Designation: ~~E18 – 11~~ E18 – 12

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 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 standard includes additional requirements in 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

1.3 This standard includes nonmandatory information in appendixes which 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

1.4 *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.

1.5 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.

1.6 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

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

[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.

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[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**

A623M Specification for Tin Mill Products, General Requirements [Metric]
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
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E92 Test Method for Vickers Hardness of Metallic Materials (Withdrawn 2010)[4]
E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness
E384 Test Method for Knoop and Vickers 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[5]

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)[6]
ISO/IEC 17011 Conformity Assessment—General Requirements for Accreditation Bodies Accrediting Conformity Assessment Bodies[6]
ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories[6]

2.4 *Society of Automotive Engineers (SAE) Standard:*
SAE J417 Hardness Tests and Hardness Number Conversions[7]

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

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

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.

3.2 *Equations:*

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

[4] The last approved version of this historical standard is referenced on www.astm.org.
[5] Available from American Bearing Manufacturers Association (ABMA), 2025 M Street, NW, Suite 800, Washington, DC 20036.
[6] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.
[7] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

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

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:

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

where:

$\overline{H}$ = average of n hardness measurements H_1, H_2, …, 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.

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.

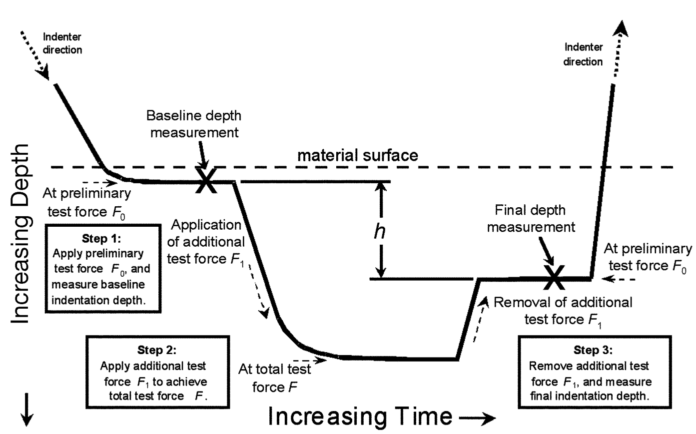

FIG. 1 Rockwell Hardness Test Method (Schematic Diagram)

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):

$$\text{Rockwell Hardness} = 100 - \frac{h}{0.002} \tag{4}$$

$$\text{Rockwell Superficial Hardness} = 100 - \frac{h}{0.001} \tag{5}$$

where h is in mm.

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

$$\text{Rockwell Hardness} = 130 - \frac{h}{0.002} \tag{6}$$

$$\text{Rockwell Superficial Hardness} = 100 - \frac{h}{0.001} \tag{7}$$

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	
L	1/4-in. (6.350-mm) ball	60	red	
M	1/4-in. (6.350-mm) ball	100	red	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect.
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

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.

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 (⅛ in.) to 12.5 mm (½ 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.

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.

7.2 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.

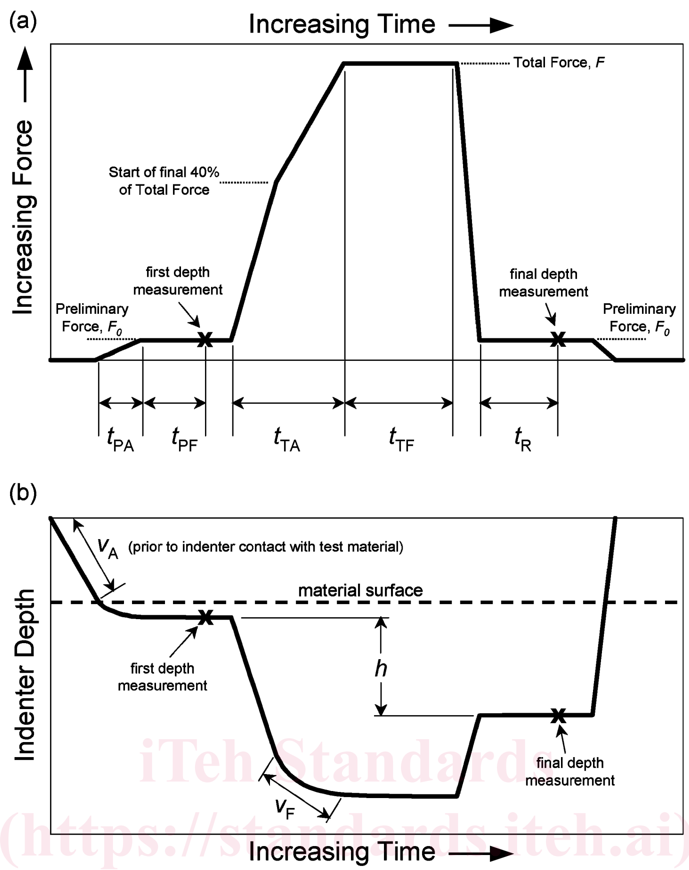

FIG. 2 Schematic of Force-Time Plot (a) and Indenter Depth-Time Plot (b) of an HRC Test Illustrating the Test Cycle Parts

(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 8), 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 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

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

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 8—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).

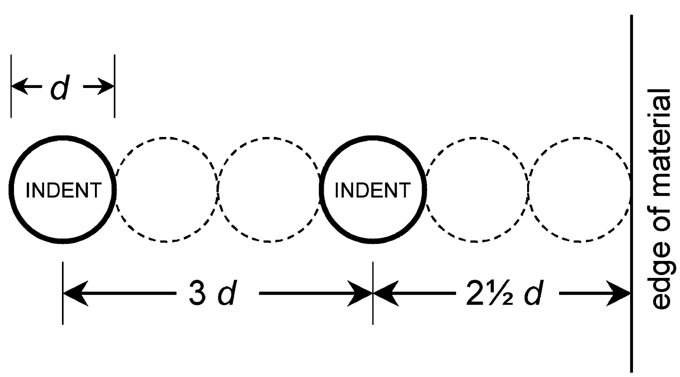

FIG. 3 Schematic of Minimum Indentation Spacing

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 9—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 10—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

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.

10. Precision and Bias[8,9]

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.[8,9]

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 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.

[8] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E28-1021.
[9] 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

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.

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]. This does not apply to machines that are designed to be moved or that move prior to each test, when it has been previously demonstrated that such a move will not affect the hardness result. 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.

A1.2.2 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.

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 ASTM 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.

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.

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

A1.3.5.1 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.

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.

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~~	~~20 to 65~~	~~2.0~~	~~± 1.0~~
	~~70 to 78~~	~~1.5~~	~~± 1.0~~
	~~80 to 84~~	~~1.0~~	~~± 0.5~~
HRA	< 70	2.0	± 1.0
	≥ 70 and < 80	1.5	± 1.0
	≥ 80	1.0	± 0.5
~~HRBW~~	~~40 to 59~~	~~2.0~~	~~± 1.5~~
	~~60 to 79~~	~~1.5~~	~~± 1.0~~
	~~80 to 100~~	~~1.5~~	~~± 1.0~~
HRBW	< 60	2.0	± 1.5
	≥ 60 and < 80	1.5	± 1.0
	≥ 80	1.5	± 1.0
~~HRC~~	~~20 to 30~~	~~2.0~~	~~± 1.0~~
	~~35 to 55~~	~~1.5~~	~~± 1.0~~
	~~60 to 65~~	~~1.0~~	~~± 0.5~~
HRC	< 35	2.0	± 1.0
	≥ 35 and < 60	1.5	± 1.0
	≥ 60	1.0	± 0.5
~~HRD~~	~~40 to 48~~	~~2.0~~	~~± 1.0~~
	~~51 to 67~~	~~1.5~~	~~± 1.0~~
	~~71 to 75~~	~~1.0~~	~~± 0.5~~
HRD	< 51	2.0	± 1.0
	≥ 51 and < 71	1.5	± 1.0
	≥ 71	1.0	± 0.5
~~HREW~~	~~70 to 79~~	~~1.5~~	~~± 1.0~~
	~~84 to 90~~	~~1.5~~	~~± 1.0~~
	~~93 to 100~~	~~1.0~~	~~± 1.0~~
HREW	< 84	1.5	± 1.0
	≥ 84 and < 93	1.5	± 1.0
	≥ 93	1.0	± 1.0
~~HRFW~~	~~60 to 75~~	~~1.5~~	~~± 1.0~~
	~~80 to 90~~	~~1.5~~	~~± 1.0~~
	~~94 to 100~~	~~1.0~~	~~± 1.0~~
HRFW	< 80	1.5	± 1.0
	≥ 80 and < 94	1.5	± 1.0
	≥ 94	1.0	± 1.0
~~HRGW~~	~~30 to 50~~	~~2.0~~	~~± 1.0~~
	~~55 to 75~~	~~2.0~~	~~± 1.0~~
	~~80 to 94~~	~~2.0~~	~~± 1.0~~
HRGW	< 55	2.0	± 1.0
	≥ 55 and < 80	2.0	± 1.0
	≥ 80	2.0	± 1.0
~~HRHW~~	~~80 to 94~~	~~2.0~~	~~± 1.0~~
	~~96 to 100~~	~~2.0~~	~~± 1.0~~
HRHW	< 96	2.0	± 1.0
	≥ 96	2.0	± 1.0
~~HRKW~~	~~40 to 60~~	~~1.5~~	~~± 1.0~~
	~~65 to 80~~	~~1.0~~	~~± 1.0~~
	~~85 to 100~~	~~1.0~~	~~± 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~~	~~70 to 77~~	~~2.0~~	~~± 1.0~~
	~~78 to 88~~	~~1.5~~	~~± 1.0~~
	~~90 to 92~~	~~1.0~~	~~± 0.7~~
HR15N	< 78	2.0	± 1.0
	≥ 78 and < 90	1.5	± 1.0
	≥ 90	1.0	± 0.7
~~HR30N~~	~~42 to 50~~	~~2.0~~	~~± 1.0~~
	~~55 to 73~~	~~1.5~~	~~± 1.0~~
	~~77 to 82~~	~~1.0~~	~~± 0.7~~
HR30N	< 55	2.0	± 1.0
	≥ 55 and < 77	1.5	± 1.0
	≥ 77	1.0	± 0.7