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SURFACE VEHICLE STANDARD

Submitted for recognition as an American National Standard

SAE J406 | REV. NOV90

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Superseding J406 MAY85

(R) 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, Surface-Area-Center (SAC) method for shallow hardening steels, subsize method for bars less than 32 mm ($1^1/_4$ in) in diameter, and methods for determining carburized hardenability. (See Appendix A.)

Any hardenability tests 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 is also 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 B. Other hardenability prediction methods are available from the selected references in Section 2. However, it should be emphasized that the use of any hardenability 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, 17 to 28. It appears none of these methods are precise, but these are often useful for estimation purposes. Final correlation on actual parts is necessary.

2. References

2.1 Applicable Documents—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE Publications shall apply.

1. SAE J417 Hardness Test and Hardness Number Conversion
2. 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
8. "Standardization Sought in Determining the Hardenability of Steels" (A symposium). SAE Journal, Vol. 49, No. 1 (July 1941) pp 266-293
9. A. E. Focke, "Hardenability of Steel," Iron Age, Aug. 20, 1942 pp 37-40: Aug. 27, 1942, pp. 43-51; Sept. 3, 1942, pp 56-59
10. Morse Hill "The End-Quench Test: Reproducibility". ASM Transactions, Vol. 31 (1943), P 923 ff.
11. Symposium on the Hardenability of Steel, Special Report No. 36, British Iron and Steel Institute, 1946
12. G. K. Manning, "End Quench Hardenability Versus Hardness of Quenched Rounds." Metal Progress, Vol. 50, No. 4 (October 1946) pp 674-650
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14. G. K. Manning, "Comparison of Tests of Hardenability of Shallow Hardening Steels", SAE Journal, Vol. 61, July 1953, pp 30-36
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16. John Birtalan, R. G. Henley, Jr., and A. L. Christenson, "Thermal Reproducibility of the End-Quench Test," ASM Transactions, Vol. 46 (1954), P 928 ff
17. M. A. Grossman and R. L. Stephenson, "The Effect of Grain Size on Hardenability," ASM Transactions, Vol. 29 (1941), pp 1-19
18. M. A. Grossmann, "Hardenability Calculated from Chemical Compositions," AIME Transactions, Vol. 150 (1942) pp 227-259
19. I. R. Kramer, S. Siegel, and J. Brooks, "Factors for the Calculation of Hardenability" ASM Transactions, Vol. 163 (1946), p 670 ff
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. A. 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 from Chemical Compositions," Heat Treatment of Metals, Vol. 8, 1981, pp 33-38
28. P. Deb, M. C. Chaturvedi and A. K. Jena, "Analytical Representation of Hardenability Data for Steels," Metals Technology, 1982, Vol 9, p 76
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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.

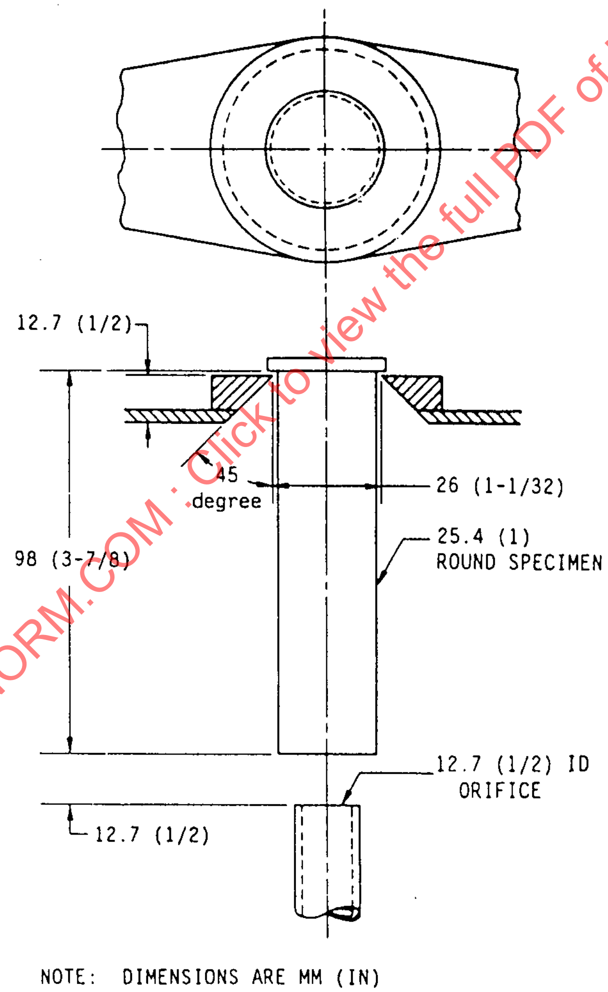
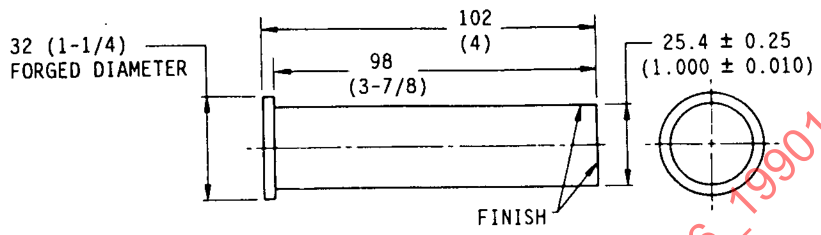


FIGURE 1—HARDENABILITY TEST SPECIMEN IN FIXTURE FOR WATER QUENCHING

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 will provide satisfactory heat transfer characteristics.



NOTE—Dimensions are mm (in)

FIGURE 2—PREFERRED TEST SPECIMEN

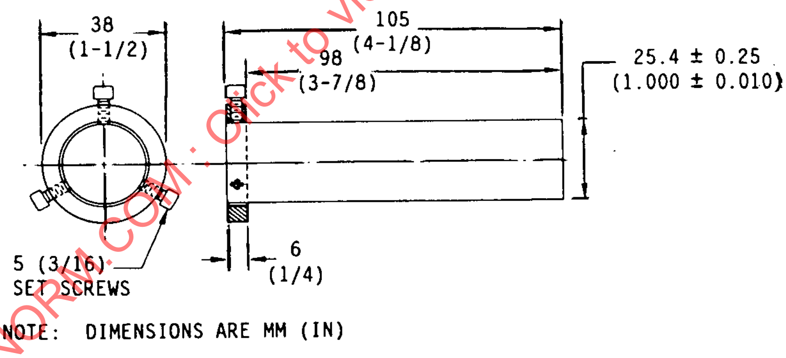


FIGURE 3—OPTIONAL TEST SPECIMEN

The bar from which the specimen is machined shall be a forged or rolled 32 mm (1 1/4 in) round representing the full cross section of the product. A cast specimen may be used in lieu of a rolled or forged specimen, except in the case of boron-treated steels; 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 since test specimens from a portion of the bloom, billet, or bar may introduce factors tending to affect the reproducibility of 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.

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 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 quenching. 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

Max 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, 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, 9200, 9300				
Up to 0.25 incl	925	1700	845	1550
0.26 to 0.36 incl	900	1650	815	1500
0.37 and over	870	1600	800	1475
0.50 and over (9200)	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 min.[1] It is necessary to determine by means of a thermocouple the time required for a test specimen to come to temperature to be sure that the heating time and temperature requirements are met.

[1] In production testing, slightly longer times up to 35 min may be used without appreciably affecting results.

It is important while heating the test specimen care be taken that its environment is such that practically no scaling or decarburization takes place on the end to be quenched. An adequately protec tive atmosphere in the furnace is suitable for meeting the preceding requirements. In the absence of such atmospheres, the specimen shall be inserted in a suitable container which maintains a nonoxidizing atmosphere. Placing fine graphite powder or cast iron chips in the base of the container are two methods of preventing oxidation of the quenched end.

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

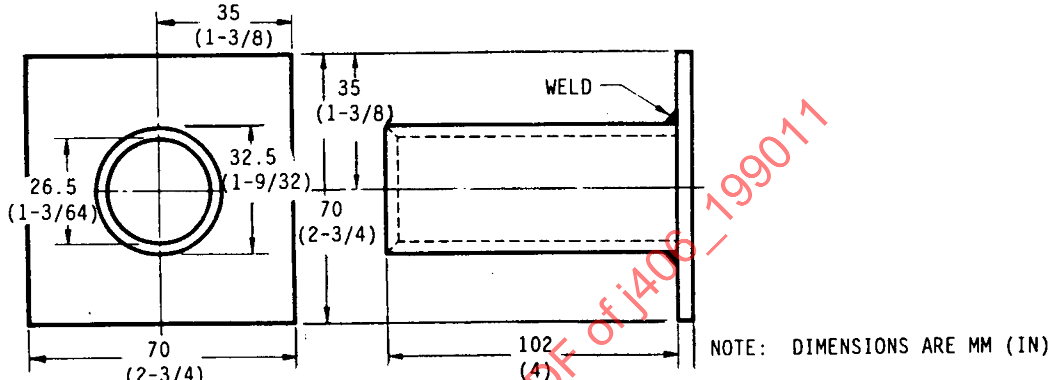


FIGURE 4—HARDENING BAR PROTECTING FIXTURE TO BE CONSTRUCTED OF HEAT RESISTING ALLOY

3.6 Quenching—The test piece 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 piece. The column of water passing through an opening 13 mm (1/2 in) in diameter shall rise to a free height of 63 mm (2 1/2 in) above the opening. 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. 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 piece during cooling.

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 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 cuts (less than 0.013 mm [0.0005 in]) with water cooling and a coarse, soft grinding wheel are recommended to avoid heating the specimen. In order to detect tempering due to grinding, the flat shall 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 readings are made, the test specimen rests 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 anvil must be constructed to move the test specimen past the penetrator in accurate steps of 1.6 mm ($^1/_{16}$ in). Figure 5 is an example of a fixture commercially available which provides for the controlled movement of the specimens.

The Rockwell tester should be checked against standard test blocks before testing the hardenability bar. 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.

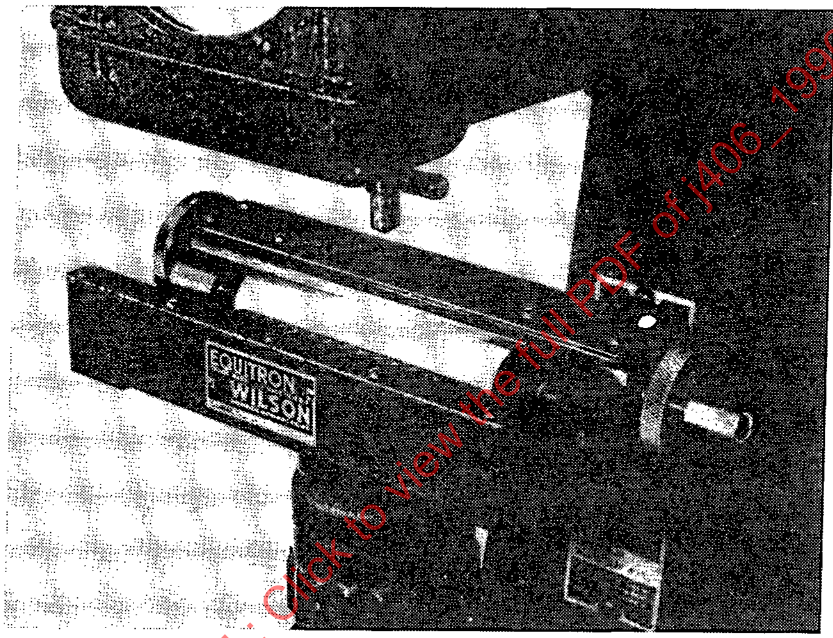


FIGURE 5—COMMERCIALLY AVAILABLE FIXTURE FOR POSITIONING SPECIMEN FOR HARDNESS INDENTATIONS

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 impression and in checking the distance from center to center of the succeeding impressions. It has been found that with reasonable operating care and a well-built fixture, it is practical to locate the center of the first impression 1.6 mm ± 0.075 (0.0625 in ± 0.003) from the quenched end. The variations between spacings should be even smaller. Obviously, it is more important to position the indenter accurately when testing low hardenability steels than when testing high 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.

Readings shall be taken in steps of 1.6 mm ($^1/_{16}$ in) for the first 25 mm (1 in). Distance between readings for the last 51 mm (2 in) may be at the discretion of the tester. When a flat on which readings have been made is used as a base, the burrs around the indentation shall be removed by grinding unless a fixture is used which has been relieved to accommodate the irregularities due to the indentations.

Hardness readings should be made on one flat, or preferably, two flats 180 degrees apart. 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 6) 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.

Figure 6 shows the Standard Form for Plotting Hardenability Curves.

3.9 Construction of Hardness U Curves—A chart is also provided for using the hardenability curve to predict hardness U curves in various sized rounds when oil or water quenched. Figure 7 shows this chart. 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 pieces in the quench and good control of temperature and cleanliness of the quench medium. The ranges given reflect variations found under experimental conditions; under production conditions even wider variations may be found.

3.10 Index of Hardenability—The hardenability of steel is usually reported as a series of values of hardness versus distance from the quenched end of the test bar, either in graphical or tabular form. Hardenability may also be designated by the use of either one or the other of the two following codes, the first of which is preferred.

a. That code which designates a minimum hardness value at a distance specified or in case of both minimum and maximum limitations may also be specified in terms of Rockwell C hardness at the required distance from the quenched end.

As an example of this method, a hardenability requirement could be specified as J 36 min = 13 mm ($^8/_{16}$ in) or in case of both minimum and maximum restrictions, could be specified as J 36-50 = 13 mm ($^8/_{16}$ in). This means that at the specified distance of 13 mm ($^8/_{16}$ in) from the quenched end the Rockwell C hardness should be a minimum of 36 and a maximum of 50.

b. The alternate method would be a code which indicates the distance from the quenched end where the following hardness reference numbers occur. The requirement may be specified as a minimum distance only or as a minimum and a maximum distance at the hardness reference number which applies. Table 2 indicates the hardness reference numbers in terms of Rockwell C values for various carbon contents.

As an example, an alloy steel of 0.34% mean carbon content could be specified to have a hardenability index of J 45 = 6.3 mm ($^4/_{16}$ in) min which means that the minimum requirements of this steel would be 45 HRC at a distance of 6.3 mm ($^4/_{16}$ in) from the quenched end.

If this steel were one having both minimum and maximum curves or limits, the index of hardenability might be specified as J 45 = 6.3 to 17 mm ($^4/_{16}$ to $^{11}/_{16}$ in).

In addition to the specification in accordance with either of the above two codes, the minimum and maximum hardness at the 1.6 mm ($^1/_6$ in) position may be specified. These hardness values should be in agreement with the maximum and minimum carbon content specified.

3.11 Subsize Test Specimen—For determining hardenability of steel received in bars less than 32 mm (1$^1/_4$ in) in diameter, the test bar may be made 19, 13, or 6.3 mm ($^3/_4$, $^1/_2$, or $^1/_4$ in) diameter, as desired, and end-quenched as prescribed for the 25 mm (1 in) round. Modifications in the water

DATE ______________________
LABORATORY ______________________
TYPE SPECIMEN ______________________
TEST NO. ______________________

ASTM END QUENCH TEST
FOR HARDENABILITY
OF STEEL (A255-48T)

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

REMARKS ____
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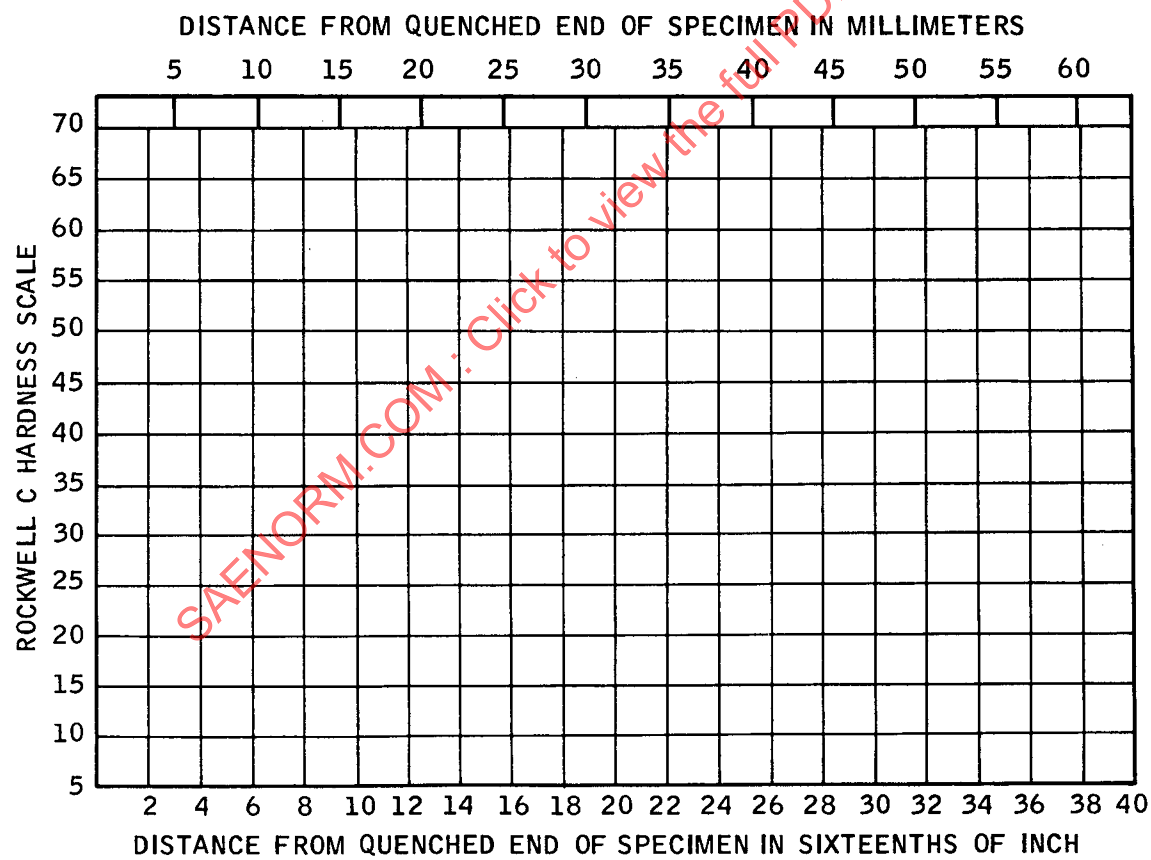


FIGURE 6—STANDARD FORM FOR PLOTTING HARDENABILITY CURVES

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 3.

TABLE 2—HARDNESS REFERENCE NUMBERS FOR STEELS OF VARIOUS CARBON CONTENTS

Mean of Ordered Carbon Range, %	Hardness Reference No., HRC Alloy Steels	Hardness Reference No., HRC Carbon Steels
0.08-0.17	25	—
0.18-0.22	30	25
0.23-0.27	35	30
0.28-0.32	40	35
0.33-0.42	45	40
0.43-0.52	50	45
0.53-0.62	55	50

TABLE 3—ORIFICES FOR QUENCHING SMALL SPECIMENS

Test Bar Dia 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)	6.3 (1/4)	9.5 (3/8)	102 (4)
6.3 (1/4)	3.2 (1/8)	6.3 (1/4)	203 (8)

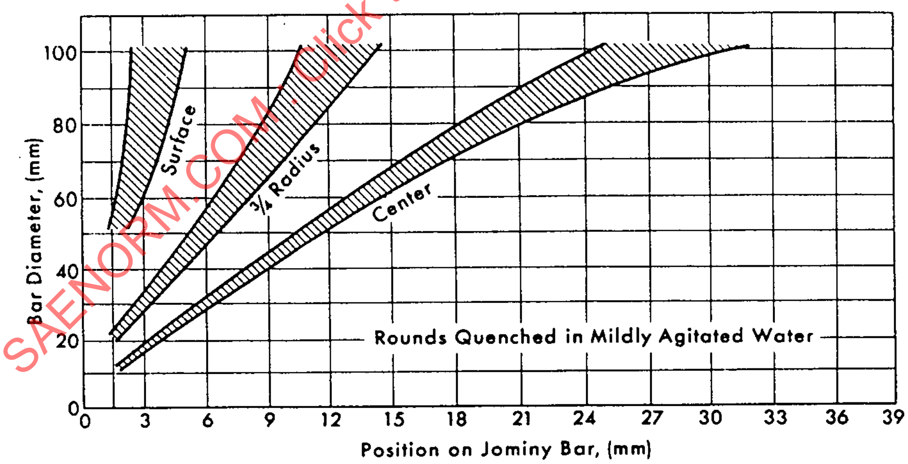


FIGURE 7A—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

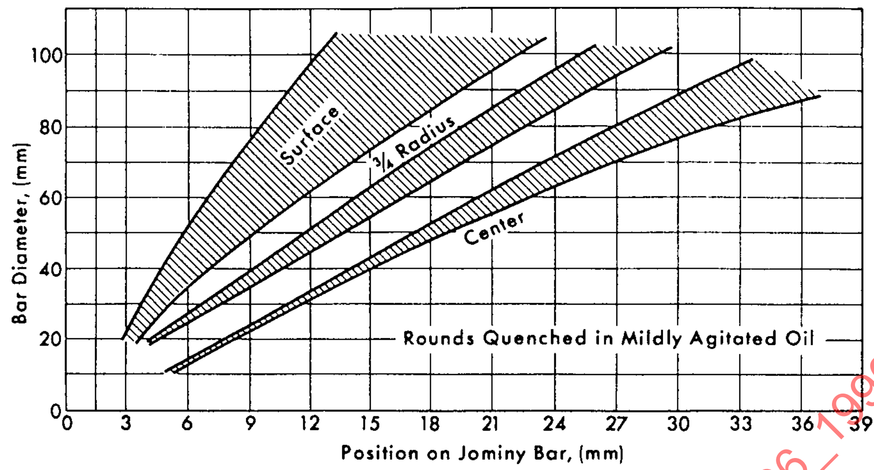


FIGURE 7B—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

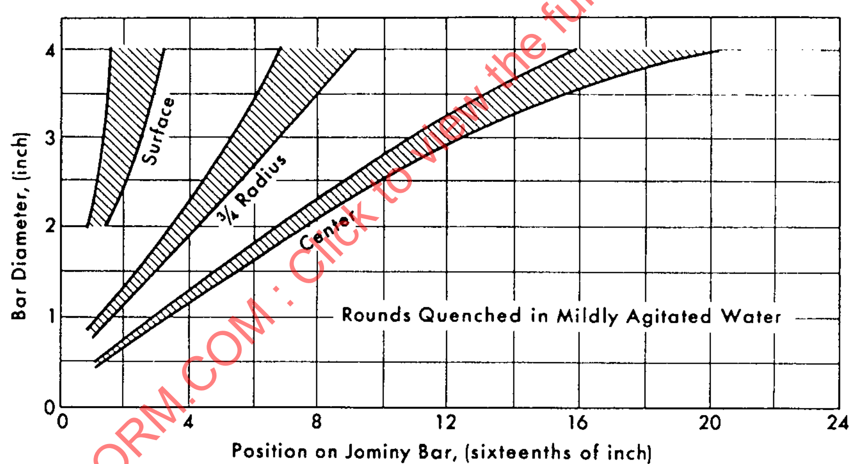


FIGURE 7C—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

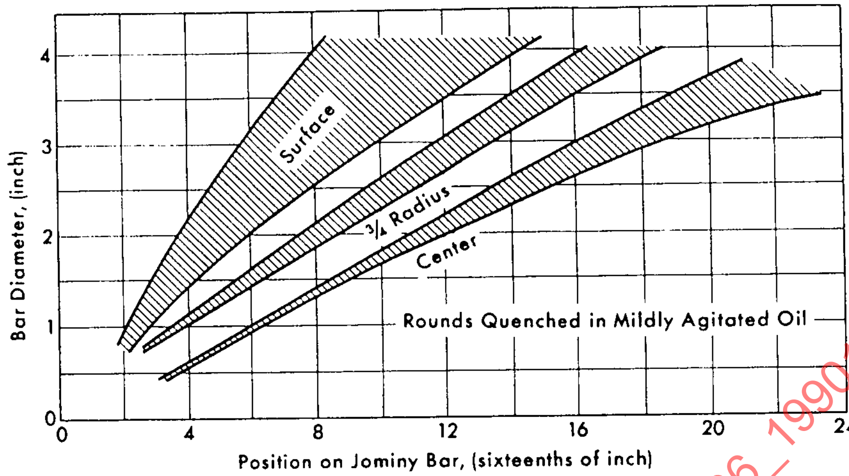


FIGURE 7D—CORRELATION OF COOLING RATES IN JOMINY BAR AND QUENCHED ROUND BARS

Because of the greater aircooling effect on test bars less than 25 mm (1 in) diameter and especially in bars 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 bar.

Hardness curves from these smaller bars are not comparable with curves from the 25 mm (1 in) diameter specimen. If the standard hardness curve from subsize specimens is needed, it becomes necessary to make actual cooling rate determination on the subsize specimen in question.

4. Hardenability Tests for Shallow Hardening Steels

4.1 Introduction—This method covers two different tests: the 25 mm (1 in) standard hardenability specimen method, and the SAC hardenability test method. These methods are applicable to carbon and low alloy steels, other than carbon tool steels, and are suitable only for shallow hardening steels which will not harden completely through in 25 mm (1 in) and larger diameters with a water quench.

4.2 The 25 mm (1 in) Standard Hardenability Specimen Method

4.2.1 PROCEDURE—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 in preparing the specimen prior to hardness measurements is that given in the section on Test Procedure for 25 mm (1 in) Standard Hardenability Specimen. An anvil providing a means of very accurately measuring the distance from the quenched end is essential.

Hardness values are obtained from 1.6 to 13 mm (1/16 to 1/2 in) from the quenched end in intervals of 0.8 mm (1/32 in). Beyond 13 mm (1/2 in) from the quenched end, the intervals are the same as for the 25 mm (1/2 in) standard hardenability specimen. For readings to 13 mm (1/2 in) from the quenched end, two hardness traverses are made, both with readings 1.6 mm (1/16 in) apart; one starting at 1.6 mm (1/16 in) and being completed at 13 mm (1/2 in) from the quenched end, and the other starting at 2.4 mm (3/32 in) and being completed at 12 mm (15/32 in) from the quenched end.

Only two flats 180 degrees apart need be ground if the mechnical 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.

For plotting test results, the Standard Form for Plotting Hardenability Curves (Figure 6) should be used. Distances for the odd number 0.8 mm (1/32 in) should be estimated with care.

4.3 SAC Hardenability Test Method

4.3.1 Introduction—This method is referred to as the SAC test. The designation SAC means Surface-Area-Center, the area being determined and calculated from a cross section hardness survey of a suitably quenched 25 mm (1 in) diameter cylindrical test specimen.

4.3.2 Sampling—The bar from which the specimen is machined shall be a forged or rolled 32 mm (1 1/4 in) diameter round representing the full cross section of the product. Specimen locations representing other than the full cross section may introduce factors tending to offset reproducibility of results and shall be subject to agreement between steel producer and user.

In all cases, specimens shall be machined from bars of sufficient diameter to ensure freedom from decarburization.

4.3.3 Normalizing Prior to Heating for Quench—The material from which the test specimen is to be machined shall be normalized, holding for 1 h at the appropriate temperature designated in Table 1 followed by cooling in air. The record of hardenability test results must always state the prior thermal history of the specimen tested.

4.3.4 Test Specimens—The test specimen is a 25 mm (1 in) diameter cylinder 102 mm (4 in) long, as shown in Figure 8. Specimen A is for use with quenching fixture A, Figure 9; and specimen B is for use with quenching fixture B, Figure 9.

4.3.5 Heating for Quenching—The specimen shall be heated to the austenitizing temperature shown in Table 1. The specimen shall be held at the specified temperature for 30 min. The furnace chamber shall be muffle type, and the amount of scaling controlled only by standardizing the time of exposure.

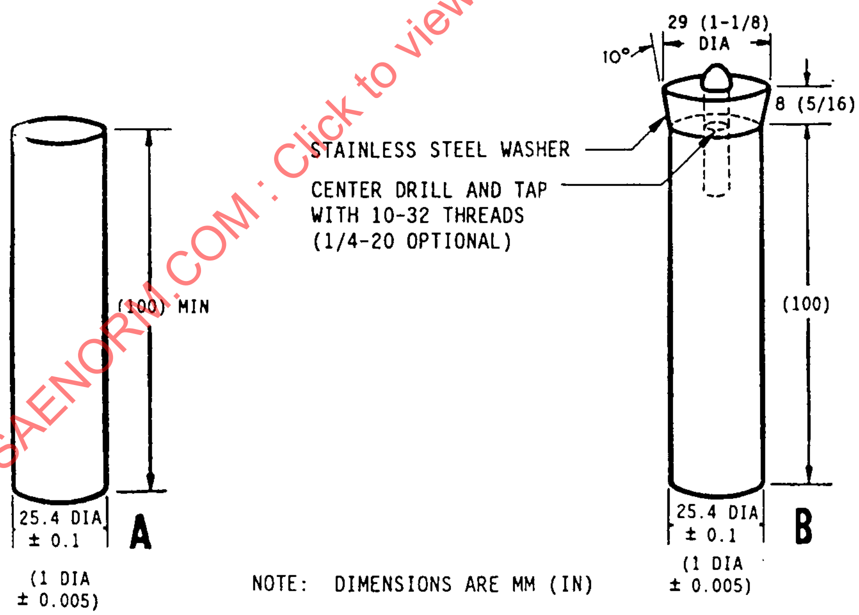


FIGURE 8—SAC TEST SPECIMENS

4.3.6 Quenching—Frequently SAC test specimens are hand quenched by laboratories that do not have the special quenching fixture shown in Figure 9. In most cases, hand quenching yields satisfactory results provided the specimen is well agitated during quenching. However, it is recommended that one of the quenching fixtures shown in Figure 9 be used. The apparatus shall be adjusted so the water flows upward through the top opening to a free height of 63 mm (2 1/2 in) without specimen, guide tube, or basket in place. The water temperature shall be 18 to 30 °C (65 to 85 °F).

The specimen shall be removed from the furnace by gripping near one end with tongs, and it shall be dropped into the basket or guide tube. Time to remove the specimen from the furnace and drop it into the quenching fixture shall be 5 s max. The specimen shall remain in the quench for 60 s and shall then be removed by lifting out the basket or guide tube and inverting.

4.3.7 Preparation for Hardness Testing—The quenched specimen shall be cut transversely so that the top portion is 50 mm (2 in) long as illustrated in Figure 10. The test slug can be 13 to 25 mm (1/2 to 1 in) long. A suitable soft cutoff wheel shall be used with precaution against heating of the specimen.

The faces of the test slug shall be ground flat and parallel and finished with a grit sufficiently fine to permit satisfactory hardness determination. Four flats shall be ground 0.12 to 0.20 mm (0.005 to 0.008 in) deep at 90 degrees spacing on the cylindrical surface of the test slug.

The test surfaces shall be checked for freedom from tempering by etching as recommended in the section on Hardness Measurement on medium hardening steels. The presence of darkened areas indicates that tempering has taken place and grinding shall be continued until tempering effects are removed.

4.3.8 Hardness Testing—Surface hardness shall be taken on the surfaces of the four ground flats. The average of these readings shall represent the surface hardness.

Face readings shall be obtained by testing 1.6 mm (1/16 in) increments across two diameters 90 degrees removed. A fixture suitable for indexing the specimen is illustrated in Figure 11. Readings for each comparable distance from the surface shall be averaged. Since only one center reading can be taken the average center hardness shall be the average of five readings; the center reading and the four readings taken at 1.6 mm (1/16 in) from the center.

If an indexing fixture is not available, the surface to be tested may be lightly scribed with two diameters 90 degrees removed, and with seven circles 1.6 mm (1/16 in) removed. Test locations shall be on each circle at the intersection of each of the four radii.

4.3.9 Estimation of Area—Area shall be computed by Rockwell millimeter (Rockwell Inch) units, as shown in Figure 12. Ordinates shall be Rockwell C units starting with Rockwell C of zero. Abscissas shall constitute 25 mm (1 in) max. Areas shall be Rockwell millimeters (Rockwell Inches) under the curve S-s', computed by the total of the trapezoids.

4.3.10 Index of Hardenability—The hardenability (and hardness) of a steel shall be designated by a code known as the SAC number. The code itself shall consist of a set of three numbers, including first, the surface hardness; second, the Rockwell millimeter (Rockwell Inch) area; and last, the center hardness, each of which shall be determined as herein described. Values shall be rounded to the nearest whole number.

EXAMPLE: SAC Number 63-52-42 indicates surface hardness of 63 HRC, Rockwell Inch area of 52, and center hardness of 42 HRC. The equivalent example using Rockwell millimeter units for area would be 63-1320-42.

4.3.11 Record of Test—Test results shall be recorded on a suitable form as illustrated in Figure 13.

5. Notes

5.1 Marginal Indicia—The (R) is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

PREPARED BY THE SAE IRON AND STEEL TECHNICAL COMMITTEE

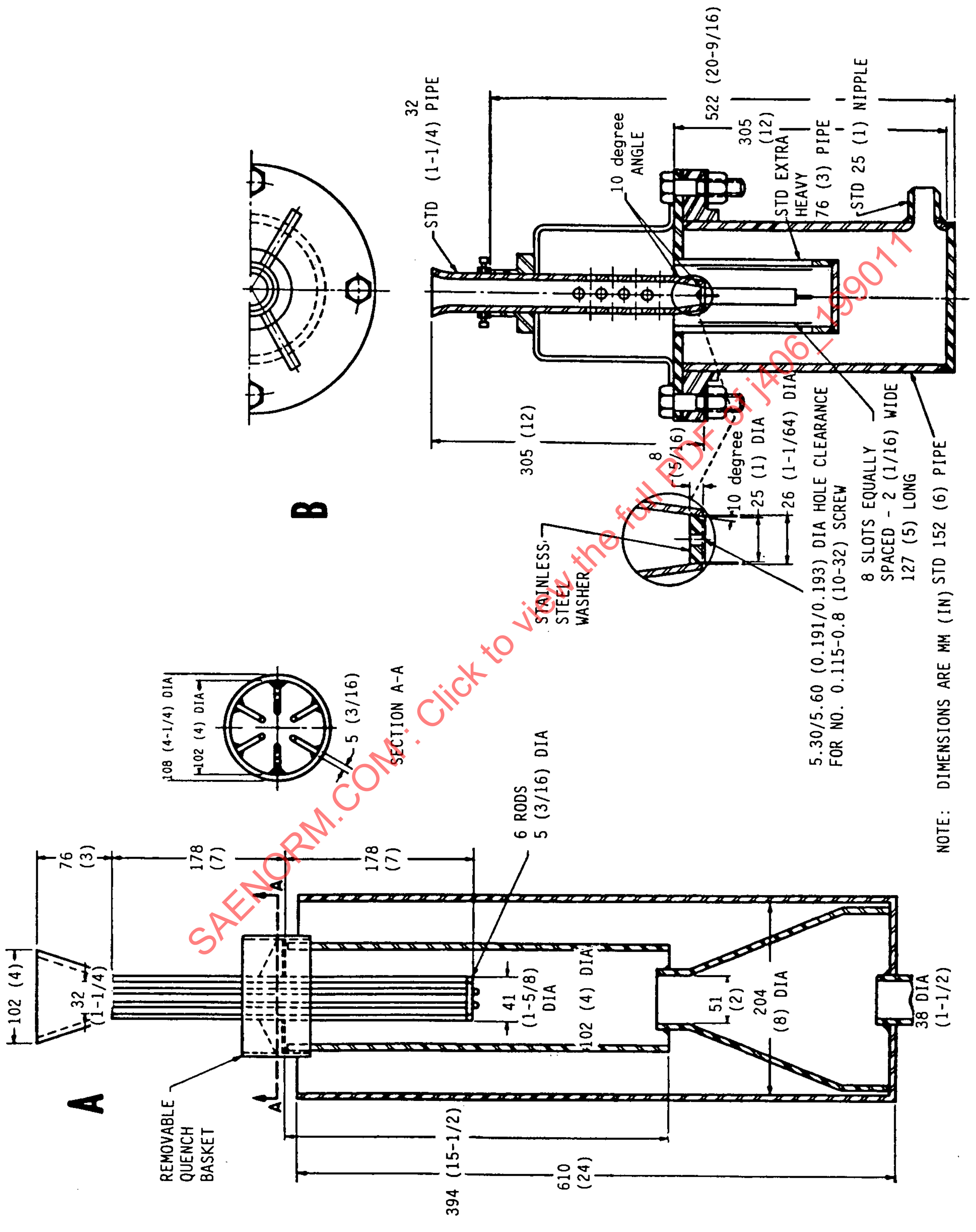


FIGURE 9—SAC QUENCHING FIXTURES

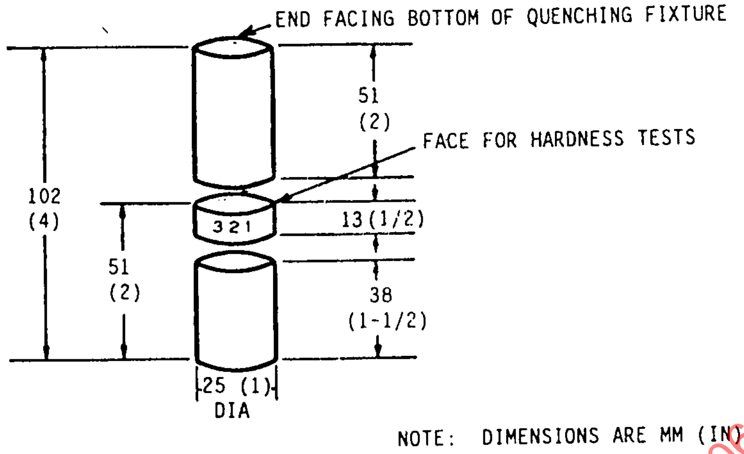


FIGURE 10—LOCATION OF TEST SLUG AND OF STAMPED IDENTIFICATION

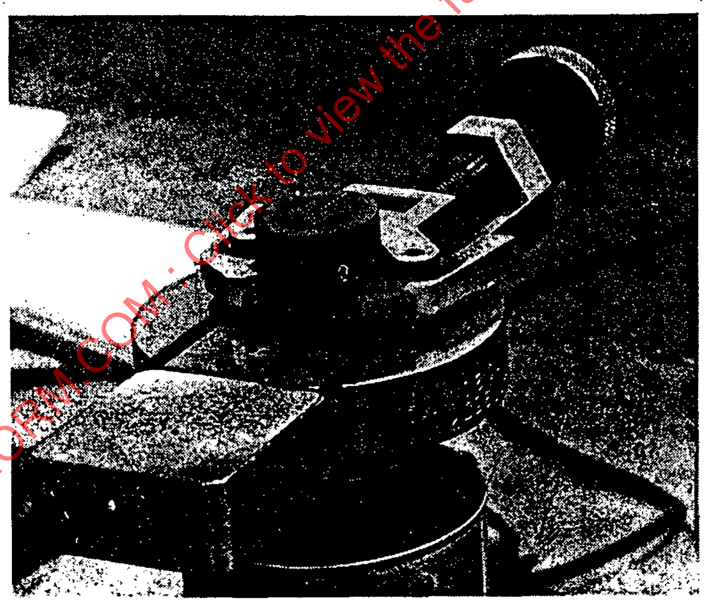
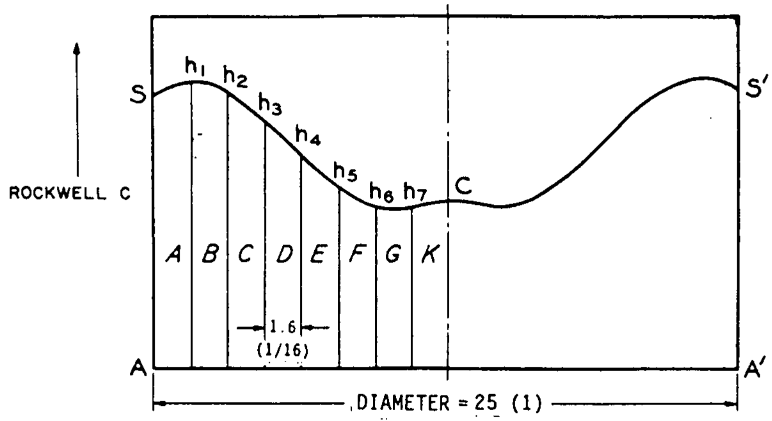


FIGURE 11—INDEX FIXTURE



Let S = average surface hardness
h_1, h_2, h_3, and so forth = average hardness at depths indicated
C = average center hardness

Then: area of $A = \frac{S + h_1}{2} \times 1.6\ (1/16)$ area of $B = \frac{h_1 + h_2}{2} \times 1.6\ (1/16)$

total area = 2 (A + B + C + D + E + F + G + K)

$= 3.2\ (1/8)\ (\frac{S}{2}\ h_1 + h_2 + h_3 + h_4 + h_5 + h_6 + h_7 + \frac{C}{2})$

NOTE: DIMENSIONS ARE MM (IN)

FIGURE 12—SAC ESTIMATION OF AREA

SAC TEST REPORT

DATE__________ TEST NO.__________

LABORATORY__________ SOURCE__________

GRADE	HEAT NO.	GRAIN	ANALYSIS									
			C	Mn	S	P	Si	Ni	Cr	Mo		

NORMALIZING TEMP (F)__________ QUENCHING TEMP (F)__________

REMARKS__________

	INDIVIDUAL READINGS				AVERAGE ORDINATES		
S						S/2	
1						1	
2						2	
3						3	
4						4	
5						5	
6						6	
7						7	
C						C/2	
TOTAL ORDINATES							
AREA = TOTAL ORDINATES DIVIDED BY 8							
HARDENABILITY RATING					S	A	C

	INDIVIDUAL READINGS				AVERAGE ORDINATES		
S						S/2	
1						1	
2						2	
3						3	
4						4	
5						5	
6						6	
7						7	
C						C/2	
TOTAL ORDINATES							
AREA = TOTAL ORDINATES DIVIDED BY 8							
HARDENABILITY RATING					S	A	C

FIGURE 13—SAC TEST REPORT

APPENDIX A

METHODS FOR DETERMINING CARBURIZED HARDENABILITY

A.1. ***Scope***—This method prescribes procedures for determining the hardenability of steels after carburizing and for subsequently recording the results. It is of interest to note that such a procedure was used by Walter Jominy when he first introduced the end-quench test. Information on carburized hardenability is important in controlling carburizing and quenching practice, and in determining the ability of a specific steel to meet the hardness-case depth requirements for a specific part.

Carburized parts are used chiefly where high surface stresses are imposed. Failures generally originate in the surface layers where the service stresses are most severe. Generally, therefore, high case strength and high endurance limit are critical factors. It has been proved that compressive stresses in the case improve the fatigue durability and that high case hardness is associated with high durability. These compressive stresses are created by developing a high-hardness high-carbon case on a low-hardness low-carbon core. The core must have adequate hardness and strength to support the hard case, but increasing core hardness over the necessary minimum reduces compressive stresses at the surface and therefore decreases the fatigue resistance.

Originally, it was considered that core hardenability alone was needed for steel selection. Equal additions of carbon, however, do not have the same effect on the hardenability of all base compositions; conclusions reached on the basis of core hardenability may not be correct for the case. It has, therefore, become clear that adequate hardenability of both case and core is essential for proper selection of the optimum grade and control of its processing to a specific part.

A.2. ***Test Procedure***—The end-quench specimens and quenching and testing procedures, described in detail in previous sections of this document, are used. When evaluating the carburized hardenability characteristics of a steel, high-carbon-potential pack carburizing procedures are employed as described in Section A.3. Results using this practice have been reported previously.[2, 3]

A.3. ***Direct Quench***—In the determination of case hardenability, a standard end-quench hardenability specimen and a carbon-gradient specimen, 25 × 152 mm (1 in diameter by 6 in) long, prepared from the same bar, are simultaneously carburized in a covered alloy steel box for 9 h at 925 °C (1700 °F). The composition of the carburizing medium is to be: charcoal 50%, coke 30%, barium carbonate 12%, sodium carbonate 3%, calcium carbonate 3%, molasses binder 2%.

All new carburizer is used for each batch to provide uniform carburizing conditions and to overcarburize so the highest carbon level to be investigated (1.10%) will be sufficiently subsurface to permit accurate location.

The hardenability specimen is end-quenched, and the carbon-gradient bar is either cooled in loose hydrated lime or immersion quenched in oil. If oil quenched, the carbon-gradient bar is tempered at 650 °C (1200 °F) for 10 min in lead or salt to soften it for machining. Samples for carbon analysis are removed by lathe turning in radial increments 0.13 mm (0.005 in) deep. The carbon-gradient curve is obtained by plotting the carbon content for each radial increment against the average depth of the increment below the surface.

[2] J. A. Halgren and E. A. Solecki, "Case Hardenability of SAE 4028, 8620, 4620, and 4815 Steels." SAE Transactions, Vol. 69 (1961), p. 662.
[3] Atlas "Hardenability of Carburized Steels." New York: Climax Molybdenum Co., 1960.

On the assumption that the distribution of carbon in the end-quench specimen is the same as in the carbon-gradient bar, parallel flats are ground on the end-quench specimen to levels corresponding to carbon concentrations of 1.10, 1.00, 0.90% and, in some cases, lower carbon levels.

To minimize the effect of softer underlying layers, Rockwell A hardness values are determined with impressions along the centerline of each flat. The A values are converted to C values using conversion tables given in SAE J417. The hardness value at the 1.6 mm (1/16 in) position is affected by carburizing the end of the bar, therefore this reading is discarded. If hardness values at the 1.6 mm (1/16 in) position are desired, the quenched end can be copper-plated to prevent carburizing.

A pictorial representation of the procedure, giving an example of a carbon-gradient curve, and the sequence of operations is shown in Figure A1. Grinding the end-quenched hardenability bar is critical. Extreme care should be exercised to avoid tempering. See the section of this document entitled Hardness Measurement.

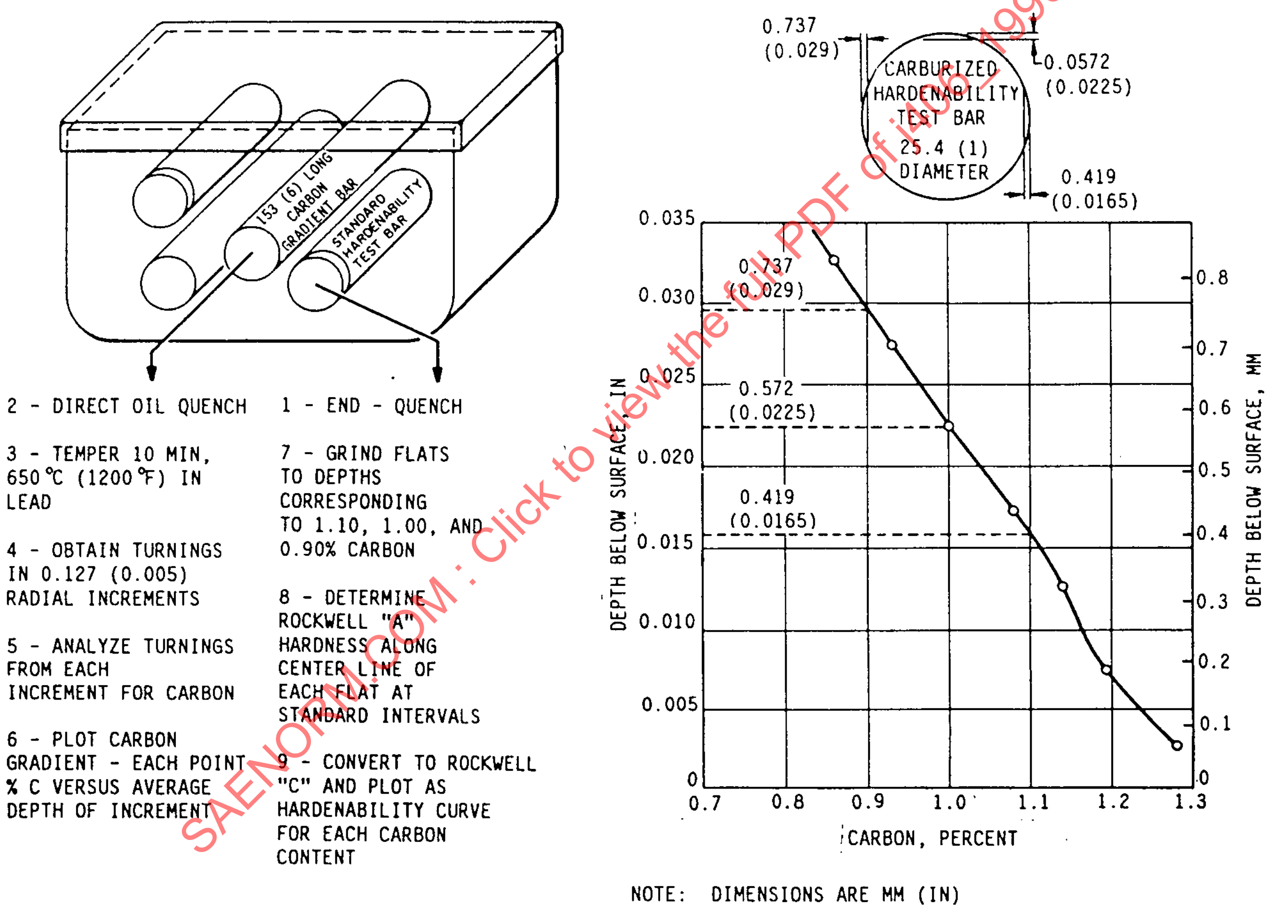


FIGURE A1—STANDARD CARBURIZING PROCEDURE, PACK CARBURIZE 9 h AT 925 °C (1700 °F)

A.4. Reheat and Quench—Steels may be tested under reheat and quench conditions by modifying the practice slightly. The end-quench specimens and the corresponding carbon-gradient bars are pack-carburized as described above, then the bars are removed from the box and either cooled in still air or oil-quenched, depending upon the proposed plant practice. The specimens are then reheated in a controlled atmosphere furnace held at 845 °C (1550 °F), for a total time of 55 min in the furnace to approximate the specified 30 min at furnace temperature. The hardenability specimen is then end-quenched and the carbon-gradient bar is either cooled in lime or oil quenched and tempered as described previously.

A.5. Alternate Procedures—It is apparent that the test can be tailored to suit individual plant practice, but the procedures described in the preceding paragraph should be used when comparing results with other laboratories.

An example of an alternate procedure would be to grind flats on the end-quench specimen before carburizing, then carburize the specimen in the same carburizing furnace with parts, end-quenching the specimen after carburizing. Surface hardenability may be determined on the pre-ground flats, and hardenability as a function of case depth can be determined by grinding flats to specified depths.

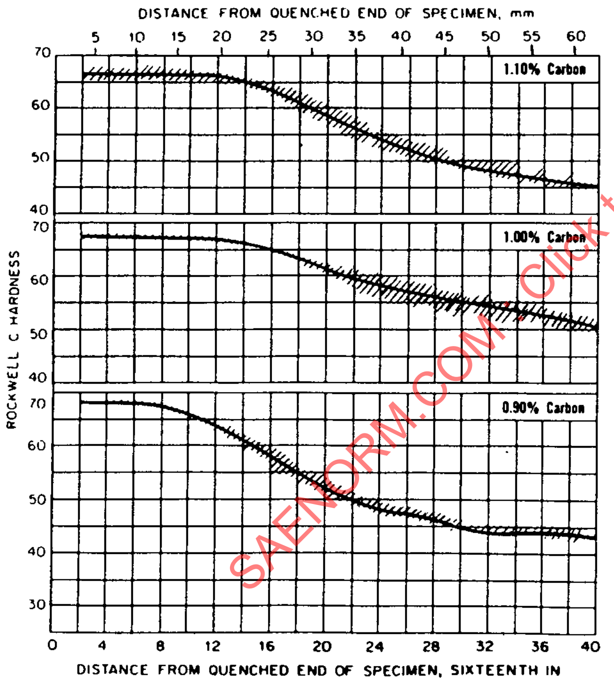
A.6. Reproducibility—The method described for direct quenching provides good reproducibility, as indicated by two tests. In the first test, four carbon-gradient bars and four end-quench bars machined from the same normalized bar stock were simultaneously carburized and sequentially quenched.

In the second test, the case hardenability of one heat was determined on three separate occasions with carburizing temperatures between 925 and 955 °C (1700 and 1750 °F).

The results of the reproducibility tests are given in Figure A2.

SINGLE BATCH

Four hardenability bars of SAE 4419 carburizing steel pack carburized 9 h at 925 °C (1700 °F) and direct end quenched. Core composition: 0.19% C, 0.52% Mn, 0.23% Si, 0.12% Ni, 0.20% Cr, 0.51% Mo.



MULTIPLE BATCH

Three hardenability bars of SAE 4419 carburizing steel each run in a separate pack carburizing batch. Each batch pack carburized 9 h at 925 to 955 °C (1700 to 1750 °F) and direct quenched. Core composition: 0.19% C, 0.52% Mn, 0.23% Si, 0.12% Ni, 0.20% Cr, 0.51% Mo.

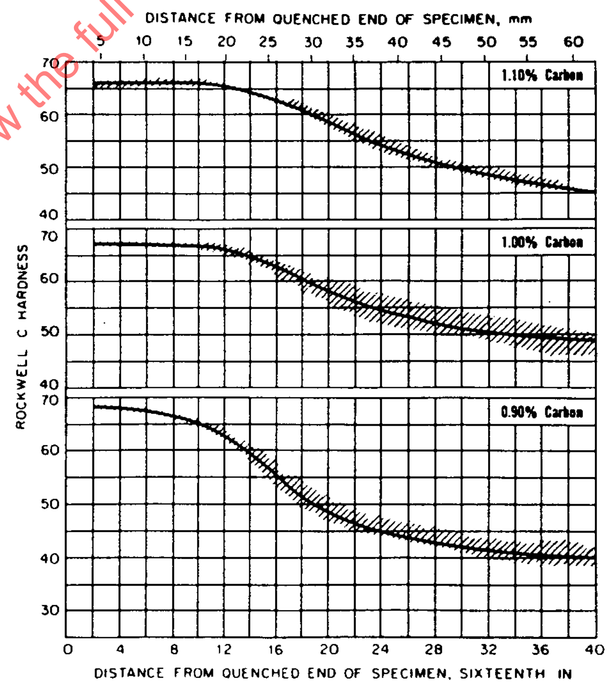


FIGURE A2—REPRODUCIBILITY OF CASE HARDENABILITY

APPENDIX B

METHOD FOR CALCULATING HARDENABILITY FROM COMPOSITION (SI/METRIC)

B.1. Introduction—This method of Jominy hardenability calculation from the chemical ideal diameter[4] (DI) 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 B1 and a range of DI as contained in Tables B2 to B5. 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, References (17) to (29).

The succeeding paragraphs describe 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 inch 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.

TABLE B1—COMPOSITION RANGE USED TO DEVELOP THE HARDENABILITY CALCULATION METHOD DESCRIBED IN THIS APPENDIX

Element	Range (%)
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

B.2. DI Calculation for Non-Boron Steels—This calculation relies on a series of hardenability factors (Table B6) for each alloying element in the composition which multiplied together give a DI value. (For simplicity, only multiplying factors for DI in inch units are given. For DI in mm, the DI 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.

An example of DI calculation is given in Table B7 for an SAE 4118 modified steel:

B.3. DI Calculation for Boron Steels—With an effective steel making 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.

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

[4] DI 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 Grossmann quench severity H = Infinity)

$$\text{B.F.} = \frac{\text{Measured DI From Jominy Data and Carbon Content}}{\text{Calculated DI From Composition Excluding Boron}} \quad \text{(Eq.B1)}$$

An example of actual boron factor determination is given in Table B8 for an SAE 15B30 modified steel:

B.3.1.1 STEP 1—Using Table B9, 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 HRC 37 occurring at a "J" distance of 13.5 mm or $^{8}/_{16}$ in from the quenched end.

B.3.1.2 STEP 2—From Table B10 (mm) or Table B11, a "J" distance of 13.5 mm or $^{8}/_{16}$ in equates to a measured DI of 78.2 mm or 2.97 in (interpolation required).

B.3.1.3 STEP 3:

$$\text{Boron Factor} = \frac{78.2 \text{ mm}}{31.5 \text{ mm}} = 2.5 \quad \text{(Eq.B2)}$$

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.

B.3.2 Calculation of DI with Boron (DI_B)

B.3.2.1 STEP 1—Calculate the DI without boron. For the above example, this DI is 31.5 mm (1.24 in).

B.3.2.2 STEP 2—Calculate the alloy factor (the product of all the multiplying factors from Table B2 excluding carbon). For the above example:

$$\text{Alloy Factor} = \frac{\text{Calculated DI (Without Boron)}}{\text{Carbon Multiplying Factor}} = \frac{1.24 \text{ in}}{0.157 \text{ in}} = 8.0 \quad \text{(Eq.B3)}$$

or

$$\text{Alloy Factor} = \frac{31.5 \text{ mm}}{0.157 \times 25.4 \text{ mm/inch}} = 8.0$$

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

B.3.2.3 STEP 3—Determine the boron multiplying factor from Table B12. For this example with 0.29% carbon and an alloy factor of 8.0, the boron multiplying factor is 2.36 (interpolation required).

B.3.2.4 STEP 4—Calculate the DI with boron as in the following equation:

$$DI_B = DI \text{ (without Boron)} \times \text{Boron Factor}$$
$$DI_B = 1.24 \text{ in} \times 2.36 \text{ or } 31.5 \text{ mm} \times 2.36 \quad \text{(Eq.B4)}$$
$$DI_B = 2.93 \text{ in or } 74.3 \text{ mm}$$

B.4 Hardenability Curves from Composition—With a predetermined DI (DI_B for boron steels), the end-quench hardenability curve can be computed by the following procedure:

B.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 B9. For the example, non-boron SAE 4118 modified heat containing 0.22% C the initial hardness is HRC 45.

B.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 B2 (mm) or B3 (inch) for non-boron steels or from Table B4 (mm) or B5 (inch) for boron steels.

For the example, (see Tables B13 and B14) non-boron heat with an IH = HRC 45 and a calculated DI 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 B2 (mm) or B3 (inch) for non-boron steels. (For simplicity, the DI should be rounded to the nearest 0.5 mm or 0.1 in).

B.5 Equations for Tables B2-B14—Tables B15 to B22 represent a least squares polynomial fit of data contained in Tables B2 to B14. The use of these questions 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 B2—DISTANCE HARDNESS DIVIDING FACTORS VS JOMINY DISTANCE FOR A SPECIFIC CALCULATED DI (NON-BORON STEELS), mm

Ideal Critical Diameter (DI), mm	Jominy End-Quench Distance (mm) 3	Jominy End-Quench Distance (mm) 4.5	Jominy End-Quench Distance (mm) 6.0	Jominy End-Quench Distance (mm) 7.5	Jominy End-Quench Distance (mm) 9.0	Jominy End-Quench Distance (mm) 10.5	Jominy End-Quench Distance (mm) 12.0	Jominy End-Quench Distance (mm) 13.5
25.0	1.13	1.44	2.01	2.35	2.61	2.77	2.85	2.99
27.5	1.11	1.38	1.89	2.23	2.50	2.68	2.76	2.89
30.0	1.09	1.32	1.76	2.11	2.38	2.56	2.65	2.77
32.5	1.07	1.27	1.66	2.00	2.27	2.46	2.54	2.65
35.0	1.06	1.22	1.57	1.91	2.17	2.35	2.44	2.55
37.5	1.05	1.18	1.50	1.82	2.08	2.26	2.35	2.45
40.0	1.04	1.15	1.43	1.74	1.99	2.17	2.25	2.35
42.5	1.03	1.12	1.38	1.66	1.90	2.08	2.16	2.26
45.0	1.02	1.10	1.32	1.60	1.83	2.00	2.08	2.17
47.5	1.02	1.08	1.29	1.54	1.76	1.92	2.00	2.09
50.0	1.01	1.07	1.25	1.49	1.70	1.85	1.92	2.01
52.5	1.01	1.06	1.23	1.44	1.63	1.78	1.86	1.94
55.0	1.00	1.06	1.20	1.39	1.58	1.72	1.79	1.88
57.5	1.00	1.05	1.18	1.35	1.52	1.66	1.73	1.82
60.0	1.00	1.05	1.16	1.32	1.48	1.61	1.67	1.75
62.5	1.00	1.04	1.14	1.29	1.44	1.56	1.62	1.70
65.0	1.00	1.04	1.13	1.26	1.40	1.51	1.57	1.65
67.5	1.00	1.03	1.12	1.24	1.36	1.47	1.53	1.61
70.0	1.00	1.03	1.10	1.21	1.33	1.43	1.49	1.57
72.5	1.00	1.03	1.09	1.19	1.30	1.39	1.45	1.53
75.0	1.00	1.02	1.08	1.17	1.27	1.36	1.41	1.49
77.5	1.00	1.01	1.07	1.15	1.24	1.33	1.38	1.45
80.0	1.00	1.00	1.06	1.13	1.22	1.30	1.35	1.42
82.5	1.00	1.00	1.06	1.12	1.20	1.28	1.33	1.39
85.0	1.00	1.00	1.05	1.11	1.18	1.25	1.30	1.36
87.5	1.00	1.00	1.05	1.09	1.16	1.23	1.28	1.33
90.0	1.00	1.00	1.04	1.08	1.14	1.20	1.25	1.31
92.5	1.00	1.00	1.03	1.07	1.13	1.18	1.23	1.28
95.0	1.00	1.00	1.03	1.07	1.12	1.17	1.21	1.26
97.5	1.00	1.00	1.02	1.06	1.10	1.15	1.20	1.25

TABLE B2—(Continued)

Ideal Critical Diameter (DI), mm	Jominy End-Quench Distance (mm) 3	Jominy End-Quench Distance (mm) 4.5	Jominy End-Quench Distance (mm) 6.0	Jominy End-Quench Distance (mm) 7.5	Jominy End-Quench Distance (mm) 9.0	Jominy End-Quench Distance (mm) 10.5	Jominy End-Quench Distance (mm) 12.0	Jominy End-Quench Distance (mm) 13.5
100.0	1.00	1.00	1.02	1.05	1.09	1.14	1.18	1.23
102.5	1.00	1.00	1.02	1.04	1.08	1.13	1.17	1.21
105.0	1.00	1.00	1.01	1.03	1.07	1.12	1.16	1.19
107.5	1.00	1.00	1.00	1.02	1.06	1.11	1.14	1.17
110.0	1.00	1.00	1.00	1.01	1.05	1.10	1.13	1.16
112.5	1.00	1.00	1.00	1.01	1.04	1.09	1.12	1.15
115.0	1.00	1.00	1.00	1.00	1.03	1.08	1.10	1.13
117.5	1.00	1.00	1.00	1.00	1.03	1.07	1.09	1.12
120.0	1.00	1.00	1.00	1.00	1.02	1.06	1.08	1.11
122.5	1.00	1.00	1.00	1.00	1.02	1.05	1.07	1.10
125.0	1.00	1.00	1.00	1.00	1.01	1.04	1.06	1.09
127.5	1.00	1.00	1.00	1.00	1.01	1.03	1.05	1.08
130.0	1.00	1.00	1.00	1.00	1.00	1.02	1.04	1.07
130.5	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.06
135.0	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.05
137.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.04
140.0	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03
142.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02
145.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02
147.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
150.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
152.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
155.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
157.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
160.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
162.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
165.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
167.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
170.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
172.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
175.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
177.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE B2—(Continued)

Ideal Critical Diameter (DI), mm	Jominy End-Quench Distance (mm) 15.0	Jominy End-Quench Distance (mm) 18.0	Jominy End-Quench Distance (mm) 21.0	Jominy End-Quench Distance (mm) 24.0	Jominy End-Quench Distance (mm) 27.0	Jominy End-Quench Distance (mm) 33.0	Jominy End-Quench Distance (mm) 39.0	Jominy End-Quench Distance (mm) 45.0	Jominy End-Quench Distance (mm) 51.0
25.0	3.14	3.41	--	--	--	--	--	--	--
27.5	3.02	3.28	--	--	--	--	--	--	--
30.0	2.89	3.14	--	--	--	--	--	--	--
32.5	2.77	3.01	3.17	--	--	--	--	--	--
35.0	2.65	2.89	3.04	3.16	--	--	--	--	--
37.5	2.55	2.78	2.92	3.04	3.16	3.44	--	--	--
40.0	2.44	2.67	2.81	2.93	3.04	3.29	--	--	--
42.5	2.35	2.57	2.71	2.82	2.92	3.16	3.37	3.55	3.72
45.0	2.26	2.48	2.62	2.72	2.82	3.02	3.24	3.41	3.58
47.5	2.18	2.39	2.53	2.63	2.72	2.92	3.12	3.28	3.43
50.0	2.09	2.30	2.44	2.54	2.63	2.81	3.00	3.16	3.31
52.5	2.02	2.22	2.36	2.46	2.55	2.71	2.89	3.04	3.18
55.0	1.95	2.15	2.28	2.38	2.46	2.62	2.79	2.94	3.09
57.5	1.89	2.09	2.22	2.31	2.39	2.54	2.70	2.85	3.00
60.0	1.82	2.02	2.15	2.23	2.31	2.47	2.62	2.76	2.89
62.5	1.77	1.95	2.08	2.17	2.24	2.40	2.55	2.68	2.81
65.0	1.72	1.89	2.02	2.10	2.18	2.34	2.48	2.60	2.72
67.5	1.67	1.84	1.97	2.05	2.13	2.28	2.42	2.54	2.66
70.0	1.63	1.79	1.91	1.99	2.07	2.22	2.36	2.47	2.57
72.5	1.58	1.74	1.86	1.94	2.02	2.16	2.30	2.41	2.51
75.0	1.54	1.70	1.81	1.89	1.97	2.10	2.24	2.34	2.44
77.5	1.51	1.65	1.76	1.84	1.92	2.05	2.18	2.28	2.38
80.0	1.47	1.61	1.72	1.80	1.88	2.01	2.13	2.23	2.33
82.5	1.44	1.57	1.68	1.76	1.84	1.97	2.09	2.19	2.29
85.0	1.41	1.54	1.64	1.72	1.80	1.92	2.04	2.09	2.14
87.5	1.38	1.51	1.60	1.68	1.76	1.87	1.99	2.05	2.10
90.0	1.36	1.47	1.57	1.65	1.73	1.84	1.95	2.01	2.06
92.5	1.33	1.44	1.53	1.61	1.69	1.80	1.91	1.96	2.00
95.0	1.31	1.41	1.50	1.58	1.66	1.76	1.86	1.92	1.97
97.5	1.28	1.38	1.47	1.55	1.63	1.73	1.83	1.89	1.94

TABLE B2—(Continued)

Ideal Critical Diameter (DI), mm	Jominy End-Quench Distance (mm) 15.0	Jominy End-Quench Distance (mm) 18.0	Jominy End-Quench Distance (mm) 21.0	Jominy End-Quench Distance (mm) 24.0	Jominy End-Quench Distance (mm) 27.0	Jominy End-Quench Distance (mm) 33.0	Jominy End-Quench Distance (mm) 39.0	Jominy End-Quench Distance (mm) 45.0	Jominy End-Quench Distance (mm) 51.0
100.0	1.26	1.36	1.44	1.52	1.60	1.70	1.80	1.86	1.91
102.5	1.24	1.34	1.41	1.49	1.56	1.66	1.76	1.82	1.87
105.0	1.22	1.31	1.39	1.47	1.53	1.63	1.73	1.78	1.82
107.5	1.20	1.28	1.36	1.44	1.50	1.59	1.69	1.75	1.80
110.0	1.19	1.27	1.34	1.41	1.47	1.57	1.66	1.71	1.75
112.5	1.18	1.25	1.32	1.39	1.44	1.53	1.62	1.67	1.71
115.0	1.16	1.23	1.29	1.36	1.42	1.50	1.59	1.64	1.68
117.5	1.15	1.21	1.27	1.34	1.40	1.47	1.55	1.60	1.64
120.0	1.14	1.20	1.26	1.33	1.38	1.43	1.51	1.57	1.62
122.5	1.13	1.18	1.24	1.31	1.36	1.40	1.48	1.54	1.59
125.0	1.11	1.17	1.22	1.28	1.33	1.38	1.45	1.51	1.56
127.5	1.10	1.16	1.21	1.27	1.31	1.35	1.42	1.48	1.53
130.0	1.09	1.15	1.20	1.25	1.29	1.33	1.40	1.45	1.50
130.5	1.08	1.14	1.19	1.23	1.27	1.31	1.37	1.43	1.47
135.0	1.07	1.13	1.17	1.21	1.25	1.29	1.35	1.40	1.44
137.5	1.06	1.12	1.16	1.20	1.23	1.26	1.32	1.38	1.42
140.0	1.05	1.10	1.15	1.19	1.21	1.24	1.31	1.35	1.39
142.5	1.04	1.10	1.14	1.17	1.19	1.22	1.29	1.33	1.37
145.0	1.03	1.08	1.13	1.16	1.18	1.21	1.27	1.31	1.35
147.5	1.02	1.07	1.12	1.15	1.16	1.19	1.25	1.29	1.33
150.0	1.01	1.06	1.11	1.14	1.15	1.18	1.24	1.28	1.31
152.5	1.01	1.05	1.10	1.12	1.13	1.16	1.22	1.27	1.30
155.0	1.00	1.04	1.09	1.11	1.12	1.15	1.21	1.25	1.28
157.5	1.00	1.03	1.08	1.10	1.11	1.14	1.20	1.24	1.27
160.0	1.00	1.03	1.07	1.09	1.10	1.13	1.19	1.23	1.26
162.5	1.00	1.02	1.06	1.08	1.09	1.12	1.18	1.22	1.25
165.0	1.00	1.01	1.05	1.07	1.08	1.11	1.16	1.20	1.24
167.5	1.00	1.01	1.04	1.06	1.07	1.10	1.15	1.18	1.22
170.0	1.00	1.00	1.03	1.05	1.06	1.09	1.14	1.17	1.21
172.5	1.00	1.00	1.02	1.04	1.05	1.08	1.12	1.16	1.20
175.0	1.00	1.00	1.02	1.03	1.04	1.07	1.10	1.14	1.19
177.5	1.00	1.00	1.01	1.02	1.03	1.06	1.09	1.12	1.18

TABLE B3—DISTANCE HARDNESS DIVIDING FACTORS VS JOMINY DISTANCE FOR A SPECIFIC CALCULATED DI (NON-BORON STEELS), INCH

Ideal Diameter (DI), 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

TABLE B3—(Continued)

Ideal Diameter (DI), 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
4.0	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
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 B3—(Continued)

Ideal Diameter (DI), 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

TABLE B3—(Continued)

Ideal Diameter (DI), 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
4.0	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
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 B4—DISTANCE HARDNESS DIVIDING FACTORS VS JOMINY DISTANCE FOR A SPECIFIC CALCULATED DI (BORON STEELS), mm

Ideal Critical Diameter (DI_B), mm	Jominy End-Quench Distance (mm) 3	Jominy End-Quench Distance (mm) 4.5	Jominy End-Quench Distance (mm) 6.0	Jominy End-Quench Distance (mm) 7.5	Jominy End-Quench Distance (mm) 9.0	Jominy End-Quench Distance (mm) 10.5	Jominy End-Quench Distance (mm) 12.0	Jominy End-Quench Distance (mm) 13.5
40.0	1.07	1.11	1.58	2.10	2.56	--	--	--
42.5	1.06	1.10	1.43	1.89	2.34	--	--	--
45.0	1.05	1.09	1.32	1.70	2.14	2.53	2.76	--
47.5	1.04	1.08	1.23	1.55	1.98	2.36	2.59	2.78
50.0	1.04	1.07	1.18	1.43	1.82	2.19	2.42	2.64
52.5	1.03	1.06	1.13	1.34	1.69	2.04	2.27	2.48
55.0	1.02	1.05	1.11	1.27	1.58	1.90	2.12	2.33
57.5	1.02	1.04	1.09	1.22	1.48	1.77	1.99	2.19
60.0	1.01	1.03	1.07	1.18	1.40	1.66	1.86	2.06
62.5	1.01	1.03	1.06	1.16	1.34	1.56	1.74	1.94
65.0	1.00	1.03	1.05	1.14	1.29	1.47	1.64	1.83
67.5	1.00	1.02	1.04	1.12	1.24	1.38	1.55	1.72
70.0	1.00	1.02	1.04	1.11	1.20	1.32	1.47	1.64
72.5	1.00	1.01	1.03	1.10	1.17	1.26	1.39	1.55
75.0	1.00	1.00	1.03	1.09	1.14	1.22	1.33	1.47
77.5	1.00	1.00	1.02	1.08	1.12	1.18	1.27	1.40
80.0	1.00	1.00	1.02	1.07	1.11	1.15	1.22	1.33
82.5	1.00	1.00	1.02	1.07	1.10	1.13	1.18	1.29
85.0	1.00	1.00	1.02	1.06	1.09	1.11	1.15	1.25
87.5	1.00	1.00	1.02	1.06	1.08	1.10	1.13	1.21
90.0	1.00	1.00	1.01	1.05	1.07	1.09	1.11	1.18
92.5	1.00	1.00	1.00	1.04	1.06	1.08	1.10	1.17
95.0	1.00	1.00	1.00	1.03	1.05	1.07	1.09	1.15
97.5	1.00	1.00	1.00	1.03	1.05	1.06	1.08	1.13
100.0	1.00	1.00	1.00	1.02	1.04	1.05	1.07	1.11
102.5	1.00	1.00	1.00	1.02	1.04	1.05	1.07	1.11
105.0	1.00	1.00	1.00	1.01	1.03	1.05	1.06	1.10
107.5	1.00	1.00	1.00	1.01	1.03	1.04	1.06	1.09
110.0	1.00	1.00	1.00	1.01	1.02	1.03	1.05	1.08
112.5	1.00	1.00	1.00	1.01	1.02	1.03	1.05	1.07

TABLE B4—(Continued)

Ideal Critical Diameter (DI_B), mm	Jominy End-Quench Distance (mm) 3	Jominy End-Quench Distance (mm) 4.5	Jominy End-Quench Distance (mm) 6.0	Jominy End-Quench Distance (mm) 7.5	Jominy End-Quench Distance (mm) 9.0	Jominy End-Quench Distance (mm) 10.5	Jominy End-Quench Distance (mm) 12.0	Jominy End-Quench Distance (mm) 13.5
115.0	1.00	1.00	1.00	1.00	1.01	1.03	1.05	1.07
117.5	1.00	1.00	1.00	1.00	1.01	1.02	1.05	1.06
120.0	1.00	1.00	1.00	1.00	1.01	1.02	1.04	1.06
122.5	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.05
125.0	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.05
127.5	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.04
130.0	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.03
132.5	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.03
135.0	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.02
137.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.02
140.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
142.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
145.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
147.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
150.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
152.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
155.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
157.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
160.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
162.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
165.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
167.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
170.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
172.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
175.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
177.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE B4—(Continued)

Ideal Critical Diameter (DI_B), mm	Jominy End-Quench Distance (mm) 15.0	Jominy End-Quench Distance (mm) 18.0	Jominy End-Quench Distance (mm) 21.0	Jominy End-Quench Distance (mm) 24.0	Jominy End-Quench Distance (mm) 27.0	Jominy End-Quench Distance (mm) 33.0	Jominy End-Quench Distance (mm) 39.0	Jominy End-Quench Distance (mm) 45.0	Jominy End-Quench Distance (mm) 51.0
40.0	--	--	--	--	--	--	--	--	--
42.5	--	--	--	--	--	--	--	--	--
45.0	--	--	--	--	--	--	--	--	--
47.5	--	--	--	--	--	--	--	--	--
50.0	--	--	--	--	--	--	--	--	--
52.5	2.66	3.02	--	--	--	--	--	--	--
55.0	2.50	2.85	3.35	--	--	--	--	--	--
57.5	2.35	2.69	3.17	--	--	--	--	--	--
60.0	2.22	2.54	3.00	--	--	--	--	--	--
62.5	2.10	2.41	2.84	3.17	--	--	--	--	--
65.0	1.98	2.28	2.70	3.01	3.26	3.60	--	--	--
67.5	1.87	2.17	2.56	2.86	3.10	3.44	3.80	4.38	--
70.0	1.78	2.06	2.44	2.72	2.95	3.28	3.61	3.96	--
72.5	1.69	1.97	2.33	2.59	2.80	3.13	3.44	3.74	4.18
75.0	1.60	1.88	2.22	2.46	2.67	3.00	3.28	3.55	3.88
77.5	1.52	1.80	2.12	2.35	2.54	2.87	3.13	3.37	3.62
80.0	1.46	1.72	2.03	2.25	2.43	2.74	2.99	3.21	3.44
82.5	1.41	1.66	1.95	2.14	2.31	2.62	2.86	3.07	3.29
85.0	1.36	1.60	1.87	2.06	2.23	2.50	2.73	2.94	3.12
87.5	1.31	1.54	1.80	1.98	2.13	2.40	2.62	2.82	3.01
90.0	1.27	1.48	1.73	1.90	2.05	2.31	2.52	2.71	2.89
92.5	1.24	1.44	1.67	1.83	1.97	2.22	2.43	2.61	2.79
95.0	1.22	1.39	1.62	1.77	1.90	2.13	2.34	2.51	2.68
97.5	1.19	1.35	1.57	1.71	1.83	2.05	2.25	2.42	2.59
100.0	1.17	1.32	1.51	1.65	1.77	1.97	2.17	2.34	2.51
102.5	1.15	1.29	1.47	1.60	1.71	1.91	2.11	2.27	2.43
105.0	1.13	1.25	1.43	1.55	1.66	1.85	2.04	2.20	2.36
107.5	1.12	1.23	1.39	1.51	1.62	1.79	1.98	2.14	2.28
110.0	1.11	1.21	1.35	1.47	1.57	1.73	1.92	2.07	2.20
112.5	1.10	1.18	1.32	1.43	1.53	1.69	1.87	2.02	2.14

TABLE B4—(Continued)

Ideal Critical Diameter (DI_B), mm	Jominy End-Quench Distance (mm) 15.0	Jominy End-Quench Distance (mm) 18.0	Jominy End-Quench Distance (mm) 21.0	Jominy End-Quench Distance (mm) 24.0	Jominy End-Quench Distance (mm) 27.0	Jominy End-Quench Distance (mm) 33.0	Jominy End-Quench Distance (mm) 39.0	Jominy End-Quench Distance (mm) 45.0	Jominy End-Quench Distance (mm) 51.0
115.0	1.09	1.17	1.29	1.40	1.49	1.64	1.82	1.97	2.08
117.5	1.08	1.16	1.26	1.36	1.45	1.60	1.77	1.92	2.05
120.0	1.08	1.15	1.24	1.33	1.42	1.56	1.72	1.87	2.02
122.5	1.07	1.13	1.22	1.31	1.40	1.53	1.68	1.83	1.98
125.0	1.06	1.12	1.20	1.29	1.37	1.50	1.64	1.79	1.92
127.5	1.05	1.11	1.18	1.27	1.35	1.47	1.61	1.75	1.89
130.0	1.04	1.10	1.17	1.25	1.33	1.44	1.57	1.71	1.85
132.5	1.04	1.08	1.15	1.23	1.30	1.41	1.54	1.67	1.79
135.0	1.03	1.07	1.14	1.21	1.28	1.39	1.52	1.64	1.75
137.5	1.03	1.07	1.12	1.19	1.26	1.37	1.49	1.60	1.70
140.0	1.02	1.06	1.11	1.18	1.24	1.34	1.46	1.57	1.67
142.5	1.02	1.05	1.10	1.16	1.22	1.32	1.43	1.54	1.65
145.0	1.02	1.05	1.09	1.15	1.21	1.30	1.41	1.51	1.61
147.5	1.01	1.04	1.08	1.14	1.19	1.28	1.38	1.48	1.58
150.0	1.01	1.04	1.07	1.13	1.18	1.27	1.37	1.46	1.55
152.5	1.00	1.03	1.06	1.11	1.16	1.25	1.35	1.44	1.53
155.0	1.00	1.02	1.06	1.11	1.15	1.22	1.32	1.41	1.50
157.5	1.00	1.01	1.05	1.09	1.13	1.21	1.30	1.38	1.46
160.0	1.00	1.01	1.04	1.08	1.12	1.19	1.28	1.35	1.42
162.5	1.00	1.01	1.03	1.07	1.11	1.17	1.25	1.33	1.41
165.0	1.00	1.01	1.03	1.06	1.09	1.15	1.23	1.30	1.37
167.5	1.00	1.01	1.02	1.05	1.08	1.13	1.20	1.27	1.34
170.0	1.00	1.00	1.01	1.04	1.07	1.11	1.17	1.24	1.31
172.5	1.00	1.00	1.00	1.03	1.05	1.09	1.15	1.20	1.25
175.0	1.00	1.00	1.00	1.03	1.05	1.08	1.12	1.17	1.22
177.5	1.00	1.00	1.00	1.02	1.04	1.06	1.10	1.14	1.18

TABLE B5—DISTANCE HARDNESS DIVIDING FACTORS VS JOMINY DISTANCE FOR A SPECIFIC CALCULATED DI (BORON STEELS), INCH

Ideal Diameter (DI_B), 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	1.03	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

TABLE B5—(Continued)

Ideal Diameter (DI_B), 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
4.5	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
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 B5—(Continued)

Ideal Diameter (DI$_B$), 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

TABLE B5—(Continued)

Ideal Diameter (DI_B), 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
4.5	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
5.3	1.04	1.10	1.16	1.26	1.31	1.36	1.50	1.63	1.74
5.4	1.04	1.09	1.14	1.24	1.29	1.34	1.47	1.60	1.70
5.5	1.03	1.08	1.13	1.22	1.27	1.32	1.44	1.57	1.67
5.6	1.03	1.07	1.12	1.20	1.25	1.30	1.41	1.54	1.63
5.7	1.03	1.07	1.11	1.19	1.24	1.28	1.39	1.51	1.60
5.8	1.02	1.06	1.10	1.17	1.22	1.26	1.37	1.48	1.57
5.9	1.02	1.05	1.09	1.16	1.20	1.25	1.35	1.45	1.53
6.0	1.01	1.04	1.08	1.14	1.18	1.23	1.33	1.43	1.50
6.1	1.01	1.03	1.08	1.13	1.16	1.21	1.30	1.40	1.47
6.2	1.00	1.02	1.07	1.11	1.15	1.19	1.28	1.38	1.44
6.3	1.00	1.02	1.06	1.10	1.14	1.17	1.26	1.35	1.41
6.4	1.00	1.01	1.05	1.09	1.12	1.15	1.24	1.32	1.39
6.5	1.00	1.01	1.04	1.08	1.10	1.13	1.21	1.30	1.35
6.6	1.00	1.01	1.03	1.07	1.09	1.12	1.18	1.27	1.32
6.7	1.00	1.00	1.02	1.06	1.08	1.10	1.16	1.24	1.29
6.8	1.00	1.00	1.01	1.05	1.07	1.08	1.14	1.20	1.25
6.9	1.00	1.00	1.01	1.05	1.06	1.07	1.12	1.17	1.21
7.0	1.00	1.00	1.00	1.04	1.05	1.05	1.10	1.14	1.17

TABLE B6—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	--
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	--

TABLE B6—(Continued)

% Element	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V
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	--	--	--
0.65	0.273	3.167	1.455	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	--	--	--

TABLE B6—(Continued)

% Element	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V
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	--	--	--
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	--	--	--
1.49	--	6.479	2.043	1.541	4.217	--	--	--
1.50	--	6.530	2.050	1.545	4.239	--	--	--

TABLE B6—(Continued)

% Element	Carbon- Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V
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	--	--	--	--
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 B7—EXAMPLE OF DI CALCULATION

Element	%	Multiplying Factor (Table B1)
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

DI = 0.119 x 3.667 x 1.126 x 1.036 x 1.929 x 1.75 x 1.04 = 1.79 in (45.5 mm)

TABLE B8—EXAMPLE OF ACTUAL BORON FACTOR DETERMINATION

Composition, %	C	Mn	Si	Ni	Cr	Mo	B	Calc DI (Boron Excluded)
	0.29	1.25	0.20	0.13	0.07	0.03	0.0015	31.5 mm (1.24 in)

End-Quench test Results, mm													
"J" Position (mm)	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	18.0	21.0	24.0
Hardness, HRC	50	50	49	49	47	46	43	40	35	30	25	23	21
End-Quench Test Results, inches													
"J" Position (1/16 in)	1	2	3	4	5	6	7	8	9	10	12	14	16
Hardness, HCR	50	50	49	48	47	45	41	38	33	28	25	22	20

TABLE B9—INITIAL HARDNESS AND 50% MARTENSITE HARDNESS VS % CARBON

% Carbon Content	Hardness--HRC Initial	Hardness--HRC 50% Martensite	% Carbon Content	Hardness--HRC Initial	Hardness--HRC 50% Martensite	% Carbon Content	Hardness--HRC Initial	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 B10—DI VS JOMINY DISTANCE FOR 50% MARTENSITE (mm)

"J" mm	DI mm	"J" mm	DI mm	"J" mm	DI mm
1.0	8.4	18.0	94.2	35.0	137.1
2.0	15.7	19.0	97.1	36.0	139.1
3.0	22.9	20.0	100.6	37.0	140.9
4.0	29.7	21.0	103.7	38.0	142.8
5.0	36.3	22.0	106.5	39.0	144.7
6.0	42.9	23.0	109.7	40.0	146.4
7.0	48.2	24.0	112.2	41.0	148.3
8.0	54.2	25.0	114.9	42.0	150.1
9.0	59.5	26.0	117.4	43.0	151.7
10.0	64.2	27.0	119.9	44.0	153.4
11.0	68.6	28.0	122.4	45.0	154.1
12.0	72.1	29.0	124.7	46.0	156.5
13.0	76.4	30.0	127.1	47.0	157.8
14.0	80.1	31.0	129.0	48.0	159.2
15.0	84.0	32.0	131.4	49.0	160.5
16.0	87.6	33.0	133.5	50.0	161.8
17.0	90.1	34.0	135.2	--	--

TABLE B11—DI VS JOMINY DISTANCE FOR 50% MARTENSITE (INCH)

"J" 1/16 in	DI in	"J" 1/16 in	DI in	"J" 1/16 in	DI 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	--	--