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Methods of Determining Hardenability of Steels

RATIONALE

The example in Table A3 is incomplete and incorrect in that some math symbols and factors are missing. The change is editorial in nature and makes the equation correct and complete.

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.

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the latest revision of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

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

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

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

14. G. K. Manning, "Comparison of Tests of Hardenability of Shallow Hardening Steels," SAE Journal, Vol. 61, July 1953, pp 30–36

15. D. J. Carney, "Another Look at Quenchants, Cooling Rates and Hardenability," ASM Transactions, Vol. 46 (1954), pp 882–925

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. 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 Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

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.

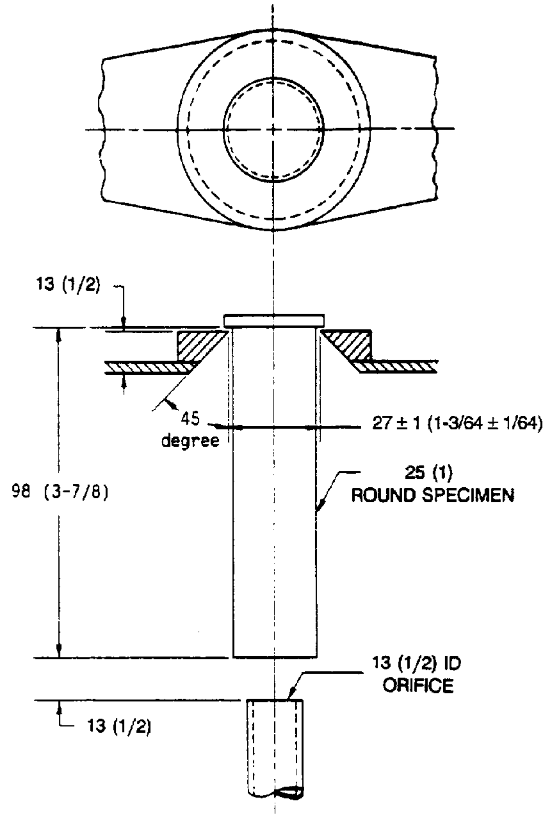


FIGURE 1 - HARDENABILITY TEST SPECIMEN IN FIXTURE FOR WATER QUENCHING

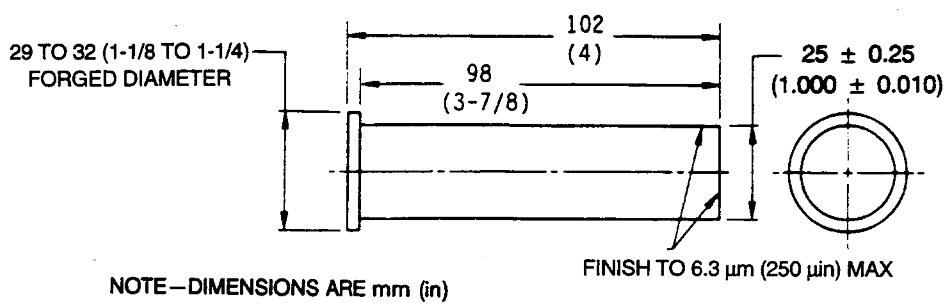
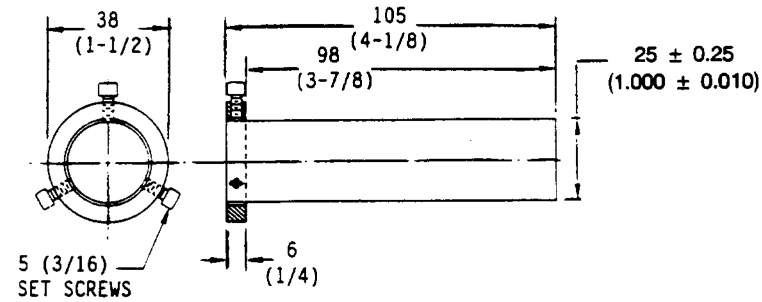


FIGURE 2 - PREFERRED TEST SPECIMEN



NOTE—DIMENSIONS ARE mm (in)

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.