for concentricity, weight control, and removal of surface defects. Drawing the machined cup into an open-ended projectile shape is accomplished by cold-working with in-process annealing as required. Several contractor-owned facilities were established with Government equipment to produce both 105-mm and 8-in. deep cavity projectiles by the HC-CD method; the unit cost of 105-mm projectiles manufactured by this process in support of Vietman requirements was significantly less than by either of the other two basic methods.

When the basic CE and HC-CD processes were developed, a need existed to improve quality and reduce production costs. The chemistry and hardness of the higher strength steels, mandated by current requirements for fragmentation and thin-wall designs, exceed the limits of the HC-CD and CE processes. Only the HF-HT facilities upgraded to manufacture high-fragmentation steel projectiles and the higher strength alloy steel carrier projectiles appear to have any potential in production of current and future generation artillery ammunition.

The HC-CD process may have limited application for future generation projectiles if the yield strength of the side wall does not exceed 689 M Pa (100,000 psi). Cold extrusion appears to have even less potential in the manufacture of deep cavity projectiles and is the least flexible of the three basic processes.

4-1.2 MANUFACTURING FACILITIES

Except for manufacturing facilities to support research and development (R&D) projects in Government arsenals, production of projectile hardware is accomplished in Government-owned contractor-operated (GOCO) or contractor-owned contractor-operated (COCO) facilities.

GOCO facilities and real estate are Government owned, and the operation and maintenance of these facilities are by contract between the Government and the operating company. The operating contractor is a private sector company with qualifying credentials in plant management and related manufacturing disciplines. Production of ammunition hardware is generally authorized under firm fixed price contracts. Some cost-type contracts are also placed with GOCO plants for engineering studies and production feasibility. Major GOCO hardware manufacturing plants (Army Ammunition Plants (AAP)) are shown in Table 4-1.

COCO facilities require the same expertise to operate as the GOCO plants, but the real estate is owned by the contractor. The Government pays for use of the contractor-owned real estate and maintenance of equipment under separate contract, but the equipment in the COCO facilities is predominantly Government owned. There may be some contractor-owned equipment, which is usually, but not necessarily, dedicated to the production base. The on-going production base modernization program encompasses both the GOCO and COCO facilities and recognizes the need to satisfy current and future ammunition production requirements.

In summary, there is a very close alliance between US industry and the Government during the product design and process and product engineering phases of the life cycle of the item because the ammunition manufacturing expertise now lies almost exclusively within the private sector.

4-1.3 STANDARDIZATION

Current manufacturing practice is dictated by the end product requirements. To the extent possible, compat.ibility of a given process with current and future ammunition hardware designs is a prime consideration in the initial line layout and procurement of equipment. Standardization of the sequence of manufacturing operations and equipment is directed toward building a facility with the versatility to accommodate a wide range of hardware.

4-1.4 CURRENTLY USED PROCESSES

The most common ammunition hardware manufacturing processes currently employed are discussed in greater detail in this chapter. These are (1) hot forge-heat treat and machine, (2) hot cup-cold draw, (3) cold extrusion, (4) machine from solid stock, and (5) deep drawing. The sequence of operations for the major high-explosive (HE) projectile production processes is shown in Figs. 4-1,4-2, and 4-3.

4-2 METAL F0RMING PROCESSES

4-2.1 HOT FORGE-HEAT TREAT (HF-HT) AND MACHINE

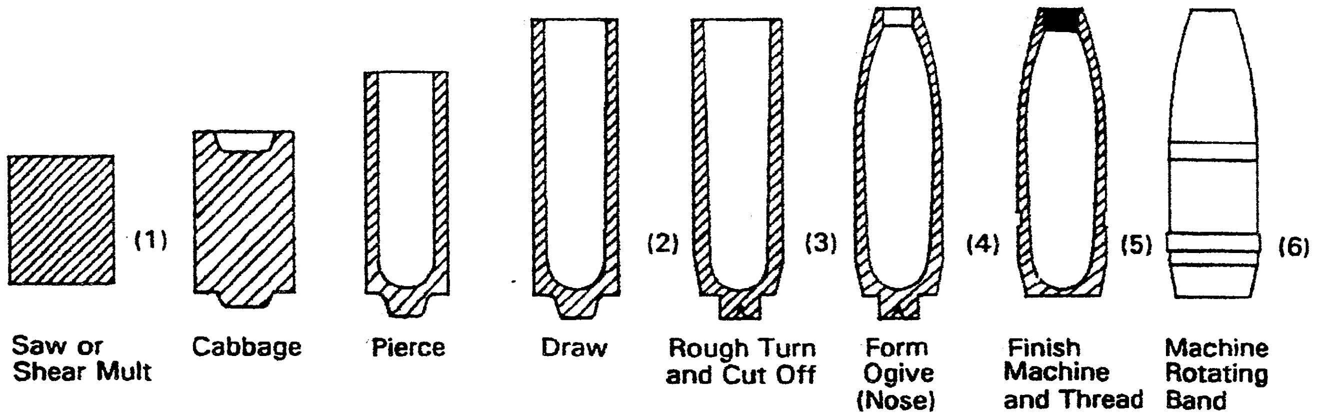
This process is the most flexible of all the metal forming processes used in the production of deep-cavity- and carrier-type projectiles. The basic equipment required for this method can be adapted to a wide variety of projectile shapes by modification of tooling for the forming and machining operations. Also the mechanical properties of these projectiles can be reduced or increased through changes in heat treatment and raw material chemistry without significant changes in other manufacturing operations.

Starting with the steel bar or billet, as received in random lengths from the rolling mill, a mult is separated by sawing, shearing, or breaking. This operation is further described in par. 4-2.1.2. The size of the separated mult is dependent upon the finished weight and caliber of the projectile and the anticipated scrap losses during production. The billet is heated to a temperature of 1038°-1204°C (1900°-2200°F) either by electric induction or gas-fired furnaces prior to forging. Billet heating is discussed in par. 4-2.1.3.

Immediately upon completion of the heating operation, the billet enters the first forging press, in which the cabbage and pierce operations take place. (These operations may also be done in separate presses.) The pierced

TABLE 4-1. AMMUNITION HARDWARE MANUFACTUREING PLANTS

GOCO Plants	Item	Manufacturing Method
Scranton AAP	155 mm and 8 in.	Hot forge-heat treat
Riverbank AAP	81 mm	Hot cup-cold draw
	Cartridge cases	Deep draw
Lousisiana AAP	155 mm and 8 in.	Hpt fprge-heat treat
Mississippi AAP	155 mm and 8 in.	Hot forge-heat treat



(1) Heat mult, descale, and size

(2) Control cool and shot blast cavity

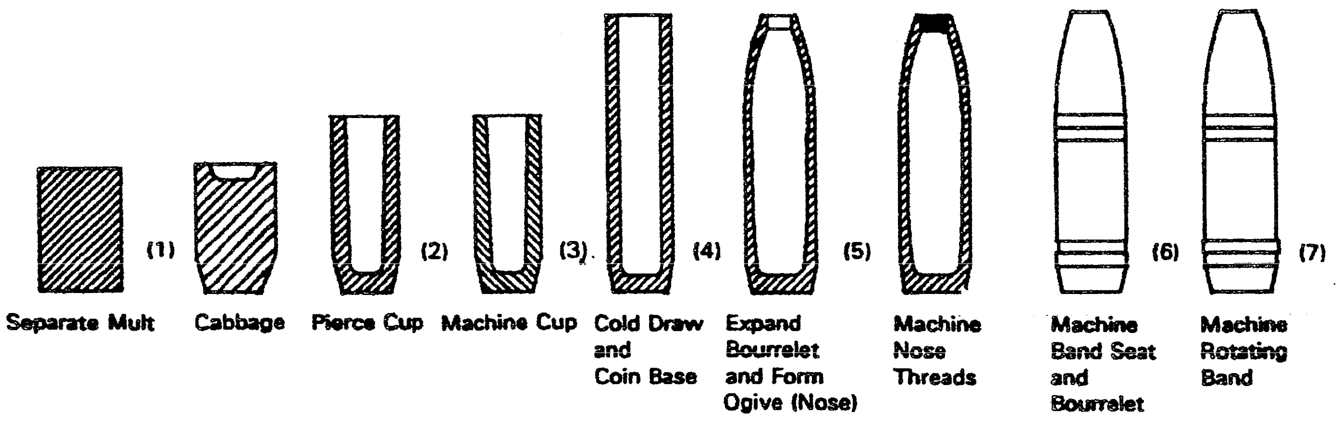
(3) Lubricate and induction heat open end

(4) Heat treat and shot blast cavity

(5) Apply rotating band and weld base cover

(6) Prepare and paint surface

Figure 4-1. Hot Forge-Heat Treat and Machine Process



(1) Weigh, wash and dry, descale, and heat mult

(2) Cycle anneal and shot blast

(3) Clean, phoscoat, soap, and dry

(4) Anneal, clean, phoscoat, soap and dry open end

(5) Stress relieve and shot blast ID and OD surfaces

(6) Knurl band seat, apply rotating band, and weld base cover

(7) Prepare and paint surface

Figure 4-2. Hot Cup-Cold Draw Process

insert page 50

The design engineer must be familiar with the specifications governing steel quality, chemistry, testing, response to heat treatment, and supplementary requirements so that he can determine their impact on material availability and product reliability, producibility, and performance. Steel made by the open hearth, electric furnace, and basic oxygen furnace processes is acceptable for use in munition production. (See Chapter 3 for further discussion.)

Having established the mechanical property requirements through stress analysis, the design engineer should specify the broadest range of steel chemistry and heat treatment consistent with sound practice and production economy. Overstating the mechanical properties and quality level results in higher acquisition costs.

4-2.1.2 Billet separation

Projectile forgings are produced from sections or "mults" that are separated from the main billet or bar by sawing breaking, or hot or cold shearing, as shown in Fig. 4-4. All of these separation methods except hot shearing are done prior to heating the mults to forging temperature. When hot shearing is used, the billet or bar is heated and sheared as it emerges from the heating station.

The nick and break process has been used for many years, and good practice results in a square and clean break. In this process incremental lengths, depending on desired mult weight, are first measured and marked on the top surface of the bar or billet. This marking is followed by the "nicking" operation, which consists of gouging a "V" notch in the surface of the billet with a carbon arc electrode or oxyacetylene torch. This notch creates a stress raiser for the full width of the bar. The bar is then fed by conveyor to a mechanical press at which the breaking operation is performed. Recent experiments have indicated that nicking across the entire top face of the bar produces the cleaner and squarer ends on high alloy steels. A clean square break, besides reducing mult weight, is essential in order to facilitate visual inspection of the end surfaces for centerline defects, such as pipe, cracks, and holes. Nicking of high-carbon and alloy steels may result in cracking through the heat-affected zone and is not recommended as a billet separation method for these steels. Low- to medium-carbon steels are not affected in this manner.

Several methods have been used to separate mults from the main bar by sawing. Billets with large cross sections, especially those made from high-carbon and alloy steel, can be economically separated by using a saw with 0.7l-m (28-in.) diameter, 50-tooth, carbide-tipped, circular saw blades. Band saws are used to separate low- to medium-carbon steel billets with smaller cross sections, i.e., 0.0129 m^2 (20 $in.^2$) or less. Saw cutting produces the squarest ends of all the billet separation methods and results in a more closely controlled mult weight than the other methods. Provisions must be made for kerf losses to assure a full yield of mults from the billet.

Cold-shearing is accomplished in a mechanical press and is generally used when separating low-carbon steels; however, it requires that the bars or billets be purchased in the annealed condition. The surface conditions of the broken or sawed ends of the separated billet influence the forging cavity surface finish, so it is imperative that surface irregularities on the billet ends be corrected prior to heating for forging. Although they mask some of the center defects visible by the nick and break method, sawed or sheared end surfaces generally result in a better forging cavity surface finish.

Separation of the billet by hot shearing is accomplished as the main bar exits the heating tunnel and the

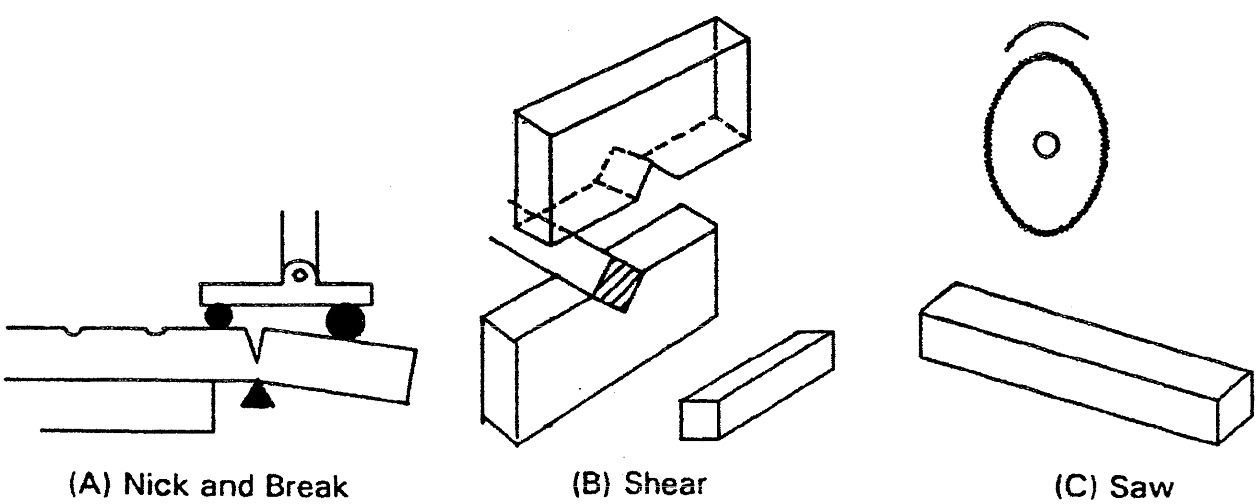


Figure 4-4. Billet Parting Methods

temperature has reached the level required for the first forging operation. The heated bar is positioned in a vertical press containing a ram-mounted, "V"-type shearing die and a corresponding stationary die mounted in the bed of the press, as shown in Fig. 4-5. Upon descent of the ram, the billet is separated from the main bar by shearing action to a predetermined size with minimum distortion.

Further discussion of the advantages and disadvantages of billet separation methods is presented in Chapters 5, 6, and 7.

4-2.1.3 Billet Heating

Heating of the billet to forging temperature is accomplished in gas-fired furnaces or electric induction heaters. Selection of the heating method depends on the accessibility and economy of the energy source. The cost differential for natural gas and the equivalent in electric energy is significant in some areas of the country but may be reversed in other areas.

Gas-fired furnaces (rotary-type) are automatically charged in a double or triple row upon an indexing hearth and conveyed under a burnered roof to achieve maximum heating efficiency. Charging and discharging of the billets are synchronized to keep pace with the capacity of the forging press. Furnace temperature is controlled in zones. Exiting work temperatures from each zone are adjusted to meet predetermined levels. The final zones are fired at 50% combustion air, the preponderance of flue gases from these zones is directed counterflow to work travel, and the remaining chemical heat is used to fuel the latter half of the first zone.

Electric induction can be applied to heating individual mults or the whole bar or billet as received from the steel mill. The billet is fed into the heater where it is held for a predetermined period that is based on the temperature required for forging operations. This heating method produces negligible scale and is accomplished quickly.

Minimizing scale formation during heating of the billet is essential because it

1. Reduces metal loss
2. Improves" product quality (forged cavity surface finish)
3. Reduces die wear and the amount of shot blast cleaning
4. Reduces descaling costs (water and shot blast).

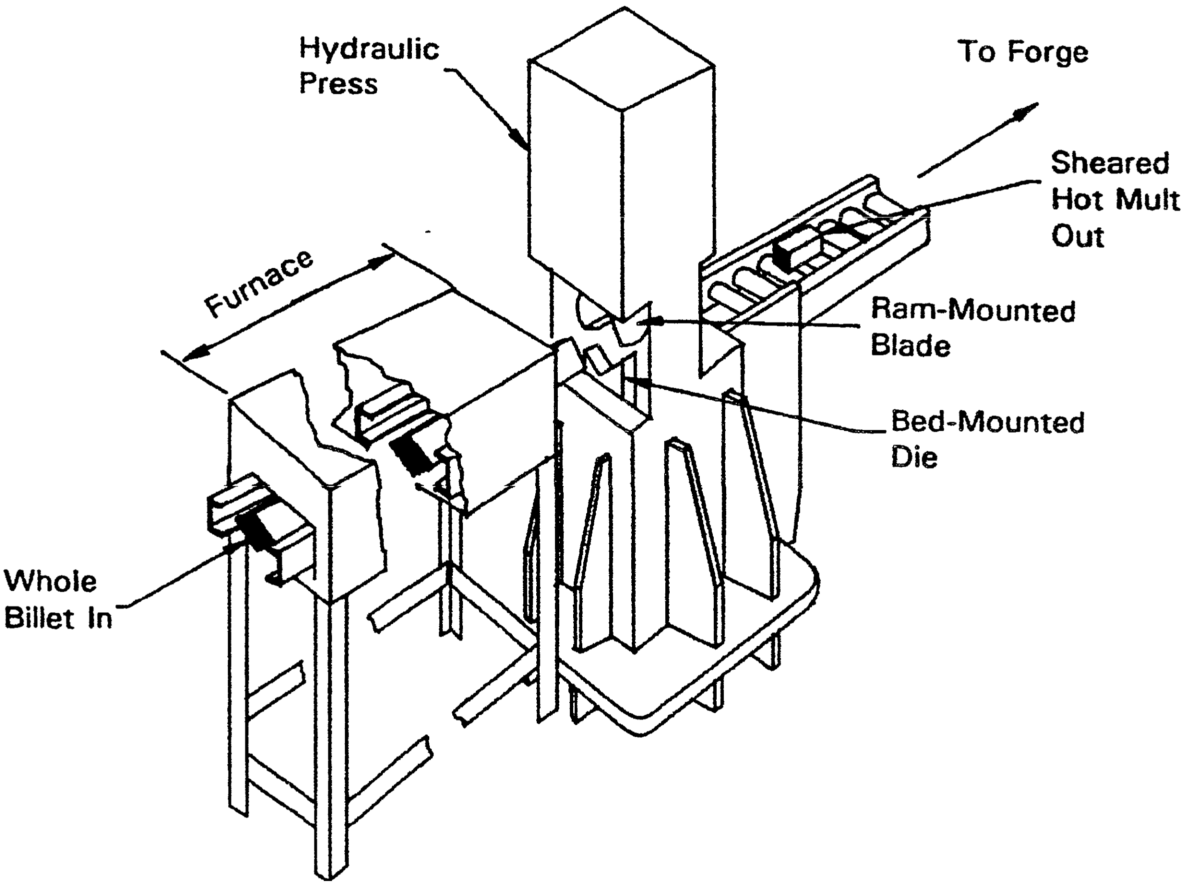


Figure 4-5. Hot Shearing of Mult After Billet Heating

4-2.1.4 Forging

Prior to the first forging operation, the heated mult is passed through a cabinet in which water under high pressure impinges on the surface to remove scale. Hot forging is usually accomplished in three separate press operations referred to as cabbage, pierce, and draw, as shown in Fig. 4-6. Hydraulic or mechanical press capacities range from 454 to 2268 tons (metric) (500 to 2500 tons) depending on forging size and weight. Cabbage and pierce operations can be performed in the same press by using a common bed-mounted die pot; the cabbage and pierce punches are mounted on movable slides on the ram (Ref.2).

After the workpiece (descaled billet) is placed in the die pot, as shown in Fig. 4-6(A), the ram-mounted punch descends and partially pierces and upsets the top of the billet; the boattail or taper at the base end is formed when the billet is forced into the die pot. Preforming in this manner serves a twofold purpose:

1. Upsetting the round-cornered square mult or billet to fill the cylindrical die pot and partial forming of the boattail at the base end create a surface for centralization of the workpiece in the piercing die pot.

2. Partial penetration of the upper end of the billet provides a pocket for guidance of the piercing punch during the piercing Operation.

The cabbaging or preform operation fills the die pot when the hot billet is compressed by the descending punch; preforming extends the life of the tooling and increases productivity of the piercing operation. Automatic lubrication of the punch and die is accomplished between press cycles.

Piercing, or backward extrusion, is done in a vertical hydraulic or mechanical press containing a ram-mounted punch and a bed-mounted die pot, as shown in Fig. 4-6(B). As the ram descends, the preformed workpiece is pierced farther and the steel is compressed which causes it to flow backward over the punch; the workpiece is elongated and its base thickness is established when the ram reaches the bottom of its stroke. The outside diameter of the workpiece is constrained by the die, and the cavity is slightly oversize to allow entrance of the draw punch in the following operation.

The draw operation shown in Fig. 4-6(C) forms the cavity to its finished contour and extends the pierced workpiece to its final length through reduction in outside diameter and sidewall thickness. Equipment used in this operation consists of a long-stroke hydraulic press (horizontal or vertical) containing a ram-mounted punch, centralizing holder, draw rings, stripping devices, and a coining die fixture. The hot, pierced forging is placed in a centralizing holder by mechanical means

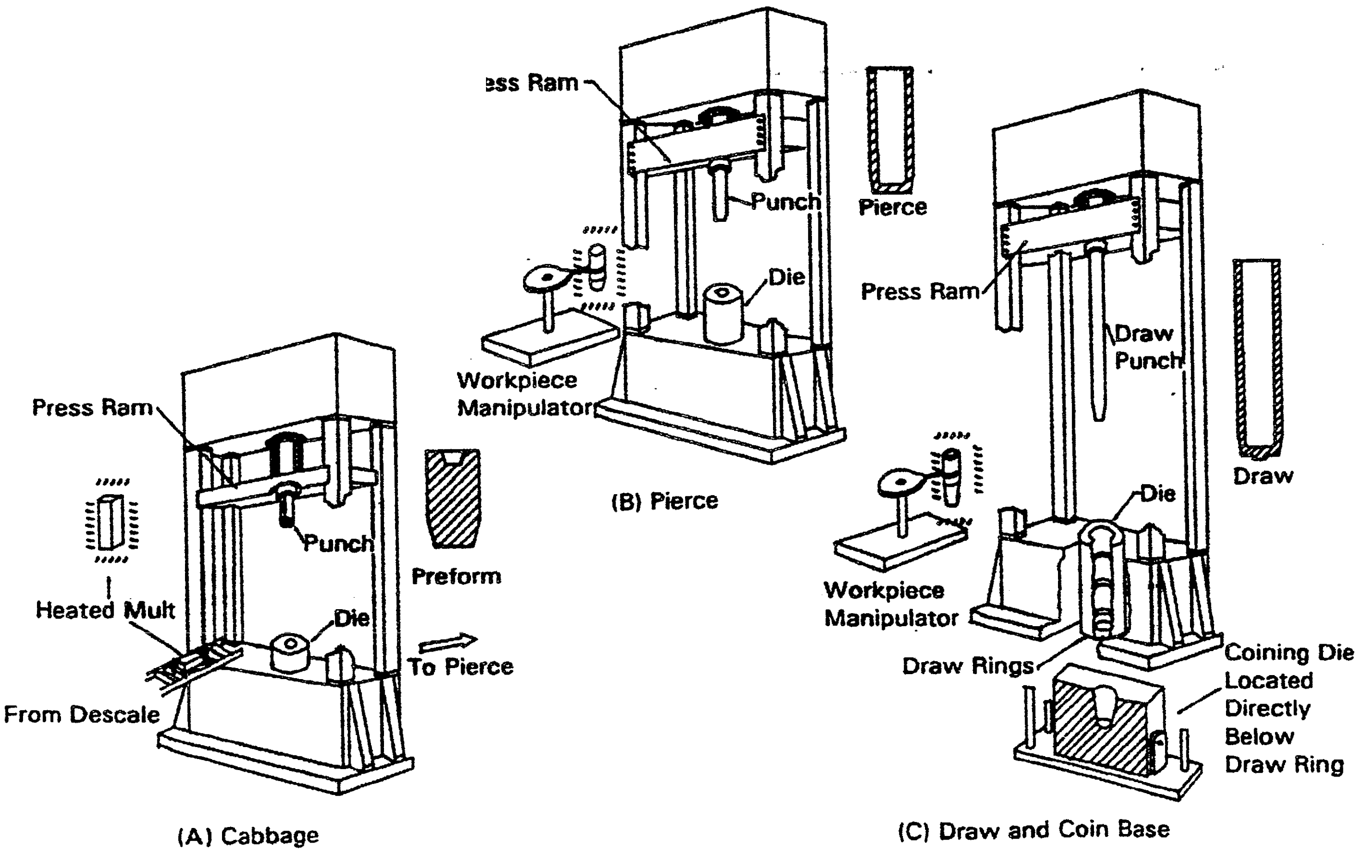


Figure 4-6. Hot Forge Press Operations

and is pushed by the lubricated punch through lubricated draw rings, which successively reduce the outside diameter and increase the length. During the last part of the press stroke, the base end of the forging is coined if required, the press stroke reverses, and the workpiece is removed from the punch by a stripping device located beyond the last draw ring. To qualify for the next operation, the hot forging is inspected to assure compliance with overall cavity length, base thickness, rind eccentricity. Realignment or replacement of punches and dies is required when process control limits or standards have been exceeded. The drawn forging is then control cooled to assure proper microstructure and hardness of the steel for subsequent machining operations.

4-2.1.5 Contour Turn and Cutoff

Prior to machining, scale is removed from the interior surfaces by shot blasting. A scale-free cavity surface is especially important because it influences the centering and concentricity turn operations that immediately follow. Scale removal from the exterior surface of the forging is optional because it is normally removed in contour turning.

The boss on the base is center drilled on a semiautomatic, single-spindle lathe specially adapted to provide a self-contained drilling power unit in a retractable slide in lieu of a conventional tailstock unit. The forging is chucked on an internally expanding mandrel and makes contact at two areas; one is at the base and the other is toward the open end at a position coincident with the chucking area of the next operation (Ref. 2). See Fig. 4-7 for the setup of this operation.

This operation is critical because subsequent metal removal operations and projectile wall variation are influenced by the amount of center drill offset from the true geometric centerline of the forging. The center-drilled projectile is released for the contour turn operation after acceptance inspection.

Contour turning is performed on a semiautomatic, multiple-slide, single-spindle, expanding mandrel tracer lathe with a retractable tailstock. The setup for this operation is shown in Fig. 4-8. The base end of the workpiece is supported on the outside by a live tailstock center. Exterior surfaces are machined to reduce eccentricity with reference to the cavity surface and to create a configuration required for the subsequent nosing operation. Cutoff of the open end to a more precise length is accomplished in the same setup by partially cutting through the wall and removing the ring section with a separate parting device. Contour turning is critical in the HF-HT process because final wall variation in the projectile ogive area after nosing and heat treating is largely dependent upon its accuracy and consistency.

4-2.1.6 Nosing

The formability of specific steels dictates whether the nosing of the ogive section should be cold, warm, or hot. Cold nosing provides the best dimensional stability, but high-carbon and many alloy steels cannot be cold nosed without incidence of tears or stress cracks.

Prior to the nose- or ogive-forming operation, the open end of the contour-turned forging is preheated to about 121°C (250°F.) A water-soluble lubricant is applied to the external surface by spray while the forging is rotated, as shown in Fig. 4-9(A). The heat of the projectile evaporates the water and an evenly applied coating of lubricant is left on the surface; this coating reduces the resistance of metal to flow during nosing.

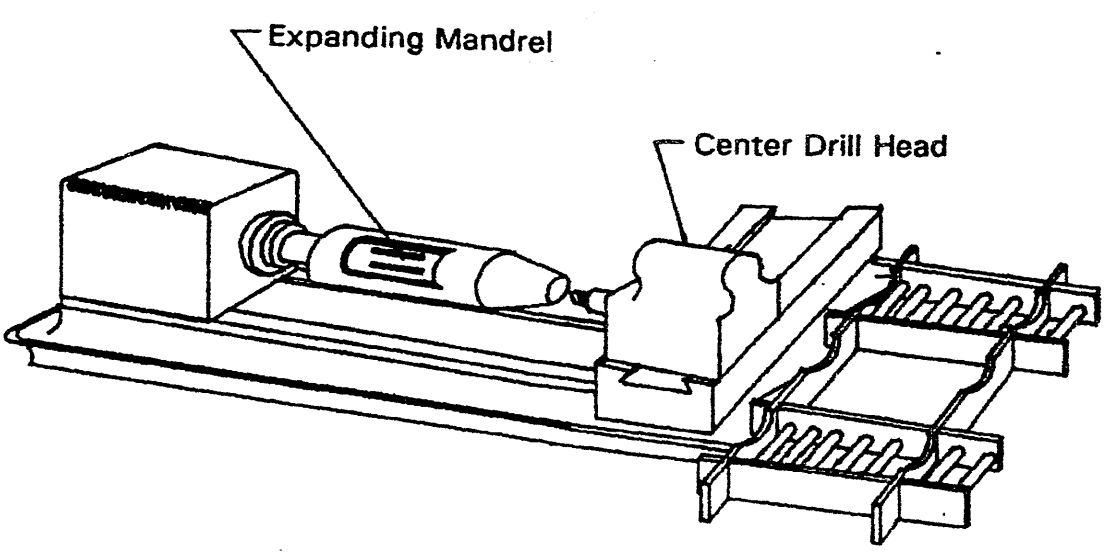


Figure 4-7. Center Drill Operation

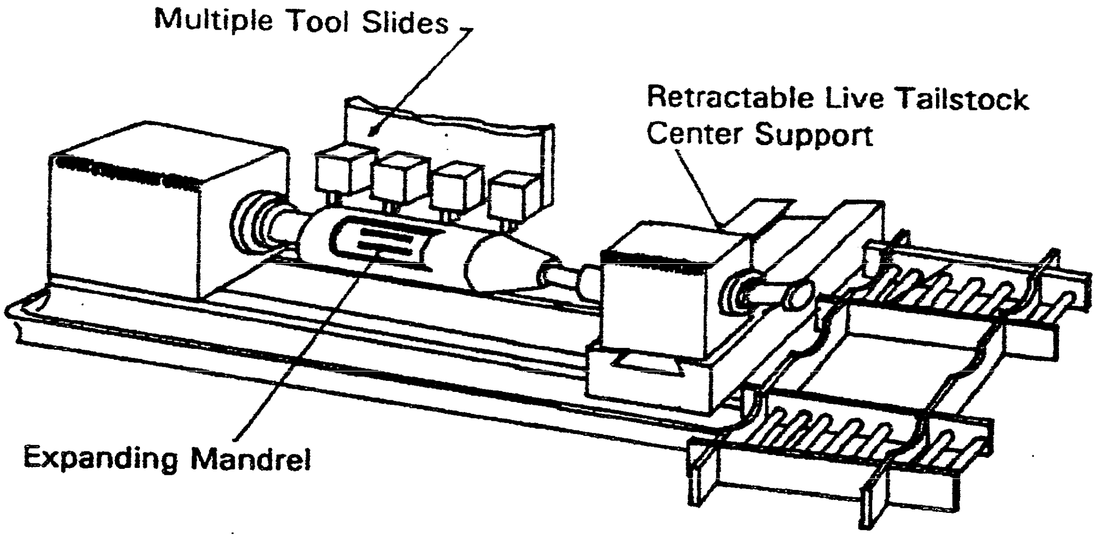


Figure 4-8. Contour Turn and Cutoff Operation

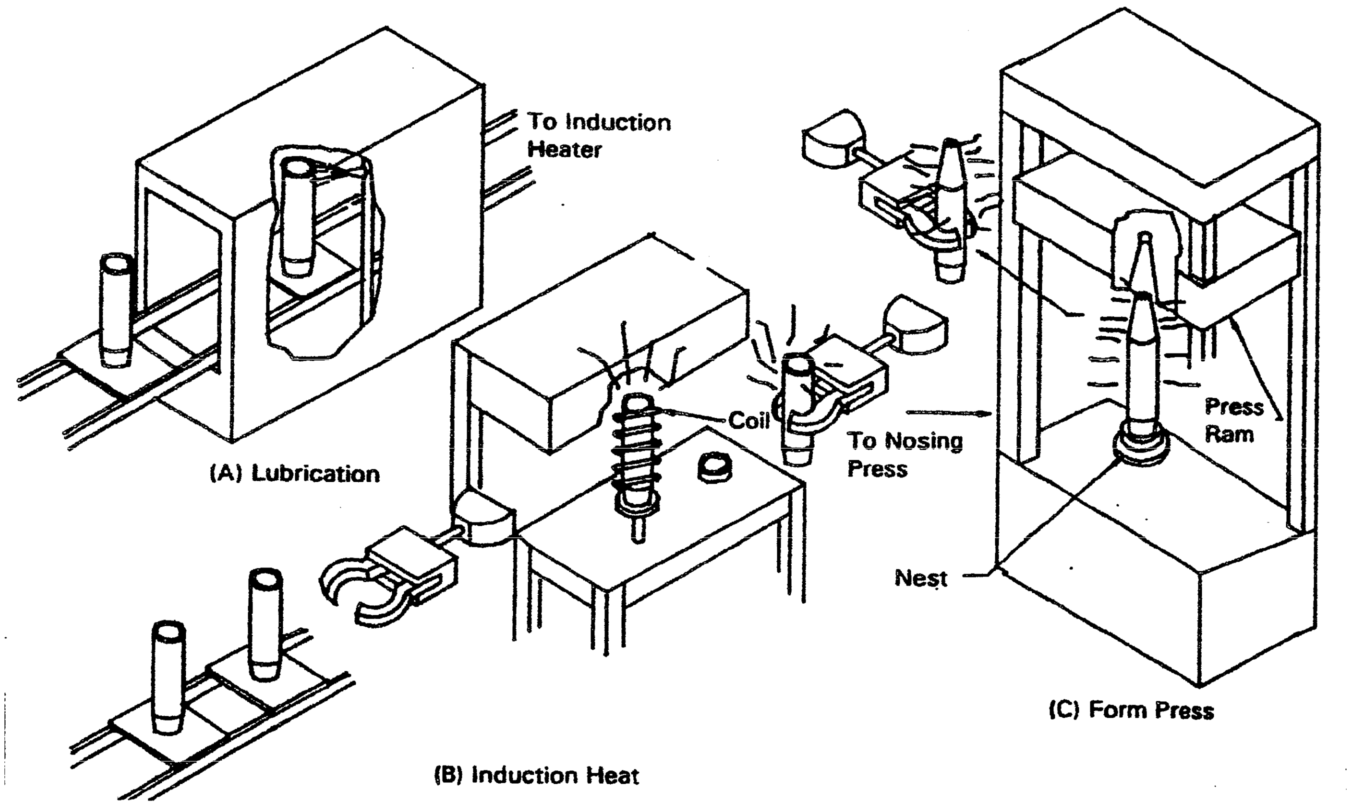


Figure 4-9. Warm and Hot Nosing Operations

Next the forging is heated for nosing, as shown in Fig. 4-9(B). When warm or hot nosing is required, induction heating is the preferred method because the application of heat can be more readily localized. Heating equipment consists of vertically mounted, tubular-wound induction coils that heat the open end of the contour-turned workpiece. After the workpiece is positioned on a rotary table, it is raised and rotated within the coil for a predetermined time to assure that it is evenly heated to the desired temperature. When the table is lowered, the projectile is automatically transferred to the nosing press to avoid unnecessary heat loss, which would hinder a consistent metal flow during the nosing operation.

Forming of the ogive is done in a vertical mechanical or hydraulic press, as shown in Fig. 4-9(C), with a press capacity of 272 to 907 tons (metric) (300 to 1000 tons), which varies depending upon the projectile size and amount of reduction required. The press contains a ram-mounted, water-jacketed nosing die and a bed-mounted centralizing nest. The heated projectile (open end up) is placed in the nest and the nosing die is brought down over the projectile to form the ogive section. On the return stroke of the press ram, the nosed projectile is ejected onto the conveyor for the next operation. Close alignment of the nosing die with the centralizing nest is essential to preclude excessive wall variation and eccentricity.

Nosing can be accomplished without prior heating, i.e., cold, provided that the amount of deformation and material hardness do not promote stress cracking.

4-2.1.7 Heat Treatment

After nosing a heat treatment is necessary to develop the final mechanical properties of the projectile. The three basic steps in the heat treatment process are austenitize, quench, and temper, sometimes referred to as harden and draw.

Austenitizing is accomplished by heating the projectile in a furnace to a temperature of 788° to 871°C (1450°-1600°F) to produce uniform austenite grain structure. Typical equipment consists of an in-line, gas-fired, radiant tube furnace. Projectiles are loaded vertically into trays or baskets and conveyed through the furnace on powered rollers or pushed through on skid rails. A protective atmosphere, normally nitrogen, is maintained in the furnace to reduce scale formation and loss of carbon in the steel. Once the projectiles are heated to a uniform temperature, they are quenched in an oil bath.

The quenching operation is critical to obtaining the desired mechanical properties. The projectiles, still on trays, are positioned over the quench tank and lowered hydraulically into the oil bath. Submerged in the bath are pipes or spuds over which the open end of each projectile is lowered. Once the projectile is completely immersed, oil is pumped through the spuds into the projectile cavities to remove entrapped air and internally quench the projectiles. The oil bath is maintained at a temperature of 66° to 121°C (150° to 250°F) and is agitated to facilitate extraction of heat from the projectiles.

After cooling to the bath temperature, the tray load of projectiles is raised out of the quench bath, drained, and detergent washed to remove the remainder of the quench oil. The projectiles are then conveyed to the tempering furnace. The tempering furnace is similar in design to the austenitizing furnace except that it is directly gas-fired and does not have a protective atmosphere. The tempering operation softens the hard, brittle-as-quenched martensitic structure to obtain the required strength and ductility. Higher tempering temperatures yield lower strengths and higher ductility. The normal temperature range for tempering is 316°-649°C (600°-1200°F); a specific temperature is selected based on the chemistry of the steal and the desired mechanical properties. Upon exiting the tempering furnace, cooling of the projectile to permit handling may be accelerated by forced air or a combination of forced air followed by a water spray after the projectile has cooled below 371°C (700° F).

4-2.1.8 Machining and Finishing Operations

Included in the projectile-finishing operations are the metal removal necessary to meet final geometry and surface finish, the assembly and machining of a rotating band where required, the welding of a base plate to high-explosive projectiles, and surface preparation and painting (Ref. 2).

The sequence and setup of machining operations are dictated by available metal-turning equipment and production economy. Suggested methodology is based on equipment and setups that will meet dimensioned requirements, but it can be combined when machines capable of' multiple operations, such as computer numerical control (CNC) lathes, are used.

Prior to rnachining the projectile cavity surfaces are shot blasted, as shown in Fig. 4-10, to remove scale formed during nosing and heat treating. The surface

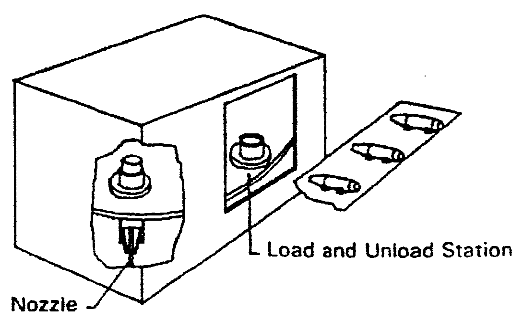


Figure 4-10. Interior Blast Operation

finish of the cavity must be acceptable at this point to qualify it for the remaining operations because machining of the cavity is not contemplated.

If the amount of scale on the outside surfaces after heat treating could result in uneconomical tool wear during subsequent metal removal operations, the projectile exterior can be shot blasted, as shown in Fig. 4-11. Shot blasting equipment is usually a part of modernized production lines as a contingency in case of a temporary loss of atmosphere control during heat treatment.

4-2.1.8.1 Bore, Face, and Chamfer

The bore, face, and chamfer operations are performed on a semiautomated lathe adapted to provide cross-axis facing, through-axis boring and chamfering, base facing and centralization of the ogival section of the projectile, as illustrated in Fig. 4-12. The projectile is driven from the base end by a compensating chuck, and the ogive section is centralized by a live-ring-type fixture. The method of centralization compensates for eccentricities resulting from the nosing and heat treating operations and reduces the possibility of excessive wall variation in the finish turn operation. Cross-axis facing removes the rough end of the nosed projectile. Through-axis boring includes rough and finish boring of the nose thread minor diameter and chamfering and butt facing at the end of the boring stroke to assure perpendicularity.

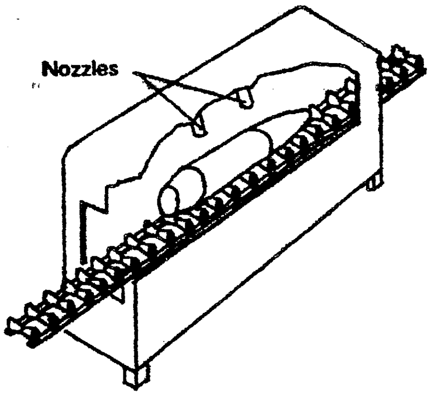


Figure 4-11. Exterior Shot Blast Operation

4-2.1.8.2 Finish Turning

Finish turning to meet required exterior geometry can be accomplished in a variety of ways. Semiautomated, multiple-slide, tracer-type equipment is used to machine the ogive, bourrelet, body, and boattail sections of the projectile. The projectile is located and driven from the base end, as shown in Fig. 4-13, by a compensating chuck that uses using the drilled center hole for centralizing and the base diameter for driving. The nose and is centralized by placing a live expanding mandrel into the bored surface. This method of chucking provides the maximum drive that is required to overcome torque setup by the machining operation and permits optimum cutting feeds and speeds. Finish-turning operations may be combined with band seat turning and threading through the use of numerical controlled lathes, but the sequence of operations would be essentially the same as described. The projectile design may dictate that the front end be finished in one setup and the base end and band seat finished in another setup; however, the most important control to be considered in finish machining is centralization of the workpiece to assure that concentricity requirements are maintained. Turning equipment with automatic handing deviees reduces operator fatigue and increases production economy.

4-2.1.8.3 Face Base and Cut Threads

Once the exterior geometry has been established using the center-drilled base end and bored nose end as references, further machining can be accomplished by chucking on the outside surfaces. Depending upon the approach taken in the exterior finish machining, some of the remaining operations can be combined into one setup. An example of such a combination is shown in Fig. 4-14 in which a specially constructed, multiposition machine is used to cut nose threads and finish the base end on two projectiles simultaneously. In this setup there are self-contained power packs, tapping units, and

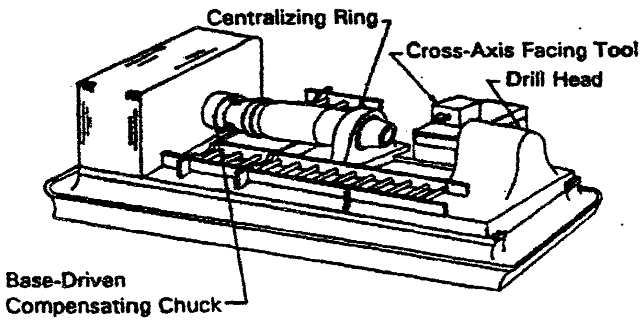


Figure 4-12. Bore, Face, and Chamfer Operation

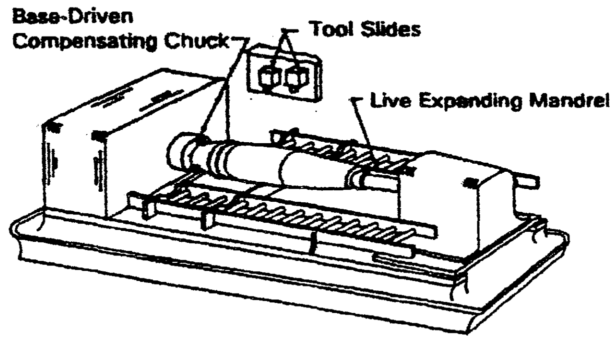


Figure 4-13. Finish Turn Outside Surfaces

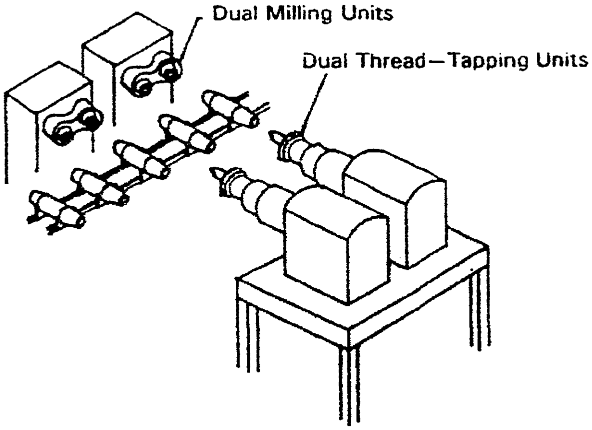


Figure 4-14. Face Base and Tap Threads

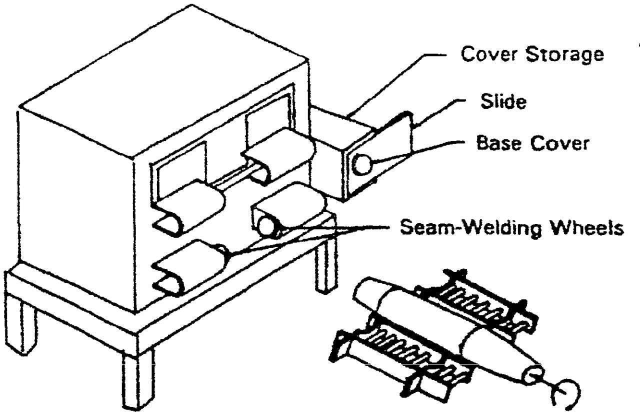


Figure 4-15. Base Cover Welding

milling heads mounted on suitable base supports grouped around a walking beam conveyor with holding devices. Thread tapping is not always practical; in the case of some high-strength alloy steels, this operation is performed on single-point threading machines or CNC lathes.

Usually at this point in the machining operation sequence, there is a final inspection for dimensional characteristics because wall thickness, surface finish, base thickness, and structural soundness arc not expected to change during the remaining operations. Dimensional inspection is discussed in Chapter 13. Nondestructive testing (NDT) for metal flaws is described in detail in Chapter 14.

4-2.1.8.4 Base Plate Assembly

The sequence of the remaining operations included under machining may vary depending upon projectile function and in-flight stabilization. If the projectile payload is HE, a disc made from steel strip is welded to the exterior base surface. This placement is done to insure against a premature detonation of the HE filler by hot propellant gases leaking through some centerline defect that may not have been detected during in-process inspection. The base cover is attached to the projectile by a continuous resistance weld by two wheel-type electrodes in a setup, as shown in Fig. 4-15. The projectile rotates one revolution during this operation, welding, is accomplished during the first half of the revolution, and annealing of the weld occurs in the second half of the cycle, during which the current density is automatically reduced.

4-2.13.5 Machine Band Seat

Rotating bands for spin-stabilized projectiles are applied either by swaging into a band seat or by welding of an overlay at a specified location on the projectile body.

The traditional practice employed in rotating band application is to swage or press the cylindrical band blank into an annular groove or seat machined into the projectile. To assure concentricity with projectile geometry, the band seat is machined in a multislide tracer lathe, as shown in Fig. 4-16. In this setup the projectile is located against the base and driven from the boattail by a three-jaw chuck, and the nose end is centralized by a live cup center. Control of the band seat location from the projectile base end is essential because of the interface with the rotating band complete round assembly (fixed or semifixed) and cambering in the weapon. The band seat sidewalls may he undercut to assure proper functioning of the rotating band. Swaging the band blank into the undercuts increases its beam strength by fixing it at both ends to reduce the possibility of failure caused by centrifugal force.

In machining the band seat a form tool is used to create ridges around the bottom of the seat. These circumferential ribs are then scored or serrated by knurling rollers. Once the band blank is swaged, or pressed tightly in the band seat, the knurled ribs prevent slipping of the band during rotation of the projectile. If projectile wall thickness and strength permit, application of the band blank by swaging is the most practical method.

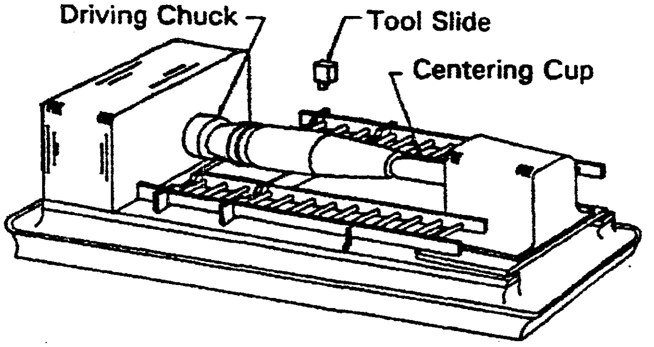


Figure 4-16. Machining of Band Seat

Figure 4-17. Centerless Grinding

4-2.1.8.6 Grind Bourrelet

After the band seat is machined, the bourrelet surfaces, which require close tolerances and finish, are completed by centerless grinding-shown in Fig. 4-17—when the required surface finish and dimensional accuracy cannot be achieved during finish machining. prior to application of the rotating band blank, the band seat is throughly cleaned to remove any loose material, such as chips or dirt, that could interfere with proper seating.

4-2.1.8.7 Rotating Band Application

Band blanks are made from various materials, such as copper, gilding metal (90% Cu + 10% Zn), soft iron, or sintered iron. Dimensions of the blank depend on the width and final thickness needed to withstand the forces of engraving and projectile rotation without failure due to wear, shear, erosion, or bending. Seating of the band blank is commonly done on a multicylinder hydraulic press or a toggle joint press, known as a tire setter, in which a number of jaws thrust radially inward against the blank and squeeze it into place.

Another method of seating the blank is shown in Fig. 4-18. Here the projectile, with the blank placed loosely in its seat, is pushed through a tapered ring die, which squeezes the blank into the seat. If the band seat sidewalls are undercut, premachined band blanks may be required to assure proper seating by the tapered ring die method. Band tightness is essential to consistent ballistics performance; therefore, nondestructive testing has been developed to assure that band gap allowances are not exceeded.

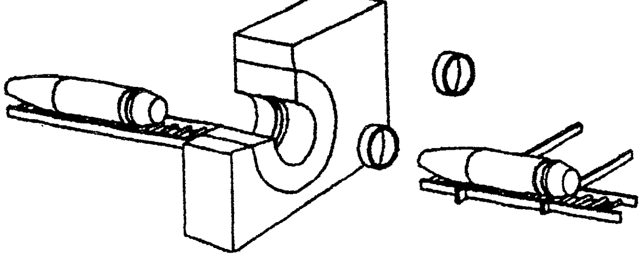


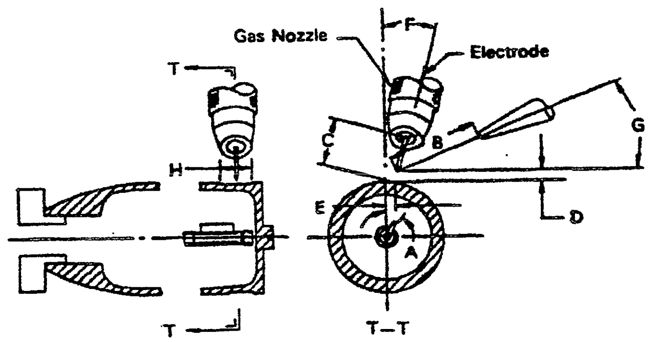
Figure 4-18. Tapered Ring Die Method of Band Application

Thin-walled projectiles would not have enough wall thickness remaining under a conventional band seat to withstand the radial forces applied during band seating and subsequent engraving in the weapon. Therefore, the welded overlay process has been developed, which requires a very shallow band seat because the band material is welded directly to the projectile body after rough turning and before heat treatment.

Copper, gilding metal, aluminum-bronze, and iron have been used successfully in welded overlay rotating band applicaitons. The metal is deposited on the projectile body surface by the oscillating motion of the welding head while the projectile is rotated slowly, as illustrated in Fig. 4-19. The gas metal-arc welding process incorporates a consumable electrode and must be used in combination with an auxilary (nonelectrode) filler wire.

The auxiliary cold wire is primarily used to buffer the steel substrate from direct impingement of the arc, which limits melting of the steel and minimizes intergranular penetration of the steel grain boundaries of the molten copper deposit. The auxiliary wire also supplies the amount of metal necessary to complete the deposit in one rotation of the projectile body. In most applications the projectile is cooled internally with water beneath the area of the weld puddle. Internal cooling minimizes intergranular penetration by limiting the weld heat affected zone.

The parameters indicated in Fig. 4-19 will remain the same regardless of the application. However, process parameters, such as amperage, wire feed rates, wire diameter, rotation speed and oscillation frequency, will vary depending on the projectile and the desired geometry of the deposit. In general, the term "overlay



Location of Water Nozzle, Electrode, and Auxiliary Wires

Welded Overlay Parameters:

A. Projectile water nozzle location
B. Auxiliary wire distance from guide tip to electrode
C. Electrode height
D. Auxiliary wire gap
E. Torch distance-electrode and projectile centerline
F. Electrode wire gap
G. Auxiliary wire angle from horizontal
H. Electrode oscillation limits

Figure 4-19. Welded Overlay Process

band machine" is a setup that includes (1) the welding head, comprised of the welding torch and electrode wire drive mechanism, auxiliary wire guide attachments, and the auxiliary wire feeder unit, (2) auxiliary and electrode wire straighteners, (3) oscillator, (4) electrical controls and timers, (5) welding power source, (6) welding contactor, and (7) projectile cooling system and all related operational and safety controls, indicators, and devices.

4-2.1.8.8 Machine Rotating Band

Machining of the band profile is performed on a semiautomatic tracer-type lathe—as shown in Fig. 4-16-on which the projectile is located against the base end and driven by a three-jaw chuck. This is the same setup used for machining the band seat in which the nose end of the projectile is centralized by a live cup center located in the tailstock ram. Chucking the projectile in this manner assures that the band profile is concentric with the band seat and bourrelet and that the projectile will be properly centered in the forcing cone when chambered in the gun.

4-2.1.8.9 Projectile Marking

Projectiles that meet acceptance criteria at this point are marked to provide nomenclature, lot number, manufacturer, and date manufactured. Identity of the projectile is essential for subsequent complete round lot formation, malfunction investigations, and general logistics. Marking of projectile hardware is done by stamping the information into the projectile, as shown in Fig. 4-20.

4-2.1.8.10 Surface Preparation

Surface treatment of the projectile consists of cleaning, phosphating, and acid rinsing to remove oils and grease and to prepare the cavity and exterior surfaces for painting. This operation can be performed in a spray cabinet, as shown in Fig. 4-21, or by immersion in tanks in which the projectile is subjected to five separate stages: (1) alkali cleaning, (2) hot water rinse, (3) zinc phosphate coating, (4) cold water rinse, and (5) chromic acid rinse. Adaptive controls are used in these surface preparation systems to titrate automatically the various solutions used and to replenish them as required.

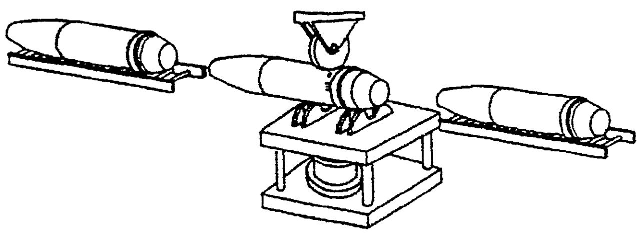


Figure 4-20. Marking and Stamping Operation

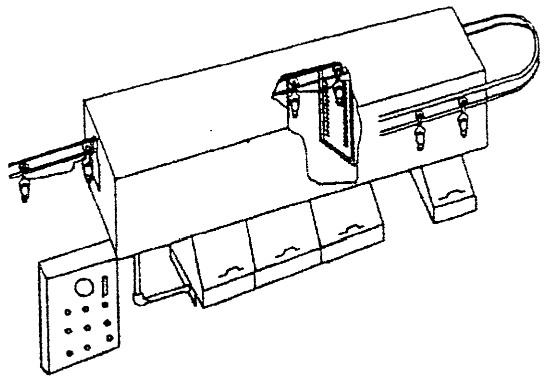


Figure 4-21. Spray Method of Surface Preparation

4-2.1.8.31 Painting

When required, the projectile cavity is spray painted electrostatically in an automated system. While the projectile rotates in its holding fixture (either horizontally or vertically), the paint spray wand enters the cavity and, when actuated by a caroming or timing device, deposits paint on the interior surfaces to a preset film thickness and length of coverage. Vapors are evacuated from the painted cavity by forced dry air in a separate setup. Acceleration of the drying cycle can be accomplished by passing the projectile through a heated cabinet. Masking of the nose threads is essential to assure that these surfaces will remain free of any material that might impede assembly with the fuze.

Once the projectile cavity has been painted and inspected, the nose end is closed by a threaded lifting plug, which prevents foreign material from entering the cavity and acts as a hanging device during painting of the exterior. The rotating band is masked during this painting to protect it from paint deposit. The projectiles are hung in rotating fixtures on a continuous conveyor. Exterior surfaces, except the rotating band, are electrostatically painted while being conveyed through the paint booth.

Projectiles are then conveyed through a baking oven in which their surface temperature is elevated to 93°-121°C (200°-250°F) and maintained for a minimum of 30 min. Following the oven bake, projectiles enter the cooling tunnel in which ambient air, supplemented with fans, is used to reduce their surface temperature to 38°C (100°F) maximum to permit handling. After this operation, the projectiles are gaged for maximum bourrelet diameter. Packaging in individual containers or pallets is the final manufacturing operation prior to transfer for loading.

4-2.2 HOT CUP-COLD DRAW

The hot cup-cold draw (HC-CD) process was developed after World War II because the HF-HT process was considered labor intensive and the CE process required many high-tonnage presses to perform the cold-forming operations. The sequence of operations is shown in Fig. 4-2. The HC-CD process combines those features of the HF-HT and CE processes that permit production of projectile metal parts at a favorable cost with a moderate facilities investment.

Advantages of the HC-CD process are in reduction in the size and number of presses required in the forming operations as compared with the CE process. Also multiple finish machining operations and heat treatment characteristics of the HF-HT process are eliminated because final geometry and mechanical properties are achieved by cold-draw-working. The HC-CD production facility requires fewer operating personnel, and this fact is especially favorable during periods of mobilization. Steel chemistry is limited to low- through medium-carbon ranges. Higher carbon and alloy steels cannot be subjected to the same degree of cold-working without cracking.

The basic hot cup-cold draw process may still have limited application in the manufacture of projectiles for which the required yield strength is less than 689 MPa (100,000 psi). Many of the advantages of the HC-CD process, which originally justified its development and adaptation to projectile production, are no longer valid now that HF-HT facilities have been modernized and thus are more versatile and efficient.

4-2.2.1 Raw Material Parameters

Steel that meets the requirements of MIL-S-10520 (discussed in par. 3-3.1.2) is acceptable for HC-CD process application. It should be noted that steels used in HC-CD are ordinary and readily available in the commercial market and have very few extra requirements. Consequently, these steels are cheaper and more available than the low-carbon steels required by the cold extrusion process.

Other than the limitation in steel chemistry associated with the cold-forming operations, selection of material would follow the rationale suggested in par. 4-2.1.1.

4-2.2.2 Billet Separation

Sawing and cold-shearing of individual mults from the bar or billet are preferred methods because they result in more precise weight control and good surface condition of the parted face. Mult weight control is more critical in the HC-CD process than in the HF-HT process because there are fewer metal removal operations in the HC-CD process. Separation methods are similar to those described in par. 4-2.1.2.

4-2.2.3 Hot Cupping

Heating of the billet prior to cupping is accomplished in gas-fired or electric induction furnaces, as described in par. 4-2. 1.3; induction heating is preferable, however, because it results in less material loss due to scale formation. Hot cupping is essentially the same as the piercing operation of the HF-HT process and is also preceded by a die pot filling or cabbaging of the hot mult, as described in par. 4-2.1.4.

4-2.2.4 Concentricity Turn and Cutoff

Machining of the hot-cupped workpiece reduces eccentricity between inside (cavity) and outside surfaces, removes surface imperfections, and establishes weight within specified limits. Equipment used for these metal removal operations is similar to that used in the contour turning of forgings described in par 4-2.1.5.

4-2.2.5 Surface Preparation

The hot-cupped and machined workpiece is pickled (light acid etch) to remove oil and grease; then it is zinc phosphate and lubricated with a soap compound. The phosphate acts as a carrier of the sodium stearate soap lubricant, which reduces the resistance of metal flow during the cold-draw operation; soap coating (phos-lube) improves die life and prevents tearing of the projectile surface.

4-2.2.6 Cold-Forming

Much greater pressures are needed for cold-working than for hot-working The metal, being in a more rigid state, is not permanently deformed until stresses exceed its elastic limit. Because there can be no recrystallization of grains in the cold-working range, there is no recovery from grain distortion. As grain deformation proceeds, greater resistance to this action is built up, which results in increased strength and hardness of the metal.

There are various types of cold-forming operations:

1. *Coining* is performed in dies that confine the metal and arose it to flow in a lateral direction, and it is normally done on the base of the projectile. Coming increases the strength of the base but reduces the ductility.
2. *Cold-drawing* is a very severe operation during which the metal is stressed above its elastic limit to permit plastic flow through the die. The maximum reduction in cross-sectional area for one pass is about 40%.
3. *Bourrelet expansion* is usually performed at the same time the base is coined. A punch is inserted into the cavity of the shell and is shaped to contact the base and expand the front bourrelet in the same operation. These operations are included in the HC-CD sequence shown in Fig. 4-2.

4-2.2.7 Thermal Treatments

If more than one cold-forming operation is required to obtain the final part configuration, the part may have to be softened to permit further cold-working. Softening is accomplished by a process anneal during which the part is heated to a typical temperature range of 538° to 677°C (1000° to 1250° F). This temperature, which is just below the lower transformation temperature, relieves all of the stresses induced by the cold-working operation.

To obtain the required mechanical properties, a final stress relief heat treatment is required after the final cold-working operation, which only partially relieves the forming stresses. During this operation the ductility of the material is increased disproportionately to the reduction in strength so that both properties meet drawing requirements. Typical stress relief temperatures range from 371° to 482°C (700° to 900°F). Furnace equipment normally resembles a tempering furnace discussed in par. 4-2.1.7.

4-2.2.8 Face-Off and Contour Open End

This operation is similar to the contour turn and cutoff operation explained in par. 4-2.1.5. After in-process annealing of the cold-drawn workpiece, the open end is faced off and contoured preparatory to nosing.

4.2.2.9 Nosing

Nosing can be performed cold or warm depending on the total change in outside contour and is performed in a manner similar to that described in par. 4-2.1.6. If the ogive is formed by cold-working, the projectile must be stress relieved immediately foil owing nosing to assure that residual or locked-in stresses will not propagate into cracks.

4-2.2.10 Machining

Much of the projectile geometry is finished to size by cold-forming in the HC-CD process; therefore, many of the finish machining operations of the HF-HT process are eliminated. HC-CD machining operations that are common to the HF-HT process are bore, face, chamfer, and thread nose end; turn band seat and knurl; weld base cover, swage band blank; turn band profile; and prepare surface and paint. Details of these operations are given in par. 4-2.1.8.

4-2.3 COLD EXTRUSION (CE)

Cold extrusion (CE) consists of three principal types, all of which involve the displacement of metal by plastic flow under steady and nearly uniform pressure:

1. *Backward.* The movement of the metal is in the direction opposite to the punch travel, as shown in Fig. 4-22(A). Parts are often cup shaped and have a wall thickness equal to the clearance between the punch and die.

2. *Forward.* The metal is forced in the direction of punch travel, as in Fig. 4-22(B). The die recess is just large enough on one end to receive the starting slug, and on the other end it has a small orifice of cross section like that of the desired part.

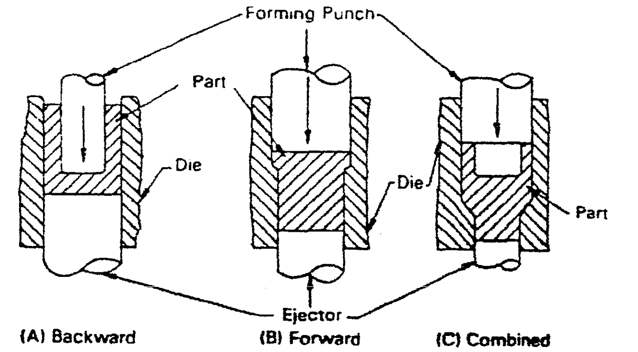


Figure 4-22. Types of Cold Extrusion

3. *Combined.* Sometimes the two methods of extrusion are combined so that some of the metal flows backward and some forward, as shown in Fig. 4-22(C).

The compressive strength of the punch and tensile strength of the die are among the most important factors influencing selection of materials for CE tools. Because the die is invariably prestressed in compression by the inner and outer shrink rings (Fig 4-23), the principal requirement for a satisfactory die is a combination of tensile yield strength and prestressing that will prevent failure. Punches require sufficient compressive strength to resist deformation without being hazardously brittle. Tools that come in contact with the workpiece must be made from steels that will harden completely through their entire cross section.

The primary advantage of CE in the manufacture of deep cavity projectiles is the production economy that results from the elimination of billet heating, many of the machining operations, and the scrap losses associated with the HF-HT process. There is also a commensurate reduction in production labor and starting mult weight.

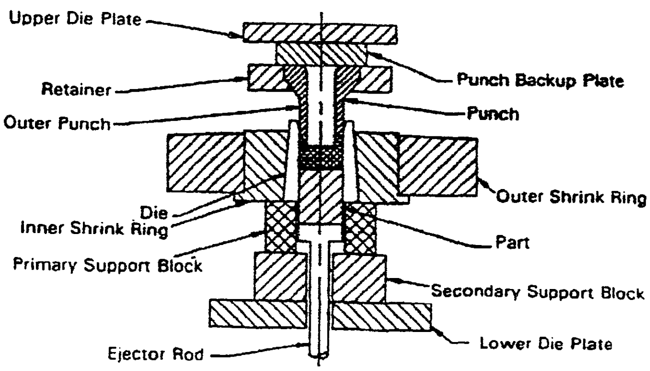


Figure 4-23. Cold Extrusion Press Tooling Setup

Steel for CE does not require as high a percentage of manganese as an alloying element as the steels used in the HF-HT process, but it must be free of those nonmetallic inclusions that inhibit the development of mechanical properties through work hardening.

The CE process eliminates some of the machining operations required in the HF-HT process; however, it 'requires more press operations and a rather complex Lubrication operation before each extrusion. The number of high-tonnage extrusion presses required in this process significantly increases the capital investment for plant equipment as compared with that for an HF-HT or HC-CD facility. The CE process is no longer considered practical for producing deep cavity projectiles due to recent modernization of HF-HT facilities and the increasing demand for high-carbon and alloy steels in the manufacture of thin-walled and high-fragmentation munitions. If CE were a practical method of producing deep cavity projectiles, current domestic steel-making facilities might not be able to supply the tremendous tonnage of high-quality steel that would be needed during wartime. CE facilities' that were built for making 105-mm and 155-mm projectiles have since been cannibalized or dismantled, and currently there are no GE production lines in place. There are, however, many other applications of the basic CE process in making ammunition components.

Under the premise that materials for cold extrusion apply to munitions components other than deep cavity explosive-filled projectiles, selection is not restricted to steel. Nonferrous materials may be cost competitive and still satisfy end product performance requirements; they should be considered substitutes for steel not only to broaden the supply base but to increase availability during mobilization periods. For most extruded shapes mechanical properties can be guaranteed only in the direction parallel to the axis of extrusion. Yield and tensile strengths are slightly lower and elongation is much' lower in the transverse, direction than in the longitudinal direction.

4-2.4 MACHINING FROM SOLID WROUGHT STOCK

Most munition components' are not machined from wrought stock simply because production economy dictates otherwise. Components such as fuze adapters, fin booms, base sections for base ejection projectiles, combustible cartridge cases, and small automatic screw machine parts are normally machined from bar stock because this method is less costly. Prototype parts are often machined from wrought stock in support of product development requirements because the cost of tooling for other methods would be prohibitive for such small quantities. In many instances this procedure is also a viable alternative because design changes can be readily accommodated.

Machining takes on many different forms. Metal removal can be accomplished by milling, cutting, grinding, boring, and tapping. The approach to machining must include all of the factors that might influence product quality and reliability. Some of the more important factors are raw material; hardness; desired surface finish; size and shape of component part; size, power, and type of available equipment; component dimensional tolerance range; and potential of equipment to perform multiple operations.

Specifics regarding machining of munitions components will be included in discussions in Chapters 5 through 10.

4-2.5 DEEP DRAWING

A detailed discussion of this process, as it applies to the manufacture of deep drawn cartridge cases, is presented in Chapter 10.

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1. Donald Liddell and Gilbert E. Dean, *Principles of Metallurgy*, McGraw-Hill Book Company, Inc., New York, NY, 1933.
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CHAPTER 5
MANUFACTURE OF CONVENTIONAL HIGH-EXPLOSIVE (HE) AND OTHER DEEP CAVITY PROJECTILES

This chapter outlines the manufacturing processes, described in Chapter 4, that are applicable to the production of deep cavity projectiles.

5-1 INTRODUCTION

The manufacturing processes discussed in Chapter 4 must now be tailored to meet the design parameters of deep cavity projectiles. The 155-mm M107 HE and M549A1 high-explosive rocket-assisted (HERA) projectile have been selected for discussion in this chapter because they are representative of the deep cavity projectiles used in artillery weapons of all calibers. Major departures from the basic manufacturing process are presented to emphasize the need to recognize potential production problems early in the development stage. Revelation of incompatibilities between projectile design and production process at this time permits solution either byproduct redesign or enhancement of the production state of the art without significant delay in the life cycle schedule.

5-1.1 DESIGN PARAMETERS

Based on desired terminal effects, the design parameters are quite different for each projectile type. Deep cavity projectiles contain fillers such as high-explosive (HE), bulk white phosphorous (WP), and bulk chemical agents, which are loaded through the fuze cavity in the nose end. HE-filled projectiles produce fragments when activated by the fuze. On the other hand, WP and chemical agent fried projectiles are equipped with a fuze-activated central burster designed to break the projectile without fragmentation so that release of the filler is most effective.

All deep cavity projectiles must redesigned to withstand the launch environment. Forces exerted by propellant gas pressure, rotating band engraving, initial setback and acceleration dictate projectile wall thickness and mechanical properties. Projectile design parameters related to launch environment are discussed in greater detail in a military handbook entitled Design for Projection.

Whenever practical, ballistic match or similitude of the various projectiles in a family of ammunition is desired. This similarity simplifies the firing procedures because only one set of firing tables is required. Logistics are also simplified because a family of ammunition (projectiles) can use a common propelling charge.

5-1.2 PHYSICAL DESCRIPTION

5-1.2.1 155-mm M549AI HERA Projectile

The M549A1 projectile-shown in Fig. 5-l0— consists of a high-explosive warhead and a rocket motor. The warhead is fabricated from high-fragmentation HF-1 steel and contains a bulk filled explosive. The rocket motor is made from a high-strength steel alloy (American Iron and Steel Institute (AISI) 4340) with a welded overlay rotating band and contains solid rocket propellant. After HE loading, the warhead and rocket motor are joined as a threaded assembly. This projectile is used only in the rocket-assisted mock. A cap at the base of the projectile must be removed before cambering the projectile. Removal of this cap exposes a pyrotechnic delay to the propelling charge gases within the gun tube.

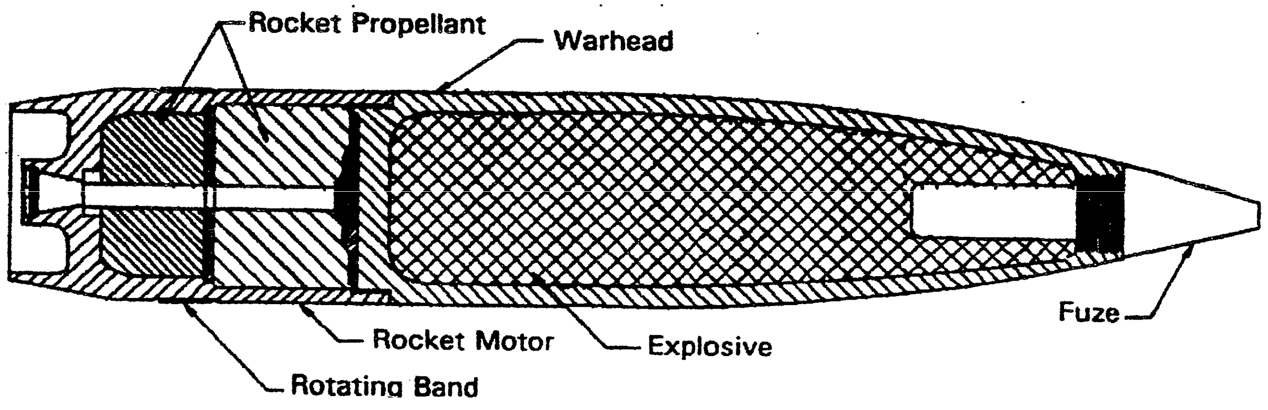

Figure 5-1. 155-mm HERA Projectile

The delay is ignited and burns for several seconds before igniting the rocket motor for its short, in-fright burn of about three seconds. The M549A1 projectile is delivered to the field with an energy-absorbing lifting plug (not shown), which is replaced by a fuze before it is loaded in the weapon.

The M549A1 projectile is used for fragmentation and blast effect against materiel and personnel. Overall length of the projectile assembly with fuze is 0.874 m (34.39 in.), and the as-fired weight is 43.54 kg (96.00 lb).

51.2.2 155-mm M107 HE Projectile

The M107 projectile-shown in Fig. 5-2—is a heavy-walled, medium-carbon steel projectile that contains an explosive charge of trinitrotoluene (TNT) or Composition B and a supplementary TNT charge. A gilding metal rotating band is swaged into a circumferential groove machined in the projectile body near its base end. A steel cover is welded to the projectile base to assure that hot propellant gases cannot come in contact with the explosive filler as a result of pipe or other voids in the base end created by the steel mill or forging practice. A threaded lifting plug (not shown) is used to close the fuze cavity for handling and storage; it is replaced by a fuze prior to loading the projectile into the weapon.

The M107 projectile is used for fragmentation and blast effects. The as-fired weight is 43.09 kg (95.00 lb), and its overall length with lifting plug is 0.698 m (27.50 in.).

5-2 MANUFACTURE OF HIGH-EXPLOSIVE PROJECTILE (M549A1 TYPE)

This projectile best exemplifies the current state of the art in metal parts manufacturing technology because it consists of a thin-walled, long ogive, high-fragmentation steel warhead (shown in Fig. 5-3 (B)), and an alloy steel rocket motor body with welded overlay rotating band (shown in Fig. 5-3(A)). Introduction of the MS49A1 into production with the new high-fragmentation steel HF-1 was preceded by significant studies regarding steel mill practice, steel chemistry, optimization of forging operations, evaluation of mult parting techniques, spheroidized annealing of forgings, heat treatment, machine tool materials and machineability. (Refs. 1 and 2). As a direct result of these preproduction studies, process controls and quality assurance measures were established and incorporated as part of the technical data requirerments. This in-depth approach may not be necessary to introduce every new item into production, but consideration should always be given to potential problems, especially with new materials, prior to release from research and development (R&D).

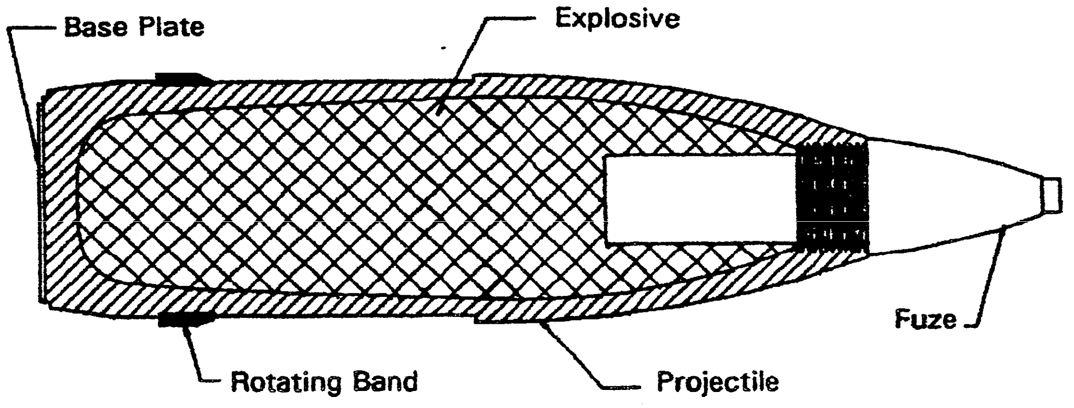

Figure 5-2. 155-mm M107 HE Projectile

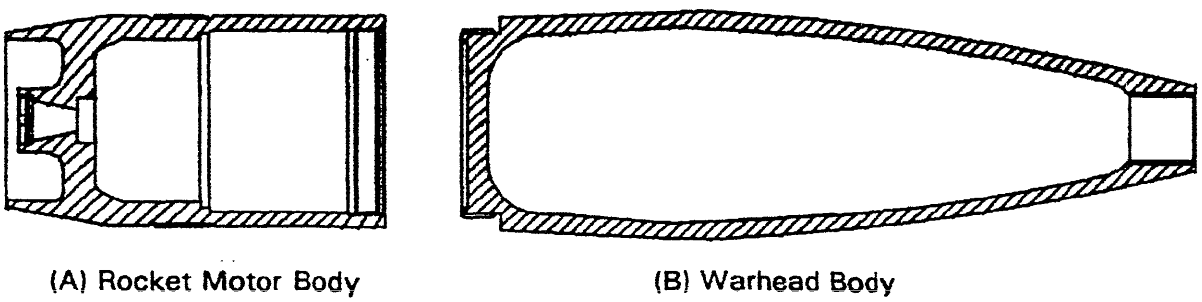

Figure 5-3. 155-mm M549A1 HERA Rocket Motor and Warhead

5-2.1 MANUFACTURE OF WARHEAD BODY

5-2.1.1 Design

The M549A1 projectile is fired with several propelling charges from 155-mm weapons and is capable of achieving a range of 30,000 m. The warhead is therefore subject to varying degrees of spin, setback, muzzle velocity, and chamber pressure while in the gun tube. it must not only successfully withstand these mechanical loads without deformation but also be capable of effective fragmentation when its explosive filler is detonated. Mechanical properties of the warhead body depend upon the shape, weight, moments of inertia, and center of gravity necessary to meet interior, exterior, and terminal ballistic requirements. Fragmentation of the warhead body is influenced by steel chemistry and heat treatment and the ratio of high-explosive charge to body mass.

Dimensional control of the warhead body is critical in that it is assembled to the rocket motor body after loading and the resulting threaded assembly must meet concentricity requirements normally applied to one-piece projectiles.

5-2.12 Selection of Manufacturing Process

Effective fragmentation dictates the use of high-fragmentation HF-1 steel in the manufacture of the warhead body. The high mechanical properties and chemistry of this steel preclude the use of mid-working to the degree normally associated with the cold extrusion and hot cup-cold draw (HC-CD) methods described in Chapter 4. The hot forge-heat treat (HF-HT) method is the most practical approach, but the process must be controlled carefully to assure production economy and product reliability. Factors that influence cost, quality, and replication are steel chemistry, steel mill cooling practice, mult parting method, forging process controls, rough machining practice, nosing operation, and heat treatment cycle (Ref. 2). Further discussion of these factors is included in par. 5-2.1.4.

5-2.1.3 Material Parameters

Special-purpose alloy steal known as HF-1 is used for the manufacture of the M549A1 warhead body. Chemistry, deoxidation practice, steel melting process, and internal soundness are specified under MIL-S-50783 (Ref. 3).

Quality of the steel as indicated by macroetch results must be equal to or better than A5, B3, and C8 of MIL-STD-1459 (Ref. 4) with defects D1 and D3 through D8 unacceptable. This steel alloy was developed by Bethlehem Steel Corporation for use in artillery warhead and mortar ammunition, and the right to have it manufactured by qualified steel suppliers, royalty free, has been granted under "Technical Data Rights and Patent License Agreement" contract DAAA09-72-C-0205. There is further discussion of high-fragmentation steel in par. 3-3.3.

5-2.1.4 Typical Sequence of Operations

The hot forge-heat treat (HF-HT) and machine process described in par. 4-2.1 represents the operations used to produce the M549A1 warhead body. Not all of the basic operations are always required and the sequence may vary. Sizing of any production line depends upon the number and caliber of projectiles to be produced on a continuing basis. The M549A1, as a two-piece 155-mm projectile, requires equipment over and above the type and number needed to produce a one-piece deep cavity projectile. Specific exceptions to the basic HF-HT process and the need for special equipment are addressed in the paragraphs that follow.

5-2.1.4.1 Forming Operations

Included in the forming operations are processing of the steel billets through heating to forging temperature, hot forging, rough machining, and forming of the ogive (nose) section. The sequence of shapes is shown in Fig. 5-4.

1. *Billet Separation.* Both cold sawing and nick and break methods have been used to part the mult from the main billet in preproduction studies with high-fragmentation steel. Cold-sawing is preferred because the sawed surface is clean with no structural degradation or crack-

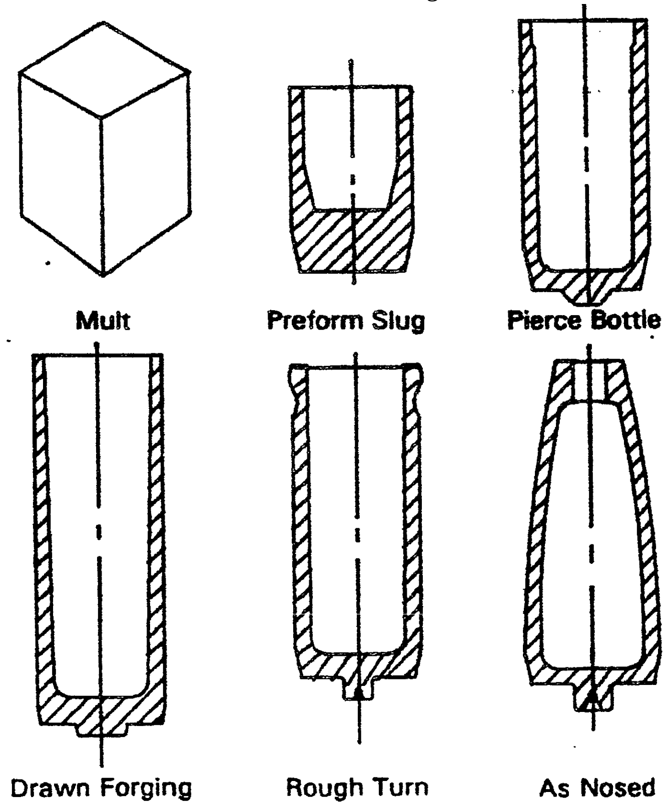

Figure 5-4. Sequence of Forming Operations, M549A1 Warhead Body

ing. Even though no abnormal defects were detected in experimental quantities of M549A1 warhead bodies made from mults separated by the nick and break method, the method is not recommended because there are cracks resulting from nicking that are visible in the heat-affected zone. These cracks are severe stress raisers and could propagate into major defects.

2. *Mult Heating.* Induction or gas-fired furnaces (described in par. 4-2.1.3) can be used to heat the M549A1 warhead body mult. A furnace temperature setting of 1149°C (2100°F) assures that the mult temperature will not exceed the allowable maximum for HF-1 steel. The actual temperature of the mult as it exits the furnace is 1093°C (2000°F). Considering the heat loss that occurs upon exit from the furnace, the temperature of the mult is about 1038°C (1900°F) when it enters the cabbaging (preform) operation. Particular attention must be given to scaling of the mult, which greatly affects the cavity condition for this projectile and material. A scale-reducing atmosphere (See par. 4-2. 1.3.) must be maintained in mult heating, or the mult must be passed through a high-pressure water descaler prior to forging.

3. *Hot Forging Operations.* Forging of the M549A1 warhead body follows the general practice described in par. 4-2.1.4. It is important that the forging presses have the tonnage and stroke to achieve the desired reduction in cross section and to accomodate the amount of workpiece elongation. Steel of HF-1 composition with a lower forging temperature requires a higher forging tonnage than conventional carbon or alloy steels. Preforming and piercing of the high-fragmentation steel mult require about 5.34 MN (600 tons); therefore, press capacity should be in excess of 7.12 MN (800 tons) to avoid overloading. Drawing of the forging requires a force of about 1.33 MN (150 tons) because metal deformation is far less severe than in the preceding press operations. Conveyor cooling of the forging to room temperature results in a microstructure and hardness of HF-1 steel that will permit rough machining by standard practice without the need for spheroidized annealing. Although rough turn tool life could be increased, the cost of spheroidized annealing is not justifiable.

4. *Rough Machining.* Centering and contour turning of the body forging follows the procedure described in par. 4-2.1.5. Again, the use of rugged metal turning equipment in conjunction with proper metal cutting feeds, speeds, and tools is essential for production economy. The need to improve continually tool design and materials cannot be overemphasized, especially with the introduction of projectile materials such as HF-1 steel. The outside profile at the open end of the forging influences the metal flow and formation of the thread flat area during the hot forming of the ogive. This is a critical operation in the manufacture of the M549A1 warhead body because of the length of the ogive, the permissible wall variation in the ogive sidewall, and the small radius behind the thread flat. Generally, the contour of the workpiece prior to nosing is best determined by the cut-and-try method.

5. *Nosing Operation.* The procedure described in par. 4-2.1.6 has been used successfully in hot forming the ogive section of the M549A1 warhead body. Preheating of the rough machined body forging is followed by application of a water-soluble graphite lubricant on the exterior surface of the area to be heated. An average nose area temperature of approximately 871°C (1600°F) is developed through induction heating. Nosing die tooling press stroke, nosing temperature, and contour of the prenosed forging are interdependent and must be developed concurrently to assure that the final contour of the ogive section is geometrically correct and its metallurgical structure is sound.

Because of the long ogive of the M549A1 warhead, a second nosing operation is required to assure all dimensions are within tolerance. This nosing operation is performed with the same tooling but at a temperature of 316°C (600° F).

5-2.1.4.2 Thermal Treatment

Although the metallurgical structure of the warhead body after nosing is stable, it should be heat treated as soon as practicable and in a manner similar to that described in par. 4-2.1.7. Because HF-1 steel has a greater propensity for quench cracking than most other alloy steels, the hardening or austenitizing temperature range should be held between 802° and 8 16°C (1475° and 1500°F), and the oil quench temperature should be maintained at 66° to 71° C (150° to 160°F). The warhead is then drawn at a temperature of approximately 538°C (1000°F), and the mechanical properties are checked immediately after the heat treated part has cooled down. Once the minimum yield strength, elongation, and fracture toughness have been checked in the bourrelet side wall area and base section for a specific heat treatment cycle, the consistency of the operation is checked by hardness testing, which is discussed further in Chapter 12. Minimum yield strength of 931 MPa (135 ksi) and elongation of 4% in the transverse direction in the base section are almost the same as those required in the longitudinal direction 965 MPa (140 ksi) and 5% elongation in the bourrelet section. Therefore, the heat treatment process must be carefully controlled (Ref. 5).

5-2.1.4.3 Finish Operations

Machining, surface preparation, and painting of the M549A1 warhead body are essentially the same as described in par. 4-2.1.8. There are several exceptions to the general sequence because of the rear external thread and the absence of a rotating band. The following is the sequence of finishing operations:

1. *Shot Blast.* Although the oxygen-reducing atmosphere in modern heat treatment furnaces minimizes scale formation, it may not completely eliminate surface oxidation; therefore, shot blasting of the warhead cavity surfaces-as shown in Fig. 4-10—may be required. Shot blasting assures that the cavity surface will meet finish requirements for loading with HE filler. Shot blasting of the exterior surfaces normally would not be required because scale can be removed during subsequent metal removal operations without significant effect on machineability.

2. *Bore, Face, and Chamfer.* The setup for this operation is similar to that shown in Fig. 4-12 and described in par. 4-2.1.8.4. This operation is particularly important in the machining of the M549A1 warhead body because it establishes the alignment between fuze thread flat surface and the center lug at the base end.

3. *Finish Turn Ogive and Body Section.* Exterior contour except for boattail and rear threads is machined in a manner similar to that described in par. 4-2.1.8.2; the setup for chucking and centering the warhead body is shown in Fig. 4-13. The concentricity of the cylindrical section of the warhead body with the fuze thread flat is established during this machining operation.

4. *Face Base and Cut Base Thread.* To assure that the base thread area also is concentric with the cylindrical seetion, the warhead body is held in a hollow chuck in a setup similar to that shown in Fig. 4-14. The base threads may be cut in this setup or machined separately, but holding the warhead in a hollow chuck is the most practical way to meet the dimensional requirements. Nose threads also can be machined in this setup or separately by using the body diameter as a reference surface.

5. *Grind Bourrelet.* Centerless grinding of the bourrelet surfaces-as shown in Fig. 4-17-may be required if surface finish and diameter tolerance cannot be met in the finish machining operation.

6. *Inspect.* Dimensional inspection may be accomplished at this point because no further machining is expected. Cavity surface defects and profile are generally checked prior to nosing of the warhead body. Other than visual inspection of the interior surfaces and checking of the wall variation, dimensional inspection is primarily for those characteristics influenced by finish machining operations. At this point, magnetic particle, hydrostatic, eddy current, and ultrasonic tests are conducted to assure compliance with requirements for metal soundness and strength. Parts that have successfully passed this inspection are permanently identified by metal stamping. ‘These types of nondestructive tests are further explained in Chapters 11, 12, and 13.

7. *Clean, Phosphate, and Rinse.* Metal surfaces are prepared for painting by applying a zinc phosphate base as shown in Fig. 4-21 and described in par. 4-2.1.8.10.

8. *Paint Cavity Surface.* Interior surfaces are coated with priming paint that is compatible with the HE filler. Fuze threads are masked so that no paint is deposited in that area.

9. *Paint Exterior Surfaces.* Prior to application of paint the exterior surfaces are primed; priming results in better protection during salt spray tests. Painted warhead bodies are baked at a temperature of 107°C (225°F) and stored for one day prior to shipping. Ring gaging of the bourrelet diameter is done at elevated temperature to assure that a warm projectile will fit in a cooler weapon.

5-2.2 MANUFACTURE OF ROCKET MOTOR BODY

The rnotor body has a recessed nozzle on its central spin axis. It is made from a high-strength steel alloy (aircraft quality AISI 4340).

The most practical process for making the rocket motor body is hot forge-heat treat and machine because it is compatible with forming and machining 4340 steel and can satisfy the minimum yield strength requirement of 1241 MPa (180 ksi). Welded overlay rotating band application allows sufficient body wall thickness under the band to withstand chamber pressure and engraving forces. Machining of the body prior to heat treatment must be controlled to avoid sharp corners, surface irregularities, and abrupt changes in (cross section thickness that could contribute to quench cracking during heat treatment. Once the welded overlay has been deposited, the motor body must be stress relieved or heat treated within eight hours to avoid crack formation in the heat affected zone.

5-2.2.1 Material Parameters

Selection of AISI 4340 aircraft steel is predicated on excellent response to hardening and ability to meet the minimum yield strength requirement of 1241 MPa (180 ksi) with minimum elongation of 10%. Aircraft quality stock is specified to assure a high quality level with regard to allowable surface defects and inclusions. After controlled cooling from forging temperature, 4340 steel requires no unusual practice to meet dimensional requirements.

5-2.2.2 Typical Sequence of Operations

Typical sequence of shapes is illustrated in Fig. 5-5. Final machining is accomplished after heat treatment to meet dimensional and surface finish requirements. Also the required internal configuration contains sharp corners and controlled radii, which are potential stress raisers if present during heat treatment. The type of equipment used to make. this component is similar to that described for the hot forge-heat treat and machine process described in par. 4-2.1.

Figure 5-5. Sequence of Shapes, M549A1 Rocket Motor Body

5-2.2.2.1 Forming Operations

The sequence of forming operations is described in the paragraphs that follow:

1. *Bar Separation.* Cold-sawing of the bar is the recommended procedure for producing individual mults. Either circular or band saws maybe used. Deburring of the mult edges is done where require&and the heat code is stamped on the cut surface that will eventually be the base end of the motor body when hot forged.

2. *Mult Heating.* Induction or gas-fired furnaces can be used to heat the mult to forging temperature. The procedure is similar to that described in par. 4-2.1.3.

3. *Hot Forging Operations*. The heated mult is cabbaged (preformed) and pierced (backward extruded) as described in par 4-2.1.4. The base and nozzle projection are partially formed during forging to reduce scrap loss and machining cost in subsequent operations.

4. *Rough Machining.* Metal removal from the forging reduces the eccentricity between internal and external surfaces and establishes a profile for application of a welded overlay rotating band and subsequent finish machining operations. Although the type of equipment and setup for rough machining may differ from that described in par. 4-2.1.5, metal removal prior to heat treatment leads to production economy and dimensional accuracy of the finished machined part. Inspection at this point is critical because, prior to heat treatment, the part must comply with preestablished configuration to preclude the possibility of quench cracking.

5-2.2.2.2 Rotating Band Application

The copper rotating band is overlay welded prior to heat treatment. If the rocket motor body cannot be heat treated immediately after application of the welded overlay, it should be stress relieved to avoid stress cracking. The method employed is similar to that described in par. 4-2.1.8.7; however, once process controls have been developed to produce consistently acceptable parts, proposed changes must be carefully scrutinized because of the stress cracking potential of 4340 steel.

5-2.2.2.3 Heat Treating

The procedures and equipment used for heat treating the rocket motor body are similar to those described in par. 4-2.1.7. There is a specific restriction on the maximum time interval between quenching and tempering; this limit (30 min) is established because 4348 steel exhibits a propensity for quench cracking. Conformance with MIL-H-6875 (Ref. 5), which covers the heat treatment process, is mandatory. Although it is essential that minimum mechanical properties be achieved, there must also be a conscious effort during heat treatment to limit the maximum material hardness to assure reasonable machinability in finish turning operations. Mechanical properties are checked after heat treatment to assure compliance.

5-2.2.2.4 Finish Operations

These operations consist of shot blasting, finish machining of body and rotating band, thread turning, knurling, surface preparation, painting, and packaging. The number of interdependent dimensions and their tolerance limitations preclude multiple machine transfers of this part in performing finish machining operations. Computer numerical control (CNC) lathes are ideally suited for finish turning of this item because of their versatility.

1. *Shot Blast.* Interior surfaces are shot blasted, where necessary, to remove scale and provide a clean surface for internal chucking of the part in the first finish machining operation.

2. *Finish Turn Front Bourrelet Section.* The rocket motor body is internally chucked on an expanding mandrel, and the outside surface forward of the welded overlay rotating band is machined to final size. This machined surface then becomes the reference for all subsequent metal removal operations.

3. *Finish Turn Outside Profile.* The front bourrelet section is held in a hollow chuck with the base end exposed, and finish turn operations are performed on the rotating band, rear bourrelet, boattail, and base end.

4. *Finish Turn Body Cavity Surfaces.* The part is

reversed and rechucked on the front bourrelet section with the front end exposed for finish machining of the cavity, counterbore, and threaded section.

5. *Inspection.* Upon completion of the finish machining operations, the part is subjected to quality conformance inspections. These inspections include measurement of dimensions, surface finish, magnetic particle testing, and base metal penetration at the rotating band weld interface. With the exception of examination for base metal penetration, inspection is nondestructive. General details regarding dimensional and nondestructive testing are included in Chapters 13 and 14. Inspection throughout the production process is continuous, but without in-process inspection removal of nonconforming material would not be done on a timely basis.

6. *Surface Preparation.* All surfaces except the rotating band are cleaned, phosphate coated, and rinsed. Acid pickling is not recommended as a cleaning method for rocket motor body steel over RC40 hardness because of the hydrogen embrittlement potential of steel. A pretreatment coating, such as wash primer, maybe used if necessary to meet salt spray test requirements after painting. See par. 4-2.1.8.10 for further discussion.

7. *Painting.* All exterior surfaces except the rotating band and knurled face are coated with lusterless olive drab paint. The coating thickness must be at least 25.4 um (1.0 mil), and the painted surface must successfully withstand a 48-hour salt spray test. See 4-2.1.8.11 for further discussion.

5-3- MANUFACTURE OF HIGH-EXPLOSIVE PROJECTILE (M107 TYPE)

The 155-mm M107 represents a heavy-walled, deep cavity projectile design that is the basis for an ammunition family used in 105-mm through 8-in. artillery weapons. This type of projectile has been successfully produced by cold extrusion, hot cup-cold draw, and hot forge-heat treat and machine methods. Manufacturing facilities are in place for all methods described in Chapter 4 except cold extrusion, which is no longer considered practical. The prognosis for manufacture of new generation one-piece, deep cavity projectiles, however, is that the hot forge-heat treat and machine method, as tailored for the M549A1 warhead, will be the most practical.

Projectiles in the M107 family of ammunition have essentially the same exterior profile, center of gravity, and weight. With very minor adjustments in firing procedure, each of the projectiles in the family can be ballistically matched. Mechanical properties of the M107 type are less than those specified for thin-walled projectiles and therefore can be made from medium carbon steel Also there is sufficient wall thickness to support seating of the rotating band by swaging. The M107 type is representative of the majority of the current ammunition stockpile, and the M804 training round is being produced to provide projectiles for training of troops. However, the more effective low drag shape represented by the 155-mm M483 and M549A1 projectiles may replace it in the future.

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CHAPTER 6
MANUFACTURE OF CARRIER PROJECTILES

This chapter covers the manufacturing processes involved in the production of carrier projectiles.

6-1 INTRODUCTION

Carrier projectiles carry payloads that are ejected through the base when a charge in the ogive is initiated. In most cases these payloads are multiple subprojectiles, which are ejected in the airburst mode and dispersed over a wide area in the target zone. The subprojectiles are designed to be lethal bomblets, obscurating or incendiary smoke pots, or delayed action mines. The carrier projectiles differ from the standard deep cavity shell in that the projectile does not detonate and fragment because carrier projectile effects are caused by the payloads.

6-1.1 DESIGN PARAMETERS

Carrier projectiles are designed to be fired in the same manner from the same weapons as the standard unitary charge high-explosive (HE) or deep cavity projectiles. In the 155-mm family of projectiles there are several different payloads that can be delivered from one basically identical 155-mm M483A1 carrier projectile body. This family of' projectiles, which includes those called improved conventional munitions (ICM), can contain dual-purpose grenades, antitank mines, antipersonnel mines, white phosphorous (WP), smoke segments, or binary canisters, all of which are ballistically matched to the unitary charge M795 HE projectile. Older carrier projectiles, which ballistically match the 155-mm M107 HE projectile, are the smoke canister type and the M485 illuminating round.

In addition to the variety of projectiles for various ground effects, the major advantage of the carrier projectiles over the so-called conventional munitions (unitary HE) is the increased lethal area coverage that is attained by expulsion and dispersion of submissiles. As an example, the lethal area coverage of a 155-mm HE M483A1 projectile against prone personnel targets is 12 times the lethal area covered by a single 155-mm HE M107 projectile (Ref. 1).

6-1.2 PHYSICAL DESCRIPTION

As mentioned, the l55-mm projectiles provide a variety of rounds with different payloads, whereas the 8-in. family has only the M509, which is a counterpart to the 155-mm M483 submissiled round. There are no carrier rounds for tank munitions. Mortar rounds include illuminating and smoke projectiles, and submissiled projectiles' are being developed for the larger caliber mortars. Descriptions of the 155-mm HE M483A1, Smoke M825, and Illuminating M485 follow.

6-1.2.1 Carrier Projectiles (155-mm M483A1 Submunition Type)

The 155-mm HE M483Al (See Fig. 2-13(B) for its configuration.) is an ICM projectile containing 88 dual-purpose grenades (64 M42 and 24 M46). The M42 grenade is embossed on the inside wall surface to provide controlled fragmentation effects. The M46 grenade has a stronger unembossed body that is able to withstand the greater load seen at the rear of the projectile due to setback upon firing. An M577 mechanical time fuze, assembled to the projectile, is preset to function over the target area and initiate the expulsion charge assembly, which is contained in a cavity in the ogive of the projectile. The force of this charge, acting upon the pusher plate, is transmitted through the grenades to the base plug shearing the threads that secure the base in the shell and expelling the grenades from the aft end of the projectile. The combination of projectile spin and forward velocity disperses the grenades to form an oval ground pattern. Upon expulsion from the projectile a nylon ribbon stabilizer deploys, which arms and orients the grenade. On impact the inertia of the arming screw and weight assembly drives the point of the screw into an M55 detonator, which initiates the firing train A shaped charge jet capable of penetrating armor plate is directed downward while the grenade body bursts into a large number of small fragments to provide the antipersonnel effect.

6-1.2.2 Carrier Projectile (155-mm M825 Smoke Type)

The 155-mm WP M825 (See Fig. 2-15(B) for the configuration.) produces a ground screening smoke of 5-to 10-min duration. The smoke is produced by burning multiple wedge-shaped pieces of felt that have been saturated with WP. The system consists principally of the projectile carrier (M483A1 body) and the payload (felt wedge WP). The projectile carrier consists of an M483A1 ogive and expulsion charge, a modified M483A1 all-steel body, and a steel, domed base. The payload consists of wedges in a hermetically sealed, thin-walled steel canister containing a central burster charge. Upon expulsion a 0.1-s delay is activated and provides ample time for the canister to clear the heavy-walled projectile body before the burster functions. In less than 45 s a dense and uniform smoke screen is created by the burning WP-saturated felt wedges. Unlike conventional WP munitions the M825 need not be stored base down. Absorption of the WP in the felt wedges prevents WP migration and an associated center of gravity shift.

6-1.2.3 Carrier Projectile (155-mm M485A2 Illuminating Canister Type)

The 155-mm illuminating M485A2 projectile (See Fig. 2-14 for configuration.) employs a double ejection system wherein the payload canister is ejected by the primary expelling charge, which is located in the ogive section. The canister, which contains the candle assembly and main parachute, has a secondary expelling charge. The mechanical time fuze functions the primary expelling charge to expel the cargo, a drogue chute deploys, and the canister fins extend to decelerate and stop rotation of the canister. A delay element ignites the secondary expelling charge in the canister after 8s, which ignites the illuminant candle and expels the main parachute. The illuminant candle has a descent rate of 4.6 m/s (15 ft/s), bums for 120 s, and produces approximately 1,000,000 candlepower.

6-2 MANUFACTURE OF PROJECTILE 155-mm M483A1

The M483A1 projectile, shown in Fig. 6-1, is multiple piece consisting of an aluminum ogive, a steel body, and an aluminum base.

6-2.1 MANUFACTURE OF PROJECTILE BODY

6-2.1.1 Design

The body is a hollow cylindrical steel shape threaded at both ends. It has a welded overlay rotating band. (See par. 4-2.1.8.7 for discussion.) The body diameter has a fiber-glass-wrapped section on the M483 to maintain the proper center of gravity for its particular payload.

6-2.1.2 Selection of Manufacturing Process

The basic hot forge-heat treat (HF-HT) and machine method of manufacture (See par. 4-2.1 for discussion.) was selected for the body since a minimum yield strength of 965 MPa (140 ksi) is required by the M483A1 design. However, additional machining operations are needed on the carrier bodies compared to the conventional HE projectile because carrier projectiles require that the bodies be internally bored in order to mate with the payloads.

6-2.1.3 Material Parameters

The material selected for the basic body is an alloy steel, American Iron and Steel Institute (AISI) 1340 or AISI 4140, (See par. 3-3.2 for discussion.) capable of meeting the requirement of 965-MPa (140-ksi) mechanical properties with proper heat treating procedures. The material selection is limited to this 0.40% carbon content because of the overlay band welding operation; this carbon limitation also allows a cold ironing operation to be incorporated in the forming sequence.

6-2.1.4 Typical Sequence of Operations

The major operations required to fabricate the M483A1 body are as follows:

1. Separate billet
2. Cabbage and pierce
3. Draw and pierce nose, slow cool, shot blast inner diameter (ID)
4. Rough turn outer diameter (OD)
5. Cut off, finish turn band seat, bore ID of nose and face
6. Weld the rotating band, stress relieve, rough turn band
7. Heat treat, quench, temper, and cool
8. Finish turn OD
9. Finish bore ID
10. Bore, face, and chamfer
11. Slot keyway and deburr
12. Grind front and rear bout-relets
13. Wash and phosphate
14. Fiberglass wrap and cure
15. Finish turn fiberglass
16. Finish turnband.

6-2.1.4.1 Billet Separation, Descaling

The billet, a 133-mm (5.25-in.) round-cornered square approximately 6.1 m (20 ft) in length, is placed on a rack that automatically feeds the billet onto a roller conveyor leading to an induction heating unit where it is hot

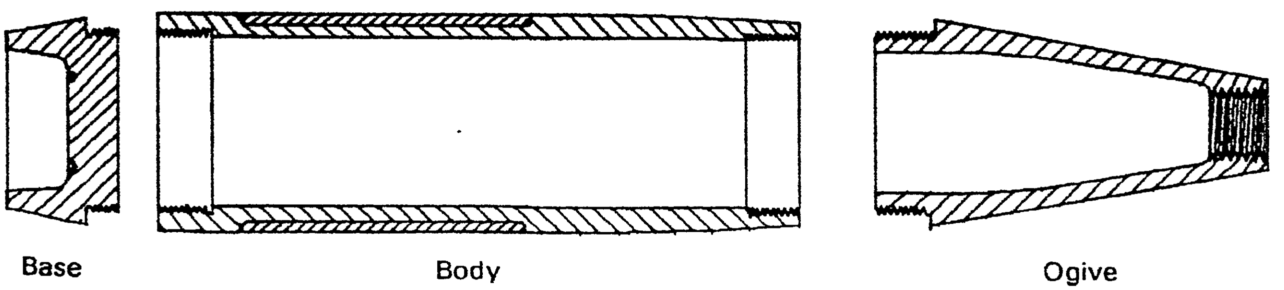

Figure 6-1. 155-mm M483A1 Components

sheared to mult length. Controls to monitor temperature and weight are incorporated, and descaling is automatically performed immediately after the shearing operation. Removal of scale is of utmost importance to prolong punch and die life and to prevent embedment of scale in projectile surfaces. The hot shear method of separation was selected because it can be used for all alloy material selections.

6-2.1.4.2 Cabbage and Pierce

This operation is performed by a multistation 22.24-MN (2500-ton) mechanical press containing a ram-mounted punch and a base-or bed-mounted die pot. The hot-sheared mult is subjected to two forming operations, which are accomplished progressively as the mult moves through the press. Specific forming operations are

1. *Cabbage.* The hot, descaled mult is placed in the die pot. The press ram descends, and the punch partially pierces and upsets the upper end of the mult while forming a cylindrical shape with an ogive taper on the lower end. This shape facilitates centralization of the workpiece in the die and provides a pocket for guiding the punch during the piercing operation while maintaining comcentricity.
2. *Pierce.* The preformed workpiece is mechanically moved to the pierce die pot. When the press is cycled, the punch descends, pierces the workpiece to a specified web thickness, and completes the ogive taper. The pierced cavity is slightly oversized to permit entrance of the draw punch in the next operation.

6-2.1.4.3 Draw and Punch Out Nose, Slow Cool, Shot Blast Inner Diameter

The pierced mult is further reduced in diameter and elongated in a long-stroke, 4.45-MN (500-ton) hydraulic press. The draw press tooling consists of a punch, centralizing holder, draw rings, stripping devices, and a specially adapted punch-out die fixture. The workpiece is mechanically placed in the centralizing holder and is pushed by the lubricated punch through lubricated draw rings, which successively reduce the diameter and increase the overall length. The stroke of the press continues, and the workpiece web is punched out during the last part of the press stroke. The press then reverses, and the workpiece is removed from the punch by a stripping device located beyond the last draw ring. The forging, as it leaves this operation, has rough cavity dimensions with sufficient material on its outer and inner surfaces to accommodate subsequent machining operations. The hot forging is inspected for overall length, length of thread stock, concentricity, presence of bow, and cavity diameter.

The forgings are then conveyed through cooling tunnels in which they are cooled at a controlled rate to maintain a uniform microstructure and hardness range. When cooled, the ID is shot blasted to remove scale and provide a clean surface for gaging and chucking in subsequent turning operations. The same parameters inspected under hot gage are now inspected cold by using automatic air or electronic gaging.

(If the alternate method of cold-, instead of hot, drawing is employed, both the ID and the OD of the cooled forging with punched out nose are shot blasted since the subsequent concentricity turn does not necessarily clean up the total circumference of the forging.)

6-2.1.4.4 Rough Turn Outer Diameter

The OD of the forging is now turned in a lathe using-an expanding mandrel to locate on the ID. During this operation the item is also cut to length.

If the alternate cold-draw method is used, the OD of the forging is now turned in a lathe using an expanding mandrel to locate on the ID. This operation establishes a better concentricity between the ID and OD and improves the OD surface for cold-drawing.

6-2.1.4.5 Cold-Draw, Stress Relief

The forging is now pickled with a light etch to remove oil and grease. It is then phosphate and lubricated with a soap compound. This lubrication reduces the resistance of metal flow during the cold-draw operation, improves the die life, and prevents tearing of the projectile during the draw operation.

The cold-draw operation is performed on a long-stroke, 4.45-MN (500-ton) hydraulic press containing a punch-centralizing holder, draw ring, and stripping device. The forging is received from the previous operation and placed in the centralizing holder. It is then pushed by the punch through the draw ring to reduce the diameter and increase the length. The stroke of the press continues and the workpiece contacts a coining die. The press releases pressure after setting the internal cavity radius. The press stroke now reverses, and the forging is removed from the punch by a stripping device located beyond the draw ring. The forging now has rough cavity dimensions and sufficient material on its outer and inner surfaces to accommodate machining operations. This draw is a cold-sizing operation, which accomplishes a minimum reduction of the wall cross-sectional area, but forms the cavity closer to drawing requirements, and results in elimination of a rough boring operation.

Next the body is placed in a furnace heated to a temperature of 649°C (1200°F) for 30 min and then air-cooled. (This operation is required to relieve residual stresses induced during the cold draw operation, and it minimizes intergranular penetration during band welding).

6-2.1.4.6 Cut Off, Finish Turn Band Seat, Bore ID of Nose and Face

A lathe similar to that used in the prior turning operation is employed to accomplish the finish turn of the band seat. Simultaneously another tool bores the inside diameter of the nose and then faces the nose end. (When cold-drawn projectiles are turned, a cutoff tool is employed to cut the projectile to length.)

6-2.1.4.7 Weld the Rotating Band, Stress Relieve, Rough Turn Band

The combination of the high-strength requirement and the thin-walled design of the M483A1 body dictates the use of a welded overlay band since a conventional band seat would weaken the structure rind the body would not be able to withstand swaging pressures of applying a band without distortion. The welded band is applied using the gas metal arc welding procedure outlined in Chapter 4. This application uses a hot wire of 99% copper to specification, i.e., MIL-E45829(Ref.2), and a cold wire of brass composition. The result is a band strong enough to withstand the engraving and rotational forces developed on firing.

Control of the arc length and erosion of the steel body is essential. After application the band material is periodically checked for iron content, which is an indication of the quality of the weld on the projectile and of the degradation of the band seat wall. The test can be made by turning off a small amount of the band, dissolving it in acid, and plating a sample in a gas absorption atomic spectrophotometer flame to determine the iron content. The test can be done in about 15 min and is an invaluable tool to use to determine when a welding machine is going out of tolerance.

Projectiles are then placed in a lathe equipped with an expanding mandrel, and the welded overlay band is rough turned to reduce the amount of copper on the projectile body, which acts as a heat sink and could cause problems in the overall heat treatment.

6-2.1.4.8 Heat Treat, Quench, Temper, and Cool

Heat treating of the body consists of the standard process of austenitizing, quenching, tempering, and cooling to develop the mechanical properties inherent in the material selected to make the body. The process used for the M483 is essentially that outlined in Chapter 4, which uses a gas-fired furnace with controlled atmosphere, an oil-quenching medium, and a gas-fired tempering chamber. Since this projectile is open at both ends, problems with trapped steam or gases in the cavity are not present; therefore, thorough quenching is easily maintained.

Each projectile is hardness tested, and t he hardest and two of the softest projectiles from the heat-treated lot are sectioned and tested for yield strength and elongation to assure that the hardness spread meets mechanical properties requirements.

6-2.1.4.9 Finish Turn Outer Diameter

The heat-treated projectiles are then turned in a lathe, which develops the finish-turned dimensions. Either a hydraulic tracer lathe with multiple tools or a computer-numerical-control (CNC)-type lathe may be used here. The tracer lathe has the advantage of reducing the cutting time due to the multiple tool setup; however, the CNC lathe can be employed to final turn the bourrelet dimensions and thereby eliminate the subsequent centerless grinding operation discussed in par. 6-2.1.4.12.

6-2.1.4.10 Finish Bore 113, Wash, and Magnetic Particle Inspect

This equipment consists of a vertical or horizontal, hollow spindle automatic boring machine. The body is located from the base end and is chucked on the rear bourrelet. The ogive end of the body is centralized by a live ring center. The boring bar consists of multiple cutters with wear guide pads to prevent hole runout. Chips are flushed away by the cooling fluid, which is under pressure.

Then the projectiles are washed by a vapor degreaser or an alkaline bath and subjected to a magnetic particle inspection for metal soundness using the wet fluorescent method discussed in Chapter 14.

6-2.1.4.11 Bore, Face, and Chamfer

The equipment used for this operation consists of a center drive, hollow spindle, CNC automatic machine. The body is located from the base end and centered on the front bourrelet. The rear bourrelet provides the area for driving. Both ends of the body are machined at once followed by threading of both ends.

6-2.1.4.12 Slot Keyway and Deburr

The keyway is made with a specially designed keyway slot cutter. The body is located from the base end and chucked on the outside using bourrelet dimensions and ogival datum diameter locations. The machine operates with a reciprocating motion, and there is a form cutter at the end of the bar that is inserted into the cavity, cam indexed for depth of cut, and hydraulically pulled to the rear to complete the cut. Successive cuts are made until the slot is complete.

An alternate method of forming a slot is by electrochemical machining (ECM), as used on the 8-in. M509 projectile. This equipment uses a cathode form to duplicate the slot, which, in the M509, is a close-toleranced dovetail shape. The equipment is progressively pushed through the bore using a reverse electroplating process in which the metallic ions from the anodic body are prevented from plating onto the cathode by a continuous flushing of the gap between the cathode and body with an electrolyte fluid. (Ref. 3)

6-2.1.4.13 Grind Front and Rear Bourrelets

Equipment for this operation is a centerless grinding machine, which finishes both front and rear bourrelet diameters to final dimensions arid maintains the surface finish values. Infeed-type grinding is used and adjustment of' the grinding wheel to compensate for wheel wear is automatically accomplished by control devices, which check the diameter and surface finish.

6-2.1.4.14 Wash and Phosphate

The surface treatment of the machined body is accomplished in a conveyorized, five-stage spray unit consisting of alkaline cleaning, hot water rinse, zinc phosphate coating, cold water rinse, and a chromic acid rinse. Both ID and OD surfaces of the body are treated. An automatically controlled sensing and replenishment unit is used to control the concentration of the processing baths.

6-2.1.4.15 Fiberglass Wrap and Cure

The phosphate bodies are placed in a special machine that locates the bodies at front and rear and rotates them while a special fiberglass filament is applied. The filament is run through an epoxy bath or a spray device, which meters the proper mixture of a resin adhesive and hardening agent, and then is wound on the rotating projectile body. An alternate method of applying the wrap is to use a filament-winding machine, which applies the impregnated filament to stationary projectiles in a vertical position. These machines allow several projectiles to be wrapped at the same time. After the bodies are wrapped they are conveyorized through a curing oven. Curing time is about 30 min at a temperature of approximately 80°C (175°F) and is followed by an ambient cure of 2.5 h.

6-2.1.4.16 Finish Turn Fiberglass

Automatic lathes are used for this operation. The projectile body is located against the base end by an internally expanding mandrel located in the area near the base and forward of the thread area. The nose end of the projectile body is centralized by a live ring centralizer on the ogive area. An alternate method is to grind the fiberglass surface while either wet (using coolant) or dry.

6-2.1.4.17 Finish Turn Band

Semiautomatic-tracer-type turning lathes are used to rough turn, skive, trim, and form the gas check grooves of the rotating band. The projectile is located against the base end and is driven by the cavity on an internally expanding mandrel located in the base and forward of the thread area. The nose end of the projectile body is centralized by a live-ring-type centralizer contacting the ogive area.

6-2.1.5 Body Manufacturing Differences for the M825 and M485A2

The body for the M485A2 projectile-shown in Fig. 6-2—follows essentially the process used for the M 107 HE projectile except that the base end is punched out in the forging operation and the interior cavity is bored similar to the operation performed on the M483. Since the M485A2 has a heavy wall and an integral ogive shape, nosing, band application, and nose-threading operations follow the M107 procedures discussed in Chapter 5.

The M825 body follows all the procedures for the M483 but it does not include the fiberglass wrap and requires only a 57-mm (2.25-in.) long keyway.

6-2.2 OGIVE AND BASE MANUFACTURE

6-2.2.1 Selection of Manufacture Process

The hot forge method of manufacture using sawed billets was selected to assure a smooth interior surface and resulted in a cavity requiring no contour machining.

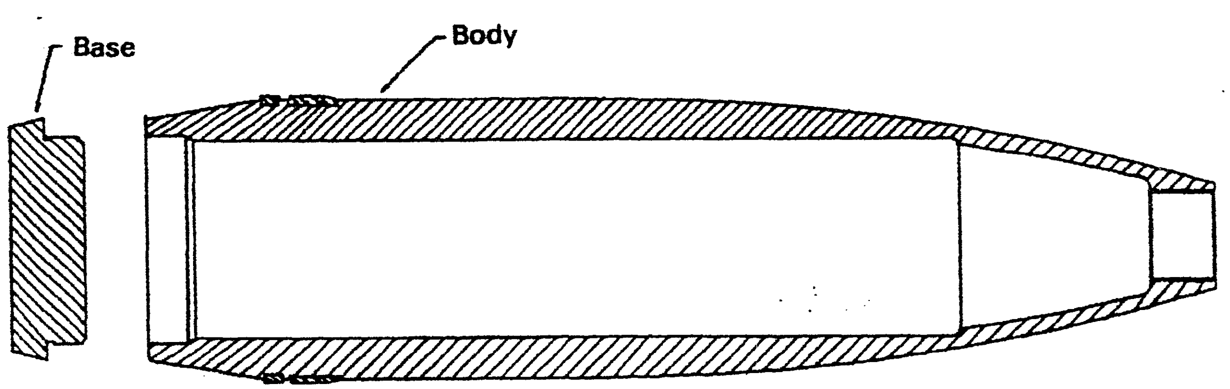

Figure 6-2. 155-mm M485A2 Components

6-2.2.2 Material

The material selected for both components is aluminum alloy 7175. After forging it is artificially aged to the T736 condition described in Chapter 3 to meet the required mechanical properties.

6-2.2.3 Typical Sequence of Operations

The major operations to fabricate the M483A1 ogive are

1. Saw billet
2. Heat billet
3. Forge ogive and punch out nose
4. Heat treat, artificially age, and test hardness
5. Turn taper, rear shoulder and thread flat, and face front and rear ends
6. Bore, finish face, chamfer, and thread front end
7. Finish form rear shoulder and O-ring groove and chase thread
8. Hydrostatic test
9. wash
10. Anodize.

Operations 1, 2, and 4 are identical for the base. Operation 3, however, uses the same type of press to forge, but the secondary operation of punching a hole is not necessary.

The remainder of the operations are standard machining types except that the ogive requires a hydrostatic test (See Chapter 13 for discussion.) to determine splits, seams, and porosity. The base is hard-coat anodized to withstand erosion from the propellant at high temperatures, but this is not necessary for the ogive (Ref. 4).

6-2.2.4 Manufacturing Difference for M825 and M485A2 Ogives and Bases

6-2.2.4.1 Ogives

Since the M825 has the same ogive as the M483 and the M485A2 has an integral ogival shape, there are no manufacturing differences.

6-2.2.4.2 Bases

The M825E1 base, shown in Fig. 6-3, differs from the M483 base in that the M825E1 is made of steel and has a different contour. The sequence followed is basically that for a HF-HT part (Chapter 4) with machining operations similar to those used on the M483 base. Since it is made from steel, the finish machined item is cleaned, phosphate, and painted for surface preservation of other than the threaded area.

The M485A2 base plug is a simple unthreaded steel plug made from medium carbon steel (AISI 1045) heat treated to a yield strength of 469 MPa (68 ksi). Either cold-rolled bar to Specification ASTM A 108 (Ref. 5) or hot-rolled bar, special quality, to Specification ASTM A576 (Ref. 6) may be used, but the mults, sawed or

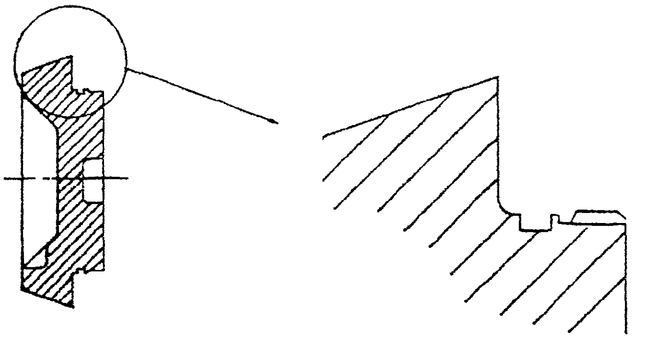

Figure 6-3. Base, 155-mm M825

sheared from the bars, must be cross-forged to assure that the grain flow is across the base and perpendicular to the centerline of the base.

The cross-forged plug is machined in a multispindle chucker or two CNC lathes. The base is held in place in the loaded item by using a press fit supplemented by shear pins inserted from the circumference of the body after drilling the assembled base and body and twist pins inserted in holes drilled through the base into the aft end of the body when assembled.

6-3 BODY AND OGIVE ASSEMBLY

6-3.1 APPLY THREAD SEALANT', THREAD, AND TORQUE

The body and ogive are placed in a fixture in which a ring seal is positioned on the ogive and both body and ogive threads are coated with a two-part polyester thread sealant. The threads of the parts are immediately engaged by hand. The partially assembled body and ogive are conveyed to a specially designed fixture where the ogive is torqued to specific requirements. The sealant is applied to assure there is no leakage of gases when the expulsion charge is initiated at firing.

6-3.2 AIR TEST OF BODY AND OGIVE JOINT

Upon completion of the torquing operation, the body and ogive assembly is subjected to an air test using a special-purpose testing machine. The subassembly is pressurized by air and submerged in water to determine any leakage in the joint area. Alternately a pressure-drop air test could be used.

6-3.3 VAPOR DEGREASE, WASH PRIME, APPLY PAINT SHIELD, MASK BAND, AND PAINT

The body and ogive subassembly continue on the conveyor through a vapor degreaser to where all bare metal areas are sprayed and coated with a wash primer. Next the subassembly is placed on a tilt table where the lifting plug and base paint shield are applied. Then it is electrostatically painted as it is conveyed through a paint booth. This painting process is discussed in Chapter 4.

6-3.4 ASSEMBLE OBTURATOR BAND AND GROMMET

The paint shield is now removed and the obturator is assembled to the painted assembly. The subassembly is now conveyed to where the rotating band grommet is assembled. This grommet protects the band from being damaged until the round is at the gun position and being readied for firing.

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CHAPTER 7
MANUFACTURE OF SHAPED CHARGE PROJECTILES

This chapter describes the manufacturing processes for shaped charge projectiles. The manufacture of projectile bodies and ancillary components is addressed, and emphasis is placed on material and process selections and typical sequences of operations. Also general comments are made on the basic design concepts and performance characteristics.

7-1 INTRODUCTION

The shaped charge concept has been used since World War II by the ammunition community as a method of defeating both light and heavy armor. This principle has been successfully incorporated in calibers ranging from 57 mm to 106 mm in recoilless rifle ammunition, in 90-mm to 152-mm tank ammunition, and in many families of rockets and missiles.

Many research and development (R&D) and product improvement programs have resulted in significant progress in the target defeat capability. Progressive changes in shaped charge liner materials and confiura-tions, piezoelectric and electromagnetic power supply and fuzing concepts, and new explosive train materials and waveshapers have all contributed to the present state of the art.

The 105-mm M456A2 high-explosive, antitank-tracer-multipurpose (HEAT-T-MP) and 120-mm M830 HEAT-T-MP projectiles will be discussed in this chapter.

7-1.1 DESIGN PARAMETERS

The 105-mm M456A2 14 HEAT-T-MP round is a fin-stabilized multipurpose projectile whose primary mission is to defeat armored targets and whose secondary mission is antipersonnel. The M456A2 is furnished to the field as a fixed round with the projectile assembled to a steel cartridge case, as shown in Fig. 2-5, and it is fired from the tank-mounted, rifled M68 cannon. Since high rotation of a shaped charge would adversely affect target plate penetration, a seal has been incorporated under the obturating band to reduce the frictional forces that arc induced by the interface of the obturating band with the tube rifling. This reduced frictional force results in a slight rotational velocity, which, in conjunction with the fins, stabilizes the round during flight. The 120-mm M830 high-explosive antitank (HEAT) round has a role similar to that of the M456A2. It is furnished to the field as a fixed round with the projectile assembled to a combustible cartridge case and is fired from a tank-mounted, smooth bore M256 cannon. This projectile is also fin stabilized, and a slight rotation is intentionally induced to give the item flight stability by incorporating an angular cant on the fin blades.

7-1.2 PHYSICAL DESCRIPTION

7-1.2.1 105-mm M456A2 HEAT-T-MP

The main components of the projectile are spike assembly, flared cone, body, fin boom assembly, seal, and obturator. An exploded view of these components is shown in Fig. 7-1.

7-1.2.2 120-mm M830 HEAT-T-MP

The main components of this projectile are spike, single-angled cone, body assembly consisting of the body and gilding metal band, rubber seal, tail boom, ease cap, and fin, as shown in Fig. 7-2.

7-2 MANUFACTURE OF HEAT PROJECTILE M456A2

7-2.1 MANUFACTURE OF BODY

7-2.1.1 Design

The design of the body is as shown in Fin. 7-1. The body is essentially the carrier for the explosive charge, the flared cone, and the fuze and is designed to withstand all of the forces and hot propellant gases associated with the launch environment.

Experience dictated that special attention be given to the boom-to-body and spike-to-body joints, which has resulted in tight tolerances on concentricity and per-pendicularity requirements of the joint interfaces to prevent leakage paths for hot propellant gases. Likewise, to prevent the introduction of residual stresses no final cold forming operations are allowed.

To assure integrity of the body, specification MIL-P-63293 (Ref. 1) requires 100% nondestructive ultrasonic and visual inspection for all metal defects. (See Chapter 14 for a detailed discussion of nondestructive testing.)

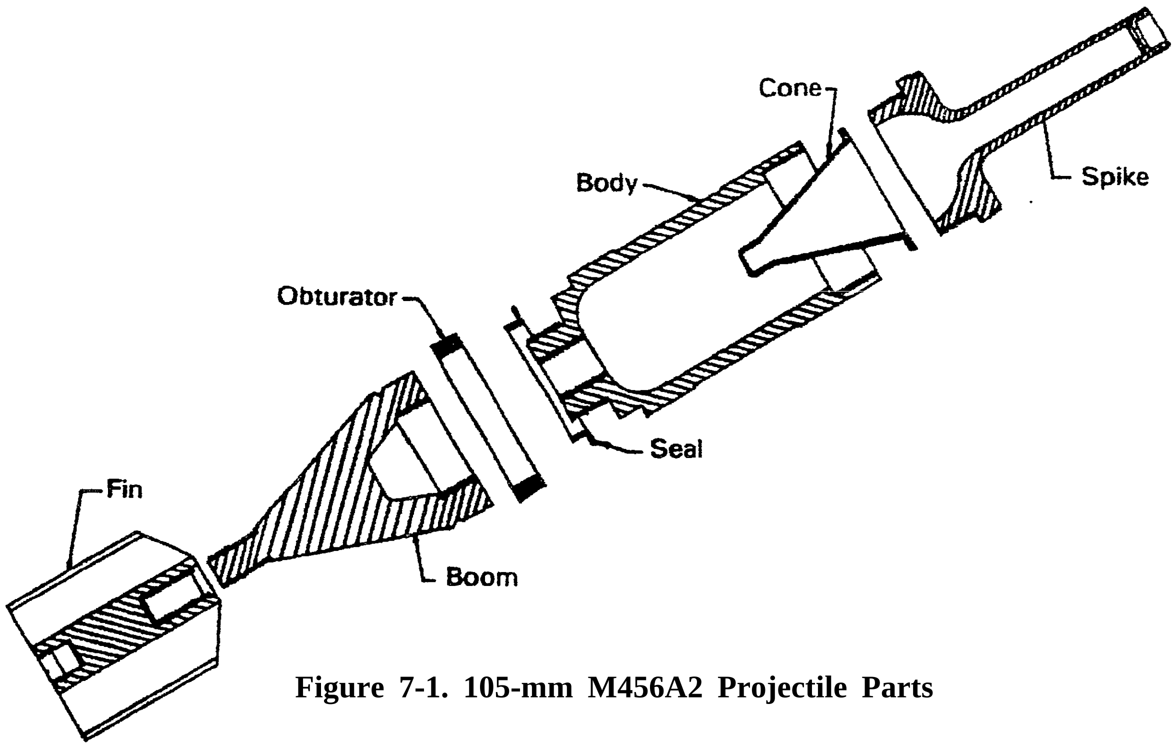

Figure 7-1. 105-mm M456A2 Projectile Parts

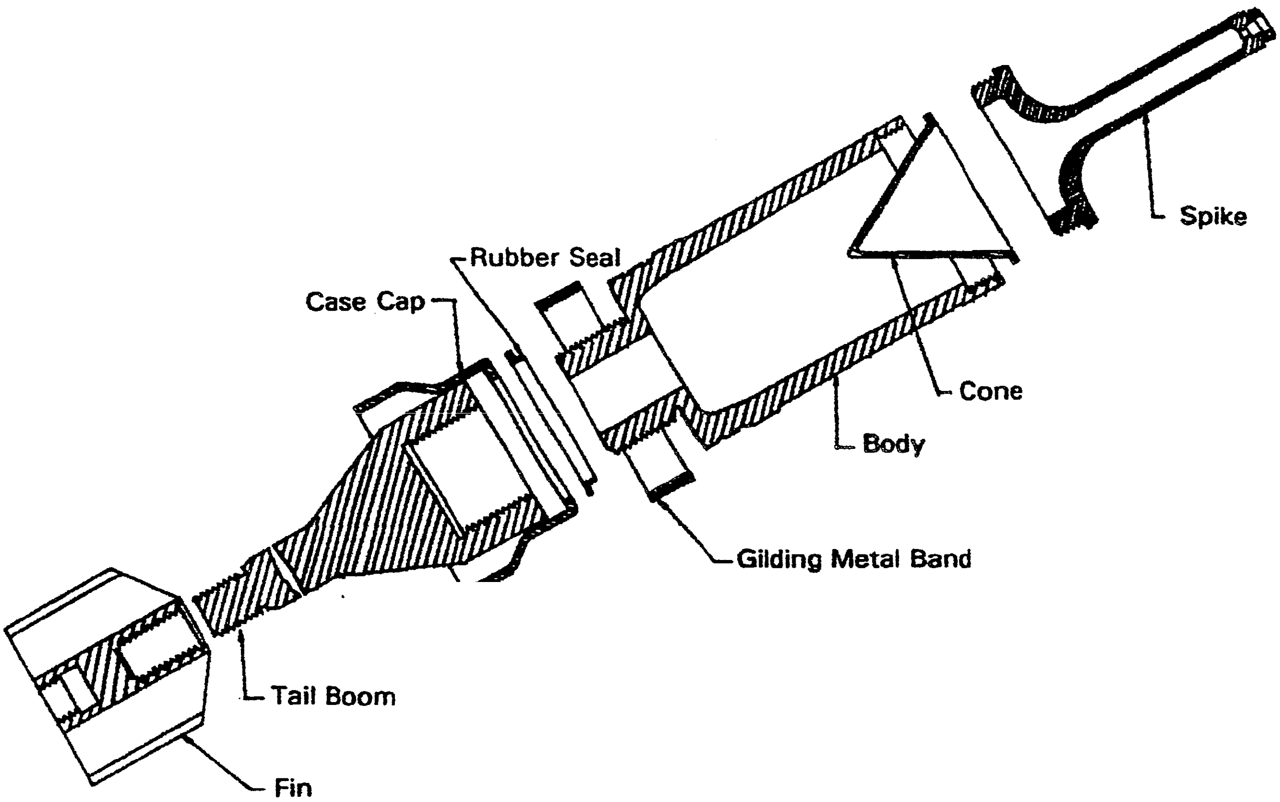

Figure 7-2. 120-mm M830 Projectile Parts

7-2.1.2 Selection of Manufacturing Process

In order to meet consistently and reliably the yield strength of 931 MPa (135,000 psi) and a tensile strength of 1070 MPa (155,000 psi), the hot forge-heat treat (HF-HT) and machine method of manufacture is used. This method is versatile enough to produce future generations of ammunition, which might require higher physical properties.

Presently, the required properties together with an elongation of 10% in 50.8 mm (2.0 in.) are beyond the capability of both the hot cup-cold draw (HC-CD) and the cold extrusion (CE) processes.

7-2.1.3 Material Parameters

The required high strength and the use of the hot forge-heat treat and machine process dictates the use of an alloy steal. Alloy steel, grade 1340, is specified on the drawing, and leaded or resulphurized treatments are not permitted. Alternate grades of steel maybe used after approval by the developer. These alternate grades would be purchased in accordance with American Society for Testing and Materials (ASTM) Specifications A322(Ref.2), ASTM A711(Ref.3), and ASTM A519 (Ref. 4).

7-2.1.4 Typical Sequence of Operations

The major steps required to produce the M456A2 body are depicted in Fig. 7-3. The typical HF-HT method, described in detail in Chapter 4, is followed. The process, however, includes a cold-sizing operation to form the inside cavity to dimensions in lieu of an internal machining operation. This process involves a phosphate and soap coat operation after the hot forging operations and then a cold-draw operation in the press. This is followed by a process anneal to relieve cold-wark-induced stresses, and the process then conforms to the standard HF-HT procedure.

7-2.1.5 Body Manufacturing Differences for 120-mm M830

The body of the M830, as shown in Fig. 7-2, essentially performs the same functions as the 105-mm M456A2 body. However, the M830 body requires a minimum yield strength of 1100 MPa (160,000 psi), a tensile strength of 1210+200 MPa(175,000 + 29,000 psi), and an elongation of 9% minimum. These high physical requirements dictate the use of the HF-HT and machine process to achieve these mechanical properties.

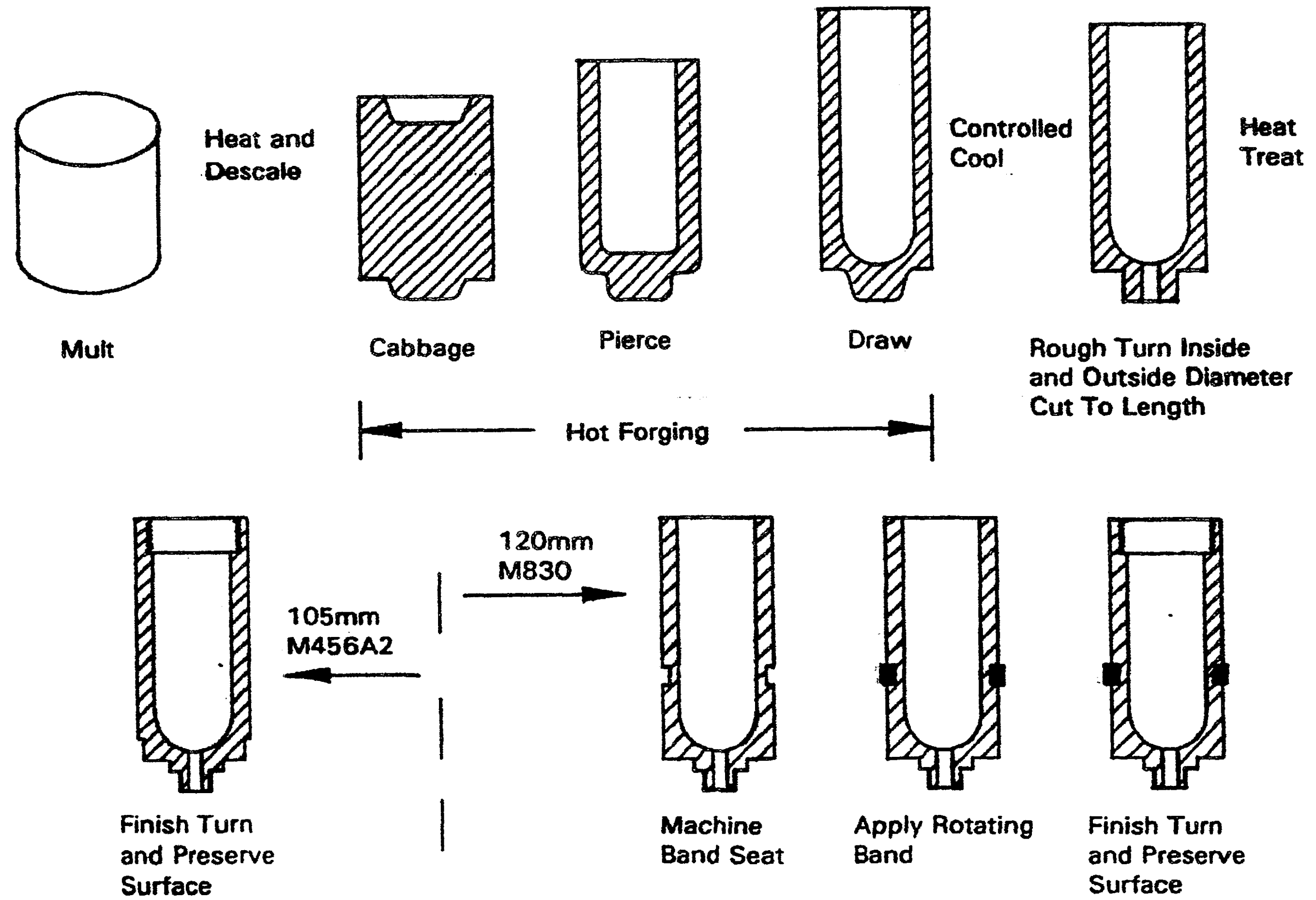

Figure 7-3. Sequence of Shapes for Body, 105-mm M456A2 and 120-mm M830

The steel used to produce the M830 body successfully, and the only steel specified on the drawing, is grade 4140 in accordance with ASTM A711 (Ref.3).

The major steps required to produce the M830 are essentially the same as for the M456A2 except for the added operations of band seat machining and band application.

7-2.2 MANUFACTURE OF SPIKE

7-22.1 Design

The 105-mm M456A2 spike, as shown in Fig. 7-1, protrudes approximately 178 mm (7.0 in.) forward of the body and provides the necessary standoff distance to permit optimum formation of the shock wave and jet in order to achieve target penetration. The spike is configured not only to enhance the stability of the fin-stabilized round but also to accept the power supply at the forward end and the array of switches that surround the base and line the sidewall of the stem.

7-2.2.2 Selection of Manufacturing Process

The shape of the spike lends itself to be formed economically by press methods. The inside taper of the stem and the inside shape of the bell end can be formed by the punch and thus eliminate the need for finish machining.

The requirement of 758-MPa (110,000-psi) yield strength in the stem section and a 620-MPa (90,000-psi) yield strength in the flange area with an elongation of 10% minimum in 25.4 mm (1.0 in.) permits the use of either the cold extrusion processor the hot forge-heat treat process.

7-2.2.3 Material Parameters

For the cold extrusion process, steel specified by ASTM A576 (Ref. 5) is required. The material must be ordered as bars of a cold extrusion quality, which are suitable for the production of solid or hollow shapes by means of severe cold plastic deformation involving forward or backward extrusion or both with or without expansion. Since the high mechanical properties will be attained by the cold-working of steel, low-carbon steels listed in ASTM A576 are selected. These steels have been successfully used in the production of the spike, although the required mechanical properties are at the upper-limit that can reliably be expected of the cold extrusion process.

For the hot forge-heat treat process, material covered by either ASTMA711 (Ref. 3) or ASTM A322 (Ref. 2) may be used. The material selected may be ordered as billets or bars, but it must be responsive to heat treatment to attain the required mechanical properties. Because of the hollow configuration of the spike, which will permit unrestricted flow of the quenching liquid, very uniform properties can be obtained. Unified Numbering Standard (UNS) Designation G13400 (Grade 1340 with 0.38 to 0.43% carbon and 1.60 to 1.90% manganese) has been successfully used in the production of the spike by the hot forge-heat treat process.

7-2.2.4 Typical Sequence of operations

7-2.2.4.1 Cold Extrusion

The sequence of operations for making the M456A2 spike by the CE method is shown in Fig 7-4. Because the interior surface will be formed to drawing dimensions by the press operations, it is essential that the billet separation be done by a sawing operation, which will assure a smooth surface to the finished extrusion. After phosphatizing and soap coat lubricating the mult, the piece requires two extrusions to achieve its shape. A process anneal followed by another phosphatizing and lubricating step are required after the first extrusion to prepare the steel for the further deformation involved in the second extrusion, during which the steel reaches the required mechanical strength.

After being stress relieved, the piece is finish machined on the outer diameter (OD) and the threaded portions of the inner diameter (ID).

7-2.2.4.2 Hot Forge-Heat Treat

There are basically two methods of forming the spike by the HF-HT process. The typical sequence of operations is depicted in Figs. 7-5 and 7-6.

Fig. 7-5 illustrates the hot upset method, which uses a bar slightly larger in diameter than the shaft of the spike. The bar is heated and the aft end is upset to increase its diameter to that required for mating to the body. The

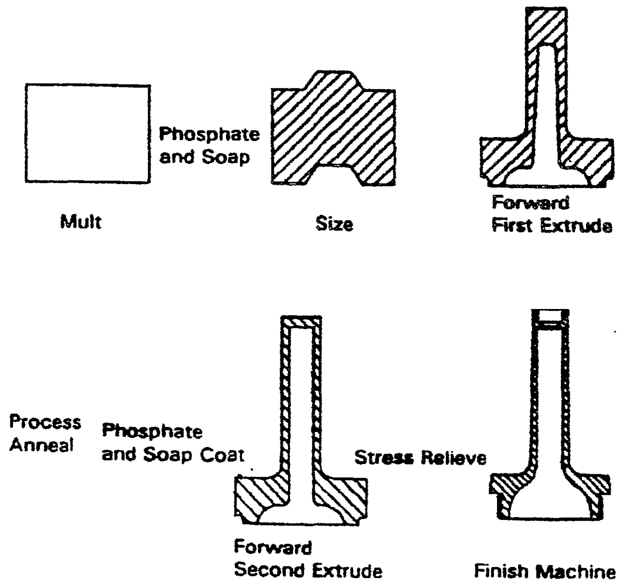

Figure 7-4. Typical Sequence of Shapes, Cold Extrusion 105-mm M456A2 Spike

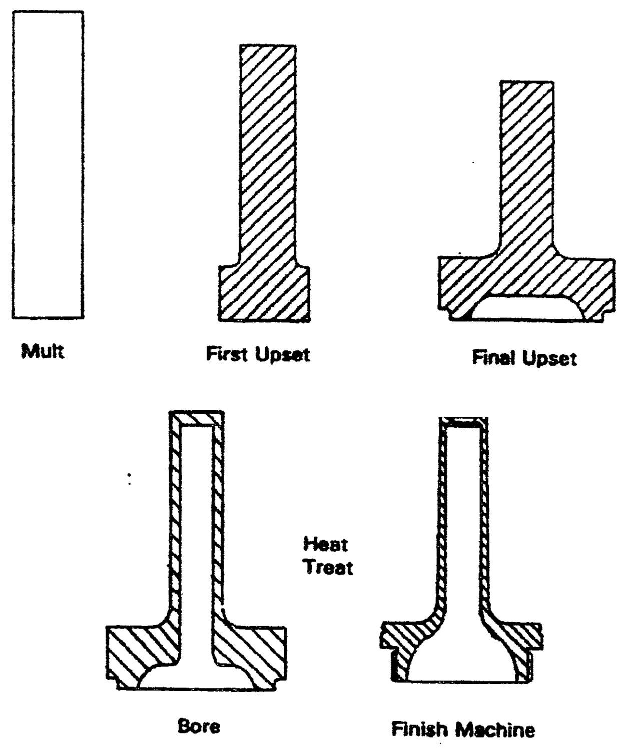

Figure 7-5. Typical Sequence of Shapes, Hot Forge (Upset) 105-mm M456A2 Spike

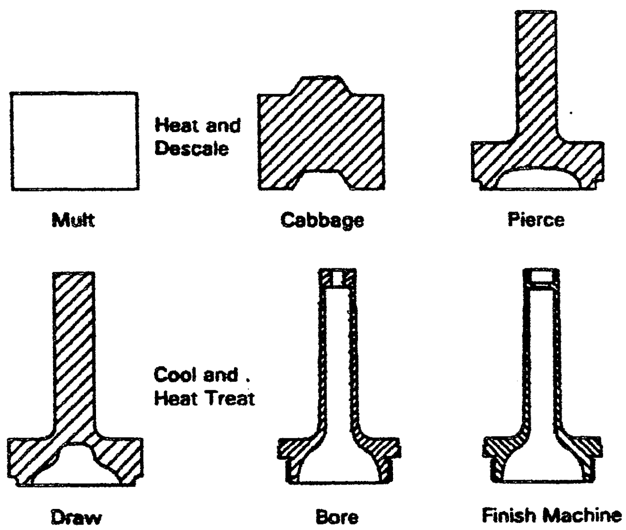

Figure 7-6. Typical Sequence of Shapes, Hot Forge (Draw) 105-mm M456A2 Spike

forging is then machine bored on the ID and heat treated to attain proper physical properties. Finish machining by conventional, numerical control (NC) lathes completes the configuration.

The second method, shown in Fig. 7-6, accomplishes the shape by starting with a mult of roughly the same diameter as the body mating surface. After heating it is pierced and drawn to basically the same shape as that in the upset method. Heat treating and finish machining are the same for both hot forge methods.

7-2.2.5 Spike Manufacturing Differences for 120-mm M830

The spike of the M830, as shown in Fig. 7-2, essentiality performs the same functions as the 105-mm M456A2 spike. The shape of the stem and bell also lends itself to be formed economically by punch and die press methods.

Since the drawing calls for a minimum yield strength of 1100 MPa (160,000 psi) and a tensile strength of 1240 + 414 MPa (180,000+60,000 psi) with an elongation of 9% minimum, the only process to achieve these mechanical properties is the HF-HT method.

To meet these requirements, the steel specified is a Chrome-Moly Grade 4140 to ASTM A322 (Ref. 2).

The major steps in the formation of the M830 spike are essentially the same as those described for the HF-HT method of manufacture of the M456A2 spike.

7-2.3 MANUFACTURE OF CONE

7-2.3.1 Design

The purpose of the cone in HEAT ammunition is to focus the shock wave and to provide a jet of hot metal particles in a single, narrow beam in a forward direction through the center of the spike. The cone also acts as a mold to form the shape of the explosive during the Composition B casting operation. Many cone configurations, ranging from a simple single-angled cone shape to a multiradii trumpet shape with and without a cylindrical section at the closed end, have been used in HEAT ammunition.

The M456A2 cone is categorized as “flared” and has two sidewall tapers connected with a Mended radius. The closed end has a short cylindrical section, and the open end is flanged to provide a controlled seat in the shell body. The design is shown in Fig. 7-1.

7-2.3.2 Selection of Manufacturing Process

Shaped charge liners can be made by conventional punch and draw techniques on a transfer press or by a shear formed spinning technique over a mandrel. The liners made by the press method are usually employed in munitions that have very low rotation in flight, whereas liners made by the spinning method are used in munitions that have rotation in flight of up to 60 rps. Liners that are spin formed over a mandrel are unique in that the reorientation of the grains caused by the rotational shaping spin-compensates the cone—i.e., the reoriented grains, which tend to follow a helicoidal angle, compensate for the loss in penetration that would result from the spinning of the projectile. Because the M456A2 projectile is fin stabilized but is designed to spin slightly to compensate for launch irregularities and round imbalance, the shear form process is suggested on the drawing.

7-2.3.3 Material Parameters

Several copper alloys purchased in accordance with ASTM B 152 (Ref. 6) have produced acceptable cones. These include alloy C10200, oxygen-free copper without residual deoxidants; C10700, oxygen-free, silver-bearing copper, Cl1000, electrolytic tough pitch copper; and C12200, phosphorized, high residual phosphorus copper.

The material is usually purchased as cold-rolled strip to facilitate the subsequent blanking operation that produces the initial disc configuration required by the shear forming equipment. Although no temper is specified, quarter-hard has been successfully used in previous production. When other tempers are used, compensating adjustments must be made in the feed, speed, and cycle time of the shear forming operation.

7-2.3.4 Typical sequence of operations

The two most prominently used machines are the Lodge & Shipley Flow Turn and the Autospin. Both machines have hydraulic feeds and may be computer controlled. The Flow Turn machine has a vertical spindle and uses two forming rollers 180 deg apart, whereas the Autospin has a horizontal spindle and uses only one forming roller. The rollers are designed to follow the contour governed by the templates incorporated in the machine.

The blank is made using a conventional punch press, which configures the disk either flat or cupped with a 12.7-mm (0.5-in.) fiat center to facilitate centering in the shear form machine.

The blank is then spun over a cone-shaped mandrel, which forms the inside dimensions. Fig.7-7 consists of progressive views of the cone during the forming process. Although the illustration shows two rollers (Flow Turn) 180 deg apart, the progression is essentiality the same for the one-roller Autospin.

The closed cylindrical section operation is performed in a conventional draw press, which also trims the flange the same press stroke.

The cone is then coined on the flange, taper, and nose surfaces by insertion into a conventional press. The outside surface and flange are machined on an NC lathe, and the conduit hole is drilled with a conventional drill.

To assure consistent compliance with the static and ballistic plate acceptance test requirements, close control of such features as temper of the copper blank; the speed, feed, and cycle time of the shear forming operation; the temperatures of the cone; the amount of coolant-lubricant used; and the cooling rate of the finished cones is essential.

7-23.5 Cone Manufacturing Differences for 120-mm M830

The M830 cone is a simple single-angled cone, as shown in Fig. 7-2. The closed end terminates in a point instead of a short cylindrical section, and the open end has no flange because the cone rests on the preformed explosive charge instead of on a shoulder of the shell body.

Although the M830 shell emerges from the smooth bore tube with no spin, at the target the shell may have a spin as high as 60 rps due to the 1.5-deg cant on the fin blades. To compensate for this induced spin, the shear form process of manufacture is mandated on the drawing

The only material specified on the drawing is Grade C1O1OO copper, i.e., an oxygen-free electrolytic sheet or strip, ASTM B152 (Ref. 6). Material is ordered with a maximum tensile strength of 230 MPa (34,000 psi), a maximum yield strength of 100 MPa (15,000 psi), a 40% elongation, and a suggested Rockwell F Hardness of 45.

The equipment used to produce the M830 cone is the same as that described for the M456A2 cone. (See Fig. 7-8.) The sequence of operations differs only in the elimination of the closed cylindrical section and the drilling operations. A notch is milled by a conventional milling machine for the conduit.

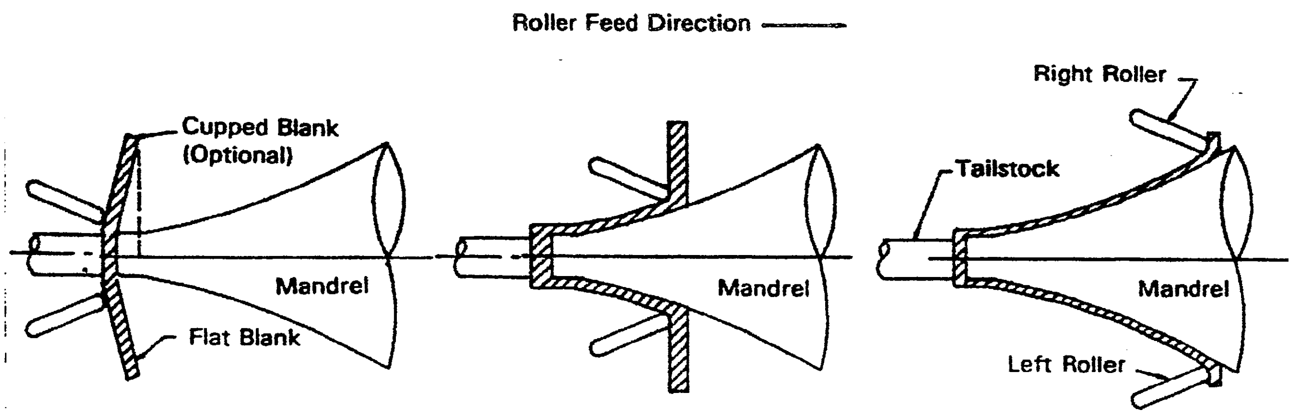

Figure 7-7. 105-mm M456A2 Cone-Shear Process

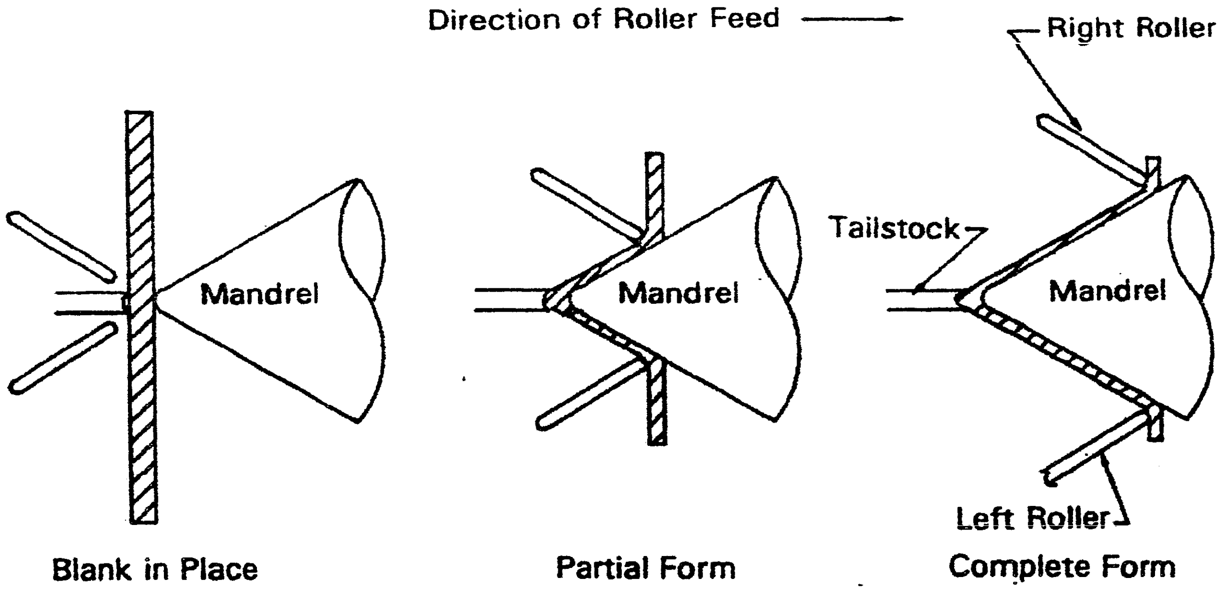

Figure 7-8. M830 Cone-Shear Form Press

7-2.4 MANUFACTURE OF OBTURATING BAND

7-2.4.1 Material Parameters (M456A2)

The obturating band seals the propellant gases behind the projectile to achieve an efficient propulsion system and engraves into the lands of the gun barrel so that a rotation of approximately 15 rps is transmitted to the projectile. The material selected for the obturator must be sufficiently pliable and have sufficient strength to accept engraving without tearing or shearing and to maintain its integrity upon exit from the tube so that it does not partially or entirely come off in flight; round stability would be affected if the material were to come off in flight.

Although tests were conducted with a number of plastic materials, only a centrifugally cast nylon material called Zytel 101* has been successful. This material is identified as PAlll in ASTM D4066(Ref.7).

The obturator is shown in Fig.7-1.

7-2.4.2 Typical Sequence of Operations

Early tests revealed that the mechanical properties required to achieve proper performance could not be obtained by the standard technique of molding the band to finished dimensions. Therefore, the only approved method of manufacture stipulated on the drawing is to machine the bands from lengths of centrifugally cast tubing made from Zytel 101*. The dimensions of the cast tubing, as well as the heat conditioning cycles required to develop the properties, are considered proprietary by the Polymer Corporation of Reading, PA.

*Zytel is a registered trade name of E.I. duPont deNemours & Co., Inc.

7-2.4.3 Obturating Band Manufacturing Differences for 120-mm M830

The obturating band incorporated on the M830 shell body serves not only to center the projectile within the bore of the tube but also to provide a second seal to prevent leakage of propellant gases past the shell body. Since the cannon is smooth bore, no rotation is imparted to the projectile. The sealing function is achieved by the machined configuration of the outside bearing surface of the band, which deforms and adjusts to the tube diameter during travel through the tube. The band, assembled to the shell body, is shown in Fig. 7-2.

The band blank is fabricated from annealed, low-zinc brass tubing, Grade C22000 (90% Cu, 10% Zn) or Grade C21OOO (95% Cu, 5% Zn) as required by MIL-B-20292 (Ref.8).

The band is pressed into the groove of the shell body by the conventional press method, which is covered in detail in Chapter 4.

7-2.5 MANUFACTURE OF FIN

7-2.5.1 Material Parameters (M456A2)

The fin, which stabilizes the projectile during its flight to target, has six blades; each of which has a bore riding pad at the blade extremity to withstand frictional wear. The fin is shown in Fig. 7-9.

To enhance stability further by moving the center of gravity as far forward as possible and to withstand the high--stress launch environment, the fin is fabricated from a lightweight, high-strength aluminum alloy. This alloy, equivalent to 7075-T651, is purchased in extruded lengths in compliance with ASTM B221 (Ref.9) to meet minimum mechanical properties of 410-MPa (60,000-psi) yield

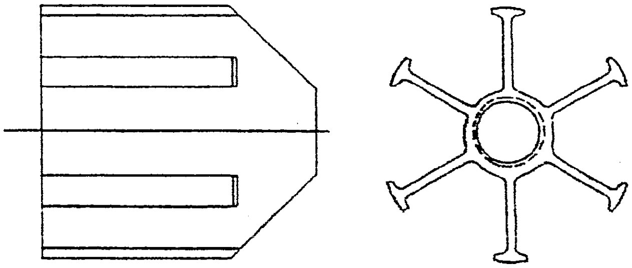

Figure 7-9. 105-mm M456A2 Fin Detail

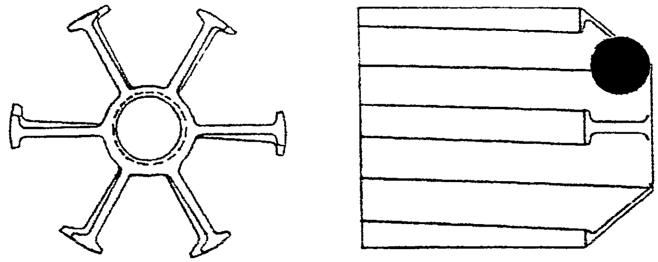

Figure 7-10. 120-mm M830 Fin Detail

strength and 7% elongation. An additional requirement of fin straightness and twist has been placed on the extruded bar length to assure meeting the indicator reading of straightness and twist permitted on the finished component.

7-2.5.2 Typical Sequence of Operations

The bulk of the machining is accomplished on multi-spindle bar machines; however, the extruded fin stock is grasped by form-fitting chucks accurately made to avoid fin blade distortion. Single-point thread-cutting equipment can be used in the threading operations, but the forward thread and the forward perpendicular face should be machined in the same setup to assure achieving the proper interface relationship with the boom. To provide surface protection against ablation by the hot propellant gases, the fin is coated with an aluminum oxide hard coat in accordance with MIL-A-8625 (Ref. 10).

7-2.5.3 Fin Manufacturing Differences for 120-mm M830

The six-bladed fin used on the M830 is similar to the M456A2 fin except for size. The drawing for the M830 not only permits the use of 7075-T6 aluminum extrusion as per ASTM B221 (Ref. 9) but also of extruded stock of 7079-T6 aluminum. Minimum mechanical properties of 480-MPa(70,000-psi) yield, 540-MPa(78,000-psi) tensile, and 6% elongation are required.

Fig. 7-10 shows the M830 fin. Although the M830 projectile emerges from the smooth bore tube with no spin, spin is achieved by providing a 1.5-deg cant angle on the six fin blades. The extrusion stock producer creates this angle by incorporating a twisting operation immediately after the extrusion operation and before heat treatment.

Machining and surface coating operations are similar to those of the M456A2 fin.

7-2.6 MANUFACTURE OF BOOM

7-2.6.1 Material Parameters

The M456A1 boom acts as a spacer to connect the fin to the shell body. Its conical contour induces airflow on the fin blades to provide flight stability to the projectile. Fig. 7-1 shows the details of the boom, which is fabricated from a lightweight, high-strength aluminum alloy. This alloy, which is equivalent to 7075-T6, maybe purchased as rolled bar in accordance with ASTMB211 (Ref. 11), as extruded bar in accordance with ASTMB221 (Ref. 9) for complete machining, or as a rough-shaped forging in accordance with ASTM B247 (Ref. 12) for minimum finish machining operations. In either ease minimum mechanical properties of 450-MPa (65,000-psi) yield strength and 7% elongation must be met.

7-2.6.2 Typical Sequence of Operations

If rolled or extruded bar is used, the bulk of the machining can be accomplished on multispindle bar machines; if rough forgings are used, machining can be accomplished on multispindle chuckers. Conventional thread-cutting equipment can be used in the thread operations, but it is advisable to machine each thread and its perpendicular face in the same setup in order to assure achieving the proper interfaces in the subsequent assemblies.

Surface protection against the ablative forces of the hot propellant gases is provided by an aluminum oxide hard coat in accordance with MIL-A-8625 (Ref. 10).

7-2.6.3 Boom Manufacturing Differences for 120-mm M830

The boom on the M830, as shown on Fig. 7-2, serves the same purpose as the boom on the M456A2, and the same aluminum alloy is specified. Minimum mechanical properties of 450-MPa (65,000-psi) yield, 540-MPa (78,000-psi) tensile, and 6% elongation are required.

Machining of the bar or rough forgings can be accomplished by methods similar to those of the M456A2.

The protective finish is an anodic film in accordance with Finish No. 7.2.1 of MIL-STD-171 (Ref. 13).

7-3 ASSEMBLY OF METAL PARTS

7-3.1 PROJECTILE, HEAT, M456A2

Fig. 7-11 shows the joint interfaces among the major components of the metal parts assembly.

Interface A is the fin-to-boom joint. This ass operation, performed in the metal parts plant, consists of

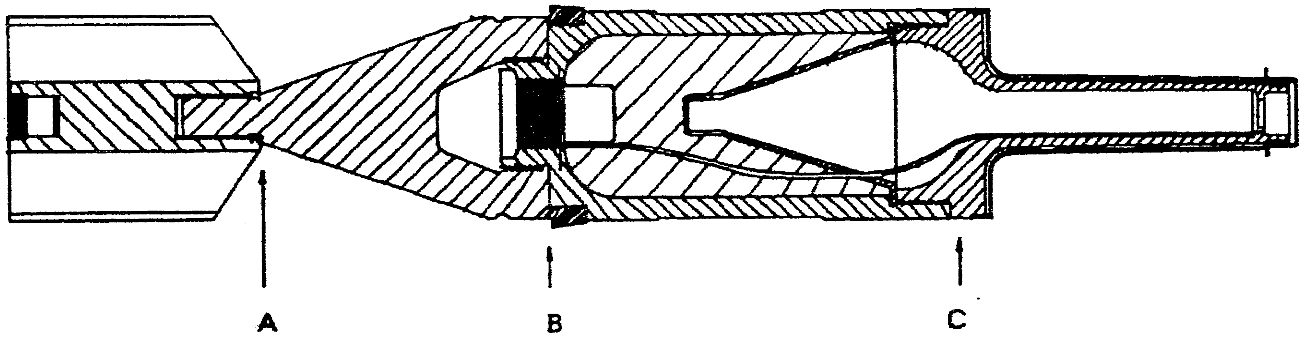

Figure 7-11. l05-mm M456A2 Projectile Assembly

coating the threads with a sealing compound (laminac) and assembling the two components with a 42.4-Nm (375-lb-in.) torque. After drying, the assembly must meet a disassembly torque of 56.5 Nm (500 lb in.).

Interface B is the body-to-boom joint and is very critical because it may offer a leakage path by which the propellant gases can. impinge on the fuze or the explosive charge. This assembly operation, performed in the loading plant, consists of slipping on the obturator, coating the threads with a sealing compound (laminac), and assembling the components with a 67.8-Nm (600-lb in.) torque. After drying, the assembly must meet a disassembly torque of 84.7 N-m (750 lb l in.). To assure a tight metal-to-metal interface, the joint must be inspected for a gap by using a 0.038-mm (0.0015-in.) feeler gage. The gage shall enter the joint no deeper than 3.17 mm 0.125 in.) along a continuous arc not exceeding 90 deg.

Interface C is the spike-to-body joint arid is very critical because it may offer a leakage path by which the propellant gases can impinge on the explosive charge at the juncture with the shaped charged cone. This assembly operation, performed in the loading plant, consists of coating the threads with a sealing compound (laminac) and assembling the components with a 67.8-N-m (600-lb-in.) torque. After drying, the assembly must meet a disassembly torque of 84.7 N·m (750 lb·in.). To assure a tight metal-to-metal interface, the joint must be inspected a full circumference for a gap with a 0.025-mm (0.001-in.) feeler gage. The gage shall not enter more than a maximum depth of 1.52mm (0.060 in.).

7-3.2 PROJECTILE, HEAT, M830

All interfaces among the fin, boom, body, and spike are controlled during the manufacture of these individual components.

The M456A2 has a cast-in-place charge, but the M830 body is loaded with precast upper and lower explosive charges and a preformed plastic wave shaper. Since the full body cavity diameter must be accessible at the load plant for insertion of the explosive components, no major assembly operations are performed at the metal parts fabricating plant.

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CHAPTER 8
MANUFACTURE OF KINETIC ENERGY PROJECTILES

This chapter describes the manufacturing processes used in the production of kinetic energy (KE) projectiles. The components unique to KE projectiles are the penetrator, sabot, windshield, and fin. The manufacturing process used for each of the components is also discussed.

8-1 INTRODUCTION

Kinetic energy projectiles of all sizes and shapes have been used since man first discovered that a thrown object could be a lethal weapon. The effectiveness of a KE projectile is based, as the name indicates, on the kinetic energy of the projectile when it reaches the target. That energy is a function of the mass and velocity of the projectile. When that energy is expended on a small area of the target, the projectile is capable of penetrating the target. The man;ufacture of KE projectile parts is discussed in this chapter by using the 105-mm M833 armor-piercing, fro-stabilized discarding sabot (APFSDS) projectile as an example.

8-1.1 DESIGN PARAMETERS

Present day KE rounds are fired from tank guns. Their primary targets are the enemy's armored vehicles. In order to increase target perforations, continual effort is expended to raise the striking velocity of the projectiles and to increase the length-to-diameter ratio to concentrate the impact of the entire mass on a small area. Consequently, KE projectile design has progressed from the spin-stabilized, solid projectile shown in Fig. 8-l(A) through discarding sabot types with subprojectile penetrators shown in Fig. 8-1(B) to fin-stabilized-discarding-sabot-type projectiles using long high-density penetrators shown in Fig. 8-1(C).

8-1.2 PHYSICAL DESCRIPTION

The monobloc or solid steel shot was a heat treated steel projectile made to the full bore diameter of the weapon. It was spin stabilized by means of a pressed-on rotating band, which engaged the rifling of the tube. A typical projectile of this type is the 90-mm M318 shown in Fig. 8-1(A).

A major improvement in perforation performance was attained by incorporating a subcaliber tungsten carbide or tungsten alloy core into a full bore, light metal cup equipped with a rotating band. The light metal cup or sabot took advantage of the full diameter of the tube to give a higher velocity to the penetrator and was discarded upon exit from the muzzle of the gun. An example of this type of projectile is the 105-mm M392 projectile shown in Fig. 8-1(B).

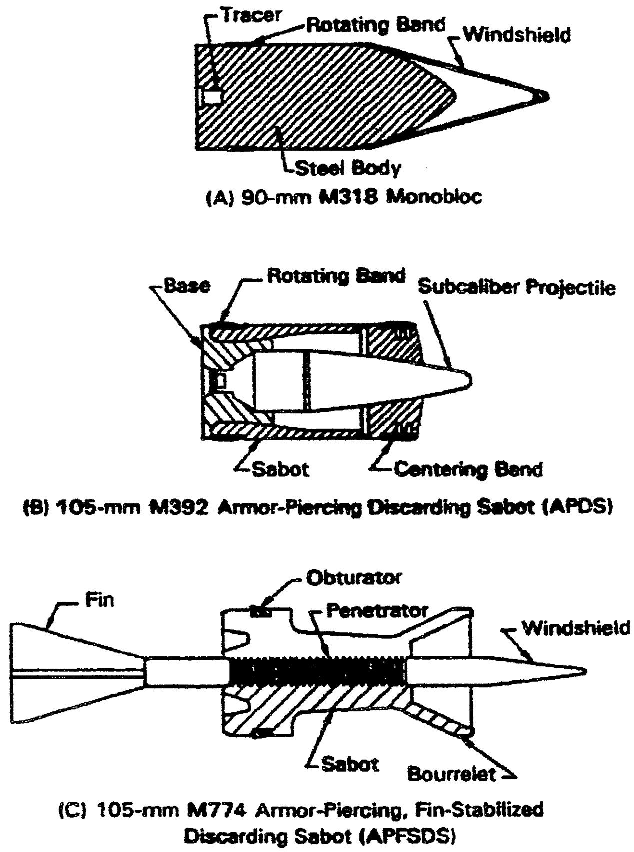

Figure 8-1. Types of Kinetic Energy Projectiles

In an effort to improve further performance against heavy armor, a reduced diameter, fin-stabilized long core was designed; it uses an obturating slip band in place of a rotating band. The core was supported and centered within the gun tube by a three-piece segmented sabot, which separated and discarded upon exit from the tube. The striking velocity of the core was increased by taking advantage of the full bore diameter of the sabot in the tube, and greater perforating performance was obtained by concentrating the effect of a high-velocity mass on a small area of imp-An example of this type of projectile is shown in Fig. 8-1(C) by the 105-mm M774.

The 105-mm M833 APFSDS projectile shown in Fig. 8-2 is an improvement on the M774 projectile because it

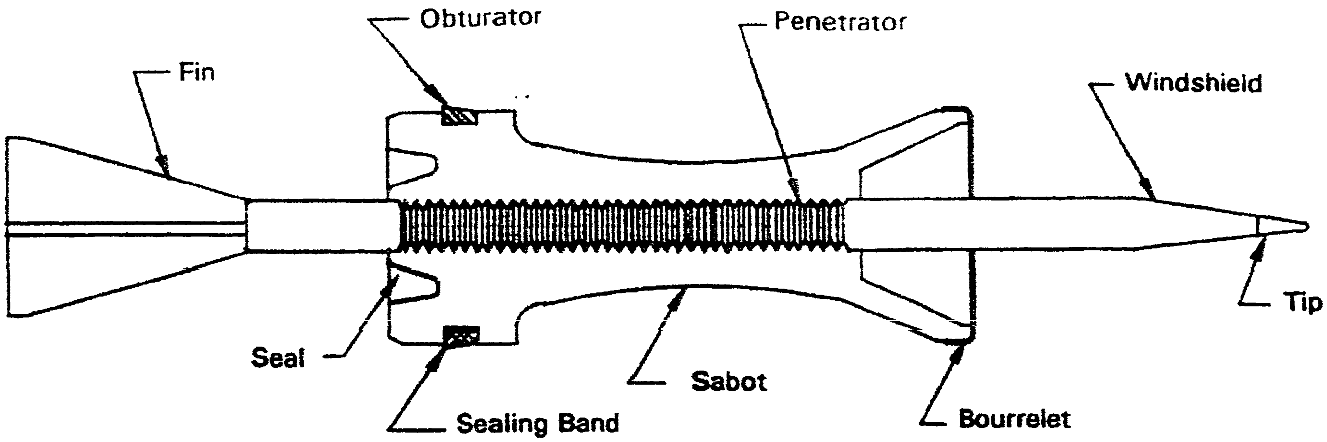

Figure 8-2. 105-mm M833 Armor-Piercing Fin-Stabilized Discarding Sabot (APFSDS) Projectile

incorporates a longer, smaller diameter penetrator that further concentrates the striking energy on a smaller cross-sectional area of the target.

8-2 MANUFACTURE OF 105-mm M833 PR0JECTILE

As shown in Fig. 8-2, the M833 projectile has two main components: (1) a subprojectile consisting of penetrator, windshield, tip, and fin and (2) a sabot assembly consisting of three sabot segments, an obturator, a base seal, and a separate bourrelet. Each of these components will be addressed in the paragraphs that follow.

8-2.1 MANUFACTURE OF PENETRATOR

8-2.1.1 Design

The penetrator is a solid piece of depleted uranium (DU) or tungsten alloy (W) with a high length-to-diameter ratio that is fitted with a pointed windshield and tip assembly to cover the spherical nose of the core. This design results in improved flight and penetration characteristics. Stability of the penetrator is attained by the addition of a fin at the rear.

8-2.1.2 Selection of Manufacturing Process

The manufacturing process is dictated by the material used. Once the heavy metal, DU or W, is in cylindrical rod form, special handling required to machine the bar into an acceptable core shape, which involves precision machining of grooves that mate with the grooves on the inner diameter (ID) of the sabot segments.

8-2.1.3 Material Pararmeters

The material used in the M833 is a DU alloy, although tungsten could be used. Selection of these materials is based mainly on density (Either material as used has a density of approximately 18,500 kg/m^3(0.69 lbm/in^3) but is tempered by cost and availability. Either material, when suitably processed into rods, possesses adeuate mechanical properties to sustain launching stresses and to give good perforating performance.

8-2.1.4 Typical Sequence of Operations

After the rods are cut to length, they are heat treated and machined in computer numerical control (CNC) lathes. Difficulties are experienced with the high length-to-diameter ratio penetrators because provisions have to be made in the turning operations to prevent bending during the cutting process. The penetrators have small dimensional tolerances, and steady rests are required for supporting the rod adjacent to the tool to maintain these tolerances. This support requires special lathe designs that have provision for backup of the rod during the cutting cycles.

8-2.2 MANUFACTURE OF SABOT

8-2.2.1 Design and Material Parameters

The design of the sabot is one of the critical factors in assuring a proper launching sequence for the penetrator. The sabot must have enough strength and contact surface with the penetrator to overcome the inertia of the high-density penetrator in order to have it reach launch velocity within the short length of the tank gun tube. Also the sabot must be made so that during assembly the three segments are completely sealed from the high-pressure gases that propel the projectile; however, the seal must not prevent the three sabot segments from separating simultaneously and cleanly from the penetrator within a short distance of the muzzle.

The sabot is essential for centering the penetrator within the projectile and the gun tube. On exit from the muzzle the sabot must not impart any asymmetrical forces during separation because they would tend to destabilize the penetrator.

In order to keep the parasitic weight, i.e., weight of components other than the penetrator, of the projectile to a minimum, the material selected for the sabot is a high-strength aluminum alloy, 7075, that is heat treated to the T6 condition, which is a solution heat treated and aged condition to develop maximum tensile properties. (See Chapter 3 for a more detailed discussion.)

8-2.2.2 Selection of Manufacturing Process and Sequence of Operations

The European method of manufacture for the saddle-shaped sabots was to machine the cylindrical shape of the complete sabot from a single piece of bar stock and slit it into three p-one of which had to be discarded due to the loss of circumference caused by the kerf width of three sawcuts. The result was two sabots for every three actually turned.

The method adopted by the United States for manufacture starts with an extruded pie-shaped bar, which presents a segment that provides the full 120 deg needed for a tight assembly. The rough segments are first passed through a special milling or a broaching machine, which finishes the two mating surfaces to forma perfect 120-deg wedge with the included are to form the internal rough diameter groove, as shown in Fig. 8-3.

The bars are then cut to length on a circular saw, and three of the segments are combined to form a 360-deg nest, and while held in this form the ends are welded together at the three joints on both ends. The assembly now can be bandied as a single unit. It is placed in a series of lathes in which the outside dimensions and the internal grooves are machined. The ends, including the welded portion, are turned off, and the segments are kept together as a unit when theyy are cleaned and anodized as described in par. 3-4.2.3.1.

8-2.3 MANUFACTURE OF WINDSHIELD AND BOURRELET

8-2.3.1 Windshield

The windshield for the M833 pro-consists of two parts: the windshield body and the windshield tip.

Both parts are readily manufactured since they have no special requirements.

The windshield tip is made from low-carbon (Society of Automotive Engineers (SAE) 1020) steel purchased to American Society of Testing and Materials (ASTM) A576 (Ref.1). SAE 1100 series steel or leaded steels are also permissible alternates. The tips are cleaned and painted black.

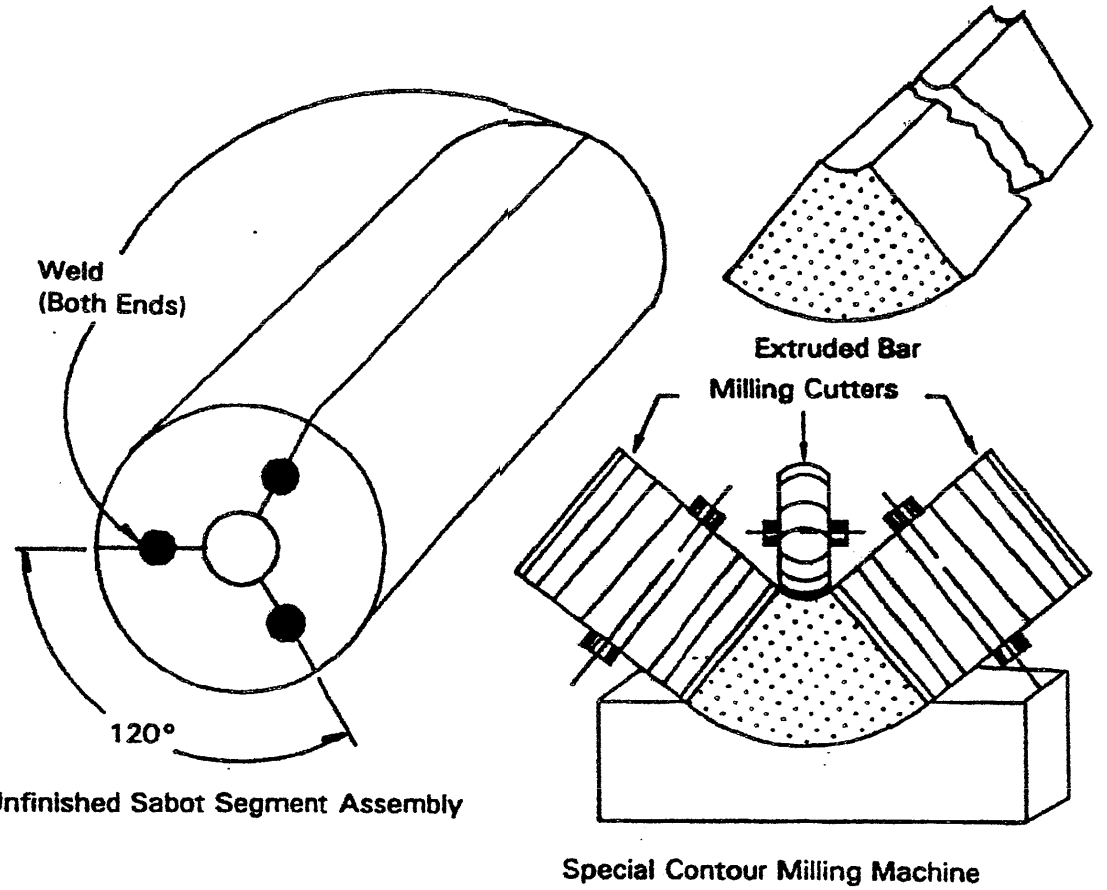

Figure 8-3. Sabot Assembly Prior to Finish Machining

The windshield is machined from aluminum bar(6061-T6) purchased to ASTM B211 or B221 (Refs. 2 and 3). After machining, it is cleaned and coated with a hardcoat anodized finish. The tip is screwed into the nose of the windshield, and the assembly is then press fitted onto the forward end of the penetrator to give the assembly a ballistic shape with low drag.

8-2.3.2 Bourrelet

The bourrelet is a stainless steel stamping purchased to ASTM A167(Ref. 4) which can be readily manufactured.

8-2.4 MANUFACTURE OF OBTURATOR, SEALING BAND, AND AFT SEAL

The obturator is made from high-strength, centrifugally cast nylon tubing purchased in accordance with ASTM D4066 (Ref.5).

Alternate methods of making obturators are available, as a molded ring or machined from extruded tubing. For the M833 the method has been specified as a centrifugally cast product because tests have determined that it meets the obturation requirements and breaks apart upon exit without interfering with the sabot discard.

The obturator is designed to fit on the sealing band, as shown in Fig. 8-2, i.e., a polypropylene-molded material purchased in accordance with Federal Specification L-P-394 (Ref. 6), which, due to its low coefficient of friction, acts as a slip band and allows movement between the obturator and the sabot to reduce the spin rate of the projectile. The sealing band is slipped over the rear of the sabot and snapped into place.

The machined obturator is heated and then expanded by being forced over the major sabot diameter so that it snaps into the obturator groove over the sealing band. Upon cooling it contracts to the groove diameter and together with the sealing band makes a tight seal.

For projectiles that have deeper obturator grooves, the technique of molding in place is being explored. This technique eliminates the expansion and contraction performance, which does have a finite limit with this material.

The aft seal (shown in Fig. 8-2), which is an essential part of the assembly, prevents the high-velocity hot propellant gases from entering the joints between sabot segments and between sabot and penetrator. Leakage at thse joints could cause separation of the sabot grooves from their seats in the penetrator grooves, which would cause a loss of acceleration or possible complete stripping of the groove interface. The end result could be a catastrophic launch of the penetrator.

This seal is made of proprietary rubber compound and is purchased in accordance with specification requirements that include yield strength, elongation, and hardness for cured samples. The compound is injected into a mold placed over the aft end of the projectile assembly after an adhesive has been brushed on the mating surface The projectile and mold are then placed in an oven and heated to approximatly 93°C (200°F) to vulcanize the rubber compound. The projectiles are removed from the oven and allowed to cool; the molds are then removed from the sealed assemblies.

8-2.5 MANUFACTURE OF FIN

The fin for the M833 is made from a 7075-aluminum extrusion heat treated to the T6 condition. After the extruded bar is cut to length by a sawing operation. the individual fin blanks are washed and the tapered fin blade is roughed out by being trimmed with a blanking shear. The trimmed piece is then machined in a CNC lathe to face, drill ream, chamfer, and thread the forward end. It is then placed in a second CNC lathe to face the aft end and to drill, ream, and thread the tracer cavity.

The blade taper and the outer diameter of the shaft are then machined in a lathe, and a series of special milling machines are used to straddle mill the blade thickness, mill the bevel and radius on the leading edge, and mill the bevel on the aft edge.

The finish-machined fin is then glass-bead blasted and given a hardcoat anodized finish to provide protection against the high temperatures of the propellant charge and the frictional temperatures developed during the high velocity flight of the projectile.

The fin is screwed onto the rear of the penetrator after the windshield and tip have been assembled to it, and the sabot segments are nested around the penetrator. With the addition of the bourrelet (which is attached to the forward end of the sabot by screws), the sealing and obturator bands (which are snapped into place) and the aft seal (which is vulcanized on the rear of the sabot), the projectile is complete.

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CHAPTER 9
MORTAR AMMUNITION

This chapter defines manufacturing methods for mortar ammunition. Differences in material requirements are described.

9-1 INTRODUCTION

Mortar ammunition is delivered to the field as complete rounds (cartridges) ready for firing. The family of ammunition for each mortar includes high explosive (HE), smoke, illuminating, and training cartridges. Hard ware for these cartridges consists of projectile bodies, stabilizing fins, obturators, ignition cartridge housings, rotating mechanisms, and adapters. The manufacture of these component parts is the subject of this chapter.

9-1.1 DESIGN PARMETERS

Mortar cartridges are designed so that they can be muzzle loaded, descend freely in the mortar tube, withstand the propellant gas pressure developed during launch, and produce the required terminal effect.

Fin-stabilized cartridges, as shown in Fig. 2-6, are fitted with a split-ring, plastic obturator that expands against the mortar tube wall to prevent escape of propellant gases. The obturating ring is heat sealed after assembly with the projectile body" to prevent expansion during muzzle loading.

Spin-stabilized cartridges for the 4.2-in. mortar are assembled with rotating bands and obturators, as shown for the M329A2 in Fig. 2-10. The welded overlay rotating band is premachined to meet the profile of the tube rifling, and the rubber obturator is designed to provide a seal when expanded through application of propellant gas pressure.

Spin-stabilized cartridges like those shown for the 4.2-in. mortar in Figs. 2-11 and 2-12 are fitted with an obturating mechanism consisting of a pressure plate and a soft metal rotating disk. Propellant gas pressure forces the pressure plate forward and thus expands the rotating disk into the rifling of the mortar tube. Engraving of the rotating disk imparts the necessary spin to the as-fired projectile and prevents escape of propellant gases.

HE projectiles are designed to produce effective fragmentation on the target. Fragment size, velocity, and distribution are dependent on the weight ratio of HE filler to projectile body, the type of HE filler, the projectile body geometry, and a combination of material properties and manufacturing process controls.

Smoke projectiles are designed to release the smoke signature by base ejection of red-phosphorus (RP)- or white-phosphorus (WP)-impregnated felt wedges above--ground or through action of a central burster that ruptures a WP-filled projectile on ground impact. Release of felt wedges above-ground produces more effective obscuration than aground burst; therefore, continued use of central bursters may be limited to 60-mm projectiles for spotting or marking.

Except for payload, base ejection smoke and illuminating projectiles are similar. The candle and parachute assembly of an illuminating projectile is ejected at a height aboveground that will produce the desired ground light intensity for the minimum burning time.

Full-range and reduced-range training cartridges use inert projectiles with spotting charges and amused in lieu of service ammunition in order to reduce training costs.

9-1.2 PHYSICAL DESCRIPTION

The metal parts for fin-stabilized mortar cartridges are the projectile body and the fin assembly. Spinstabilized mortar ammunition is equipped with either a rotating band with obturator or an obturating mechanism that engages the tube rifling to develop the required spin rate. Regardless of the method of in-flight stabilization each cartridge has a housing or container to accommodate an ignition cartridge that also serves as a means of attaching the main propelling charge. Holes are radially drilled in the housing or container through which the hot propellant gases from the ignition cartridge can escape and set off the main propelling charge. The projectile body carries a payload such as HE, WP, RP, or an illuminating candle and parachute assembly.

9-1.2.1 High-Exlosive Cartridge

The metal components of the fro-stabilized mortar cartridge are shown in Fig. 9-1. They consist of a projectile body assembly and a fin assembly. The nose section of the projectile body is internally threaded to accept the fuze and the base lug is externally threaded for assembly with the cartridge housing. A groove is machined in the area of the bourrelet to accommodate the obturating ring.

The fin assembly consists of a cartridge housing section and a fin section. Cartridge housings are internally threaded at the base end and bored, where necessary, to

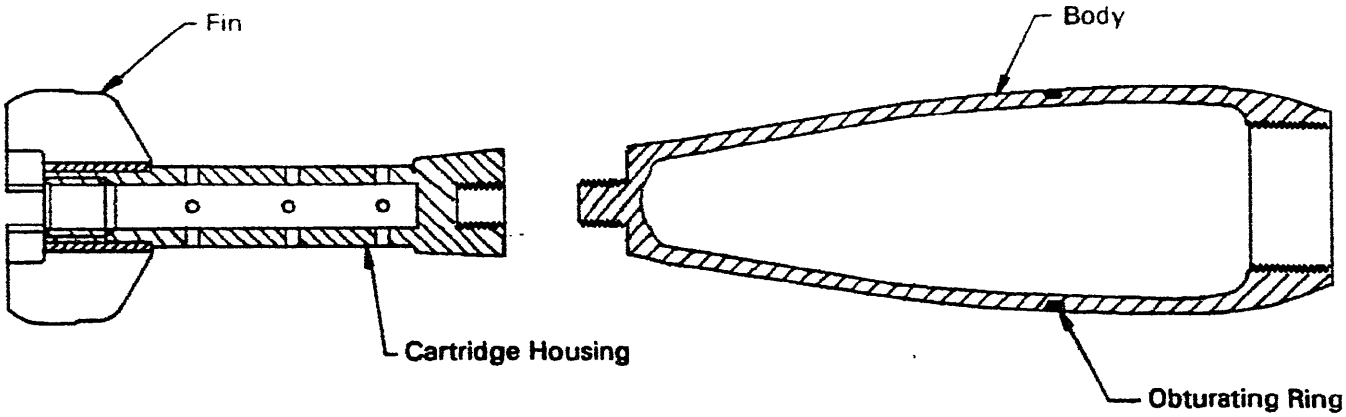

Figure 9-1. Fin-stabilized High-Explosive Cartridge

accept the ignition cartridge. Flash holes are radially drilled along the length of the housing to permit escape of hot propellant gases from the ignition cartridge; these gases ignite the main propellant charge increments that are attached to the housing. Fin sections are cut from longer extrusions and are machined to final fin profile and internally bored to permit press fit assembly with cartridge housings.

The 60-mm fin is made from a one-piece extrusion for production economy.

An example of spin-stabilized, HE cartridge metal parts is shown in Fig. 9-2. The one-piece steel projectile body is threaded at the nose end to accept the fuze and at the base lug to accept the ignition cartridge container. The striker nut assembly fits on the base of the cartridge container.

9-1.2.2 Smoke Cartridge

Smoke cartridges with central bursters are shown in Figs.2-7 and 2-11. The nose end of the projectile body is bored for press fit or brazing assembly with the buster easing. Press fitting or brazing of the burster casing in the body forms a seal to prevent escape of the smoke agent. The burster casing is internally threaded to accommodate the fuze. Other components of smoke cartridges are similar to those described for HE cartridges. Although smoke cartridges with central bursters are currently in the stockpile, further production, except for the 60-mm, may be deferred in favor of the base ejection type.

Major component metal parts of the fin-stabilized, base ejection, smoke cartridge are the body assembly, tail cone assembly, and fin assembly, as shown in Fig. 9-3 The body assembly consists of a body tube and full adapter that are seared by pins inserted in radially drilled holes. The fuze adapter is internally threaded for later assembly with the fuze. The body assembly and tail cone are assembled and secured by pins inserted in radially drilled holes. The fin assembly is similar to that described for HE cartridges.

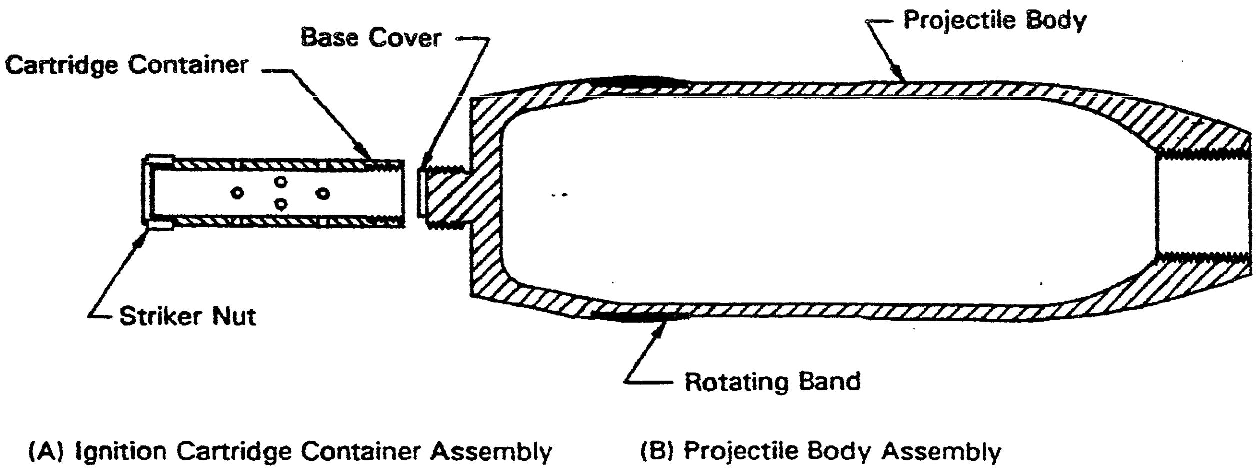

Figure 9-2. Spiri-Stabilized High-Explosive Cartridge

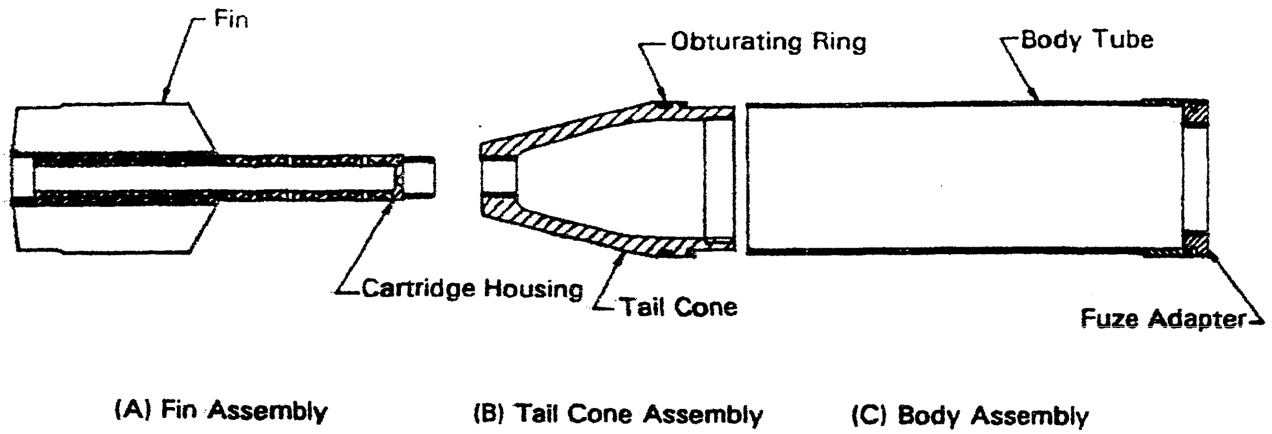

Figure 9-3. Fin-Stabilized Smoke Cartridge

9-1.2.3 Illuminating Cartridge

Illuminating cartridges are shown in Figs. 9-4 and 9-5; metal parts, except for payload, are similar to base ejection, smoke cartridge components. Their payloads are ejected when the tail cone or base plug is separated from the projectile body upon failure of the shear pins.

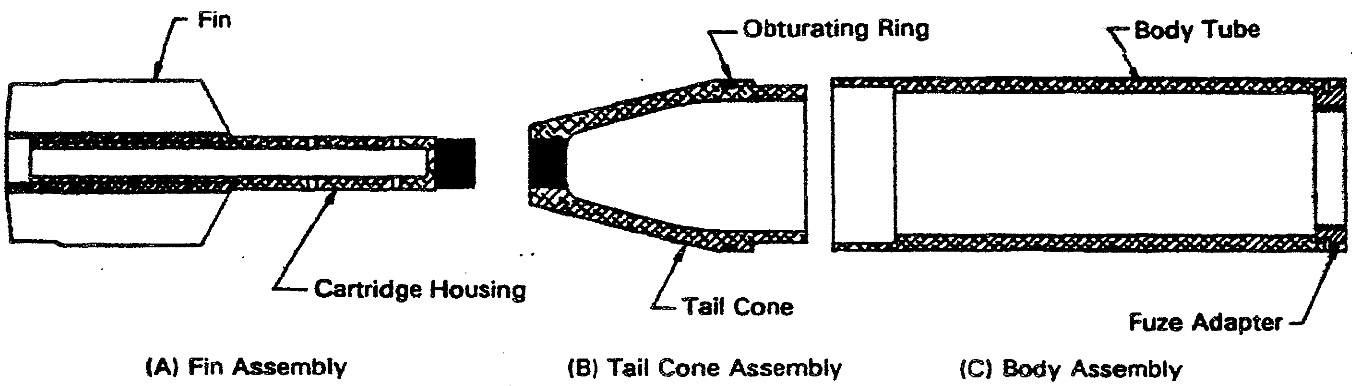

Figure 9-4. Fin-Stabilized Illuminating Cartridge, Metal Parts

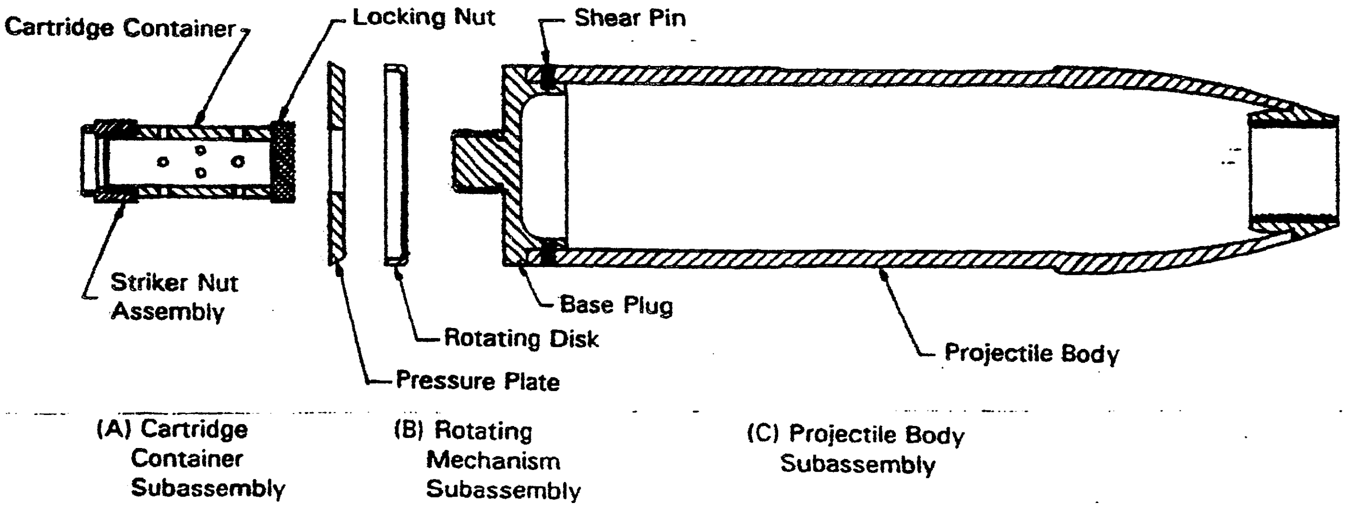

Figure 9-5. Spin-Stabilized Illuminating Cartridge, Metal Parts

9-2 MANUFACTURE OF HIGH-EXPLOSIVE PROJECTILE (M374 Type)

Mortar projectile bodies made from ductile and pearlitic malleable iron castings produce effective fragmentation; however, sand mold casting practice precludes the manufacture of a one-piece projectile body. The core must be supported in the cope and drag sections of the sand mold (as shown in Fig.9-6) to prevent shifting during pouring and solidification The open base end of the casting must then be closed by a brazing assembly with a steel plug; this method necessitates both hydrostatic and air pressure testing to assure the soundness and strength of the brazed joint.

A one-piece projectile body is preferable because it provides more reliable protection of the high-explosive filler. The high production and quality verification costs associated with cast iron projectile bodies have led to the development of alternate manufacturing processes involving variations in the basic hot cup-cold draw (Hc-cD) process using American Iron and Steel Institute (AISI) 1340 steel.

Control of the projectile body manufacturing process is essential in order to preclude degradation of terminal effectiveness during production. The baseline process description established during the manufacture of the first article sample must not be changed by the contractor without review and approval by the Government. This requirement precludes the introduction of any process change that may influence hardness, microstructure, and other mechanical properties that may degrade terminal ballistics performance.

The fin section is machined from an aluminum extrusion; the aluminum ignition cartridge housing section, however, can be made from either an extrusion or a forging.

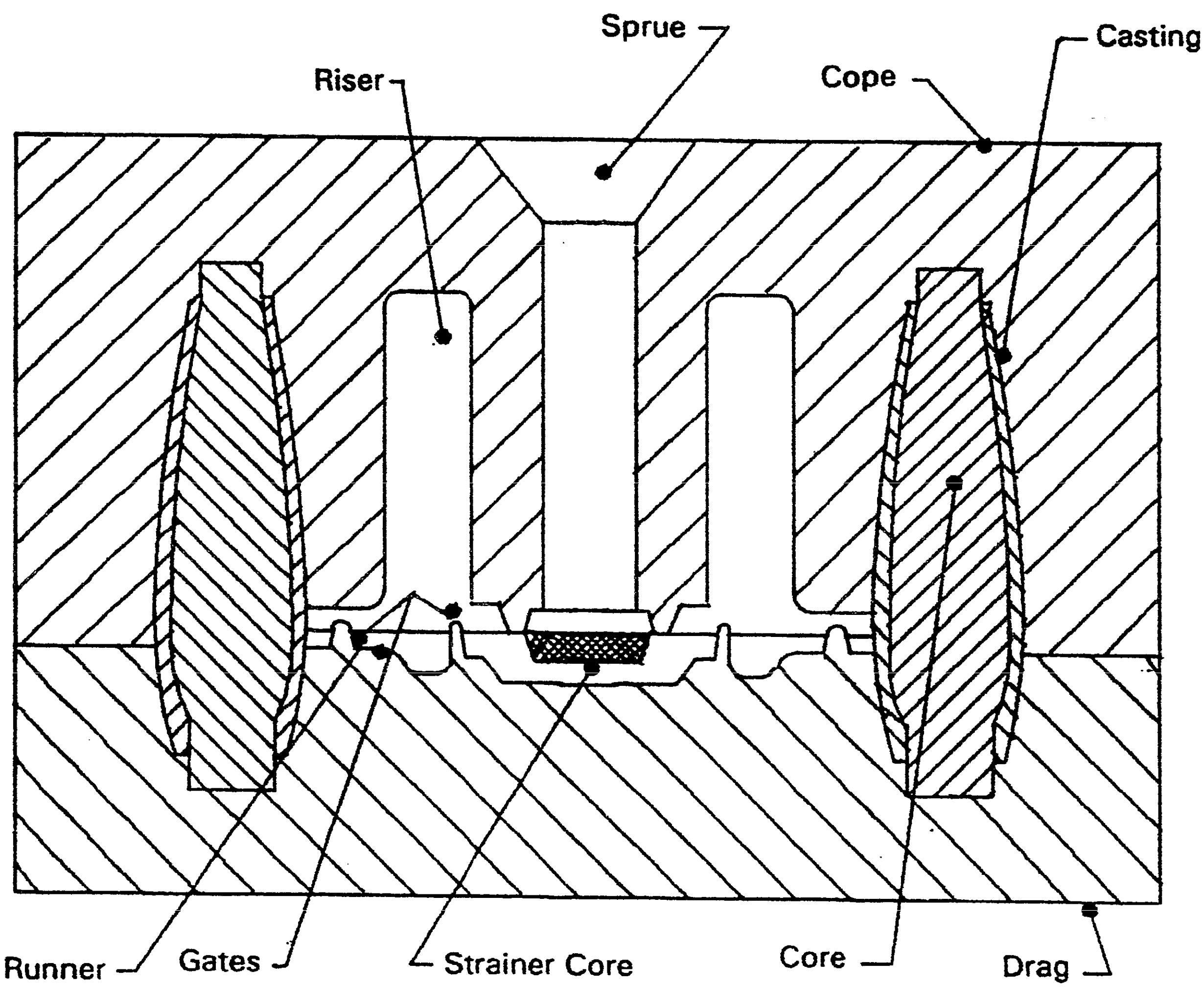

Figure 9-6. Cross Section of a Sand Mold for Casting Projectile Bodies

9-2.1 MANUFACTURE OF PROJECTILE BODY

9-2.1.1 Design

The projectile body is the key to terminal effectiveness, which is measured by the lethal area developed upon detonation. Terminal effectiveness is dependent on the number, weight, velocity, and distribution of body fragments. Design factors that contribute to effective fragmentation are (1) projectile body weight and shape, (2) material properties, (3) weight ratio of HE charge to projectile body, and (4) HE filler composition. The optimum number, size, and distribution of fragments are established as a bench mark prior to the start of production, and process controls are established to assure a consistent product. Projectile body design, therefore, should include requirements such as hardness pattern, microstructure heat treatment and material specification requirements.

9-2.1.2 Selection of Manufacturing Process

Performance requirements dictate what production process should be selected. Currently, HE projectile bodies for 60-mm mortars are made by hot cup-cold coin (HC-CC), the 81-mm by the hot cup-cold draw, and the 4.2-in. by warm cup-cold draw (WC-CD). In the HC-CC process, cold coining of the projectile body base section prior to cold-drawing produces higher mechanical properties in a transverse direction than could be achieved by the basic HC-CD process. in the WC-CD process, warm cupping is accomplished in a temperature range of 649°-704°C (1200°-1300°F). This approach is practical, provided that reduction in the cross section of the workpiece does not exceed the limits of the material and that subsequent cold-forming operations are followed by appropriate in-process annealing or stress relief. In the HC-CD process, hot cupping parallels the forging practice described for hot forge-heat treat (HF-HT) process in par. 4-2.1.

Future designs may dictate the use of other variations in the basic HC-CD processor the use of hot forge-heat treat (HF-HT) methods. A typical sequence of forming operations for the HC-CD process is shown in Fig. 9-7(A). HF-HT is included in Fig. 9-7(B) because future designs of HE projectiles may require use of high-

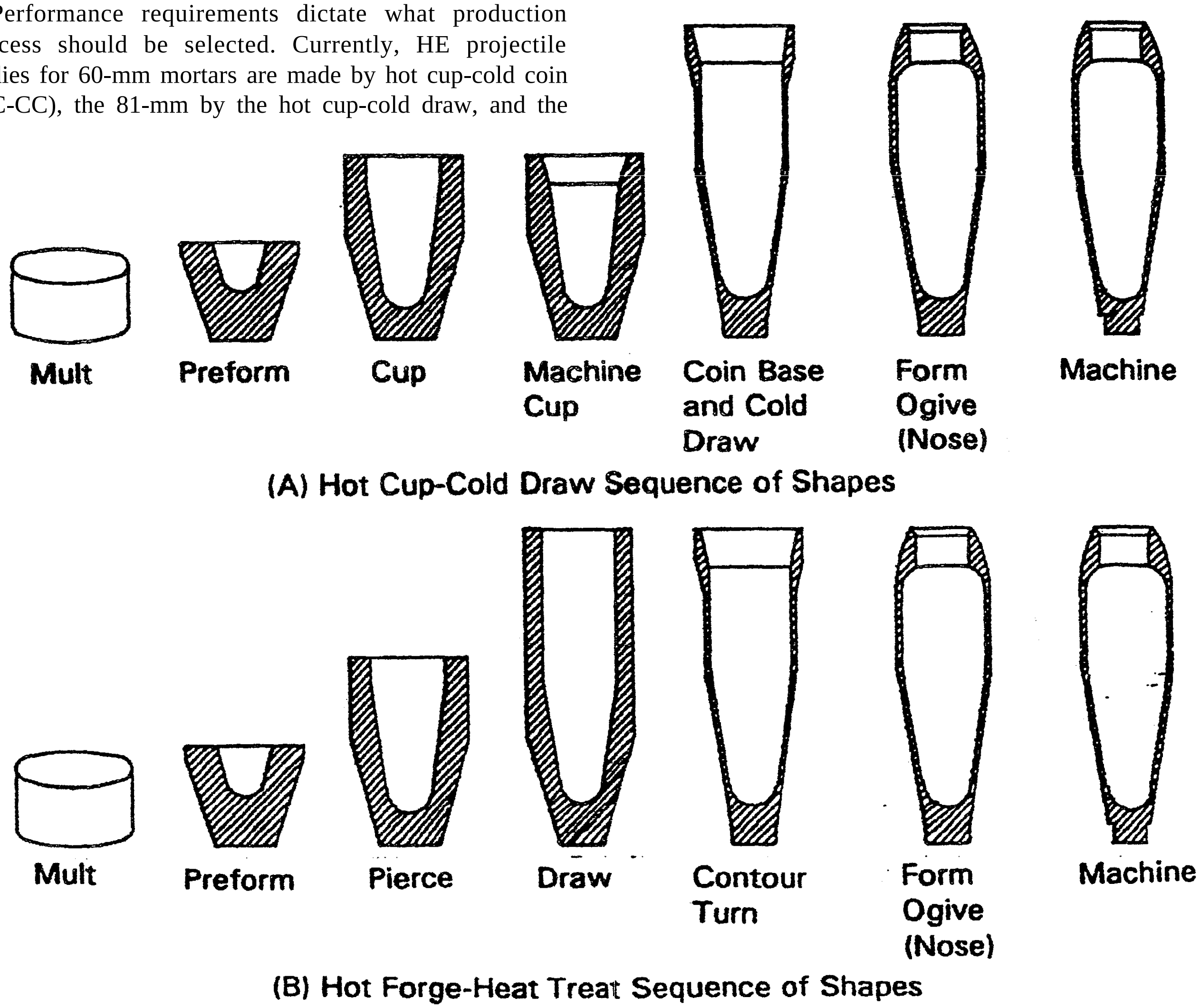

Figure 9-7. Typical Forming Operations for High-Explosive Mortar Projectiles

fragmentation steel from a modified form 0f the HF-HT process.

The HC-CD process represents the least cost because of: (1) lower initial investment, (2) reduction of machining operations, (3) lower direct labor, and (4) lowest raw material cost. However, the HF-HT process is more flexible than the HC-CD method because it can satisfy wider variations in projectile design and mechanical properties. Process selection and grade of steel are interdependent. If the HC-CD process is selected, a cold-workable alloy steel, such as AISI 1340, is mandatory, whereas if the HF-HT process is selected, a high-carbon, high-fragmentation, steel, such as HF-1, is appropriate.

9-2.103 Raw Material Parameters

The carbon content of AISI 1340 steel allows it to be odd-worked to meet mechanical property requirements and also to produce the desired fragmentation effectiveness. Steel that meets the quality requirements of the applicable American Society for Testing and Materials (ASTM) A322 (Ref. 1) assures that cleanliness, internal soundness, and surface condition are compatible with the production process. For details on high-fragmentation steels refer to Chapter 3.

9-2.1.4 Typical Sequence of Operations

The sequences of in-process shapes for the HF-HT and HC-CD processes are illustrated in Fig 9-7. Manufacturing operations consist of forming, machining, thermal treatment, surface preparation, and painting. Detailed descriptions of these operations are included in Chapter 4.

9-2.1.4.1 Forming Operations

9-2.1.4.1.1 HF-HT Process

Prior to forming, the mult is separated from the main billet or bar by sawing or hot shearing, as described in par. 4-2.1.2, and heated to forging temperature in a furnace, as described in par. 4-2.1.3. Forming consists of cabbage (preform), pierce, and draw. Heating of the nose end is necessary prior to press forming of the ogive if the projectile body is made from high-carbon steel, such as HF-1.

9-2.1.4.l.2 HC-CD Process

Separating the mult and heating to forging temperature are similar to procedures described in par. 4-2.1.2. Hot forming operations consist of preform and cupping and are similar to operations described in par. 4-2.1.4 for cabbage and pierce of hot forgings. Prior to each cold-forming operation, the part is phosphate and soap coated for the reasons stated in par. 4-2.2.5. Cold-forming includes coining of the base end, a partial draw to develop sidewall mechanical properties and the outside contour at the open end (discussed in par. 4-2.2.6), and nosing of the ogive section (discussed in par- 4-2.2.9). If a partial draw is impractical, a full draw followed by nose end stres relief and contour turn will also produce the profile necessary for cold nosing.

9-2.1.4.2 Machining

9-2.1.4.2.1 HF-HT Process

Machining of the forging after cooling and interior shot blasting reduces wall thickness variation and creates the open end contour needed to achieve ogive geometry after nosing. For details of contour machining see par. 4-2.1.5. Finish machining of all outside surfaces, obturating ring groove, rotating band, internal nose threads, and external base threads is accomplished afterfinal thermal treatment, as described in par. 4-2.1.8.

9-2.1.4.2.2 HC-CD Process

Following spheroidizing and interior shot blast of the cup, the outside surfaces are machined to be concentric with the cavity surfaces to remove imperfections and to assure that concentricity and weight are compatible with subsequent cold-forming operations. Further in-process machining may be required if the prenosing contour cannot be developed during the cold-drawing operation. Details of this operation are described in par. 4-2.1.5. Finish machining consists of the same Operations Specified under the HF-HT process.

9-2.1.43 Thermal Treatments

9-2.1.4.3.1 HF-HT Process

Spheroidizing of the forging may be required if the surface hardness level exceeds the limits of normal machining practice. Prior to forming the ogive section, the open end of the contour-turned forging is lubricated and then heated by electric induction, as shown in Fig. 4-9. After the nosing operation, the projectile body is subjected to a final heat treatment that includes harden, quench, and draw cycles, as described in par. 4-2.1.7.

9-2.1.4.3.2 HC-CD Process

The hot cupped part may be spheroidize annealed for subsequent cold-draw operations. In-process annealing may also be required if the total cross section-reduction approaches the limits beyond which metal failure can be expected. After all cold-forming operations are completed, mortar projectile bodies are stress relieved by heating in a furnace at a minimum temperature of 371°C (700°F) for a specified minimum period of time in order to meet final mechanical properties.

9-2.1.4.4 Surface Preparation and Painting

Procedures and equipment are common for both the HF-HT and HC-CD processes. Details of surface preparation are included in par. 4-2.1.8.10; for painting, see par. 4-2.1.8.11.

9-2.1.5 Smoke Projectile Body

The design and manufacture of smoke projectile bodies vary depending on the method used to release the smoke signature.

Fin-stabilized projectiles with central bursters have the same exterior configuration as their HE projectile counterparts. This similarity is more readily apparent through a comparison of Fig. 2-6 with Fig. 2-7. The smoke projectile body can be made by the same manufacturing methods described in par. 9-2.1.4 for the HC-CD process; however, the material requirements are less stringent because there is no fragmentation requirement. The nose end is not internally threaded, as in the HE projectile body, but it is bored to a tolerance and surface finish required to accommodate the press fit closure with the burster easing after filling. This feature of the smoke projectile is most critical because it assures that the smoke agent will not leak after assembly with the burster casing.

These design Similarities do not exist between the spin-stabilized, 4.2-in. HE projectile (Fig. 2-10) and the smoke projectile (Fig. 2-11) because the smoke projectile has not been redesigned to match the most recent modification in the HE projectile design.

Fin-stabilized, base ejection, smoke projectiles consist of the body and tail cone sections as shown in Fig. 9-3. The body section is cylindrical and is manufactured from seamless or welded steal tubing, which is both practical and economical. Tubing that conforms to commercial wall thickness and straightness requirements generally will suffice for the manufacturing of the body tube and adapter parts.

Finish machining, surface preparation, and painting of the body assembly can be accomplished on the equipment, as described in Chapter 4 for HE projectile manufacture, with minor changes in tooling and fixtures.

9-2.3.6 Illuminating Projectiles

Projectile body assemblies are designed for base ejection of the parachute and candle; examples of the component parts are shown in Figs. 9-4 and 9-5.

The body tube section of the fin-stabilized projectile, shown in Fig. 9-4, is made from an aluminum alloy forging or extrusion for reasons of production economy. Its light weight partially compensates for higher payload weight. A fuze adapter is assembled to the body tube and held in place by pins that are inserted in radially drilled holes as shown in Fig. 9-4.

Spin-stabilized, illuminating projectile metal parts are the base plug, body, and fuze adapter. The base plug is machined from a steel forging and is assembled with the projectile body after loading. It is held in place by radially drilled pins that are designed to shear so that the base plug can separate from the body to permit release of the payload. The fuze adapter is machined from steel bar stock and assembled to the projectile body by brazing. The long cylindrical shape Of the projectile body readily lends itself to manufacture from steel tubing. Secondary machining operations are rquired to facilitate assembly with the base plug and fuze adapter. Forming of the ogive section can be accomplished cold because there is very little change in the cross-sectional area of the wall. Machining, forming, surface preparations, and painting of illuminating projectile metal parts can be accomplished on basic equipment used in the manufacture of HE projectile bodies and described in more detail in Chapter 4.

9-2.2 CARTRIDGE HOUSING AND FIN

There are significant differences between projectile manufacturing facilities and those required to produce cartridge housings and fins. Consequently, they are established and operated independently. For reasons of economy and practicability, fin assemblies for 8l-mm and larger projectiles are made from two pi-whereas the 60-mm fin is made from one piece. The fin assembly shown in Fig. 9-1 is typical of the design used in fin-stabilized mortar projectiles. In the spin-stabilized cartridge shown in Fig. 9-2, however, the ignition cartridge container is the counterpart of the cartridge housing of the fin assembly.

9-2.2.1 Raw Material Parameters

Material quality, mechanical properties, chemical composition, and other requirements for aluminum alloys used in the manufacture of cartridge housings, cartridge containers, and fins are governed by ASTM B221 (Ref. 2). Aluminum rod is cut into slugs by a band saw; the slug length is controlled to produce the material volume that will accomplish the required geometry after extrusion and secondary machining operations. Final mechanical property requirements, aluminum alloy chemistry, and heat treatment are interrelated, are specified by product drawings, and are varied with projectile caliber and weapon operating pressure.

9-2.2.2 Forming Operations

9-2.2.2.1 Cartridge Housing

For projectiles 81 mm and larger, the cartridge-housing is formed by extrusion or forging and machined separately from the fin. Prior to cold-forming the aluminum slug is phosphate and lubricated in spray units that include(1) clean, (2) hot water rinse, (3) etch, (4) hot water rinse, (5) deoxidize, (6) cold water rinse, (7) phosphate, (8) cold water rinse, (9) neutralize, and (10) soap coat operations. Preforming of the slug, hot or cold, is accomplished in a hydraulic press; the slug is partially pierced and its length is extended. In-process annealing and a repeat of the phosphating and lubricating operations are required prior to each new cold extrusion (CE) operation. The cross-sectional area of the extrusion or forging is increased by upsetting or expanding the metal in a heading press to form the tapered boss, which is later internally threaded to facilitate assembly with the projectile body, as shown in Fig. 9-1.

Cartridge housings for base ejection cartridges, such as those shown in Figs. 9-3 and 9-4, do not require the extra metal required for internal threading therefore, forming operations can be simplified.

9-2.2.2.2 Fin

Extrusions for fin sections are procured from the raw material supplier. The hub section is specified as solid rather than hollow to reduce the potential of voids due to incomplete fill of the extrusion die.

9-2.2.3 Thermal Treatment

Thermal treatment of aluminum extrusions is necessary to meet mechanical property requirements and is accomplished by the supplier.

9-2.2.4 Machining Operations

9-2.2.4.1 Cartridge Housing

Special double-ended, multispindle boring machines are employed to drill, counterbore, face, taper, and thread both ends of the cartridge housing simultaneously to assure functional fit. Flash holes are drilled simultaneously in a special machine, burrs caused by the drilling operation are removed by reaming the ignition cartridge cavity in a drill press, and external sharp edges are removed in a vibratory deburring machine. Knurling of the rear surface area facilitates press fit assembly with fin blade section.

92.2.4.2 Fin

After trimming and canting, the fin blade section is machined in a multispindle lathe and held in a specially designed chuck to avoid distortion of the blades. Maching operations consist of facing, drilling, turning, and counterboring.

9-2.2.5 Finishing Operations

Fins and cartridge housings are washed after machining and deburring to remove dirt, chips, cutting fluids, and other foreign matter. Protective coating is not required because the mortar cartridges are overpacked for storage and supply.

9-2.3 TAIL CONE

Examples of tail cones are shown in Figs. 9-3 and 9-4. The most practical method of producing the tail cone section is to machine it from an aluminum alloy extrusion or forging that has been heat treated to meet mechanical properties. Machining operations have been successfully and economically performed on multispindle lathes.

After machining and cleaning a chromate film protective finish is applied to the entire surface. This application is followed by painting of the exterior surface.

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2. ASTM B22-85, *Alumimum and Aluminum Extrusion Bars, Rods, Wire, Shapes, and Tubes,* December 1985.

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CHAPTER 10
MANUFACTURE OF STEEL CARTRIDGE CASES

This chapter discusses the design parameters, physical description, and the selection of manufacturing processes for the three types of steel cartridge cases used in artillery and tank ammunition: (1) deep drawn, (2) multipiece, spirally wrapped, and (3)forged.

10-1 INTRODUCTION

Historically, all cartridge cases were made from brass, but the critical shortage of copper and copper alloys during national emergencies created a requirement for conversion to steel. Changing the material also required a simultaneous revision of the production processes, which are detailed in the paragraphs that follow.

10-1.1 DESIGN PARAMETERS

All fixed, semifixed, and Separated ammunition employ a cartridge case as one component of the complete round. The prime function of the cartridge case is to facilitate the handling of the propellant charge (Ref. 1). To perform its function properly, it must protect the propellant. charge from moisture and survive storage and handling.

Upon insertion into the weapon the cartridge case is required to position the projectile in the forcing cone and, upon firing of the round, it must not crack or split, it must obturate the breech of the weapon, it must retain the primer, and it must be free to ejector be extracted.

10-1.2 PHYSICAL DESCRIPTION

A cartridge ease is a thin-walled, hollow container (usually metallic) that has an outside contour to fit the chamber of a weapon. Typical shapes are shown in Figs. 10-1 and 10-2.

10-1.2.1 Deep Drawn

The deep drawn steel cartridge case starts as a precut disc or blank of the prescribed dimensions that goes through a series of drawing forming and machining operations to arrive at its final configuration The manufacturing process is detailed in par. 10-2.

10-1.2.2 Multipiece, Spirally Wrapped

The spirally wrapped steel cartridge ease starts with a standard mill tolerance, low-carbon steel sheet that is sheared and trimmed to a trapezoidal figure, which is wrapped around a tapered cylinder to form a hollow cylinder or body. A forged base or head, also steel, is fastened to the body by a stamped steel collar to complete the configuration. The manufacturing process is detailed in par. 10-3.

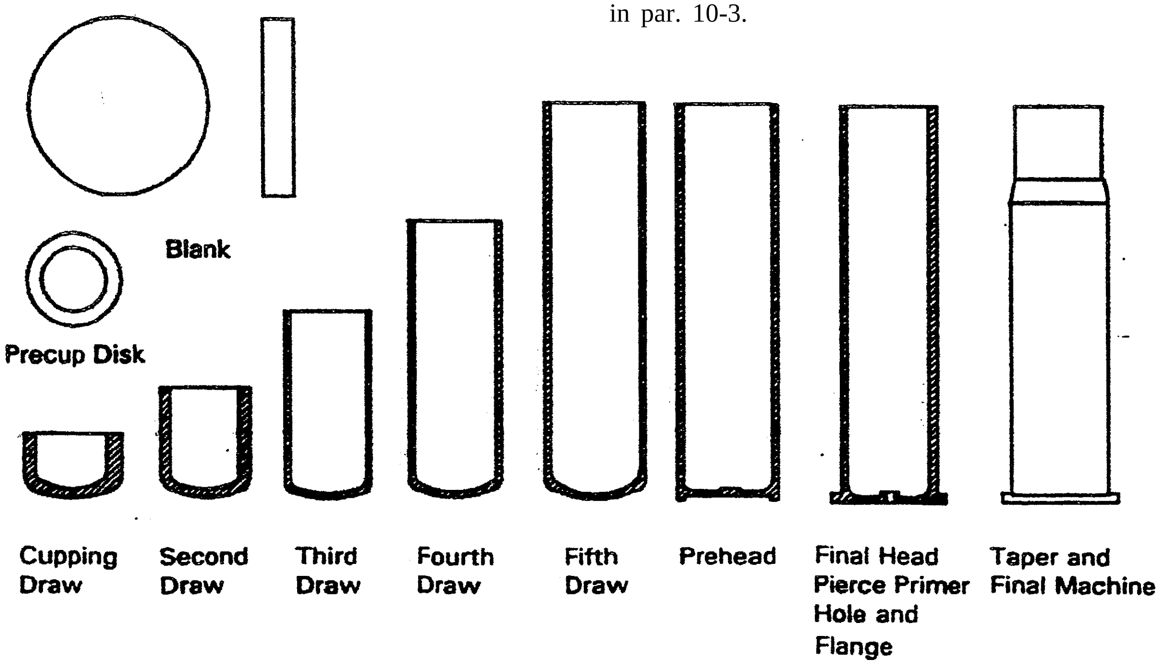

Figure 10-1. Progressive Drawing, Forming, and Machineing Operations

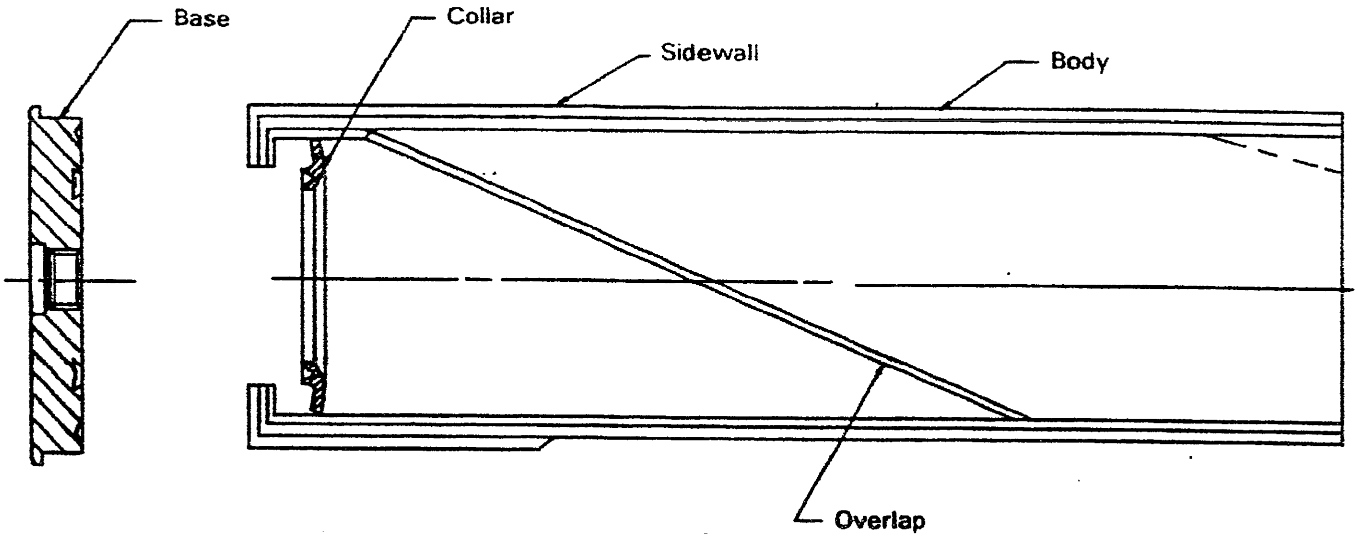

Figure 10-2. Spirally Wrapped Case Components

10-1.2.3 Forged

Basically, forged cartridge cases are bases for combustible cartridge cases. Present usage is in the 120-mm tank gun. The ease base starts with a high-alloy steel bar that is cut into slugs, heated, forged, and then machined to shape for assembly to the combustible ease. The process is detailed in par. 10-4.

10-1.3 SELECTION OF MANUFACTURING PROCESS

Two basic manufacturing methods have been used in the production of the 105-mm howitzer cartridge ease, i.e., the deep draw method for the M14B3 and the spiral wrap design for the M14B4. Because of the success of the spiral wrap design and the associated economics of low facility and operating costs, it is the preferred method for future production faclities.

The higher pressure type tank cartridge eases are presently produced by the deep draw process at existing production facilities, although a spiral wrap design has been recently developed.

10-2 DEEP DRAWN MANUFACTURING PROCESS

10-2.1 MATERIAL

Deep drawn cartridge cases are made from medium-carbon steel as specified in MIL-S-3289 (Ref. 2). It maybe purchased as plate or disks in either the spheroidized or nonspheroidized condition. The sequence of forming shapes is shown in Fig. 10-1.

10-2.1.1 Disk Conjuration Ready for Processing

When purchased as a spheroidized disk, no further processing is required other than surface preparation before introduction into the process. If the surface were idea it would be smooth on both sides and free from all imperfections. Since this is impossible, surface defects are classified as those that iron out and those that do not. Among those that do not iron out are notches, which, during the drawing operations, may become stress raisers. surface blemishes may be salvaged by grinding.

10-2.1.2 Unspheroidized Disks or Plate

The steel plate or disks have to be spheroidized before cupping and precupping operations in order to increase the amount of deformation the steel can withstand without fracture. In the ease of purchased plate, disks may be blanked before or after the spheroidization process depending on the economics of the furnace design employed. If blanked from as-rolled plate, the disks are subsequently spheroidized by themselves.

10-2.2 PREPARTION FOR CUPPING

The blanks are (1) rinsed to remove soap, which may have been picked up from the conveyor work holders, (2) washed in an alkali cleaning solution to remove oil and dirt, (3)given a rinse with trisodium phosphate to remove the cleaner and promote uniform soap coating and (4) soap coated. These steps are done in one continuous operation. Many lubricants, such as oils, greases, and graphitized compounds, have &tried as lubricants for the drawing operations, but the intense pressures of the tools during the cold-working operations broke through the lubricating films and caused excessive friction. A layer of soap is, however, easy to apply, remains intact during the forming and drawing operations, and can be removed wit h hot water.

10-2.3 PRECUP AND CUP

The first drawing operation in the manufacture of the steel cartridge case is the cup, which forms the head and first few millimeters of the sidewall. This operation was done in one step, but the common occurrence of fracture of the cup, especially when 0.30% carbon steel was used for the higher strength cartridge cases, caused the operation to be divided into two steps. Following the first of these, the "precup", an inspection determines whether there is any sign of a rupture or potential rupture. If none is observed, the precup is placed in the cupping die and the punch carries the component through the die to iron out the sidewalls. Finished cups are inspected for evidence of "tool loading”, that is, the incipient or actual welding of steel particles from the cup to the die, punch, or stripper fingers. Tool loading maybe caused by inadequate soap coat, which leaves bare spots.

10-2.4 PROCESS ANNEAL

The cold-work on the cup distorts the ferrite grains and greatly increases the strength and hardness of the steel; consequently, the cold-work drastically reduces the ductility of the cup. Before any further work can be done, the cup must be annealed by heating above the recrystallizing temperature (that is, by heating to around 621°C (1l50°F) and holding at this temperature for five minutes). After heating, it has been necessary to “pickle” the cups to remove the scale. Although the use of a controlled atmosphere does not entirely obviate the necessity of pickling, the amount of scale formed is considerably reduced, as is the pickling time. Because the presence of soapy film on the components during annealing would produce hard scale deposits, which would be difficult to remove in the pickling bath, the cups are thoroughly washed to remove all soap prior to annealing.

10-2.5 DRAWING

Prior to drawing, the cups are phosphate coated and then soap coated. The phosphate acts as a host to the soap, which is a lubricant to prevent metal-to-metal contact during the drawing operations. These operations progressively reduce the thickness of and lengthen the sidewall. The number of draws required depends on the total reduction in wall thickness required from cup to finished ease. Each draw is designed to produce a reduction of approximately 40%, which is the maximum that can be sustained without causing excessive variation in the thickness, or a fracture, of the sidewall. Consecutive draws may be made without intermediate lubrication if the total reduction required in wall thickness is limited to 70%.

10-2.6 TRIMMING

Between draws the mouth of the case is trimmed to eliminate “dead metal”, which develops because, during the draw, the outer surface of the case elongates more than the inner surface. Hence the lines of grain flow curve inward near the lip of the case and show end grain on the inside of the case. This weakens the steel and may cause circumferential rupture Another purpose of the trim, particularly after the final draw and before and after tapering, is to secure uniformity in the length of the sidewall Trimming is done both by a nibbling operation, which shears the surplus metal in a series of strokes of a cutter while the ease is mounted On a mandrel, and by a rotary trim before the taper. The rotary trim produces a burr-free edge, whereas the shearing action of the nibble trim produces burrs, which necessitate a mouth ream to prevent scratching of the chrome plating of the punch during the subsequent draw.

10-2.7 PREHEAD AND FINAL HEAD

Cold-worked steel is much more “notch sensitive”than brass; therefore, all stress risers must be eliminated, especially from the internal radius of the head. Actual cold shuts in this area maybe tolerated in brass eases, but in a steel cartridge case ballistic failure could result. The steel cartridge case is headed in two operations. The preheating operation, done by gathering metal at the center of the head and at the periphery, redistributes the metal in the head of the case to facilitate the formation of the primer boss and the flange during the final heading operation. Preheating is done by a heavy squeeze in a hydraulic- or knuckle-type press between a stationary post and a die mounted on the face of the ram of the press. Final heading forms the flange of the case and the primer boss and shapes the entire interior of the head. Heading is a critical operation because roughness of the internal radius of the head may raise the stress in the steel during firing to a point at which the head separates from the body.

10-2.8 PIERCING THE PRIMER HOLE

By using a press, the primer hole is pierced in the boss of the cartridge ease. Piercing at this stage allows finish machining of the primer pocket during the machining of the head. Following the piercing operation the ease is passed through a combination wash and pickle machine where the soap coat, phosphate coating, and incidental rust are removed and the case is thoroughly dried preparatory to heat treatment of the sidewall.

10-2.9 HEAT TREATMENT

The amount of elastic recovery of the cartridge case after firing depends primarily on the elastic limit of the steel in the sidewalls. If the elastic limit is low, there will be more plastic deformation and consequently a smaller recovery (Ref. 1). Because of the high pressures used, especially in the tank rounds, and the tendency of the head or base to rupture as mentioned in par. 10-2.7, all steel cartridge eases are overall heat treated by immersion in a hot salt bath, quenched, and tempered.

10-2.10 ANNEAL SURFACE OF HEAD

Since the hardened cartridge case is difficult to machine in its quenched and tempered state and the major portions of the machining operations are performed on the exterior portion of the base end, the surface is annealed by processing the cases through a flat induction coil. This processing heats and softens the surface of the base and flange, which are subsequently machined to final dimensions.

10-2.11 HIGH-STRESS EXPANSION TEST

To be assured that none of the cartridge cases will develop cracks or leak hot gases into the gun chamber during actual firing, each cartridge case is subjected to the high-stress expansion test. During this test the lower sidewall of each case is expanded diametrically by placing the case in a die whose inner diameter is at least 1.27 mm (0.050 in.) larger than the cartridge case and by applying an internal pressure to expand the case to fill the die.

10-2.12 TAPERING, NECKING, AND SIZING

Heat treatment is required before the tapering of the case because of the severe strains imposed on the steel of the sidewall. To obtain a maximum increase in percentage of elongation without appreciable loss of hardness, a temperature between 538° and 566°C (1000°-1050°F) is required. If the temperature is allowed to rise to 566°C (1050°F), recrystallization takes place and the steel loses much of its hardness and yield strength. Therefore, the mouth end of the case is immersed in a salt pot at 549°C (1020°F) and held for approximately 45s. The cartridge case is then pickled to remove scale, and a coat of soap is applied to the outside for lubrication. The tapering operation develops the final contour of the body section including the necking and sizing of the forward section by forcing the case into a tapered die in a vertical hydraulic press.

10-2.13 MACHINE HEAD AND OVERALL LENGTH

After washing and drying, the head of the case, the shoulder, the primer hole, and the mouth of the case are finish machined on a special single-spindle, center-chive lathe.

10-2.14 MOUTH ANNEAL

Mouth annealing is done to increase the ductility of the steel for two reasons: to reduce the possibility of splitting of the mouth upon firing and to soften the mouth so that, if required, the projectile maybe crimped to the case.

10-2.15 SIZE MOUTH

The mouth of the case, which is tapered slightly undersized, is resized to the correct dimensions holding the case in a special fixture and forcing a sizing plug into the mouth to a depth of 25.4 mm (1 in.).

10-2.16 PROTECTIVE COATING

Before plating, cases are stress-relief annealed and cleaned electrolytically in an alkaline bath. After rinsing in an acid dip to neutralize all traces of the alkali cleaner, the outside and the inside of the case are zinc plated in an eletrolytic plating machine.

10-3 SPIRALLY WRAPPED CARTRIDGE CASES

For purposes of illustration, the manufacture of the trapezoidal, wrapped steel cartridge case, 105 mm, M14B4 is typical of the manufacture of this type of case. The physical description of this ease is outlined in par. 10-1.2.2 The spirally wrapped cartridge case is less costly to produce than the deep drawn ease and requires much less equipment and space. Since no heat treatment is required anywhere in the process, the expensive furnaces with their exacting controls are eliminated. An additional advantage is that production line machines are not highly specialized and can be found in many sheet metal and machine shops. This advantage greatly expands the potential prod mobilization base.

10-3.1 COMPONENT MATERIALS

The three major components of the ease are the base, collar, and body, as shown in Fig. 10-2. The base, or head, of the case and the collar arc forged or blanked from ASTM A576 (Ref. 3) steel bar or QQ-S-635 plate. The body of the case is made from low-carbon steel sheet AISI 1007-1020, ASTM A109 (Ref. 4), with a varnished finish.

10-3.2 METHODS OF MANUFACTURE

10-3.2.1 Base

The steps in base manufacture are shown in Fig. 10-3.

10-3.2.1.1 Heat, Shear, and Forge Bar

Steel bars are supplied to the bar handling table, which automatically feeds the bar into an induction heater at a Predetermined rate of speed and heats it to an approximate temperature of 1121°C (2050°F).

The heated bar is carried on a conveyor from the induction heater into a 8.9-MN (1000-ton) vertical mechanical press containing a ram-mounted, "V"-t ype shearing die and a stationary three-station die mounted on the bed. The sheared slug is automatically y positioned into the first station of the press where it is cabbage then moved to the second and third stations where

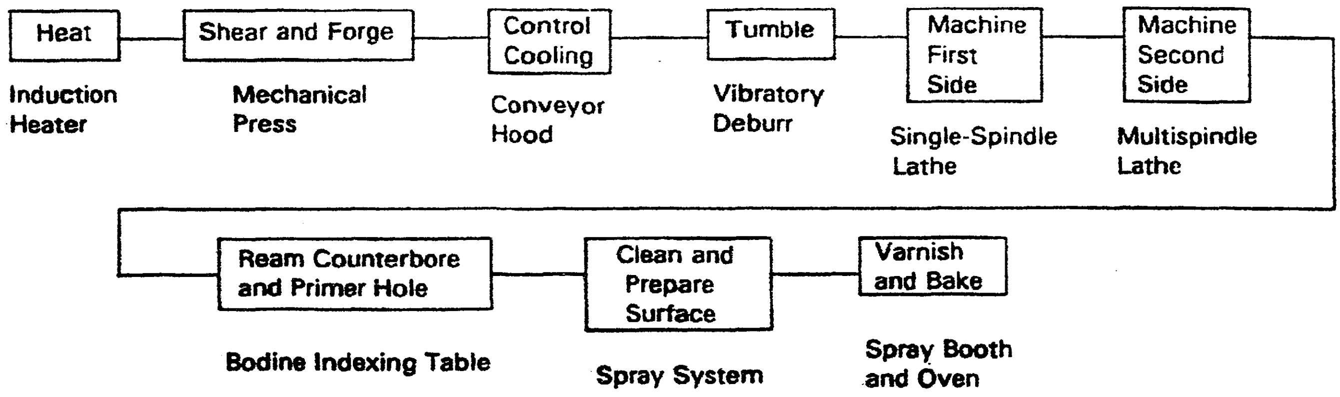

Figure 10-3. Base Sequence of Operations

progressively formed into a forged blank suitable for machining, Upon exiting the press, the slug is passed through a cooling tunnel where the forging is allowed to cool at a predetermined rate to meet the physical property requirements. The forging is then transferred to the tumbling machine for descaling.

10-3.2.1.2 Machine First Side (Outside)

The forgings are placed in a magazine-fed, single-spindle lathe and chucked on the step of the flange. The machining of the outside diameter of the flange, rough drilling of the primer hole, and machining of the rear face of the base are performed in this operation.

10-3.2.1.3 Machine Second Side (Inside)

The parts are loaded into a magazine, fed into a multispindle lathe, and held by the outside diameter; the forward face of the base including the flange step and the dovetail groove are machined.

10-3.2.1.4 Ream and Counterbore Primer Hole

Parts are then loaded into a lathe, located on the flange step, for finish machining of the primer hole and counter-bore.

10-3.2.1.5 Clean and Prepare Surface

Parts are manually loaded onto a tree-type fixture and conveyed into a cleaning and phosphating system.

10-3.2.1.6 Varnish and Bake

Parts are conveyed into a spray booth and electrostatically sprayed with varnish, transferred into a curing oven at 191°-2320 C (375°-450°F) for 0.5 h, removed, and transferred to the storage area.

10-3.2.2 Collar

The steps in collar manufacture are shown in Fig. 10-4.

16-3.2.2.1 Blank

Steel strip is supplied to a handling table from which it is fed into a 7.1-MN (800-ton) mechanical press, which blanks out a ring. The blanking operation is done on a two-station die. The blanks are then loaded into a basket for transfer to the annealing station.

16-3.2.2.2 Anneal

The rings are batch loaded into a furnace, heated to 871°C (1600°F) for 1 h, and control cooled at a rate of

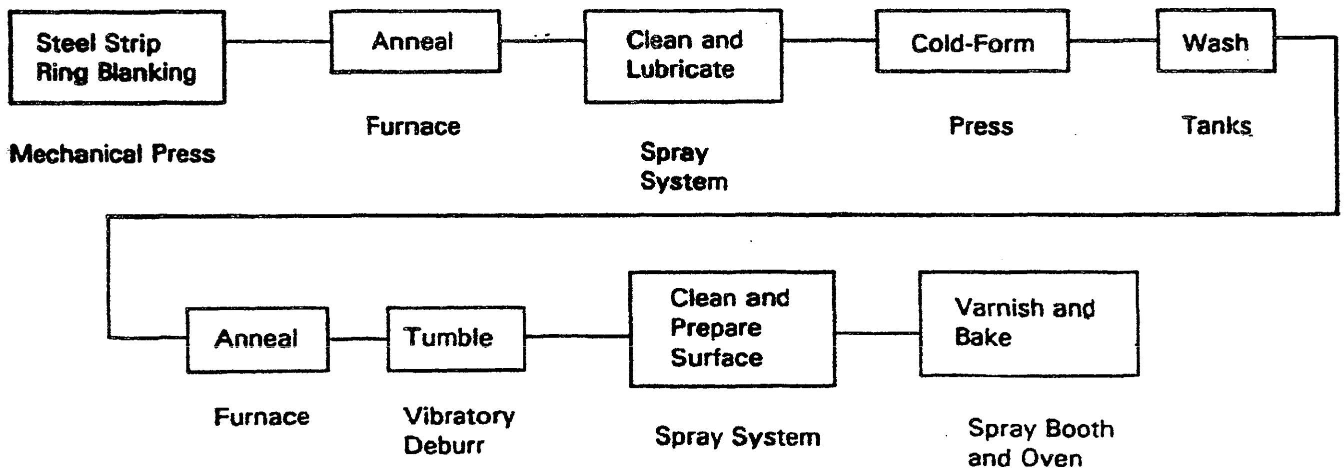

Figure 10-4. Collar Sequence of Operations

16.7 deg C (30 deg F) per hour to 727°C (1340°F). The rings are then removed from the furnace, air cooled to ambient temperature, and transferred to a cleaning and lubricating station.

10-3.2.2.3 Clean, Lubricate, and Cold-Form

The rings are batch loaded into a cleaning, phosphating, and lubricating system and positioned in a five-station (i.e., load, first form, trim, final form, and unload), 8.9-MN (l000-ton) mechanical press, in which the ring is formed to its finished collar configuration--shown in Fig. 10-5—and transferred to a wash station.

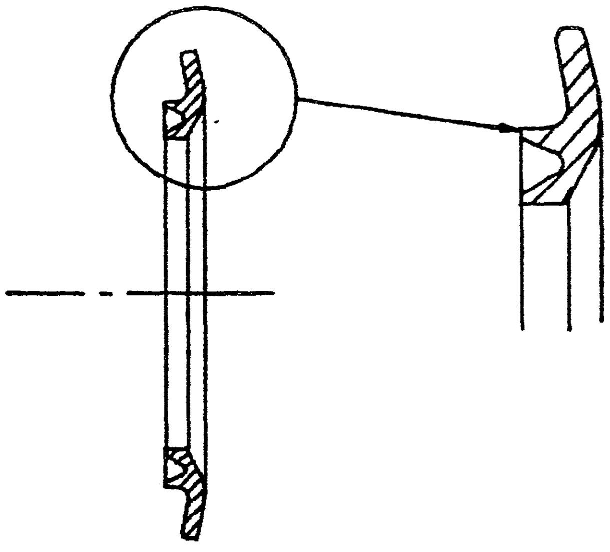

Figure 10-5. Collar Configuration

10-3.2.2.4 Wash, Process Anneal, and Tumble

The collars are put through an alkaline rinse system remove lubricant and grease, batch loaded into a furnace heated to 649°C (1200°F) for 1 h, removed from the furnace, cooled to ambient temperature, and loaded into a tumbling machine where the parts are descaled.

10-3.2.2.5 Clean and Prepare Surface

The parts are manually loaded on a tree-type fixture, conveyorized into a spray booth, electrostatically sprayed with varnish, and earned on a conveyor into a curing oven that is 191°-232°C (375° -450°F) for 0.5 h, removed from the tree, and transferred to a storage area.

10-3.2.3 Body

The steps in body manufacture are shown in Fig. l0-6.

10-3.2.3.1 Uncoil, Straighter, and Blank

The varnished steel sheet coils are loaded on a coil cradle where the coil is automatically unwound and straightened. They are then fed into a shear press where the sheet is cut into trapezoidal sections and automatically stacked. The edges of the stacks are sprayed with varnish and allowed to dry before being transferred to the rolling machine.

10-3.2.3.2 Roll and Flange Body

Body blanks are fed automatically from the stack into rolling-machine where the blank is coiled into a cylindrical shape and approximate body size, automatically ejected, and carried on a conveyor to a flanging machine where the base end is flanged inward, automatically ejected, and carried by a conveyor to the assembly press area.

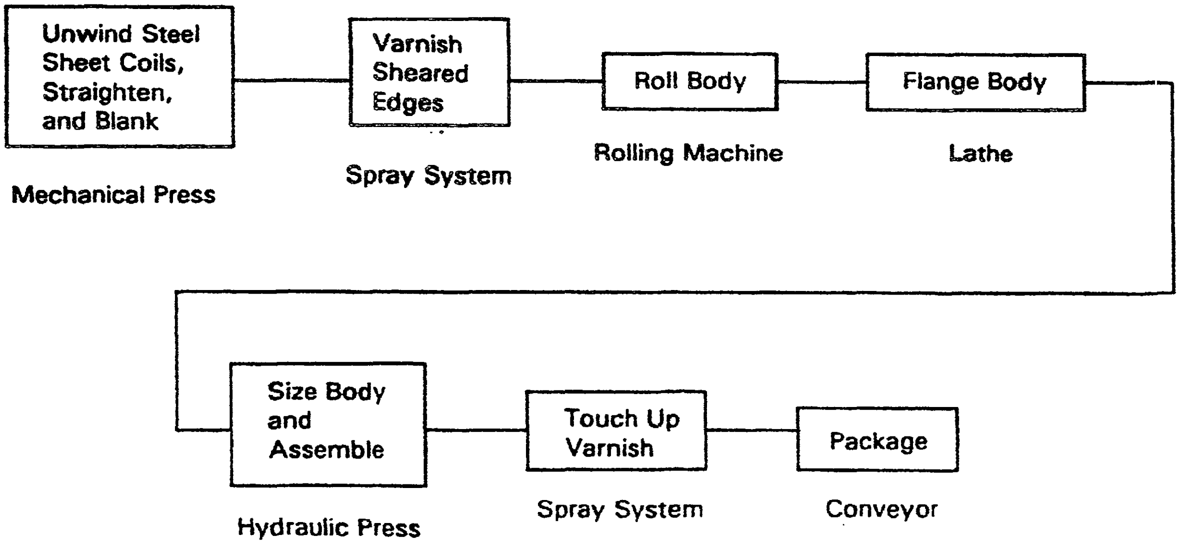

Figure 10-6. Body Sequence of Operations

10-3.3 SIZE BODY AND ASSEMBLE COMPONENTS

The collar, body, and base are loaded into a 1.33-MN (150-ton) hydraulic press, which contains three assembly dies located on a rotary indexing bed. The first position is a loading position where the collar, body, and base are loaded in sequence. The bed is then rotated into the second position under a ram which descends, mechanically assembles the parts by spreading the fingers on the ring into the dovetail groove of the base (shown on Fig. 10-7), and sizes the body and stamps the appropriate nomenclature on the base. The table then rotates to a third position where the assembled ease is unloaded.

10-3.4 M115 SPIRALLY WRAPPED CARTRIDGE CASE

As mentioned in par. 10-1.3, a spirally wrapped cartridge case has been developed for tank ammunition. This ease differs from the M14B4 howitzer case in that it has a tapered mouth end and is crimped to the projectile to make a fixed round.

The operations are essentially identical to those of the M14B4 process except that in the body assembly operation the taper is formed during the sizing and assembly operation caused by the expanding of the solid rubber insert, which makes the body conform to the tapered internal configuration of the die.

Upon removal, the mouth end is then spot welded to maintain rigidity. Locating detents for the projectile are pressed into the mouth area by a device similar to a crimping machine, and the weld areas are touched up with varnish after spot cleaning.

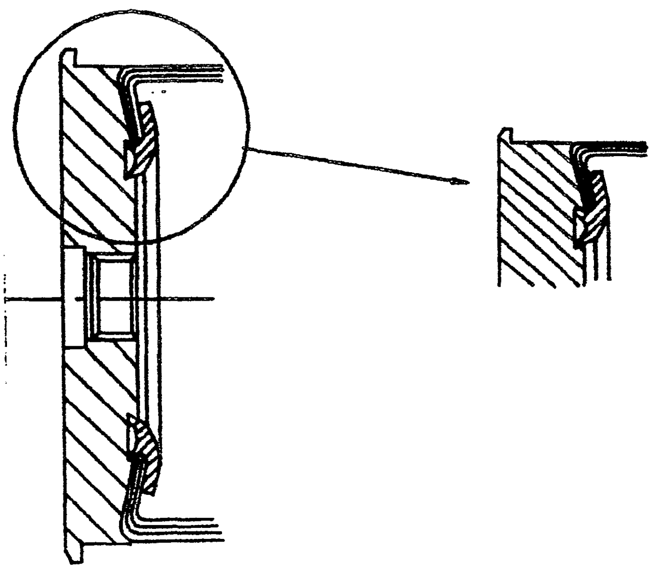

Figure 10-7. Final Assembly Detail

10-4 FORGED BASE FOR COMBUSTIBLE CARTRIDGE CASE (Ref. 5)

10-4.1 MATERIAL

Because of the high physical requirements of this stub base—1200-MPa (174-ksi) yield strength, a high-alloy steel is required. In this instance a modified 4337 with vanadium is specified per MIL-S-46119.

10-4.2 MULT PREPARATION

Since this item is forged by the closed die method, slug weight and surface condition are important factors in preparation of the mult. By purchasing bar, rather than billet, steel, the surface finish and dimensions of the material are improved. By using the circular saw method of parting, better control of weight and finish on the parted surface is maintained.

l0-4.3 FORGING AND NORMALIZING

The mult is heated by an induction heater and placed in the first cavity of a 2.2-MN (250-ton} mechanical press where it is upset or flattened, as show in Fig. l0-8. By upsetting the mult, the grain flow of the part now becomes essentially parallel to the face of the base and forms a surface impervious to leakage of hot propellant gases within the base.

The upset mult is automatically transferred to the second cavity where it is backward extruded to form a cup shape. The cup is transferred to the third cavity where it is pressed between the bottom fixed die and a punch die, which together form a closed cavity at the bottom of the stroke. With perfect weight and volume control, the mult will perfectly fill the cavity and have the final shape. However, process controls are such that the ideal is too difficult to achieve on a production basis and weight is always toleranced on the high side to assure enough metal. This will result in some flash extruded between the mating surfaces of the two dies. Therefore, the forging is next placed in a 1.78-MN (200-ton) press where the flash is trimmed off by a shearing action.

The sheared forging is then placed in an atmosphere-controlled furnace and normalized to give the forging a homogeneous structure in order to prevent hard spots, which would adversely affect the machining operations.

10-4.4 ROUGH MACHINING

The forging is placed in a series of lathes, preferably computer controlled, where the flange outer diameter and the face are rough turned, then the item is grasped by the outer diameter flange, and it is cut to length. The body outer diameter and the interior cavity are profiled, and the primer hole rough drilled.

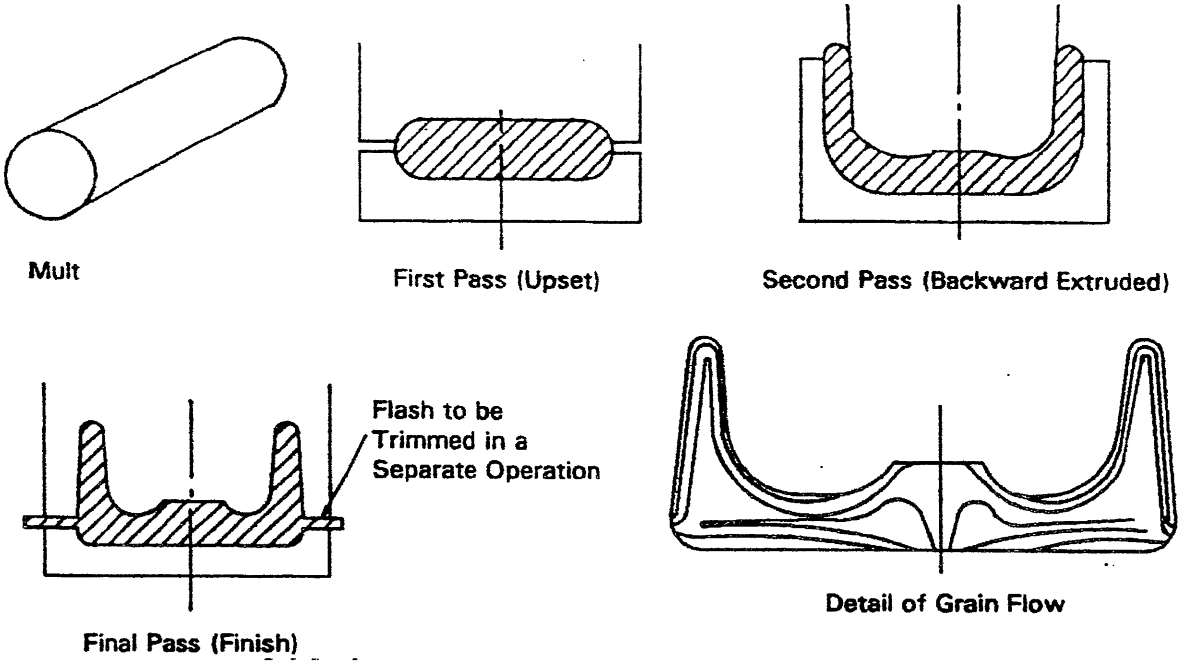

Figure 10-8. Forging Sequence for Stub Base

10-4.5 HEAT TREAT

The rough-machined forgings arc next heated in an atmosphere-controlled furnace to a temperature of approximately 843°C (1550°F), quenched in oil, washed, and tempered in another furnace at approximately 538°C (1000°F) to obtain a final hardness of 400-430 Brinell. Since the atmospheres in both furnaces have been controlled, there is no need for scale removal, and the forgings are now ready for finish machining operations.

10-4.6 FINISH MACHINE

The finish machining operations follow the same sequence as the rough machining operations except that the use of computer numerical control (CNC) lathes is practically mandatory for economical production rates due to the dose tolerances and detailed grooves and contours required in the finished product, as shown in Fig. 10-9, in order for it to mate with the combustible case.

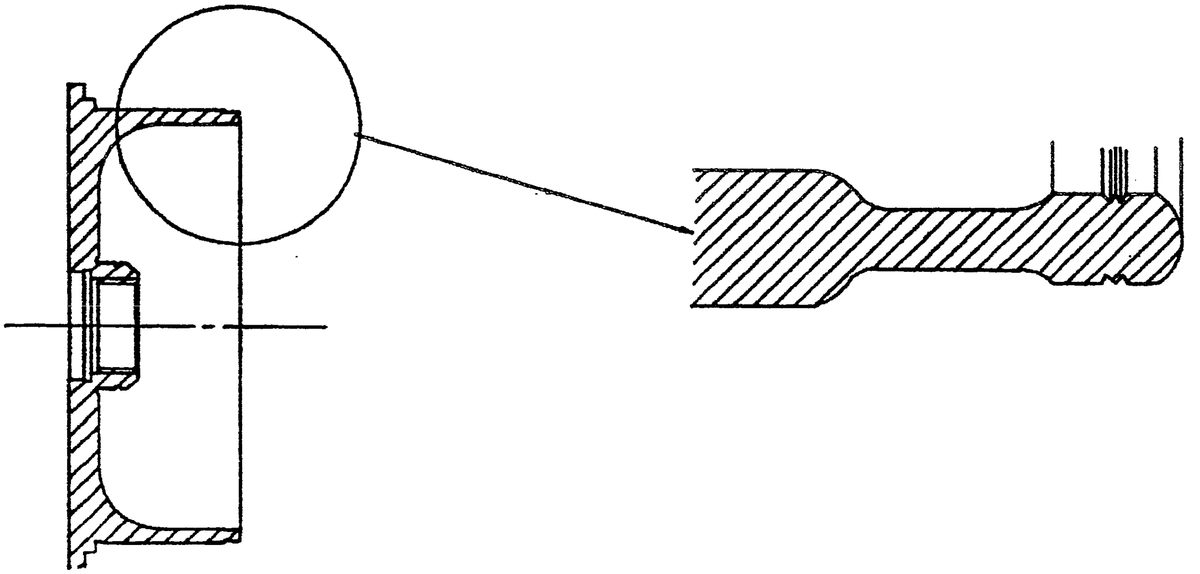

Figure 10-9. Stub Base

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CHAPTER 11
PRODUCT ASSURANCE

This chapter discusses the product assurance responsibilities of the contractor and the Government as they relate to the manufacture of projectiles.

11-1 INTRODUCTION

Product assurance is an integral part of the technical data package (TDP), which is controlled through the configuration management system. Test and evaluation is an essential element in the proof of the design and a necessary function in the production phases to assure acceptable items. The requirements covered in this chapter are supplemented by Chapters 12, 13, and 14.

11-2 INSPECTION SYSTEM AND QUALITY PROGRAM REQUIREMENTS

Projectile designs should be producible with standard tooling machinery, test equipment, and, where possible, readily available materials. Therefore, development engineers will benefit from having product and process engineers and product assurance personnel involved in the design of the projectile. New and unfamiliar production test and inspection devices should be avoided whenever possible because they arc more likely to be costly, cause production slippage (Time-consuming use certifications are required.), and create problems for operating personnel who may be unfamiliar with the equipment.

The principal components of the projectile technical data package, which is developed by the design engineer, are the item drawings and the item specifications. The drawings dimensionally depict the components, subassemblies, and the item assembly and also specify the materials, mechanical properties, assembly instructions, etc., which are required to produce a satisfactory item. The projectile specification may specify performance requirements, such as terminal effectiveness, range and accuracy, and the method of test and evaluation to assure these requirements are met.

11-2.1 INSPECTION SYSTEM REQUIREMENTS

A vital part of the TDP, in addition to the item drawings and specifcations, are the inspection system requirements required of the contractor under military specification MIL-I-45208 (Ref. 1), which is usually specified for developmental items. This specification requires the contractor to establish a plan of inspection subject to Government approval prior to the production of these items. The plan must cover the details of procedure, equipment and implementation to assure quality parts. It is then monitored by the Government inspectors, who oversee the inspection performed by the contractor.

This procedure gives the designer control of the process and confidence that the items truly represent his design as specified in his detail item specification and drawings.

11-2.2 QUALITY PROGRAM REQUIREMENTS

More extensive and detailed requirements for quality management are incorporated in MIL-Q-9858, Quality Program Requirements (Ref. 2). This specification is ordinarily specified during the production phases of systems or items to control more fully the production processes that are critical to produce quality items consistently.

The quality management program covers areas, such as organization, plans, work instructions, record keeping and corrective action procedures. It also provides for the contractor to furnish inspection gages or devices for acceptance of production. These may be mechanical measurement devices, such as those covered in Chapter 13, physical property testing devices, such as those discussed in Chapter 12, or nondestructive soundness tests, such as those described in Chapter 14.

All phases of the production process come within the puview of these program requirements. Such functions as purchasing and control of quality of materials or components, production processing and fabrication, completed item inspection and testing, handling, storage, and delivery are covered.

11-3 QUALITY ASSURANCE TESTING

11-3.1 FIRST ARTICLE TESTS

First article tests are outlined in the item specification and generally require verification tests to assure that the production processes employed have not altered the items in any way that would interfere with their acceptability concerning form, fit, or function. The test program on first articles, inmost cases, duplicates the tests that were performed on the developmental item during its standardization acceptance tests. These tests include, in addition to the mechanical, dimensional, and physical property testing, ballistic tests of the projectiles themselves under various environmental conditions to verify the integrity of the projectile during launch and flight and its accuracy, lethality, and penetrating capability.

11-3.2 CONFORMANCE TESTS

Conformance tests are those conducted on appropriate samples of all production lots of projectiles for acceptance of the lot. Ordinarily these tests would be less stringent than those for first article testing. For example, tests would be run only at ambient temperatures rather than at the high and low tcmperature extremes, the number of items tested would be reduced, or transportation and vibration requirements would be eliminated.

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CHAPTER 12
EVALUATION OF PROPERTIES

The Manufacturer must assure that the raw materials from which munition components are produced meet the specifications established by the designer. Assurance through evaluation of properties is the subject of this chapter. The discussion includes the types Of tests conducted, equipment required, specimens used, and the applicable specifications and standards.

12-1 INTRODUCTION

12-1.1 BACKGROUND

A manufacturer of munitions specifies the raw material needed to produce components and purchases his wrought and cast products in the various forms necessary to meet his needs for welding, forging or machining to make the desired end product. He designs his plant operation for the most efficient use of his equipment and incorporates test equipment in the sequence of metalworking operations for the evaluation of material properties during the process.

12-1.2 SPECIFICATIONS

Specifications of the finished product cited in the contract must be met in accordance with the Government or commercial standards quoted. The contract wiil stipulate the tests required in the quality conformance inspection listings, which are in the classification of defects and tests section of the end-item specification. These tests for defects listed as critical, major, or minor specify the acceptance quality level (AQL) and the acceptance method. For metals the tests are generally nondestructive tests (NDT) conducted for defects, such as cracks, holes, and pits. Mechanical tests are required for hardness, yield, and elongation determinations, and chemical tests are required for qualitative and quantitative analyses and macrometallurgical acceptance.

12-1.3 STANDARDS

Where possible the American Society for Testing and Materials (ASTM) standards are used to define the testing required for the evaluation of materials. Military specifications are used if no commercial specification exists to define unique requirements for a munition component. Generally, the major test requirement for munition materials is the load test for tensile strength values, such as yield strength, yield point, elongation, and reduction of area to determine strength and ductility of a sample (Ref.1). Hardness testing, either Rockwell or Brinell, is an NDT conducted on 100% of the production lot to confirm the efficacy oft he heat treat process to harden steels (Refs. 2 and 3). Metallographic specimen tests for microstructure examinations are sometimes required to confirm heat treat processes on a lot basis (Ref. 4).

12-2 TENSILE TESTING

12-2.1 PURPOSE OF TEST

Tensile testing is a major material evaluation test to determine the strength of materials, and it is used as a requirement for acceptance testing of materials arid components. Specifically, this test is used to determine the yield strength, ultimate tensile strength, elongation, and reduction of area of a specimen. Also this testing which exposes a material sample to measured forces to the point of rupture, defines the reaction of materials to loading. It defines those properties of the material associated with elastic and inelastic reaction when fbrce is applied and shows the relationship between stress and strain.

12-2.2 EQUIPMENT USED

Tensile testing machinery provides a constant rate of pull, which applies a force to a specimen machined either from the material supplied or from a specified area of the projectile. The purpose of the apparatus is to provide a measured force on a standard specimen and thereby acquire a measured elongation and calculated yield strength, ultimate tensile strength, and reduction of area value on that specimen as a result of pulling it to the point of rupture.

12-2.3 SPECIMENS USED

There are basically two types of specimens normally used for tensile tests of materials and projectile components (Ref. 5). One is the round specimen with threaded ends, as shown in Fig. 12-1(A), which is machined from a specified area of the material or projectile component. The standard 12.7-mm (0.50-in.) round specimen with a gage length four times the diameter is normally required in projectile specifications; however, when necessary because of size limitations, smaller specimens having the same gage-to-diameter ratio maybe used.

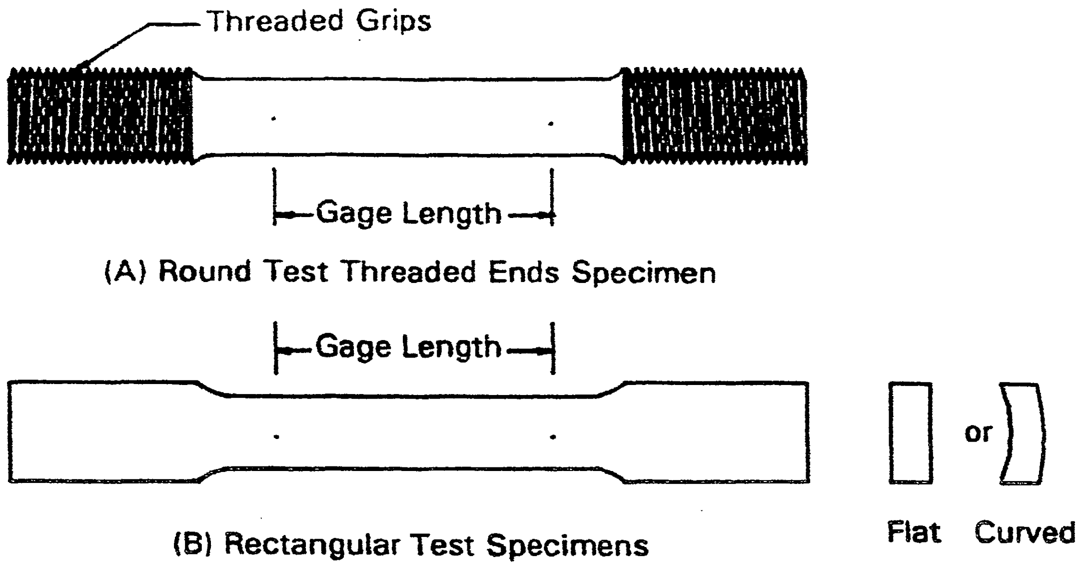

Figure 12-1. Tensile Testing of Materials (Ref. 5)

It is important for the design engineer to realize that the mechanical properties of materials differ if tested longitudinally or transversely to grain direction. Consequently, attention must be paid to stresses developed in an item to assure that an adverse grain flow will not cause failure. In the manufacture of a projectile body, the grain flow is in a radial direction in the base section and in the longitudinal direction in the sides of the body. Therefore, in a closed end projectile body, the grain flow across the base will be transverse to a horizontal tensile specimen cut from that section. Based on thorough stress analysis studies, consideration may be given to thickening the base section to compensate for the lower mechanical strength, or provisions maybe made in the manufacturing process to alter the grain flow so that it is longitudinal to the base stresses. The base area is one that requires a tensile specimen smaller than the normal 12.7-mm (0.50-in.) diameter.

For components that are to thin for round specimens, flat sections similar to Fig. 12-1(B) are used.

The tensile specimens are machined to include a reduced section of constant cross-sectional area in the middle. This section facilites breaking of the specimen near the center, and this reduced section is established as the gage length.

12-2.4 TEST RESULTS

When a tensile specimen is pulled in a proper tensile test machine, a graph of the strain versus stress is developed. The strain is measured by a device called an extensometer, which is attached to the gage length of the tensile specimen and measures the extension of gage length of the specimen as it is exposed to additional stress. The test machine uses the strain information and the stress applied and plots a stress-strain diagram similar to that shown in Fig. 12-2. The tensile strength is determined by the maximum load divided by the original cross-sectional area of the gage length. A specimen is said to "yield" under load when it starts to deform plastically. This is evident on the stress-strain curve when the curve becomes nonlinear. By convention, the onset of yielding is determined by drawing a line parallel to the elastic or linear portion of the curve at a specified offset distance of 0.2% strain. The intersection of this line with the stress-strain curve denotes the load at yield. The yield strength is the load at this point divided by the original cross-sectional area of the gage length. The elongation is established by putting the ruptured specimen together and measuring the distance

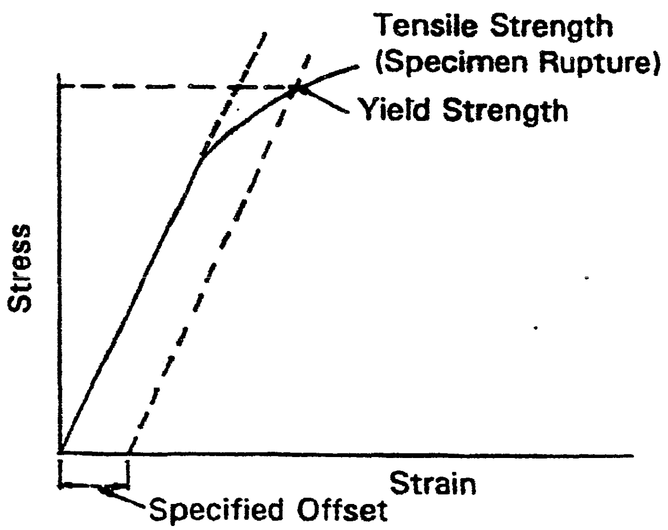

Figure 12-2. Tensile Testing Yield Strength by the Offset Method (Ref. 1)

between gage marks. The difference in measurement from the original gage length determines the percentage of elongation. The reduction of area is determined by measuring the diameter at the point of fracture of the specimen and dividing it by the original diameter.

12-3 FRACTURE TOUGHNESS TESTING

12-3.1 PURPOSE OF TEST

Since the trends in design of projectiles have been to (1) use higher strength steels to reduce thickness and weight on carrier projectiles and (2) use high-fragmentation steels on fragmenting projectiles, the problems of size of allowable defects, cracks, gouges, nicks, and internal defects have necessitated the use of fracture toughness tests on projectile materials.

The fracture toughness test as described in ASTM E813 (Ref. 6) is used to determine the resistance of a specimen to crack growth. It provides an environment of an artificially induced sharp crack under severe tensile constraint to characterize the resistance of the material to fracture. Generally, the less ductile the material, the lower the fracture toughness.

The standard fracture toughness specimen prescribed by ASTM E813 is too large to be removed from most heat treated projectile configurations. Therefore, a slow-bend, precracked Charpy test specimen, specified in ASTM E812 (Ref. 7), which shows good correlation with the standard specimen, is normally used.

12-3.2 EQUIPMENT USED

The test method involves a three point bend test of notched specimens. A fatigue crack of specified length is formed at the root of the "V" to simulate a naturally occurring crack. The maximum load in the test is recorded, and the nominal crack strength is determined from this value and the orginal dimensions of the specimen. The precracked Charpy slow-bend specimen is shown in the test fixture depicted in Fig. 12-3. It is cut from a sample shell of a heat treated inspection lot to a size specified in ASTM E399 (Ref. 9).

12-4 HARDNESS TESTING

12-4.1 PURPOSE OF TEST

Static indentation hardness testing determines plastic flow stress in a material. A penetrator is pressed into the surface of the material with a measured force. The penetration in relation to the force is the measure of hardness.

Hardness of a metal has a correlation to the tensile strength and therefore is used to confirm the proper manufacturing processes of an item Hardness tests on l00% of projectiles are conducted after final heat treatment to assure a proper range of tensile strength for each "heat" of steel processed. Initial tests are conducted on a representative sample of a "heat", which has been processed through the heat treat cycle. These tests provide the high and low hardness measurements on the projectile samples. The two extremes are selected as

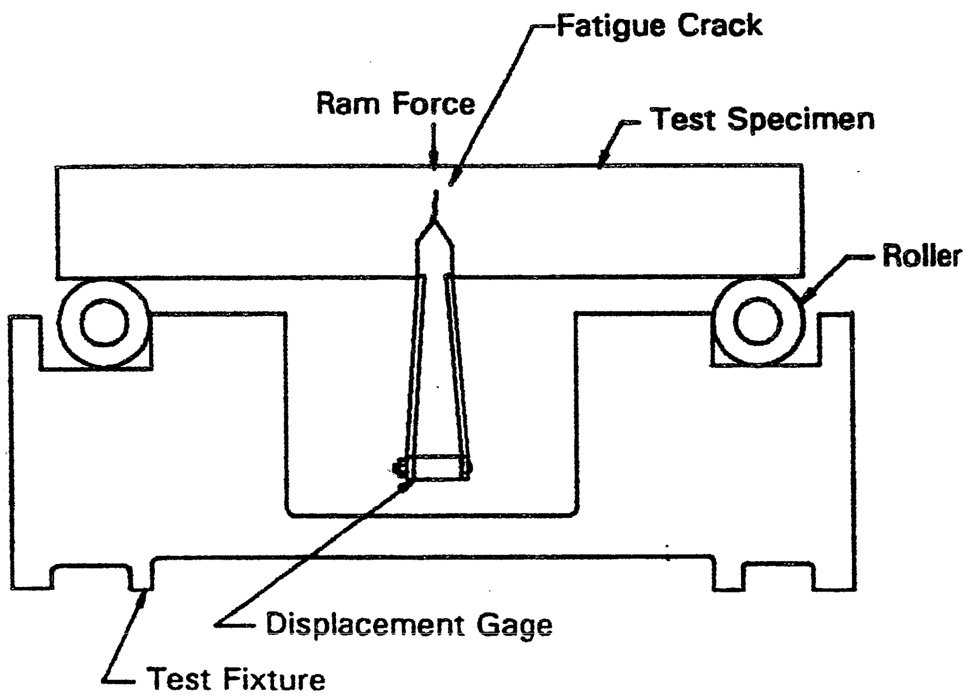

Figure 12-3. Bend Test Fixture With Specimen (Ref. 8)

samples for the tensile tests. If the measurements of tensile yield and elongation are acceptable. these hardness values are established as the acceptable hardness range for the rest of the "heat" lot, which will be similarly heat treated.

12-4.2 EQUIPMENT USED

There are a number of hardness tests, and each uses its specific measurement equipment. The tests clone on projectile components are either Brinell or Rockwell. These testers apply a constant load on an indenter to the flat surface of a workpiece. The load is applied for a specific time, after which the diameter or depth of the indention is measured. The Brinell process uses a hardened steel or tungsten carbide ball to measure the diameter of the indent, whereas the Rockwell test measures the depth of penetration by use of either a Brale indenter (a diamond cone ground to 120 deg) or a steel ball much smaller in diameter than the Brinell bail. Different Rockwell scales identified by letters are available by varying indenters and/or loads. Selection is made based on hardness ranges and thickness of material tested. Most designers now require testers with automatic digital readout.

12-4.3 SPECIFICATION REQUIREMENTS

The processes for hardness testing are defined in ASTM E18, E10, and E103 (Refs. 2,3, and 10), which are specified in the item drawings.

12-4.4 SPECIMENS USED

Test specimens for hardness tests are usually the heat treated item in the manufacturing process. For projectile bodies it is necessary for the test area to be free from scale and/or be a decarburization zone, so a small area is normally ground on the surface to be tested unless the heat treat process has been sufficiently controlled to eliminate both scale and decarburization. These tests are conducted on the production line. Conditions for preparation of test specimens are specified in the ASTM E18 (Ref. 2).

12-4.5 TEST RESULTS

Because hardness is an indication of the mechanical properties, i.e., tensile strenth, yield strength and elongation, it is a useful tool in determiningacceptablility of a product without being a destructive test. It is often used as an in-process check to determine conformity of the manufacturing process, as a check on purchased materials, and as a criterion for acceptance of finished items.

The combinations of different indenter materials and shapes and the loads applied give a wide range of values that can be applied to most solid materials, such as metals and plastics.

12-5 CHEMICAL ANALYSIS

12-5.1 PURPOSE OF TEST

All materials used in the manufacture of projectiles are purchased in accordance with a specification that specifies chemical composition within controlled limits; therefore, it is necessary to conduct a chemical analysis to determine compliance. The elements measured are those listed in each specification; however, for ferrous metals the main elements of concern are the alloying metals and impurities, such as phosphorus or sulfur. For nonferrous metals limitations are specified for various elements depending on whether or not they are desired in that particular alloy. Materials for projectile components are purchased with mill certification of chemistry.

12-5.2 EQUIPMENT USED

Chemical analyses can be conducted by standard chemical laboratory procedures that use acids, bases, arid other reagents described in ASTM E173 (Ref. 11). However, this method is relegated to occasional spot cheeks made for a manufacturer since most projectile manufacturers do not have chemical laboratory equipment.

The spectrographic method of analysis of metals is used instead of the wet chemistry method because it is simpler and quicker. Depending on the type of in ment used, the metal sample is either directly exposed or dissolved. With the development of this type of equipment and the speed with which an analysis can be performed, metal mills use it as a process technique for checking the chemical analysis in the ladle prior to pouring so adjustments to additive amounts can be made, if necessary.

An example of chemical analysis required for process control and conducted by the projectile manufacturer is the use of an atomic gas absorption spectrophotometer to determine the amount of iron in the welded overlay rotating bands. (See discussion in Chapter 6.)

12-5.3 SPECIFICATION REQUIREMENTS

All military specifications list the chemical ranges for alloying and/or trace elements that are determined at the ladle at the time of pouring. The specifications also list the permissible variations allowed for product analysis. The product analysis is conducted on two material samples obtained from the top end of the top bloom, billet, or bar of the first usable ingot and from the bottom of the bottom bloom, billet, or bar of the last usable ingot of the heat.

All metals are bought by projectile manufacturers after analyses conducted by the metal producer are certified. Certificates are supplied with each delivered and become part of the projectile lot history

12-5.4 SAMPLE PREPARATION

Ordinary samples for chemical analysis are obtained by drilling or machining the item.

12-5.5 TEST RESULTS

In chemical analyses the percentage content of the alloying or residual elements are obtained and can be compared to the specification requirements.

12-6 SALT SPRAY

12-6.1 PURPOSE OF TEST

Salt spray, or the salt fog, test is an accelerated corrosion test in which specimens are exposed to a fine mist of a salt solution. It is used to assure proper application of the protective coatings specified by the designer.

Tests are continuous for a test period designated by the item specification.

12-6.2 DESCRIPTION OF EQUIPMENT USED

The salt fog test is conducted on specimens placed in a cabinet specifically designed to simulate environmental conditions. The cabinet requires a salt solution in a reservoir, a fog chamber, atomizing nozzles to spray the solution using forced air, controlled heating within the chamber, and brackets or supports to mount the test specimens.

12-6.3 SPECIFICATION REQUIREMENTS

ASTM B117 (Ref. 12), which replaces Federal 'Test Method Standard No. 151b, defines the test requirements for salt spray. Other standards used are cleaning method, ASTM D609 (Ref. 13); solution preparation specification, ASTM D1193 (Ref. 14); and pH measurement method ASTM E70 (Ref. 15). The amount of corrosion allowed after a timed exposure is specified by the designer in the item specification.

12-6.4 SAMPLE PREPARATION

Items tested are usually selected at random from a finished lot of components and therefore represent the lot as a whole. In special cases, due to the size or expense of an item, provisions can be made for test panel specimens to be used as representative of the finishing process used on the final item. These test panels are processed through the finishing operations along with actual items to represent fully the finishing conditions.

12-6.5 TEST RESULTS

Most tests require the items to be scratched in a given manner prior to insertion in the cabinet to provide a starting point for corrosion.

After a test specimen is washed in clear running water to remove the salt deposits and dried by a compressed airstream, an examination is made for the extent of corrosion. Observations are made to determine the extent of corrosive failure in accord with the test specification covering the test material, and the amount of corrosion creep from the exposed b-metal gives an indication of the adequacy of the finish.

The test requirements are for constant operation@ a controlled temperature and a constant rate of spray for a specified time. All parameters are to be recorded. Each of these conditions presents problems especially considering the corrosive environment in which ail operations occur.

There is seldom a direct relation between salt spray resistance and resistance to corrosion in other media; therefore, it is difficult to specify a salt spray test that would be indicative of the life span of the item under various environmental conditions for comparative purposes. However, historical environmental corrosion data on test items over the life of the item have been recorded, and coating parameters have been established that would assure adequate field service protection for projectiles for a period of approximately 20 yr.

12-7 OTHER TESTS

The designer should be aware of the existence of other mechanical property or functional tests that he might want to specify to assure acceptable production items. A few of these are mentioned in the paragraphs that follow.

12-7.1 CHEMICAL ETCHING

Chemical reagents used in the microetching procedures preferentially attack the material at the grain boundaries or areas under stress to enable an observer to determine compliance with required grain size and structures. Microetching requirements include such criteria as amount of decarburization of carbon steel materials, amount of reduction performed on aluminum bars, and peripheral grain growth of magnesium, which could be caused by extrusion at too low a temperature. Chemicals are also used to macroetch cross sections of bars, billets, and blooms to determine compliance with specification requirements concerning soundness. Macroetching can also be required to assure proper grain flow in critical areas of a projectile or component.

In the macroetch process performed on a full-size material section, any method of acquiring a smooth surface with minimum cold-work is satisfactory. Cutting with sharp tools or grinding is acceptable. if fine detail is required the specimen should be finished with abrasive paper. After surface preparation, solvents may be required to clean contamination from the sample. Microetching is performed on small samples cut from in-process or finished items. These samples are ordinarily mounted in plastic, polished on wheels, and then etched for observation under the microscope.

In macroetching, test results of the effect of etching solutions on the metal surface arc observed and compared with standard photographs, such as those found in MIL-STD-1459 (Ref. 16). In microetching, structures observed under the microscope are usually photographed and the photographs compared to required standards.

12-7.2 COMPRESSION TEST

When an item—e.g., the M42 grenade, which comprises the payload of the M483 projectile-is subject to compressive loads, it is important to include a compression test requirement to assure the columnar strength of the item. Basically, the compression test is the reverse of the tensile test in that the test specimen is exposed to a compressive force, as shown in Fig. 12-4, rather than a tensile force. Specimens for the compression test may be either the finished item or a cylindrical specimen of the material to be used in the manufacture of the item (Ref. 17).

12-7.3 BEND TEST

If extreme deformity of the item is essential, a bend test may be prescribed to assure that the item or material is capable of being bent through a specified angle without fracturing or developing cracks during the bending process.

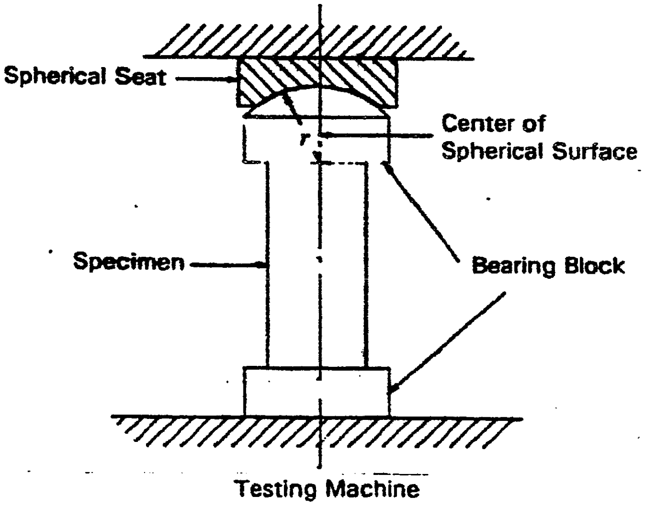

Figure 12-4. Spherical-Seated Bearing Block Used in Compression Testing (Ref. 17)

The criterion most often used is a semiguided bend test in which the test specimen is held at one end and bent over a rod of specified diameter, as shown in Fig. 12-5, to assure its bendability to a specified inside radius of curvature without failing or cracking.

12-7.4 IMPACT TEST

In situations in which components could be subjected to sudden force or impact, it is possible to specify a requirement for an impact test that subjects a test specimen, usually prenotched, to a sudden blow produced by a given mass traveling at a specified velocity, as shown in Fig. 12-6. It is possible by this method to determine the amount of energy absorbed by the specimen when subjected to a breaking force.

For some materials the impact test predicts the eventuality of brittle fracture at extreme temperatures better than the tensile tests (Ref. 19).

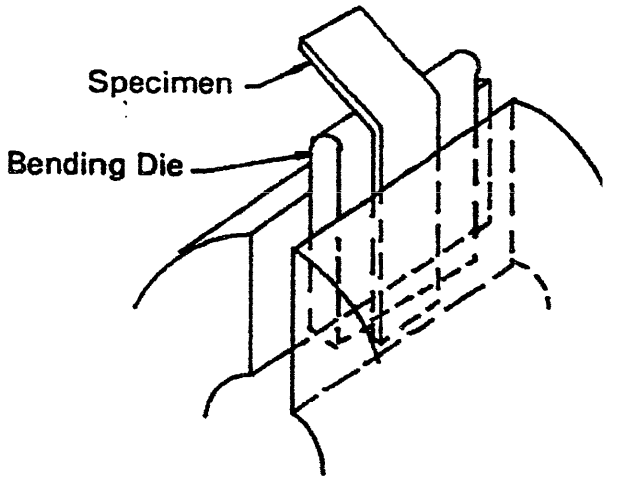

Figure 12-5. Semiguided Bend Test, One End Held (Ref. 18)

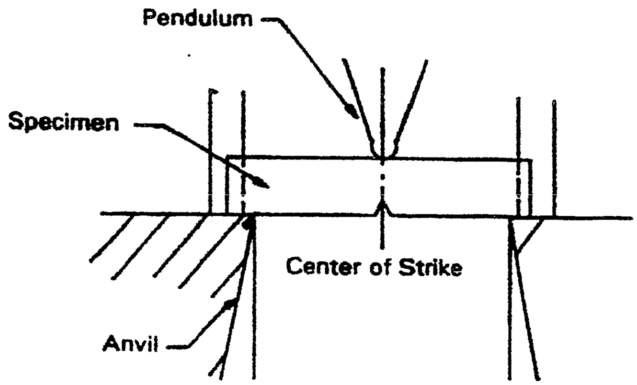

Figure 12-6. Charpy (Single-Beam) impact Test (Ref. 19)

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CHAPTER 13
DIMENSIONAL INSPECTION

This chapter outlines the various types of measuring equipment and systems used to Verify that proper dimensions are being maintained during the manufacturing process of the components and assemblies of a projectile or cartridge case.

13-1 INTRODUCTION

The dimensional information that is placed on the detail drawing must be precise and complete. It must be adequate to insure that the gages and all other measuring equipment, which is designed directly from the information on the detail drawing, can be built without reference to any other source of dimensional information. In addition, the gages and other special measuring equipment, when properly designed from the information on the detail drawing, must insure that the components will assemble and function correctly in the assembled product. Improvements in expressing such information clearly, concisely, and without ambiguity should be sought continually.

Dimensional inspection is necessary to guarantee that component parts will meet the design goals of interchangeability and function. No two parts can be made exactly alike, so each dimension of a part is specified with a tolerance. Tolerances are determined by such things as the function for which the part is designed, manufacturing techniques, and inspection costs. Generally, as part tolerances decrease, manufacturing and inspection costs increase. The size limits of each dimension are absolute and do not allow for test and measuring equipment tolerances. The tolerances needed for manufacturing will be reduced by the wear allowances and gage maker's tolerances required for the test and measuring equipment. Manufacturing tolerances are usually further reduced by in-process inspection equipment that is used on the production lines. This reductionism to guarantee that parts checked with in-process equipment will pass the test of the final acceptance inspection equipment.

13-2 MANUAL EQUIPMENT PRESENTLY USED

Manual equipment can take many forms depending on where and what the equipment must do. In-process inspection equipment may be different from final acceptance equipment. A machine operator' needs to know the actual dimensions of the features as an item is being made so that adjustments to the manufacturing process can be made. In-process inspection equipment is usually the direct reading type, such as dial indicators, micrometers, and verniers Other types of inspection equipment gages used are flush pin, thread plug, spanner, caliper, template, comparator, fixture chamber, and plug. Equipment of this type can determine the exact size of a measured feature. Final acceptance inspection equipment frequently is of the limit type, which indicates only whether the dimension being checked is within acceptable limits. Production and final acceptance inspection equipment may differ in design depending on operator skills, costs, durability of the equipment, and production quantities. However, the main reason in-process gages are the direct reading type is to plot dimensional trends so corrective action can be taken before production starts to fall out of tolerance. An example of the differences would be the requirement to check an outside diameter of a part One could use a dial snap gage, whose dial indicator would be set with a master plug and actual dimensions then recorded. Limit-type gages such as a "Go" ring gage and a “Not Go" fixed snap gage could be used. A ring gage is the best “Go” gage. It must pass freely over the diameter being checked with only light finger pressure. Acceptance with the ring gage guarantees assembly with the mating part. A fixed snap gage is used to check for an undersize or oval condition. The diameter being checked is acceptable if the snap gage cannot be fully applied to the diameter at any point. Plain ring and snap gages are durable, easy to use, reliable, and inexpensive. Dial snap gages require neither the gage maker's tolerance nor any of the wear allowances of ring- and snap-type gages, so they allow use of more of the manufacturing tolerance. Inspection equipment that can make exact readings is necessary for production lines, test quantities, and other conditions for which size must be known or documented. Limit gages are suitable for final acceptance where sample quantities are inspected for acceptance. Combinations of direct reading and limit types that are automated could be used when large quantities of parts must be inspected and the cost of automated equipment would be justified by very large production quantities and/or 100% inspection requirements. The 10 basic gages are shown in Fig. 13-1. MIL-HDBK-204 (Ref.1) discusses the uses, capabilities, and limitations of these gages.

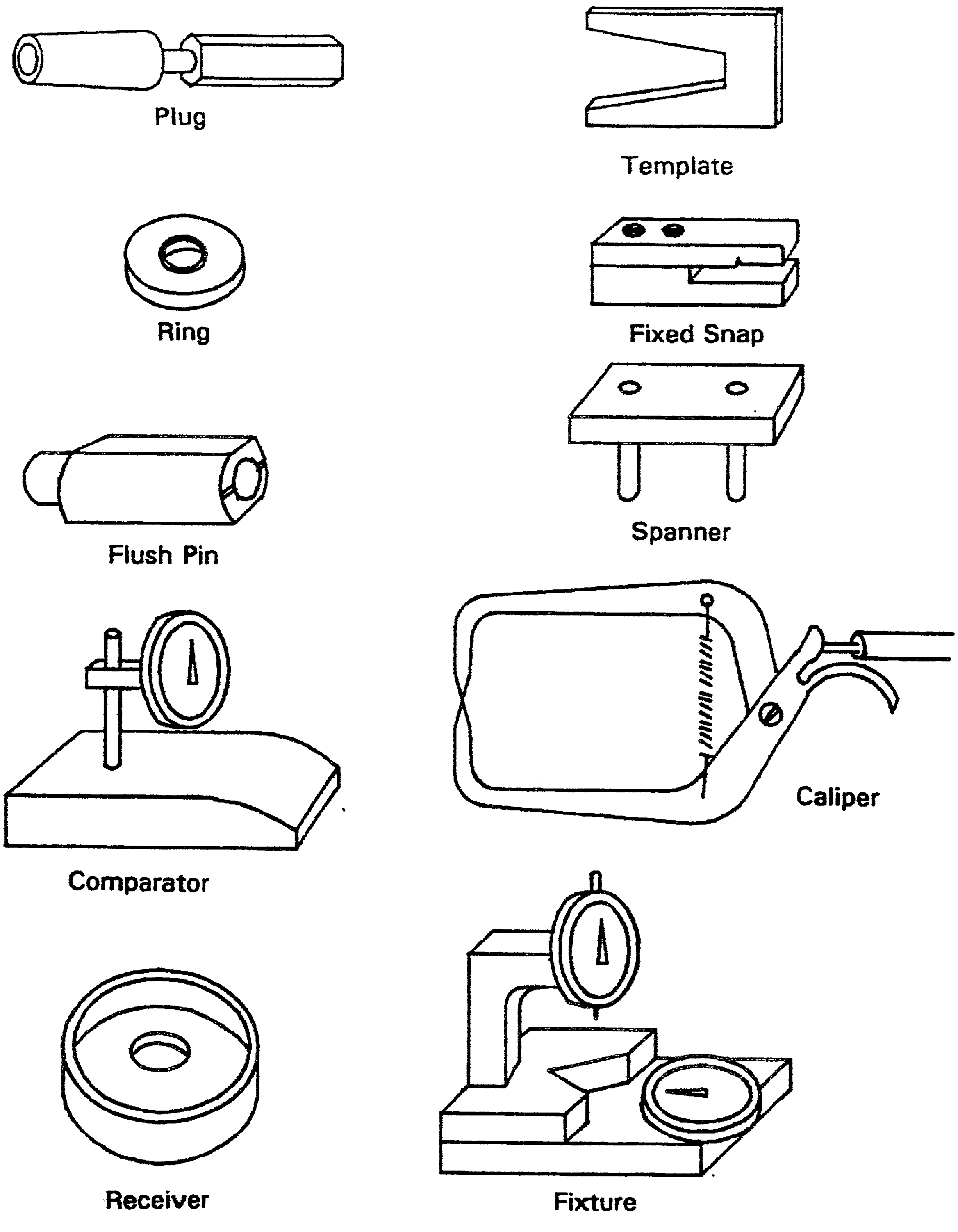

Figure 13-1. Ten Basic Gages (Ref. 1)

13-3 CURRENT AUTOMATION

13-3.1 AUTOMATED INSPECTION EQUIPMENT

The use of automated inspection systems (AIS) has increased tremendously in the last decade due to more stringent manufacturing accuracy requirements, the economic benefits of reject-free production, the advantages of in-process controls, and the need to keep up with automatic machines with very short manufacturing cycles. The requirement for AIS has resulted in use of the latest technology to perform continuous inspection, which incorporates computer speed, logic, and control. Not only can an automated inspection system measure or gage the required parameters of mass-produced products, but item also send signals to the production operators or equipment for appropriate action based on these measurements.

AIS can be either contact or noncontact types. Tool probes, which are a contact type, are discussed in par. 13-3.2. An example of a noncontact type is optical equipment, in which the item is passed between a camera and alight source and the basic measurement intelligence is fed through an encoder, which is joined to a computer bus via cable and interface modules. The computer can communicate with the process, the operator, or a remote system to create a capability to select reject, or grade the product. Atypical system consists of a camera, encoder, light source, machine interface, operator interface, and the computer system. (See Ref. 1.)

Computer-aided inspection systems(CAIS) may consist of positioning controllers, sensing devices, signal generators, output devices, and the required hardware and software necessary to control the complete system. The configuration, capabilities, and functions of the hardware and software are so integrated and varied that it is essential to consider the combination of hardware and software to be a system when designing or selecting CAIS.

13-3.2 IN-PROCESS INSPECTION

In-process automated inspection (AI) involves monitoring the product while it is being formed or machined and signaling for stopping, resetting, or readjusting of the process to keep the product parameters within the tolerance zone. This system helps to eliminate the need for rework, increases net yield, and allows close control of the product parameters. The ideal situation is to be able to perform this inspection at each piece of equipment without slowing down the production rate.

Tool probes and part probes are a form of automatic in-process inspection. These probes, when supplied as part of a computer numerical control (CNC) lathe, can automatically sense tool wear and part dimensions and can automatically make the necessary tool offsets.

13-4 FUTURE COMPUTER MANUFACTURING

13-4.1 COMPUTER-AIDED MANUFACTURE (CAM)

Many contractors are using CAM integrated with computer-aided design (CAD). When manufacturing personnel are involved in the design process, a common CAD and CAM data base can be established and can result in reduced risk in the transition from development to production. A common data base between the design and manufacturing functions has the highest potential payoff in product quality and productivity. Using computers to control manufacturing operations (fabrication, assembly, test, and inspection) and to collect shop floor data can increase productivity, reduce shop floor space, and improve product quality.

13-4.2 FUTURE ACCEPTANCE INSPECTION PROCESS EQUIPMENT

As projectiles become more sophisticated and require a higher degree of tolerance control and the use of more robotic production processes, the design engineers and the product and process engineers should be aware of the precision measuring equipment available that can be applied to the manufacture and test of munition components, all of which can be an integral part of the production line. Examples of these are

1. Image analyzers that can be used without contact for quantitative examination of the microstructure of materials such as metals and alloys. Some equipment is capable of 30 million binary decisions per second.

2. Ruby spheres, or optical sensors, that probe the specimen and relay the information to a computer, which collects the data and compares measurement parameters

3. Electronically controlled microscopic measuring instruments with, in some instances, a laser autofocus and the acoustic microscope, which uses ultrasound echo signals to look under the surface

4. Coordinate measuring machines (CMMs) are a combination of mechanics and electronics, and present the optimum answer for efficient, high-precision dimension control. These machines can be used to measure gages, jigs, easings, rocket and projectile components, tools of all kinds, and die-cast and injection-molded parts. CMM seaming can be defined as being in continuous contact with a workpiece moving along it at a predetermined rate while maintaining a constant probing force, regardless of the angle of contact. CMMs are capable of high-speed, high-precision, and coordinate measuring thus they enhance accuracy and reproducibility y and reduce manufacturing downtime and scrap.

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CHAPTER 14
NONDESTRUCTIVE TESTING

This chapter provides a general discussion of nondestructive testing (NDT) as applied to projectile metal parts. These methods are used specifically to detect nonvisible and to enhance visible metal soundness critical defects.

14-1 INTRODUCTION

By definition, any testing, inspection, or evaluation that does not cause harm to or impair the usefulness of the test sample satisfies the meaning of the word "non-destructive".

The purpose of this chapter is to describe the theory and test of the NDT methods that maybe employed to detect various types of discontinuities that may affect the strength of a projectile and thereby be the cause of a catastrophic event.

This so-called discontinuity, or critical defect, is defined as defect that experience and judgment indicate is likely to result in hazardous or unsafe conditions for individuals using, depending upon, or maintaining the product or is likely to impair the tactical performance of a major end-item (Ref. 1). The relationships among the various NDT methods and their capabilities and limitations when applied to the detection of a specific discontinuity will be addressed with specific examples of how these tests and procedures are applied to projectile metal parts. In selecting the NDT method for the evaluation of a specific discontinuity, it should be kept in mind that NDT methods may supplement each other and, conversely, that several NDT methods may be capable of performing the same test. The selection of one method over another is based upon variables such as the type and origin of the discontinuity, material manufacturing processes, material physical properties, accessibility of the article, level of acceptability desired, equipment available, and cost.

14-1.1 NONDESTRUCTIVE TEST CRITERIA

The designer of the item to be tested is responsible to establish acceptance criteria. Regarding cracks, the critical crack size, which is defined as that which will cause failure in the presence of a specified stress, can be determined by a fracture mechanics analysis. This subject is discussed in par. 12-3. Because the critical crack size is dependent on the yield strength of the material, it is necessary to test to assure that the minimum yield strength has been met. Standard practice is to determine yield strength by destructive tensile testing of a small sample from a heat-treated lot. In some eases it is deemed necessary to perform a 100% NDT, and methods are available to do this.

14-1.2 NDT METHODS APPLICABLE TO PROJECTILE METAL PARTS

Methods that have been used are (Asterisks denote those test methods most Widely used.)

1. Acoustic analysis
2. Eddy current*
3. Electro-optical cavity inspection system
4. Hydrostatic pressure*
5. Liquid penetrant*
6. Magnetic flux leakage*
7. Magnetic particle*
8. Optical holography
9. Radiography, X ray, and gamma my
10. Ultrasonic*
11. Electromagnetic acoustic transducer system
12. Visual*
13. Air pressure
14. X-ray diffraction.

14-2 LEAK TESTING (LT)

A discontinuity or passage through which a fluid flows or permeates is defined as a leak. The quantity of fluid per unit time that flows through a leak or leaks is the leak rate. For a complete list of LT terms, see Ref. 2.

LT is used to detect fluid leaks through the wall or joint of a container. In the case of projectile components, hot gas leakage can cause premature initiation of explosives or propellants. Realistic leak rate requirements must be established based on assessment of the item in its use environment and must include anticipated shelf life.

LT is normally applied at a finished stage of a component or assembly, but before painting. Normally, when a forged component is being manufactured, there is extremely low likelihood that a leak will develop through the wall, except for a pipe (grain flow voids perpendicular to the finished base section), which could occur through the base of a projectile body. Leakage through the base of the projectile is normally protected against by welding a base plate across the aft end, described in par. 4-2.1.8.4.

The most like}y leakage path to occur would be at the joint between two sections of a projectile, such as the ogive-body or base-body joint of a cargo carrying projectile.

The usual procedure is to establish a pressure differential between the inside and the outside of' the container to be tested. Indication of the leak may be direct, i.e., by observing the fluid appearing on the low pressure side (chops or a stream of liquid) or bubbles of a gas escaping through a liquid bath in which the unit under test (UUT) is immersed. It maybe indirect, i.e., by noting a change of pressure within the UUT or in a surrounding chamber, by using a sensitive flow meter to sense the fluid flow, or by using a sonic detector to "hear" the sound of escaping gas. A more direct method, however, is to use a tracer gas, such as helium, as the fluid and a special detector to sense the presence of helium leakage at the joint.

An example of the fluid flow method is shown in Fig. 14-1, which illustrates test equipment used to leak test the body-ogive joint of a cargo-carrying projectile, such as the 155-mm M483A1. Air is pumped into the cavity of the sealed assembly through the plug assembled into the fuze threads; this pressure is maintained throughout the test. After a specified time the pressure gage attached to the test chamber is observed. if the differential is greater than that allowed by specification, the item is rejected.

To determine projectile integrity for a chemical agent shell, helium gas is introduced into the projectile body through a plug sealing the fuze threaded area. A helium-sensitive "sniffer" detector is used to check that no leakage is occurring through the projectile walls.

14-3 MAGNETIC PARTICLE INSPECTION (MPI)

MPI is used to detect discontinuities at or near the Surface of ferromagnetic materials that are strongly influenced by magnetic fields. These materials are iron steel, nickel, cobalt, and series a stainless steel.

The probing medium used is an induced magnetic field. The field is distorted by the presence of a discontinuity that causes magnetic flux lines to project outside of the part and thereby attract finely divided ferromagnetic particles (the sensitive detector). The presence of an accumulation of particles at the site of the discontinuity constitutes the indication. Typically, a trained observer looks for any indications and evaluates them according to the requirements of the applicable specification, which might state length, width depth, or presence of a defect that is unacceptable.

The magnetization must be applied so that the magnetic flux lines are in the range of 45 to 90 deg to the direction of the discontinuity to be dctected. Therefore, to assure detection of discontinuities in any direction it is necessary to magnetize in two directions that are at right angles to eaeh other. A projectile body can circularly magnetized (The magnetic field or flux lines run circularly around the circumference of the shell at right angles to the axis.) by applying a magnetizing current in a typical magnetic particle testing machine, shown in Fig. 14-2. This procedure is satisfactory for longitudinally oriented discontinuities at or near the surfaces. In order to detect discontinuities oriented in a circumferential direction, it is also necessary to place the projectile body in an encircling coil, which induces a longitudinal magnetic field in the projectile.

The ferromagnetic particles can be colored (magnaflux method)--chosen for maximum contrast with the color of the test part-or they can be fluorescent (magnaglow method). They may be applied either dry (dry method) or in a liquid suspension (wet method). Dry powders are applied by dusting the surface of the magnetized item and are best for subsurface discontinuities on rough surfaces, e.g., unmachined castings, forgings, and welds, and are convenient for field use and for very large items. The

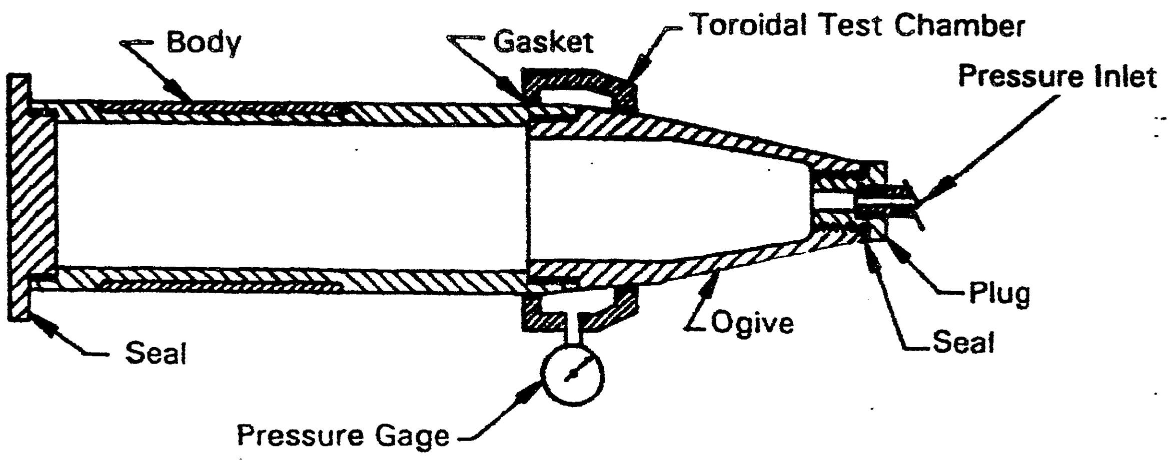

Figure 14-1. Cross Section of a Typical Pressure Change Measuring Device

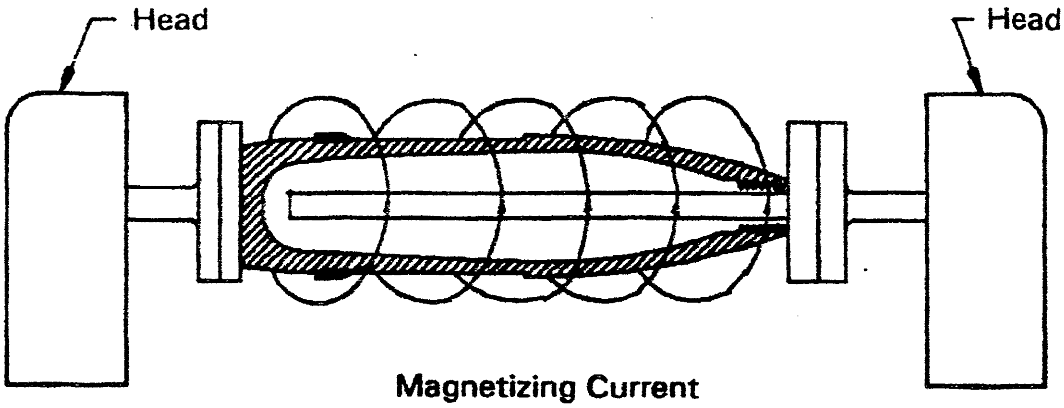

Figure 14-2. Magnetic Particle Testing Machine

liquid suspensions are applied by spraying, flooding, or immersing the part. The liquid vehicle is either water with appropriate wetting, corrosion inhibiting, antifoam and antifungous agents or a kerosene or light oil.

The wet method provides greater sensitivity to small discontinuities, and proper illumination must be provided to assure detection. For fluorescent particles, ultraviolet light should have adequate intensity at the inspection surface, but the booth in which inspection occurs must be as dark as possible.

There are two basic methods of particle application: continuous and residual. In the continuous method the particles are applied while the magnetizing current is flowing. In the residual method the current is turned on and off; then the particles are applied and attracted to the residual magnetic field in the part.

The continuous method is always more sensitive in detecting and indicating the presence of a discontinuity because the magnetic field is always stronger in the presence of the magnetizing current than after it is removed. When dealing with low-carbon steels and other materials with low magnetic retentivity, use of the continuous method is essential. The residual method may be used for highly retentive steels, such as medium-carbon and alloy steels.

After the particles and the magnetizing current have been applied and the current flow stopped, excess particles, i.e., those not adhering to indications, are removed by gently blowing them away in the dry method or by allowing them to drain away in the wet method. The next operation is examination by a trained inspector for any indications. Any indications that are found are evaluated in accordance with specification requirements. Such requirements may include a minimum length, which is considered rejectable. Because depth of the indication is not determinable, it is often permissible to grind the location of the indication to some depth, e.g., 0.127 mm (0.005 in.), as long as the part remains within design dimensions and then to reinspect. If the indication does not reappear, the part may be accepted. The item is then demagnetized and cleaned for subsequent operations.

Present applications include many of the 155-mm and 8-in. projectiles. In all eases, the tests are performed on 100% of the product and require inspection of both exterior and interior surfaces.

14-4 HYDROSTATIC TESTING (HYDROTEST)

Hydrostatic testing (HT), is used to stress vessels to a level that will equal or exceed the stress levels expected to be experienced during use. If the unit under test survives the test, there is some assurance that it will also survive use. The hydrotest is not strictly in the normal class of NDT because a UUT that fails the test does so catastrophically, i.e., typically breaking apart. This test is included here, however, because a UUT that survives is fit to be used.

Typically, the test is applied to a machine-finished projectile body, warhead body, or rocket motor body. The UUT is connected to a hydraulic, high-pressure source. If required, openings in projectile bodies are sealed. The UUT is filled with fluid, normally water with corrosion inhibitor added, and the pressure is raised to, or slightly above, the specified level. The WUT is then held for a specified time, typically between 5 and 15 s. If these conditions are met, the UUT is acceptable; if the pressure is not reached or is not maintained for the minimum required time, the UUT is not acceptable.

Generally, the maximum stress applied is 75% of the yield strength of the material. This value can be determined by a theoretical stress analysis of the item design. It is also recommended that a representative sample be equipped with resistance strain gages and that a physical test be conducted to verify the theory.

The stresses expected in actual use of the item are determined by mathematical means, usually a computer program finite element analysis. When actual hardware is available, it is highly desirable to obtain strain gage data from firing tests by using telemetry methods to transmit the information to the data collection point. Stresses determined by either method can then be compared with the hydrotest effects to determine what segments of the UUT are adequately stressed. Those areas that are not may have to be tested by some other NDT method.

As can be seen from comparison of the tensile hoop stresses induced by the HT to launch stresses, as shown in Fig. 14-3, the XT provides an adequate overtest but does not exceed the specification requirements for the 155-mm M549 warhead (Ref. 3).

14-5 EDDY CURRENT TESTING

Eddy current testing is the process of electromagnetically inducing small electrical currents into an electrically conductive specimen and observing the changes in the effects caused by these currents on the electromagnetic fields. Every variable that affects the induction of eddy currents, their flow in the material, and the reactions to their electromagnetic field is a potential test variable.

Eddy currents normally travel in a circular path. If there is a discontinuity in the test specimen, the path of the eddy current will be distorted. This distortion will make the magnetic field of the eddy current change its geometric shape When this change in geometry occurs, the magnetic field of the coils will be opposed in a different manner and a change in the magnetic field will be indicated.

In eddy current testing there are three basic types of coils: the probe, the outside coil, and the inside coil.

When any of these probes is being used for flaw detection in ferrous materials, a second coil must be used in conjunction with it. Eddy current will detect discontinuities such as cracks, inclusions, heat treatment of metals, alloying, dimension changes, and magnetic permeability, but it will not distinguish between permeability and the defects.

Eddy current penetration is dependent on two things. The first is the conductivity of the test sample, and the second is the frequency of the eddy current, When using eddy currents, the higher the frequency, the lower the penetration, and the lower the frequency, the higher the penetration.

Typical basic circuitry is a Whetstone bridge, as shown in Fig. 14-4. In this bridge circuit, A3 is made equal to the test coil impedance. Initial conditions are balanced by varying Al to equal A2. The current passing through the amplifler is then zero. Any change in conductivity or permeability of the test object from the standard, caused by the presence of a discontinuity that interrupts the eddy currents or a variation of composition, thickness, heat treat condition or the like, will cause a current to flow though the amplifier. Associated instrumentation, such as meters, strip charts, recorders, or an oscillograph, cart display the amplitude and phase of the current. Reference to a standard will enable setting reject limits.

Eddy currents may be used to determine thickness of nonconductive coatings on metal because the magnetic

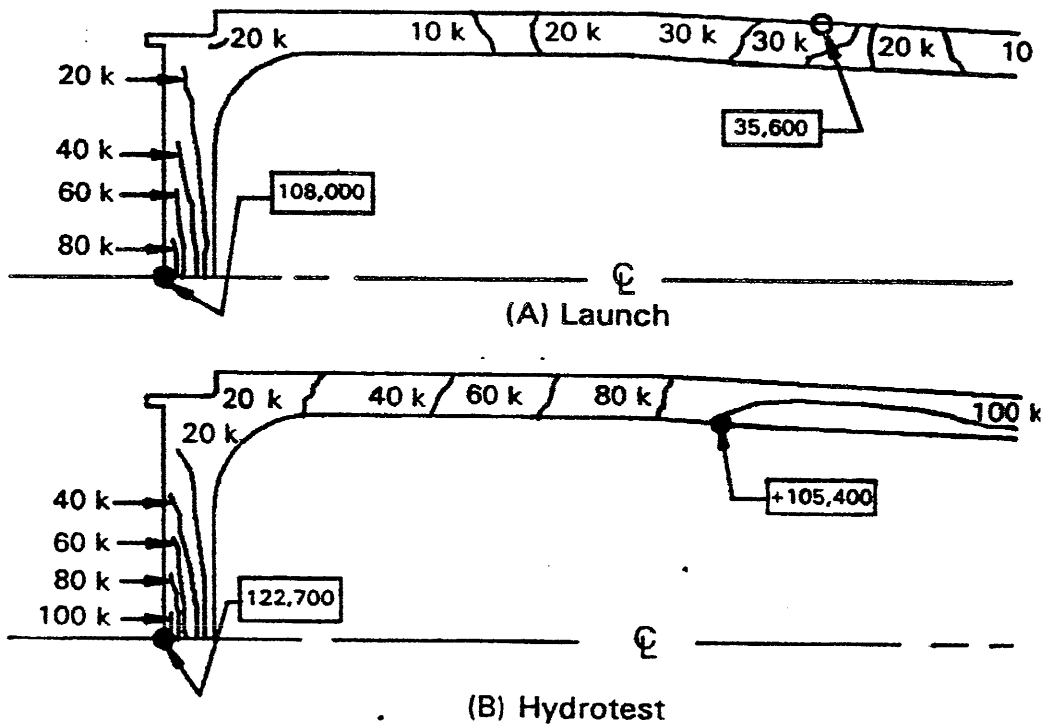

Figure 14-3. 155-mm M549 RAP Warhead Tensile Hoop Stress Comparison (Ref. 3)

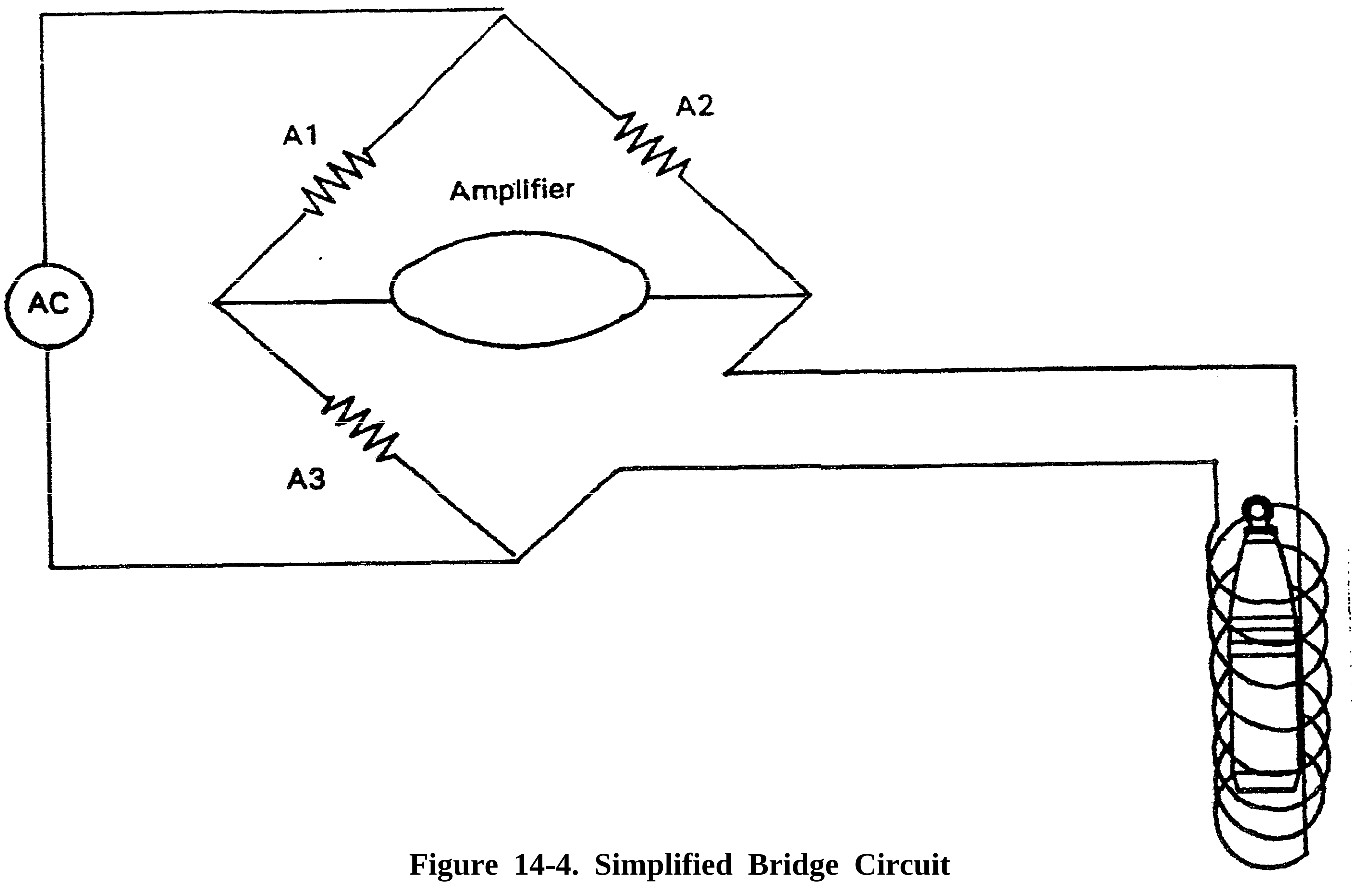

Figure 14-4. Simplified Bridge Circuit

field of the coil will penetrate to the metal and variance in the coating will cause change in the distance of the probe from the piece. This phenomenon is called the lift-off effect, and it is widely used in the inspection of coating and plating.

Current applications include inspection of the aluminum bases of all 155-mm carrier projectiles, except the threads, for cracks. There is also a conductivity test, which, in conjunction with a Rockwell hardness test, assures that the base has been properly heat treated.

14-6 ULTRASONIC TESTING

Ultrasonics is defined as mechanical energy in a range above 20,000 Hz It is the ability of this mechanical energy to transmit through most materials that has made possible the ultrasonic flaw detector.

Ultrasonics makes use of low-energy, high-frequency mechanical vibrations or sound waves that are beamed into the material being tested. These waves reflect from geometric boundaries or from other boundaries, such as those formed by cracks, lack of fusion, porosity, or inclusions.

The general principles used in ultrasonic testing are quite similar to those in sonar and radar echo-ranging techniques. The equipment uses conventional echo-ranging instrumentation and incorporates electronic circuits for the generation of electrical signals. A transducer is the device that emits the sound into the test object and receives the reflected sound beam. Transducers also convert the electrical signals into the mechanical vibrations or sound and reversibly convert the sound ethos into electrical voltage pulses. Additional circuitry amplifies the weak returning signals and displays them on a cathode-ray tube.

Ultrasonic waves, like light waves, have three basic characteristics: They tend to travel in straight lines; they are reflected by discontinuities in the medium through which they pass; and they undergo refraction when passing from one medium to another. They are unlike light waves in that they cannot travel through air and must be “coupled” to the material being tested.

In order to introduce ultrasonic energy into the material being tested, all air must be excluded between the transducers and the surface of the material by use of a couplant. The most commonly used couplants are water, motor oil, and glycerin.

When cylindrical and conical items, such as projectile and warhead bodies, are to be inspected, equipment is provided that rotates the body while the transducers are moved axially to inspect the entire volume of the shell. Similar provisions maybe made for the base areas. Fig. 14-5(A) shows atypical projectile test setup. Fig. 14-5(B)

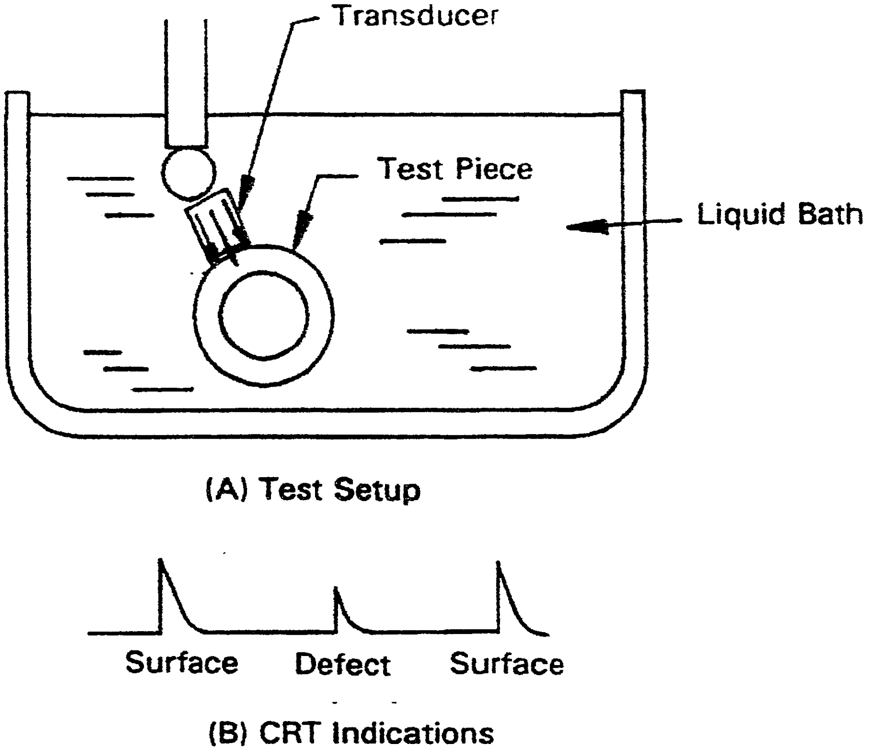

Figure 14-5. Ultrasonic Testing Method Cross-Sectional Schematic

depicts the defect pip, which would appear between the blips caused by both surfaces of the cross section being observed.

Because of the nature of the ultrasonic waves, the surface condition of the piece to be tested is important. If the surface is too rough, ultrasonic energy cannot be transmitted satisfactorily. In general, the smoother the surface of the material, the better the transmission w-ill be.

In order to specify adequately any ultrasonic test, it is essential that some standard be available for the purpose of defining equipment performance in terms of the smallest flaw that is considered significant.

Based on the data developed by a fracture mechanics analysis, a critical flaw size is determined and then duplicated in a sample part to determine the sensitivity setting required for the ultrasonic test.

The ultrasonic test standard procedure that has probably achieved the widest acceptance to date is to specify a standard of the same material as the part to be tested. Into this standard are introduced artificial defects of known dimension, configuration, and orientation in the form of flat-bottomed cavities of designated width and depth below the test surface. The sensitivity of the instrument can then be defined as that which enables a specified cavity to produce a readable indication. The standard specimen should be used on a set periodic basis to check and/or correct the calibration.

The advantages of ultrasonic testing are

1. Internal inspection method
2. Can be adapted for thick or thin panels
3. Extremely sensitive to many specimen variables: porosity, delamination, microcracks, geometry, density changes, grain or fiber size, and orientation.

The disadvantages are

1. Nonlinear responses (variable relationships between flaw size and indication size)
2. Sometimes too sensitive (cannot separate desired parameter)
3. Limited by geometry and surface roughness
4. Often must have special standards.

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GLOSSARY

A

Ablation. An errosive action that wears away the surface of any material.

Acoustic Analysis. Method of analysis using the measurement of frequency and amplitude of sound emitted from an item that is held and struck to produce that sound.

Accoustic Transducer. A device that converts sound into electrical energy.

Annealing. To soften a material by application of heat followed by cooling at a controlled temperature.

B

Ballistic Test. A performance test of a projectile conducted in a weapon firing.

Bar. A piece of material long in proportion to its width and thickness and whose width-to-thickness ratio is much smaller than that of sheet or plate.

Billet. A solid, semifinished round or square that has been hot worked by forging, rolling, or extrusion and that has a minimum width or thickness of 38 mm (1 1/2 in.). The cross-sectional area varies from 1452 to 23,226 mm^2 (2 1/4 to 36 in^2).

Black Light. An electromagnetic radiation not visible to the human eye. The ultraviolet portion of the spectrum used in fluorescent inspection.

Blanking. Cutting a disk to specified dimensions and ironing out defects.

Bloom. A solid, semifinished hot-rolled product that is rectangular in cross section and produced on a Mooning MIL The cross-sectional area is not less than 23,226 mm^2 (36 $in.^2$)

Boattail. The projectile base when shaped like a frustrum of a cone.

Boss. A protuberance on the surface of the projectile base designed to provide extra metal for location of a center drill cavity.

Bourrelet. The cylindrical surface of a projectile on which the projectile rests while in the bore of the weapon.

Breech. The rear part of the gun bore, especially the opening that permits the projectile to be inserted at the rear of the bore.

C

Cabbaging. A preforming operation that fills the die pot and compensates for irregularities in the cross section of the as-rolled bar or billet.

Caliber. The diameter of a projectile or the diameter of the bore of a gun tube. In rifled tubes the caliber is measured from the surface of one land to the surface Of the land directly opposite.

Caliper Gage. Any gage with movable arms (or a combination of freed and movable arms) that transfers a part feature, which is inserted between or placed over the arms, to an indicating mechanism.

Capacitor. Conductive plates used to store eletrical energy.

Cartridge. A round of ammunition in which the propellant and primer are contained in a casing and in which the propellant, primer, and projectile are assembled, stored, shipped, and issued as a complete unit.

Chamber. That portion of the interior of a gun in which the propelling charge is placed.

Chamber Gages. Specialized profile and alignment gages that are used to inspect the external features of ammunition to assure that the assembled round will fit satisfactorily into the chamber of the gun.

Coating. Application of a layer of any substance.

Coin. A closed die squeezing operation usually performed without surface restrain to give a well-defined contour.

Composition A3. An explosive containing RDX and wax.

Composition B. An explosive containing RDX, TNT, and wax.

Comparator Gage. Any gage that uses an indicating device to contact the work directly and indicate the departure of the work from a preset size with a minimum of auxiliary devices.

Cope. The top part or section of a molding box.

Core. The internal part of a mold that forms a hollow in the casting.

Cupping. Forming of the disk into a cup shape in order to form the head and first few inches of the sidewall by means of pressure.

D

Delaminations. Areas in which the material being tested has separated into layers.

Deoxidation. The process of removing free or combined oxygen from molten metal by the addition of substances that have a high affinity for oxygen, such as silicon and aluminum.

Diode. An eletronic device that restricts current flow in one direction.

Drag. The bottom part or section of a molding box.

Drawing. A series of presses over a specified size and shape of die to produce the desired configuration, i.e., elongating of sidewalk with correponding thinning.

E

Eddy Current. An electrical current caused to flow in a conductor by the time and/or space variation of an applied magnetic field.

Electromagnetic. A term applied to materials that become magnetized by passage of a surrounding electrical current and lose magnetism when the current is turned off.

F

Ferromagnetic. A term applied to materials that can be magnetized or strongly attracted by a magnetic field.

Fin. A freed or movable airfoil whose chief function is to give stability in-fight.

Fixed Ammunition. Ammunition in which the primer and propellant are contained in a cartridge case firmly attached to the projectile forming a round to be handled and loaded as a unit.

Fixture Gage. Any gage consisting predominately of devices arranged to verify the features of a part.

Flange. A raised or projecting edge.

Flurescence. The emission of visible radiation by a substance as a result of, and only during, the absorption of black light radiation.

Flush Pin Gage. A gage that uses a pin of known length moving in relation to a reference surface to indicate acceptability or unacceptability.

Forcing Cone. A slightly conical passage from the chamber to the bore into which the projectile is firmly pressed or rammed in loading in order to prevent escape of propellant gas past the projectile before the increasing gas pressure drives the projectile fully into the bore.

Forging. Forming or shaping metal by the application of external forces.

Fracture Mechanics Analysis. A method of analysis that can determine the stress required to induce fracture in an item containing a crack-like flaw of known size and shape.

G

Gamma Ray. One kind of ray emitted by radioactive substances that is similar to an X ray but has a shorter wavelength.

Gate. A channel that directs the flow of molten metal from the runners to the casting cavity.

H

Hardenability. The property that determines the depth and distribution of hardness induced by quenching.

Heading. Upsetting of the metal to form parts having some of the cross-sectional area larger than the cross-sectional area of the original cartridge.

Heat Treating. Applying a designated temperature to a metal to alter its hardness and crystallization properties.

Holography. A lensless photographic method that uses laser-generated light to produce three-dimensional images.

Howitzer. A complete weapon of cannon-size bore, with mount and all equipment, designed for medium velocity and medium curvature of projectile trajectory to target.

Hydrogen Embrittlement. A condition of low ductility in metal resulting from absorption of hydrogen.

Hydrostatic Pressure. The pressure developed in a test fixture when an incompressible liquid, such as water, is exposed to an outside force.

I

Inclusions. Particles of insoluble foreign substances in a metallic matrix.

K

Killed. Term normally used when referring to steel that has been deoxidized by additions of silicon or aluminum in the molten state.

Kinetic Energy. The energy of a body that results from its motion and is a function of velocity.

M

Magnetic Flux Density. The strength of a magnetic field expressed in flux lines per unit area.

Magnetic Particle Inspection. A nondestructive test method using magnetic leakage fields and suitable indicating materials to disclose surface and near-surface discontinuity indications.

Martempering. Quenching of an austenitized material in a medium, such as salt, heated to temperatures in the upper martensitic, range that results in a tempered martensitic structure.

Mortar. A complete weapon of cannon-size bore, with mount and all equipment, designed for low-velocity projectile and highly arched trajectory to target.

Mult. A section of steel bar or billet that is removed by sawing, breaking, or shearing so that it can be further formed or machined into a projectile.

Muzzle. The forward end of a gun tube or barrel.

O

Obturator. A device (usually a ring or a pad) incorporated in a projectile or breechblock to make the tube of a weapon gastight.

Ogive. The curved or tapered front of a projectile. (The fuze may or may riot be included as a part of the ogive.)

P

Panel Testing. A test designed to determine distribution and velocity of fragments produced by an exploding device suspended in open air and surrounded by panels.

Penetrator. That part of a kinetic energy projectile designed to pierce a hard target.

Piezo. A ceramic-type crystal that generates electric energy when subjected to mechanical stress.

Pit Testing. A test conducted in a pit of sand or sawdust by exploding a fragmenting device. The test enables the designer to compare the sizes and numbers of fragments developed.

Plug Gage. Any gage that simulates a male part or has an outside measuring surface that tests the size of a hole.

Primer. A relatively small and sensitive explosive assembly that ignites the propellant charge in a gun when activated by percussion, electric current, or friction.

Propellant. A low-explosive substance or mixture whose combustion produces the hot gases that propel the projectile through the gun bore.

R

Radiography. The process of producing radiographs, which are pictures produced on a sensitized film by X rays or gamma rays.

Resistor. An electric element that restricts or opposes the movement of electric energy in a circuit.

Rifling. The helical grooves cut in a gun bore to impart rotation to the projectile about its longitudinal axis as it is impelled through the bore.

Ring Gage. Any gage of circular cross section that verifies the size of a single cylindrical or tapered surface.

Riser. An opening through a mold into which the metal rises as the mold fills.

Rotating Band. A band of copper alloy or similar material placed firmly around the circumference of a projectile, which is engraved by the rifling in the weapon and thereby transfers rotation to the projectile when fired.

Runner. A channel through which molten metal moves in a mold.

S

Sabot. Lightweight carrier in which a subcaliber projectile is centered to permit firing of the projectile in the larger caliber weapon. The carrier fills the bore of the weapon from which the projectile is fired. Its light weight permits it to be fired safely at very high velocities. It is normally discarded a short distance from the muzzle, in which case it is known as discarding sabot.

Semifixed Ammunition. Ammunition in which the cartridge case and projectile are joined for handling and loading as a single unit but are separable for adjustment of propelling charge.

Separate-Loading Ammunition. Ammunition in which the projectile, propellant, and primer are separate components of a round and are separately loaded into a gun.

Sizing. Forcing a plug into the mouth of the cartridge ease to attain correct dimensions by a slight movement of metal.

Skive. To slice or cut off material in thin layers; to shave or pare.

Slip Band. A band similar in diameter to a rotating band but not firmly attached circumferentially to the projectile so that it slips around the projectile when the band engages the rifling. Slip bands give little or no rotation to the projectile.

Snap Gage. Any gage used for gaging diameters, lengths, and thicknesses and whose gaging surfaces are flat, parallel, opposing, and separated by a frame or spacer.

Spanner Gage. A gage consisting of a holder and precisely located pins or bushings that verify the relative position of features such as plain or threaded holes, bosses, or slots.

Spheroidizing. Prolonged heating at a temperature within or slightly below the critical temperature range followed by relatively slow cooling to form a spheroid-shaped crystal structure which increases the ductility of the steel.

Spin Stabilization. Method of stabilizing a projectile during flight by causing it to rotate about the longitudinal axis.

Sprue. The ingate or hole through which molten metal is poured into the mold during the casting process.

Static Test. A performance test of a projectile usually conducted on a stationary test stand.

Strainer Core. A sieve-like device that prevents slag and other undesirable impurities from entering the casting.

T

Tapering. Forcing the caridge case into a die having decreasing diameters to develop the final tapered contour.

Template Gage. Any gage that is merely a guide to the form of the work being executed and that has a profile, a sighting surface, a scribe line, or a similar comparison feature.

Thread Plug Gages. Plain, cylindrical plug gages applicable to the inspection of the minor diameters of standard classes of internal threads.

Trapezoid. A quadrilateral shape, only two sides of which are parallel.

Trajectory. The curve in space traced by the center of gravity of the projectile.

Trimming. Eliminating "dead metal" and smoothing the edges to the desired dimension or configuration by cutting or shearing.

W

Whetstone Bridge. An impedance measurement technique containing four legs that are balanced to a null point with an unknown balanced against a standard.

Windshield. A cap for the forward end of a projectile which is designed to improve the ballistic efficiency of the projectile.

X

X-Ray Diffraction. A back reflection method using photographic film to determine the orientation of the metal crystals.

Y

Yield Strength. The stress at which a material exhibits a specified deviation front stress/strain proportionality.

Z

Zone of Fire. The range interval that can be covered by a round containing a given number of increments of propellants, i.e., the coverage obtained by changing weapon quadrant “elevation at a constant muzzle velocity.

Zoned Ammunition. Semi fixed or separate-loading ammunition in which provision is made for adding or removing propellant increments.

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