Designation: E18 − 19

An American National Standard

Standard Test Methods for Rockwell Hardness of Metallic Materials[1,2]

This standard is issued under the fixed designation E18; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 These test methods cover the determination of the Rockwell hardness and the Rockwell superficial hardness of metallic materials by the Rockwell indentation hardness principle. This standard provides the requirements for Rockwell hardness machines and the procedures for performing Rockwell hardness tests.

1.2 This test method includes requirements for the use of portable Rockwell hardness testing machines that measure Rockwell hardness by the Rockwell hardness test principle and can meet all the requirements of this test method, including the direct and indirect verifications of the testing machine. Portable Rockwell hardness testing machines that cannot meet the direct verification requirements and can only be verified by indirect verification requirements are covered in Test Method E110.

1.3 This standard includes additional requirements in the following annexes:

Verification of Rockwell Hardness Testing Machines	Annex A1
Rockwell Hardness Standardizing Machines	Annex A2
Standardization of Rockwell Indenters	Annex A3
Standardization of Rockwell Hardness Test Blocks	Annex A4
Guidelines for Determining the Minimum Thickness of a Test Piece	Annex A5
Hardness Value Corrections When Testing on Convex Cylindrical Surfaces	Annex A6

1.4 This standard includes nonmandatory information in the following appendixes that relates to the Rockwell hardness test.

List of ASTM Standards Giving Hardness Values Corresponding to Tensile Strength	Appendix X1
Examples of Procedures for Determining Rockwell Hardness Uncertainty	Appendix X2

1.5 *Units*—At the time the Rockwell hardness test was developed, the force levels were specified in units of kilograms-force (kgf) and the indenter ball diameters were specified in units of inches (in.). This standard specifies the units of force and length in the International System of Units (SI); that is, force in Newtons (N) and length in millimeters (mm). However, because of the historical precedent and continued common usage, force values in kgf units and ball diameters in inch units are provided for information and much of the discussion in this standard refers to these units.

1.6 The test principles, testing procedures, and verification procedures are essentially identical for both the Rockwell and Rockwell superficial hardness tests. The significant differences between the two tests are that the test forces are smaller for the Rockwell superficial test than for the Rockwell test. The same type and size indenters may be used for either test, depending on the scale being employed. Accordingly, throughout this standard, the term Rockwell will imply both Rockwell and Rockwell superficial unless stated otherwise.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

A370 Test Methods and Definitions for Mechanical Testing of Steel Products

A623 Specification for Tin Mill Products, General Requirements

A623M Specification for Tin Mill Products, General Requirements [Metric]

---

[1] These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E28.06 on Indentation Hardness Testing.

Current edition approved Jan. 1, 2019. Published February 2019. Originally approved in 1932. Last previous edition approved in 2018 as E18 – 18a. DOI: 10.1520/E0018-19

[2] In this test method, the term Rockwell refers to an internationally recognized type of indentation hardness test as defined in Section 3, and not to the hardness testing equipment of a particular manufacturer.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

A883 Test Method for Ferrimagnetic Resonance Linewidth and Gyromagnetic Ratio of Nonmetallic Magnetic Materials
A956 Test Method for Leeb Hardness Testing of Steel Products
A1038 Test Method for Portable Hardness Testing by the Ultrasonic Contact Impedance Method
B19 Specification for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks
B36/B36M Specification for Brass Plate, Sheet, Strip, And Rolled Bar
B96/B96M Specification for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes and Pressure Vessels
B103/B103M Specification for Phosphor Bronze Plate, Sheet, Strip, and Rolled Bar
B121/B121M Specification for Leaded Brass Plate, Sheet, Strip, and Rolled Bar
B122/B122M Specification for Copper-Nickel-Tin Alloy, Copper-Nickel-Zinc Alloy (Nickel Silver), and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar
B130 Specification for Commercial Bronze Strip for Bullet Jackets
B134/B134M Specification for Brass Wire
B152/B152M Specification for Copper Sheet, Strip, Plate, and Rolled Bar
B370 Specification for Copper Sheet and Strip for Building Construction
B647 Test Method for Indentation Hardness of Aluminum Alloys by Means of a Webster Hardness Gage
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E74 Practices for Calibration and Verification for Force-Measuring Instruments
E92 Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials
E110 Test Method for Rockwell and Brinell Hardness of Metallic Materials by Portable Hardness Testers
E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness
E384 Test Method for Microindentation Hardness of Materials
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *American Bearings Manufacturer Association Standard:*

ABMA 10-1989 Metal Balls[4]

2.3 *ISO Standards:*

ISO 6508-1 Metallic Materials—Rockwell Hardness Test—Part 1: Test Method (scales A, B, C, D, E, F, G, H, K, N, T)[5]
ISO/IEC 17011 Conformity Assessment—General Requirements for Accreditation Bodies Accrediting Conformity Assessment Bodies[5]
ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories[5]

2.4 *Society of Automotive Engineers (SAE) Standard:*

SAE J417 Hardness Tests and Hardness Number Conversions[6]

3. Terminology and Equations

3.1 *Definitions:*

3.1.1 *calibration*—determination of the values of the significant parameters by comparison with values indicated by a reference instrument or by a set of reference standards.

3.1.2 *standardization*—to bring in conformance to a known standard through verification or calibration.

3.1.3 *verification*—checking or testing to assure conformance with the specification.

3.1.4 *Rockwell hardness test*—an indentation hardness test using a verified machine to force a diamond spheroconical indenter or tungsten carbide (or steel) ball indenter, under specified conditions, into the surface of the material under test, and to measure the difference in depth of the indentation as the force on the indenter is increased from a specified preliminary test force to a specified total test force and then returned to the preliminary test force.

3.1.5 *Rockwell superficial hardness test*—same as the Rockwell hardness test except that smaller preliminary and total test forces are used with a shorter depth scale.

3.1.6 *Rockwell hardness number*—a number derived from the net increase in the depth of indentation as the force on an indenter is increased from a specified preliminary test force to a specified total test force and then returned to the preliminary test force.

3.1.7 *Rockwell hardness machine*—a machine capable of performing a Rockwell hardness test and/or a Rockwell superficial hardness test and displaying the resulting Rockwell hardness number.

3.1.7.1 *Rockwell hardness testing machine*—a Rockwell hardness machine used for general testing purposes.

3.1.7.2 *Rockwell hardness standardizing machine*—a Rockwell hardness machine used for the standardization of Rockwell hardness indenters, and for the standardization of Rockwell hardness test blocks. The standardizing machine differs from a regular Rockwell hardness testing machine by having tighter tolerances on certain parameters.

3.1.7.3 *portable Rockwell hardness testing machine*—a Rockwell hardness testing machine that is designed to be transported, carried, set up, and operated by the users, and that measures Rockwell hardness by the Rockwell indentation hardness test principle.

3.1.7.4 *movable Rockwell hardness testing machine*—a Rockwell hardness testing machine that is designed to be

[4] Available from American Bearing Manufacturers Association (ABMA), 2025 M Street, NW, Suite 800, Washington, DC 20036.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[6] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

moved to different locations on a moveable frame, table or similar support that is integral to the testing machine (for example, securely fixed to a rolling table), or a Rockwell hardness testing machine that is designed to move into testing position prior to a test, (for example, securely fixed to a moving support arm), and has been previously verified to ensure that such a move will not affect the hardness result.

3.2 *Equations:*

3.2.1 The *average* $\bar{H}$ of a set of n hardness measurements $H_1, H_2, \ldots, H_n$ is calculated as:

$$\bar{H} = \frac{H_1 + H_2 + \ldots + H_n}{n} \quad (1)$$

3.2.2 The *error E* in the performance of a Rockwell hardness machine at each hardness level, relative to a standardized scale, is determined as:

$$E = \bar{H} - H_{STD} \quad (2)$$

where:

$\bar{H}$ = average of n hardness measurements $H_1, H_2, \ldots, H_n$ made on a standardized test block as part of a performance verification, and

H_{STD} = certified average hardness value of the standardized test block.

3.2.3 The *repeatability R* in the performance of a Rockwell hardness machine at each hardness level, under the particular verification conditions, is estimated by the range of n hardness measurements made on a standardized test block as part of a performance verification, defined as:

$$R = H_{max} - H_{min} \quad (3)$$

where:

H_{max} = highest hardness value, and

H_{min} = lowest hardness value.

4. Significance and Use

4.1 The Rockwell hardness test is an empirical indentation hardness test that can provide useful information about metallic materials. This information may correlate to tensile strength, wear resistance, ductility, and other physical characteristics of metallic materials, and may be useful in quality control and selection of materials.

4.2 Rockwell hardness tests are considered satisfactory for acceptance testing of commercial shipments, and have been used extensively in industry for this purpose.

4.3 Rockwell hardness testing at a specific location on a part may not represent the physical characteristics of the whole part or end product.

4.4 Adherence to this standard test method provides traceability to national Rockwell hardness standards except as stated otherwise.

5. Principles of Test and Apparatus

5.1 *Rockwell Hardness Test Principle*—The general principle of the Rockwell indentation hardness test is illustrated in Fig. 1. The test is divided into three steps of force application and removal.

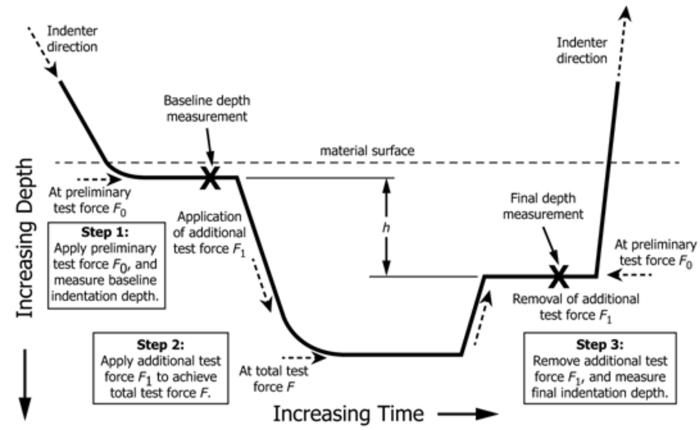


FIG. 1 Rockwell Hardness Test Method (Schematic Diagram)

Step 1—The indenter is brought into contact with the test specimen, and the preliminary test force F_0 is applied. After holding the preliminary test force for a specified dwell time, the baseline depth of indentation is measured.

Step 2—The force on the indenter is increased at a controlled rate by the additional test force F_1 to achieve the total test force F. The total test force is held for a specified dwell time.

Step 3—The additional test force is removed, returning to the preliminary test force. After holding the preliminary test force for a specified dwell time, the final depth of indentation is measured. The Rockwell hardness value is derived from the difference h in the final and baseline indentation depths while under the preliminary test force. The preliminary test force is removed and the indenter is removed from the test specimen.

5.1.1 There are two general classifications of the Rockwell test: the Rockwell hardness test and the Rockwell superficial hardness test. The significant difference between the two test classifications is in the test forces that are used. For the Rockwell hardness test, the preliminary test force is 10 kgf (98 N) and the total test forces are 60 kgf (589 N), 100 kgf (981 N), and 150 kgf (1471 N). For the Rockwell superficial hardness test, the preliminary test force is 3 kgf (29 N) and the total test forces are 15 kgf (147 N), 30 kgf (294 N), and 45 kgf (441 N).

5.1.2 Indenters for the Rockwell hardness test include a diamond spheroconical indenter and tungsten carbide ball indenters of specified diameters.

5.1.2.1 Steel indenter balls may be used only for testing thin sheet tin mill products specified in Specifications A623 and A623M using the HR15T and HR30T scales with a diamond spot anvil. Testing of this product may give significantly differing results using a tungsten carbide ball as compared to historical test data using a steel ball.

NOTE 1—Previous editions of this standard have stated that the steel ball was the standard type of Rockwell indenter ball. The tungsten carbide ball is considered the standard type of Rockwell indenter ball. The use of tungsten carbide balls provide an improvement to the Rockwell hardness test because of the tendency of steel balls to flatten with use, which results in an erroneously elevated hardness value. The user is cautioned that Rockwell hardness tests comparing the use of steel and tungsten carbide balls have been shown to give different results. For example, depending on the material tested and its hardness level, Rockwell B scale tests using a tungsten carbide ball indenter have given results approximately one

Rockwell point lower than when a steel ball indenter is used.

5.1.3 The Rockwell hardness scales are defined by the combinations of indenter and test forces that may be used. The standard Rockwell hardness scales and typical applications of the scales are given in Tables 1 and 2. Rockwell hardness values shall be determined and reported in accordance with one of these standard scales.

5.2 *Calculation of the Rockwell Hardness Number*—During a Rockwell test, the force on the indenter is increased from a preliminary test force to a total test force, and then returned to the preliminary test force. The difference in the two indentation depth measurements, while under the preliminary test force, is measured as *h* (see Fig. 1).

5.2.1 The unit measurement for *h* is mm. From the value of *h*, the Rockwell hardness number is derived. The Rockwell hardness number is calculated as:

5.2.1.1 For scales using a diamond spheroconical indenter (see Tables 1 and 2):

$$\text{Rockwell Hardness} = 100 - \frac{h}{0.002} \quad (4)$$

$$\text{Rockwell Superficial Hardness} = 100 - \frac{h}{0.001} \quad (5)$$

where *h* is in mm.

5.2.1.2 For scales using a ball indenter (see Tables 1 and 2):

$$\text{Rockwell Hardness} = 130 - \frac{h}{0.002} \quad (6)$$

$$\text{Rockwell Superficial Hardness} = 100 - \frac{h}{0.001} \quad (7)$$

where *h* is in mm.

5.2.2 The Rockwell hardness number is an arbitrary number, which, by method of calculation, results in a higher number for harder material.

5.2.3 Rockwell hardness values shall not be designated by a number alone because it is necessary to indicate which indenter and forces have been employed in making the test (see Tables 1 and 2). Rockwell hardness numbers shall be quoted with a scale symbol representing the indenter and forces used. The hardness number is followed by the symbol HR and the scale designation. When a ball indenter is used, the scale designation is followed by the letter "W" to indicate the use of a tungsten carbide ball or the letter "S" to indicate the use of a steel ball (see 5.1.2.1).

5.2.3.1 *Examples:*

64 HRC = Rockwell hardness number of 64 on Rockwell C scale

81 HR30N = Rockwell superficial hardness number of 81 on the Rockwell 30N scale

72 HRBW = Rockwell hardness number of 72 on the Rockwell B scale using a tungsten carbide ball indenter

5.2.4 A reported Rockwell hardness number or the average value of Rockwell hardness measurements shall be rounded in accordance with Practice E29 with a resolution no greater than the resolution of the hardness value display of the testing machine. Typically, the resolution of a Rockwell hardness number should not be greater than 0.1 Rockwell units.

NOTE 2—When the Rockwell hardness test is used for the acceptance testing of commercial products and materials, the user should take into account the potential measurement differences between hardness testing machines allowed by this standard (see Section 10, Precision and Bias). Because of the allowable ranges in the tolerances for the repeatability and error of a testing machine, as specified in the verification requirements of Annex A1, one testing machine may have a test result that is one or more hardness points different than another testing machine, yet both machines can be within verification tolerances (see Table A1.3). Commonly for acceptance testing, Rockwell hardness values are rounded to whole numbers following Practice E29. Users are encouraged to address rounding practices with regards to acceptance testing within their quality management system, and make any special requirements known during contract review.

5.3 *Rockwell Testing Machine*—The Rockwell testing machine shall make Rockwell hardness determinations by applying the test forces and measuring the depth of indentation in accordance with the Rockwell hardness test principle.

5.3.1 See the Equipment Manufacturer's Instruction Manual for a description of the machine's characteristics, limitations, and respective operating procedures.

5.3.2 The Rockwell testing machine shall automatically convert the depth measurements to a Rockwell hardness number and indicate the hardness number and Rockwell scale by an electronic device or by a mechanical indicator.

TABLE 1 Rockwell Hardness Scales

Scale Symbol	Indenter	Total Test Force, kgf	Dial Figures	Typical Applications of Scales
B	1/16-in. (1.588-mm) ball	100	red	Copper alloys, soft steels, aluminum alloys, malleable iron, etc.
C	diamond	150	black	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case hardened steel, and other materials harder than B100.
A	diamond	60	black	Cemented carbides, thin steel, and shallow case-hardened steel.
D	diamond	100	black	Thin steel and medium case hardened steel, and pearlitic malleable iron.
E	1/8-in. (3.175-mm) ball	100	red	Cast iron, aluminum and magnesium alloys, bearing metals.
F	1/16-in. (1.588-mm) ball	60	red	Annealed copper alloys, thin soft sheet metals.
G	1/16-in. (1.588-mm) ball	150	red	Malleable irons, copper-nickel-zinc and cupro-nickel alloys. Upper limit G92 to avoid possible flattening of ball.
H	1/8-in. (3.175-mm) ball	60	red	Aluminum, zinc, lead.
K	1/8-in. (3.175-mm) ball	150	red	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect. (applies to K, L, M, P, R, S, V)
L	1/4-in. (6.350-mm) ball	60	red	
M	1/4-in. (6.350-mm) ball	100	red	
P	1/4-in. (6.350-mm) ball	150	red	
R	1/2-in. (12.70-mm) ball	60	red	
S	1/2-in. (12.70-mm) ball	100	red	
V	1/2-in. (12.70-mm) ball	150	red	

TABLE 2 Rockwell Superficial Hardness Scales

Total Test Force, kgf (N)	Scale Symbols				
	N Scale, Diamond Indenter	T Scale, 1⁄16-in. (1.588-mm) Ball	W Scale, 1⁄8-in. (3.175-mm) Ball	X Scale, 1⁄4-in. (6.350-mm) Ball	Y Scale, 1⁄2-in. (12.70-mm) Ball
15 (147)	15N	15T	15W	15X	15Y
30 (294)	30N	30T	30W	30X	30Y
45 (441)	45N	45T	45W	45X	45Y

5.4 *Indenters*—The standard Rockwell indenters are either diamond spheroconical indenters or tungsten carbide balls of 1.588 mm (1⁄16 in.), 3.175 mm (1⁄8 in.), 6.350 mm (1⁄4 in.), or 12.70 mm (1⁄2 in.) in diameter. Indenters shall meet the requirements defined in Annex A3. Steel ball indenters may be used in certain circumstances (see 5.1.2.1).

5.4.1 Dust, dirt, or other foreign materials shall not be allowed to accumulate on the indenter, as this will affect the test results.

NOTE 3—Indenters certified to revision E18-07 or later meet the requirements of this standard.

5.5 *Specimen Support*—A specimen support or "anvil" shall be used that is suitable for supporting the specimen to be tested. The seating and supporting surfaces of all anvils shall be clean and smooth and shall be free from pits, deep scratches, and foreign material. Damage to the anvil may occur from testing too thin material or accidental contact of the anvil by the indenter. If the anvil is damaged from any cause, it shall be repaired or replaced. Anvils showing the least visibly perceptible damage may give inaccurate results, particularly on thin material.

5.5.1 Common specimen support anvils should have a minimum hardness of 58 HRC. Some specialty support anvils require a lower material hardness.

5.5.2 Flat pieces should be tested on a flat anvil that has a smooth, flat bearing surface whose plane is perpendicular to the axis of the indenter.

5.5.3 Small diameter cylindrical pieces shall be tested with a hard V-grooved anvil with the axis of the V-groove directly under the indenter, or on hard, parallel, twin cylinders properly positioned and clamped in their base. These types of specimen supports shall support the specimen with the apex of the cylinder directly under the indenter.

5.5.4 For thin materials or specimens that are not perfectly flat, an anvil having an elevated, flat "spot" 3 mm (1⁄8 in.) to 12.5 mm (1⁄2 in.) in diameter should be used. This spot shall be polished smooth and flat. Very soft material should not be tested on the "spot" anvil because the applied force may cause the penetration of the anvil into the under side of the specimen regardless of its thickness.

5.5.5 When testing thin sheet metal with a ball indenter, it is recommended that a diamond spot anvil be used. The highly polished diamond surface shall have a diameter between 4.0 mm (0.157 in.) and 7.0 mm (0.2875 in.) and be centered within 0.5 mm (0.02 in.) of the test point.

5.5.5.1 CAUTION: A diamond spot anvil should only be used with a maximum total test force of 45 kgf (441 N) and a ball indenter. This recommendation should be followed except when directed otherwise by material specification.

5.5.6 Special anvils or fixtures, including clamping fixtures, may be required for testing pieces or parts that cannot be supported by standard anvils. Auxiliary support may be used for testing long pieces with so much overhang that the piece is not firmly seated by the preliminary force.

5.6 *Verification*—Rockwell testing machines shall be verified periodically in accordance with Annex A1.

5.7 *Test Blocks*—Test blocks meeting the requirements of Annex A4 shall be used to verify the testing machine in accordance with Annex A1.

NOTE 4—Test blocks certified to revision E18-07 or later meet the requirements of this standard.

NOTE 5—It is recognized that appropriate standardized test blocks are not available for all geometric shapes, or materials, or both.

5.8 *Use of Portable Rockwell Hardness Testing Machines:*

5.8.1 A fixed-location Rockwell hardness testing machine may not be capable of testing certain samples because of the sample size or weight, sample location, accessibility of the test point or other requirements. In these circumstances, the use of a portable Rockwell hardness testing machine is an acceptable method to test these samples. This method allows the use of a portable Rockwell hardness testing machine as follows.

5.8.1.1 The portable Rockwell hardness testing machine shall meet the requirements of this method, including the test principle, apparatus, indenters, applied forces, test procedures and the direct and indirect verifications of the testing machine (except as indicated in Table A1.1). Test Method E110 covers portable Rockwell hardness testing machines that cannot be directly verified or cannot pass direct verification but meet the other requirements of this method.

5.8.1.2 A portable Rockwell hardness testing machine shall be used only when testing circumstances make it impractical to use a fixed-location Rockwell hardness testing machine. In such cases, it is recommended that an agreement or understanding be made between all parties involved (for example, testing service and customer) that a portable Rockwell hardness testing machine will be used instead of a fixed-location Rockwell hardness testing machine (see 5.8.1.)

5.8.1.3 The portable Rockwell hardness testing machine shall measure hardness by the Rockwell hardness test principle (see 5.1). Portable hardness testing machines or instruments that measure hardness by other means or procedures different than the Rockwell hardness test principle, such as those defined in Test Methods A883, A956, A1038 or B647, produce converted Rockwell hardness values and do not comply with this method.

5.8.2 *Daily Verification of portable hardness testing machines*—Portable hardness testing machines are susceptible to damage when they are transported or carried from one test site to another. Therefore, in addition to complying with the daily verification requirements specified in 7.1 and Annex A1, a daily verification shall be performed at each test worksite where the hardness tests are to be made just prior to making the hardness tests. The verification shall be performed with the portable hardness testing machine oriented as closely as practical to the position that it will be used. It is recommended that the daily verification be repeated occasionally during testing and after testing is completed.

5.8.3 Additional reporting requirements when using a portable Rockwell hardness testing machine are given in 9.2.

5.8.4 Portable hardness testing machines by the nature of their application may induce errors that could influence the test results. To understand the differences in results expected between portable and fixed-location Rockwell hardness testing machines, the user should compare the results of the precision and bias studies given in Section 10 and in Test Method E110.

6. Test Piece

6.1 For best results, both the test surface and the bottom surface of the test piece should be smooth, even and free from oxide scale, foreign matter, and lubricants. An exception is made for certain materials such as reactive metals that may adhere to the indenter. In such situations, a suitable lubricant such as kerosene may be used. The use of a lubricant shall be defined on the test report.

6.2 Preparation shall be carried out in such a way that any alteration of the surface hardness of the test surface (for example, due to heat or cold-working) is minimized.

6.3 The thickness of the test piece or of the layer under test should be as defined in tables and presented graphically in Annex A5. These tables were determined from studies on strips of carbon steel and have proven to give reliable results. For all other materials, it is recommended that the thickness should exceed 10 times the depth of indentation. In general, no deformation should be visible on the back of the test piece after the test, although not all such marking is indicative of a bad test.

6.3.1 Special consideration should be made when testing parts that exhibit hardness gradients; for example, parts that were case-hardened by processes such as carburizing, carbonitriding, nitriding, induction, etc. The minimum thickness guidelines given in Annex A5 only apply to materials of uniform hardness, and should not be used to determine the appropriate scale for measuring parts with hardness gradients. The selection of an appropriate Rockwell scale for parts with hardness gradients should be made by special agreement.

NOTE 6—A table listing the minimum effective case depth needed for different Rockwell scales is given in SAE J417.

6.4 When testing on convex cylindrical surfaces, the result may not accurately indicate the true Rockwell hardness; therefore, the corrections given in Annex A6 shall be applied. For diameters between those given in the tables, correction factors may be derived by linear interpolation. Tests performed on diameters smaller than those given in Annex A6 are not acceptable. Corrections for tests on spherical and concave surfaces should be the subject of special agreement.

NOTE 7—A table of correction values to be applied to test results made on spherical surfaces is given in ISO 6508-1.

6.5 When testing small diameter specimens, the accuracy of the test will be seriously affected by alignment between the indenter and the test piece, by surface finish, and by the straightness of the cylinder.

7. Test Procedure

7.1 A daily verification of the testing machine shall be performed in accordance with A1.5 prior to making hardness tests. Hardness measurements shall be made only on the calibrated surface of the test block.

7.1.1 The results of a daily verification shall comply with the current values specified in Table A1.3 regardless of any maximum error E value marked on the test block (see Note 8).

NOTE 8—Different editions of this method have revised some maximum error E values given in Table A1.3. Consequently, the maximum error E values marked on older standardized test blocks may not reflect the current values.

7.2 Rockwell hardness tests should be carried out at ambient temperature within the limits of 10 to 35 °C (50 to 95 °F). Users of the Rockwell hardness test are cautioned that the temperature of the test material and the temperature of the hardness tester may affect test results. Consequently, users should ensure that the test temperature does not adversely affect the hardness measurement.

7.3 The test piece shall be supported rigidly so that displacement of the test surface is minimized (see 5.5).

7.4 *Test Cycle*—This standard specifies the Rockwell test cycle by stating recommendations or requirements for five separate parts of the cycle. These parts are illustrated for a Rockwell C scale test in Fig. 2, and defined as follows:

(1) Contact Velocity, v_A—The velocity of the indenter at the point of contact with the test material.

(2) Preliminary Force Dwell Time, t_{PF}—The dwell time beginning when the preliminary force is fully applied and ending when the first baseline depth of indentation is measured, (also see 7.4.1.3).

(3) Additional Force Application Time, t_{TA}—The time for applying the additional force to obtain the full total force.

(4) Total Force Dwell Time, t_{TF}—The dwell time while the total force is fully applied.

(5) Dwell Time for Elastic Recovery, t_R—The dwell time at the preliminary force level, beginning when the additional force is fully removed, and ending when the second and final depth of indentation is measured.

7.4.1 The standard Rockwell test cycle is specified in Table 3. The test cycle used for Rockwell hardness tests shall be in accordance with these test cycle values and tolerances (see Note 9), with the following exceptions.

7.4.1.1 *Precautions for Materials Having Excessive Time-Dependent Plasticity (Indentation Creep)*—In the case of materials exhibiting excessive plastic flow after application of the total test force, special considerations may be necessary since the indenter will continue to penetrate. When materials require the use of a longer total force dwell time than for the standard test cycle stated in Table 3, this should he specified in the product specification. In these cases, the actual extended

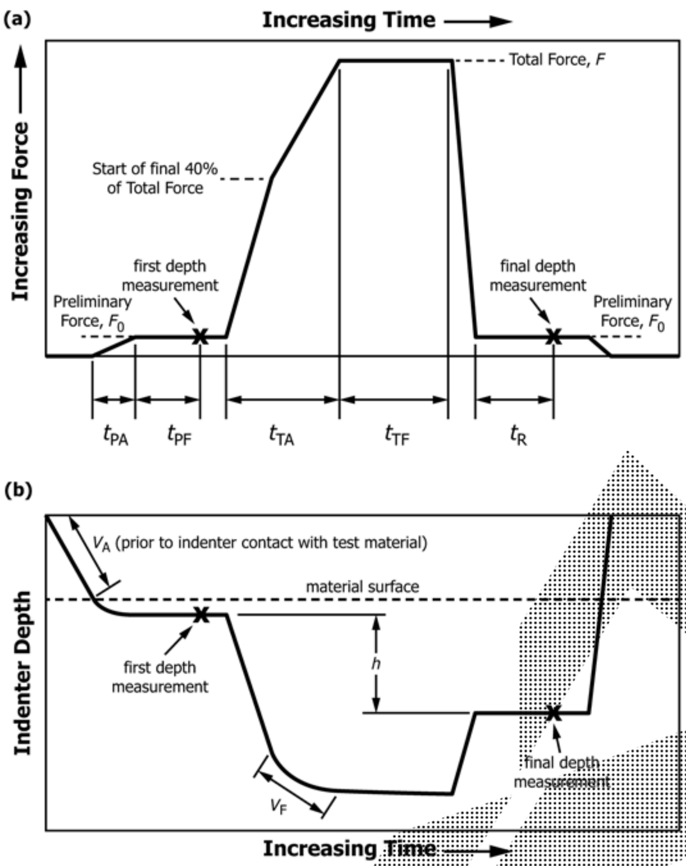


FIG. 2 Schematic of Force-Time Plot (a) and Indenter Depth-Time Plot (b) of an HRC Test Illustrating the Test Cycle Parts

TABLE 3 Test Cycle Tolerances

Test Cycle Parameter	Tolerance
Indenter contact velocity, v_A (recommended)	≤2.5 mm/s
Dwell time for preliminary force, t_{PF} (when the time to apply the preliminary force $t_{PA} \geq 1$ s, then calculate this parameter as $\frac{t_{PA}}{2}+t_{PF}$)	0.1 to 4.0 s
Time for application of additional force, t_{TA}	1.0 to 8.0 s
Dwell time for total force, t_{TF}	2.0 to 6.0 s
Dwell time for elastic recovery, t_R	0.2 to 5.0 s

total force dwell time used shall be recorded and reported after the test results (for example, 65 HRFW, 10 s).

7.4.1.2 There are testing conditions that may require that the indenter contact velocity exceed the recommended maximum stated in Table 3. The user should ensure that the higher contact velocity does not cause a shock or overload which would affect the hardness result. It is recommended that comparison tests be made on the same test material using a test cycle within the requirements stated in Table 3.

7.4.1.3 For testing machines that take 1 s or longer to apply the preliminary force t_{PA}, the preliminary force dwell time value t_{PF} shall be adjusted before comparing the parameter with the tolerances of Table 3 by adding to it one half of t_{PA} as $\frac{t_{PA}}{2}+t_{PF}$. For testing machines that apply the preliminary force t_{PA} in 1 s or less, this adjustment to the preliminary force dwell time value t_{PF} is optional.

NOTE 9—It is recommended that the test cycle to be used with the hardness machine match, as closely as possible, the test cycle used for the indirect verification of the hardness machine. Varying the values of the testing cycle parameters within the tolerances of Table 3 can produce different hardness results.

7.5 *Test Procedure*—There are many designs of Rockwell hardness machines, requiring various levels of operator control. Some hardness machines can perform the Rockwell hardness test procedure automatically with almost no operator influence, while other machines require the operator to control most of the test procedure.

7.5.1 Bring the indenter into contact with the test surface in a direction perpendicular to the surface and, if possible, at a velocity within the recommended maximum contact velocity v_A.

7.5.2 Apply the preliminary test force F_0 of 10 kgf (98 N) for the Rockwell hardness test or 3 kgf (29 N) for the Rockwell superficial hardness test.

7.5.3 Maintain the preliminary force for the specified preliminary force dwell time t_{PF}.

7.5.4 At the end of the preliminary force dwell time t_{PF}, immediately establish the reference position of the baseline depth of indentation (see manufacturer's Instruction Manual).

7.5.5 Increase the force by the value of the additional test force F_1 needed to obtain the required total test force F for a given hardness scale (see Tables 1 and 2). The additional force F_1 shall be applied in a controlled manner within the specified application time range t_{TA}.

7.5.6 Maintain the total force F for the specified total force dwell time t_{TF}.

7.5.7 Remove the additional test force F_1 while maintaining the preliminary test force F_0.

7.5.8 Maintain the preliminary test force F_0 for an appropriate time to allow elastic recovery in the test material and the stretch of the frame to be factored out.

7.5.9 At the end of the dwell time for elastic recovery, immediately establish the final depth of indentation (see manufacturer's Instruction Manual). The testing machine shall calculate the difference between the final and baseline depth measurements and indicate the resulting Rockwell hardness value. The Rockwell hardness number is derived from the differential increase in depth of indentation as defined in Eq 4, Eq 5, Eq 6, and Eq 7.

7.6 Throughout the test, the apparatus shall be protected from shock or vibration that could affect the hardness measurement result.

7.7 After each change, or removal and replacement, of the indenter or the anvil, at least two preliminary indentations shall be made to ensure that the indenter and anvil are seated properly. The results of the preliminary indentations shall be disregarded.

7.8 After each change of a test force or removal and replacement of the indenter or the anvil, it is strongly recommended that the operation of the machine be checked in accordance with the daily verification method specified in Annex A1.

7.9 *Indentation Spacing*—The hardness of the material immediately surrounding a previously made indentation will usually increase due to the induced residual stress and work-hardening caused by the indentation process. If a new indentation is made in this affected material, the measured hardness value will likely be higher than the true hardness of the material as a whole. Also, if an indentation is made too close to the edge of the material or very close to a previously made indentation, there may be insufficient material to constrain the deformation zone surrounding the indentation. This can result in an apparent lowering of the hardness value. Both of these circumstances can be avoided by allowing appropriate spacing between indentations and from the edge of the material.

7.9.1 The distance between the centers of two adjacent indentations shall be at least three times the diameter *d* of the indentation (see Fig. 3).

7.9.2 The distance from the center of any indentation to an edge of the test piece shall be at least two and a half times the diameter of the indentation (see Fig. 3).

8. Conversion to Other Hardness Scales or Tensile Strength Values

8.1 There is no general method of accurately converting the Rockwell hardness numbers on one scale to Rockwell hardness numbers on another scale, or to other types of hardness numbers, or to tensile strength values. Such conversions are, at best, approximations and, therefore, should be avoided except for special cases where a reliable basis for the approximate conversion has been obtained by comparison tests.

NOTE 10—The Standard Hardness Conversion Tables for Metals, E140, give approximate conversion values for specific materials such as steel, austenitic stainless steel, nickel and high-nickel alloys, cartridge brass, copper alloys, and alloyed white cast irons. The Rockwell hardness data in the conversion tables of E140 was determined using steel ball indenters.

NOTE 11—ASTM standards giving approximate hardness-tensile strength relationships are listed in Appendix X1.

9. Report

9.1 The test report shall include the following information:

9.1.1 The Rockwell hardness number. All reports of Rockwell hardness numbers shall indicate the scale used. The reported number shall be rounded in accordance with Practice E29 (see 5.2.4 and Note 2),

9.1.2 The total force dwell time, if outside the specified standard test cycle tolerances (see Table 3), and

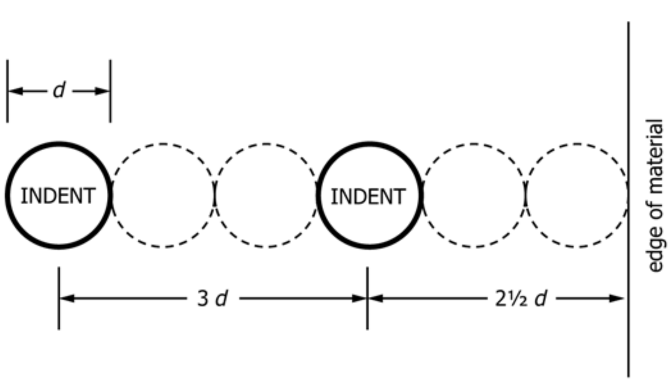


FIG. 3 Schematic of Minimum Indentation Spacing

9.1.3 The ambient temperature at the time of test, if outside the limits of 10 to 35 °C (50 to 95 °F), unless it has been shown not to affect the measurement result.

9.2 When using a portable Rockwell hardness testing machine, the measured hardness number shall be reported in accordance with 9.1, and appended with a /P to indicate that it was determined by portable Rockwell hardness testing machine, For example:
40 HRC/P = Rockwell hardness number of 40 on the Rockwell C scale.
72 HRBW/P = Rockwell hardness number of 72 on the Rockwell B scale with a tungsten carbide ball indenter.

10. Precision and Bias[7, 8]

10.1 *Precision*—A Rockwell hardness precision and bias study was conducted in 2000 in accordance with Practice E691. Tests were performed in the following six Rockwell scales: HRA, HRC, HRBS, HR30N, HR30TS, and HRES. The tests in the HRBS, HR30TS and HRES scales were made using steel ball indenters. A total of 18 Rockwell scale hardness test blocks of the type readily available were used for this study. Test blocks at three different hardness levels (high, medium, and low) in each scale were tested three times each. The results from the first study are filed under ASTM Research Report RR:E28-1021.[7,8]

10.2 Starting with version E18-05, this standard changed from the use of steel balls to carbide balls for all scales that use a ball indenter. Due to this change, a second study was conducted in 2006. The second study was performed in accordance with Practice E691 and was identical to the initial study except it was limited to the HRBW, HR30TW, and HREW scales, all of which use carbide ball indenters. The results from that study are filed under ASTM Research Report RR:E28-1022.

10.3 A total of 14 different labs participated in the two studies. Eight participated in the first study and nine in the second study. Three labs participated in both studies. The labs chosen to participate in this study were a combination of commercial testing labs (6), in-house labs (5) and test block manufacturer's calibration labs (3). Each lab was instructed to test each block in three specific locations around the surface of the blocks. All testing was to be done according to ASTM E18-05.

10.4 The results given in Table 4 may be useful in interpreting measurement differences. It is a combination of the two studies. The diamond scales, HRC, HRA, and HR30N are from the first study and the ball scales, HRBW, HREW, and HR30TW are from the second study. This combination reflects the testing that is being done currently.

10.5 The value of r_{PB} indicates the typical amount of variation that can be expected between test results obtained for the same material by the same operator using the same

[7] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E28-1021.

[8] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E28-1022.

TABLE 4 Results of the Precision and Bias Study

Test Block	Average Hardness	Sr	SR	r_{PB}	R_{PB}
Data from 2000 study					
62.8 HRA	62.50	0.164	0.538	0.459	1.506
73.1 HRA	73.04	0.138	0.358	0.387	1.002
83.9 HRA	84.54	0.085	0.468	0.238	1.309
25.0 HRC	24.99	0.335	0.440	0.937	1.232
45.0 HRC	45.35	0.156	0.259	0.438	0.725
65.0 HRC	65.78	0.153	0.389	0.427	1.089
45.9 HR30N	46.75	0.299	2.489	0.837	6.969
64.0 HR30N	64.74	0.248	0.651	0.694	1.822
81.9 HR30N	82.52	0.195	0.499	0.547	1.396
Data from 2006 study					
40 HRBW	43.90	0.492	0.668	1.378	1.871
60 HRBW	61.77	0.663	0.697	1.855	1.953
95 HRBW	91.09	0.250	0.292	0.701	0.817
62 HREW	64.07	0.346	0.675	0.970	1.890
81 HREW	81.61	0.232	0.406	0.649	1.136
100 HREW	96.22	0.177	0.322	0.497	0.901
22 HR30TW	18.33	0.702	0.901	1.965	2.522
56 HR30TW	58.0	0.476	0.517	1.333	1.447
79 HR30TW	81.0	0.610	0.851	1.709	2.382

hardness tester on the same day. When comparing two test results made under these conditions, a measurement difference of less than the r_{PB} value for that Rockwell scale is an indication that the results may be equivalent.

10.6 The value of R_{PB} indicates the typical amount of variation that can be expected between test results obtained for the same material by different operators using different hardness testers on different days. When comparing two test results made under these conditions, a measurement difference of less than the R_{PB} value for that Rockwell scale is an indication that the results may be equivalent.

10.7 Any judgments based on 10.5 and 10.6 would have an approximately 95 % probability of being correct.

10.8 This precision and bias study was conducted on a selected number of the most commonly used Rockwell scales. For Rockwell scales not listed, the r_{PB} and R_{PB} values may be estimated using the conversion tables of E140 to determine a corresponding increment of hardness for the scale of interest at the hardness level of interest. The user is cautioned that estimating the r_{PB} and R_{PB} values in this way, decreases the probability of them being correct.

10.9 Although the precision values given in Table 4 provide guidance on interpreting differences in Rockwell hardness measurement results, a complete evaluation of measurement uncertainty will provide a more definitive interpretation of the results for the specific testing conditions.

10.10 The data generally indicated reasonable precision except for the 45.9 HR30N scale. In that scale the SR and R_{PB} values are very high compared to all of the other scales. An examination of the raw data reveled that one lab's results were much higher than the others, significantly affecting the overall results in that scale. The results from all of the other scales seem to be reasonable.

10.11 *Bias*—There are no recognized standards by which to fully estimate the bias of this test method.

11. Keywords

11.1 hardness; mechanical test; metals; Rockwell

ANNEXES

(Mandatory Information)

A1. VERIFICATION OF ROCKWELL HARDNESS TESTING MACHINES

A1.1 Scope

A1.1.1 Annex A1 specifies three types of procedures for verifying Rockwell hardness testing machines: *direct verification*, *indirect verification*, and *daily verification*.

A1.1.2 Direct verification is a process for verifying that critical components of the hardness testing machine are within allowable tolerances by directly measuring the test forces, depth measuring system, machine hysteresis, and testing cycle.

A1.1.3 Indirect verification is a process for periodically verifying the performance of the testing machine by means of standardized test blocks and indenters.

A1.1.4 The daily verification is a process for monitoring the performance of the testing machine between indirect verifications by means of standardized test blocks.

A1.1.5 Adherence to this standard and annex provides traceability to national standards, except as stated otherwise.

A1.2 General Requirements

A1.2.1 The testing machine shall be verified at specific instances and at periodic intervals as specified in Table A1.1, and when circumstances occur that may affect the performance of the testing machine.

A1.2.2 The temperature at the verification site shall be measured with an instrument having an accuracy of at least ±2.0 °C or ±3.6 °F. It is recommended that the temperature be monitored throughout the verification period, and significant temperature variations be recorded and reported. The temperature at the verification site does not need to be measured for a daily verification or when qualifying additional user's indenters in accordance with A1.4.10.

A1.2.3 All instruments used to make measurements required by this Annex shall be calibrated traceable to national standards when a system of traceability exists, except as noted otherwise.

TABLE A1.1 Verification Schedule for a Rockwell Testing Machine

Verification Procedure	Schedule
Direct verification	When a testing machine is new, or when adjustments, modifications or repairs are made that could affect the application of the test forces, the depth measuring system, or the machine hysteresis. When a testing machine fails an indirect verification (see A1.4.9.4).
Indirect verification	Recommended every 12 months, or more often if needed. Shall be no longer than every 18 months. When a testing machine is installed or moved, [only a partial indirect verification is performed by following the procedure given in A1.4.7 for verifying the as-found condition]. Indirect verification is not required after moving a portable or movable Rockwell hardness testing machine (see 3.1.7.3, 3.1.7.4, and 5.8). Following a direct verification. To qualify an indenter that was not verified in the last indirect verification, (only a partial indirect verification is performed, see A1.4.10).
Daily verification	Required each day that hardness tests are to be made. Recommended whenever the indenter, anvil, or test force is changed.

A1.2.4 Direct verification of newly manufactured or rebuilt testing machines shall be performed at the place of manufacture, rebuild or repair. Direct verification may also be performed at the location of use.

A1.2.5 Indirect verification of the testing machine shall be performed at the location where it will be used.

NOTE A1.1—It is recommended that the calibration agency that is used to conduct the verifications of Rockwell hardness testing machines be accredited to the requirements of ISO 17025 (or an equivalent) by an accrediting body recognized by the International Laboratory Accreditation Cooperation (ILAC) as operating to the requirements of ISO/IEC 17011.

A1.3 Direct Verification

A1.3.1 A direct verification of the testing machine shall be performed at specific instances in accordance with Table A1.1. The test forces, depth-measuring system, machine hysteresis, and testing cycle shall be verified as follows.

NOTE A1.2—Direct verification is a useful tool for determining the sources of error in a Rockwell hardness testing machine. It is recommended that testing machines undergo direct verification periodically to make certain that errors in one component of the machine are not being offset by errors in another component.

A1.3.2 *Verification of the Test Forces*—For each Rockwell scale that will be used, the corresponding test forces (preliminary test force at loading, total test force, and preliminary test force during elastic recovery) shall be measured. The test forces shall be measured by means of a Class A elastic force measuring instrument having an accuracy of at least 0.25 %, as described in Practices E74.

A1.3.2.1 Make three measurements of each force. The forces shall be measured as they are applied during testing.

A1.3.2.2 Each preliminary test force F_0 and each total test force F shall be accurate to within the tolerances given in Table A1.2, and the range of the three force measurements (highest minus lowest) shall be within 75 % of the tolerances of Table A1.2.

TABLE A1.2 Tolerances on Applied Force for a Rockwell Testing Machine

Force		Tolerance	
kgf	N	kgf	N
10	98.07	0.20	1.96
60	588.4	0.45	4.41
100	980.7	0.65	6.37
150	1471	0.90	8.83
3	29.42	0.060	0.589
15	147.1	0.100	0.981
30	294.2	0.200	1.961
45	441.3	0.300	2.963

A1.3.3 *Verification of the Depth Measuring System*—The depth measuring system shall be verified by means of an instrument, device or standard having an accuracy of at least 0.0002 mm.

A1.3.3.1 Verify the testing machine's depth measurement system at not less than four evenly spaced increments covering the full range of the normal working depth measured by the testing machine. The normal working depth range shall correspond to the lowest and highest hardness values for the Rockwell scales that will be tested.

A1.3.3.2 The indentation-depth measuring device shall be accurate within ±0.001 mm for the regular Rockwell hardness scales and ±0.0005 mm for the Rockwell superficial hardness scales. These accuracies correspond to 0.5 hardness units.

A1.3.3.3 Some testing machines have a long-stroke depth measuring system where the location of the working range of the depth measuring system varies depending on the thickness of the test material. This type of testing machine shall have a system to electronically verify that the depth measuring device is continuous over its full range and free from dirt or other discontinuities that could affect its accuracy. These types of testers shall be verified using the following steps.

(1) At the approximate top, mid point, and bottom of the total stroke of the measuring device, verify the accuracy of the device at no less than four evenly spaced increments of approximately 0.05 mm at each of the three locations. The accuracy shall be within the tolerances defined above.

(2) Operate the actuator over its full range of travel and monitor the electronic continuity detection system. The system shall indicate continuity over the full range.

A1.3.4 *Verification of Machine Hysteresis*—Each time a Rockwell hardness test is made, the testing machine will undergo flexure in some of the machine components and the machine frame. If the flexure is not entirely elastic during the application and removal of the additional force F_1, the testing machine may exhibit hysteresis in the indenter-depth measurement system, resulting in an offset or bias in the test result. The goal of the hysteresis verification is to perform a purely elastic test that results in no permanent indentation. In this way, the level of hysteresis in the flexure of the testing machine can be determined.

A1.3.4.1 Perform repeated Rockwell tests using a blunt indenter (or the indenter holder surface) acting directly onto the anvil or a very hard test piece. The tests shall be conducted using the highest test force that is used during normal testing.

A1.3.4.2 Repeat the hysteresis verification procedure for a maximum of ten measurements and average the last three tests. The average measurement shall indicate a hardness number of 130 ± 1.0 Rockwell units when Rockwell ball scales B, E, F, G, H and K are used, or within 100 ± 1.0 Rockwell units when any other Rockwell scale is used.

A1.3.5 *Verification of the Testing Cycle*—Section 7 specifies the Rockwell testing cycle by stating requirements and recommendations for five separate parameters of the cycle. The testing machine shall be verified to be capable of meeting the tolerances specified in Table 3 for the following four test cycle parameters: the dwell time for preliminary force, the time for application of additional force, the dwell time for total force and the dwell time for elastic recovery. The tolerance for the indenter contact velocity is a recommendation. Direct verification of the testing cycle is to be verified by the testing machine manufacturer at the time of manufacture, and when the testing machine is returned to the manufacturer for repair when a problem with the testing cycle is suspected. Verification of the testing cycle is not required as part of the direct verification at other times.

A1.3.5.1 Rockwell hardness testing machines manufactured before the implementation of E18–07 may not have undergone the direct verification of the machine's testing cycle. Since this verification often must be performed at the manufacturer's site, the test cycle verification requirement does not apply to testing machines manufactured before the implementation of E18–07, unless the testing machine is returned to the manufacturer for repair.

A1.3.6 *Direct Verification Failure*—If any of the direct verifications fail the specified requirements, the testing machine shall not be used until it is adjusted or repaired. If the test forces, depth measuring system, machine hysteresis, or testing cycle may have been affected by an adjustment or repair, the affected components shall be verified again by direct verification.

A1.3.7 An indirect verification shall follow a successful direct verification.

A1.4 Indirect Verification

A1.4.1 An indirect verification of the testing machine shall be performed, at a minimum, in accordance with the schedule given in Table A1.1. The frequency of indirect verifications should be based on the usage of the testing machine.

A1.4.2 The testing machine shall be verified for each Rockwell scale that will be used prior to the next indirect verification. Hardness tests made using Rockwell scales that have not been verified within the schedule given in Table A1.1 do not meet this standard.

A1.4.3 Standardized test blocks meeting the requirements of Annex A4 (see Note 4) shall be used in the appropriate hardness ranges for each scale to be verified. These ranges are given in Table A1.3. Hardness measurements shall be made only on the calibrated surface of the test block.

TABLE A1.3 Maximum Allowable Repeatability and Error of Testing Machines for Ranges of Standardized Test Blocks

Range of Standardized Test Blocks[A]		Maximum Repeatability, *R* (HR units)	Maximum Error, *E* (HR units)
HRA	< 70	2.0	± 1.0
	≥ 70 and < 80	1.5	± 1.0
	≥ 80	1.0	± 0.5
HRBW	< 60	2.0	± 2.5
	≥ 60 and < 88	1.5	± 2.5
	≥ 88	1.5	± 1.0
HRC	< 35	2.0	± 1.0
	≥ 35 and < 60	1.5	± 1.0
	≥ 60	1.0	± 0.5
HRD	< 51	2.0	± 1.0
	≥ 51 and < 71	1.5	± 1.0
	≥ 71	1.0	± 0.5
HREW	< 84	1.5	± 1.0
	≥ 84 and < 93	1.5	± 1.0
	≥ 93	1.0	± 1.0
HRFW	< 80	1.5	± 1.0
	≥ 80 and < 94	1.5	± 1.0
	≥ 94	1.0	± 1.0
HRGW	< 55	2.0	± 1.0
	≥ 55 and < 80	2.0	± 1.0
	≥ 80	2.0	± 1.0
HRHW	< 96	2.0	± 1.0
	≥ 96	2.0	± 1.0
HRKW	< 65	1.5	± 1.0
	≥ 65 and < 85	1.0	± 1.0
	≥ 85	1.0	± 1.0
HRLW[B]		2.0	± 1.0
HRMW[B]		2.0	± 1.0
HRPW[B]		2.0	± 1.0
HRRW[B]		2.0	± 1.0
HRSW[B]		2.0	± 1.0
HRVW[B]		2.0	± 1.0
HR15N	< 78	2.0	± 1.0
	≥ 78 and < 90	1.5	± 1.0
	≥ 90	1.0	± 0.7
HR30N	< 55	2.0	± 1.0
	≥ 55 and < 77	1.5	± 1.0
	≥ 77	1.0	± 0.7
HR45N	< 37	2.0	± 1.0
	≥ 37 and < 66	1.5	± 1.0
	≥ 66	1.0	± 0.7
HR15TW	< 81	2.0	± 1.5
	≥ 81 and < 87	1.5	± 1.0
	≥ 87	1.5	± 1.0
HR30TW	< 57	2.0	± 1.5
	≥ 57 and < 70	1.5	± 1.0
	≥ 70	1.5	± 1.0
HR45TW	< 33	2.0	± 1.5
	≥ 33 and < 53	1.5	± 1.0
	≥ 53	1.5	± 1.0
HR15WW[B]		2.0	± 1.0
HR30WW[B]		2.0	± 1.0
HR45WW[B]		2.0	± 1.0
HR15XW[B]		2.0	± 1.0
HR30XW[B]		2.0	± 1.0
HR45XW[B]		2.0	± 1.0
HR15YW[B]		2.0	± 1.0
HR30YW[B]		2.0	± 1.0
HR45YW[B]		2.0	± 1.0

[A] The user may find that high, medium and low range test blocks are unavailable commercially for some scales. In these cases one or two standardized blocks where available may be used. It is recommended that all high range test blocks for Rockwell scales using a ball indenter should be less than 100 HR units.

[B] Appropriate ranges of standardized test blocks for the L, M, P, R, S, V, W, X, and Y scales shall be determined by dividing the usable range of the scale into two ranges, if possible.

A1.4.3.1 The results of an indirect verification shall comply with the current values specified in Table A1.3 regardless of any maximum error *E* value marked on the test block (see Note 8).

A1.4.4 The indenters to be used for the indirect verification shall meet the requirements of Annex A3 (see Note 3).

A1.4.5 The testing cycle to be used for the indirect verification shall be the same as is typically used by the user.

A1.4.6 Prior to performing the indirect verification, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a suitable test piece to seat the indenter and anvil. The results of these measurements need not be recorded.

A1.4.7 *As-found Condition:*

A1.4.7.1 It is recommended that the as-found condition of the testing machine be assessed as part of an indirect verification. This is important for documenting the historical performance of the machine in the scales used since the last indirect verification. This procedure should be conducted prior to any cleaning, maintenance, adjustments, or repairs.

A1.4.7.2 When the as-found condition of the testing machine is assessed, it shall be determined with the user's indenter(s) that are normally used with the testing machine. At least two standardized test blocks, each from a different hardness range as defined in Table A1.3, should be tested for each Rockwell scale that will undergo indirect verification. The difference in hardness between any of the standardized test blocks shall be at least 5 hardness points for each Rockwell scale.

A1.4.7.3 On each standardized test block, make at least two measurements distributed uniformly over the test surface.

A1.4.7.4 Determine the repeatability *R* and the error *E* (Eq 2 and Eq 3) in the performance of the testing machine for each standardized test block that is measured.

A1.4.7.5 The error *E* and the repeatability *R* should be within the tolerances of Table A1.3. If the calculated values of error *E* or repeatability *R* fall outside of the specified tolerances, this is an indication that the hardness tests made since the last indirect verification may be suspect.

A1.4.8 *Cleaning and Maintenance*—Perform cleaning and routine maintenance of the testing machine (when required) in accordance with the manufacturer's specifications and instructions.

A1.4.9 *Indirect Verification Procedure*—The indirect verification procedure requires that the testing machine be verified using one or more of the user's indenters.

A1.4.9.1 One standardized test block shall be tested from each of the hardness ranges (usually three ranges) for each Rockwell scale to be verified, as given in Table A1.3. The difference in hardness between any of the standardized test blocks shall be at least 5 hardness points for each Rockwell scale. The user may find that high, medium and low range test blocks are unavailable commercially for some scales. In these cases, one of the following two procedures shall be followed.

(1) Alternative Procedure 1—The testing machine shall be verified using the standardized blocks from the one or two ranges that are available. Also, the testing machine shall be verified on another Rockwell scale which uses the same test forces and for which three blocks are available. In this case, the testing machine is considered verified for the entire Rockwell scale.

(2) Alternative Procedure 2—This procedure may be used when standardized blocks from two ranges are available. The testing machine shall be verified using the standardized blocks from the two available ranges. In this case, the testing machine is considered verified for only the part of the scale bracketed by the levels of the blocks.

A1.4.9.2 On each standardized test block, make five measurements distributed uniformly over the test surface. Determine the error *E* and the repeatability *R* in the performance of the testing machine using Eq 2 and Eq 3 for each hardness level of each Rockwell scale to be verified.

A1.4.9.3 The error *E* and the repeatability *R* shall be within the tolerances of Table A1.3. The indirect verification shall be approved only when the testing machine measurements of repeatability and error meet the specified tolerances using at least one of the user's indenters.

A1.4.9.4 In the case that the testing machine cannot pass the repeatability and error verifications with the user's indenter, a number of corrective actions may be attempted to bring the testing machine within tolerances. These actions include cleaning and maintenance, replacing the anvil or using another of the user's indenters. The indirect verification procedures shall be repeated after making the allowed corrective actions.

NOTE A1.3—When a testing machine fails indirect verification, it is recommended that the testing machine be verified again using a Class A (or better) indenter for those scales and hardness levels that failed the indirect verification with the user's indenter. If the testing machine passes the repeatability and error tests with a Class A indenter, it is an indication that the user's indenter is out of tolerance. A new indenter may be acquired by the user as a corrective action (see A1.4.9.4) allowing the indirect verification procedures to be repeated without having to perform a direct verification. If the testing machine continues to fail the repeatability or error tests of an indirect verification with the Class A indenter, it is an indication that there is a problem with the machine and not the user's indenter.

A1.4.9.5 If the testing machine continues to fail the repeatability or error tests following corrective actions, the testing machine shall undergo adjustment and/or repair followed by a direct verification.

A1.4.10 *Qualifying Additional User's Indenters*—In cases where the testing machine passes indirect verification using only one of the user's indenters, only that one indenter is considered verified for use with the specific testing machine for the Rockwell scales that were indirectly verified using that indenter. Before any other indenter may be used for testing the same Rockwell scales, it must be verified for use with the specific verified testing machine. This requirement does not apply to changing an indenter ball. The indenter verifications may be made at any time after the indirect verification, and may be performed by the user as follows.

A1.4.10.1 The testing machine and indenter shall be verified together using the indirect verification procedures of A1.4.9 with the following exception. The verification shall be performed on at least two standardized test blocks (high and low ranges) for each Rockwell scale that the indenter will be used.

A1.4.10.2 The indenter may be used with the specific verified testing machine only when the verification measurements of repeatability and error meet the specified tolerances.

A1.4.11 The user shall identify and keep track of the indenters verified for use with the testing machine.

A1.5 Daily Verification

A1.5.1 The daily verification is intended for the user to monitor the performance of the testing machine between indirect verifications. At a minimum, the daily verification shall be performed in accordance with the schedule given in Table A1.1 for each Rockwell scale that will be used.

A1.5.2 It is recommended that the daily verification procedures be performed whenever the indenter, anvil, or test force is changed.

A1.5.3 *Daily Verification Procedures*—The procedures to use when performing a daily verification are as follows.

A1.5.3.1 Daily verification shall use standardized test block(s) that meet the requirements of Annex A4 (see Note 4). Daily verification shall be done for each Rockwell scale that is to be used that day. At least one test block shall be used, and when commercially available, the hardness range of the test block shall be chosen to be within 15 Rockwell points of the hardness value that the testing machine is expected to measure. Alternatively, two test blocks can be used, (when commercially available), one higher and one lower than the hardness range that the testing machine is expected to measure. In cases where the configuration of the anvil to be used is not suitable for the testing of blocks, a suitable anvil or adapter for testing a test block must be used temporarily.

A1.5.3.2 The indenter to be used for the daily verification shall be the indenter that is normally used for testing.

A1.5.3.3 Before performing the daily verification tests, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a suitable test piece. The results of these measurements need not be recorded.

A1.5.3.4 Make at least two hardness measurements on each of the daily verification test blocks adhering to the spacing requirements given in 7.9.

NOTE A1.4—Proper indentation spacing may be ensured by various techniques, such as using devices that correctly space indentations, using test blocks having appropriately spaced gridlines or circles marked on the test surface, using systems that move the test block to the correct position, or by measuring the distance between the indentation and adjacent indentations or the block edge after making the indentation. The user is cautioned that depending on the spacing between the boundaries of spaced gridlines or circles marked on the test surface, proper indentation spacing may not be ensured since indentations can be placed anywhere within the marked test areas.

A1.5.3.5 For each test block, calculate the error E (see Eq 2) and the repeatability R (see Eq 3) from the measured hardness values. The testing machine with the indenter is regarded as performing satisfactorily if both E and R for all test blocks are within the maximum tolerances given in Table A1.3. Note that if the differences between the individual hardness values and the certified value for a test block are all within the maximum error E tolerances marked on the test block and given in Table A1.3, the above criteria will be met for that block and it is not necessary to calculate E and R.

A1.5.3.6 If the daily verification measurements for any of the test blocks do not meet the criteria of A1.5.3.5, the daily verification may be repeated with a different indenter or after cleaning the tester, or both (see the manufacturer's instructions). If any of the test block measurements continue to not meet the criteria of A1.5.3.5, an indirect verification shall be performed. Whenever a testing machine fails a daily verification, the hardness tests made since the last valid daily verification may be suspect.

A1.5.3.7 If the anvil to be used for testing is different than the anvil used for the daily verification, it is recommended that the daily verification be repeated on an appropriate part of known hardness.

NOTE A1.5—It is highly recommended that the results obtained from the daily verification testing be recorded using accepted Statistical Process Control techniques, such as, but not limited to, X-bar (measurement averages) and R-charts (measurement ranges), and histograms.

A1.6 Verification Report

A1.6.1 The verification report shall include the following information as a result of the type of verification performed.

A1.6.2 *Direct Verification:*

A1.6.2.1 Reference to this ASTM test method.

A1.6.2.2 Identification of the hardness testing machine, including the serial number, manufacturer and model number.

A1.6.2.3 Identification of all devices (elastic proving devices, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A1.6.2.4 Test temperature at the time of verification (see A1.2.2).

A1.6.2.5 The individual measurement values and calculated results used to determine whether the testing machine meets the requirements of the verification performed. It is recommended that the uncertainty in the calculated results used to determine whether the testing machine meets the requirements of the verification performed also be reported.

A1.6.2.6 Description of adjustments or maintenance done to the testing machine, when applicable.

A1.6.2.7 Date of verification and reference to the verifying agency or department.

A1.6.2.8 Identification of the person performing the verification.

A1.6.3 *Indirect Verification:*

A1.6.3.1 Reference to this ASTM test method.

A1.6.3.2 Identification of the hardness testing machine, including the serial number, manufacturer and model number.

A1.6.3.3 Identification of all devices (test blocks, indenters, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A1.6.3.4 Test temperature at the time of verification (see A1.2.2).

A1.6.3.5 The Rockwell hardness scale(s) verified.

A1.6.3.6 The individual measurement values and calculated results used to determine whether the testing machine meets the requirements of the verification performed. Measurements made to determine the as-found condition of the testing machine shall be included whenever they are made. It is recommended that the uncertainty in the calculated results used to determine whether the testing machine meets the requirements of the verification performed also be reported.

A1.6.3.7 Description of maintenance done to the testing machine, when applicable.

A1.6.3.8 Date of verification and reference to the verifying agency or department.

A1.6.3.9 Identification of the person performing the verification.

A1.6.4 *Daily Verification:*

A1.6.4.1 No verification report is required; however, it is recommended that records be kept of the daily verification results, including the verification date, measurement results, certified value of the test block, test block identification, and the name of the person that performed the verification, etc. (see also Note A1.5). These records can be used to evaluate the performance of the hardness machine over time.

A2. ROCKWELL HARDNESS STANDARDIZING MACHINES

A2.1 Scope

A2.1.1 Annex A2 specifies the requirements for the capabilities, usage, periodic verification, and monitoring of a Rockwell hardness standardizing machine. The Rockwell hardness standardizing machine differs from a Rockwell hardness testing machine by having tighter tolerances on certain performance attributes such as force application and machine hysteresis. A Rockwell standardizing machine is used for the standardization of Rockwell hardness indenters as described in Annex A3, and for the standardization of Rockwell test blocks as described in Annex A4.

A2.1.2 Adherence to this standard and annex provide traceability to national standards, except as stated otherwise.

A2.2 Accreditation

A2.2.1 The agency conducting direct and/or indirect verifications of Rockwell hardness standardizing machines shall be accredited to the requirements of ISO 17025 (or an equivalent) by an accrediting body recognized by the International Laboratory Accreditation Cooperation (ILAC) as operating to the requirements of ISO/IEC 17011. An agency accredited to perform verifications of Rockwell hardness standardizing machines may perform the verifications of its own standardizing machines. The standardizing laboratory shall have a certificate/scope of accreditation stating the types of verifications (direct and/or indirect) and the Rockwell scales that are covered by the accreditation.

A2.3 Apparatus

A2.3.1 The standardizing machine shall satisfy the requirements of Section 5 for a Rockwell hardness testing machine with the following additional requirements.

A2.3.1.1 The standardizing machine shall be designed so that: *(1)* each test force can be selected by the operator, and *(2)* adjustments to test forces cannot be made by the operator.

A2.3.1.2 The system for displaying the hardness measurement value shall be digital with a resolution of 0.1 Rockwell units or better.

A2.3.1.3 Deviation in parallelism between the indenter mounting surface and the anvil mounting surface shall not be greater than 0.002 mm/mm (0.002 in./in.). This characteristic of the standardizing machine is not likely to vary with time. As such, the accuracy of this dimension shall only be certified by the machine manufacturer and need not be periodically verified by direct verification unless the components have been changed.

A2.3.1.4 *Indenters*—Class A ball indenters and Class A or Reference diamond indenters as described in Annex A3 (see Note 3) shall be used.

A2.3.1.5 *Testing Cycle*—The standardizing machine shall be capable of meeting each part of the testing cycle within the tolerances specified in Table A2.1. The manufacturer of the standardizing machine shall verify each of the five components of the testing cycle at the time of manufacture, or when the testing machine is returned to the manufacturer for repair.

A2.3.1.6 It is important that the final portion of the additional force application be controlled. Two recommended procedures for properly applying the additional force are as follows: *(1)* the average indenter velocity v_F (see Fig. 2) during the final 40 % of additional force application should be between 0.020 mm/s and 0.040 mm/s; or *(2)* the amount of force applied during the final 10 % of the additional force application time should be less than 5 % of the additional force.

A2.3.1.7 During the period between verifications, no adjustments may be made to the force application system, the force measurement system, the indenter depth measurement system, or the test cycle that is used for each Rockwell scale.

A2.4 Laboratory Environment

A2.4.1 The standardizing machine shall be located in a temperature and relative-humidity controlled room with tolerances for these conditions given in Table A2.2. The accuracy of the temperature and relative-humidity measuring instruments

TABLE A2.1 Testing Cycle Requirements

Test Cycle Parameter	Tolerance
Indenter contact velocity, v_A	≤1.0 mm/s
Dwell time for preliminary force, t_{PF} (when the time to apply the preliminary force $t_{PA} \geq 1$ s, then calculate this parameter as $\frac{t_{PA}}{2} + t_{PF}$)	3.0 ± 1.0 s
Additional force application, t_{TA} (see A2.3.1.6)	1.0 to 8.0 s
Dwell time for total force, t_{TF}	5.0 ± 1.0 s
Dwell time for elastic recovery, t_R	4.0 ± 1.0 s

TABLE A2.2 Standardization Laboratory Environmental Requirements

Environmental Parameter	Tolerance	Accuracy of Measuring Instrument
Temperature	23.0 ± 3.0 °C (73.4 ± 5.4 °F)	±1.0 °C (1.8 °F)
Relative humidity	≤70 %	±10 %

shall be as given in Table A2.2. The display of the temperature measuring device shall have a resolution of at least 1 °C.

A2.4.2 The temperature and relative-humidity of the standardizing laboratory shall be monitored beginning at least one hour prior to standardization and throughout the standardizing procedure.

A2.4.3 The standardizing machine, indenter(s), and test blocks to be standardized must be in an environment meeting the tolerances of Table A2.2 for at least one hour prior to standardization.

A2.4.4 During the standardization process, the standardizing machine shall be isolated from any vibration that may affect the measurements.

A2.4.5 The power supply to the standardizing machine shall be isolated from any electrical surges that could affect its performance.

A2.5 Verifications

A2.5.1 The standardizing machine shall undergo direct and indirect verifications at periodic intervals and when circumstances occur that may affect the performance of the standardizing machine, according to the schedule given in Table A2.3.

A2.5.2 A standardizing machine used for the standardization of test blocks shall undergo monitoring verifications each day that standardizations are made, according to the schedule given in Table A2.3.

A2.5.3 All instruments used to make measurements required by this Annex shall be calibrated traceable to national standards where a system of traceability exists, except as noted otherwise.

A2.5.4 The standardizing machine shall be directly and indirectly verified at the location where it will be used.

TABLE A2.3 Verification Schedule for a Rockwell Hardness Standardizing Machine

Verification Procedure	Schedule
Direct verification	Shall be every 12 months. When a standardizing machine is new, moved, or when adjustments, modifications or repairs are made that could affect the application of the test forces, the depth measuring system, or the machine hysteresis.
Indirect verification	Shall be within 12 months prior to standardization testing. Following a direct verification(limited number of scales).
Monitoring verification	Shall be before and after each lot is standardized, and at the end of each day and the start of the following day when a single lot is standardized over multiple days.

A2.6 Periodic Verification Procedures

A2.6.1 *Perform Cleaning and Maintenance*—If required, cleaning and routine maintenance of the standardizing machine shall be made before conducting direct or indirect verifications in accordance with the manufacturer's specifications and instructions.

A2.6.2 *Direct Verification*—Perform a direct verification of the standardizing machine in accordance with the schedule given in Table A2.3. The test forces, depth measuring system, and machine hysteresis shall be verified.

A2.6.2.1 *Verification of the Test Forces*—For each Rockwell scale that will be used, the associated forces (preliminary test force, total test force, and test force during elastic recovery) shall be measured. The test forces shall be measured by means of a Class AA elastic force measuring instrument having an accuracy of at least 0.05 %, as described in Practices E74.

A2.6.2.2 Make three measurements of each force. The forces shall be measured as they are applied during testing.

A2.6.2.3 Each preliminary test force F_0 and each total test force F shall be accurate to within 0.25 % in accordance with Table A2.4.

A2.6.2.4 *Verification of the Depth Measuring System*—The depth measuring system shall be verified by means of an instrument having an accuracy of at least 0.0001 mm.

A2.6.2.5 Verify the standardizing machine's measurement of depth at not less than four evenly spaced increments of approximately 0.05 mm at the range of the normal working depth of the standardizing machine. The normal working depth range shall correspond to the lowest and highest hardness values for the Rockwell scales that will be standardized or that will be used for indenter calibrations.

A2.6.2.6 For testing machines with long stroke actuators and fixed anvils, the depth measurement verification shall be repeated at positions corresponding to each thickness of test block that will be standardized or that will be used for indenter calibrations.

A2.6.2.7 The indentation depth measuring device shall have an accuracy of at least 0.0002 mm over the normal working depth range which corresponds to 0.1 regular Rockwell hardness units and 0.2 Rockwell Superficial hardness units.

A2.6.2.8 *Verification of Machine Hysteresis*—Most Rockwell hardness machines will undergo flexure in the machine frame and some machine components each time a test is made. If the flexure is not entirely elastic during the application and removal of the additional force F_1, the testing machine may exhibit hysteresis in the indenter depth measuring system, resulting in an offset or bias in the test result. The goal of the

TABLE A2.4 Tolerances on Applied Force for the Standardizing Machine

Force, kgf	(N)	Tolerance, kgf	(N)
10	(98.07)	0.025	(0.245)
60	(588.4)	0.150	(1.471)
100	(980.7)	0.250	(2.452)
150	(1471)	0.375	(3.678)
3	(29.42)	0.008	(0.074)
15	(147.1)	0.038	(0.368)
30	(294.2)	0.075	(0.736)
45	(441.3)	0.113	(1.103)

hysteresis verification is to perform a purely elastic test that results in no permanent indentation. In this way, the level of hysteresis in the flexure of the testing machine can be determined.

A2.6.2.9 Perform repeated Rockwell tests using a blunt indenter (or the indenter holder surface) acting directly onto the anvil or a very hard test piece. The tests shall be conducted on a Rockwell scale having the highest test force that is used for normal standardizations.

A2.6.2.10 Repeat the hysteresis tests for a maximum of ten measurements and average the last three tests. The average measurement shall indicate a hardness number within 130 ± 0.3 Rockwell units when Rockwell ball scales B, E, F, G, H and K are used, or within 100 ± 0.3 Rockwell units when any other Rockwell scale is used.

A2.6.2.11 *Direct Verification Failure*—If any of the direct verifications fail the specified requirements, the standardizing machine shall not be used until it is adjusted or repaired. Any parameter that may have been affected by an adjustment or repair shall be verified again by direct verification.

A2.6.3 *Indirect Verification*—Indirect verification involves verifying the performance of the standardizing machine by means of standardized test blocks and indenters. Prior to performing standardizations for any Rockwell scale, an indirect verification of the standardizing machine for that scale shall be made within the time period given in Table A2.3. A selected number of Rockwell scales shall be indirectly verified at the time of the direct verification as described below. The indirect verification of all other Rockwell scales may be made at any time as long as it occurs within the time period given in Table A2.3 prior to standardization.

A2.6.3.1 Immediately following the direct verification, indirect verifications of a selected number of scales shall be performed to determine the performance of the standardizing machine at each force level that the standardizing machine is capable of applying. An example of an indirect verification for a standardizing machine capable of applying all force levels is given in Table A2.5. It is recommended that Rockwell scales be chosen that will also verify each indenter that will be used. When national primary standardized test blocks (see Note A2.1) are available, they should be used for the periodic indirect verification.

NOTE A2.1—Primary standardized test blocks are certified at the national standardizing laboratory level. In the United States, the national Rockwell hardness standardizing laboratory is the National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899.

TABLE A2.5 Suggested Rockwell Scales for the Indirect Verification of Machines Capable of Performing Both Regular and Superficial Scale Tests and that Will Use Only Diamond and 1/16 in. (1.588 mm) Diameter Carbide Ball Indenters

Preliminary Force kgf (N)	Total Force kgf (N)	Indenter Type	Rockwell Scale
10 (98.07)	60 (588.4)	diamond	HRA
10 (98.07)	100 (980.7)	1⁄16 in. ball	HRB
10 (98.07)	150 (1471)	diamond	HRC
3 (29.42)	15 (147.1)	diamond	HR15N
3 (29.42)	30 (294.2)	1⁄16 in. ball	HR30T
3 (29.42)	45 (441.3)	diamond	HR45N

A2.6.3.2 Standardized test blocks shall be used in the appropriate hardness ranges for each scale to be verified. These ranges are given in Table A2.6. The standardizing testing machine shall not be adjusted during the indirect verification procedures.

TABLE A2.6 Maximum Allowable Repeatability and Error of Standardizing Machines

Range of Standardized Test Blocks		Maximum Repeatability, *R* (HR units)	Maximum Error, *E* (HR units)
HRA	20 to 65	1.0	± 0.5
	70 to 78	0.7	± 0.5
	80 to 84	0.5	± 0.3
HRBW	40 to 59	1.0	± 0.7
	60 to 79	0.7	± 0.5
	80 to 100	0.7	± 0.5
HRC	20 to 30	1.0	± 0.5
	35 to 55	0.7	± 0.5
	60 to 65	0.5	± 0.3
HRD	40 to 48	1.0	± 0.5
	51 to 67	0.7	± 0.5
	71 to 75	0.5	± 0.3
HREW	70 to 79	0.7	± 0.5
	84 to 90	0.7	± 0.5
	93 to 100	0.5	± 0.5
HRFW	60 to 75	0.7	± 0.5
	80 to 90	0.7	± 0.5
	94 to 100	0.5	± 0.5
HRGW	30 to 50	1.0	± 0.5
	55 to 75	1.0	± 0.5
	80 to 94	1.0	± 0.5
HRHW	80 to 94	1.0	± 0.5
	96 to 100	1.0	± 0.5
HRKW	40 to 60	0.7	± 0.5
	65 to 80	0.5	± 0.5
	85 to 100	0.5	± 0.5
HRLW[A]		1.0	± 0.5
HRMW[A]		1.0	± 0.5
HRPW[A]		1.0	± 0.5
HRRW[A]		1.0	± 0.5
HRSW[A]		1.0	± 0.5
HRVW[A]		1.0	± 0.5
HR15N	70 to 77	1.0	± 0.5
	78 to 88	0.7	± 0.5
	90 to 92	0.5	± 0.4
HR30N	42 to 50	1.0	± 0.5
	55 to 73	0.7	± 0.5
	77 to 82	0.5	± 0.4
HR45N	20 to 31	1.0	± 0.5
	37 to 61	0.7	± 0.5
	66 to 72	0.5	± 0.4
HR15TW	74 to 80	1.0	± 0.7
	81 to 86	0.7	± 0.5
	87 to 93	0.7	± 0.5
HR30TW	43 to 56	1.0	± 0.7
	57 to 69	0.7	± 0.5
	70 to 83	0.7	± 0.5
HR45TW	13 to 32	1.0	± 0.7
	33 to 52	0.7	± 0.5
	53 to 73	0.7	± 0.5
HR15WW[A]		1.0	± 0.5
HR30WW[A]		1.0	± 0.5
HR45WW[A]		1.0	± 0.5
HR15XW[A]		1.0	± 0.5
HR30XW[A]		1.0	± 0.5
HR45XW[A]		1.0	± 0.5
HR15YW[A]		1.0	± 0.5
HR30YW[A]		1.0	± 0.5
HR45YW[A]		1.0	± 0.5

[A] Appropriate ranges of standardized test blocks for the L, M, P, R, S, V, W, X, and Y scales shall be determined by dividing the usable range of the scale into two ranges, high and low. Standardized test blocks for the R and S scales may be available at only one hardness level.

A2.6.3.3 The indenter(s) to be used for the indirect verification shall be the same indenter(s) that will be used for future standardizations. If more than one indenter will be used for the same hardness scale, an additional verification shall be made for each indenter.

A2.6.3.4 The test cycle to be used for the indirect verification should be the same as the test cycle used by the standardizing laboratory when calibrating the standardized test blocks.

A2.6.3.5 Prior to testing the standardized test blocks, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a uniform test piece for the scale to be verified. The results of these measurements need not be recorded.

A2.6.3.6 On each standardized block, make at least five hardness measurements distributed uniformly over the surface of the block.

A2.6.3.7 *Error*—Using Eq 2, determine the error *E* in the performance of the standardizing machine for each standardized test block that is measured. The error *E* shall be within the tolerances of Table A2.6.

A2.6.3.8 *Repeatability*—Using Eq 3, determine the repeatability *R* in the performance of the standardizing machine for each standardized test block that is measured. The repeatability *R* shall be within the tolerances of Table A2.6. If the calculated repeatability is outside the tolerances of Table A2.6, it may be due to the non-uniformity of the test block. The repeatability *R* may be determined again by making an additional five measurements on each standardized block in close proximity to each other adhering to indentation spacing restrictions (see Fig. 3). A pattern such as illustrated in Fig. A2.1 is recommended. The close proximity of the measurements will reduce the effect of test block non-uniformity.

A2.6.3.9 If any of the error *E* or repeatability *R* measurements fall outside of the specified tolerances, the standardizing machine shall not be considered to have passed the indirect verification. A number of corrective actions may be attempted to bring the standardizing machine within tolerances. These actions include cleaning and maintenance or replacing the anvil. No adjustments to the force application system, force measurement system, or depth measuring system may be made. The indirect verification procedures may be repeated after making the allowed corrective actions. If the standardizing machine continues to fail the repeatability or error tests following corrective actions, the standardizing machine must undergo adjustment and/or repair followed by a direct verification.

A2.6.3.10 It is recommended that immediately following the successful completion of an indirect verification, user test blocks are calibrated for use as monitoring blocks as outlined in A2.7.

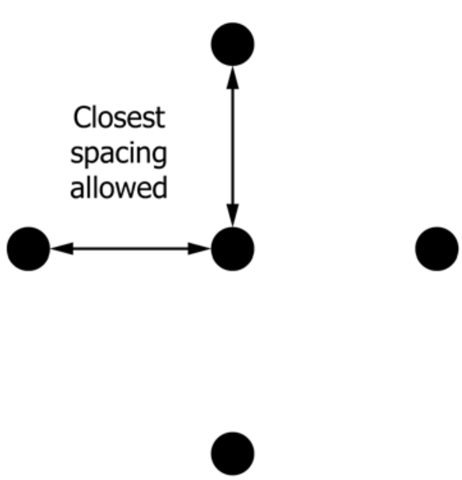


FIG. A2.1 Suggested Pattern for Repeatability Measurements

A2.7 Monitoring Verification

A2.7.1 This section describes the monitoring procedures for a standardizing hardness machine used for the standardization of test blocks, and the calibration and use of monitoring test blocks.

A2.7.2 The standardizing laboratory shall monitor the performance of a standardizing machine used for the standardization of test blocks between periodic direct and indirect verifications by performing monitoring verifications each day that standardizations are made, according to the schedule given in Table A2.3. Monitoring verifications are indirect verifications performed with monitoring test blocks that bracket the standardization hardness level.

A2.7.3 The standardizing laboratory should track the performance of the standardizing machine using control-charting techniques or other comparable methods. The control charts are intended to indicate whether there is a loss of measurement control in the performance of the standardizing machine

A2.7.4 *Monitoring Test Blocks*—Test blocks that meet the physical requirements (see Table A4.1) and the uniformity requirements (see Table A4.2) of Annex A4 shall be used. The monitoring test blocks shall be at each of the appropriate hardness ranges of each hardness scale that will be used. These ranges are given in Table A2.6. It is to the advantage of the laboratory to use test blocks that exhibit high uniformity in hardness across the test surface. The laboratory may, in all cases, perform the monitoring tests using primary standardized test blocks.

A2.7.5 *Procedure for Calibrating Monitoring Test Blocks*—Monitoring test blocks for a specific Rockwell scale shall be calibrated by the standardizing laboratory following an indirect verification of the scales for which monitoring blocks will be calibrated. An adequate number of monitoring blocks should be calibrated for each hardness scale and hardness level. The number of blocks required is dependent on each laboratory's needs and experience.

A2.7.5.1 Prior to calibrating the monitoring test blocks, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Each time the hardness scale is changed, make at least two hardness measurements on a uniform test piece for the scale to be verified. The results of these measurements need not be recorded.

A2.7.5.2 Make at least five measurements distributed uniformly over the surface of one of the monitoring test blocks. Repeat this procedure, as required, for the quantity of blocks needed at the appropriate ranges of each Rockwell scale.

A2.7.5.3 For each of the monitoring test blocks, let $\bar{H}_M$ be the average of the calibration values as measured by the standardizing machine. The value of $\bar{H}_M$ may be corrected for the error *E* that was determined for that Rockwell scale and hardness level as a result of the indirect verification.

A2.7.6 For each monitoring block, the following information shall be recorded and retained for at least the time period during which the monitoring block calibration is valid.

A2.7.6.1 Serial number.

A2.7.6.2 Calibrated hardness value, $\bar{H}_M$.

A2.7.6.3 Date of calibration.

A2.7.7 *Monitoring Methods*—It is recommended that control charts or other comparable methods be used to monitor the performance of the standardizing machine between verifications. Control charts provide a method for detecting lack of statistical control. There are many publications available that discuss the design and use of control charts, such as the ASTM "Manual on Presentation of Data and Control Chart Analysis: 6th Edition," prepared by Committee E11 on Quality and Statistics. The standardizing laboratory should develop and use control charts that best apply to their specific needs.

A2.7.8 *Monitoring Procedures*—The following monitoring procedures shall be performed before and after each lot of test blocks is standardized. When standardizations of a single lot of test blocks spans multiple days, the monitoring procedures shall be performed at the end of the work day and at the start of the following day during the period that the lot is standardized. In addition, the monitoring procedures shall be performed whenever the indenter, anvil, or test force is changed.

A2.7.8.1 At least two monitoring test blocks shall be used in the appropriate hardness ranges that bracket the hardness level to be standardized. These ranges are given in Table A2.6. For some Rockwell scales (for example, HRR and HRS) there may be only one monitoring test block that can be used.

A2.7.8.2 Prior to testing the monitoring test blocks, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a uniform test piece for the scale to be verified. The results of these measurements need not be recorded. Repeat this procedure each time the hardness scale is changed.

A2.7.8.3 On each monitoring test block, make at least four measurements distributed uniformly over the surface of the block.

A2.7.8.4 *Error*—Determine the error *E* (Eq 2) in the performance of the standardizing machine for each monitoring test block that is measured. The error *E* shall be within the tolerances of Table A2.6.

A2.7.8.5 *Repeatability*—Determine the repeatability *R* in the performance of the standardizing machine (Eq 3) for each standardized test block that is measured. The repeatability *R* shall be within the tolerances of Table A2.6.

A2.7.8.6 If any of the error *E* measurements or the repeatability *R* measurements fall outside of the specified tolerances, the standardizing machine shall not be considered to have passed the monitoring verification, and shall not be used for standardizations. A number of corrective actions may be attempted to bring the standardizing machine within tolerances. These actions include cleaning and maintenance or replacing the anvil. No adjustments to the force application system, force measurement system, or depth measuring system may be made. The monitoring verification procedures may be repeated after making the allowed corrective actions. If the standardizing machine continues to fail the error tests following corrective actions, the standardizing machine must undergo adjustment and/or repair followed by a direct verification.

A2.7.8.7 Whenever a standardizing machine fails a monitoring verification, the standardizations made since the last valid monitoring verification may be suspect.

A2.7.8.8 Examine the measurement data using control charts or other monitoring systems that are being used (see Note A2.2). If the monitoring verification data indicates that the standardizing machine is within control parameters, standardizations are considered to be valid.

NOTE A2.2—Control chart data should be interpreted by the laboratory based on past experience. The need for corrective action does not depend solely on data falling outside the control limits, but also on the prior data leading to this occurrence. As a general rule, however, once the standardizing machine is determined to be in control, a single occurrence of data falling outside the control limits should alert the laboratory to a possible problem. The level of action that is required depends on the history of the machine performance. It may be precautionary such as increasing the monitoring frequency, or corrective such as performing new direct and indirect verifications.

A2.8 Verification Report

A2.8.1 *Direct Verification:*

A2.8.1.1 Reference to this ASTM test method.

A2.8.1.2 Identification of the hardness standardizing machine, including the serial number, manufacturer and model number.

A2.8.1.3 Identification of all devices (elastic proving devices, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A2.8.1.4 Test temperature at the time of verification reported to a resolution of at least 1 °C.

A2.8.1.5 The individual measurement values and calculated results used to determine whether the standardizing machine meets the requirements of the verification performed. It is recommended that the uncertainty in the calculated results used to determine whether the standardizing machine meets the requirements of the verification performed also be reported.

A2.8.1.6 Description of adjustments or maintenance done to the standardizing machine, when applicable.

A2.8.1.7 Date of verification and reference to the verifying agency or department.

A2.8.1.8 Identification of the person performing the verification.

A2.8.1.9 Accreditation certification number.

A2.8.2 *Indirect Verification:*

A2.8.2.1 Reference to this ASTM test method.

A2.8.2.2 Identification of the standardizing machine, including the serial number, manufacturer and model number.

A2.8.2.3 Identification of all devices (test blocks, indenters, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A2.8.2.4 Test temperature at the time of verification reported to a resolution of at least 1 °C.

A2.8.2.5 The Rockwell hardness scale(s) verified.

A2.8.2.6 The individual measurement values and calculated results used to determine whether the standardizing machine meets the requirements of the verification performed. Measurements made to determine the as-found condition of the standardizing machine shall be included whenever they are made. It is recommended that the uncertainty in the calculated results used to determine whether the standardizing machine meets the requirements of the verification performed also be reported.

A2.8.2.7 Description of maintenance done to the standardizing machine, when applicable.

A2.8.2.8 Date of verification and reference to the verifying agency or department.

A2.8.2.9 Identification of the person performing the verification.

A2.8.2.10 Accreditation certification number.

A2.8.3 *Monitoring Verification:*

A2.8.3.1 No verification report is required; however, it is required that records be kept of the monitoring verification results, see A2.7.8.8.

A3. STANDARDIZATION OF ROCKWELL INDENTERS

A3.1 Scope

A3.1.1 Annex A3 specifies the requirements and procedures to manufacture and standardize the Rockwell diamond spheroconical indenter and Rockwell ball indenters for use with all Rockwell scales.

NOTE A3.1—Previous versions of this standard specified that diamond indenters used for calibrations meet the following geometrical requirements:

included angle of 120 ± 0.1°,
mean radius of 0.200 ± 0.005 mm, and
radius in each measured section of 0.200 ± 0.007 mm.

It is believed that diamond indenters meeting these tolerances are not reliably available on the world market at this time. Consequently, for this revision, the tolerances for the geometric features of the Class A and Reference diamond indenters have been temporarily widened to the levels of Class B indenters until such time as indenters having tighter tolerances become reliably available.

A3.1.2 The Annex covers two levels of ball indenters, designated by this standard as Class B, and Class A. Class B indenters are intended for every day use with Rockwell hardness testing machines and for the indirect verification of Rockwell hardness testing machines in accordance with Annex A1. Class A indenters are intended for the indirect verification of Rockwell standardizing machines in accordance with Annex A2, and for the standardization of test blocks in accordance with Annex A4.

A3.1.3 The Annex covers three levels of diamond indenters, designated by this standard as Class B, Class A and Reference indenters. Class B indenters are intended for every day use with Rockwell hardness testing machines. Class A indenters are intended for the standardization of Class B indenters in accordance with this Annex, and for the standardization of test blocks in accordance with Annex A4. Reference indenters are intended for the standardization of Class A indenters.

A3.1.4 This Annex also provides the schedule for verifying indenters.

A3.1.5 Adherence to this standard and annex provides traceability to national standards, except as stated otherwise.

A3.2 Accreditation

A3.2.1 The agency conducting the standardizations of indenters shall be accredited to the requirements of ISO 17025 (or an equivalent) by an accrediting body recognized by the International Laboratory Accreditation Cooperation (ILAC) as operating to the requirements of ISO/IEC 17011. The standardizing laboratory shall have a certificate of accreditation stating the class and types of indenters that are covered by the accreditation. Only indenters of the class and types within the laboratory's scope of accreditation are considered to meet this standard, except as stated below.

A3.3 General Requirements

A3.3.1 The standard Rockwell hardness indenters are the *diamond spheroconical indenter*, and *tungsten carbide (WC)* ball indenters with diameters of 1⁄16 in. (1.588 mm), 1⁄8 in. (3.175 mm), 1⁄4 in. (6.350 mm), and 1⁄2 in. (12.70 mm) to be used for the Rockwell hardness scales as given in Table A3.1. Steel ball indenters may be used in special circumstances (see 5.1.2.1).

A3.3.2 The standardizing laboratory environment, the standardizing machine, and the standardizing test cycle shall satisfy the requirements of Annex A2.

A3.3.3 All instruments used to make measurements required by this Annex shall be calibrated traceable to national standards where a system of traceability exists, except as noted otherwise.

A3.3.4 All classes of diamond indenters and ball indenters shall be verified for correct geometry and performance in accordance with the schedule specified in Table A3.2.

A3.4 Ball Indenters

A3.4.1 Ball indenters frequently consist of a holder, a cap and a ball. The standardization process defined in this section involves the assembled unit. The ball may be changed without affecting the assembly's verification provided the ball conforms to all the requirements in this section.

TABLE A3.1 Indenter Types for Specific Rockwell Scales

Scale Symbol	Indenter Type
HRA	Diamond Spheroconical
HRBW	WC Ball - 1⁄16 in. (1.588 mm)
HRC	Diamond Spheroconical
HRD	Diamond Spheroconical
HREW	WC Ball - 1⁄8 in. (3.175 mm)
HRFW	WC Ball - 1⁄16 in. (1.588 mm)
HRGW	WC Ball - 1⁄16 in. (1.588 mm)
HRHW	WC Ball - 1⁄8 in. (3.175 mm)
HRKW	WC Ball - 1⁄8 in. (3.175 mm)
HRLW	WC Ball - 1⁄4 in. (6.350 mm)
HRMW	WC Ball - 1⁄4 in. (6.350 mm)
HRPW	WC Ball - 1⁄4 in. (6.350 mm)
HRRW	WC Ball - 1⁄2 in. (12.70 mm)
HRSW	WC Ball - 1⁄2 in. (12.70 mm)
HRVW	WC Ball - 1⁄2 in. (12.70 mm)
HR15N	Diamond Spheroconical
HR30N	Diamond Spheroconical
HR45N	Diamond Spheroconical
HR15TW	WC Ball - 1⁄16 in. (1.588 mm)
HR30TW	WC Ball - 1⁄16 in. (1.588 mm)
HR45TW	WC Ball - 1⁄16 in. (1.588 mm)
HR15WW	WC Ball - 1⁄8 in. (3.175 mm)
HR30WW	WC Ball - 1⁄8 in. (3.175 mm)
HR45WW	WC Ball - 1⁄8 in. (3.175 mm)
HR15XW	WC Ball - 1⁄4 in. (6.350 mm)
HR30XW	WC Ball - 1⁄4 in. (6.350 mm)
HR45XW	WC Ball - 1⁄4 in. (6.350 mm)
HR15YW	WC Ball - 1⁄2 in. (12.70 mm)
HR30YW	WC Ball - 1⁄2 in. (12.70 mm)
HR45YW	WC Ball - 1⁄2 in. (12.70 mm)

TABLE A3.2 Indenter Verification Schedule

Indenter Type	Geometrical Features	Performance
Class B diamond	When an indenter is new.	When an indenter is new, and when suspected damage has occurred.
Class A diamond	When an indenter is new.	Shall be within 12 months prior to standardization testing and when suspected damage has occurred.
Reference diamond	When an indenter is new.	When an indenter is new, and when suspected damage has occurred.
Class A and Class B ball	Balls shall be verified for dimensions when new. Ball holders shall be verified for ball protrusion when new.	Ball holders shall be verified when new, and when suspected damage has occurred. (This requirement does not apply when simply replacing a ball.)

A3.4.2 One-piece fixed-ball indenters are allowed provided the indenter meets the same requirements as removable ball indenters. The manufacturer shall ensure that the method used to affix the ball to the holder does not affect the dimensions or properties of the ball.

A3.4.3 *Indenter Balls*—The balls shall meet the following requirements:

A3.4.3.1 The mean surface roughness of the ball shall not exceed 0.00005 mm (2 µin.).

A3.4.3.2 The diameter of Class B balls, when measured at not less than three positions, shall not differ from the nominal diameter by more than 0.0025 mm (0.0001 in.).

A3.4.3.3 The diameter of Class A balls, when measured at not less than three positions, shall not differ from the nominal diameter by more than 0.0010 mm (0.00004 in.).

NOTE A3.2—Balls that conform to ABMA Grade 24 satisfy the requirements for size and finish for Class A and Class B as specified in ABMA Standard 10-1989.

A3.4.3.4 The hardness of a tungsten carbide ball shall not be less than 1500 HV1 in accordance with Test Method E92 or E384.

A3.4.3.5 The material of tungsten carbide balls shall have a density of 14.8 ± 0.2 g/cm^3, and the following chemical composition:

Total other carbides	2.0 % maximum
Cobalt (Co)	5.0 to 7.0 %
Tungsten carbide (WC)	balance

A3.4.3.6 The surface hardness of a steel ball shall not be less than 746 HV1 in accordance with Test Method E92 or E384.

A3.4.3.7 For the purpose of verifying the requirements of the ball given in A3.4.3, it is considered sufficient to test a sample set of balls selected at random from a batch in accordance with the schedule specified in Table A3.2. The balls verified for hardness shall be discarded.

A3.4.3.8 To meet the above requirements for indenter balls, the indenter standardizing laboratory may either verify that the balls meet the requirements, or obtain a certificate of verification from the ball manufacturer.

A3.4.4 *Ball Holder*—The ball holder shall meet the following requirements:

A3.4.4.1 The material used to manufacture the portion of the ball holder that supports the test force should have a minimum hardness of 25 HRC.

A3.4.4.2 The ball shall protrude outside the holder a minimum of 0.3 mm. This requirement may be verified by direct measurement or by performing the appropriate Rockwell scale test on a standardized test block that has an equivalent hardness of 10 HRBW or softer. The protrusion is sufficient if the hardness result is within ± 1.5 of the certified value of the block.

A3.4.5 *Performance Verification of Ball Indenter Holders*—The influence of the ball indenter on the hardness value is not due solely to the previously specified features of the ball, but also on characteristics of the ball holder that may vary due to manufacturing procedures. To examine these influences, the performance of each new Class B and Class A ball holder shall be verified in accordance with the schedule specified in Table A3.2.

A3.4.5.1 The performance verification is accomplished by making hardness measurements on test blocks meeting the manufacturing requirements of A4.3 and having been standardized using a standardizing machine which successfully passed direct verification in accordance with A2.6.2. At least one test block shall be tested for the Rockwell hardness scale and hardness range given in Table A3.3, corresponding to the ball size being verified. Some specially designed 1⁄16 in. (1.588 mm) Class B indenters may not be able to perform tests using the Rockwell scales required for verification of normal indenters in Table A3.3. For example, this applies to thin-tip 1⁄16 in. (1.588 mm) ball indenters that cannot support HRB scale test forces. These limited scale indenters may be used provided they are certified for the scale or scales they are designed to perform by

TABLE A3.3 Test Blocks to be Used for Class A and Class B Ball Indenter Performance Verifications and the Maximum Tolerance on the Performance with Respect to Standardized Reference Blocks

Ball Size in. (mm)	Ranges of Required Test Blocks	Class A Tolerance	Class B Tolerance
1⁄16 (1.588)	20 to 100 HRBW	± 0.4 HRBW	± 0.8 HRBW
1⁄8 (3.175)	68 to 92 HREW	± 0.4 HREW	± 0.8 HREW
1⁄4 (6.350)	HRLW, HRMW, or HRPW (any level)	± 0.4 HR	± 0.8 HR
1⁄2 (12.70)	HRRW, HRSW, or HRVW (any level)	± 0.4 HR	± 0.8 HR

using the test block or blocks for those scales as defined in Table A3.4. In all cases the test report shall define the scale or scales the indenter is certified to perform.

A3.4.5.2 Prior to the performance verification, ensure that the testing machine is working freely, and that the indenter to be verified and anvil are seated adequately. Make at least two hardness measurements on a uniform test piece. The results of these measurements need not be recorded.

A3.4.5.3 On the standardized test block, make at least three measurements distributed uniformly over the test surface. Determine the difference between the average of the three or more measurements and the calibrated value of the test block.

A3.4.5.4 For acceptability, the difference shall be within the tolerances specified in Table A3.3 for the class of indenter being verified or Table A3.4 for the singular or limited scale indenter being verified.

A3.4.6 Ball indenters frequently consist of a holder and a removable cap that allows periodic changing of the ball. Indenter caps can be damaged during use and therefore may have to be replaced. When the cap is replaced with a new cap, the ball indenter assembly shall be performance tested before use by performing a daily verification according to A1.5.3.1. The test block used should have a hardness equal to or softer than the softest material that is expected to be tested using the indenter. The verification may be performed by the indenter owner or a calibration agency. A testing machine that meets the requirements of Annex A1 shall be used for this verification.

A3.5 Class B Diamond Indenters

A3.5.1 Class B diamond indenters are intended for every day use to perform Rockwell hardness measurements. They shall be verified for correct geometry and performance in accordance with the schedule specified in Table A3.2.

TABLE A3.4 Test Blocks to be used for Singular or Limited Scale Ball Indenter Performance Verifications and the Maximum Tolerance on the Performance with Respect to Standardized Reference Blocks

Ball Size in. (mm)	Ranges of Required Test Blocks	Tolerance
1⁄16 (1.588) HR15TW scale	67 to 90 HR15TW	± 0.8 HR15TW
1⁄16 (1.588) HR30TW scale	30 to 77 HR30TW	± 0.8 HR30TW

A3.5.2 *Geometric Requirements of Class B Diamond Indenters:*

A3.5.2.1 The polished portion of the diamond indenter shall be free from surface defects (cracks, chips, pits, etc.) when observed under a 20× magnification. The indenter shall be polished to such an extent that no unpolished part of its surface makes contact with the test piece when the indenter penetrates to a depth of 0.3 mm.

A3.5.2.2 Verification of the following geometric features shall be made at not less than four approximately equally spaced full cross-section profiles. For example, four profiles would be spaced at approximately 45° intervals.

A3.5.2.3 The diamond shall have an included angle of 120 ± 0.35° (see Fig. A3.1).

A3.5.2.4 The tip of the diamond shall be spherical with a mean radius of 0.200 ± 0.010 mm (see Fig. A3.1). In each measured section, the radius shall be within 0.200 ± 0.015 mm, and local deviations from a true radius shall not exceed 0.002 mm.

A3.5.2.5 The surfaces of the cone and spherical tip shall blend in a tangential manner. The location where the spherical tip and the cone of the diamond blend together will vary depending on the geometrical values of the tip radius and cone angle. An indenter with a perfect geometry will have a blend point located at 100 µm from the indenter axis measured along a line normal to the indenter axis. To avoid including a blend area that does not occur at 100 µm in the measurement of the tip radius or cone angle, the portion of the diamond surface between 80 µm and 120 µm may be ignored.

A3.5.2.6 The instrument(s) used to verify the geometrical features shall be capable of measuring to the accuracies given in Table A3.5.

A3.5.2.7 The verification of the geometrical features of the diamond may be made by direct measurement or by measurement of it's projection on a screen provided the accuracy requirements are met.

A3.5.2.8 When the projection on a screen method is used, the contour of the diamond projection is compared to lines on the screen that indicate the dimensional tolerance limits. In this case, measurement values for the geometrical features are not required. It is sufficient to state that the features are within tolerances.

A3.5.3 *Performance Verification of Class B Diamond Indenters:*

A3.5.3.1 The influence of the diamond indenter on the hardness value is not due solely to the previously specified features of the indenter, but also on other characteristics that

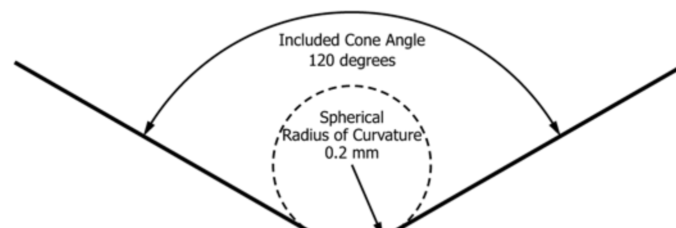


FIG. A3.1 Diagram of Cross-Sectional View of Spheroconical Diamond Indenter Tip

TABLE A3.5 Minimum Measuring Instrument Accuracies for Verifying the Geometrical Features of Class B, Class A and Reference Diamond Indenters

Geometrical Feature	Minimum Accuracy
Angles	0.1°
Radius	0.001 mm
Straightness of the generatric line of the cone (Class A and Reference indenters only)	0.001 mm

vary due to manufacturing procedures. To examine these influences, the performance of each Class B indenter shall be verified by comparison to the performance of a *qualifying* Class A or Reference indenter.

A3.5.3.2 Diamond indenters may be verified for use on limited Rockwell scales as follows: regular Rockwell scales only; superficial Rockwell scales only; or both regular and superficial Rockwell scales. Special diamond indenters intended for single or limited scale use and indenters, such as side cut diamond indenters, that because of their geometries cannot support the heavier loads of some Rockwell scales are also allowed. In all cases the test report shall define the scale or scales the indenter is certified to perform.

A3.5.3.3 The performance verification is accomplished by making hardness measurements on test blocks meeting the manufacturing requirements of A4.3.

A3.5.3.4 Prior to the performance verification, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a uniform test piece using a total force of 150 kgf, or the greatest test force that the indenter can support. The results of these measurements need not be recorded. This procedure shall be repeated each time the indenter is changed.

A3.5.3.5 Using the *qualifying* indenter, perform the daily verification procedures of A1.5.3 for the scales and hardness levels that will be used for the indenter performance verification. If any of the error E measurements or the repeatability R measurements fall outside of the specified tolerances, the standardizing machine shall not be considered to have passed the verification, and shall not be used for standardization until the problem is determined and corrections have been made. Once corrections have been made, the verification procedure shall be repeated. This verification procedure is required only at the start of the indenter performance verification.

A3.5.3.6 The following procedures for performance verification involve making *qualifying* hardness tests on test blocks with a Class A or Reference indenter, then performing *verification* tests on the same blocks with the Class B indenters to be verified.

A3.5.3.7 Using the *qualifying* indenter, perform one set of at least three qualifying tests on each test block from each range defined in Table A3.6 for the type of indenter to be verified. Special singular or limited scale indenters (see A3.5.3.2) shall be certified for use on singular or limited scales using the test blocks defined in Table A3.7. For example, if an HRA scale only diamond indenter is desired, the two HRA scale test blocks defined in the table would be used. If an indenter to be used in the 15N and 30N scales only is desired, then 4 test blocks would be used, 2 in the 15N scale and 2 in the 30N scale as defined in the table. Record each test result and the location of the indentation. Let $\bar{H}_Q$ be the average of the qualifying measurements.

TABLE A3.6 Test Blocks to be Used Class B Diamond Indenter Performance Verifications and the Maximum Tolerance on the Performance Relative to the Class A or Reference Indenter

Indenter Type	Ranges of Required Test Blocks	Class B Tolerance as Compared to Class A or Reference Indenter $\bar{H}_Q - \bar{H}_V$
Regular Scales Diamond	22 to 28 HRC	± 0.8 HRC
	60 to 65 HRC	± 0.4 HRC
Superficial Scales Diamond	88 to 94 HR15N	± 0.5 HR15N
	60 to 69 HR30N	± 0.5 HR30N
	22 to 29 HR45N	± 0.8 HR45N
Combination Regular and Superficial Scales Diamond	22 to 28 HRC	± 0.8 HRC
	60 to 65 HRC	± 0.5 HRC
	88 to 94 HR15N	± 0.5 HR15N
	60 to 69 HR30N	± 0.5 HR30N

TABLE A3.7 Test Blocks to be Used for Singular or Limited Scale Diamond Indenter Performance Verifications and the Maximum Tolerance on the Performance Relative to the Class A or Reference Indenter

Indenter Type	Ranges of Required Test Blocks	Tolerance as Compared to Class A or Reference Indenter $\bar{H}_Q - \bar{H}_V$
HRA Scale	61 to 65 HRA	± 0.8 HRA
	81 to 84 HRA	± 0.5 HRA
HRD Scale	41 to 46 HRD	± 0.8 HRD
	70 to 75 HRD	± 0.5 HRD
HR15N Scale	70 to 74 HR15N	± 0.8 HR15N
	88 to 94 HR15N	± 0.5 HR15N
HR30N Scale	43 to 49 HR30N	± 0.8 HR30N
	77 to 82 HR30N	± 0.5 HR30N

A3.5.3.8 Using the Class B indenter to be verified, perform *verification* tests on the test blocks previously tested with the Class A or Reference indenter. One *verification* test shall be made within 6 mm of each qualifying indent. Let $\bar{H}_V$ be the average of the verifying measurements.

A3.5.3.9 The number of verifying tests that can be made adjacent to each qualifying test is limited by the requirements to be within 6 mm of the qualifying indent while adhering to the indent to indent spacing requirements given in 7.9. To make additional verifying tests, perform additional qualifying tests with the Class A or Reference indenter, and repeat the above verifying procedure. This process may be repeated until there is no longer space on the test block.

A3.5.3.10 For acceptability, the difference between the qualifying and verifying averages, $\bar{H}_Q - \bar{H}_V$, shall be within the tolerances for Class B indenters of Table A3.6 or Table A3.7 for the singular or limited scale indenter being verified.

A3.6 Class A Diamond Indenters

A3.6.1 Class A indenters are intended to be used for the standardization of Class B indenters in accordance with this Annex; the standardization of Rockwell hardness test blocks as described in Annex A4, and as a troubleshooting tool during the indirect verification of Rockwell hardness testing machines in accordance with Annex A1. They are verified for correct geometry and performance in accordance with the schedule specified in Table A3.2.

A3.6.1.1 The instrument(s) used to verify the geometrical features shall be capable of measuring to the accuracies given in Table A3.5.

A3.6.2 A Class A diamond indenter shall meet all of the manufacture and geometric requirements for a Class B diamond indenter given in A3.5.2 with the following additional requirements. See also Note A3.1.

A3.6.2.1 The deviation from straightness of the generatric line of the diamond cone adjacent to the blend shall not exceed 0.002 mm over a minimum length of 0.40 mm.

A3.6.2.2 The angle between the axis of the indenter and the axis normal to the seating surface of the indenter shall not exceed 0.5°.

A3.6.3 Class A diamond indenters have tighter performance tolerances than Class B diamond indenters. The performance of each Class A indenter shall be verified by comparison to the performance of a Reference indenter.

A3.6.4 Perform the qualifying and verifying measurements as described in A3.5.3 for a Class B diamond indenter, except that the qualifying measurements shall be made using a Reference diamond indenter on each test block from each range defined in Table A3.8 for the type of indenter to be verified.

A3.6.4.1 For acceptability, the difference of the average of the three qualifying measurements and the average of the three verifying measurements, $\bar{H}_Q - \bar{H}_V$, shall be within the tolerance specified for Class A diamond indenters in Table A3.8.

TABLE A3.8 Test Blocks to be Used for Class A Diamond Indenter Performance Verifications and the Maximum Tolerance on the Performance Relative to the Reference Indenter

Indenter Type	Ranges of Required Test Blocks	Class A Tolerance as Compared to Reference Indenter $\bar{H}_Q - \bar{H}_V$
Regular Scales Diamond	80 to 83 HRA	± 0.3 HRA
	22 to 28 HRC	± 0.4 HRC
	42 to 50 HRC	± 0.4 HRC
	60 to 65 HRC	± 0.3 HRC
Superficial Scales Diamond	88 to 94 HR15N	± 0.3 HR15N
	60 to 69 HR30N	± 0.3 HR30N
	42 to 50 HR30N	± 0.4 HR45N
	22 to 29 HR45N	± 0.4 HR45N
Combination Regular and Superficial Scales Diamond	22 to 28 HRC	± 0.4 HRC
	60 to 65 HRC	± 0.3 HRC
	88 to 94 HR15N	± 0.3 HR15N
	60 to 69 HR30N	± 0.3 HR30N

A3.7 Reference Diamond Indenters

A3.7.1 Reference diamond indenters are intended for the standardization of Class A diamond indenters. The reference indenter shall have tighter performance tolerances than Class A and Class B indenters and shall be verified for performance by comparison to an indenter recognized as the national reference indenter(s) of a national Rockwell hardness standardizing laboratory (see Note A3.3).

NOTE A3.3—In the United States, the national Rockwell hardness standardizing laboratory is the National Institute of Standards and Technology (NIST).

A3.7.2 *Geometric Requirements of Reference Diamond Indenters:*

A3.7.2.1 Verification of the following geometric features of a Reference diamond spheroconical indenter shall be made at not less than eight approximately equally spaced full cross-section profiles. For example, eight profiles would be spaced at approximately 22.5 degree intervals.

A3.7.3 A Reference diamond indenter shall meet all of the manufacture and geometric requirements for a Class A diamond indenter given in A3.6.2. See also Note A3.1.

A3.7.4 *Performance Verification of Reference Diamond Indenters:*

A3.7.4.1 The performance comparison shall be performed by a national Rockwell hardness standardizing laboratory, and shall meet the performance tolerances of Table A3.9.

A3.7.4.2 Perform the qualifying and verifying measurements as described in A3.5.3 for a Class B indenter, except that at least four qualifying measurements shall be made using a national reference indenter (see A3.7.1) on each test block from each range defined in Table A3.9 for the type of indenter to be verified.

A3.7.4.3 For acceptability, the difference of the average of the five qualifying measurements and the average of the five verifying measurements, $\bar{H}_Q - \bar{H}_V$, shall be within the tolerance specified for Reference indenters in Table A3.9 for each test block used in the verification.

TABLE A3.9 Test Blocks to be Used for Reference Indenter Performance Verifications and the Maximum Tolerance on the Performance Relative to a National Reference Indenter

Indenter Type	Ranges of Required Test Blocks	Reference Indenter Tolerance as Compared to a National Reference Indenter $\bar{H}_Q - \bar{H}_V$
Regular Scales Diamond	22 to 28 HRC	± 0.3 HRC
	62 to 65 HRC	± 0.3 HRC
Superficial Scales Diamond	88 to 94 HR15N	± 0.3 HR15N
	40 to 48 HR45N	± 0.3 HR45N
Combination Regular and Superficial Scales Diamond	20 to 28 HRC	± 0.3 HRC
	62 to 65 HRC	± 0.3 HRC
	88 to 94 HR15N	± 0.3 HR15N
	40 to 48 HR45N	± 0.3 HR45N

A3.8 Marking

A3.8.1 All indenters shall be serialized. When it is not practical to mark the serial number on the indenter due to size limitations, the serial number shall be marked on the container.

A3.8.2 Diamond indenters should be marked to indicate the scales that they are certified to perform. For example, regular scale diamond indenters may be marked with a "C" and superficial scale diamond indenters may be marked with an "N". Combination indenters may be marked with both a "C" and an "N".

A3.8.3 Single or limited scale indenters shall be marked to indicate the scale(s) they are certified to perform. When it is not practical to mark the scale on the indenter due to size limitations, the scale shall be marked on the container.

A3.9 Certificate

A3.9.1 *Ball Indenters*—Each Class B and Class A ball indenter holder shall have a calibration certificate with the following information:

A3.9.1.1 Reference to this ASTM test method.

A3.9.1.2 Serial number of the indenter.

A3.9.1.3 Date of standardization.

A3.9.1.4 A statement declaring that the indenter meets all of the material hardness, ball protrusion and performance requirements for the particular Class of Rockwell ball indenter.

A3.9.1.5 Accreditation agency certification number.

A3.9.1.6 The scale(s) that the indenter is certified to perform when certified for singular or limited scales.

A3.9.2 Indenter balls for Class B and Class A indenters shall have a report, applicable to one or more balls, with the following information:

A3.9.2.1 Reference to this ASTM test method.

A3.9.2.2 Identification of the lot or batch.

A3.9.2.3 A statement declaring that the ball meets all of the geometrical, density, chemical composition and hardness requirements for the particular Class of Rockwell ball indenter.

A3.9.3 *Class B Diamond Indenters*—Each Class B diamond indenter shall have a calibration certificate with the following information:

A3.9.3.1 Reference to this ASTM test method.

A3.9.3.2 Serial number of the indenter.

A3.9.3.3 Date of standardization.

A3.9.3.4 A statement declaring that the indenter meets all of the geometrical and performance requirements for a Class B indenter.

A3.9.3.5 Accreditation agency certification number.

A3.9.3.6 The scale(s) that the indenter is certified to perform when certified for singular or limited scales.

A3.9.4 *Class A Diamond Indenters*—Each Class A diamond indenter shall have a calibration certificate with the following information:

A3.9.4.1 Reference to this ASTM test method.

A3.9.4.2 Serial number of the indenter.

A3.9.4.3 Date of standardization.

A3.9.4.4 The results of all geometrical verifications.

A3.9.4.5 All qualifying and verifying performance measurements with the hardness levels of the test blocks used.

A3.9.4.6 The performance differences between the Reference standardizing indenter and the verified Class A indenter $\bar{H}_Q - \bar{H}_V$ for each test block used.

A3.9.4.7 A statement declaring that the indenter meets all of the geometrical and performance requirements for a Class A indenter.

A3.9.4.8 Accreditation agency certification number.

A3.9.5 *Reference Diamond Indenters*—Each Reference diamond indenter shall have a calibration certificate or report with the following information:

A3.9.5.1 Serial number of the indenter.

A3.9.5.2 Date of standardization.

A3.9.5.3 The results of all geometrical verifications.

A3.9.5.4 Serial number of the reference indenter.

A3.9.5.5 All qualifying and verifying performance measurements with the hardness levels of the test blocks used.

A3.9.5.6 The performance differences between the reference indenter and the verified Reference indenter $\bar{H}_Q - \bar{H}_V$ for each test block used.

A4. STANDARDIZATION OF ROCKWELL HARDNESS TEST BLOCKS

A4.1 Scope

A4.1.1 Annex A4 specifies the requirements and procedures for the standardization of Rockwell hardness test blocks that are traceable to specific Rockwell hardness standards. These standardized test blocks are to be used for the verification of the performance of Rockwell and Rockwell superficial hardness testing machines by way of daily verifications and indirect verifications as described in Annex A1. The standardized test blocks are also to be used for the monitoring verifications of Rockwell standardizing machines as described in Annex A2.

A4.1.2 Adherence to this standard and annex provides traceability to national standards, except as stated otherwise.

A4.2 Accreditation

A4.2.1 The agency conducting the standardizations of test blocks shall be accredited to the requirements of ISO 17025 (or an equivalent) by an accrediting body recognized by the International Laboratory Accreditation Cooperation (ILAC) as operating to the requirements of ISO/IEC 17011. The standardizing agency shall have a certificate/scope of accreditation stating the Rockwell hardness scales that are covered by the accreditation, and the standards to which the test block standardizations are traceable.

A4.3 Manufacture

A4.3.1 The attention of the manufacturer of test blocks is drawn to the need to use material and a manufacturing process which will give the necessary homogeneity, stability of structure, and uniformity of surface hardness. For quality control purposes, test blocks should be examined for homogeneity and uniformity of surface hardness in accordance with a statistically acceptable sampling procedure.

A4.3.2 The test blocks, if of steel, shall be demagnetized at the end of the manufacturing process.

A4.3.3 To assure that material is not removed from the test surface after standardization, an identifying mark shall be made on the test surface. The mark shall be such that it can not be removed by any method other than removal of test block material.

A4.3.4 The standardized test block shall meet the physical requirements of Table A4.1.

A4.4 General Requirements

A4.4.1 The standardizing laboratory environment, the standardizing machine, and the standardizing test cycle shall satisfy the requirements of Annex A2.

A4.4.2 All instruments used to make measurements required by this Annex shall have been calibrated traceable to national standards where a system of traceability exists, except as noted otherwise.

A4.5 Standardization Procedure

A4.5.1 A test block is standardized by calibrating the average hardness of the test surface to a specific Rockwell hardness standard. Only one surface of the test block shall be calibrated. When possible, the test blocks should be calibrated traceable to national Rockwell standards (see Note A4.1). The Rockwell standard to which the test blocks are traceable shall be stated in the certification.

NOTE A4.1—In the United States, the national Rockwell hardness standardizing laboratory is the National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899.

NOTE A4.2—Primary standardized test blocks are available as Standard Reference Material from NIST, Gaithersburg, MD 20899.

A4.5.2 Class A ball indenters and Class A or Reference diamond indenters as described in Annex A3 (see Note 3) shall be used for the standardization of test blocks.

TABLE A4.1 Physical Requirements of Standardized Test Blocks

Test Block Parameter	Tolerance
Thickness	≥6.0 mm (0.236 in.) ≤16.0 mm (0.630 in.)
Test surface area	≤2600 mm^2 (4 in.^{2})
Deviation from surface flatness (test & bottom)	≤0.005 mm (0.0002 in.)
Deviation from surface parallelism (test & bottom)	≤0.0002 mm per mm (0.0002 in. per in.)
Mean surface roughness (test & bottom)	R_a ≤ 0.003 mm (12 µin.) center line average

A4.5.3 The standardization procedure involves making hardness measurements on the test block surface using the forces and type of indenter that are appropriate for the hardness scale.

A4.5.3.1 Make at least five measurements distributed uniformly over the test surface.

A4.5.4 Determine the nonuniformity range H_R of the measurements as:

$$H_R = H_{max} - H_{min} \tag{A4.1}$$

where:

H_{max} = highest hardness value, and
H_{min} = lowest hardness value.

A4.5.4.1 The nonuniformity range H_R of the standardizing measurements provides an indication of the non-uniformity of the test block hardness. For acceptability, the nonuniformity range H_R shall be within the tolerances of Table A4.2.

A4.5.5 The standardized value of the test block is defined as the average of the standardization measurements $\bar{H}$.

A4.5.6 In some cases, a more accurate standardized value for the test block may be obtained by correcting the measured average hardness value by a performance offset value for the standardizing machine. The offset value may be based on the error E values measured during the last indirect verification of the standardizing machine. For example, an appropriate offset correction curve for each standardizing machine may be calculated for a specific Rockwell scale by fitting a linear line to the error values measured during the indirect verification. The laboratory should be cautioned that the validity of calculating a correction curve in this way is dependent on the linearity of the fit of the offset data across the entire scale.

TABLE A4.2 Maximum Nonuniformity for Standardized Test Blocks

	Nominal Hardness of Standardized Test Block	Max. Nonuniformity Range, H_R (HR units)
HRA	≥20 and <80	1.0
	≥80 and <92	0.5
HRBW	≥0 and <45	1.5
	≥45 and <100	1.0
HRC	≥20 and <60	1.0
	≥60 and <70	0.5
HRD	≥40 and <60	1.0
	≥60 and <87	0.5
HREW, HRFW, HRGW, HRHW, HRKW, HRLW, HRMW, HRPW, HRRW, HRSW, HRVW		1.0
HR15N	≥69 and <90	1.0
	≥90 and <97	0.7
HR30N	≥41 and <77	1.0
	≥77 and <92	0.7
HR45N	≥19 and <66	1.0
	≥66 and <87	0.7
HR15TW, HR30TW, HR45TW		1.0
HR15WW, HR30WW, HR45WW, HR15XW, HR30XW, HR45XW, HR15YW, HR30YW, HR45YW		1.0

A4.6 Marking

A4.6.1 Markings placed on the side of the block shall be upright when the calibrated test surface is the upper surface.

A4.6.2 Each standardized block shall be marked with the following.

A4.6.2.1 The standardized hardness value, $\bar{H}$, of the test block, rounded to no less than one decimal place in accordance with Practice E29, for example 61.4 HRC.

A4.6.2.2 The appropriate tolerance value for error *E* given in Table A1.3.

A4.6.2.3 Name or identifying mark of the standardizing agency.

A4.6.2.4 A mark identifying the test surface, which will be obliterated if the surface is reground.

A4.6.2.5 Unique serial number.

A4.6.2.6 Year of standardization. It is sufficient that the year of standardization be incorporated into the serial number of the block.

A4.7 Certificate

A4.7.1 Each standardized test block shall be supplied with a certificate from the standardizing laboratory stating the following standardization information:

A4.7.1.1 Serial number of the test block.

A4.7.1.2 The standardized hardness value, $\bar{H}$, of the test block with the scale designation, rounded to no less than one decimal place in accordance with Practice E29, for example 61.4 HRC.

A4.7.1.3 Value of the uncertainty in the standardized value with a detailed explanation of how the uncertainty was calculated.

A4.7.1.4 The individual standardizing hardness measurements.

A4.7.1.5 A description of the testing cycle used, including the dwell times for the preliminary force, total force and elastic recovery.

A4.7.1.6 The body that maintains the Rockwell scale to which the test block is traceable. For example, the national Rockwell C scale maintained at NIST.

A4.7.1.7 Date of standardization.

A4.7.1.8 Accreditation agency certification number.

A5. GUIDELINES FOR DETERMINING THE MINIMUM THICKNESS OF A TEST PIECE

TABLE A5.1 A Minimum Thickness Guide for Selection of Scales Using the Diamond Indenter (see Fig. A5.1)

NOTE 1—For any given thickness, the indicated Rockwell hardness is the minimum value acceptable for testing. For a given hardness, material of any greater thickness than that corresponding to that hardness can be tested on the indicated scale.

Minimum Thickness		Rockwell Scale		
		A		C
in.	mm	Hardness Reading	Approximate Hardness C-Scale[A]	Hardness Reading
0.014	0.36	...	...	...
0.016	0.41	86	69	...
0.018	0.46	84	65	...
0.020	0.51	82	61.5	...
0.022	0.56	79	56	69
0.024	0.61	76	50	67
0.026	0.66	71	41	65
0.028	0.71	67	32	62
0.030	0.76	60	19	57
0.032	0.81	...	...	52
0.034	0.86	...	...	45
0.036	0.91	...	...	37
0.038	0.96	...	...	28
0.040	1.02	...	...	20

[A] These approximate hardness numbers are for use in selecting a suitable scale and should not be used as hardness conversions. If necessary to convert test readings to another scale, refer to Hardness Conversion Tables E140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness, and Knoop Hardness).

TABLE A5.2 A Minimum Thickness Guide for Selection of Scales Using the 1/16 in. (1.588 mm) Diameter Ball Indenter (see Fig. A5.2)

NOTE 1—For any given thickness, the indicated Rockwell hardness is the minimum value acceptable for testing. For a given hardness, material of any greater thickness than that corresponding to that hardness can be tested on the indicated scale.

Minimum Thickness		Rockwell Scale		
		F		B
in.	mm	Hardness Reading	Approximate Hardness B-Scale[A]	Hardness Reading
0.022	0.56	...	...	...
0.024	0.61	98	72	94
0.026	0.66	91	60	87
0.028	0.71	85	49	80
0.030	0.76	77	35	71
0.032	0.81	69	21	62
0.034	0.86	...	...	52
0.036	0.91	...	...	40
0.038	0.96	...	...	28
0.040	1.02	...	...	...

[A] These approximate hardness numbers are for use in selecting a suitable scale and should not be used as hardness conversions. If necessary to convert test readings to another scale refer to Hardness Conversion Tables E140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness and Knoop Hardness).

TABLE A5.3 A Minimum Thickness Guide for Selection of Scales Using the Diamond Indenter (see Fig. A5.1)

NOTE 1—For any given thickness, the indicated Rockwell hardness is the minimum value acceptable for testing. For a given hardness, material of any greater thickness than that corresponding to that hardness can be tested on the indicated scale.

Minimum Thickness		Rockwell Superficial Scale					
		15N		30N		45N	
in.	mm	Hardness Reading	Approximate Hardness C-Scale[A]	Hardness Reading	Approximate Hardness C-Scale[A]	Hardness Reading	Approximate Hardness C-Scale[A]
0.006	0.15	92	65	...	...	. ..	...
0.008	0.20	90	60	...	...	...	...
0.010	0.25	88	55	...	...	...	...
0.012	0.30	83	45	82	65	77	69.5
0.014	0.36	76	32	78.5	61	74	67
0.016	0.41	68	18	74	56	72	65
0.018	0.46	...	...	66	47	68	61
0.020	0.51	...	...	57	37	63	57
0.022	0.56	...	...	47	26	58	52.5
0.024	0.61	...	...	...	...	51	47
0.026	0.66	...	...	...	...	37	35
0.028	0.71	...	...	...	...	20	20.5
0.030	0.76	...	...	...	...	...	...

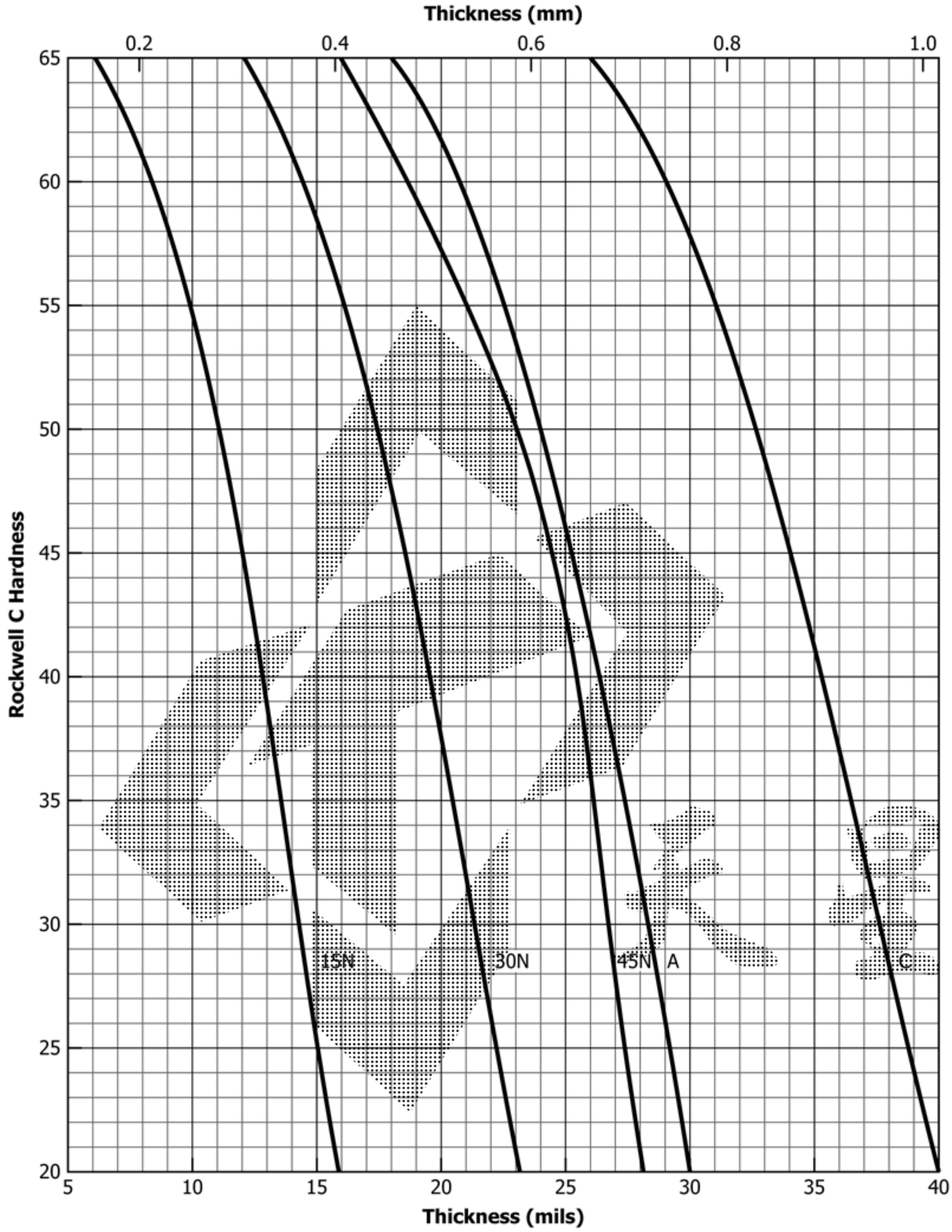
[A] These approximate hardness numbers are for use in selecting a suitable scale, and should not be used as hardness conversions. If necessary to convert test readings to another scale, refer to Hardness Conversion Tables E140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness and Knoop Hardness).

TABLE A5.4 A Minimum Thickness Guide for Selection of Scales Using the 1/16 in. (1.588 mm) Diameter Ball Indenter (see Fig. A5.2)

NOTE 1—For any given thickness, the indicated Rockwell hardness is the minimum value acceptable for testing. For a given hardness, material of any greater thickness than that corresponding to that hardness can be tested on the indicated scale.

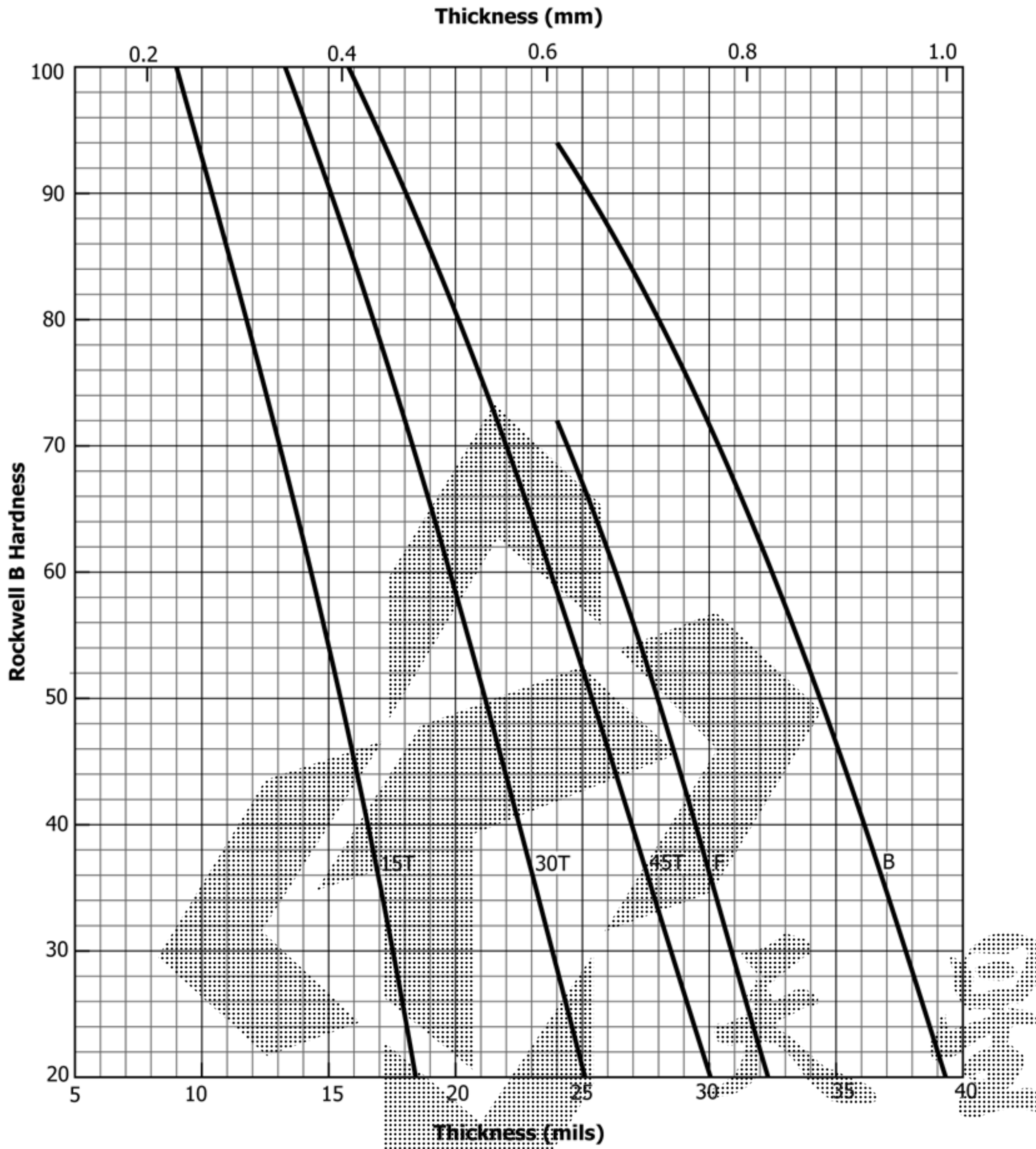
Minimum Thickness		Rockwell Superficial Scale					
		15T		30T		45T	
in.	mm	Hardness Reading	Approximate Hardness B-Scale[A]	Hardness Reading	Approximate Hardness B-Scale[A]	Hardness Reading	Approximate Hardness B-Scale[A]
0.010	0.25	91	93	...	...	...	...
0.012	0.30	86	78	...	...	...	...
0.014	0.36	81	62	80	96	...	...
0.016	0.41	75	44	72	84	71	99
0.018	0.46	68	24	64	71	62	90
0.020	0.51	...	...	55	58	53	80
0.022	0.56	...	...	45	43	43	70
0.024	0.61	...	...	34	28	31	58
0.026	0.66	...	...	...	...	18	45
0.028	0.71	...	...	...	...	4	32
0.030	0.76	...	...	...	...	...	...

[A] These approximate hardness numbers are for use in selecting a suitable scale, and should not be used as hardness conversions. If necessary to convert test readings to another scale refer to Hardness Conversion Tables E140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness and Knoop Hardness).



NOTE 1—Locate a point corresponding to the thickness-hardness combination to be tested. Only scales falling to the left of this point may be used to test this combination.

FIG. A5.1 Thickness Limits for Rockwell Hardness Testing Using the Diamond Indenter



NOTE 1—Locate a point corresponding to the thickness-hardness combination to be tested. Only scales falling to the left of this point may be used to test this combination.

FIG. A5.2 Thickness Limits for Rockwell Hardness Testing Using the 1/16-in. (1.588-mm) Diameter Ball Indenter

A6. HARDNESS VALUE CORRECTIONS WHEN TESTING ON CONVEX CYLINDRICAL SURFACES

TABLE A6.1 Corrections to be Added to Rockwell C, A, and D Values Obtained on Convex Cylindrical Surfaces of Various Diameters[A]

Dial Reading	Diameters of Convex Cylindrical Surfaces								
	¼ in. (6.4 mm)	⅜ in. (10 mm)	½ in. (13 mm)	⅝ in. (16 mm)	¾ in. (19 mm)	⅞ in. (22 mm)	1 in. (25 mm)	1¼ in. (32 mm)	1½ in. (38 mm)
	Corrections to be Added to Rockwell C, A, and D Values[B]								
20	6.0	4.5	3.5	2.5	2.0	1.5	1.5	1.0	1.0
25	5.5	4.0	3.0	2.5	2.0	1.5	1.0	1.0	1.0
30	5.0	3.5	2.5	2.0	1.5	1.5	1.0	1.0	0.5
35	4.0	3.0	2.0	1.5	1.5	1.0	1.0	0.5	0.5
40	3.5	2.5	2.0	1.5	1.0	1.0	1.0	0.5	0.5
45	3.0	2.0	1.5	1.0	1.0	1.0	0.5	0.5	0.5
50	2.5	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5
55	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0
60	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
65	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
70	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0	0
75	1.0	0.5	0.5	0.5	0.5	0.5	0	0	0
80	0.5	0.5	0.5	0.5	0.5	0	0	0	0
85	0.5	0.5	0.5	0	0	0	0	0	0
90	0.5	0	0	0	0	0	0	0	0

[A] When testing cylindrical specimens, the accuracy of the test will be seriously affected by alignment of elevating screw, V-anvil, indenters, surface finish, and the straightness of the cylinder.
[B] These corrections are approximate only and represent the averages to the nearest 0.5 Rockwell number, of numerous actual observations.

TABLE A6.2 Corrections to be Added to Rockwell B, F, and G Values Obtained on Convex Cylindrical Surfaces of Various Diameters[A]

Hardness Reading	Diameters of Convex Cylindrical Surfaces						
	¼ in. (6.4 mm)	⅜ in. (10 mm)	½ in. (13 mm)	⅝ in. (16 mm)	¾ in. (19 mm)	⅞ in. (22 mm)	1 in. (25 mm)
	Corrections to be Added to Rockwell B, F, and G Values[B]						
0	12.5	8.5	6.5	5.5	4.5	3.5	3.0
10	12.0	8.0	6.0	5.0	4.0	3.5	3.0
20	11.0	7.5	5.5	4.5	4.0	3.5	3.0
30	10.0	6.5	5.0	4.5	3.5	3.0	2.5
40	9.0	6.0	4.5	4.0	3.0	2.5	2.5
50	8.0	5.5	4.0	3.5	3.0	2.5	2.0
60	7.0	5.0	3.5	3.0	2.5	2.0	2.0
70	6.0	4.0	3.0	2.5	2.0	2.0	1.5
80	5.0	3.5	2.5	2.0	1.5	1.5	1.5
90	4.0	3.0	2.0	1.5	1.5	1.5	1.0
100	3.5	2.5	1.5	1.5	1.0	1.0	0.5

[A] When testing cylindrical specimens, the accuracy of the test will be seriously affected by alignment of elevating screw, V-anvil, indenters, surface finish, and the straightness of the cylinder.
[B] These corrections are approximate only and represent the averages to the nearest 0.5 Rockwell number, of numerous actual observations.

TABLE A6.3 Corrections to be Added to Rockwell Superficial 15N, 30N, and 45N Values Obtained on Convex Cylindrical Surfaces of Various Diameters[A]

Hardness Reading	Diameters of Convex Cylindrical Surfaces					
	⅛ in. (3.2 mm)	¼ in. (6.4 mm)	⅜ in. (10 mm)	½ in. (13 mm)	¾ in. (19 mm)	1 in. (25 mm)
	Corrections to be Added to Rockwell Superficial 15N, 30N, and 45N Values[B]					
20	6.0	3.0	2.0	1.5	1.5	1.5
25	5.5	3.0	2.0	1.5	1.5	1.0
30	5.5	3.0	2.0	1.5	1.0	1.0
35	5.0	2.5	2.0	1.5	1.0	1.0
40	4.5	2.5	1.5	1.5	1.0	1.0
45	4.0	2.0	1.5	1.0	1.0	1.0
50	3.5	2.0	1.5	1.0	1.0	0.5
55	3.5	2.0	1.5	1.0	0.5	0.5
60	3.0	1.5	1.0	1.0	0.5	0.5
65	2.5	1.5	1.0	0.5	0.5	0.5
70	2.0	1.0	1.0	0.5	0.5	0.5
75	1.5	1.0	0.5	0.5	0.5	0
80	1.0	0.5	0.5	0.5	0	0
85	0.5	0.5	0.5	0.5	0	0
90	0	0	0	0	0	0

[A] When testing cylindrical specimens the accuracy of the test will be seriously affected by alignment of elevating screw, V-anvil, indenters, surface finish, and the straightness of the cylinder.
[B] These corrections are approximate only and represent the averages, to the nearest 0.5 Rockwell superficial number, of numerous actual observations.

TABLE A6.4 Corrections to be Added to Rockwell Superficial 15T, 30T, and 45T Values Obtained on Convex Cylindrical Surfaces of Various Diameters[A]

Hardness Reading	Diameters of Convex Cylindrical Surfaces						
	⅛ in. (3.2 mm)	¼ in. (6.4 mm)	⅜ in. (10 mm)	½ in. (13 mm)	⅝ in. (16 mm)	¾ in. (19 mm)	1 in. (25 mm)
	Corrections to be Added to Rockwell Superficial 15T, 30T, and 45T Values[B]						
20	13.0	9.0	6.0	4.5	4.5	3.0	2.0
30	11.5	7.5	5.0	3.5	3.5	2.5	2.0
40	10.0	6.5	4.5	3.5	3.0	2.5	2.0
50	8.5	5.5	4.0	3.0	2.5	2.0	1.5
60	6.5	4.5	3.0	2.5	2.0	1.5	1.5
70	5.0	3.5	2.5	2.0	1.5	1.0	1.0
80	3.0	2.0	1.5	1.5	1.0	1.0	0.5
90	1.5	1.0	1.0	0.5	0.5	0.5	0.5

[A] When testing cylindrical specimens, the accuracy of the test will be seriously affected by alignment of elevating screw, V-anvil, indenters, surface finish, and the straightness of the cylinder.
[B] These corrections are approximate only and represent the averages to the nearest 0.5 Rockwell number, of numerous actual observations.

APPENDIXES

(Nonmandatory Information)

X1. LIST OF ASTM SPECIFICATIONS GIVING HARDNESS VALUES CORRESPONDING TO TENSILE STRENGTH

X1.1 The following ASTM standards give approximate Rockwell hardness or Rockwell superficial hardness values corresponding to the tensile strength values specified for the materials covered: Test Methods and Definitions A370 and Specifications B19, B36/B36M, B96/B96M, B103/B103M, B121/B121M, B122/B122M, B130, B134/B134M, B152/B152M, and B370.

X2. EXAMPLES OF PROCEDURES FOR DETERMINING ROCKWELL HARDNESS UNCERTAINTY

X2.1 Scope

X2.1.1 The intent of this appendix is to provide a basic approach to evaluating the uncertainty of Rockwell hardness measurement values in order to simplify and unify the interpretation of uncertainty by users of Rockwell hardness.

X2.1.2 This appendix provides basic procedures for determining the uncertainty of the following values of hardness:

X2.1.2.1 *The Hardness Machine "Error" Determined as Part of an Indirect Verification* (see X2.6)—As part of an indirect verification, a number of Rockwell hardness measurements are made on a reference test block. The average of the measurement values is compared to the certified value of the reference block to determine the "error" (see 3.2.2) of the hardness machine. The procedure described in section X2.6 provides a method for determining the uncertainty in this measurement "error" of the hardness machine. The uncertainty value may be reported on the verification certificate and report.

X2.1.2.2 *Rockwell Hardness Value Measured by a User* (see X2.7)—The procedure provides a method for determining the uncertainty in the hardness values measured by a user during the normal use of a Rockwell hardness machine. The user may report the uncertainty value with the measurement value.

X2.1.2.3 *Certified Value of a Rockwell Hardness Test Block* (see X2.8) —The procedure provides a method for determining the uncertainty in the certified value of standardized test blocks. The standardizing agency may report the uncertainty value on the test block certificate.

NOTE X2.1—When calculated, uncertainty values reported by a field calibration agency (see X2.6) are not the measurement uncertainties of the hardness machine in operation, but only that of the measurements made at the time of verification to determine machine "error."

NOTE X2.2—The procedures outlined in this appendix for the determination of uncertainties are based primarily on measurements made as part of the verification and standardization procedures of this test method. This is done to provide a method that is based on familiar procedures and practices of Rockwell hardness users and standardizing agencies. The reader should be aware that there are other methods that may be employed to determine the same uncertainties, which may provide more accurate estimations of the uncertainty values.

NOTE X2.3—This standard states tolerances or limits on the acceptable repeatability and error of a Rockwell hardness machine (Table A1.3) and the nonuniformity of standardized blocks (Table A4.2). These limit values were originally established based on the testing experience of many users of the Rockwell hardness test, and therefore reflect the normal performance of a properly functioning Rockwell hardness machine, including the normal errors associated with the measurement procedure and the machine's performance. Because the limits are based on testing experience, it is believed that the stated limit values take into account a level of uncertainty that is typical for valid Rockwell hardness measurements. Consequently, when determining compliance with Table A1.3 and Table A4.2, the user's measurement uncertainty should not be subtracted from the tolerance limit values given in the tables, as is commonly done for other types of metrological measurements. The calculated values for repeatability, error or block nonuniformity should be directly compared to the tolerance limits given in the tables.

NOTE X2.4—Most product specification tolerances for Rockwell hardness were established based on testing and performance experience. The tolerance values reflect the normal performance of a properly functioning Rockwell hardness machine, including the normal acceptable errors associated with the hardness measurement process. For these products, the stated tolerance limits take into account a level of uncertainty that is typical for valid Rockwell hardness measurements. Consequently, when acceptance testing most products for Rockwell hardness, the user's measurement uncertainty should not be subtracted from the tolerance limit values given in the specification. The measured hardness values should be directly compared to the tolerances. There may be exceptional circumstances where the hardness of a product must fall within determined ranges to a high level of confidence. In these rare occasions, special agreement between the parties involved should be obtained before the hardness measurement uncertainty is subtracted from the tolerance limits. Before such an agreement is made, it is recommended that the product design take into consideration the anticipated influence of material and metallurgical factors on the product variation as well as typical industry hardness uncertainty values.

X2.1.3 This appendix does not address uncertainties at the primary reference standardizing level.

X2.2 Equations

X2.2.1 The average (*AVG*), $\bar{H}$, of a set of *n* hardness measurements $H_1, H_2, \ldots, H_n$ is calculated as:

$$AVG(H_1, H_2, \ldots, H) = \overline{H} = \frac{H_1 + H_2 + \ldots + H_n}{n} \tag{X2.1}$$

X2.2.2 The standard deviation (*STDEV*) of a set of *n* hardness measurements $H_1, H_2, \ldots, H_n$ is calculated as:

$$STDEV(H_1, H_2, \ldots, H_n) = \sqrt{\frac{(H_1 - \overline{H})^2 + \ldots + (H_n - \overline{H})^2}{n-1}} \tag{X2.2}$$

where $\bar{H}$ is the average of the set of *n* hardness measurements $H_1, H_2, \ldots, H_n$ as defined in Eq X2.1.

X2.2.3 The absolute value (*ABS*) of a number is the magnitude of the value irrespective of the sign, for example:

$$ABS(0.12) = 0.12$$
and
$$ABS(-0.12) = 0.12$$

X2.3 General Requirements

X2.3.1 The approach for determining uncertainty presented in this appendix considers only those uncertainties associated with the overall measurement performance of the Rockwell hardness machine with respect to reference standards. These performance uncertainties reflect the combined effect of the separate uncertainties associated with the numerous individual components of the machine, such as the force application system and indentation depth measuring system. Therefore, the uncertainties associated with the individual components of the machine are not included in the calculations. Because of this approach, it is important that the individual machine components are operating within tolerances. It is strongly recommended that this procedure be applied only after successfully passing a direct verification.

X2.3.2 The procedures given in this appendix are appropriate only when the Rockwell hardness machine has passed an indirect verification in accordance with the procedures and schedules of this test method standard.

X2.3.3 The procedures for calculating the uncertainty of Rockwell hardness measurement values are similar for both a standardizing machine and testing machine. The principal difference is in the hierarchy level of the reference test blocks normally used for the indirect verification. Generally, standardizing machines are verified using primary reference standards, and testing machines are standardized using secondary reference standards.

X2.3.4 To estimate the overall uncertainty of Rockwell hardness measurement values, contributing components of uncertainty must be determined. Because many of the uncertainties may vary depending on the specific hardness scale and hardness level, an individual measurement uncertainty should be determined for each hardness scale and hardness level of interest. In many cases, a single uncertainty value may be applied to a range of hardness levels based on the laboratory's experience and knowledge of the operation of the hardness machine.

X2.3.5 Uncertainty should be determined with respect to a country's highest level of reference standard or the national reference standard of another country. In some cases, the highest level of reference standard may be a commercial reference standard.

X2.4 General Procedure

X2.4.1 This procedure calculates a combined standard uncertainty u_c by combining the contributing components of uncertainty $u_1, u_2, \ldots, u_n$, such that:

$$u_c = \sqrt{u_1^2 + u_2^2 + \ldots + u_n^2} \tag{X2.3}$$

X2.4.2 Measurement uncertainty is usually expressed as an expanded uncertainty *U* which is calculated by multiplying the combined standard uncertainty u_c by a numerical coverage factor *k*, such that:

$$U = k \times u_c \tag{X2.4}$$

X2.4.3 A coverage factor is chosen that depends on how well the standard uncertainty was estimated (number of measurements), and the level of uncertainty that is desired. For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

X2.4.4 The measurement bias *B* of the hardness machine is the difference between the expected hardness measurement values as displayed by the hardness machine and the "true" hardness of a material. Ideally, measurement biases should be corrected. When test systems are not corrected for measurement bias, as often occurs in Rockwell hardness testing, the bias then contributes to the overall uncertainty in a measurement. There are a number of possible methods for incorporating biases into an uncertainty calculation, each of which has both advantages and disadvantages. A simple and conservative method is to combine the bias with the calculation of the expanded uncertainty as:

$$U = ku_c + ABS(B) \tag{X2.5}$$

where *ABS*(*B*) is the absolute value of the bias.

X2.4.5 Because several approaches may be used to evaluate and express measurement uncertainty, a brief description of what the reported uncertainty values represent should be included with the reported uncertainty value.

X2.5 Sources of Uncertainty

X2.5.1 This section describes the most significant sources of uncertainty in a Rockwell hardness measurement and provides procedures and formulas for calculating the total uncertainty in the hardness value. In later sections, it will be shown how these sources of uncertainty contribute to the total measurement uncertainty for the three measurement circumstances described in X2.1.2.

X2.5.2 The sources of uncertainty to be discussed are (*1*) the hardness machine's lack of repeatability, (*2*) the non-uniformity in hardness of the material under test, (*3*) the hardness machine's lack of reproducibility, (*4*) the resolution of the hardness machine's measurement display, and (*5*) the uncertainty in the certified value of the reference test block standards. An estimation of the measurement bias and its inclusion into the expanded uncertainty will also be discussed.

X2.5.3 *Uncertainty Due to Lack of Repeatability* (u_{Repeat}) *and when Combined with Non-uniformity* ($u_{Rep\& NU}$)—The repeatability of a hardness machine is an indication of how well it can continually produce the same hardness value each time a measurement is made. Imagine there is a material, which is perfectly uniform in hardness over its entire surface. Also imagine that hardness measurements are made repeatedly on this uniform material over a short period of time without varying the testing conditions (including the operator). Even though the actual hardness of every test location is exactly the same, it would be found that due to random errors each measurement value would differ from all other measurement values (assuming sufficient measurement resolution). Therefore, lack of repeatability prevents the hardness machine from being able to always measure the true hardness of the material, and hence contributes to the uncertainty in the measurement.

X2.5.3.1 The contribution that a hardness machine's lack of repeatability makes to the overall measurement uncertainty is determined differently depending on whether a single measurement value or an average of multiple measurements is to be reported. Additionally, in cases where the reported average measurement value is intended to be an estimate of the average hardness of the material tested, the uncertainty contributions due to the machine's lack of repeatability and the non-uniformity in the hardness of the test material are difficult to separate and must be determined together. The uncertainty contributions for each of these circumstances may be estimated as follows.

X2.5.3.2 *Single Hardness Measurement*—For a future single hardness measurement, the standard uncertainty contribution u_{Repeat}, due to the lack of repeatability, may be estimated by the standard deviation of the values from a number of hardness measurements made on a uniform test sample as:

$$u_{Repeat} = STDEV(H_1, H_2, \ldots, H_n) \quad \text{(X2.6)}$$

where H_1, H_2, ..., H_n are the n hardness values. In general, the estimate of repeatability is improved as the number of hardness measurements is increased. Usually, the hardness values measured during an indirect verification will provide an adequate estimate of u_{Repeat}; however, the caution given in Note X2.6 should be considered. It may be more appropriate for the user to determine a value of u_{Repeat} by making hardness measurements close together (within spacing limitations) on a uniform material, such as a test block.

NOTE X2.5—The uncertainty u_{Repeat}, due to the lack of repeatability of a hardness machine as discussed above, should not be confused with the historically defined "repeatability" that is a requirement to be met as part of an indirect verification (see 3.2.3). The calculations of the uncertainty u_{Repeat} and of the historically defined repeatability do not produce the same value. The uncertainty u_{Repeat} is the contribution to the overall uncertainty of a hardness measurement value due to a machine's lack of repeatability, while the historically defined repeatability is the range of hardness values measured during an indirect verification.

NOTE X2.6—All materials exhibit some degree of hardness non-uniformity across the test surface. Therefore, the above evaluation of the uncertainty contribution due to the lack of repeatability will also include a contribution due to the hardness non-uniformity of the measured material. When evaluating repeatability as discussed above, any uncertainty contribution due to the hardness non-uniformity should be minimized as much as possible. The laboratory should be cautioned that if the measurements of repeatability are based on tests made across the surface of the material, then the repeatability value will likely include a significant uncertainty contribution due to the material's non-uniformity. A machine's repeatability is better evaluated by making hardness measurements close together (within spacing limitations).

X2.5.3.3 *Average of Multiple Measurements*—When the average of multiple hardness test values is to be reported, the standard uncertainty contribution $u_{\overline{Repeat}}$, due to the lack of repeatability of the hardness machine, may be estimated by dividing the standard uncertainty contribution u_{Repeat} (previously calculated from a number of hardness measurements made on a uniform test sample, see X2.5.3.1) by the square-root of the number of hardness test values being averaged, as:

$$u_{\overline{Repeat}} = \frac{u_{Repeat}}{\sqrt{n_T}} \quad \text{(X2.7)}$$

where u_{Repeat} is calculated by Eq X2.6 and n_T is the number of individual hardness test values being averaged.

X2.5.3.4 *Estimate of the Material Hardness*—Hardness measurements are often made at several locations and the values averaged in order to estimate the average hardness of the material as a whole. For example, this may be done when making quality control measurements during the manufacture of many types of products; when determining the machine "error" as part of an indirect verification; and when calibrating a test block. Because all materials exhibit some degree of hardness non-uniformity across the test surface, the extent of a material's non-uniformity also contributes to the uncertainty in this estimate of the average hardness of the material. When the average of multiple hardness measurement values is calculated as an estimate of the average material or product hardness, it may be desired to state the uncertainty in this value with respect to the true hardness of the material. In this case, the combined uncertainty contributions due to the lack of repeatability in the hardness machine and the non-uniformity in the test material may be estimated from the "standard deviation of the mean" of the hardness measurement values. This is calculated as the standard deviation of the hardness values, divided by the square-root of the number of measurements as:

$$u_{Rep\&\ NU} = \frac{STDEV(H_{T1}, H_{T2}, \ldots, H_{Tn})}{\sqrt{n_T}} \quad (X2.8)$$

where H_{T1}, H_{T2}, ..., H_{Tn} are the n_T measurement values.

X2.5.4 *Uncertainty Due to Lack of Reproducibility (u_{Reprod})*—The day-to-day variation in the performance of the hardness machine is known as its level of reproducibility. Variations such as different machine operators and changes in the test environment often influence the performance of the hardness machine. The level of reproducibility is best determined by monitoring the performance of the hardness machine over an extended period of time during which the hardness machine is subjected to the extremes of variations in the testing variables. It is very important that the test machine be in control during the assessment of reproducibility. If the machine is in need of maintenance or is operated incorrectly, the lack of reproducibility will be over estimated.

X2.5.5 An assessment of a hardness machine's lack of reproducibility should be based on periodic monitoring measurements of the hardness machine, such as daily verification measurements made on the same test block over time. The uncertainty contribution may be estimated by the standard deviation of the average of each set of monitoring values, as:

$$u_{Reprod} = STDEV(M_1, M_2, \ldots, M_n) \quad (X2.9)$$

where M_1, M_2, ..., M_n are individual averages of each of the n sets of multiple monitoring measurement values.

NOTE X2.7—The uncertainty contribution due to the lack of reproducibility, as calculated in Eq X2.10, also includes a contribution due to the machine's lack of repeatability and the non-uniformity of the monitoring test block; however, these contributions are based on the average of multiple measurements and should not significantly over-estimate the reproducibility uncertainty.

X2.5.6 *Uncertainty Due to the Resolution of the Hardness Measurement Display (u_{Resol})*—The finite resolution of the hardness value display prevents the hardness machine from providing an absolutely accurate hardness value. However, the influence of the display resolution on the measurement uncertainty is usually only significant when the hardness display resolution is no better than 0.5 Rockwell hardness units, such as for some dial displays. The uncertainty contribution u_{Resol}, due to the influence of the display resolution, may be described by a rectangular distribution and estimated as:

$$u_{Resol} = \frac{r/2}{\sqrt{3}} = \frac{r}{\sqrt{12}} \quad (X2.10)$$

where r is the resolution limit that a hardness value can be estimated from the measurement display in Rockwell hardness units.

X2.5.7 *Standard Uncertainty in the Certified Average Hardness Value of the Reference Test Block (u_{RefBlk})*—Reference test blocks provide the link to the Rockwell standard to which traceability is claimed. The certificate accompanying reference test blocks should provide an uncertainty in the stated certified value, and should state to which Rockwell standard the reference test block value is traceable. This uncertainty contributes to the measurement uncertainty of hardness machines calibrated or verified with the reference test blocks. Note that the uncertainty reported on reference test block certificates is typically stated as an expanded uncertainty. As indicated by Eq X2.4, the expanded uncertainty is calculated by multiplying the standard uncertainty by a coverage factor (often 2). This analysis uses the standard uncertainty and not the expanded uncertainty value. Thus, the uncertainty value due to the uncertainty in the certified value of the reference test block usually may be calculated as:

$$u_{RefBlk} = \frac{U_{RefBlk}}{k_{RefBlk}} \quad (X2.11)$$

where U_{RefBlk} is the reported expanded uncertainty of the certified value of the reference test block, and k_{RefBlk} is the coverage factor used to calculate the uncertainty in the certified value of the reference standard (usually 2).

X2.5.8 *Measurement Bias (B)*—The measurement bias is the difference between the hardness measurement values as displayed by the hardness machine and the "true" hardness of a material. The measurement bias B may be estimated by the "error" determined as part of the indirect verification as:

$$B = \bar{H} - \bar{H}_{RefBlk} \quad (X2.12)$$

where $\bar{H}$ is the mean hardness value as measured by the hardness machine during the indirect verification, and $\bar{H}_{RefBlk}$ is the certified average hardness value of the reference test block standard used for the indirect verification.

X2.6 Procedure for Calculating Uncertainty: Indirect Verification

X2.6.1 As part of an indirect verification, the "error" of the hardness machine is determined from the average value of measurements made on a reference test block (see 3.2.2). This value provides an indication of how well the hardness machine can measure the "true" hardness of a material. Since there is always uncertainty in a hardness measurement, it follows that there must be uncertainty in the determination of the average value of the measurements, and thus the determination of the machine "error." This section provides a procedure that can be used, for example by a field calibration agency, to estimate the uncertainty U_{Mach} in the measurement "error" of the hardness machine determined as the difference between the average of the measurement values and the certified value of the reference block used for the verification.

X2.6.2 The contributions to the standard uncertainty of the measurement "error," u_{Mach}, are (*1*) $u_{Rep\&\ NU}$ (*Ref. Block*), the uncertainty due to the lack of repeatability of the hardness machine combined with the uncertainty due to the non-uniformity in the reference test block (Eq X2.9), which is determined from the hardness measurements made on a reference test block to determine the "error" of the hardness machine, (*2*) u_{Resol}, the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.11), and (*3*) u_{RefBlk}, the standard uncertainty in the certified value of the reference test block (Eq X2.12). The notation (*Ref. Block*) is added to the term $u_{Rep\&\ NU}$ to clarify that the uncertainty is determined from measurements made on the reference block used for the indirect verification.

X2.6.3 The combined standard uncertainty u_{Mach} and the expanded uncertainty U_{Mach} are calculated by combining the appropriate uncertainty components described above for each hardness level of each Rockwell scale as:

$$u_{Mach} = \sqrt{u^2_{Rep\&\ NU}(Ref.\ Block) + u^2_{Resol} + u^2_{RefBlk}} \quad (X2.13)$$

and

$$U_{Mach} = ku_{Mach} \quad (X2.14)$$

X2.6.4 For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

NOTE X2.8—The uncertainty contribution u_{Mach} as calculated in Eq X2.14 does not include a contribution due to the machine's lack of reproducibility. This is because it is assumed that the indirect verification is made while the hardness machine is operating at its optimal performance level with the best possible environmental conditions.

NOTE X2.9—The expanded uncertainty U_{Mach} will commonly be larger than the value of the hardness machine "error."

X2.6.5 *Reporting the Measurement Uncertainty*—This expanded uncertainty U_{Mach} may be reported by a verification agency to its customer as an indication of the uncertainty in the hardness machine "error" reported as part of the indirect verification of the Rockwell hardness machine. The value of U_{Mach} should be supplemented with a statement defining to what Rockwell scale and hardness level the uncertainty is applicable, with an explanatory statement such as, "The expanded uncertainty of the hardness machine "error" reported as part of the indirect verification for the stated Rockwell scale(s) and hardness level(s) is with respect to Rockwell hardness reference standards maintained at _______________ (for example, NIST), and was calculated in accordance with Appendix X2 of ASTM E18 with a coverage factor of 2 representing a confidence level of approximately 95 %."

X2.6.6 The standard uncertainty value u_{Mach} can be used as an uncertainty contribution when determining the measurement uncertainty of future measurements made with the hardness machine (see X2.7 and X2.8).

X2.6.7 *Example X2.1*— As part of an indirect verification of a Rockwell hardness machine, a verification agency needs to report an estimate of the uncertainty of the hardness machine "error." For this example, an evaluation will only be made for measurements made on the low range of the HRC scale. The hardness machine has a digital display with a resolution of 0.1 HRC. The agency performs five verification measurements on a low range HRC hardness block. The reported certified value of the reference test block is 25.7 HRC with an expanded uncertainty of U_{RefBlk} = 0.45 HRC. The five verification measurements values are: 25.4, 25.3, 25.5, 25.3, and 25.7 HRC, resulting in an average value of 25.44 HRC, a repeatability (range) value of 0.4 HRC and an "error" of −0.26 HRC. Therefore:

$$u_{Rep\&\ NU}(Ref.\ Block) = \frac{STDEV(25.4, 25.3, 25.5, 25.3, 25.7)}{\sqrt{5}}$$

$$\text{or } u_{Rep\&\ NU}(Ref.\ Block) = 0.075\ HRC$$

$$u_{Resol} = \frac{0.1}{\sqrt{12}} = 0.029\ HRC, \text{ and}$$

$$u_{RefBlk} = \frac{0.45}{2} = 0.225\ HRC$$

Thus,

$$u_{Mach} = \sqrt{0.075^2 + 0.029^2 + 0.225^2} = 0.239\ HRC, \text{ and}$$

$$U_{Mach} = (2 \times 0.239) = 0.48\ HRC$$

Therefore, the uncertainty in the −0.26 HRC "error" in the hardness machine is 0.48 HRC. Although this evaluation was made on material having a hardness of approximately 25 HRC, the uncertainty may be considered to apply to the entire low range of the HRC scale. This calculation must be made for the mid and high ranges of the HRC scale, as well as for the ranges of the other Rockwell scales that are verified.

NOTE X2.10—The reader should be aware that in computing the final uncertainty value in all examples in this appendix, no rounding of results was done between steps. Consequently, if individual equations are solved using the rounded values that are given at each step of this example, some computed results might differ in value in the last decimal place from the results stated.

X2.7 Procedure for Calculating Uncertainty: Rockwell Hardness Measurement Values

X2.7.1 The uncertainty U_{Meas} in a hardness value measured by a user may be thought of as an indication of how well the measured value agrees with the "true" value of the hardness of the material.

X2.7.2 *Single Measurement Value*—When measurement uncertainty for a single hardness measurement value is to be determined, the contributions to the standard uncertainty u_{Meas} are (*1*) u_{Repeat}, the uncertainty due to the machine's lack of repeatability (Eq X2.6), (*2*) u_{Reprod}, the uncertainty contribution due to the lack of reproducibility (Eq X2.10), (*3*) u_{Resol}, the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.11), and (*4*) u_{Mach}, the uncertainty in determining the "error" of the hardness machine (Eq X2.14). The combined standard uncertainty u_{Meas} is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Rockwell scale as:

$$u_{Meas} = \sqrt{u^2_{Repeat} + u^2_{Reprod} + u^2_{Resol} + u^2_{Mach}} \quad (X2.15)$$

X2.7.3 *Average Measurement Value*—In the case that measurement uncertainty is to be determined for an average value of multiple hardness measurements, made either on the same test piece or multiple test pieces, the contributions to the standard uncertainty u_{Meas} are (*1*) $u_{\overline{Repeat}}$, the uncertainty due to the machine's lack of repeatability based on the average of multiple measurements (Eq X2.8), (*2*) u_{Reprod}, the uncertainty contribution due to the lack of reproducibility (Eq X2.10), (*3*) u_{Resol} , the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.11), and (*4*) u_{Mach}, the uncertainty in determining the "error" of the hardness machine (Eq X2.14). The combined standard uncertainty u_{Meas} is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Rockwell scale as:

$$u_{Meas} = \sqrt{u^2_{\overline{Repeat}} + u^2_{Reprod} + u^2_{Resol} + u^2_{Mach}} \quad (X2.16)$$

X2.7.4 The measurement uncertainty discussed above for the single and average hardness values only represents the uncertainties of the measurement process and are independent of any test material non-uniformity.

X2.7.5 *Average Measurement Value as an Estimate of the Average Material Hardness*—Measurement laboratories and manufacturing facilities often measure the Rockwell hardness of a test sample or product for the purpose of estimating the average hardness of the test material. Usually, multiple hardness measurements are made across the surface of the test piece, and then the average of the hardness values is reported as an estimation of the average hardness of the material. If it is desired to report the uncertainty as an indication of how well the average measurement value represents the true average hardness of the material, then the contributions to the standard uncertainty u_{Meas} are (*1*) $u_{Rep\&\ NU}$ (*Material*), the uncertainty due to the machine's lack of repeatability combined with the uncertainty due to the material's non-uniformity (Eq X2.9), which is determined from the hardness measurements made on the test material, (*2*) u_{Reprod}, the uncertainty contribution due to the lack of reproducibility (Eq X2.10), (*3*) u_{Resol}, the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.11), and (*4*) u_{Mach}, the uncertainty in determining the "error" of the hardness machine (Eq X2.14). The notation (*Material*) is added to the term $u_{Rep\&\ NU}$ to clarify that the uncertainty is determined from measurements made on the material under test. The combined standard uncertainty u_{Meas} is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Rockwell scale as:

$$u_{Meas} = \sqrt{u^2_{Rep\&\ NU}(Material) + u^2_{Reprod} + u^2_{Resol} + u^2_{Mach}} \quad (X2.17)$$

X2.7.6 When reporting uncertainty as an indication of how well the average measurement value represents the true average hardness of the material, it is important to assure that a sufficient number of measurements are made at the appropriate test locations to provide an appropriate sampling of any variations in the hardness of the material.

X2.7.7 The expanded uncertainty U_{Meas} is calculated for the three cases discussed above as:

$$U_{Meas} = ku_{Meas} + ABS(B) \quad (X2.18)$$

For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

X2.7.8 *Reporting Measurement Uncertainty:*

X2.7.8.1 *Single and Average Measurement Values*—When the reported measurement value is for a single hardness test or the average of multiple hardness tests, then the value of U_{Meas} should be supplemented with an explanatory statement such as, "The expanded measurement uncertainty of the reported hardness value (or average hardness value) is with respect to Rockwell hardness reference standards maintained at ______________ [for example, NIST], and was calculated in accordance with Appendix X2 of ASTM E18 with a coverage factor of 2 representing a confidence level of approximately 95 %."

X2.7.8.2 *Average Measurement Value as an Estimate of the Average Material Hardness*—When it is desired to report the uncertainty as an indication of how well the average measurement value represents the true average hardness of the material, then the value of U_{Meas} should be supplemented with an explanatory statement such as, "The expanded uncertainty of the reported average hardness of the material under test is based on uncertainty contributions from the measurement process and from the hardness non-uniformity of the material. The uncertainty is with respect to Rockwell hardness reference standards maintained at ______________ [for example, NIST], and was calculated in accordance with Appendix X2 of ASTM E18 with a coverage factor of 2 representing a confidence level of approximately 95 %." If the test report does not state the number of measurements that were averaged and the locations that the measurements were made, then this information should also be included as part of the brief explanation of how the uncertainty was calculated.

X2.7.8.3 *Example X2.2*— For this example, a company tests its product by making six Rockwell hardness measurements across its surface as an estimate of the product hardness. The hardness machine has a dial display that is judged to have a reading resolution of 0.5 HRC. The values of the hardness measurements of the product were 33, 31.5, 31.5, 32, 31, 32.5, resulting in an average value of 31.92 HRC. The testing facility would like to determine the measurement uncertainty in the average hardness value. A hardness of 31.92 HRC is closest to the low range of the HRC scale (see Table A1.3). The last indirect verification of the low range of the HRC scale reported U_{Mach} = 0.8 HRC and an "error" of −0.3 HRC. Therefore:

$$u_{Rep\&\ NU}(Material) = \frac{STDEV(33, 31.5, 31.5, 32, 31, 32.5)}{\sqrt{6}} \text{ or}$$

$$u_{Rep\&\ NU}(Material) = 0.300\ HRC$$

For this example, assume the hardness machine has been monitored for an extended period of time, and from Eq X2.10, it was determined that u_{Reprod} = 0.21 HRC for the low range of the HRC scale. Other uncertainty contributions are calculated as:

$$u_{Resol} = \frac{0.5}{\sqrt{12}} = 0.144\ HRC \text{ and}$$

$$u_{Mach} = \frac{0.8}{2} = 0.4\ HRC\text{, therefore}$$

$$u_{Meas} = \sqrt{0.300^2 + 0.21^2 + 0.144^2 + 0.4^2} = 0.561\ HRC$$

and since B = −0.3 HRC, U_{Meas} = (2 × 0.561) + *ABS*(−0.3), or U_{Meas} = 1.42 HRC for the average value of the hardness measurements made on the single product item.

X2.8 Procedure for Calculating Uncertainty: Certified Value of Standardized Test Blocks

X2.8.1 Standardizing laboratories engaged in the calibration of reference test blocks must determine the uncertainty in the reported certified value. This uncertainty UCert provides an indication of how well the certified value would agree with the "true" average hardness of the test block.

X2.8.2 Test blocks are certified as having an average hardness value based on calibration measurements made across the surface of the test block. This analysis is essentially identical to the analysis given in 5.3.1 for measuring the average hardness of a product. In this case, the product is a calibrated reference test block. The contributions to the standard uncertainty u_{Cert} of the certified average value of the test block are *(1)* $u_{Rep\&\ NU}$ *(Calib. Block)*, the uncertainty due to the standardizing machine's lack of repeatability combined with the uncertainty due to the calibrated block's non-uniformity (Eq X2.9), which is determined from the calibration measurements made on the test block, *(2)* u_{Reprod}, the uncertainty contribution due to the lack of reproducibility (Eq X2.10), *(3)* u_{Resol}, the uncertainty due to the resolution of the standardizing machine's measurement display (Eq X2.11), and *(4)* u_{Mach}, the uncertainty in determining the "error" of the standardizing machine (Eq X2.14). The notation *(Calib.Block)* is added to the term $u_{Rep\&\ NU}$ to clarify that the uncertainty is determined from calibration measurements made on the calibrated block.

X2.8.3 The combined standard uncertainty u_{Cert} and the expanded uncertainty u_{Cert} are calculated by combining the appropriate uncertainty components described above for each hardness level of each Rockwell scale as:

$$u_{Cert} = \sqrt{u^2_{Rep\&\ NU}(Calib.\ Block) + u^2_{Reprod} + u^2_{Resol} + u^2_{Mach}} \qquad (X2.19)$$

and

$$U_{Cert} = ku_{Cert} + ABS(B) \qquad (X2.20)$$

X2.8.4 For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

X2.8.5 *Reporting the Measurement Uncertainty*—The value of U_{Cert} is an estimate of the uncertainty in the reported certified average hardness value of a reference test block. The reported value should be supplemented with a statement defining to what Rockwell scale and hardness level the uncertainty is applicable, with an explanatory statement such as, "The expanded uncertainty in the certified value of the test block is with respect to Rockwell hardness reference standards maintained at ______________ [for example, NIST], and was calculated in accordance with Appendix X2 of ASTM E18 with a coverage factor of 2 representing a confidence level of approximately 95 %."

X2.8.6 *Example X2.3*— A secondary level test-block standardizing laboratory has completed the calibration of a test block in the hardness range of 40 HRC. The values of the calibration measurements of the block were 40.61, 40.72, 40.65, 40.61, and 40.55 HRC, resulting in an average value of 40.63 HRC and an E18 repeatability range of 0.17 HRC. The laboratory must determine the uncertainty in the certified average hardness value of the block. A hardness of 40 HRC is considered within the mid-range of the HRC scale (see Table A1.3). The last indirect verification of the mid range of the HRC scale reported U_{Mach} = 0.16 HRC and an "error" of +0.11 HRC. The standardizing machine has a digital display with a resolution of 0.01 HRC. Therefore:

$$u_{Rep\&\ NU}(Calib.\ Block) = \frac{STDEV(40.61,\ 40.72,\ 40.65,\ 40.61,\ 40.55)}{\sqrt{5}} \text{ or}$$

$$u_{Rep\&\ NU}(Calib.\ Block) = 0.028\ HRC$$

For this example, let's assume that the standardizing machine has been monitored for an extended period of time, and from Eq X2.10, it was determined that u_{Reprod} = 0.125 HRC for the mid range of the HRC scale. Other uncertainty contributions are calculated as:

$$u_{Resol} = \frac{0.01}{\sqrt{12}} = 0.003\ HRC \text{ and}$$

$$u_{Mach} = \frac{0.16}{2} = 0.08\ HRC \text{ therefore,}$$

$$u_{Cert} = \sqrt{0.028^2 + 0.125^2 + 0.003^2 + 0.08^2} = 0.151\ HRC$$

and, since B = +0.11 HRC, U_{Cert} = (2 × 0.151) + ABS(+0.11), or U_{Cert} = 0.41 HRC for the certified hardness value of the single calibrated test block.

SUMMARY OF CHANGES

Committee E28 has identified the location of selected changes to this standard since the last issue (E18–18a) that may impact the use of this standard. (Approved January 1, 2019.)

(1) Added 7.1.1 and Note 8.
(2) Revised Table A1.3.
(3) Added A1.4.3.1.

Committee E28 has identified the location of selected changes to this standard since the last issue (E18–18) that may impact the use of this standard. (Approved October 1, 2018.)

(1) Removed Notes A2.1, A2.2, A3.2, and A4.1.

Committee E28 has identified the location of selected changes to this standard since the last issue (E18–17$^{\varepsilon 1}$) that may impact the use of this standard. (Approved July 1, 2018.)

(1) Added 1.2.
(2) Added 3.1.7.3.

(3) Added 3.1.7.4.
(4) Added 5.8.
(5) Added 9.2.
(6) Revised Table A1.1.

Committee E28 has identified the location of selected changes to this standard since the last issue (E18–16) that may impact the use of this standard. (Approved July 1, 2017.)

(1) Note A1.4 was added.
(2) The word "signature" was replaced with "identification" in A1.6.2.8, A1.6.3.9, A2.8.1.8, and A2.8.2.9.