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SURFACE VEHICLE STANDARD

An American National Standard

SAE J406

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Superseding J406 FEB95

Methods of Determining Hardenability of Steels

1. ***Scope—***This SAE Standard prescribes the procedure for making hardenability tests and recording results on shallow and medium hardening steels, but not deep hardening steels that will normally air harden.

Included are procedures using the 25 mm (1 in) standard hardenability end-quench specimen for both medium and shallow hardening steels and subsize method for bars less than 32 mm (1-1/4 in) in diameter. Methods for determining case hardenability of carburized steels are given in SAE J1975.

Any hardenability test made under other conditions than those given in this document will not be deemed standard and will be subject to agreement between supplier and user. Whenever check tests are made, all laboratories concerned must arrange to use the same alternate procedure with reference to test specimen and method of grinding for hardness testing.

For routine testing of the hardenability of successive heats of steel required to have hardenability within certain limits, it is sufficient to designate hardenability simply in terms of distance from the quenched end to the point at which a certain hardness is obtained. This designation may also be adequate for comparing steels of different compositions to see whether they have similar hardenability.

Hardenability limits for specifying steel in this manner are obtained by measuring the hardenability of a steel which has proved satisfactory for the use intended. The hardenability test may be used in this way as an empirical test.

For new components where manufacturing experience is lacking, hardenability data may be effectively used to estimate the hardness profile provided by any given steel. Attendantly, the ability to predict hardenability from chemical composition has become increasingly important when comparing various steel grades or developing new steels for specific applications. One such procedure is described in Appendix A. Other hardenability prediction methods are available from the selected references in Section 2. However, it should be emphasized that the use of any hardenability prediction procedure does not preclude the importance of conducting Jominy end-quench tests to determine the actual hardenability of any specific grade of steel.

Hardenability data may be used to estimate hardnesses obtainable with any steel in new machine parts not yet in production and not similar to any parts on which production experience is available. Various hardenability application methods are described in the selected references, Section 2.1, 23 to 25. It appears none of these methods are precise, but these are often useful for estimation purposes. Final correlation on actual parts is necessary.

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2. *References*

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the lastest revision of SAE publications shall apply.

1. SAE J417—Hardness Test and Hardness Number Conversion
2. SAE EA 406—Hardenability Prediction Calculator
3. W. E. Jominy and A. L. Boegehold, "A Hardenability Test for Carburizing Steel," ASM Transactions, Vol. 26 (1938, No. 2, pp 574–599)
4. J. L. Burns, T. L. Moore, and R. S. Archer, "Quantitative Hardenability," ASM Transactions, Vol 26 (1938), No. 1, pp 1–33
5. W. E. Jominy, "A Hardenability Test for Shallow Hardening Steels," ASM Transactions, Vol. 27 (1939) pp 1072–1085
6. Symposium on Hardenability of Alloy Steels, ASM 1939
7. M. Asimow and M. A. Grossmann, "Hardening Characteristics of Various Shapes," AMS Transactions, Vol. 28 (1940) pp 949–977
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12. G. K. Manning, "End Quench Hardenability Versus Hardness of Quenched Rounds," Metal Progress, Vol. 50, No. 4 (October 1946) pp 674-650
13. E. W. Wienman, R. F. Thomson, and A. L. Boegehold, "Correlation of End Quenched Test Bars and Rounds in Terms of Hardness and Cooling Characteristics," ASM Transactions, Vol. 44 (1952) pp 802–834
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18. M. A. Grossmann, "Hardenability Calculated from Chemical Compositions," AIME Transactions, Vol. 150 (1942) pp 227–259
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20. C. F. Jatczak and D. J. Girardi, "Multiplying Factors for the Calculation of Hardenability of Hypereutectoid Steels Hardened from 1700 F," ASM Transactions Vol. 51 (1960) p 335 ff
21. E. Just, "New Formulas for Calculating Hardenability Curves," Metal Progress, November 1969, pp 87–88
22. C. F. Jatczak, "Determining Hardenability from Composition," Metal Progress, Vol. 100, No. 3 (September 1971), p 60
23. D. H. Breen, G. H. Walter, C. J. Keith, and J. T. Sponzilli, "Computer-Based System Selects Optimum Cost Steels," Metal Progress, I: Dec. 1972, p. 42; II: Feb. 1973, p. 76; III: April 1973, p. 105; IV: June 1973, p. 83; V: Nov. 1973, p. 43
24. C. S. Siebert, D. V. Doane, and D. H. Breen, "The Hardenability of Steels," American Society for Metals, Metals Park, OH 1977, p 64 ff
25. D. V. Doane, J. S. Kirkaldy, "Hardenability Concepts with Applications to Steel," The Metallurgical Society of AIME, Warrendale, PA 1978
26. C. T. Kunze and G. Keil," A New Look at Boron Effectiveness in Heat Treated Steels," Symposium on Boron Steels, TMS-AIME, Milwaukee, WI Sept. 18, 1979

27. W. Hewitt, "Hardenability - Its Prediction form Chemical Compositions," Heat Treatment of Metals, Vol. 8, 1981, pp 33–38
28. Deb. M. C. Chaturvedi and A. K. Jena, "Analytical Representation of Hardenability Data for Steels," Metals Technology, 1982, Vol 9, p 76
29. J. M. Tartaglia and G. T. Eldis, "Core Hardenability Calculations for Carburizing Steels," Met. Trans., Vol. 15A, No. 6, June 1984, pp. 1173–1183

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 ASTM—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM A 255—End-quench Test for Hardenability of Steel

2.2.2 OTHER PUBLICATIONS

DIN 50191—Hardenability Testing of Steel by End Quenching

JIS G 0561—Method of Hardenability Testing (End-Quenching Method)

3. Hardenability Test for Medium Hardening Steels

3.1 Introduction—This method covers the procedure for determining the hardenability of steel by the end-quench test for both the 25 mm (1 in) standard specimen and the subsize test specimen. Also included are charts for plotting hardenability test results and for predicting hardness U curves in various sizes of rounds.

Please note that in this revision the metric dimensions are shown to the nearest whole millimeter. Tolerances, where not indicated, are assumed to be ±0.5 mm or ±1/32 in (0.03 in).

3.2 Test Specimen—The test specimen is a 25 mm (1 in) diameter cylinder 102 mm (4 in) long with means for hanging it in a vertical position for end-quenching. Figure 1 shows a test specimen in the fixture ready for quenching illustrating the preferred form of specimen. Figure 2 gives the details of the preferred test specimen. Figure 3 is an example of an optional specimen which provides the same diameter and approximately the same length and which will provide satisfactory heat transfer characteristics.

The bar from which the specimen is machined shall be a forged or rolled 29 to 32 mm (1-1/8 to 1-1/4 in) round representing the full cross section of the product (or rolled 26 mm, 1-1/16 in, round if optional test specimen, Figure 3, is used). A cast specimen may be used in lieu of a rolled or forged specimen, except in the case of boron-treated steel; experience has shown that cast specimens of boron-treated steels give erratic results. The option of using as-cast specimens for non-boron steels, deletion of normalizing prior to heating for end-quenching or modification of other testing details shall be negotiated between supplier and user. It is of primary importance that the specimen represent the full cross section of the ingot, cast bloom or cast billet since test specimens from a portion of the bloom, billet, or bar may introduce factors tending to affect the reproducibility of test results. The condition of this hot formed bar shall be such that there is no decarburization on the 25 mm (1 in) specimen machined from it. If any test specimen shows obvious defects or flaws, the specimen should be discarded and a new specimen obtained.

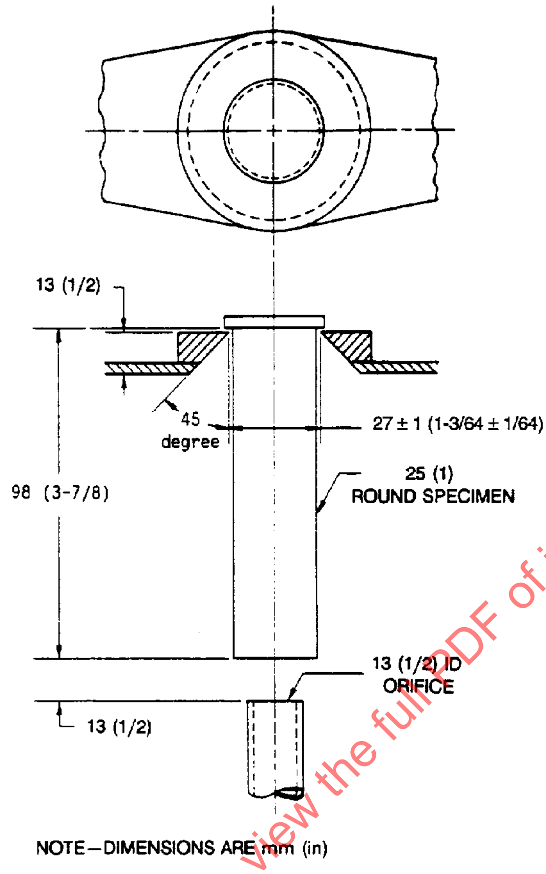


FIGURE 1—HARDENABILITY TEST SPECIMEN IN FIXTURE FOR WATER QUENCHING

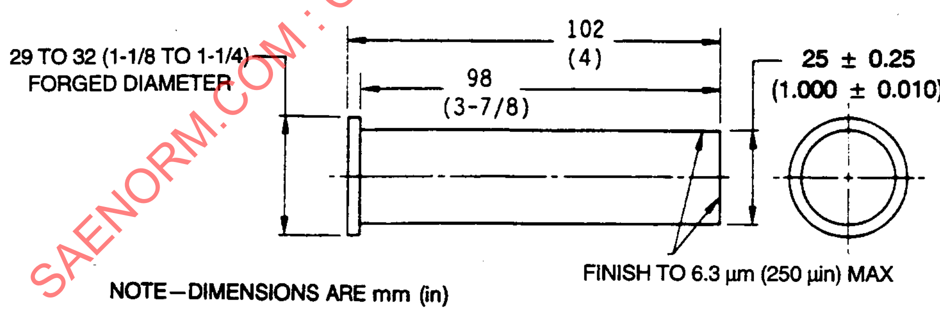


FIGURE 2—PREFERRED TEST SPECIMEN

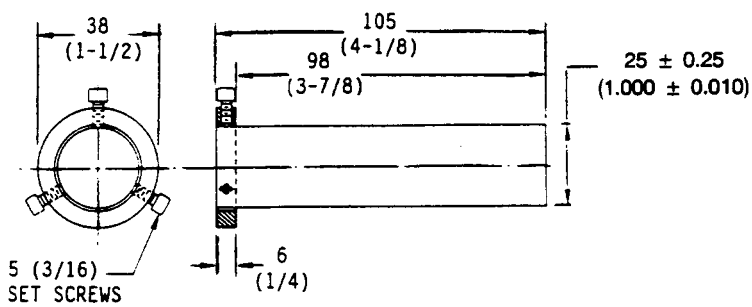


FIGURE 3—OPTIONAL TEST SPECIMEN

3.3 Optional Specimen Preparation—The following method is satisfactory for most purposes, but for check testing against specifications, the method in the preceding paragraph is mandatory.

The test specimen shall be machined from the center of the bar in the case of sections from 32 to 51 mm (1-1/4 to 2 in) round or square. In sections over 51 mm (2 in), the test specimen shall be machined from one-half of the section with the axis of the specimen located at a point halfway between the center and surface of the bar and marked to identify the position of the test bar with reference to the original bar. The hardness readings shall be made on the two sides of the test specimen corresponding to a position in the bar approximately halfway between the center and the surface.

3.4 Normalizing Prior to Heating for End-Quenching—The forged or rolled round shall be normalized prior to machining the test specimen. This is of importance since the structure of material before the final austenitizing treatment may materially affect the hardening characteristics. In order that variations in prior structure may be controlled as much as possible, the normalizing temperature listed in Table 1 should be used. The steel shall be held at such temperature for 1 h and cooled to ambient in still air. If the normalized specimen is too hard, it may be given a short time temper at about 55 °C (100 °F) below the Ac_1 to improve machinability. *Cast specimens usually are not normalized before machining*. The record of hardenability test results must always state the prior thermal history of the specimen tested.

TABLE 1—NORMALIZING AND QUENCHING TEMPERATURES[1][2] APPLICABLE TO STEEL ORDERED TO END-QUENCH HARDENABILITY REQUIREMENTS

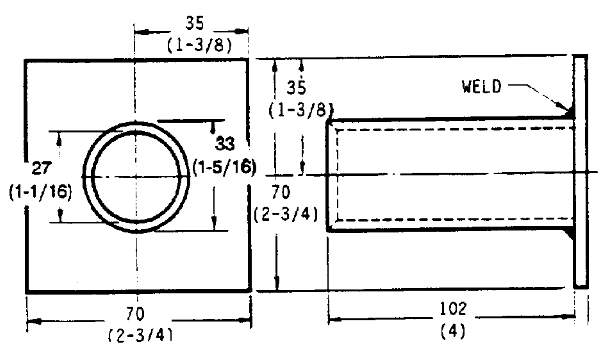
Maximum Ordered Carbon Content, %	Normalizing Temperature °C	Normalizing Temperature °F	Austenitizing Temperature °C	Austenitizing Temperature °F
Steel Series 1000, 1300, 1500, 4000, 4100, 4300, 4600, 4700, 5000, 5100, 6100 [3], 8100, 8600, 8700, 8800, 9400				
Up to 0.25 incl	925	1700	925	1700
0.26 to 0.36 incl	900	1650	870	1600
0.37 and over[3]	870	1600	845	1550
Steel Series 4800, 9300				
Up to 0.25 incl	925	1700	845	1550
Steel Series 9200				
0.50 and over	900	1650	870	1600

1. A variation of ±5 °C (±10 °F) from the above temperature is permissible.
2. When testing H steels, the normalizing and austenitizing should be the same as for the equivalent standard steels. EXAMPLES: For 8622 H, the normalizing and austenitizing temperature should be the same as for SAE 8622; for 4032 H (carbon 0.30/0.37), the temperature should be the same as for SAE 4032 (carbon 0.30/0.35).
3. Normalizing and austenitizing temperatures shall be 30 °C (50 °F) higher for the 6100 series.

3.5 Heating for End-Quenching—The specimen shall be heated to the austenitizing temperature shown in Table 1. The specimen shall be placed in a furnace which is at the specified temperature and shall be held at this temperature for 30 to 35 min. It is necessary to determine by means of a thermocouple the time required for a test specimen to come to the required temperature.

While heating the test specimen it is important to insure that practically no scaling or decarburization takes place on the end to be quenched. This may be achieved through the use of protective furnace atmospheres or by placing the specimen in a container which maintains a non-oxidizing atmosphere, e.g., by placing fine graphite powder or cast iron chips in the base of the container.

Figure 4 illustrates a type of container which has been used with success. However, any similar type will be satisfactory.



NOTE—DIMENSIONS ARE mm (in)

FIGURE 4—SPECIMEN PROTECTING FIXTURE TO BE CONSTRUCTED OF HEAT-RESISTING ALLOY

3.6 **Quenching—**The test specimen shall be placed on a fixture so that a column of water at a temperature of 5 to 30 °C (40 to 85 °F) may be directed against the bottom face of the specimen. The column of water passing through an orifice 13 mm (1/2 in) in diameter shall rise to a free height of 63 mm (2-1/2 in) above the orifice. The fixture shall be dry at the beginning of each test.

In performing the test, the water supply shall be shut off with a quick-opening valve and the hot specimen placed over the water pipe so that the bottom of the specimen is 13 mm (1/2 in) from the opening of the water pipe and the water shall then be turned on. A preferred alternate procedure is to keep the water flowing, but impose a deflecting plate above the water pipe while transferring the test specimen from the furnace to the fixture, and quickly removing the plate to start the end-quench. The time between removal of the specimen from the furnace and the beginning of the quench shall be not more than 5 s. The sample shall remain on the fixture for at least 10 min. A condition of still air shall be maintained around the specimen during cooling. (If the quenched end of the specimen is not cool when removed from the fixture, investigate whether water temperature or water flow is within specification.)

3.7 **Hardness Measurement—**Two flats 180 degrees apart shall be ground to a minimum depth of 0.38 mm (0.015 in) along the entire length of the bar and Rockwell C hardness measurements made along the length of the bar. Deviation from the standard depth can affect reproducibility of test results, and correlation with cooling rates in quenched bars.

The preparation of the two flats must be carried out with considerable care. They should be mutually parallel and the grinding done in such a manner that no change of the quenched structure takes place. Very light passes (less than 0.013 mm (0.0005 in)) with water cooling and a coarse, soft grinding wheel are recommended to avoid overheating the specimen. To detect tempering due to grinding, the flats may be etched as follows:

Two etchant solutions are used:

No. 1—5% nitric acid (concentrated) and 95% water by volume.

No. 2—50% hydrochloric acid (concentrated) and 50% water by volume.

Wash the sample in hot water. Etch in solution No. 1 until black. Wash in hot water. Immerse in solution No. 2 for 3 s and wash in hot water. Dry in air blast.

The presence of lighter or darker areas indicates that hardness and structure have been altered in grinding. All structural changes caused by grinding shall be removed before hardness tests are made. This may be accomplished by resurfacing and again etching, or new flats may be prepared.

When hardness indentations are made, the test specimen must rest on one of its flats on an anvil firmly attached to the hardness machine. It is important that no vertical movement be allowed when the major load is applied. The fixture must be constructed to move the test specimen past the penetrator in accurate steps of 0.5 mm (for metric fixture) or 1/16 in (for U.S. customary fixture). (Resting specimen on a V-block is not permitted.)

Figure 5 is an example of a commercially available fixture which provides for the controlled movement of the specimen.

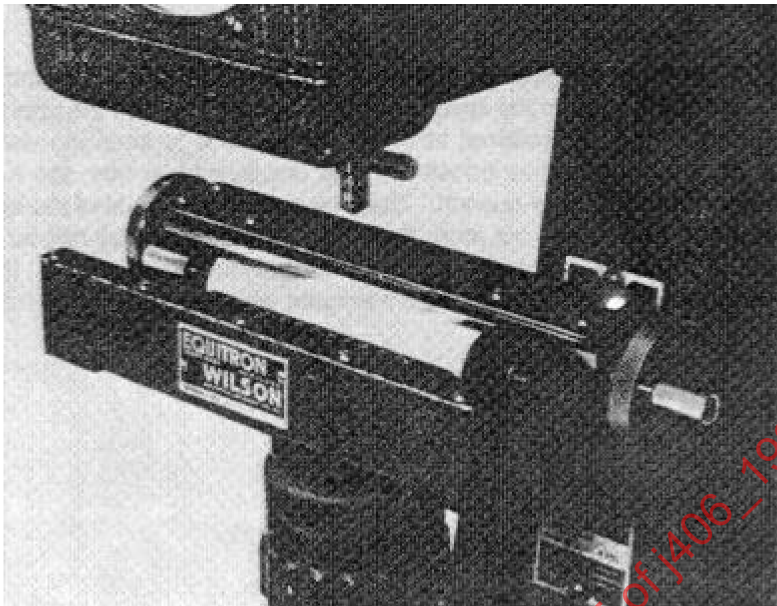


FIGURE 5—COMMERCIALLY AVAILABLE FIXTURE FOR POSITIONING SPECIMEN FOR HARDNESS INDENTATIONS

The Rockwell tester should be checked against standard test blocks before testing the hardenability specimen. It is recommended that the test block be interposed between the specimen and the indenter to check the seating of the indenter and the specimen simultaneously.

Care must be exercised in registering the point of the indenter with the hardened end of the specimen, as well as providing for accurate spacing between indentations. A low power measuring microscope is suitable for use in determining the distance from the quenched end to the center of the first indentation and in checking the distance from center to center of the succeeding indentation. It has been found that with reasonable operating care and a well-built fixture, it is practical to locate the center of the first indentation 1.5 mm ± 0.075 mm (0.0625 in ± 0.003 in) from the quenched end. The variations between spacings should be even smaller. Obviously, it is more important to position the indenter accurately when testing shallow hardenability steels than when testing medium hardenability steels. The positioning of the indenter should be checked with sufficient frequency to provide assurance that accuracy requirements are being met. In cases of lack of reproducibility or of differences between laboratories, indenter spacing should be measured immediately.

3.7.1 METRIC DISTANCES BETWEEN READINGS—Readings shall be taken at 1.5, 3, 5, 7, 9, 11, 13, and 15 mm, then at 5 mm intervals to 50 mm, or until 20 HRC is reached (if less than 50 mm).

3.7.2 DISTANCES BETWEEN READINGS IN SIXTEENTHS OF AN INCH—Readings shall be taken at intervals of 1/16 in for the first inch. Distances between readings beyond 1 in may be at the discretion of the tester, but usually are taken at intervals of 1/8 in until 20 HRC is reached. (Less frequent intervals may be agreed upon between supplier and user.)

Hardness readings should be made on one flat, or preferably, two flats 180 degrees apart. When a flat on which readings have been made is used as a base, the ridges around the hardness indentations shall be removed by grinding unless a fixture is used which has been relieved to accommodate the irregularities due to the indentations. Testing on two flats will assist in the detection of errors in specimen preparation and hardness measurement. If the two probes on opposite sides differ by more than 4 HRC points at any one position, the test should be repeated on new flats, 90 degrees from the first two flats. If the retest also has greater than 4 HRC points spread, a new specimen should be tested.

For reporting purposes, hardness readings should be recorded to the nearest integer, with 0.5 HRC values rounded to the next higher integer.

3.8 Plotting of Tests—Tests should be plotted on a standard chart prepared for this purpose (Figure 6A or 6B) in which the ordinates represent hardness and the abscissas represent distance from the quenched end. Readings at identical distances should be averaged and the resultant values used for plotting.

Figures 6A and 6B are Standard Forms for Plotting Hardenability Curves.

3.9 Construction of Hardness U Curves—Charts are provided for using the hardenability curve to predict hardness U curves in various sized rounds when oil or water quenched. Figure 7 shows these charts. The curves show the locations in various sizes of rounds where the cooling rates are the same as at various positions along the end-quenched hardenability test bar. It should be noted that these curves assume good heat treatment practice—separation of parts in the quench, good agitation, and good control of temperature and cleanliness of the quenchant. The ranges given reflect variations found under laboratory conditions. Under production conditions, even wider variations may be found.

DATE ____________________
LABORATORY ____________________
TYPE SPECIMEN ____________________
TEST NO. ____________________

TYPE	HEAT NO.	GRAIN SIZE	C	Mn	P	S	Si	Ni	Cr	Mo		NORMAL. TEMP. °C	QUENCH TEMP. °C

REMARKS ____________________

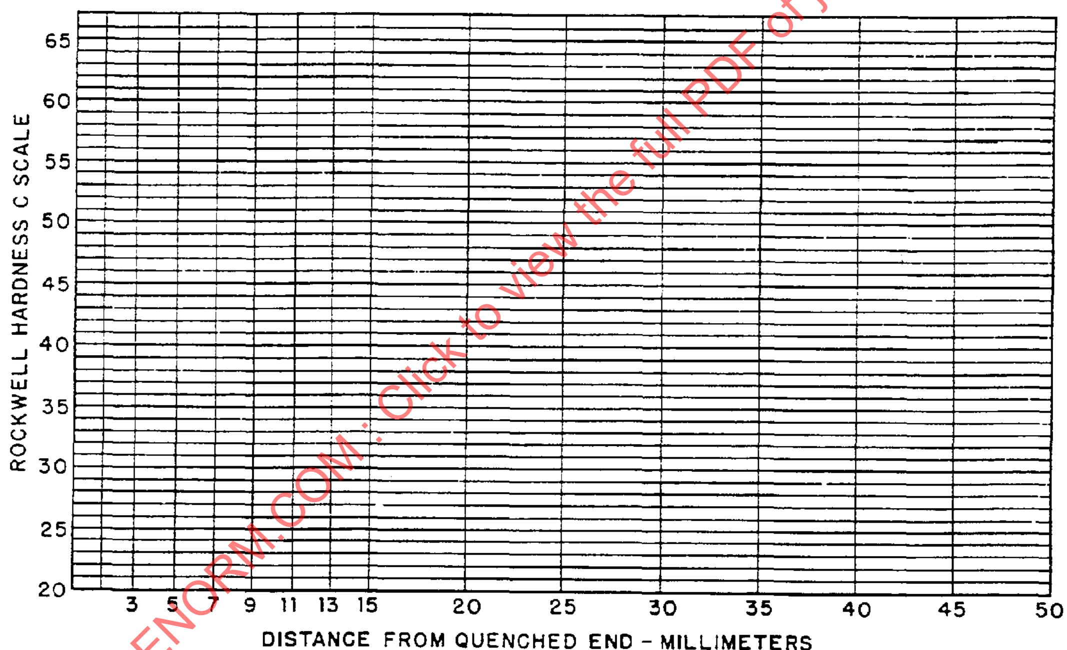


FIGURE 6A—STANDARD FORM FOR PLOTTING HARDENABILITY CURVES (MILLIMETER DISTANCES)

DATE ______________________
LABORATORY ______________________
TYPE SPECIMEN ______________________
TEST NO. ______________________

TYPE	HEAT NO.	GRAIN SIZE	C	Mn	P	S	Si	Ni	Cr	Mo		NORMAL. TEMP.°F	QUENCH TEMP.°F

REMARKS ______________________

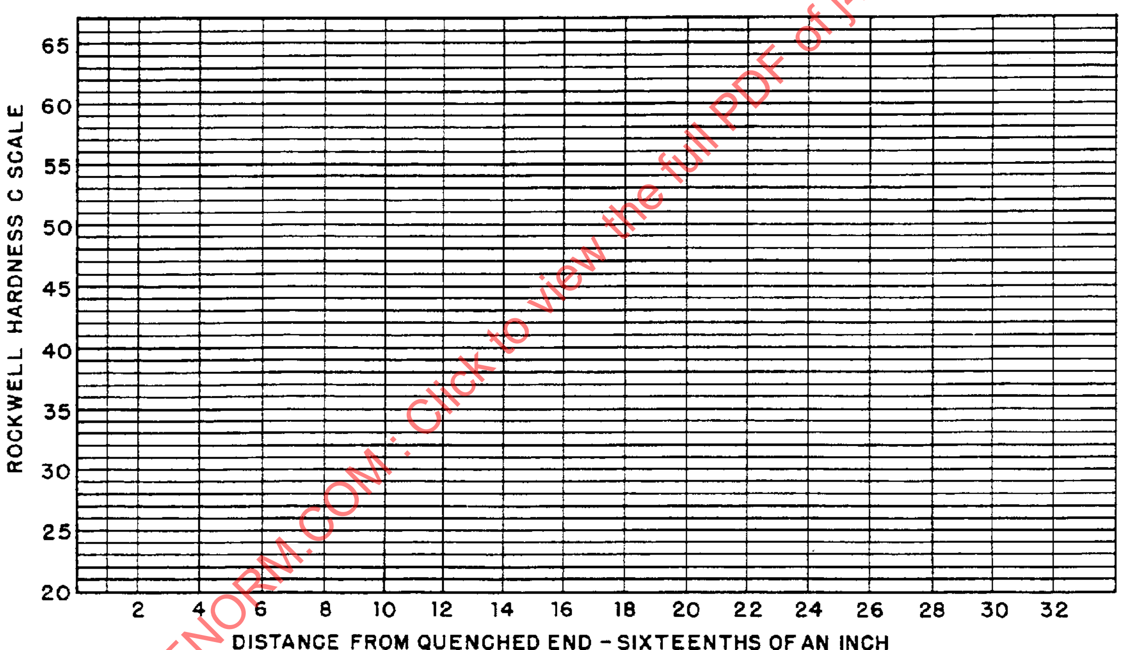


FIGURE 6B—STANDARD FORM FOR PLOTTING HARDENABILITY CURVES (SIXTEENTHS OF AN INCH DISTANCES)

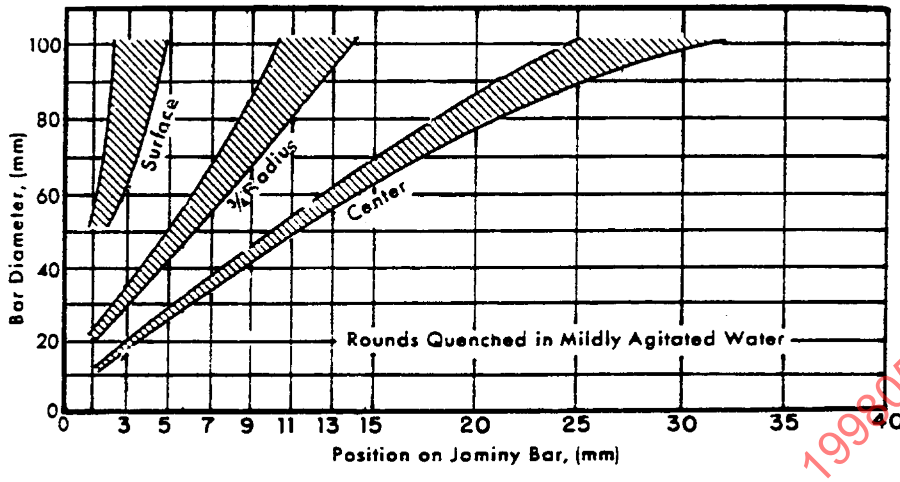


FIGURE 7A—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

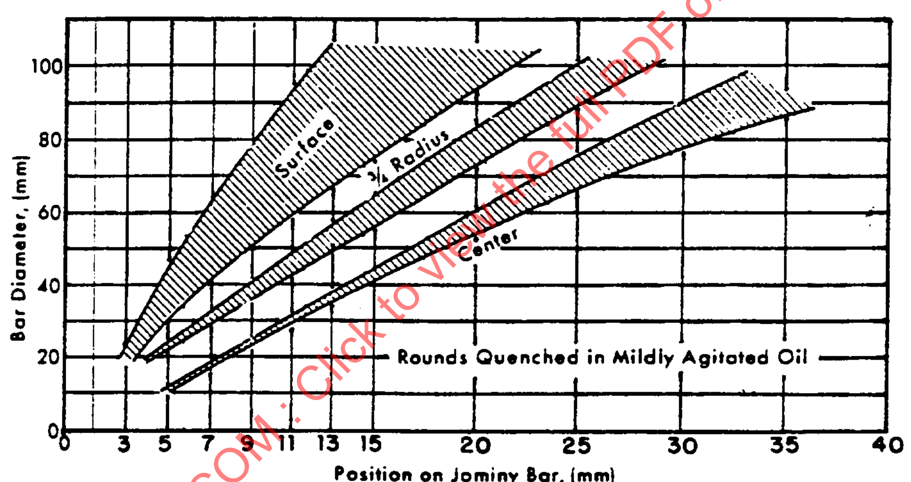


FIGURE 7B—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

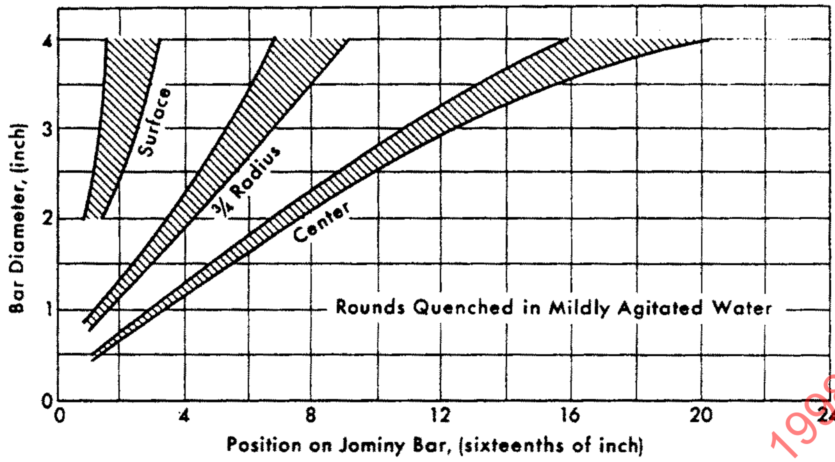


FIGURE 7C—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

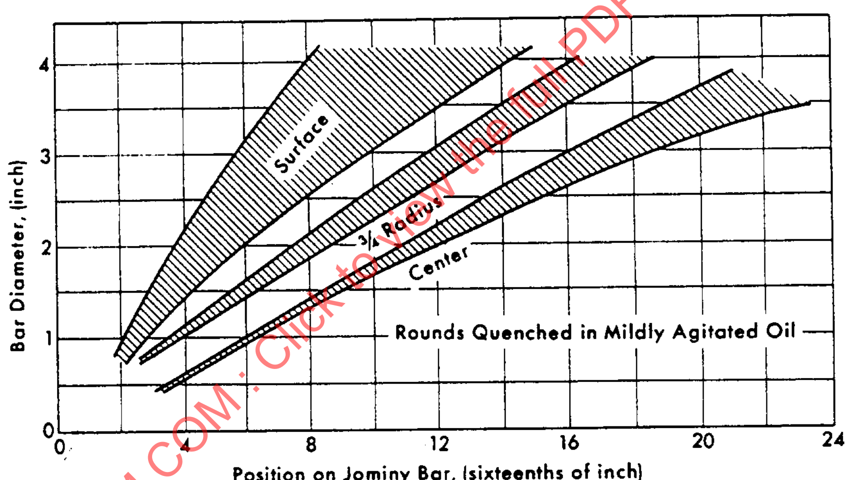


FIGURE 7D—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

3.10 Subsize Test Specimen—For determining hardenability of steel received in bars less than 26 mm (1-1/6 in) in diameter, the test bar may be made 19, 13, or 6 mm (3/4, 1/2, or 1/4 in) in diameter, as desired, and end-quenched as prescribed for the 25 mm (1 in) round. Modifications in the water orifice are required for quenching cylinders of less than 25 mm (1 in) diameter. The details of orifices for quenching specimens less than 25 mm (1 in) diameter are given in Table 2.

TABLE 2—ORIFICES FOR QUENCHING SUBSIZE SPECIMENS

Test Specimen Diameter mm (in)	Orifice Size mm (in)	Distance from Orifice to Quenched End of Specimen mm (in)	Free Height of Water Column mm (in)
19 (3/4)	13 (1/2)	13 (1/2)	63 (2–1/2)
13 (1/2)	6 (1/4)	10 (3/8)	102 (4)
6 (1/4)	3 (1/8)	6 (1/4)	203 (8)

Because of the greater air-cooling effect on test specimens less than 25 mm (1 in) diameter and especially in specimens smaller than 19 mm (3/4 in) diameter, the cooling rates at various distances from the quenched end will not be the same as in the standard test specimen.

Hardenability curves obtained from smaller specimens are not comparable with curves obtained from the 25 mm (1 in) round specimen. If the standard hardenability curve is needed from subsize specimens, it becomes necessary to determine the actual cooling rates on the subsize specimens.

4. Hardenability Tests for Shallow Hardening Steels—The 25 mm (1 in) standard hardenability specimen may be used to determine the hardenability of shallow hardening steels other than the carbon tool steels by a modification in the hardness survey. The procedure for preparing the specimen prior to hardness measurement is specified in 3.1 to 3.9 for standard 25 mm (1 in) hardenability specimens. An anvil providing a means of very accurately measuring the distance from the quenched end is essential.

Only two flats 180 degrees apart need be ground if the mechanical fixture has a grooved bed which will accommodate the indentations on the flat surveyed first. The second hardness traverse is made after turning the bar over. If the fixture does not have such a grooved bed, two pairs of flats should be ground, the flats of each pair being 180 degrees apart. The two hardness surveys are made on adjacent flats.

4.1 Procedure for Distance from the Quenched End in Millimeters—Hardness values are obtained from 1 to 15 mm in intervals of 1 mm. For this distance, two hardness traverses are made, each with hardness indentations 2 mm apart, one traverse starting at 1 mm from the quenched end, the other starting at 2 mm from the quenched end. Beyond 15 mm from the quenched end, intervals can be increased to 5 mm until 20 HRC is reached.

4.2 Procedure for Distance from the Quenched End in Sixteenths of an Inch—Hardness values are obtained from 1/16 to 8/16 in from the quenched end in intervals of 1/32 in. For this distance, two hardness traverses are made, each with hardness indentations 1/16 in apart, one traverse starting at 1/16 in from the quenched end, the other starting at 3/32 in from the quenched end. Beyond 8/16 in from the quenched end, intervals can be increased to a minimum of 2/16 in until 20 HRC is reached.

For plotting test results, the Standard Form for Plotting Hardenability Curves (Figure 6A or 6B) should be used.

5. Notes

5.1 Marginal Indicia—The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE IRON AND STEEL TECHNICAL COMMITTEE —DIVISION 8—HARDENABILITY OF CARBON AND ALLOY STEELS

APPENDIX A

METHOD FOR CALCULATING HARDENABILITY FROM COMPOSITION

A.1 Introduction—This method of Jominy hardenability calculation from the chemical ideal diameter[1] (D_I) of a steel is based on the original work of M. A. Grossman, Reference 18, and provides increased accuracy by refinement of the carbon multiplying factors and the correlation of a boron factor (B.F.) with carbon and alloy content. These refinements were based on analysis of thousands of heats of boron and non-boron 1500, 4100, 5000, and 8600 series steels encompassing a range of compositions as shown in Table A1 and a range of D_I as contained in Tables A9 to A12. The accuracy of this method and the techniques used to develop it have been documented, Reference 26. For comparison of this method to others, or for steel compositions outside the above-mentioned grades, the user should refer to other articles listed in Section 2.1, 17 to 29.

The succeeding paragraphs outline this method for calculating hardenability from chemical composition. The calculation method and data tables are also embodied in a computer program, EA406 "Hardenability Prediction Calculator" available through SAE. The program runs on an IBM compatible PC with a 3-1/2 in disc drive. It provides both tabular and graphical output of end-quench hardenability data calculated from chemical composition. To obtain a copy of the program, contact the SAE Customer Service Department, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

TABLE A1—COMPOSITION RANGE USED TO DEVELOP THE HARDENABILITY CALCULATION METHOD DESCRIBED IN THIS APPENDIX

Element[(1)]	Range (%)[(1)]
Carbon	0.10–0.70
Manganese	0.50–1.65
Silicon	0.15–0.60
Chromium	1.35 max
Nickel	1.50 max
Molybdenum	0.55 max

1. For element percentages outside the ranges shown, and for elements not shown (copper and vanadium), the original Grossman factors are shown in Table A2.

A.2 D_I Calculation for Non-Boron Steels—This calculation relies on a series of hardenability factors (Table A2) for each alloying element in the composition which multiplied together give a D_I value. (For simplicity, only multiplying factors for D_I in inch units are given. For D_I in mm, the D_I in inches should be converted.) The effects of phosphorus and sulfur are not considered since they tend to cancel one another. A No. 7 austenitic grain size is assumed since most steels with hardenability control are melted to a fine grain practice where experience has demonstrated that an extremely high percentage of heats conform to this grain size. For austenitic grain sizes other than No. 7, Grossman's data suggest that the calculated D_I be increased about 8% for each grain size number less than 7 and decreased by about 8% for each grain size number greater than 7. Specific suggestions are:

a. For grain size 6 multiply D_I by 1.083
b. For grain size 5 multiply D_I by 1.172
c. For grain size 4 multiply D_I by 1.270

An example of D_I calculation is given in Table A3 for an SAE 4118 modified steel.

1. D_I (or DI in some computer programs) represents the diameter of a round steel bar that will harden at the center to 50% martensite when subjected to an ideal quench (i.e., a Grossman quench severity H = infinity).

A.3 D_I Calculation for Boron Steels—With an effective steelmaking process, the boron factor (signifying the contribution of boron to increased hardenability) is an inverse function of the carbon and alloy content. The higher the carbon and/or alloy content the lower the boron factor.

A.3.1 Actual Boron Factor—The actual boron factor is expressed by the following relationship:

$$\text{B.F.} = \frac{\text{Measured } D_1 \text{ from Jominy Data and Carbon Content}}{\text{Calculated } D_1 \text{ from Composition Excluding Boron}} \quad \text{(Eq. A1)}$$

Data for an actual boron factor determination are given in Table A4 for an SAE 15B30 modified steel.

A.3.1.1 STEP 1—Using Table A5, determine the nearest location on the end-quench curve where a hardness corresponding to 50% martensite occurs for the actual carbon content. For the example heat with 0.29% carbon this hardness is 37 HRC occurring at a "J" distance of 13 mm or 8/16 in from the quenched end.

A.3.1.2 STEP 2—From Table A6 (mm) or Table A7 (in), a "J" distance of 13 mm or 8/16 in equates to a measured D_I of 76.4 mm or 2.97 in (interpolation may be required).

A.3.1.3 STEP 3

$$\text{Boron Factor} = \frac{76.4\text{mm}}{31.5\text{mm}} = 2.43 \quad \text{(Eq. A2)}$$

or

$$\text{Boron Factor} = \frac{2.97\text{in}}{1.24\text{in}} = 2.4$$

NOTE—Difference in B.F. using inch versus mm is due to the use of nearest standard "J" distance. Use of exact "J" distances would resolve this difference.

A.3.2 Calculation of D_I with Boron (D_{IB})

A.3.2.1 STEP 1—Calculate the D_I without boron. For the previous example, this D_I is 31.5 mm (1.24 in).

A.3.2.2 STEP 2—Calculate the alloy factor (the product of all the multiplying factors from Table A2 excluding carbon). For the previous example:

$$\text{Alloy Factor} = \frac{\text{Calculated } D_1 \text{ (without Boron)}}{\text{Carbon Multiplying Factor}} = \frac{1.24\text{in}}{0.157\text{in}} = 8.0 \quad \text{(Eq. A3)}$$

or

$$\text{Alloy Factor} = \frac{31.5\text{mm}}{0.157\text{in} \times 25.4\text{mm/in}} = 8.0 \quad \text{(Eq. A4)}$$

NOTE—For simplicity, alloy factors should be rounded to the nearest whole number.

A.3.2.3 STEP 3—Determine the boron multiplying factor from Table A8. For this example with 0.29% carbon and an alloy factor of 8.0, the boron multiplying factor is 2.36 (interpolation required).

A.3.2.4 STEP 4—Calculate the D_I with boron as in the following equation:

$$D_{I_B} = D_I \text{ (without Boron)} \times \text{Boron Factor} \quad \text{(Eq. A5)}$$
$$D_{I_B} = 1.24\text{in} \times 2.36 \text{ or } 31.5 \text{ mm} \times 2.36$$
$$D_{I_B} = 2.93\text{in or } 74.3 \text{ mm}$$

A.4 ***Hardenability Curves from Composition***—With a predetermined D_I (D_{IB} for boron steels), the end-quench hardenability curve can be computed by the following procedure:

A.4.1 Step 1—The initial hardness (IH) at the J = 1.5 mm or 1/16 in position is a function of carbon content and independent of hardenability, and is selected from Table A5. For the example, non-boron SAE 4118 modified heat containing 0.22% C the initial hardness is 45 HRC.

A.4.2 Step 2—The hardness at other positions along the end-quench specimen (termed distance hardness) is determined by dividing the initial hardness by the appropriate factor from Table A9 (mm) or A10 (inch) for non-boron steels or from Table A11 (mm) or A12 (inch) for boron steels.

For the example shown in Tables A13 and A14, a non-boron heat of steel with an IH = 45 HRC and a calculated D_I of 45.5 mm (1.79 in), the hardness at the respective end-quench positions can be calculated by dividing 45 by the appropriate dividing factor listed in Table A9 (mm) or A10 (inch) for non-boron steels. (For simplicity, the D_I should be rounded to the nearest 0.5 mm or 0.1 in.)

A.5 ***Equations for Tables A2-A12***—Tables A15 to A22 represent a least squares polynomial fit of data contained in Tables A2 to A12. The use of these equations to plot curves may result in random inflection points due to the characteristics of the polynomial equations. These inflections will be minor, however, and should be disregarded.

TABLE A2—HARDENABILITY MULTIPLYING FACTORS VS. % ELEMENT (NON-BORON STEELS), INCH

% Element	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V
0.01	0.005	1.033	1.007	1.004	1.022	1.03	1.00	1.02
0.02	0.011	1.067	1.014	1.007	1.043	1.06	1.01	1.03
0.03	0.016	1.100	1.021	1.011	1.065	1.09	1.01	1.05
0.04	0.021	1.133	1.028	1.015	1.086	1.12	1.02	1.07
0.05	0.026	1.167	1.035	1.018	1.108	1.15	1.02	1.09
0.06	0.032	1.200	1.042	1.022	1.130	1.18	1.02	1.11
0.07	0.038	1.233	1.049	1.026	1.151	1.21	1.03	1.12
0.08	0.043	1.267	1.056	1.029	1.173	1.24	1.03	1.14
0.09	0.049	1.300	1.063	1.033	1.194	1.27	1.03	1.16
0.10	0.054	1.333	1.070	1.036	1.216	1.30	1.04	1.17
0.11	0.059	1.367	1.077	1.040	1.238	1.33	1.04	1.19
0.12	0.065	1.400	1.084	1.044	1.259	1.36	1.05	1.21
0.13	0.070	1.433	1.091	1.047	1.281	1.39	1.05	1.22
0.14	0.076	1.467	1.098	1.051	1.302	1.42	1.05	1.24
0.15	0.081	1.500	1.105	1.055	1.324	1.45	1.06	1.26
0.16	0.086	1.533	1.112	1.058	1.346	1.48	1.06	1.28
0.17	0.092	1.567	1.119	1.062	1.367	1.51	1.06	1.29
0.18	0.097	1.600	1.126	1.066	1.389	1.54	1.07	1.31
0.19	0.103	1.633	1.133	1.069	1.410	1.57	1.07	1.33
0.20	0.108	1.667	1.140	1.073	1.432	1.60	1.07	1.35
0.21	0.113	1.700	1.147	1.077	1.454	1.63	1.08	--
0.22	0.119	1.733	1.154	1.080	1.475	1.66	1.08	--
0.23	0.124	1.767	1.161	1.084	1.497	1.69	1.09	--

TABLE A2—HARDENABILITY MULTIPLYING FACTORS VS. % ELEMENT (NON-BORON STEELS), INCH (CONTINUED)

% Element	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V
0.24	0.130	1.800	1.168	1.088	1.518	1.72	1.09	—
0.25	0.135	1.833	1.175	1.091	1.540	1.75	1.09	—
0.26	0.140	1.867	1.182	1.095	1.562	1.78	1.10	—
0.27	0.146	1.900	1.189	1.098	1.583	1.81	1.10	—
0.28	0.151	1.933	1.196	1.102	1.605	1.84	1.10	—
0.29	0.157	1.967	1.203	1.106	1.626	1.87	1.11	—
0.30	0.162	2.000	1.210	1.109	1.648	1.90	1.11	—
0.31	0.167	2.033	1.217	1.113	1.670	1.93	1.11	—
0.32	0.173	2.067	1.224	1.117	1.691	1.96	1.12	—
0.33	0.178	2.100	1.231	1.120	1.713	1.99	1.12	—
0.34	0.184	2.133	1.238	1.124	1.734	2.02	1.12	—
0.35	0.189	2.167	1.245	1.128	1.756	2.05	1.13	—
0.36	0.194	2.200	1.252	1.131	1.776	2.08	1.13	—
0.37	0.200	2.233	1.259	1.135	1.799	2.11	1.14	—
0.38	0.205	2.267	1.266	1.139	1.821	2.14	1.14	—
0.39	0.211	2.300	1.273	1.142	1.842	2.17	1.14	—
0.40	0.213	2.333	1.280	1.146	1.864	2.20	1.15	—
0.41	0.216	2.367	1.287	1.150	1.886	2.23	1.15	—
0.42	0.218	2.400	1.294	1.153	1.907	2.26	1.15	—
0.43	0.221	2.433	1.301	1.157	1.929	2.29	1.16	—
0.44	0.223	2.467	1.308	1.160	1.950	2.32	1.16	—
0.45	0.226	2.500	1.315	1.164	1.972	2.35	1.16	—
0.46	0.228	2.533	1.322	1.168	1.994	2.38	1.17	—
0.47	0.230	2.567	1.329	1.171	2.015	2.41	1.17	—
0.48	0.233	2.600	1.336	1.175	2.037	2.44	1.18	—
0.49	0.235	2.633	1.343	1.179	2.058	2.47	1.18	—
0.50	0.238	2.667	1.350	1.182	2.080	2.50	1.18	—
0.51	0.242	2.700	1.357	1.186	2.102	2.53	1.19	—
0.52	0.244	2.733	1.364	1.190	2.123	2.56	1.19	—
0.53	0.246	2.767	1.371	1.193	2.145	2.59	1.19	—
0.54	0.249	2.800	1.378	1.197	2.166	2.62	1.20	—
0.55	0.251	2.833	1.385	1.201	2.188	2.65	1.20	—
0.56	0.253	2.867	1.392	1.204	2.210	—	—	—
0.57	0.256	2.900	1.399	1.208	2.231	—	—	—
0.58	0.258	2.933	1.406	1.212	2.253	—	—	—
0.59	0.260	2.967	1.413	1.215	2.274	—	—	—
0.60	0.262	3.000	1.420	1.219	2.296	—	—	—
0.61	0.264	3.033	1.427	1.222	2.318	—	—	—
0.62	0.267	3.067	1.434	1.226	2.339	—	—	—
0.63	0.269	3.100	1.441	1.230	2.361	—	—	—
0.64	0.271	3.133	1.448	1.233	2.382	—	—	—

TABLE A2—HARDENABILITY MULTIPLYING FACTORS VS. % ELEMENT (NON-BORON STEELS), INCH (CONTINUED)

% Element	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V
0.65	0.273	3.167	1.465	1.237	2.404	—	—	—
0.66	0.275	3.200	1.462	1.241	2.426	—	—	—
0.67	0.277	3.233	1.469	1.244	2.447	—	—	—
0.68	0.279	3.267	1.476	1.248	2.469	—	—	—
0.69	0.281	3.300	1.483	1.252	2.490	—	—	—
0.70	0.283	3.333	1.490	1.255	2.512	—	—	—
0.71	0.285	3.367	1.497	1.259	2.534	—	—	—
0.72	0.287	3.400	1.504	1.262	2.555	—	—	—
0.73	0.289	3.433	1.511	1.266	2.577	—	—	—
0.74	0.291	3.467	1.518	1.270	2.596	—	—	—
0.75	0.293	3.500	1.525	1.273	2.620	—	—	—
0.76	0.295	3.533	1.532	1.276	2.642	—	—	—
0.77	0.297	3.567	1.539	1.280	2.663	—	—	—
0.78	0.299	3.600	1.546	1.284	2.685	—	—	—
0.79	0.301	3.633	1.553	1.287	2.706	—	—	—
0.80	0.303	3.667	1.560	1.291	2.728	—	—	—
0.81	0.305	3.700	1.567	1.294	2.750	—	—	—
0.82	0.307	3.733	1.574	1.298	2.771	—	—	—
0.83	0.309	3.767	1.581	1.301	2.793	—	—	—
0.84	0.310	3.800	1.588	1.306	2.814	—	—	—
0.85	0.312	3.833	1.595	1.309	2.836	—	—	—
0.86	0.314	3.867	1.602	1.313	2.858	—	—	—
0.87	0.316	3.900	1.609	1.317	2.879	—	—	—
0.88	0.318	3.933	1.616	1.320	2.900	—	—	—
0.89	0.319	3.967	1.623	1.324	2.922	—	—	—
0.90	0.321	4.000	1.630	1.327	2.944	—	—	—
0.91	—	4.033	1.637	1.331	2.966	—	—	—
0.92	—	4.067	1.644	1.334	2.987	—	—	—
0.93	—	4.100	1.651	1.338	3.009	—	—	—
0.94	—	4.133	1.658	1.343	3.030	—	—	—
0.95	—	4.167	1.665	1.345	3.052	—	—	—
0.96	—	4.200	1.672	1.349	3.074	—	—	—
0.97	—	4.233	1.679	1.352	3.095		—	—
0.98	—	4.267	1.686	1.356	3.117	—	—	—
0.99	—	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	1.382	3.268	—	—	—
1.06	—	4.533	1.742	1.386	3.290	—	—	—

TABLE A2—HARDENABILITY MULTIPLYING FACTORS VS. % ELEMENT (NON-BORON STEELS), INCH (CONTINUED)

% Element	Carbon- Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V
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	3.984	—	—	—
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	—	—	—

TABLE A2—HARDENABILITY MULTIPLYING FACTORS VS. % ELEMENT (NON-BORON STEELS), INCH (CONTINUED)

% Element	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V
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	—	—	—	—
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	—	8.264	2.288	1.708	—	—	—	—
1.85	—	8.315	2.295	1.715	—	—	—	—
1.86	—	8.366	2.302	1.722	—	—	—	—
1.87	—	8.417	2.309	1.729	—	—	—	—
1.88	—	8.468	2.316	1.736	—	—	—	—
1.89	—	8.519	2.323	1.743	—	—	—	—
1.90	—	8.570	2.330	1.750	—	—	—	—

TABLE A2—HARDENABILITY MULTIPLYING FACTORS VS. % ELEMENT (NON-BORON STEELS), INCH (CONTINUED)

% Element	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V
1.91	—	8.671	2.337	1.753	—	—	—	—
1.92	—	8.672	2.344	1.756	—	—	—	—
1.93	—	8.723	2.351	1.759	—	—	—	—
1.94	—	8.774	2.358	1.761	—	—	—	—
1.95	—	8.825	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	—	—	—	—

TABLE A3—EXAMPLE OF D_I CALCULATION (FOR A MODIFIED SAE 4118 STEEL, GRAIN SIZE 7)

Element	%	Multiplying Factor (Table A2)
Carbon	0.22	0.119
Manganese	0.80	3.667
Silicon	0.18	1.126
Nickel	0.10	1.036
Chromium	0.43	1.929
Molybdenum	0.25	1.75
Copper	0.10	1.04
D_I = 0.119 x 3.667 x 1.126 x 1.036 x 1.929 x 1.75 x 1.79 in (45.5 mm)		

TABLE A4—DATA FOR AN ACTUAL BORON FACTOR DETERMINATION (FOR AN SAE 15B30 STEEL)

Composition, %	C	Mn	Si	Ni	Cr	Mo	B						
	0.29	1.25	0.20	0.13	0.07	0.03	0.0015						
Calc DI (Boron Excluded)	31.5 mm (1.24 in)												
End-Quench Test Results, mm													
"J" Position (mm)	1.5	3	5	7	9	11	13	15	20	25			
Hardness, HRC	50	50	49	48	46	41	37	30	24	20			
End-Quench Test Results, inches													
"J" Position (1/16 in)	1	2	3	4	5	6	7	8	9	10	12	14	16
Hardness, HRC	50	50	49	48	47	45	41	38	33	28	25	22	20

TABLE A5—INITIAL HARDNESS AND 50% MARTENSITE HARDNESS VS. % CARBON

% Carbon Content	Initial Hardness—HRC 100% Martensite	Hardness—HRC 50% Martensite	% Carbon Content	Initial Hardness—HRC 100% Martensite	Hardness—HRC 50% Martensite	% Carbon Content	Initial Hardness—HRC 100% Martensite	Hardness—HRC 50% Martensite
0.10	38	26	0.30	50	37	0.50	61	47
0.11	39	27	0.31	51	38	0.51	61	47
0.12	40	27	0.32	51	38	0.52	62	48
0.13	40	28	0.33	52	39	0.53	62	48
0.14	41	28	0.34	53	40	0.54	63	48
0.15	41	29	0.35	53	40	0.55	63	49
0.16	42	30	0.36	54	41	0.56	63	49
0.17	42	30	0.37	55	41	0.57	64	50
0.18	43	31	0.38	55	42	0.58	64	50
0.19	44	31	0.39	56	42	0.59	64	51
0.20	44	32	0.40	56	43	0.60	64	51
0.21	45	32	0.41	57	43	0.61	64	51
0.22	45	33	0.42	57	43	0.62	65	51
0.23	46	34	0.43	58	44	0.63	65	52
0.24	46	34	0.44	58	44	0.64	65	52
0.25	47	35	0.45	59	45	0.65	65	52
0.26	48	35	0.46	59	45	0.66	65	52
0.27	49	36	0.47	59	45	0.67	65	53
0.28	49	36	0.48	59	46	0.68	65	53
0.29	50	37	0.49	60	46	0.69	65	53

TABLE A6—D_I VS. JOMINY DISTANCE FOR 50% MARTENSITE (mm)

"J" mm	D_I mm	"J" mm	D_I mm	"J" mm	D_I mm
1.0	7.9	18.0	94.5	35.0	137.3
2.0	15.8	19.0	97.7	36.0	139.3
3.0	23.2	20.0	100.8	37.0	141.2
4.0	30.2	21.0	103.7	38.0	143.0
5.0	36.6	22.0	106.6	39.0	144.8
6.0	42.7	23.0	109.3	40.0	146.6
7.0	48.4	24.0	112.0	41.0	148.3
8.0	53.8	25.0	114.7	42.0	149.9
9.0	58.9	26.0	117.2	43.0	151.5
10.0	63.7	27.0	119.7	44.0	153.1
11.0	68.2	28.0	122.1	45.0	154.6
12.0	72.5	29.0	124.5	46.0	156.1
13.0	76.6	30.0	126.7	47.0	157.6
14.0	80.5	31.0	129.0	48.0	159.0
15.0	84.3	32.0	131.2	49.0	160.5
16.0	87.8	33.0	133.3	50.0	161.9
17.0	91.2	34.0	135.3	—	—

TABLE A7—D_I VS. JOMINY DISTANCE FOR 50% MARTENSITE (inch)

"J" 1/16 in	D_I in	"J" 1/16 in	D_I in	"J" 1/16 in	D_I in
0.5	0.27	11.5	3.74	22.5	5.46
1.0	0.50	12.0	3.83	23.0	5.51
1.5	0.73	12.5	3.94	23.5	5.57
2.0	0.95	13.0	4.04	24.0	5.63
2.5	1.16	13.5	4.13	24.5	5.69
3.0	1.37	14.0	4.22	25.0	5.74
3.5	1.57	14.5	4.32	25.5	5.80
4.0	1.75	15.0	4.40	26.0	5.86
4.5	1.93	15.5	4.48	26.5	5.91
5.0	2.12	16.0	4.57	27.0	5.96
5.5	2.29	16.5	4.64	27.5	6.02
6.0	2.45	17.0	4.72	28.0	6.06
6.5	2.58	17.5	4.80	28.5	6.12
7.0	2.72	18.0	4.87	29.0	6.16
7.5	2.86	18.5	4.94	29.5	6.20
8.0	2.97	19.0	5.02	30.0	6.25
8.5	3.07	19.5	5.08	30.5	6.29
9.0	3.20	20.0	5.15	31.0	6.33
9.5	3.32	20.5	5.22	31.5	6.37
10.0	3.43	21.0	5.28	32.0	6.42
10.5	3.54	21.5	5.33	—	—
11.0	3.64	22.0	5.39	—	—

TABLE A8—BORON FACTORS VS. % CARBON AT SPECIFIC ALLOY FACTOR LEVELS

% Carbon	Alloy Factor(1) 5	Alloy Factor(1) 7	Alloy Factor(1) 9	Alloy Factor(1) 11	Alloy Factor(1) 13	Alloy Factor(1) 15	Alloy Factor(1) 18	Alloy Factor(1) 22	Alloy Factor(1) 26
0.10	6.18	5.38	5.09	4.61	4.28	4.14	3.72	3.68	3.55
0.11	5.76	5.07	4.77	4.35	4.05	3.88	3.54	3.48	3.35
0.12	5.38	4.78	4.48	4.10	3.84	3.65	3.37	3.30	3.18
0.13	5.04	4.52	4.22	3.88	3.64	3.44	3.21	3.14	3.03
0.14	4.72	4.28	3.98	3.68	3.47	3.26	3.07	2.99	2.88
0.15	4.44	4.06	3.77	3.50	3.31	3.09	2.94	2.86	2.76
0.16	4.19	3.86	3.57	3.34	3.16	2.94	2.82	2.74	2.64
0.17	3.96	3.68	3.40	3.19	3.03	2.81	2.71	2.63	2.54
0.18	3.75	3.51	3.24	3.05	2.91	2.70	2.61	2.53	2.44
0.19	3.57	3.36	3.10	2.93	2.80	2.59	2.52	2.44	2.36
0.20	3.40	3.22	2.98	2.82	2.70	2.50	2.43	2.35	2.28
0.21	3.25	3.09	2.86	2.72	2.60	2.42	2.35	2.28	2.20
0.22	3.12	2.98	2.76	2.63	2.52	2.34	2.28	2.20	2.13
0.23	3.00	2.88	2.61	2.55	2.44	2.27	2.21	2.14	2.07
0.24	2.90	2.78	2.59	2.47	2.37	2.21	2.15	2.07	2.01
0.25	2.81	2.70	2.52	2.40	2.30	2.15	2.09	2.01	1.95
0.26	2.73	2.62	2.45	2.34	2.24	2.10	2.03	1.96	1.89
0.27	2.66	2.55	2.39	2.28	2.18	2.05	1.98	1.91	1.84
0.28	2.60	2.49	2.34	2.23	2.13	2.00	1.93	1.86	1.79
0.29	2.54	2.43	2.29	2.18	2.08	1.96	1.88	1.81	1.74
0.30	2.49	2.38	2.24	2.14	2.04	1.92	1.83	1.76	1.70
0.31	2.44	2.33	2.20	2.10	1.99	1.88	1.79	1.72	1.65
0.32	2.40	2.28	2.16	2.06	1.95	1.84	1.74	1.68	1.61
0.33	2.36	2.24	2.12	2.02	1.91	1.80	1.70	1.64	1.57
0.34	2.32	2.20	2.09	1.98	1.87	1.76	1.66	1.60	1.53
0.35	2.29	2.17	2.05	1.95	1.84	1.72	1.63	1.56	1.49
0.36	2.26	2.13	2.02	1.92	1.80	1.69	1.59	1.52	1.45
0.37	2.23	2.10	1.99	1.89	1.77	1.65	1.55	1.49	1.42
0.38	2.20	2.07	1.96	1.85	1.74	1.62	1.52	1.46	1.38
0.39	2.18	2.04	1.93	1.82	1.70	1.58	1.49	1.42	1.35
0.40	2.15	2.01	1.90	1.79	1.67	1.55	1.46	1.39	1.32
0.41	2.12	1.98	1.87	1.76	1.64	1.52	1.43	1.36	1.29
0.42	2.09	1.96	1.84	1.73	1.62	1.49	1.40	1.34	1.26
0.43	2.06	1.93	1.82	1.70	1.58	1.46	1.37	1.31	1.23
0.44	2.04	1.90	1.78	1.68	1.56	1.43	1.35	1.28	1.21
0.45	2.01	1.87	1.75	1.65	1.53	1.40	1.32	1.25	1.19
0.46	1.98	1.85	1.72	1.62	1.51	1.38	1.30	1.23	1.17
0.47	1.94	1.82	1.69	1.59	1.48	1.36	1.28	1.21	1.15
0.48	1.91	1.80	1.67	1.57	1.46	1.34	1.26	1.19	1.13
0.49	1.89	1.77	1.64	1.54	1.43	1.32	1.24	1.17	1.10

TABLE A8—BORON FACTORS VS. % CARBON AT SPECIFIC ALLOY FACTOR LEVELS

% Carbon	Alloy Factor[1] 5	Alloy Factor[1] 7	Alloy Factor[1] 9	Alloy Factor[1] 11	Alloy Factor[1] 13	Alloy Factor[1] 15	Alloy Factor[1] 18	Alloy Factor[1] 22	Alloy Factor[1] 26
0.50	1.87	1.75	1.61	1.51	1.41	1.30	1.22	1.15	1.08
0.51	1.83	1.72	1.58	1.48	1.39	1.27	1.20	1.12	1.06
0.52	1.80	1.70	1.56	1.46	1.37	1.26	1.18	1.10	1.04
0.53	1.77	1.67	1.53	1.44	1.34	1.24	1.16	1.07	1.02
0.54	1.74	1.65	1.51	1.42	1.32	1.23	1.14	1.05	1.00
0.55	1.71	1.62	1.48	1.39	1.30	1.21	1.12	1.02	1.00
0.56	1.68	1.60	1.46	1.37	1.28	1.20	1.10	1.00	1.00
0.57	1.65	1.57	1.44	1.35	1.26	1.18	1.07	1.00	1.00
0.58	1.62	1.55	1.42	1.33	1.24	1.17	1.05	1.00	1.00
0.59	1.60	1.52	1.40	1.31	1.22	1.14	1.02	1.00	1.00
0.60	1.57	1.50	1.38	1.29	1.20	1.12	1.00	1.00	1.00
0.61	1.54	1.48	1.36	1.27	1.18	1.09	1.00	1.00	1.00
0.62	1.51	1.46	1.34	1.25	1.16	1.06	1.00	1.00	1.00
0.63	1.49	1.43	1.32	1.23	1.13	1.03	1.00	1.00	1.00
0.64	1.47	1.41	1.30	1.21	1.11	1.00	1.00	1.00	1.00
0.65	1.45	1.39	1.29	1.19	1.08	1.00	1.00	1.00	1.00
0.66	1.42	1.37	1.28	1.17	1.05	1.00	1.00	1.00	1.00
0.67	1.40	1.35	1.26	1.15	1.02	1.00	1.00	1.00	1.00
0.68	1.38	1.33	1.24	1.14	1.00	1.00	1.00	1.00	1.00
0.69	1.36	1.31	1.22	1.12	1.00	1.00	1.00	1.00	1.00
0.70	1.35	1.28	1.20	1.10	1.00	1.00	1.00	1.00	1.00
0.71	1.33	1.26	1.18	1.07	1.00	1.00	1.00	1.00	1.00
0.72	1.32	1.25	1.16	1.05	1.00	1.00	1.00	1.00	1.00
0.73	1.30	1.22	1.14	1.02	1.00	1.00	1.00	1.00	1.00
0.74	1.29	1.20	1.12	1.00	1.00	1.00	1.00	1.00	1.00
0.75	1.27	1.17	1.08	1.00	1.00	1.00	1.00	1.00	1.00
0.76	1.26	1.15	1.05	1.00	1.00	1.00	1.00	1.00	1.00
0.77	1.24	1.12	1.02	1.00	1.00	1.00	1.00	1.00	1.00
0.78	1.22	1.10	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.79	1.20	1.07	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.80	1.18	1.05	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.81	1.15	1.02	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.82	1.12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.83	1.08	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.84	1.04	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.85	1.02	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.86	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

1. Alloy factor is the product of all the multiplying factors (Table A2) excluding that for carbon.

TABLE A9—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_I (NON-BORON STEELS), mm

Ideal Critical Diameter (DI), mm	Jominy End-Quench Distance (mm) 3.0	Jominy End-Quench Distance (mm) 5.0	Jominy End-Quench Distance (mm) 7.0	Jominy End-Quench Distance (mm) 9.0	Jominy End-Quench Distance (mm) 11.0	Jominy End-Quench Distance (mm) 13.0	Jominy End-Quench Distance (mm) 15.0	Jominy End-Quench Distance (mm) 20.0	Jominy End-Quench Distance (mm) 25.0	Jominy End-Quench Distance (mm) 30.0	Jominy End-Quench Distance (mm) 35.0	Jominy End-Quench Distance (mm) 40.0	Jominy End-Quench Distance (mm) 45.0	Jominy End-Quench Distance (mm) 50.0
25.0	1.13	1.62	2.11	2.62	2.82	2.96	3.15	3.52						
27.5	1.11	1.54	1.99	2.50	2.70	2.84	3.01	3.37						
30.0	1.09	1.47	1.88	2.38	2.58	2.72	2.89	3.24	3.48					
32.5	1.07	1.40	1.78	2.27	2.48	2.61	2.77	3.11	3.34	3.58				
35.0	1.06	1.35	1.69	2.17	2.37	2.51	2.65	2.99	3.20	3.43				
37.5	1.05	1.30	1.61	2.07	2.28	2.41	2.54	2.87	3.08	3.28	3.52			
40.0	1.04	1.26	1.54	1.99	2.19	2.31	2.44	2.77	2.96	3.15	3.37	3.56		
42.5	1.03	1.22	1.48	1.90	2.10	2.22	2.35	2.67	2.86	3.03	3.23	3.41	3.55	
45.0	1.02	1.19	1.42	1.83	2.02	2.14	2.26	2.57	2.75	2.92	3.10	3.27	3.41	3.54
47.5	1.02	1.16	1.37	1.76	1.95	2.06	2.17	2.48	2.66	2.81	2.98	3.14	3.28	3.46
50.0	1.01	1.13	1.33	1.70	1.87	1.99	2.10	2.40	2.57	2.72	2.87	3.02	3.16	3.29
52.5	1.01	1.11	1.29	1.64	1.81	1.92	2.02	2.32	2.48	2.63	2.77	2.92	3.05	3.18
55.0	1.00	1.10	1.26	1.58	1.75	1.85	1.95	2.24	2.40	2.54	2.68	2.82	2.95	3.07
57.5	1.00	1.08	1.23	1.53	1.69	1.79	1.89	2.17	2.33	2.46	2.60	2.73	2.85	2.97
60.0	1.00	1.07	1.21	1.48	1.63	1.74	1.83	2.10	2.26	2.39	2.52	2.65	2.76	2.88
62.5	1.00	1.06	1.18	1.44	1.58	1.68	1.77	2.04	2.20	2.32	2.45	2.57	2.68	2.79
65.0	1.00	1.05	1.17	1.40	1.54	1.63	1.72	1.98	2.13	2.26	2.38	2.50	2.60	2.70
67.5	1.00	1.04	1.15	1.36	1.49	1.59	1.67	1.92	2.07	2.20	2.32	2.43	2.53	2.62
70.0	1.00	1.04	1.13	1.33	1.45	1.54	1.63	1.87	2.02	2.14	2.26	2.37	2.46	2.55
72.5	1.00	1.03	1.12	1.30	1.41	1.50	1.58	1.82	1.97	2.09	2.21	2.31	2.40	2.48
75.0	1.00	1.03	1.11	1.27	1.38	1.46	1.54	1.77	1.92	2.04	2.15	2.25	2.34	2.41
77.5	1.00	1.03	1.10	1.25	1.34	1.43	1.51	1.73	1.87	1.99	2.10	2.20	2.28	2.35
80.0	1.00	1.02	1.09	1.22	1.31	1.40	1.47	1.68	1.83	1.95	2.06	2.15	2.22	2.29
82.5	1.00	1.02	1.08	1.20	1.29	1.37	1.44	1.64	1.79	1.90	2.01	2.10	2.17	2.23
85.0	1.00	1.02	1.07	1.18	1.26	1.34	1.41	1.60	1.75	1.86	1.97	2.05	2.12	2.17
87.5	1.00	1.02	1.07	1.16	1.24	1.31	1.38	1.57	1.71	1.82	1.92	2.01	2.07	2.12
90.0	1.00	1.02	1.06	1.14	1.22	1.29	1.35	1.53	1.67	1.78	1.88	1.97	2.03	2.07
92.5	1.00	1.01	1.05	1.13	1.20	1.27	1.33	1.50	1.64	1.75	1.84	1.92	1.98	2.02
95.0	1.00	1.01	1.05	1.11	1.18	1.24	1.31	1.47	1.60	1.71	1.81	1.88	1.94	1.98
97.5	1.00	1.01	1.04	1.10	1.16	1.22	1.28	1.44	1.57	1.67	1.77	1.84	1.90	1.93
100.0	1.00	1.01	1.04	1.09	1.15	1.21	1.26	1.41	1.54	1.64	1.73	1.80	1.86	1.89
102.5	1.00	1.01	1.03	1.08	1.13	1.19	1.24	1.39	1.51	1.61	1.69	1.76	1.82	1.85
105.0	1.00	1.01	1.03	1.07	1.12	1.17	1.23	1.36	1.48	1.58	1.66	1.73	1.78	1.81
107.5	1.00	1.00	1.02	1.06	1.11	1.16	1.21	1.34	1.46	1.55	1.63	1.69	1.74	1.77
110.0	1.00	1.00	1.02	1.05	1.09	1.15	1.19	1.32	1.43	1.51	1.59	1.65	1.71	1.73
125.0	1.00	1.00	1.00	1.02	1.04	1.08	1.11	1.20	1.29	1.35	1.41	1.46	1.52	1.54
127.5	1.00	1.00	1.00	1.01	1.04	1.07	1.10	1.19	1.27	1.33	1.39	1.44	1.49	1.52
130.0	1.00	1.00	1.00	1.01	1.03	1.06	1.09	1.18	1.25	1.31	1.36	1.41	1.46	1.49
132.5	1.00	1.00	1.00	1.01	1.02	1.05	1.08	1.16	1.24	1.28	1.34	1.38	1.44	1.47
135.0	1.00	1.00	1.00	1.01	1.02	1.04	1.07	1.15	1.22	1.26	1.32	1.36	1.42	1.44
137.5	1.00	1.00	1.00	1.00	1.01	1.04	1.06	1.14	1.20	1.24	1.30	1.34	1.39	1.42
140.0	1.00	1.00	1.00	1.00	1.01	1.03	1.05	1.13	1.19	1.22	1.28	1.32	1.37	1.40
142.5	1.00	1.00	1.00	1.00	1.00	1.02	1.04	1.12	1.17	1.21	1.26	1.30	1.35	1.38
145.0	1.00	1.00	1.00	1.00	1.00	1.02	1.03	1.11	1.16	1.19	1.24	1.28	1.33	1.36
147.5	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.10	1.14	1.17	1.23	1.26	1.32	1.34
150.0	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.09	1.13	1.16	1.21	1.25	1.30	1.32
152.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.08	1.12	1.15	1.20	1.23	1.29	1.31
155.0	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.07	1.10	1.13	1.19	1.22	1.27	1.29
157.5	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.06	1.09	1.12	1.18	1.21	1.26	1.28
160.0	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.05	1.08	1.11	1.17	1.20	1.24	1.27
162.5	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.05	1.07	1.10	1.16	1.19	1.23	1.26
165.0	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.04	1.06	1.09	1.15	1.17	1.22	1.25
167.5	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.03	1.05	1.08	1.14	1.16	1.21	1.24
170.0	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.02	1.04	1.07	1.13	1.15	1.20	1.23
172.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.06	1.12	1.14	1.18	1.22
175.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.05	1.11	1.12	1.17	1.21
177.5	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.01	1.04	1.10	1.10	1.15	1.20

TABLE A10A—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_I (NON-BORON STEELS), inch

Ideal Critical Diameter (D_I), inch	Jominy End-Quench Distance (1/16 in) 2	Jominy End-Quench Distance (1/16 in) 3	Jominy End-Quench Distance (1/16 in) 4	Jominy End-Quench Distance (1/16 in) 5	Jominy End-Quench Distance (1/16 in) 6	Jominy End-Quench Distance (1/16 in) 7	Jominy End-Quench Distance (1/16 in) 8	Jominy End-Quench Distance (1/16 in) 9
1.0	1.15	1.50	2.15	2.46	2.72	2.81	2.92	3.07
1.1	1.12	1.42	1.98	2.32	2.60	2.70	2.80	2.94
1.2	1.10	1.35	1.85	2.20	2.48	2.59	2.69	2.81
1.3	1.08	1.29	1.74	2.09	2.38	2.48	2.58	2.69
1.4	1.07	1.24	1.64	1.99	2.27	2.38	2.47	2.58
1.5	1.05	1.19	1.56	1.90	2.18	2.28	2.37	2.47
1.6	1.04	1.16	1.49	1.81	2.09	2.19	2.28	2.38
1.7	1.03	1.13	1.43	1.73	2.00	2.10	2.19	2.28
1.8	1.02	1.10	1.37	1.66	1.92	2.02	2.11	2.19
1.9	1.02	1.09	1.33	1.60	1.85	1.94	2.03	2.11
2.0	1.01	1.08	1.29	1.54	1.78	1.87	1.95	2.03
2.1	1.01	1.07	1.26	1.48	1.71	1.80	1.89	1.96
2.2	1.00	1.07	1.23	1.43	1.66	1.73	1.82	1.90
2.3	1.00	1.06	1.21	1.39	1.60	1.68	1.76	1.83
2.4	1.00	1.06	1.18	1.35	1.55	1.62	1.70	1.77
2.5	1.00	1.05	1.16	1.32	1.50	1.57	1.65	1.72
2.6	1.00	1.05	1.15	1.29	1.45	1.52	1.60	1.67
2.7	1.00	1.04	1.13	1.26	1.41	1.48	1.56	1.62
2.8	1.00	1.04	1.12	1.23	1.37	1.44	1.51	1.58
2.9	1.00	1.03	1.11	1.21	1.34	1.40	1.48	1.54
3.0	1.00	1.02	1.10	1.19	1.31	1.37	1.44	1.50
3.1	1.00	1.01	1.09	1.17	1.28	1.34	1.41	1.47
3.2	1.00	1.00	1.08	1.15	1.25	1.31	1.38	1.43
3.3	1.00	1.00	1.07	1.13	1.23	1.29	1.35	1.40
3.4	1.00	1.00	1.06	1.12	1.20	1.26	1.33	1.37
3.5	1.00	1.00	1.05	1.10	1.18	1.24	1.30	1.35
3.6	1.00	1.00	1.04	1.09	1.17	1.22	1.28	1.32
3.7	1.00	1.00	1.04	1.08	1.15	1.20	1.25	1.30
3.8	1.00	1.00	1.03	1.07	1.14	1.18	1.24	1.28
3.9	1.00	1.00	1.03	1.06	1.12	1.17	1.22	1.26
4.0	1.00	1.00	1.02	1.05	1.11	1.15	1.20	1.24
4.1	1.00	1.00	1.01	1.04	1.10	1.14	1.18	1.22
4.2	1.00	1.00	1.00	1.03	1.09	1.13	1.17	1.20
4.3	1.00	1.00	1.00	1.02	1.08	1.12	1.15	1.18
4.4	1.00	1.00	1.00	1.01	1.07	1.10	1.14	1.16
4.5	1.00	1.00	1.00	1.00	1.06	1.09	1.13	1.15
4.6	1.00	1.00	1.00	1.00	1.05	1.08	1.11	1.13
4.7	1.00	1.00	1.00	1.00	1.04	1.07	1.10	1.12

TABLE A10A—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_I (NON-BORON STEELS), inch (CONTINUED)

Ideal Critical Diameter (D_I), inch	Jominy End-Quench Distance (1/16 in) 2	Jominy End-Quench Distance (1/16 in) 3	Jominy End-Quench Distance (1/16 in) 4	Jominy End-Quench Distance (1/16 in) 5	Jominy End-Quench Distance (1/16 in) 6	Jominy End-Quench Distance (1/16 in) 7	Jominy End-Quench Distance (1/16 in) 8	Jominy End-Quench Distance (1/16 in) 9
4.8	1.00	1.00	1.00	1.00	1.03	1.06	1.09	1.11
4.9	1.00	1.00	1.00	1.00	1.02	1.05	1.08	1.10
5.0	1.00	1.00	1.00	1.00	1.01	1.04	1.07	1.09
5.1	1.00	1.00	1.00	1.00	1.00	1.03	1.06	1.08
5.2	1.00	1.00	1.00	1.00	1.00	1.02	1.05	1.07
5.3	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.06
5.4	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.05
5.5	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.04
5.6	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03
5.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02
5.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
5.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE A10B—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_1 (NON-BORON STEELS), inch

Ideal Critical Diameter (D1), inch	Jominy End-Quench Distance (1/16 in) 10	Jominy End-Quench Distance (1/16 in) 12	Jominy End-Quench Distance (1/16 in) 14	Jominy End-Quench Distance (1/16 in) 16	Jominy End-Quench Distance (1/16 in) 18	Jominy End-Quench Distance (1/16 in) 20	Jominy End-Quench Distance (1/16 in) 24	Jominy End-Quench Distance (1/16 in) 28	Jominy End-Quench Distance (1/16 in) 32
1.0	3.22	3.50	—	—	—	—	—	—	—
1.1	3.07	3.34	—	—	—	—	—	—	—
1.2	2.94	3.20	3.32	3.44	—	—	—	—	—
1.3	2.81	3.07	3.19	3.30	3.53	—	—	—	—
1.4	2.69	2.95	3.06	3.17	3.37	3.50	3.78	—	—
1.5	2.58	2.83	2.94	3.05	3.22	3.35	3.61	—	—
1.6	2.47	2.73	2.83	2.94	3.09	3.20	3.45	3.67	3.77
1.7	2.38	2.62	2.73	2.83	2.96	3.08	3.30	3.51	3.63
1.8	2.29	2.53	2.63	2.73	2.85	2.96	3.17	3.37	3.49
1.9	2.20	2.44	2.54	2.64	2.74	2.85	3.05	3.24	2.36
2.0	2.12	2.35	2.45	2.55	2.65	2.74	2.94	3.12	3.24
2.1	2.05	2.27	2.37	2.47	2.56	2.65	2.83	3.00	3.13
2.2	1.98	2.20	2.30	2.39	2.47	2.56	2.74	2.90	3.03
2.3	1.91	2.13	2.22	2.32	2.40	2.48	2.65	2.81	2.93
2.4	1.85	2.06	2.16	2.25	2.32	2.41	2.57	2.72	2.84
2.5	1.80	2.00	2.09	2.19	2.26	2.34	2.50	2.64	2.76
2.6	1.74	1.94	2.03	2.13	2.19	2.27	2.43	2.56	2.68
2.7	1.69	1.88	1.97	2.07	2.14	2.21	2.37	2.50	2.61
2.8	1.65	1.83	1.92	2.02	2.08	2.16	2.31	2.43	2.54
2.9	1.60	1.78	1.87	1.97	2.03	2.10	2.25	2.37	2.48
3.0	1.57	1.73	1.82	1.92	1.98	2.05	2.20	2.31	2.41
3.1	1.53	1.68	1.77	1.87	1.94	2.00	2.14	2.26	2.36
3.2	1.49	1.64	1.73	1.83	1.89	1.96	2.10	2.21	2.30
3.3	1.46	1.60	1.69	1.79	1.85	1.92	2.05	2.16	2.25
3.4	1.43	1.56	1.65	1.75	1.81	1.87	2.00	2.11	2.20
3.5	1.40	1.53	1.61	1.71	1.77	1.83	1.96	2.07	2.15
3.6	1.37	1.49	1.58	1.68	1.73	1.80	1.92	2.02	2.10
3.7	1.35	1.46	1.54	1.64	1.70	1.76	1.87	1.98	2.06
3.8	1.32	1.43	1.51	1.61	1.66	1.72	1.83	1.94	2.01
3.9	1.30	1.40	1.48	1.58	1.63	1.69	1.79	1.90	1.97
4.0	1.28	1.38	1.45	1.55	1.60	1.65	1.76	1.86	1.93
4.1	1.26	1.35	1.42	1.52	1.57	1.62	1.72	1.82	1.89
4.2	1.24	1.32	1.39	1.49	1.54	1.58	1.68	1.78	1.86
4.3	1.22	1.30	1.37	1.46	1.51	1.55	1.65	1.75	1.82
4.4	1.21	1.28	1.35	1.43	1.48	1.52	1.61	1.71	1.78
4.5	1.19	1.26	1.32	1.41	1.45	1.49	1.58	1.67	1.75
4.6	1.18	1.24	1.30	1.39	1.42	1.46	1.54	1.64	1.71
4.7	1.16	1.22	1.28	1.36	1.40	1.43	1.50	1.60	1.68

TABLE A10B—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_1 (NON-BORON STEELS), inch (CONTINUED)

Ideal Critical Diameter (D1), inch	Jominy End-Quench Distance (1/16 in) 10	Jominy End-Quench Distance (1/16 in) 12	Jominy End-Quench Distance (1/16 in) 14	Jominy End-Quench Distance (1/16 in) 16	Jominy End-Quench Distance (1/16 in) 18	Jominy End-Quench Distance (1/16 in) 20	Jominy End-Quench Distance (1/16 in) 24	Jominy End-Quench Distance (1/16 in) 28	Jominy End-Quench Distance (1/16 in) 32
4.8	1.15	1.20	1.26	1.34	1.37	1.40	1.47	1.57	1.65
4.9	1.13	1.19	1.24	1.32	1.35	1.37	1.44	1.54	1.62
5.0	1.12	1.18	1.23	1.30	1.32	1.35	1.41	1.51	1.59
5.1	1.11	1.17	1.21	1.28	1.30	1.32	1.38	1.48	1.56
5.2	1.10	1.16	1.20	1.26	1.28	1.30	1.36	1.45	1.53
5.3	1.09	1.15	1.18	1.24	1.26	1.28	1.33	1.42	1.50
5.4	1.08	1.14	1.17	1.22	1.24	1.25	1.31	1.39	1.48
5.5	1.07	1.13	1.16	1.21	1.22	1.23	1.30	1.37	1.45
5.6	1.06	1.12	1.15	1.19	1.20	1.21	1.28	1.34	1.43
5.7	1.05	1.10	1.14	1.18	1.18	1.20	1.26	1.32	1.41
5.8	1.04	1.09	1.13	1.16	1.17	1.18	1.25	1.30	1.38
5.9	1.03	1.08	1.12	1.15	1.16	1.16	1.24	1.28	1.36
6.0	1.02	1.07	1.11	1.13	1.14	1.15	1.22	1.26	1.34
6.1	1.01	1.06	1.10	1.12	1.13	1.14	1.21	1.24	1.32
6.2	1.00	1.05	1.09	1.11	1.12	1.13	1.20	1.23	1.30
6.3	1.00	1.04	1.08	1.10	1.11	1.12	1.19	1.21	1.28
6.4	1.00	1.03	1.07	1.09	1.10	1.11	1.18	1.20	1.27
6.5	1.00	1.02	1.06	1.08	1.09	1.10	1.17	1.18	1.25
6.6	1.00	1.01	1.05	1.07	1.08	1.09	1.16	1.17	1.23
6.7	1.00	1.00	1.04	1.06	1.07	1.08	1.14	1.16	1.21
6.8	1.00	1.00	1.03	1.05	1.06	1.07	1.12	1.15	1.19
6.9	1.00	1.00	1.02	1.04	1.05	1.06	1.10	1.14	1.17
7.0	1.00	1.00	1.01	1.03	1.04	1.05	1.08	1.13	1.15

TABLE A11—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_I (BORON STEELS), mm

Ideal Critical Diameter (D_{IB}), mm	Jominy End-Quench Distance (mm) 3.0	Jominy End-Quench Distance (mm) 5.0	Jominy End-Quench Distance (mm) 7.0	Jominy End-Quench Distance (mm) 9.0	Jominy End-Quench Distance (mm) 11.0	Jominy End-Quench Distance (mm) 13.0	Jominy End-Quench Distance (mm) 15.0	Jominy End-Quench Distance (mm) 20.0	Jominy End-Quench Distance (mm) 25.0	Jominy End-Quench Distance (mm) 30.0	Jominy End-Quench Distance (mm) 35.0	Jominy End-Quench Distance (mm) 40.0	Jominy End-Quench Distance (mm) 45.0	Jominy End-Quench Distance (mm) 50.0
40.00	1.07	1.25	1.92	2.56										
42.5	1.06	1.21	1.73	2.34										
45.0	1.05	1.18	1.57	2.14	2.64									
47.5	1.04	1.14	1.45	1.97	2.44									
50.0	1.03	1.12	1.35	1.83	2.26	2.57								
52.5	1.03	1.09	1.28	1.70	2.10	2.40								
55.0	1.02	1.08	1.22	1.59	1.96	2.24	2.52							
57.5	1.02	1.06	1.17	1.49	1.83	2.10	2.37							
60.0	1.01	1.05	1.14	1.41	1.71	1.97	2.23							
62.5	1.01	1.04	1.11	1.35	1.61	1.86	2.10							
65.0	1.01	1.03	1.09	1.29	1.53	1.75	1.99	2.56						
67.5	1.00	1.02	1.08	1.24	1.45	1.66	1.88	2.43						
70.0	1.00	1.02	1.07	1.20	1.38	1.57	1.78	2.32						
72.5	1.00	1.01	1.06	1.17	1.32	1.50	1.70	2.21						
75.0	1.00	1.01	1.06	1.15	1.27	1.43	1.62	2.11	2.53					
77.5	1.00	1.01	1.05	1.12	1.23	1.37	1.55	2.01	2.42	2.71				
80.0	1.00	1.00	1.05	1.11	1.19	1.32	1.48	1.93	2.31	2.59	2.82			
82.5	1.00	1.00	1.04	1.09	1.16	1.27	1.43	1.85	2.21	2.47	2.70	2.89	3.06	3.26
85.0	1.00	1.00	1.04	1.08	1.13	1.23	1.38	1.77	2.11	2.37	2.59	2.77	2.92	3.11
87.5	1.00	1.00	1.03	1.08	1.11	1.20	1.33	1.71	2.03	2.27	2.48	2.66	2.80	2.98
90.0	1.00	1.00	1.03	1.07	1.09	1.17	1.29	1.65	1.95	2.18	2.38	2.55	2.69	2.86
92.5	1.00	1.00	1.02	1.06	1.08	1.15	1.26	1.59	1.87	2.09	2.29	2.45	2.59	2.75
95.0	1.00	1.00	1.02	1.06	1.07	1.13	1.23	1.54	1.81	2.01	2.20	2.37	2.50	2.65
97.5	1.00	1.00	1.01	1.06	1.06	1.11	1.20	1.49	1.74	1.94	2.12	2.28	2.42	2.56
100.0	1.00	1.00	1.00	1.05	1.05	1.09	1.18	1.45	1.69	1.87	2.05	2.21	2.34	2.48
102.5	1.00	1.00	1.00	1.05	1.04	1.08	1.16	1.41	1.63	1.81	1.98	2.13	2.27	2.41
105.0	1.00	1.00	1.00	1.05	1.04	1.07	1.14	1.37	1.58	1.75	1.92	2.07	2.21	2.34
107.5	1.00	1.00	1.00	1.04	1.03	1.06	1.13	1.34	1.54	1.70	1.86	2.01	2.15	2.27
110.0	1.00	1.00	1.00	1.04	1.03	1.06	1.12	1.31	1.50	1.65	1.80	1.95	2.09	2.21
112.5	1.00	1.00	1.00	1.03	1.03	1.05	1.11	1.28	1.46	1.61	1.75	1.89	2.03	2.16
115.0	1.00	1.00	1.00	1.03	1.03	1.05	1.10	1.25	1.43	1.56	1.70	1.84	1.98	2.10
117.5	1.00	1.00	1.00	1.03	1.02	1.05	1.09	1.23	1.39	1.53	1.66	1.80	1.93	2.05
120.0	1.00	1.00	1.00	1.02	1.02	1.04	1.08	1.21	1.36	1.49	1.62	1.75	1.88	2.01
122.5	1.00	1.00	1.00	1.02	1.02	1.04	1.07	1.19	1.34	1.46	1.58	1.71	1.84	1.96
125.0	1.00	1.00	1.00	1.02	1.02	1.04	1.07	1.17	1.31	1.43	1.55	1.67	1.79	1.92
127.5	1.00	1.00	1.00	1.01	1.02	1.04	1.06	1.15	1.29	1.40	1.52	1.64	1.75	1.87

TABLE A11—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_I (BORON STEELS), mm (CONTINUED)

Ideal Critical Diameter (D_{IB}), mm	Jominy End-Quench Distance (mm) 3.0	Jominy End-Quench Distance (mm) 5.0	Jominy End-Quench Distance (mm) 7.0	Jominy End-Quench Distance (mm) 9.0	Jominy End-Quench Distance (mm) 11.0	Jominy End-Quench Distance (mm) 13.0	Jominy End-Quench Distance (mm) 15.0	Jominy End-Quench Distance (mm) 20.0	Jominy End-Quench Distance (mm) 25.0	Jominy End-Quench Distance (mm) 30.0	Jominy End-Quench Distance (mm) 35.0	Jominy End-Quench Distance (mm) 40.0	Jominy End-Quench Distance (mm) 45.0	Jominy End-Quench Distance (mm) 50.0
130.0	1.00	1.00	1.00	1.01	1.02	1.03	1.06	1.14	1.27	1.38	1.49	1.60	1.71	1.83
132.5	1.00	1.00	1.00	1.00	1.01	1.03	1.05	1.13	1.25	1.36	1.46	1.57	1.68	1.79
135.0	1.00	1.00	1.00	1.00	1.01	1.03	1.05	1.11	1.23	1.33	1.44	1.54	1.64	1.76
137.5	1.00	1.00	1.00	1.00	1.01	1.03	1.04	1.10	1.21	1.31	1.41	1.51	1.61	1.72
140.0	1.00	1.00	1.00	1.00	1.01	1.02	1.04	1.09	1.19	1.29	1.39	1.48	1.57	1.69
142.5	1.00	1.00	1.00	1.00	1.01	1.02	1.03	1.08	1.18	1.27	1.37	1.45	1.54	1.65
145.0	1.00	1.00	1.00	1.00	1.01	1.01	1.03	1.07	1.16	1.25	1.35	1.43	1.52	1.62
147.5	1.00	1.00	1.00	1.00	1.00	1.01	1.02	1.06	1.15	1.24	1.32	1.41	1.49	1.59
150.0	1.00	1.00	1.00	1.00	1.00	1.01	1.02	1.05	1.14	1.22	1.30	1.38	1.46	1.56
152.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.05	1.12	1.20	1.28	1.36	1.44	1.53
155.0	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.11	1.18	1.26	1.34	1.42	1.51
157.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.10	1.17	1.24	1.31	1.39	1.48
160.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.09	1.15	1.22	1.29	1.37	1.45
162.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.08	1.13	1.20	1.27	1.35	1.43
165.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.06	1.12	1.18	1.25	1.32	1.40
167.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.05	1.10	1.16	1.22	1.30	1.37
170.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.04	1.08	1.14	1.20	1.26	1.33
172.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.07	1.12	1.17	1.23	1.30
175.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.05	1.10	1.14	1.19	1.25
177.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.01	1.04	1.08	1.11	1.14	1.20

TABLE A12A—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_I (BORON STEELS), inch

Ideal Critical Diameter (D_{IB}), inch	Jominy End-Quench Distance (1/16 in) 2	Jominy End-Quench Distance (1/16 in) 3	Jominy End-Quench Distance (1/16 in) 4	Jominy End-Quench Distance (1/16 in) 5	Jominy End-Quench Distance (1/16 in) 6	Jominy End-Quench Distance (1/16 in) 7	Jominy End-Quench Distance (1/16 in) 8	Jominy End-Quench Distance (1/16 in) 9
1.5	1.10	1.14	1.88	2.52	2.90	3.22	—	—
1.6	1.08	1.12	1.65	2.20	2.70	3.02	—	—
1.7	1.07	1.10	1.47	1.95	2.50	2.82	3.00	—
1.8	1.06	1.09	1.34	1.75	2.31	2.63	2.82	3.00
1.9	1.05	1.08	1.25	1.59	2.14	2.45	2.66	2.83
2.0	1.04	1.07	1.19	1.46	1.98	2.28	2.51	2.70
2.1	1.03	1.06	1.14	1.36	1.83	2.12	2.36	2.52
2.2	1.02	1.05	1.11	1.29	1.70	1.98	2.21	2.38
2.3	1.02	1.04	1.09	1.24	1.58	1.84	2.08	2.24
2.4	1.01	1.03	1.08	1.20	1.48	1.72	1.95	2.11
2.5	1.01	1.03	1.07	1.17	1.39	1.61	1.83	1.99
2.6	1.00	1.03	1.06	1.15	1.31	1.52	1.72	1.87
2.7	1.00	1.02	1.05	1.14	1.25	1.43	1.62	1.77
2.8	1.00	1.02	1.05	1.13	1.20	1.36	1.53	1.69
2.9	1.00	1.01	1.04	1.12	1.16	1.30	1.45	1.59
3.0	1.00	1.00	1.04	1.11	1.14	1.24	1.38	1.50
3.1	1.00	1.00	1.03	1.10	1.12	1.20	1.31	1.42
3.2	1.00	1.00	1.03	1.09	1.10	1.17	1.25	1.37
3.3	1.00	1.00	1.02	1.08	1.09	1.14	1.20	1.32
3.4	1.00	1.00	1.02	1.07	1.08	1.12	1.17	1.28
3.5	1.00	1.00	1.01	1.06	1.07	1.10	1.14	1.24
3.6	1.00	1.00	1.00	1.05	1.06	1.09	1.12	1.22
3.7	1.00	1.00	1.00	1.04	1.05	1.08	1.10	1.19
3.8	1.00	1.00	1.00	1.04	1.05	1.07	1.09	1.17
3.9	1.00	1.00	1.00	1.03	1.04	1.06	1.08	1.15
4.0	1.00	1.00	1.00	1.02	1.04	1.06	1.08	1.13
4.1	1.00	1.00	1.00	1.02	1.04	1.06	1.07	1.12
4.2	1.00	1.00	1.00	1.02	1.03	1.05	1.07	1.11
4.3	1.00	1.00	1.00	1.01	1.03	1.04	1.06	1.10
4.4	1.00	1.00	1.00	1.01	1.03	1.04	1.06	1.09
4.5	1.00	1.00	1.00	1.00	1.03	1.04	1.06	1.08
4.6	1.00	1.00	1.00	1.00	1.02	1.04	1.06	1.07
4.7	1.00	1.00	1.00	1.00	1.02	1.03	1.05	1.07
4.8	1.00	1.00	1.00	1.00	1.01	1.03	1.05	1.06
4.9	1.00	1.00	1.00	1.00	1.01	1.03	1.04	1.06
5.0	1.00	1.00	1.00	1.00	1.00	1.02	1.04	1.05
5.1	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.04
5.2	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.04

TABLE A12A—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_I (BORON STEELS), inch (CONTINUED)

Ideal Critical Diameter (D_{IB}), inch	Jominy End-Quench Distance (1/16 in) 2	Jominy End-Quench Distance (1/16 in) 3	Jominy End-Quench Distance (1/16 in) 4	Jominy End-Quench Distance (1/16 in) 5	Jominy End-Quench Distance (1/16 in) 6	Jominy End-Quench Distance (1/16 in) 7	Jominy End-Quench Distance (1/16 in) 8	Jominy End-Quench Distance (1/16 in) 9
5.3	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.03
5.4	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.03
5.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.02
5.6	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.02
5.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
5.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
5.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE A12B—DISTANCE HARDNESS DIVIDING FACTORS VS. JOMINY DISTANCE FOR A SPECIFIC CALCULATED D_1 (BORON STEELS), inch

Ideal Critical Diameter (DIB), inch	Jominy End-Quench Distance (1/16 in) 10	Jominy End-Quench Distance (1/16 in) 12	Jominy End-Quench Distance (1/16 in) 14	Jominy End-Quench Distance (1/16 in) 16	Jominy End-Quench Distance (1/16 in) 18	Jominy End-Quench Distance (1/16 in) 20	Jominy End-Quench Distance (1/16 in) 24	Jominy End-Quench Distance (1/16 in) 28	Jominy End-Quench Distance (1/16 in) 32
1.5	—	—	—	—	—	—	—	—	—
1.6	—	—	—	—	—	—	—	—	—
1.7	—	—	—	—	—	—	—	—	—
1.8	—	—	—	—	—	—	—	—	—
1.9	3.08	—	—	—	—	—	—	—	—
2.0	2.88	3.34	—	—	—	—	—	—	—
2.1	2.70	3.15	3.70	—	—	—	—	—	—
2.2	2.53	2.98	3.48	3.87	—	—	—	—	—
2.3	2.38	2.82	3.29	3.65	—	—	—	—	—
2.4	2.24	2.67	3.11	3.45	3.64	—	—	—	—
2.5	2.12	2.54	2.95	3.26	3.45	3.62	4.00	—	—
2.6	2.00	2.41	2.79	3.09	3.28	3.46	3.86	4.23	—
2.7	1.90	2.29	2.65	2.93	3.12	3.30	3.67	4.00	—
2.8	1.80	2.18	2.52	2.78	2.97	3.15	3.50	3.78	4.27
2.9	1.72	2.08	2.40	2.64	2.83	3.01	3.33	3.59	4.01
3.0	1.64	1.99	2.29	2.52	2.70	2.88	3.18	3.41	3.78
3.1	1.57	1.91	2.19	2.40	2.57	2.75	3.03	3.25	3.57
3.2	1.51	1.83	2.10	2.30	2.46	2.63	2.90	3.10	3.39
3.3	1.45	1.75	2.01	2.20	2.35	2.51	2.77	2.97	3.22
3.4	1.40	1.69	1.93	2.10	2.25	2.40	2.66	2.84	3.07
3.5	1.35	1.62	1.85	2.01	2.16	2.30	2.55	2.73	2.94
3.6	1.31	1.57	1.78	1.93	2.07	2.21	2.45	2.63	2.82
3.7	1.27	1.51	1.72	1.86	2.00	2.12	2.35	2.54	2.71
3.8	1.24	1.47	1.66	1.80	1.92	2.04	2.26	2.44	2.61
3.9	1.21	1.42	1.60	1.74	1.85	1.96	2.18	2.36	2.52
4.0	1.19	1.38	1.55	1.68	1.78	1.89	2.11	2.29	2.44
4.1	1.16	1.34	1.50	1.63	1.73	1.82	2.04	2.21	2.37
4.2	1.14	1.31	1.46	1.58	1.68	1.76	1.98	2.15	2.30
4.3	1.13	1.28	1.42	1.54	1.62	1.71	1.92	2.09	2.23
4.4	1.11	1.25	1.38	1.50	1.58	1.66	1.86	2.03	2.17
4.5	1.10	1.23	1.35	1.46	1.54	1.61	1.81	1.97	2.11
4.6	1.09	1.21	1.32	1.43	1.50	1.57	1.76	1.92	2.06
4.7	1.09	1.19	1.29	1.40	1.47	1.53	1.72	1.87	2.00
4.8	1.08	1.17	1.26	1.37	1.44	1.50	1.67	1.83	1.96
4.9	1.07	1.15	1.24	1.35	1.41	1.47	1.63	1.79	1.91
5.0	1.06	1.14	1.21	1.32	1.38	1.44	1.60	1.75	1.87
5.1	1.05	1.13	1.19	1.30	1.36	1.41	1.56	1.71	1.82
5.2	1.05	1.11	1.17	1.28	1.34	1.39	1.53	1.67	1.78