MIL-S-70703
12 January 1987

MILITARY SPECIFICATION

STRAND CAST STEEL, CARBON AND ALLOY, FOR PROJECTILE APPLICATIONS

This specification is approved for use within US Army, Armament, Munitions and Chemical Command, and is available for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers the strand cast process for manufacturing hot-rolled carbon and alloy steel for projectile applications. The requirements of this specification supplement existing material specification requirements on individual projectile metal parts drawings when the steel being furnished is made by the strand cast process.

1.2 Classification. Strand casting process, equipment and reduction ratios shall be in accordance with the following classes and types as specified (see 6.2):

Class I - Steel made using submerged ceramic shrouding from tundish to mold.

Class II - Steel made using a centrifugal caster.

Class III - Steel made using either submerged ceramic shrouding or gaseous type shrouding from tundish to mold.

Type A - Steel rolled to a 4 to 1 minimum reduction ratio.

Type B - Steel rolled to a 2.5 to 1 minimum reduction ratio.

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document, should be addressed to: Commander, US Army Armament, Research and Development Center, ATTN: SMCAR-ESC-AS, Dover, New Jersey 07801-5001 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

AMSC N/A MECA

2. APPLICABLE DOCUMENTS

2.1 Specifications, standards and handbooks. This paragraph is not applicable to this specification.

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. The issues of the documents which are indicated as DoD adopted shall be the issue listed in the current DoDISS and the supplement thereto, if applicable.

ASTM

ASTM E381 - Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms, Method Of

(Application for copies should be addressed to ASTM, 1916 Race Street, Philadelphia, PA 19103)

Society of Automotive Engineers

SAE J422 - Microscopic Determination of Inclusions in Steels, Recommended Practice

(Application for copies of SAE publications should be addressed to the Society of Automotive Engineers, 400 Commonwealth Dr, Warrendale, Pa. 15096).

American Iron and Steel Institute (AISI)

AISI Steel Products Manual - Alloy, Carbon and High Strength, Low Alloy Steel, Semi-finished for Forging, Hot Rolled Bars, Cold Finished Bars, Hot Rolled Deformed and Plain Carbon Reinforcing Bars.

(Application for copies should be addressed to the American Iron and Steel Institute, 1000 - 16th Street NW, Washington, DC 20036)

(Industry association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal Agencies).

2.3 Order of precedence. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification shall take precedence.

3. REQUIREMENTS

3.1 Process.

3.1.1 Classes.

3.1.1.1 Class I.

3.1.1.1.1 Shrouding. A submerged ceramic shroud or a "box type" gaseous shroud is required from the ladle to the tundish. Submerged ceramic shrouding is required from the tundish to the mold. Adequate sealing is required at all shrouding couplings to insure the prevention of atmospheric air aspiration.

3.1.1.1.2 Tundish. The size and design of the tundish shall be adequate to assure proper residual time, promote inclusion flotation, and minimize turbulence.

3.1.1.1.3 Computer control. Computer control of casting variables such as casting speed, mold oscillation and stroke, secondary cooling spray pressures and flows, etc. is preferred. When computer control is not available, data shall be monitored and recorded for these process variables, and the process variables to be monitored and the frequency of recording shall be submitted to the cognizant Government contracting officer for approval.

3.1.1.2 Class II. Class II steel is produced by a centrifugal mold caster. With the exception of the tundish-to-mold submerged ceramic shroud requirement, Class II steel must be produced using equipment and procedures which meet all of the requirements listed above for Class I steel.

3.1.1.3 Class III.

3.1.1.3.1 Shroud, ladle to tundish. Either a submerged ceramic shroud or a "box-type" gaseous shroud is required from the ladle to the tundish. Adequate sealing is required at all shrouding couplings to insure the prevention of atmospheric aspiration.

3.1.1.3.2 Shroud, tundish to mold. Either submerged ceramic or gaseous shroud is required from the tundish to the mold. For gaseous shroud systems, the oxygen levels in the vicinity of the molten stream must be monitored and shall be below 0.5%. Adequate control systems must be in place to assure that all critical variables associated with the operation of gaseous shrouds are being monitored and recorded periodically during the casting operation. As a minimum, oxygen levels shall be measured at the beginning and end of each heat and at approximately the 1/4, 1/2 and 3/4 intervals during casting of each heat. This is particularly critical, because consistency of operation is imperative when using any gaseous shrouding system.

3.1.1.3.3 Tundish. The size and design of the tundish should be adequate to consistently produce material meeting the internal quality requirements specified herein.

3.1.2 Reduction ratio. Reduction ratios shall be in accordance with that specified for Type A or B, as specified.

3.1.3 Deoxidizers and grain refiners. Deoxidizers and grain refiners shall be ladle added. Wire feeding of these additions directly into individual strand molds of the tundish is prohibited.

3.1.4 Oxygen lancing. Oxygen lancing to open clogged tundish nozzles is permitted only when the steelmaker has demonstrated the ability to locate and discard all steel affected by the process.

3.1.5 Ladle stirring. Ladle stirring for chemical homogeneity, uniformity of temperature and to promote flotation of the inclusions is required.

3.1.6 Slag cover. With the exception of initial casts, until the tundish is full, the tundish shall have a slag cover at all times.

3.1.7 Sequence casting. When sequence casting heats of different grades, transition material between the two grades of steel shall not be furnished under this specification.

3.2 Material soundness. Imperfections observable in strand cast steel are illustrated in Figure 1. Using Figure 1 as reference guidance, strand cast steel shall conform to the material soundness requirement specified herein.

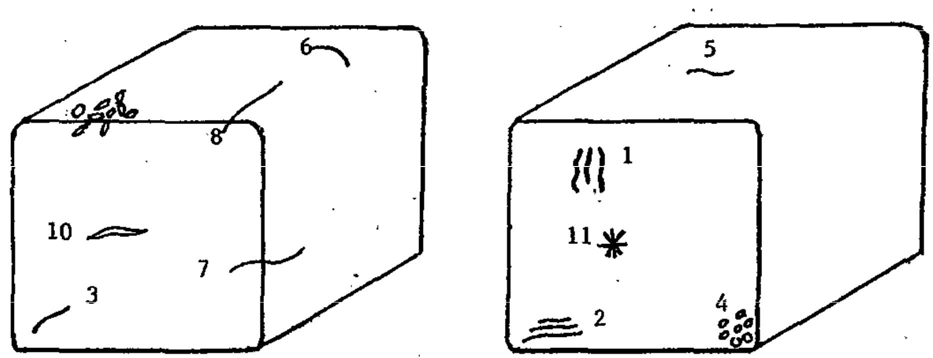


Figure 1. Potential imperfections in continuous cast steel.

1. Halfway Cracks
2. Hinge Cracks
3. Diagonal Cracks
4. Subsurface Blowholes/Pinpoints
5. Transverse Facial Crack
6. Transverse Corner Crack
7. Longitudinal Facial Crack
8. Longitudinal Corner Crack
9. Pinholes
10. Center Rupture
11. Centerline (Star) Cracks

3.2.1 As cast macroetch (see 4.2.4 & 6.3).

3.2.1.1 Halfway cracks. Halfway cracks shall be no greater than $0.11\sqrt{x}$ where x equals the cross sectional area of the as cast strand.

3.2.1.2 Hinge cracks. Hinge cracks shall be no longer than $0.05\sqrt{x}$ (see 3.2.1.1).

3.2.1.3 Center ruptures. Center ruptures shall be no longer than $0.07\sqrt{x}$ (see 3.2.1.1).

3.2.1.4 Diagonal and chill zone cracks. Diagonal and chill zone cracks (see Figure 1, nos. 5.6, 7, & 8) shall not be permitted.

3.2.1.5 Center segregation (as cast). Center segregation, or observable areas of "dark center" condition on an etched section, shall have maximum diameter of $.04\sqrt{x}$ (see 3.2.1.1).

3.2.1.6 Center looseness. The diameter of discontinuous center looseness shall not exceed $.04\sqrt{x}$ (see 3.2.1.1). Fine, scattered porosity is not considered to be center looseness.

3.2.2 Finished product macroetch requirements.

3.2.2.1 Internal cracks. All product after rolling to final size shall be sound and shall contain no internal cracks.

3.2.2.2 Center looseness or porosity. No center looseness or porosity shall be permitted.

3.2.2.3 Center segregation (finished product). The maximum permitted diameter of dark center or center segregation shall be $0.04\sqrt{y}$, where y equals the cross sectional area of the final mill product.

3.3 Chemical composition. Chemical analysis shall be used to determine compliance with the specific grade of steel specified in the applicable material specification. For all steels furnished to this specification, product analysis tolerance for control of carbon shall be ± 0.01% and all other elements shall conform to the heat analysis ranges specified in the material specification with no product analysis tolerance. Both the "A" and "Z" sample selected in accordance with 4.2.6.1 and 4.2.6.2 shall comply with the applicable specification requirements for the grade being furnished.

3.3.1 Transition material. Assignment of the transition material in sequence cast heats to one of the adjacent heats shall be based on relative calculated Ideal Diameter (DI) hardenability based on composition (See 4.6.6 and Appendix).

3.4 Data and sample retention.

3.4.1 Macroetch samples, sulphur prints and samples. All macroetch samples or sulphur prints and corresponding samples shall be retained for at least six months.

3.4.2 Heat records. Heat records shall be maintained in a permanent file for one year after the last heat of order is shipped. Heat records shall be adequate to demonstrate conformance to all specification requirements and shall at least include the following:

a. The number of strands cast and the number of blooms produced from each strand.

b. Shrouding method used and description of shrouding problems encountered.

c. Periodic oxygen level measurements in the vicinity of the molten streams (for gas type shrouding only).

d. Rating of macroetch sections.

e. Reason for rejecting any portion of the heat and documentation that the portion was either scrapped or salvaged under 4.3.1 if applicable.

f. Records of heat segregation and identification during sequence casting including results of chemical analysis and DI calculations used to determine disposition of transition material.

g. Record of type of deoxidizers and grain refiners used.

3.5 Workmanship.

3.5.1 Surface defects. Steel supplied to this specification shall be free from harmful surface defects such as cracks, tears, pinholes, or entrapped slag. Bar and billet may be conditioned to remove surface defects provided that no subsurface defects are exposed in the process and that the section dimensions conform to the specified tolerances. Surface conditioning must not expose the columnar zone (see 6.3) to any free surface.

3.5.2 Reoxidation. Evidence of reoxidation in any portion of a heat shall be cause for rejection of the entire heat.

3.5.3 Shape defects. Shape defects are restricted to the same extent as for bar or billet rolled from ingots; i.e., all bars and billets shall conform to the appropriate tolerances as contained in referenced material specifications and AISI steel product manual.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or purchase order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.1 Responsibility for compliance. All material must meet all requirements of Section 3. The inspection set forth in this specification shall become a part of the contractor's overall inspection system or quality program. The absence of any inspection requirements in the specification shall not relieve the contractor of the responsibility of assuring that all products or supplies submitted to the Government for acceptance comply with all requirements of the contract. Sampling in quality conformance does not authorize submission of known defective material, either indicated or actual, nor does it commit the Government to acceptance of defective material.

4.2 Sampling.

4.2.1 Transverse sections (as cast). Transverse sections representing the entire strand cast section shall be cut from the front and back of each heat in the as-cast condition for macroetching.

4.2.2 Macroetch sections (finished product). Macroetch sections shall be taken from the front, middle, and last rolled product after final reduction from each strand for each heat of steel.

4.2.3 Macroetching. Macroetching shall be performed in accordance with ASTM E381.

4.2.4 Sulphur printing. For as-cast macroetch samples, sulphur printing may be substituted for ASTM E381 macroetching provided written procedures to be followed are approved by the cognizant Government contracting officer.

4.2.5 Additional or reduced samples. The Government reserves the right to require additional samples. The Government may authorize a reduced sampling schedule on an individual supplier basis. All changes in sampling schedule shall be approved by the cognizant Government contracting officer.

4.2.6 Chemical analysis.

4.2.6.1 Strand cast billets or blooms (individual heats). After suitable discard back from the starter bar, an "A" sample representing the first useable metal in the heat shall be taken from any one of the strands, and at the end of the cast a "Z" sample representing the last useable metal in the heat shall be taken from any one of the strands.

4.2.6.2 Continuous strand cast blooms (sequence cast).

4.2.6.2 Limits of transition material. A reliable method must be employed to locate the limits of transition material between sequence cast heats to allow representative "A" and "Z" samples to be obtained. The initial "A" sample shall be taken after suitable discard back from the starter bar. Successive "Z" and "A" samples shall be taken immediately before and after the limits of the transition material when sequence casting (See Examples 1 and 2 in 4.6.6).

4.3 Rejected as-cast strands. Additional macroetch sections may be taken from strands which are rejected based on macroetch testing per paragraph 4.2.1. If macroetch examination of the additional sections isolates the rejectable material to a specific portion of the strand, only the isolated defective portion must be rejected.

4.3.1 Salvage of rejected strands. Strands or portions of strands that have been rejected in the as-cast condition may be salvaged by rolling to final size to heal the as-cast defects. Such material must be identified as having been rejected in the as-cast condition. Macroetch sections shall be taken from the front, 1/4, middle, 3/4, and last rolled product from each previously rejected strand or portion of strand. These macroetches shall conform to the requirements of 3.2.2.

4.4 Rejected product after final reduction. Any macroetch on final reduced product which fail to meet the macroetch requirements specified herein shall be cause for rejection of all product from the specific strand for the specific heat represented by the rejected sample.

4.5 Magnetic particle inspection. Macroetch sections shall be inspected by magnetic particle inspection method in instances where visual indications of cracks are uncertain.

4.6 Conformance inspections and certifications.

4.6.1 Class I, II or III equipment and procedures. Inspection of equipment and stated contractor steel making procedures shall indicate compatibility with "Classes" described in 3.1.1.

4.6.2 Reduction ratio. Reduction ratios associated with Types A and B shall be determined by dividing the "cross sectional area of the cast strand" by the "cross sectional area of the rolled bar or billet" being procured.

4.6.3 As-cast macroetch. Size of halfway cracks, hinge cracks, center ruptures, diagonal cracks, center segregation and center looseness shall be calculated in accordance with relationships indicated in 3.2.1. Failure of either front or back macroetch to meet 3.2.1 shall be cause for rejection.

4.6.4 Finished product macroetch. Failure of any macroetch to meet the requirements of 3.2.2 shall be cause for rejection.

4.6.4.1 Visual inspection. All product after rolling to final size shall be visually inspected for conformance to 3.2.2. and 3.5.

4.6.4.2 Center segregation. The diameter of dark center (center segregation) shall be determined using relationship indicated in 3.2.2.3.

4.6.5 Steel certification. A certification shall be provided with each heat of steel which certifies the heat to having met all the requirements of this specification and any other applicable material specifications. The following information shall be included in the certification as a minimum:

a. "A" and "Z" chemistry results of each heat.

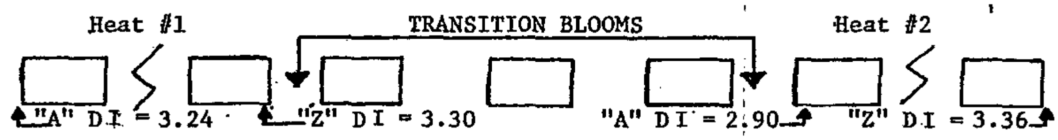
b. Heat identification number. If the heat was sequence cast, specify the consecutive number of the heat within the sequence.

c. Indicate if heat contains all or portion of transition material.

4.6.6 Transition material acceptance criteria. Assignment of transition material shall be based on DI hardenability (See Appendix I). If the ratios of the DI of a sample over both the DI of the "Z" sample and DI of the "A" sample of the following adjacent heat are between 0.80 and 1.25, then the entire quantity of transition material shall be assigned to the later adjacent heat provided that both adjacent heats satisfy specified chemical composition (See Example 1). If either adjacent heat does not satisfy specified requirements, all transition material must be rejected. If the DI ratios calculated as described above are not between 0.80 and 1.25 but both adjacent heats satisfy specified requirements, chemical compositions and DI hardenabilities must be determined for individual transition blooms. The individual blooms shall be assigned to appropriate adjacent heats such that the ratios of the DI of each bloom (at the end of the bloom away from the heat to which the bloom can potentially be applied) and the "A," and "Z" samples of the heat are between 0.80 and 1.25 (See Example 2). Blooms that cannot be assigned to either adjacent heat shall be rejected.

4.7 Reoxidation. In the case of gaseous shrouded heats, oxygen levels in excess of 0.5% shall be considered evidence of reoxidation. Individual steel heats do not require determination of inclusion content and reporting of inclusion ratings on a routine basis is not necessary. However, maximum inclusion content for all steel furnished to this specification shall conform to silicate and oxide inclusion ratings S-4 and O-4 respectively of SAE J422. Inclusion ratings in excess of S-4 and O-4 shall be considered evidence of reoxidation and form the basis for rejection of the entire heat.

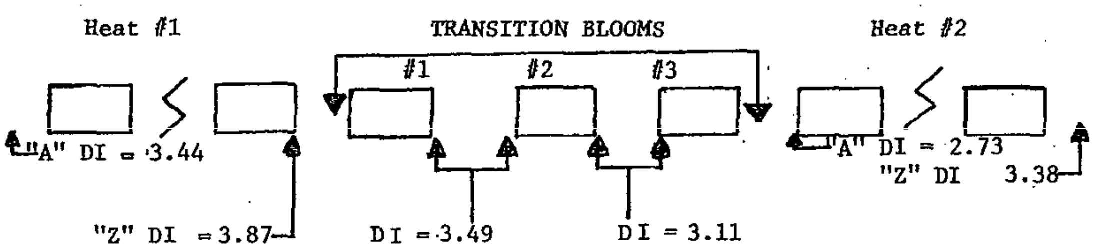
Example 1



$$\frac{DI \quad \text{"Z" (HEAT 1)}}{DI \quad \text{"A" (HEAT 2)}} = \frac{3.30}{2.90} = 1.14 \quad \& \quad \frac{DI \quad \text{"Z" (HEAT 1)}}{DI \quad \text{"Z" (HEAT 2)}} = \frac{3.30}{3.36} = 0.98$$

The entire quantity of transition material can be assigned to the following adjacent heat (Heat 2 without testing transition blooms.

Example 2



DI ratios calculated as in Example 1 are not between 0.80-1.25. Chemical compositions must be determined near the ends of the transition blooms to assign blooms to the appropriate heats.

$$\frac{\text{DI (End of Bloom 1 away from Heat 1)}}{\text{DI "A" (Heat 1)}} = \frac{3.49}{3.44} = 1.01 \text{ and } \frac{\text{DI (Bloom 1)}}{\text{DI "Z" (Heat 1)}} = \frac{3.49}{3.87} = 0.90$$

Bloom 1 can be assigned to Heat 1.

$$\frac{\text{DI (End of Bloom 2 away from Heat 1)}}{\text{DI "A" (Heat 1)}} = \frac{3.11}{3.44} = 0.90 \text{ and } \frac{\text{DI (Bloom 2)}}{\text{DI "Z" (Heat 1)}} = \frac{3.11}{3.87} = 0.80$$

Bloom 2 can be assigned to Heat 1.

$$\frac{\text{DI (End of Bloom 3 away from Heat 2)}}{\text{DI "A" (Heat 2)}} = \frac{3.11}{2.73} = 1.14 \text{ and } \frac{\text{DI (Bloom 3)}}{\text{DI "Z" (Heat 2)}} = \frac{3.11}{3.38} = 0.92$$

Bloom 3 can be assigned to Heat 2.

5. PACKAGING

This section is not applicable to this specification.

6. NOTES

6.1 Intended use. This specification is intended for application whenever an existing document, used in the manufacture of projectiles, options or allows for the use of strand cast steel.

6.2 Ordering data. Procurement documents should specify the following:

a. Title, number and date of this specification.

b. Strand cast Class and Type.

6.3 Cast structure. As cast, strand cast steel usually exhibits three distinct zones of solidification as follows:

a. Chill Zone - A fine grained columnar structure at surface.

b. Columnar Zone - An intermediate coarse grain, columnar structure.

c. Equiaxed Zone - An equiaxed structure at center.

Evidence of the cast structure will typically persist through considerable amounts of reduction. Whenever the cast structure is observed, a uniform continuous chill zone must be present as determined by a macroetch test.

Custodians:
Army - AR
Air Force - 99

Review Activities:
Army - MR
Air Force - 70

Preparing Activity
Army - AR

(Project MECA-0120)

APPENDIX

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PROCEDURE FOR CALCULATION OF

DI HARDENABILITY

10. SCOPE

10.1 Scope. This appendix outlines the procedures for equating hardenability to chemical composition.

20. APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

30. DI

30.1 DI hardenability. Ideal Diameter (DI) represents the diameter (in inches) of a round bar of steel that will harden at the center to 50% martensite when subjected to an ideal quench, i.e., $H=\infty$

30.2 DI calculation. This calculation relies on a series of hardenability factors (Table I) for each alloying element in the composition which multiplied together give a DI value. The effects of phorphorus and sulfur are not considered since they tend to cancel one another. Also, a No. 7 austenstic grain size is assumed since steel purchased to this specification will normally be melted to a fine grain. In this practice experience has demonstrated that the average grain size is No. 7 in a vast majority of the heats.

30.3 Sample calculation. An example of the application of this method is given below for a SAE 4118 modified steel:

ELEMENT	%	MULTIPLYING FACTOR (TABLE 1)
Carbon	.22	.119
Manganese	.80	3.667
Silicon	.18	1.126
Nickel	.10	1.036
Chromium	.43	1.929
Mulybdenum	.25	1.75
Copper	.10	1.04

$$DI = .119 \times 3.667 \times 1.126 \times 1.036 \times 1.929 \times 1.75 \times 1.04 = 1.79$$

APPENDIX

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% Alloy	Carbon Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V	Zr
.01	.005	1.033	1.007	1.004	1.022	1.03	1.00	1.02	1.02
.02	.011	1.067	1.014	1.007	1.043	1.06	1.01	1.03	1.05
.03	.016	1.100	1.021	1.011	1.065	1.09	1.01	1.05	1.07
.04	.021	1.133	1.028	1.015	1.086	1.12	1.02	1.07	1.10
.05	.026	1.167	1.035	1.018	1.108	1.15	1.02	1.09	1.12
.06	.032	1.200	1.042	1.022	1.130	1.18	1.02	1.11	1.15
.07	.038	1.233	1.049	1.026	1.151	1.21	1.03	1.12	1.17
.08	.043	1.267	1.056	1.029	1.173	1.24	1.03	1.14	1.20
.09	.049	1.300	1.063	1.033	1.194	1.27	1.03	1.16	1.22
.10	.054	1.333	1.070	1.036	1.216	1.30	1.04	1.17	1.25
.11	.059	1.367	1.077	1.040	1.238	1.33	1.04	1.19	1.27
.12	.065	1.400	1.084	1.044	1.259	1.36	1.05	1.21	1.30
.13	.070	1.433	1.091	1.047	1.281	1.39	1.05	1.22	1.32
.14	.076	1.467	1.098	1.051	1.302	1.42	1.05	1.24	1.35
.15	.081	1.500	1.105	1.055	1.324	1.45	1.06	1.26	1.37
.16	.086	1.533	1.112	1.058	1.346	1.48	1.06	1.28	1.40
.17	.092	1.567	1.119	1.062	1.367	1.51	1.06	1.29	1.42
.18	.097	1.600	1.126	1.066	1.389	1.54	1.07	1.31	1.45
.19	.103	1.633	1.133	1.069	1.410	1.57	1.07	1.33	1.47
.20	.108	1.667	1.140	1.073	1.432	1.60	1.07	1.35	1.50
.21	.113	1.700	1.147	1.077	1.454	1.63	1.08		1.52
.22	.119	1.733	1.154	1.080	1.475	1.66	1.08		1.55
.23	.124	1.767	1.161	1.084	1.497	1.69	1.09		1.57
.24	.130	1.800	1.168	1.088	1.518	1.72	1.09		1.60
.25	.135	1.833	1.175	1.091	1.540	1.75	1.09		1.62
.26	.140	1.867	1.182	1.095	1.562	1.78	1.10		
.27	.147	1.900	1.189	1.098	1.583	1.81	1.10		
.28	.151	1.933	1.196	1.102	1.605	1.84	1.10		
.29	.157	1.967	1.203	1.106	1.626	1.87	1.11		
.30	.162	2.000	1.210	1.109	1.648	1.90	1.11		
.31	.167	2.033	1.217	1.113	1.670	1.93	1.11		
.32	.173	2.067	1.224	1.117	1.691	1.96	1.12		
.33	.178	2.100	1.231	1.120	1.713	1.99	1.12		
.34	.184	2.133	1.238	1.124	1.734	2.02	1.12		
.35	.189	2.167	1.245	1.128	1.756	2.05	1.13		
.36	.194	2.200	1.252	1.131	1.776	2.08	1.13		
.37	.200	2.233	1.259	1.135	1.799	2.11	1.14		
.38	.205	2.267	1.266	1.139	1.821	2.14	1.14		
.39	.211	2.300	1.273	1.142	1.842	2.17	1.14		
.40	.213	2.333	1.280	1.146	1.864	2.20	1.15		
.41	.216	2.367	1.287	1.150	1.886	2.23	1.15		
.42	.218	2.400	1.294	1.153	1.907	2.26	1.15		
.43	.221	2.433	1.301	1.157	1.929	2.29	1.16		

TABLE 1. HARDENABILITY FACTORS

% Alloy	Carbon Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu
.44	.223	2.467	1.308	1.160	1.950	2.32	1.16
.45	.226	2.500	1.315	1.164	1.972	2.35	1.16
.46	.228	2.533	1.322	1.168	1.994	2.38	1.17
.47	.230	2.567	1.329	1.171	2.015	2.41	1.17
.48	.233	2.600	1.336	1.175	2.037	2.44	1.18
.49	.235	2.633	1.343	1.179	2.058	2.47	1.18
.50	.238	2.667	1.350	1.182	2.080	2.50	1.18
.51	.242	2.700	1.357	1.186	2.102	2.53	1.19
.52	.244	2.733	1.364	1.190	2.123	2.56	1.19
.53	.246	2.767	1.371	1.193	2.145	2.59	1.19
.54	.249	2.800	1.378	1.197	2.166	2.62	1.20
.55	.251	2.833	1.385	1.201	2.188	2.65	1.20
.56	.253	2.867	1.392	1.204	2.210		
.57	.256	2.900	1.399	1.208	2.231		
.58	.258	2.933	1.406	1.212	2.253		
.59	.260	2.967	1.413	1.215	2.274		
.60	.262	3.000	1.420	1.219	2.296		
.61	.264	3.033	1.427	1.222	2.318		
.62	.267	3.067	1.434	1.226	2.339		
.63	.269	3.100	1.441	1.230	2.361		
.64	.271	3.133	1.448	1.233	2.382		
.65	.273	3.167	1.455	1.237	2.404		
.66	.275	3.200	1.462	1.241	2.426		
.67	.277	3.233	1.469	1.244	2.447		
.68	.279	3.267	1.476	1.248	2.469		
.69	.281	3.300	1.483	1.252	2.490		
.70	.283	3.333	1.490	1.255	2.512		
.71	.285	3.367	1.497	1.259	2.534		
.72	.287	3.400	1.504	1.262	2.555		
.73	.289	3.433	1.511	1.266	2.577		
.74	.291	3.467	1.518	1.270	2.596		
.75	.293	3.500	1.525	1.273	2.620		
.76	.295	3.533	1.532	1.276	2.642		
.77	.297	3.567	1.539	1.280	2.663		
.78	.299	3.600	1.546	1.284	2.685		
.79	.301	3.633	1.553	1.287	2.706		
.80	.303	3.667	1.560	1.291	2.728		
.81	.305	3.700	1.567	1.294	2.750		
.82	.307	3.733	1.574	1.298	2.771		
.83	.309	3.767	1.581	1.301	2.793		
.84	.310	3.800	1.588	1.306	2.814		
.85	.312	3.833	1.595	1.309	2.836		
.86	.314	3.867	1.602	1.313	2.858		
.87	.316	3.900	1.609	1.317	2.879		
.88	.318	3.933	1.616	1.320	2.900		
.89	.319	3.967	1.623	1.324	2.922		

TABLE 1. HARDENABILITY FACTORS (CONT'D)

% Alloy	Carbon Grain Size 7	Mn	Si	Ni	Cr
.90	.321	4.000	1.630	1.327	2.944
.91		4.033	1.637	1.331	2.966
.92		4.067	1.644	1.334	2.987
.93		4.100	1.651	1.338	3.009
.94		4.133	1.658	1.343	3.030
.95		4.167	1.665	1.345	3.052
.96		4.200	1.672	1.349	3.074
.97		4.233	1.679	1.352	3.095
.98		4.267	1.686	1.356	3.117
.99		4.300	1.693	1.360	3.138
1.00		4.333	1.700	1.364	3.160
1.01		4.367	1.707	1.367	3.182
1.02		4.400	1.714	1.370	3.203
1.03		4.433	1.721	1.375	3.225
1.04		4.467	1.728	1.378	3.246
1.05		4.500	1.735	1.383	3.268
1.06		4.533	1.742	1.386	3.290
1.07		4.567	1.749	1.389	3.311
1.08		4.600	1.756	1.393	3.333
1.09		4.633	1.763	1.396	3.354
1.10		4.667	1.770	1.400	3.376
1.11		4.700	1.777	1.403	3.398
1.12		4.733	1.784	1.406	3.419
1.13		4.767	1.791	1.411	3.441
1.14		4.800	1.798	1.414	3.462
1.15		4.833	1.805	1.418	3.484
1.16		4.867	1.812	1.422	3.506
1.17		4.900	1.819	1.426	3.527
1.18		4.933	1.826	1.429	3.549
1.19		4.967	1.833	1.433	3.570
1.20		5.000	1.840	1.437	3.592
1.21		5.051	1.847	1.440	3.614
1.22		5.102	1.854	1.444	3.635
1.23		5.153	1.861	1.447	3.657
1.24		5.204	1.868	1.450	3.678
1.25		5.255	1.875	1.454	3.700
1.26		5.306	1.882	1.458	3.722
1.27		5.357	1.889	1.461	3.743
1.28		5.408	1.896	1.465	3.765
1.29		5.459	1.903	1.470	3.786
1.30		5.510	1.910	1.473	3.808
1.31		5.561	1.917	1.476	3.830
1.32		5.612	1.924	1.481	3.851
1.33		5.663	1.931	1.484	3.873
1.34		5.714	1.938	1.487	3.894

TABLE 1. HARDENABILITY FACTORS (CONT'D)

% Alloy	Mn	Si	Ni	Cr
1.35	5.765	1.945	1.491	3.916
1.36	5.816	1.952	1.495	3.938
1.37	5.867	1.959	1.498	3.959
1.38	5.918	1.966	1.501	3.981
1.39	5.969	1.973	1.506	4.002
1.40	6.020	1.980	1.509	4.024
1.41	6.071	1.987	1.512	4.046
1.42	6.122	1.994	1.517	4.067
1.43	6.173	2.001	1.520	4.089
1.44	6.224	2.008	1.523	4.110
1.45	6.275	2.015	1.527	4.132
1.46	6.326	2.022	1.531	4.154
1.47	6.377	2.029	1.535	4.175
1.48	6.428	2.036	1.538	4.197
1.49	6.479	2.043	1.541	4.217
1.50	6.530	2.050	1.545	4.239
1.51	6.581	2.057	1.556	4.262
1.52	6.632	2.064	1.561	4.283
1.53	6.683	2.071	1.565	4.305
1.54	6.734	2.078	1.569	4.326
1.55	6.785	2.085	1.574	4.348
1.56	6.836	2.092	1.578	4.369
1.57	6.887	2.099	1.582	4.391
1.58	6.938	2.106	1.586	4.413
1.59	6.989	2.113	1.591	4.434
1.60	7.040	2.120	1.595	4.456
1.61	7.091	2.127	1.600	4.478
1.62	7.142	2.134	1.604	4.499
1.63	7.193	2.141	1.609	4.521
1.64	7.224	2.148	1.613	4.542
1.65	7.295	2.155	1.618	4.564
1.66	7.346	2.162	1.622	4.586
1.67	7.397	2.169	1.627	4.607
1.68	7.448	2.176	1.631	4.629
1.69	7.499	2.183	1.636	4.650
1.70	7.550	2.190	1.640	4.672
1.71	7.601	2.197	1.644	4.694
1.72	7.652	2.204	1.648	4.715
1.73	7.703	2.211	1.652	4.737
1.74	7.754	2.218	1.656	4.759
1.75	7.805	2.225	1.660	4.780
1.76	7.856	2.232	1.664	
1.77	7.907	2.239	1.668	
1.78	7.958	2.246	1.672	
1.79	8.009	2.253	1.676	
1.80	8.060	2.260	1.680	

TABLE 1. HARDENABILITY FACTORS (CONT'D)

APPENDIX

MIL-S-70703

% Alloy	Mn	Si	Ni
1.81	8.111	2.267	1.687
1.82	8.162	2.274	1.694
1.83	8.213	2.281	1.701
1.84	8.315	2.288	1.708
1.85	8.366	2.295	1.715
1.86	8.417	2.302	1.722
1.87	8.468	2.309	1.729
1.88	8.519	2.316	1.736
1.89	8.570	2.323	1.743
1.90	8.621	2.330	1.750
1.91	8.672	2.337	1.753
1.92	8.723	2.344	1.756
1.93	8.774	2.351	1.759
1.94	8.825	2.358	1.761
1.95	8.876	2.364	1.765
1.96		2.372	1.767
1.97		2.379	1.770
1.98		2.386	1.773
1.99		2.393	1.776
2.00		2.400	1.779*

*Nickel Over 2%: Factor = $1.00 + .333 (\% Ni) + .066 (\% Ni)^2 - .055 (\% Ni)^3 + .018 (\% Ni)^4$

TABLE I. HARDENABILITY FACTORS