



Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials^{1,2}

This standard is issued under the fixed designation E 18; 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.

^{ε1} NOTE—Table 15 was editorially revised in June 2004.

1. Scope*

1.1 These test methods cover the determination of the Rockwell hardness and the Rockwell superficial hardness of metallic materials, including test methods for the verification of machines for Rockwell hardness testing (Part B) and the calibration of standardized hardness test blocks (Part C).

1.2 Values stated in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.3 *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.* (See Note 6.)

NOTE 1—The National Institute of Standards and Technology (NIST) maintains the national Rockwell hardness standards for the United States. In June 1998, NIST released new Rockwell C scale (HRC) test blocks as Standard Reference Materials (SRMs). The blocks were calibrated using NIST's primary reference standardizing machine. The major benefit of the NIST standards is that their HRC levels are in line with the other industrialized countries around the world. The NIST HRC levels establish the hardness of materials slightly harder than the historical standards used in the United States for the past 75 years. The revision of E 18 requires that all performance verifications of Rockwell hardness indenters and hardness machines must be made using test blocks calibrated traceable to the Rockwell standards maintained by NIST. This can be accomplished through the use of commercial test blocks calibrated traceable to the NIST standards or by directly using the NIST SRMs. This requirement will apply only to the Rockwell scale(s) for which NIST supplies primary reference test blocks

NOTE 2—In previous editions of this standard, ball indenters were required to be of hard steel. Beginning with this edition, tungsten-carbide balls are also allowed. This change is a first step in a planned future transition to eliminate steel balls and allow only the use of tungsten carbide balls. The elimination of steel ball indenters is scheduled to occur

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.

in about two years. The use of tungsten carbide balls will 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. In addition, NIST is planning to standardize the HRB scale using tungsten-carbide balls. As a result of this change, this edition also requires that when a ball indenter is used, the Rockwell hardness value must be reported with the scale designation followed by the letter "S" to indicate the use of a steel ball or the letter "W" to indicate the use of a tungsten carbide ball. 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 up to one Rockwell point lower than when a steel ball indenter is used.

2. Referenced Documents

2.1 ASTM Standards:

- A 370 Test Methods and Definitions for Mechanical Testing of Steel Products³
- B 19 Specification for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (Blanks)⁴
- B 36/B36 M Specification for Brass Plate, Sheet, Strip, and Rolled Bar⁴
- B 96 Specification for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes and Pressure Vessels⁴
- B 97 Specification for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes⁵
- B 103/B 103 M Specification for Phosphor Bronze Plate, Sheet, Strip, and Rolled Bar⁴
- B 121/B 121 M Specification for Leaded Brass Plate, Sheet, Strip, and Rolled Bar⁴
- B 122/B 122 M Specification for Copper-Nickel-Tin Alloy, Copper-Nickel-Zinc Alloy (Nickel Silver), and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar⁴
- B 130 Specification for Commercial Bronze Strip for Bullet Jackets⁴
- B 134 Specification for Brass Wire⁴

³ Annual Book of ASTM Standards, Vol 01.03.

⁴ Annual Book of ASTM Standards, Vol 02.01.

⁵ Discontinued, see 1981 Annual Book of ASTM Standards, Part 6.

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

- B 152 Specification for Copper Sheet, Strip, Plate, and Rolled Bar⁴
- B 291 Specification for Copper-Zinc-Manganese Alloy (Manganese Brass) Sheet and Strip⁴
- B 370 Specification for Copper Sheet and Strip for Building Construction⁴
- E 4 Practices for Force Verification of Testing Machines⁶
- E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications⁷
- E 140 Hardness Conversion Tables for Metals⁶

3. Terminology

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 *Rockwell hardness number, HR*—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.

3.1.2.1 *Discussion—Indenters*—Indenters for the Rockwell hardness test include a diamond spheroconical indenter and ball indenters (steel or tungsten carbide) of several specified diameters.

3.1.2.2 *Discussion*—Rockwell hardness numbers are always 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 “S” to indicate the use of a steel ball or the letter “W” to indicate the use of a tungsten carbide ball.

3.1.2.3 *Examples*—64 HRC = Rockwell hardness number of 64 on Rockwell C scale. 81 HR30N = Rockwell superficial hardness number of 81 on Rockwell 30N scale. 72 HRBW = Rockwell hardness number of 72 on the Rockwell B scale measured using a tungsten carbide ball indenter.

3.1.3 *Rockwell hardness test*—an indentation hardness test using a verified machine to force a diamond spheroconical indenter (diamond indenter), or a ball indenter (steel or tungsten carbide) under specified conditions, into the surface of the material under test in two operations, and to measure the difference in depth of the indentation under the specified conditions of preliminary and total test forces (minor and major loads, respectively).

3.1.4 *Rockwell superficial hardness test*—same as the Rockwell hardness test except that smaller preliminary and total test forces are used.

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

4. Significance and Use

4.1 The Rockwell hardness test is an empirical indentation hardness test. Rockwell hardness tests 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 testing at a specific location on a part may not represent the physical characteristics of the whole part or end product.

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

4.4 Performance verifications of Rockwell hardness indenters and hardness machines shall be made using test blocks calibrated traceable to the Rockwell standards maintained by NIST when primary reference test blocks are available from NIST for the specific Rockwell scale.

⁶ Annual Book of ASTM Standards, Vol 03.01.
⁷ Annual Book of ASTM Standards, Vol 14.02.

A. GENERAL DESCRIPTION AND TEST PROCEDURE FOR ROCKWELL HARDNESS AND ROCKWELL SUPERFICIAL HARDNESS TESTS

5. Principles of Test and Apparatus

5.1 *General Principles*—The general principles of the Rockwell hardness test are illustrated in Fig. 1 (diamond indenter) and Fig. 2 (ball indenters) and the accompanying Table 1 and Table 2. In the case of the Rockwell superficial test the general principles are illustrated in Fig. 3 (diamond indenter) and Fig. 4 (ball indenter) and the accompanying Table 3 and Table 4.

5.1.1 See *Equipment Manufacturer’s Instruction Manual* for a description of the machine’s characteristics, limitations, and respective operating procedures. Typical applications of the various hardness scales are shown in Tables 5 and 6. Rockwell hardness values are usually determined and reported in accordance with one of these standard scales. An indenter is forced into the surface of a test piece in two steps under

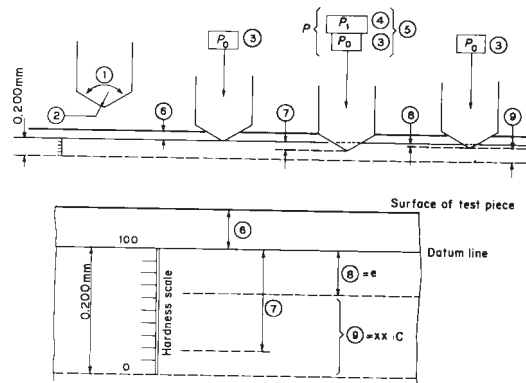


FIG. 1 Rockwell Hardness Test with Diamond Indenter (Rockwell C Example) (Table 1)

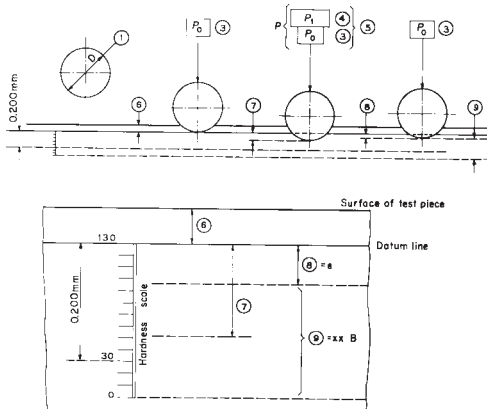


FIG. 2 Rockwell Hardness Test with Ball Indenter (Rockwell B Example) (Table 2)

TABLE 1 Symbols and Designations Associated with Fig. 3

Number	Symbol	Designation
1	...	Angle at the top of the diamond indenter (120°)
2	...	Radius of curvature at the tip of the cone (0.200 mm)
3	P_0	Preliminary Test Force = 10 kgf (98 N)
4	P_1	Additional Force = 140 kgf (1373 N)
5	P	Total Test Force = $P_0 + P_1 = 10 + 140 = 150$ kgf (1471 N)
6	...	Depth of penetration under preliminary test force before application of additional force
7	...	Increase in depth of penetration under additional force
8	e	Permanent increase in depth of penetration under preliminary test force after removal of additional force, the increase being expressed in units of 0.002 mm
9	xx HRC	Rockwell C hardness = $100 - e$

TABLE 2 Symbols and Designations Associated with Fig. 2

Number	Symbol	Designation
1	D	Diameter of ball = $\frac{1}{16}$ in. (1.588 mm)
3	P_0	Preliminary Test Force = 10 kgf (98 N)
4	P_1	Additional force = 90 kgf (883 N)
5	P	Total Test Force = $P_0 + P_1 = 10 + 90 = 100$ kgf (981 N)
6	...	Depth of penetration under preliminary test force before application of additional force
7	...	Increase in depth of penetration under additional force
8	e	Permanent increase in depth of penetration under preliminary test force after removal of the additional force, the increase being expressed in units of 0.002 mm
9	xx HRB	Rockwell B hardness = $130 - e$

specified conditions (see Section 7) and the difference in depth of indentation is measured as e .

5.1.2 The unit measurement for e is 0.002 mm and 0.001 mm for the Rockwell hardness test and Rockwell superficial hardness test, respectively. From the value of e , a number known as the Rockwell hardness is derived. There is no Rockwell hardness value designated by a number alone because it is necessary to indicate which indenter and force have been employed in making the test (see Table 5 and Table 6).

5.2 Description of Machine and Method of Test—The tester for making Rockwell hardness determinations is a machine that

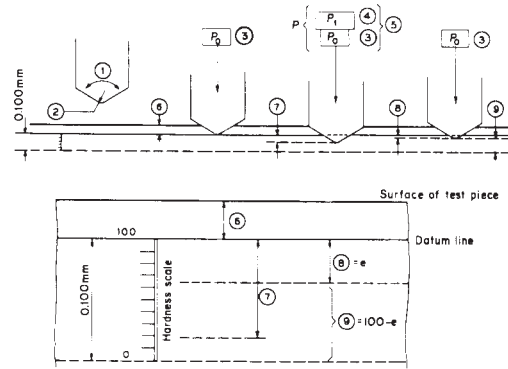


FIG. 3 Rockwell Superficial Hardness Test with Diamond Indenter (Rockwell 30N Example) (Table 3)

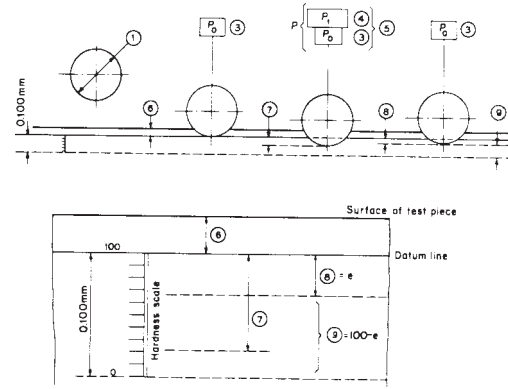


FIG. 4 Rockwell Superficial Hardness Test with Ball Indenter (Rockwell 30T Example) (Table 4)

TABLE 3 Symbols and Designations Associated with Fig. 3

Number	Symbol	Designation
1	...	Angle at the tip of the diamond indenter (120°)
2	...	Radius of curvature at the tip of the cone (0.200 mm)
3	P_0	Preliminary Test Force = 3 kgf (29 N)
4	P_1	Additional force = 27 kgf (265 N)
5	P	Total Test Force = $P_0 + P_1 = 3 + 27 = 30$ kgf (294 N)
6	...	Depth of penetration under preliminary test force before application of additional force
7	...	Increase in depth of penetration under additional force
8	e	Permanent increase in depth of penetration under preliminary test force after removal of additional force, the increase being expressed in units of 0.001 mm
9	xx HR30N	Rockwell 30N hardness = $100 - e$

measures hardness by determining the difference in penetration depths of an indenter under two specified forces, called preliminary and total test forces.

5.2.1 There are two general classifications of the Rockwell test: the Rockwell hardness test and the Rockwell superficial hardness test.

5.2.2 In the Rockwell hardness test the preliminary test force is 10 kgf (98 N). Total test forces are 60 kgf (589 N), 100 kgf (981 N) and 150 kgf (1471 N). In the Rockwell superficial hardness test the preliminary test force is 3 kgf (29 N) and total test forces are 15 kgf (147 N), 30 kgf (294 N), and 45 kgf (441 N). The indenter for either test shall be of a spheroconical or

TABLE 4 Symbols and Designations Associated with Fig. 4

Number	Symbol	Designation
1	D	Diameter of ball = $\frac{1}{16}$ in. (1.588 mm)
3	P_0	Preliminary Test Force = 3 kgf (29 N)
4	P_1	Additional force = 27 kgf (265 N)
5	P	Total Test Force = $P_0 + P_1 = 3 + 27 = 30$ kgf (294 N)
6	...	Depth of penetration under preliminary test force before application of additional force
7	...	Increase in depth of penetration under additional force
8	e	Permanent increase in depth of penetration under preliminary test force after removal of the additional force, the increase being expressed in units of 0.001 mm
9	XXHR30T	Rockwell 30T hardness = 100-e

spherical configuration. Scales vary by a combination of total test force and type of indenter.

5.2.3 The difference in depth is normally measured by an electronic device or by a dial indicator. The hardness value, as read from the instrument, is an arbitrary number which is related to the difference in the depths produced by the two forces; and since the scales are reversed, the higher the number the harder the material.

5.2.4 In accordance with the operating procedures recommended by the manufacturer of the hardness tester, the test is started by applying the preliminary test force causing an initial penetration of the specimen. Since measurement of the difference in depth starts after the preliminary force has been applied, the dial gage pointer is set to zero if the instrument is a dial indicator model. On a digital readout instrument, the zero point is captured by the electronics automatically. The instrument shall be designed to eliminate the effect of impact in applying the preliminary test force.

5.2.5 The additional force is applied for the required dwell time and then removed. The return to the preliminary test force position holds the indenter at the point of deepest penetration yet allows elastic recovery to occur and the stretch of the frame to be factored out. The test result is displayed by the testing machine.

5.3 Indenters:

5.3.1 The standard indenters are the diamond spheroconical indenter and steel ball indenters having steel or tungsten carbide balls $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ in. (1.588, 3.175, 6.350, and 12.70 mm) in diameter.

5.3.2 The diamond indenter shall conform to the requirements prescribed in 13.1.2.1.

5.3.3 Indenter balls can be either tungsten carbide or hardened steel; however, tungsten carbide balls are recommended to reduce errors associated with the tendency of steel balls to flatten with use. Indenter balls shall conform to the requirements prescribed in 13.1.2.2.

5.3.4 Dust, dirt, grease, and scale shall not be allowed to accumulate on the indenter as this will affect the test results.

5.4 *Anvils*—An anvil shall be used that is suitable for 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. If the provisions of 6.3 on thickness of the test piece are complied with, there will be no danger of indenting the anvil, but, if it is so thin that the

impression shows through on the under side, the anvil may be damaged. Damage may also occur from accidental contacting of the anvil by the indenter. If the anvil is damaged from any cause, it shall be replaced. Anvils showing the least visible dent will give inaccurate results on thin material.

5.4.1 Cylindrical pieces shall be tested with a V-grooved anvil that will support the specimen with the axis of the V-groove directly under the indenter or on hard, parallel, twin cylinders properly positioned and clamped in their base.

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

5.4.3 For thin materials or specimens that are not perfectly flat, an anvil having an elevated, flat spot about $\frac{1}{4}$ in. (6 mm) in diameter shall be used. This spot shall be polished smooth and flat and shall have a Rockwell hardness of at least 60 HRC. 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.

5.4.4 When testing thin sheet material with a ball indenter, it is recommended that a diamond spot anvil be used.

NOTE 3—**Caution:** A diamond spot anvil should only be used with a superficial hardness tester and ball indenter. This recommendation should be followed, except when directed otherwise by material specification.

5.5 *Test Blocks*—Test blocks meeting the requirements of Part C shall be used to periodically verify the hardness tester.

6. Test Piece

6.1 The test shall be carried out on a smooth, even surface that is free from oxide scale, foreign matter, and, in particular, completely free from lubricants. An exception is made for reactive metals, such as titanium, 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 reported on the test report.

6.2 Preparation shall be carried out in such a way that any alteration of the surface hardness (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 dictated in Tables 7-9, and Table 10 and as presented graphically in Figs. 5 and 6. These tables were determined from studies on strips of carbon steel and give reliable results. For all other materials it is recommended that the thickness exceed 10 times the depth of indentation with a diamond indenter and 15 times the depth of indentation with a ball indenter. As a rule, 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.

6.4 For tests on convex cylindrical surfaces the corrections given in Tables 11-14 shall be applied. Corrections for tests on spherical and concave surfaces should be the subject of special agreement. 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. For diameters between those given in the tables, correction factors may be derived by linear interpolation. Tests

TABLE 5 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. Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect.
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	
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 6 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

TABLE 7 A Minimum Thickness Guide for Selection of Scales Using the Diamond Indenter (see Fig. 5)

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	Dial 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 E 140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness, and Knoop Hardness).

TABLE 8 A Minimum Thickness Guide for Selection of Scales Using the 1/16-in. (1.588-mm) Diameter Ball Indenter (see Fig. 6)

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 E 140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness and Knoop Hardness).

performed on diameters smaller than those given in Tables 11-14 are not acceptable.

6.5 *Precautions for materials having excessive, time-dependent plasticity (indentation creep):* In the case of materials exhibiting plastic flow after application of the total test force, the indenter will continue to move. The total test force should be removed after the specified dwell time, and the time

recorded after the test results (that is, 65 HRFW, 4 s) if longer than 3 s. When materials require the use of a dwell time greater than 3 s, this should be specified in the product specification.

7. Procedure

7.1 As part of the test procedure, periodic checks shall be performed. See Section 14 for recommendations.

7.2 The test is normally carried out at ambient temperature within the limits of 50 to 95°F (10 to 35°C). However, because

TABLE 9 A Minimum Thickness Guide for Selection of Scales Using the Diamond Indenter (see Fig. 5)

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 E 140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness and Knoop Hardness).

TABLE 10 A Minimum Thickness Guide for Selection of Scales Using the 1/16 in. (1.588 mm) Diameter Ball Indenter (see Fig. 6)

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 E 140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness and Knoop Hardness).

temperature variation may affect the results, users of the Rockwell test may choose to control the temperature within a tighter range.

7.3 The test piece shall be supported rigidly so that no effects of displacement occur during the test.

7.4 Bring the indenter into contact with the test surface and apply the preliminary test force P_0 (minor load) of 10 kgf (98 N) for the Rockwell hardness test or 3 kgf (29 N) for Rockwell superficial hardness test in a direction perpendicular to the surface without shock or vibration. (See Table 15 for tolerances of test forces.) The dwell time for the preliminary test force shall not exceed 3 s.

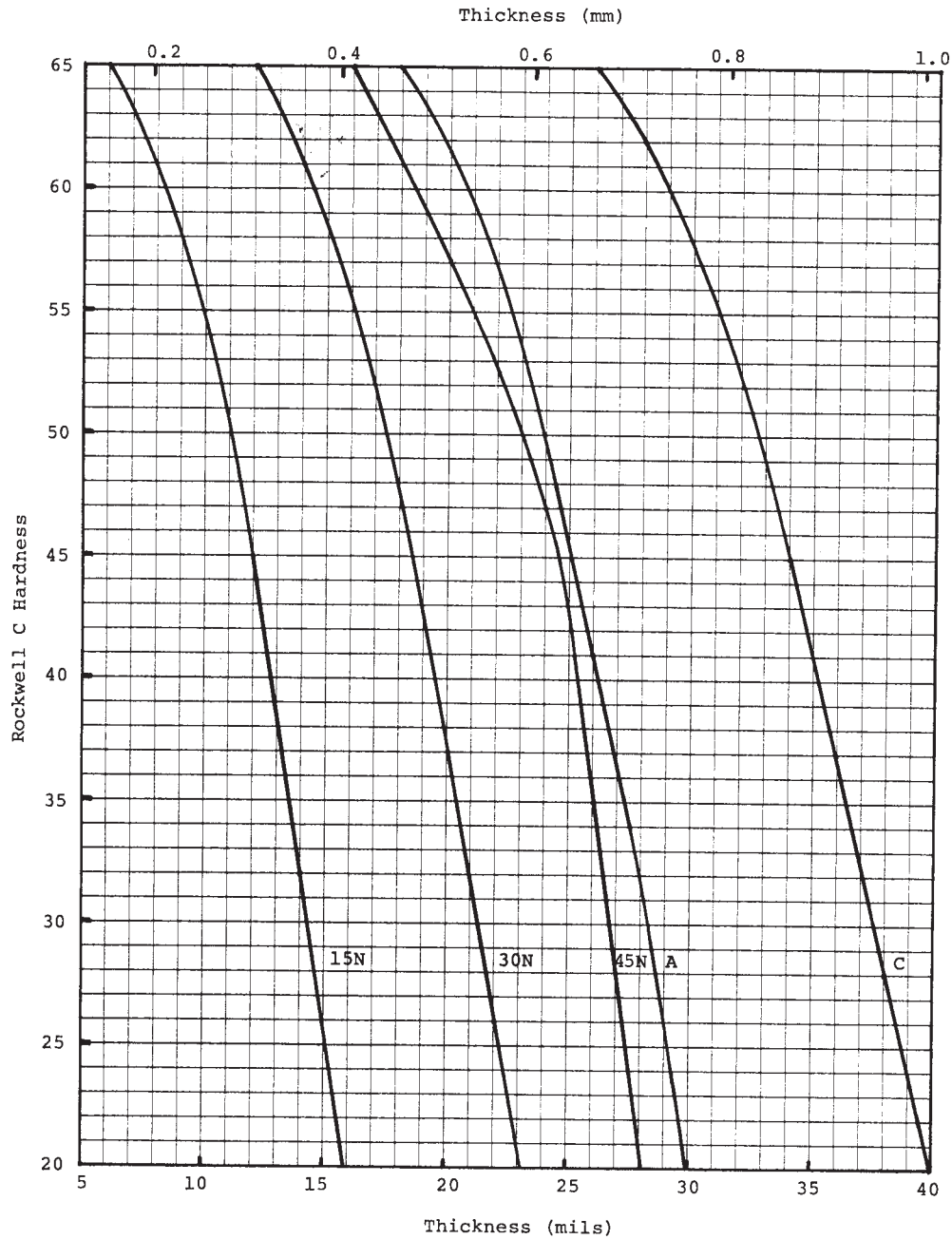
7.5 Establish the reference position (see *Manufacturer's Instruction Manual*) and increase the force, without shock or

vibration, over a period of 1 to 8 s by the value of the additional test force, P_1 (additional load) needed to obtain the required total test force P for a given hardness scale (see Tables 5 and 6).

7.6 While maintaining the preliminary test force P_0 , remove the additional test force P_1 in accordance with the following:

7.6.1 For materials which, under the conditions of the test, show no time-dependent plasticity, remove P_1 within 3 s after the total test force is applied.

7.6.2 For materials which, under the conditions of the test, show some time-dependent plasticity, remove P_1 within 5 to 6 s when using diamond cone indenter and within 6 to 8 s when using steel ball indenter after the application of the total test force begins.



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. 5 Thickness Limits for Rockwell Hardness Testing Using the Diamond Indenter

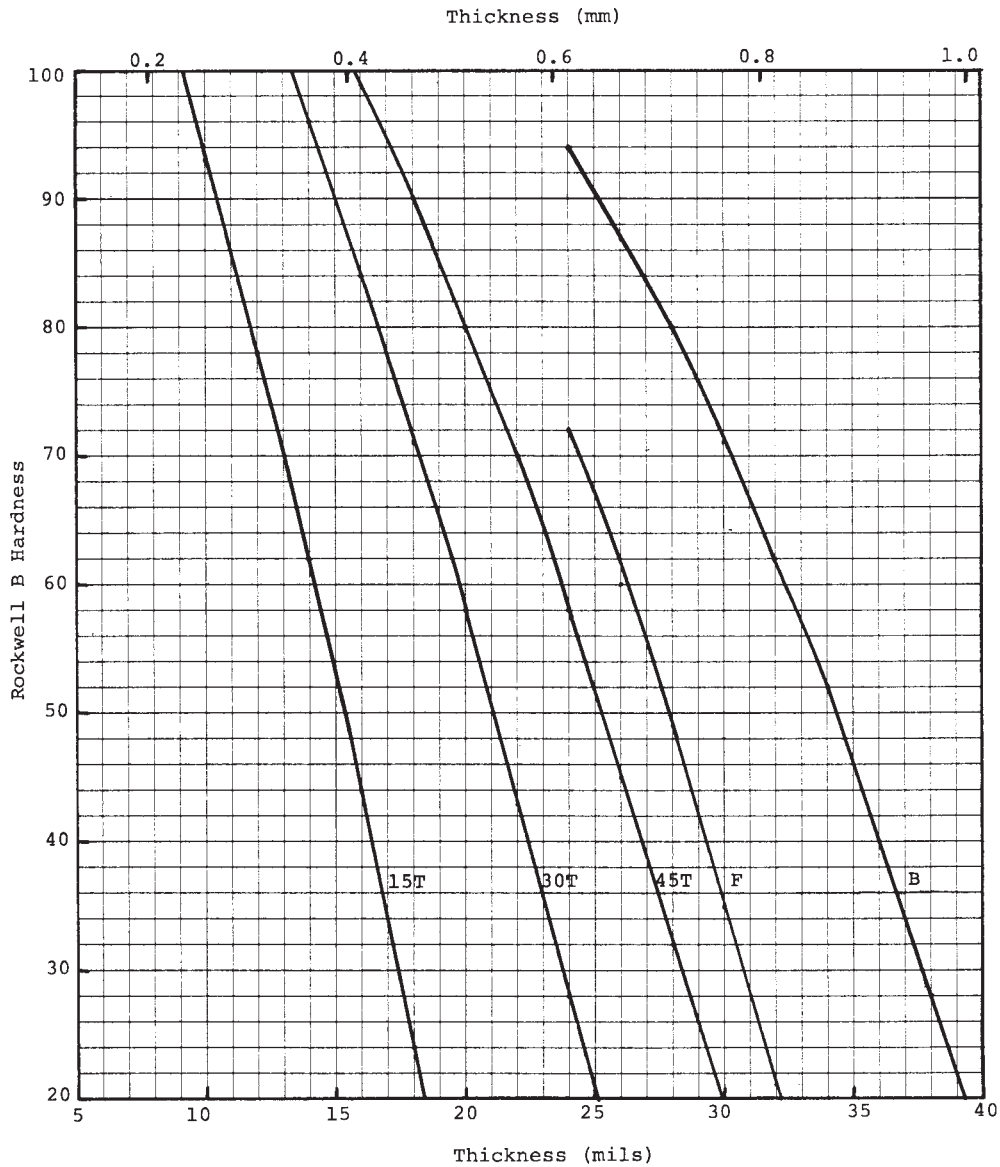
7.6.3 In special cases where the material, under the conditions of the test, shows considerable time-dependent plasticity, remove P_1 within 20 to 25 s after the application of the total test force begins.

7.6.4 When materials require the use of a dwell time greater than 3 s, this shall be specified in the product specification, and the dwell time shall be recorded.

7.7 Throughout the test, the apparatus shall be protected from shock or vibration.

7.8 The Rockwell hardness number is derived from the differential increase in depth of indentation e and is usually read directly. The derivation of the Rockwell hardness number is illustrated in Figs. 1-4.

7.9 After each change, or removal and replacement, of the indenter or the anvil, it shall be ascertained that the indenter (or the new anvil) is correctly mounted in its housing.



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

7.9.1 The first two readings after an indenter or anvil has been mounted shall be disregarded, and the operation of the machine checked with the appropriate standardized hardness test block.

NOTE 4—It is recognized that appropriate standardized test blocks are not available for all geometric shapes, or materials, or both.

7.10 The distance between the center of two adjacent indentations shall be at least three times the diameter of the indentation.

7.10.1 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.

7.11 Unless otherwise specified, all readings are to be reported to the nearest whole number, rounding in accordance with Practice E 29.

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 5—The Standard Hardness Conversion Tables E 140, for Metals, 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.

NOTE 6—ASTM Specifications giving approximate hardness-tensile strength relationships are listed in Appendix X1.

TABLE 11 Corrections to Be Added to Rockwell C, A, and D Values Obtained on Convex Cylindrical Surfaces^A of Various Diameters

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 12 Corrections to Be Added to Rockwell B, F, and G Values Obtained on Convex Cylindrical Surfaces^A of Various Diameters

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.

9. Report

9.1 The report shall include the following information:

9.1.1 The Rockwell hardness number (see 3.1.2).

9.1.1.1 All reports of Rockwell hardness test readings shall indicate the scale used and also the ambient temperature of test if it was outside the 50 to 95°F (10 to 35°C) range (see 7.2). Unless otherwise specified, all readings are to be reported to the nearest whole number, rounding to be in accordance with Practice E 29.

9.1.2 The time of application of the total test force if greater than 3 s.

9.1.3 Any lubricant that is used on the test surface (see 6.1).

10. Precision and Bias

10.1 *Precision*—An interlaboratory test program is now in progress. When completed, it will be the basis of a statement on precision.

10.2 *Bias*—There is no basis for defining the bias for this method.

TABLE 13 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						
	1/8 in. (3.2 mm)	1/4 in. (6.4 mm)	3/8 in. (10 mm)	1/2 in. (13 mm)	3/4 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 14 Corrections to Be Added to Rockwell Superficial 15T, 30T, and 45T Values Obtained on Convex Cylindrical Surfaces^A of Various Diameters

Hardness Reading	Diameters of Convex Cylindrical Surfaces						
	1/8 in. (3.2 mm)	1/4 in. (6.4 mm)	3/8 in. (10 mm)	1/2 in. (13 mm)	5/8 in. (16 mm)	3/4 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 superficial number, of numerous actual observations.

TABLE 15 Tolerances on Applied Forces

Load, kgf (N)	Tolerance, kgf (N)
10 (98)	±0.20 (±1.96)
60 (589)	±0.45 (±4.41)
100 (981)	±0.65 (±6.37)
150 (147)	±0.90 (±8.83)
3 (29)	±0.060 (±0.589)
15 (147)	±0.100 (±0.981)
30 (294)	±0.200 (±1.961)
45 (441)	±0.300 (±2.943)

B. VERIFICATION OF MACHINES FOR ROCKWELL HARDNESS AND ROCKWELL SUPERFICIAL HARDNESS TESTING

11. Scope

11.1 Part B covers two procedures for the verification of machines for Rockwell hardness and Rockwell superficial hardness testing and a procedure which is recommended for use to confirm that the machine is operating satisfactorily in the intervals between the periodical routine checks made by the user. The two methods of verification are:

11.1.1 Separate verification of test force, indenter, and the depth measuring device followed by a performance test (13.2). This method shall be used for new and rebuilt machines.

11.1.2 Verification by standardized test block method. This test method shall be used in referee, laboratory, or routine testing to assure the operator that the machine for Rockwell hardness testing is operating properly (see 13.2).

12. General Requirements

12.1 Before a Rockwell hardness testing machine is verified, it shall be checked to ensure that:

12.1.1 The machine is properly set up.

12.1.2 The indenter-holder is properly seated in the plunger.

12.1.3 When the indenter is a steel ball, the holder is fitted with a new ball that complies with 13.1.2.2. A new ball is not required when a tungsten carbide ball is used.

12.1.4 When the indenter is a diamond indenter, it must be free from defects which may affect the accuracy of the test (See 13.1.2.1).

12.1.5 The test force can be applied and removed without shock or vibration and in such a manner that the readings are not influenced.

12.1.6 The readings are not affected by deformations of the frame.

13. Verification

13.1 Direct Verification—Direct verification involves verification of the test force, verification of the indenter, and verification of the measuring device.

13.1.1 *Verification of the Test Force:*

13.1.1.1 The preliminary test force P_0 and each total test force P used (see Table 15) shall be measured, and this shall be done at not less than three positions of the plunger uniformly spaced throughout its range of movement during testing.

13.1.1.2 The forces shall be measured by one of the following two methods described in Practices E 4.

(1) Measuring by means of an elastic proving device previously calibrated to Class A accuracy of $\pm 0.25\%$, or

(2) balancing against a force, accurate to $\pm 0.25\%$ applied by means of standardized masses with mechanical advantage.

13.1.1.3 Three readings shall be taken for each force at each position of the plunger. Immediately before each reading is taken, the plunger shall have been moved in the same direction as during testing.

13.1.1.4 Each measurement of the preliminary test force before application and after removal of the additional test force and each measurement of the total force shall be within the tolerances given in Table 15.

13.1.2 Verification of the indenter.

13.1.2.1 *Diamond Indenter:*

(1) The diamond indenter shall be free from surface defects (cracks, chips, pits, etc.) and 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 for Rockwell hardness testing and 0.2 mm for Rockwell superficial hardness testing.

(2) The verification of the shape of the indenter can be made by direct measurement or by measurement of its projection on a screen. The verification shall be made at not less than four approximately equally spaced sections.

(3) The diamond indenter shall have an included angle of $120^\circ \pm 0.35^\circ$.

(4) The angle between the axis of the diamond indenter and the axis of the indenter holder (normal to the seating surface) shall not exceed 0.5° .

(5) The spherical tip of the diamond cone shall have a mean radius of 0.200 ± 0.010 mm. In each measured section the radius shall not exceed 0.200 ± 0.015 mm and local deviations from a true radius shall not exceed 0.002 mm. The surfaces of the cone and spherical tip shall blend in a truly tangential manner.

(6) The hardness values given by the testing machine do not depend only on the dimensions given in 13.1.2.1 (c-e), but also on the surface roughness and the position of the crystallographic axis of the diamond and the seating of the diamond in its holder. For this reason, a performance test is considered necessary. The indenter shall be used in a standardizing machine in which the test force applied and the measuring device can be verified by fundamental measurement. Tests shall be made on a minimum of two standardized blocks, that comply with the requirements of Part C, one from each of the minimum and maximum ranges specified in Table 16. Three test impressions shall be made on each of these blocks. The

TABLE 16 Hardness Ranges Used in Verification by Standardized Test Block Method^A

Rockwell Scale	Hardness Ranges
C	{ 20 to 30 35 to 55 59 to 65
B	{ 40 to 59 60 to 79 80 to 100
30N	{ 40 to 50 55 to 73 75 to 80
30T	{ 43 to 56 57 to 70 incl over 70 to 82

^A For scales not listed, use equivalent hardness ranges as those shown; for example, 20 HRC to 30 HRC corresponds to 69.4 HR 15N to 75.0 HR 15N.

mean of these readings shall not differ from the value of the standardized test block by more than the amount shown in Table 17.

13.1.2.2 Indenter Balls:

NOTE 7—**Caution:** Steel balls have been shown to give different results than tungsten carbide balls.

(1) For the purpose of verifying the size and the hardness of the indenter, it is considered sufficient to test a sample selected at random from a batch. The ball(s) verified for hardness shall be discarded.

(2) The ball shall be polished and free from surface defects.

(3) The user shall either measure the balls to ensure that they meet the following requirements, or he shall obtain balls from a supplier who can certify that the following conditions are met. The diameter, when measured at not less than three positions, shall not differ from the nominal diameter by more than the tolerance given in Table 18.

Steel ball: The hardness of the steel ball shall not be less than 746 HV10. Mean diagonals of Vickers impressions corresponding to this hardness level are given in Table 19.

Tungsten carbide ball: The hardness of the tungsten carbide ball shall not be less than 1500 HV10. The material of the tungsten carbide balls shall have a density of 14.8 g/cm³ ± 0.2 g/cm³ and the following chemical composition:

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

13.1.3 Verification of the Measuring Device:

13.1.3.1 The depth-measuring device shall be verified over not less than three intervals, including the intervals corresponding to the lowest and highest hardnesses for which the scales are normally used by making known incremental movements of the indenter.

13.1.3.2 The instrument used to verify the depth measuring device shall have an accuracy of 0.0002 mm.

13.1.3.3 The depth-measuring device shall correctly indicate within ±0.5 of Rockwell unit, over each interval. This corresponds to ±0.001 mm for regular Rockwell ranges and ±0.0005 mm on Rockwell superficial ranges.

13.2 Indirect Verification—Indirect verification may be carried out by means of standardized blocks calibrated in accordance with Part C. For Rockwell hardness scales that use a ball indenter, the standardized blocks to be used for the indirect verification shall have been calibrated with the same type of ball indenter (that is, steel or tungsten carbide) as the indenter that will be used for the indirect verification.

13.2.1 Procedure:

13.2.1.1 For indirect verification of a testing machine, the following procedures shall be applied: The testing machine

TABLE 17 Allowable Deviation in Hardness Readings for Verified Diamond Indenters

For Hardness Readings in Range of:	Allowable Deviation, Rockwell Units
C 63	±0.5
C 25	±1.0
30N 80	±0.5
30N 45	±1.0

TABLE 18 Tolerances for Rockwell Hardness Ball Indenters

Diameter of Ball		Tolerance ^A	
in.	mm	in.	mm
1/16	1.588	±0.0001	±0.0025
1/8	3.175	±0.0001	±0.0025
1/4	6.350	±0.0001	±0.0025
1/2	12.700	±0.0001	±0.0025

^A For balls in the range of diameters specified, these tolerances and the permissible variation in the diameter of any one ball, as specified in 19.1.3, are met by Grade 24 balls of the Anti-Friction Bearing Manufacturers' Association (ABMA).

TABLE 19 Maximum Mean Diagonal of Vickers Hardness Indentation on Steel Balls

Ball Diameters		Maximum Mean Diagonal of Indentation on the Ball Made with Vickers Indenter Under 10-kgf (98-N) Load, mm
in.	mm	
1/16	1.588	0.141
1/8	3.175	0.144
1/4	6.350	0.145
1/2	12.700	0.147

shall be verified using standardized test blocks in the low, middle, and high hardness ranges for each scale to be used. Commonly used hardness scales and hardness ranges are given in Table 16. The testing machine shall not be adjusted between tests made on the three test blocks. The verification is incomplete unless the requirements of 13.5 are met.

13.2.1.2 In accordance with Part A of this test method, make five indentations on each standardized block, distributed uniformly over the block's surface and report the hardness values to within 0.2 of a Rockwell unit. Before making these indentations, at least two indentations shall be made to ensure that the machine is working freely and that the standardized block, the indenter, and the anvil are seating correctly. The results of these preliminary indentations shall be ignored.

13.2.1.3 For each standardized test block, let R₁, R₂... R₅ be the hardness readings of the 5 indentations arranged in increasing order of magnitude.

13.2.2 Repeatability:

13.2.2.1 The repeatability of the testing machine under the particular verification conditions is determined by the following quantity:

$$R_5 - R_1 \tag{1}$$

13.2.2.2 The repeatability of the testing machine verified is considered satisfactory if it satisfies the conditions given in Table 20.

13.2.3 Error:

13.2.3.1 The error of the testing machine under the particular verification conditions is expressed by the following quantity:

$$\bar{R} - R \tag{2}$$

where:

$$\bar{R} = \frac{R_1 + R_2 + \dots + R_5}{5}, \text{ and}$$

R = stated hardness of the standardized test block used.

TABLE 20 Repeatability of Machines

Range of Standardized Hardness Test Blocks	The Repeatability ^A of the Machine Shall Be Not Greater Than:
<i>Rockwell C Scale:</i>	
25 to 30	2.0
35 to 55	1.5
59 to 65	1.0
<i>Rockwell B Scale:</i>	
40 to 59	2.5
60 to 79	2.0
80 to 100	2.0
<i>Rockwell 30N Scale:</i>	
40 to 50	2.0
55 to 73	1.5
75 to 80	1.0
<i>Rockwell 30T Scale:</i>	
43 to 56	2.5
57 to 70, incl	2.0
Over 70 to 82	2.0

^A The repeatability of machines on Rockwell or Rockwell superficial hardness scales other than those given in Table 20 shall be the equivalent converted difference in hardness for those scales, except for the 15N and 15T scales. In the case of the 15N and 15T scales, the repeatability shall be no greater than 1.0 for all ranges.

Example—At C 60, typical readings of a series of indentations might range from 59 to 60, 59.5 to 60.5, 60 to 61, etc. Thus, converted A-scale values corresponding to C 59 to 60 (see Table II of Hardness Conversion Tables E 140) would be A 80.7 to 81.2 and the repeatability for the A-scale would be 0.5.

13.2.3.2 The mean hardness value for the five tests shall not differ from the mean corresponding to the hardness of the standardized test block by more than the tolerance of the latter (shown in Table 21).

13.3 It should be understood that hardness test blocks, diamond indentors, and machine designs vary between manufacturers and that if all parameters are met under 13.1, it is possible that change of one or more of the parameters may be needed to meet indirect verification on test blocks. Consult manufacturer's instructions on the proper method to make corrections *within the tolerances specified in this test method*.

13.4 *Time Interval Between Verifications*—It is recommended that testing machines be verified annually or more frequently if required. In no case shall the time interval between verifications exceed 18 months.

13.5 *Verification Report:*

13.5.1 The verification report shall include the following information:

- 13.5.1.1 Reference to this ASTM Test Method,
- 13.5.1.2 Method of verification (direct or indirect),
- 13.5.1.3 Identification data of the hardness testing machine,
- 13.5.1.4 Means of verification (test blocks, elastic proving devices, etc.)
- 13.5.1.5 The Rockwell hardness scale(s) verified,
- 13.5.1.6 The result obtained,

TABLE 21 Tolerance Values for Standardized Test Blocks

Nominal Hardness of Standardized Test Block	Tolerance Values of the Test Block Shall Not Be Greater Than
<i>C Scale^A</i>	
60 and Greater	±0.5
Below 60	±1.0
<i>A Scale</i>	
80 and Greater	±0.5
Below 80 to 60.5, incl	±1.0
<i>15N Scale</i>	
90 and Greater	±0.7
Below 90 to 69.4, incl	±1.0
<i>30N Scale</i>	
77.5 and Greater	±0.7
Below 77.5 to 41.5, incl	±1.0
<i>45N Scale</i>	
66.5 and Greater	±0.7
Below 66.5 to 19.6, incl	±1.0
<i>B Scale^B</i>	
45 and Greater	±1.0
Below 45 to 1.5, incl	±1.5
<i>F Scale</i>	
99.6 to 57.0, incl	±1.0
<i>15T Scale</i>	
75.3 and Greater	±1.0
Below 75.3 to 60.5, incl	±1.5
<i>30T Scale</i>	
46.2 and Greater	±1.0
Below 46.2 to 15.0, incl	±1.5
<i>45T Scale</i>	
17.6 and Greater	±1.0
Below 17.6 to 1.0, incl	±1.5

^A All other scales on steel blocks of the equivalent converted values are as follows: 70.0 HRC to 60.0 HRC = ±0.5 and 59.9 HRC to 20.0 HRC = ±1.0.

^B All other scales on brass blocks of the equivalent converted values are as follows: 100.0 HRB to 1.0 HRB = ±1.0.

13.5.1.7 Date of verification and reference to the verifying agency, and

13.5.1.8 Signature of verifying agency representative.

14. Procedure for Periodic Checks by the User

14.1 Verification by the standardized test block method (13.2) is too lengthy for daily use. Instead, the following is recommended:

14.1.1 Make at least one routine check each day that the testing machine is used. See Part A of this test method.

14.1.2 Before making the check, make at least two preliminary indentations to ensure that the hardness testing machine is working freely and that the test block, indenter, and anvil are seated correctly. The results of these preliminary indentations should be ignored.

14.1.3 Make at least three hardness readings on a standardized hardness test block on the scale and at the hardness level at which the machine is being used. If the mean of these values falls within the tolerances marked on the standardized hardness test block, the machine may be regarded as satisfactory. If not, the machine should be verified as described in 13.2.

C. CALIBRATION OF STANDARDIZED TEST BLOCKS FOR MACHINES USED FOR ROCKWELL AND ROCKWELL SUPERFICIAL HARDNESS TESTING

15. Scope

15.1 Part C specifies a test method for the calibration of standardized blocks to be used in Rockwell hardness testing machines for the indirect verification of these machines as described in Part B.

16. Manufacture

16.1 The attention of the manufacturer of the block is drawn to the need to use a manufacturing process which will give the necessary homogeneity, stability of structure, and uniformity of surface hardness.

16.2 Each metal block to be standardized shall be of a thickness not less than 0.236 in. (6 mm).

16.3 The area of the test surface of the block shall not be more than 4 in.² (2581 mm²).

16.4 The standardized block shall be free of magnetism. It is recommended that the manufacturer ensure that the blocks, if of steel, have been demagnetized at the end of the manufacturing process.

16.5 The maximum deviation in flatness of the surfaces shall not exceed 0.0002 in. (0.005 mm).

16.6 The maximum error in parallelism shall not exceed 0.0002 in. per in. (mm per mm).

16.7 The test surface shall be free from scratches which interfere with the measurement of the indentation. The mean surface roughness (R_a) shall not exceed 12 μ in. (0.0003 mm) center line average.

16.8 The bottom surface shall have a fine ground finish.

16.9 To assure that material is not removed from the test surface, its thickness at the time of standardization (to the nearest \pm 0.005 in. (0.1 mm)) shall be marked on the block or an identifying mark shall be made on the test surface. Resurfacing of a test block for reuse is not recommended; however, if a standard test block is reconditioned, the new test surface must be recalibrated in accordance with this section.

17. Standardizing Machine

17.1 In addition to fulfilling the general requirements specified in Sections 12 and 13, the standardizing machine shall also meet the following requirements:

17.1.1 The machine shall be verified directly. Direct verification involves the following:

17.1.1.1 Verification of the test force (see 13.1.1),

17.1.1.2 Verification of the indenter (see 13.1.2), and

17.1.1.3 Verification of the measuring device (see 13.1.3).

17.1.2 Each preliminary test force shall be correct to within \pm 0.5 %. Each total test force shall be correct to within \pm 0.25 %.

17.1.3 The verification of the shape of the indenter can be made by direct measurement or by measurement of its projection on a screen. The verification shall be made at not less than eight approximately equally spaced sections.

17.1.4 The diamond indenter shall have an included angle of $120^\circ \pm 0.1^\circ$.

17.1.5 The angle between the axis of the diamond indenter and the axis of the indenter holder (normal to the seating surface) shall not exceed 0.3° .

17.1.6 The tip of the diamond indenter shall be spherical with a mean radius of 0.200 ± 0.005 mm. In each measured section the radius shall not exceed 0.200 ± 0.007 mm and local deviations from a true radius shall not exceed 0.002 mm. The surface of the cone and spherical tip shall blend in a truly tangential manner.

17.1.7 The diameter of the indenter ball shall be within the tolerance of 0.001 mm.

17.1.8 The measuring device shall be capable of accurately measuring vertical displacements corresponding to ± 0.1 of a regular Rockwell unit and ± 0.1 for a superficial Rockwell unit.

18. Standardizing Procedure

18.1 The standardized test blocks shall be calibrated in a standardizing machine as described in Section 17 at a temperature of $73^\circ\text{F} \pm 5^\circ\text{F}$ ($23^\circ\text{C} \pm 2^\circ\text{C}$) using the general test procedure described in Part A.

18.2 The standardized test blocks shall be calibrated traceable to the national Rockwell standards maintained at NIST when primary standardized test blocks are available from NIST for the specific Rockwell scale.

19. Number of Indentations

19.1 In accordance with Part A of this test method, make at least five indentations on each standardized block, distributed uniformly over the block's surface.

20. Uniformity of Hardness

20.1 Let R_1, R_2, \dots, R_5 be the measured values in Rockwell units arranged in increasing order of magnitude.

20.2 The nonuniformity of the block under the particular conditions of standardization is characterized by $R_5 - R_1$.

20.3 The nonuniformity of the block must satisfy the conditions of Table 22.

21. Marking and Certification Requirements

21.1 Each standardized test block shall be marked with the following:

21.1.1 Arithmetic mean of the hardness values found in the standardizing test reported to the nearest tenth, for example: 66.3 HRC or 80.2 HRBW,

21.1.2 Tolerance value (see Table 21),

21.1.3 Name or mark of the supplier,

21.1.4 Unique serial number,

21.1.5 Name or mark of the calibrating agency if different from supplier,

21.1.6 Thickness of the block or an identifying mark on the test surface, and

21.1.7 *Year of Calibration*. It is sufficient that the year of calibration be incorporated into the serial number of the block.

21.2 All of the markings, except the official mark, should be placed outside of the test area or on the side of the block. When

TABLE 22 Maximum Nonuniformity of Standardized Test Blocks

Nominal Hardness of Standardized Test Block	Nonuniformity of the Test Block Shall Not Be Greater Than
<i>C Scale</i> ^A	
60 and Greater	0.5
Below 60	1.0
<i>A Scale</i>	
80 and Greater	0.5
Below 80 to 60.5, incl	1.0
<i>15N Scale</i>	
90 and Greater	0.7
Below 90 to 69.4, incl	1.0
<i>30N Scale</i>	
77.5 and Greater	0.7
Below 77.5 to 41.5, incl	1.0
<i>45N Scale</i>	
66.5 and Greater	0.7
Below 66.5 to 19.6, incl	1.0
<i>B Scale</i> ^B	
45 and Greater	1.0
Below 45 to 1.5, incl	1.5
<i>F Scale</i>	
99.6 to 57.0, incl	1.0
<i>15T Scale</i>	
75.3 and Greater	1.0
Below 75.3 to 60.5, incl	1.5
<i>30T Scale</i>	
46.2 and Greater	1.0
Below 46.2 to 15.0, incl	1.5
<i>45T Scale</i>	
17.6 and Greater	1.0
Below 17.6 to 1.0, incl	1.5

^A All other scales on steel blocks of the equivalent converted values are as follows: 70.0 HRC to 60.0 HRC = 0.5 and 59.9 HRC to 20.0 HRC = 1.0.

^B All other scales on brass blocks of the equivalent converted values are as follows: 100.0 HRB to 1.0 HRB = 1.0.

the markings are on the side of the block, the markings shall be upright when the test surface is the upper surface.

21.3 Each block shall be supplied with a certificate showing the results of the individual standardizing tests and the arithmetic mean of those tests, including the following:

21.3.1 Date of standardization,

21.3.2 Serial number of block, and

21.3.3 Name of manufacturer or mark of supplier.

22. Keywords

22.1 metallic; Rockwell Hardness

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 A 370 and Specifications B 19, B 36, B 96, B 97, B 103, B 121/B 121 M, B 122/B 122 M, B 130, B 134, B 152, B 291, and B 370.

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 13.2) 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 (Tables 20 and 21) and the nonuniformity of standardized blocks (Table 22). 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 Tables 20-22, 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, \dots, H_n is calculated as:

$$AVG(H_1, H_2, \dots, H) = \bar{H} = \frac{H_1 + H_2 + \dots + H_n}{n} \quad (X2.1)$$

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

$$STDEV(H_1, H_2, \dots, H_n) = \sqrt{\frac{(H_1 - \bar{H})^2 + \dots + (H_n - \bar{H})^2}{n - 1}} \quad (X2.2)$$

where \bar{H} is the average of the set of n hardness measurements H_1, H_2, \dots, 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, \dots, u_n , such that:

$$u_c = \sqrt{u_1^2 + u_2^2 + \dots + u_n^2} \quad (X2.3)$$

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:

$$U = k \times u_c \quad (\text{X2.4})$$

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:

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

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:

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

where H_1, H_2, \dots, 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 13.2). 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_{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:

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

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:

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

where $H_{T1}, H_{T2}, \dots, H_{Tn}$ 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:

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

where M_1, M_2, \dots, 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 X2.9, 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 13.2). 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 X2.8), 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 X2.10), and (3) u_{RefBlk} , the standard uncertainty in the certified value of the reference test block (Eq X2.11). 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:

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

and

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

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 X2.13 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 E 18 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:

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

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

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

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

Thus,

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

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

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 X2.9), (3) u_{Resol} , the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.10), and (4) u_{Mach} , the uncertainty in determining the “error” of the hardness machine (Eq

X2.13). 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:

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

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_{Repeat} , the uncertainty due to the machine’s lack of repeatability based on the average of multiple measurements (Eq X2.7), (2) u_{Reprod} , the uncertainty contribution due to the lack of reproducibility (Eq X2.9), (3) u_{Resol} , the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.10), and (4) u_{Mach} , the uncertainty in determining the “error” of the hardness machine (Eq X2.13). 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:

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

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 X2.8), 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 X2.9), (3) u_{Resol} , the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.10), and (4) u_{Mach} , the uncertainty in determining the “error” of the hardness machine (Eq X2.13). 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:

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

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:

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

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 E 18 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 E 18 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 16). 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:

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

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

For this example, assume the hardness machine has been monitored for an extended period of time, and from Eq X2.9, it was determined that $u_{Reprod} = 0.21$ HRC for the low range of the HRC scale. Other uncertainty contributions are calculated as:

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

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

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

and since $B = -0.3$ HRC, $U_{Meas} = (2 \times 0.561) + ABS(-0.3)$, 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 U_{Cert} 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 7.1 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 X2.8), 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 X2.9), (3) u_{Resol} , the uncertainty due to the resolution of the standardizing machine’s measurement display (Eq X2.10), and (4) u_{Mach} , the uncertainty in determining the “error” of the standardizing machine (Eq X2.13). 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:

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

and

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

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 E 18 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 16). 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:

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

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

For this example, let’s assume that the standardizing machine has been monitored for an extended period of time, and from Eq X2.9, it was determined that $u_{Reprod} = 0.125$ HRC for the mid range of the HRC scale. Other uncertainty contributions are calculated as:

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

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

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

and, since $B = +0.11$ HRC, $U_{Cert} = (2 \times 0.151) + ABS(+0.11)$, 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 changes to this standard since the last issue, E 18-02, that may impact the use of this standard. (Approved June 10, 2003.)

- (1) Addition of Appendix X2, Examples of Procedures for Determining Rockwell Hardness Uncertainty. (2) Summary of Changes revised.

Committee E28 has identified the location of changes to this standard since the last issue, E 18-00, that may impact the use of this standard. (Approved Jan. 10, 2002.) Note- Most of the changes listed below resulted from the new addition of allowing the use of tungsten-carbide indenter balls.

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| (1) Note 2 - added | (14) Note 4 - renumbered |
| (2) Paragraph 3.1.2.1 - revised | (15) Note 5 - renumbered |
| (3) Paragraph 3.1.2.2 - revised | (16) Note 6 - renumbered |
| (4) Paragraph 3.1.2.3 - revised | (17) Paragraph 9.1.3 - added |
| (5) Paragraph 3.1.3 - revised | (18) Paragraph 13.1.2.2 - revised |
| (6) Figure 2 caption - revised | (19) Note 7 - replaced and renumbered |
| (7) Paragraph 5.1.1 - revised | (20) Paragraph 13.1.2.2 (c) - revised |
| (8) Figure 4 caption - revised | (21) Table 18 footnote A - revised |
| (9) Paragraph 5.3.1 - revised | (22) Table 19 title - revised |
| (10) Paragraph 5.3.3 - revised | (23) Paragraph 17.1.7 - revised |
| (11) Paragraph 6.1 - revised | (24) Paragraph 21.1.1 - revised |
| (12) Note 3 - renumbered | (25) SUMMARY OF CHANGES added. |
| (13) Paragraph 6.5 - revised | |

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