Designation: E10 – 17

American Association State Highway and Transportation Officials Standard
AASHTO No.: T70–86

Standard Test Method for Brinell Hardness of Metallic Materials[1]

This standard is issued under the fixed designation E10; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope*

1.1 This test method covers the determination of the Brinell hardness of metallic materials by the Brinell indentation hardness principle. This standard provides the requirements for a Brinell testing machine and the procedures for performing Brinell hardness tests.

1.2 This standard includes additional requirements in four annexes:

Verification of Brinell Hardness Testing Machines	Annex A1
Brinell Hardness Standardizing Machines	Annex A2
Standardization of Brinell Hardness Indenters	Annex A3
Standardization of Brinell Hardness Test Blocks	Annex A4

1.3 This standard includes nonmandatory information in an appendix which relates to the Brinell hardness test:

Table of Brinell Hardness Numbers	Appendix X1
Examples of Procedures for Determining Brinell Hardness Uncertainty	Appendix X2

1.4 At the time the Brinell hardness test was developed, the force levels were specified in units of kilograms-force (kgf). Although this standard specifies the unit of force in the International System of Units (SI) as the Newton (N), because of the historical precedent and continued common usage of kgf units, force values in kgf units are provided for information and much of the discussion in this standard refers to forces in kgf units.

1.5 *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.*

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E74 Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines

E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness

E384 Test Method for Microindentation Hardness of Materials

2.2 *American Bearings Manufacturer Association Standard:*

ABMA 10-1989 Metal Balls[3]

2.3 *ISO Standards:*

ISO/IEC 17011 Conformity Assessment—General Requirements for Accreditation Bodies Accrediting Conformity Assessment Bodies[4]

ISO/IEC 17025 General Requirements for the Competence of Calibration and Testing[4]

3. Terminology and Equations

3.1 *Definitions:*

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

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

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[1] This test method is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.06 on Indentation Hardness Testing.

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

[3] Available from American Bearing Manufacturers Association (ABMA), 2025 M Street, NW, Suite 800, Washington, DC 20036, http://www.americanbearings.org.

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

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

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

3.1.4 *Brinell hardness test*—an indentation hardness test using a verified machine to force an indenter (tungsten carbide ball with diameter D), under specified conditions, into the surface of the material under test. The diameter of the resulting indentation d is measured after removal of the force.

3.1.5 *Brinell hardness number*—a number, which is proportional to the quotient obtained by dividing the test force by the curved surface area of the indentation which is assumed to be spherical and of the diameter of the ball.

3.1.6 *Brinell hardness scale*—a designation that identifies the specific combination of ball diameter and applied force used to perform the Brinell hardness test.

3.1.7 *Brinell hardness testing machine*—a Brinell hardness machine used for general testing purposes.

3.1.8 *Brinell hardness standardizing machine*—a Brinell hardness machine used for the standardization of Brinell hardness test blocks. The standardizing machine differs from a regular Brinell hardness testing machine by having tighter tolerances on certain parameters.

3.1.9 *force-diameter ratio*—a number calculated as the ratio of the test force in kgf to the square of the indenter ball diameter in mm (see Table 1).

TABLE 1 Symbols and Designations

Symbol	Designation
D	Diameter of the ball, mm
F	Test force, N
F_{kgf}	Test force, kgf $F_{kgf} = \frac{1}{g_n} \times F$ where g_n is the acceleration due to gravity. g_n = 9.80665 N/kgf
d	Diameter value of the indentation, mm $d = \frac{d(1) + d(2) + ... + d(N)}{N}$ where $d(1)$, $d(2)$ ... $d(N)$ are the measured indentation diameters in mm, and N is the number of diameter measurements (typically 2).
h	Depth of the indentation, mm $h = \frac{D - \sqrt{D^2 - d^2}}{2}$
Force-Diameter ratio	$= \frac{F_{kgf}}{D^2}$
HBW	Brinell hardness $= \frac{Test\ Force}{Surface\ area\ of\ indentation}$ $= \frac{2F_{kgf}}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$

3.2 *Equations:*

3.2.1 The *Brinell hardness number* is calculated as:

$$HBW = \frac{2F_{kgf}}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \quad (1)$$

where:

F_{kgf} = test force in kgf,
D = diameter of the indenter ball in mm, and
d = measured mean diameter of the indentation in mm (see Table 1).

3.2.2 The average mean diameter $\bar{d}$ of a set of n indentations is calculated as:

$$\bar{d} = \frac{d_1 + d_2 + \ldots + d_n}{n} \quad (2)$$

where:

d_1, d_2, ... d_n = diameter values of the indentations in mm, and
n = number of indentations (see Annex A4).

3.2.3 The *repeatability* R in the performance of a Brinell hardness machine at each hardness level, under the particular verification conditions, is estimated by the percent range of diameter values of n indentations made on a standardized test block as part of a performance verification, relative to the average of the n measured diameter values $\bar{d}$ (Eq 2), defined as:

$$R = 100 \times \frac{d_{max} - d_{min}}{\bar{d}} \quad (3)$$

where:

d_{max} = diameter value of the largest measured indentation
d_{min} = diameter value of the smallest measured indentation, and
$\bar{d}$ (Eq 2) = average of the diameter values of the n indentations.

3.2.4 The *average* $\bar{H}$ of a set of n Brinell hardness measurement values H_1, H_2, ..., H_n is calculated as:

$$\bar{H} = \frac{H_1 + H_2 + \ldots + H_n}{n} \quad (4)$$

3.2.5 The *error* E in the performance of a Brinell hardness machine at each hardness level, under the particular verification conditions, is estimated by the percent error of the average of n indentation measurements made on a standardized test block as part of a performance verification relative to the certified average hardness value of the standardized test block, defined as:

$$E = 100 \times \left(\frac{\left|\bar{H} - H_{STD}\right|}{H_{STD}}\right) \quad (5)$$

where:

$\bar{H}$ (Eq 4) = average of n hardness tests H_1, H_2, ..., H_n made on a standardized test block as part of a performance verification,
H_{STD} = certified average hardness value of the standardized test block, and

$|\bar{H} - H_{STD}|$ = absolute value (non-negative value without regard to its sign) of the difference between $\bar{H}$ and H_{STD}.

4. Significance and Use

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

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

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

5. Principles of Test and Apparatus

5.1 *Brinell Hardness Test Principle*—The general principle of the Brinell indentation hardness test consists of two steps (see Fig. 1).

5.1.1 *Step 1*—The indenter is brought into contact with the test specimen in a direction perpendicular to the surface, and the test force F is applied. The test force is held for a specified dwell time and then removed.

5.1.2 *Step 2*—The diameter of the indentation is measured in at least two directions perpendicular to each other. The Brinell hardness value is derived from the mean of the diameter measurements.

5.2 *Brinell Testing Machine*—Equipment for Brinell hardness testing usually consists of a testing machine, which supports the test specimen and applies an indenting force to a ball in contact with the specimen, and a system for measuring the mean diameter of the indentation in accordance with the Brinell hardness test principle. The design of the testing machine shall be such that no rocking or lateral movement of the indenter or specimen occurs while the force is being applied. The design of the testing machine shall ensure that the force to the indenter is applied smoothly and without impact forces. Precautions shall be taken to prevent a momentary high test force caused by the inertia of the system, hydraulic system overshoot, etc.

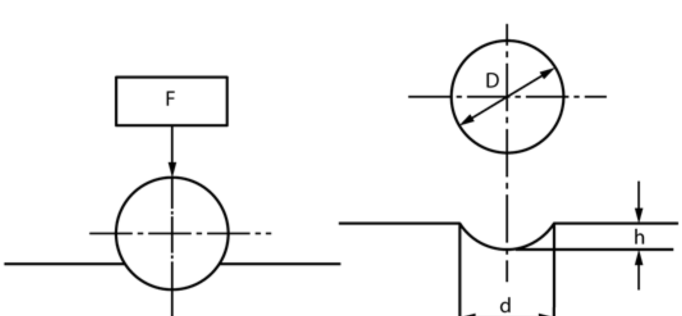

FIG. 1 Principle of Test

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

5.2.2 *Anvils*—An anvil, or specimen support, should be used that is suitable for the specimen to be tested. The seating and supporting surfaces of all anvils should be clean and free of foreign material. Typically, anvils need only be replaced if they fail to support the test surface perpendicular to the indenter, or they are deemed unsafe.

5.2.3 *Indenters*—Indenters for the Brinell hardness test shall be tungsten carbide balls of four allowed diameters (1, 2.5, 5 and 10 mm). Indenters shall meet the requirements defined in Annex A3.

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

5.2.5 *Measurement Device*—The measurement device used for the measurement of the diameter of Brinell indentations may be an integral part of the hardness machine or a separate stand-alone instrument. The allowable measurement devices are classified into two types. The Type A device includes microscopes having movable measuring lines with some type of indicator or computerized measuring system, or an image analysis system. The Type B device is a hand-held microscope (usually 20× or 40×) with fixed measuring lines.

5.2.5.1 *Type A Device*—The acceptable minimum resolution for a Type A device shall be as given in Table 2.

5.2.5.2 *Type B Device*—The acceptable maximum spacing between the graduated lines of Type B devices shall be as given in Table 2. Type B devices shall not be used for measuring indentations made with 2.5 mm and 1 mm ball indenters.

5.3 *Verification*—Brinell testing machines and indentation measurement devices shall be verified periodically in accordance with Annex A1.

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

5.5 *Brinell Hardness Scales*—The combinations of indenters and test forces define the Brinell hardness scales. The standard Brinell hardness scales and test forces are given in Table 3, corresponding to force-diameter ratios (see Table 1) of 1, 1.25, 2.5, 5, 10 and 30. Brinell hardness values should be determined and reported in accordance with one of these standard scales. Other scales using non-standard test forces may be used by special agreement. Examples of other scales and the corresponding force-diameter ratio (in parentheses) are

TABLE 2 Resolution and Graduation Spacing of Indentation Measuring Devices

Ball Diameter mm	Type A: Minimum Indicator Resolution mm	Type B: Maximum Graduation Spacing mm
10	0.0100	0.100
5	0.0050	0.050
2.5	0.0025	–
1	0.0010	–

TABLE 3 Test Conditions and Recommended Hardness Range

Brinell Hardness Scale	Ball Diameter D mm	Force-Diameter Ratio[A]	Nominal Value of Test Force, F		Recommended Hardness Range HBW
			N	kgf	
HBW 10/3000	10	30	29420	3000	95.5 to 650
HBW 10/1500	10	15	14710	1500	47.7 to 327
HBW 10/1000	10	10	9807	1000	31.8 to 218
HBW 10/500	10	5	4903	500	15.9 to 109
HBW 10/250	10	2.5	2452	250	7.96 to 54.5
HBW 10/125	10	1.25	1226	125	3.98 to 27.2
HBW 10/100	10	1	980.7	100	3.18 to 21.8
HBW 5/750	5	30	7355	750	95.5 to 650
HBW 5/250	5	10	2452	250	31.8 to 218
HBW 5/125	5	5	1226	125	15.9 to 109
HBW 5/62.5	5	2.5	612.9	62.5	7.96 to 54.5
HBW 5/31.25	5	1.25	306.5	31.25	3.98 to 27.2
HBW 5/25	5	1	245.2	25	3.18 to 21.8
HBW 2.5/187.5	2.5	30	1839	187.5	95.5 to 650
HBW 2.5/62.5	2.5	10	612.9	62.5	31.8 to 218
HBW 2.5/31.25	2.5	5	306.5	31.25	15.9 to 109
HBW 2.5/15.625	2.5	2.5	153.2	15.625	7.96 to 54.5
HBW 2.5/7.8125	2.5	1.25	76.61	7.8125	3.98 to 27.2
HBW 2.5/6.25	2.5	1	61.29	6.25	3.18 to 21.8
HBW 1/30	1	30	294.2	30	95.5 to 650
HBW 1/10	1	10	98.07	10	31.8 to 218
HBW 1/5	1	5	49.03	5	15.9 to 109
HBW 1/2.5	1	2.5	24.52	2.5	7.96 to 54.5
HBW 1/1.25	1	1.25	12.26	1.25	3.98 to 27.2
HBW 1/1	1	1	9.807	1	3.18 to 21.8

[A] See Table 1.

HBW 10/750 (7.5), HBW 10/2000 (20), HBW 10/2500 (25), HBW 5/187.5 (7.5), and HBW 5/500 (20).

5.6 *Calculation of the Brinell Hardness Number*—The Brinell hardness number shall be calculated from the mean diameter d of the indentation using Eq 1 or from the values given in Appendix X1.

5.6.1 Brinell hardness values shall not be designated by a number alone because it is necessary to indicate which indenter and which force has been employed in making the test (see Table 3). Brinell hardness numbers shall be followed by the symbol HBW, and be supplemented by an index indicating the test conditions in the following order:

5.6.1.1 Diameter of the ball, mm,

5.6.1.2 A value representing the test force, kgf, (see Table 3) and,

5.6.1.3 The applied force dwell time, s, if other than 10 s to 15 s.

5.6.2 The only exception to the above requirement is for the HBW 10/3000 scale when a 10 s to 15 s dwell time is used. Only in the case of this one Brinell hardness scale may the designation be reported simply as HBW.

5.6.3 *Examples:*

220 HBW = Brinell hardness of 220 determined with a ball of 10 mm diameter and with a test force of 29.42 kN (3000 kgf) applied for 10 s to 15 s

350 HBW 5/750 = Brinell hardness of 350 determined with a ball of 5 mm diameter and with a test force of 7.355 kN (750 kgf) applied for 10 s to 15 s

600 HBW 1/30/20 = Brinell hardness of 600 determined with a ball of 1 mm diameter and with a test force of 294.2 N (30 kgf) applied for 20 s

6. Test Piece

6.1 There is no standard shape or size for a Brinell test specimen. The test piece on which the indentation is made should conform to the following:

6.1.1 *Thickness*—The thickness of the specimen tested shall be such that no bulge or other marking showing the effect of the test force appears on the side of the piece opposite the indentation. The thickness of the material under test should be at least ten times the depth of the indentation h (see Table 4). Table 4 can also be used as a guideline for the minimum depth of a layer of a material, such as a coating.

NOTE 1—Brinell hardness testing can use high test forces. Under certain conditions of testing a relatively thin material or coating on a material with high hardness, there is a potential for the test material to break or shatter under load resulting in serious personal injury or damage to equipment. Users are strongly cautioned to exercise extreme care when testing a material that could potentially fail under load. If there is a concern or doubt, do not test the material.

6.1.2 *Width*—The minimum width shall conform to the requirements for indentation spacing.

6.1.3 *Finish*—When necessary, the surface on which the indentation is to be made should be filed, ground, machined or

TABLE 4 Minimum Specimen Thickness Based on Ten-Times the Indentation Depth

Diameter of Indentation, d	Minimum Specimen Thickness							
	10 mm Ball		5 mm Ball		2.5 mm Ball		1 mm Ball	
mm	mm	in.	mm	in.	mm	in.	mm	in.
0.2							0.1	0.004
0.3							0.2	0.009
0.4							0.4	0.016
0.5							0.7	0.026
0.6					0.4	0.014	1.0	0.039
0.7					0.5	0.020		
0.8					0.7	0.026		
0.9					0.8	0.033		
1.0					1.0	0.041		
1.1					1.3	0.050		
1.2			0.7	0.029	1.5	0.060		
1.3			0.9	0.034	1.8	0.072		
1.4			1.0	0.039	2.1	0.084		
1.5			1.2	0.045	2.5	0.098		
1.6			1.3	0.052				
1.7			1.5	0.059				
1.8			1.7	0.066				
1.9			1.9	0.074				
2.0			2.1	0.082				
2.2			2.6	0.100				
2.4	1.5	0.058	3.1	0.121				
2.6	1.7	0.068	3.6	0.144				
2.8	2.0	0.079	4.3	0.169				
3.0	2.3	0.091	5.0	0.197				
3.2	2.6	0.104						
3.4	3.0	0.117						
3.6	3.4	0.132						
3.8	3.8	0.148						
4.0	4.2	0.164						
4.2	4.6	0.182						
4.4	5.1	0.201						
4.6	5.6	0.221						
4.8	6.1	0.242						
5.0	6.7	0.264						
5.2	7.3	0.287						
5.4	7.9	0.312						
5.6	8.6	0.338						
5.8	9.3	0.365						

polished flat with abrasive material so that the edge of the indentation can be clearly defined to permit the measurement of the diameter to the specified accuracy. Preparation shall be carried out in such a way that any alteration of the surface hardness of the test surface (for example, due to overheating or cold-working) is minimized.

7. Test Procedure

7.1 The diameter of the indentation should be between 24 and 60 % of the ball diameter. Approximate Brinell hardness numbers are given in Table 3 for the above range of indentation diameters.

NOTE 2—A lower limit in indentation diameter is recommended because of the risk in damaging the ball and the difficulty in measuring the indentation. The upper limit is recommended because of a reduction in sensitivity as the diameter of the indentation approaches the ball diameter. The thickness and spacing requirements may determine the maximum permissible diameter of indentation for a specific test.

NOTE 3—It is not mandatory that Brinell tests conform to the hardness scales of Table 3. It should be realized that different Brinell hardness numbers may be obtained for a given material by using different forces on the same size of ball. For the purpose of obtaining a continuous scale of values, it may be desirable to use a single force to cover the complete range of hardness for a given class of materials.

7.2 The Brinell hardness test is not recommended for materials above 650 HBW 10/3000.

7.3 Direct comparisons of Brinell hardness numbers for tests using different scales can be made only if the force-diameter ratio is maintained (see Table 3). Brinell hardness tests made on the same test material, but using different force-diameter ratios, will produce different Brinell hardness numbers.

7.3.1 *Example*—An HBW 10/500 test will usually approximate an HBW 5/125 test since the force-diameter ratio is 5 for both scales. However, a value of 160 HBW 10/500 will be approximately equal to 180 HBW 10/3000 on the same test material because of different force-diameter ratios (5 and 30, respectively).

7.4 *Daily Verification*—A daily verification of the testing machine shall be performed in accordance with Annex A1 prior to making hardness tests. Hardness measurements shall be made only on the calibrated surface of the test block. It is also recommended that the operation of the machine be checked in accordance with the daily verification method specified in Annex A1 after each change of the test force, anvil or the indenter.

7.5 *Indentation Procedure*—The Brinell hardness test shall be carried out as follows:

7.5.1 Bring the indenter into contact with the test surface in a direction perpendicular to the surface without shock, vibration or overshoot. The angle between the indenter force-line and the surface of the specimen should be perpendicular.

7.5.2 Apply the test force F within 1 to 8 s. Faster force application times are permitted if it is demonstrated that test results are not affected.

7.5.3 Maintain the fully applied test force for 10 s to 15 s, with the following exception.

7.5.3.1 In the case of materials exhibiting excessive plastic flow after application of the test force, special considerations may be necessary since the indenter will continue to penetrate into the material. Testing of these materials may require the use of a longer applied force dwell time than stated above, which should be specified in the product specification. When an extended applied force dwell time is used, the dwell time shall be recorded and reported with the test results (see 5.6.1).

7.5.4 At the end of the dwell time, immediately remove the test force without shock or vibration.

7.6 *Measurement of Indentation:*

7.6.1 Measure the diameter of each indentation in two directions, perpendicular (90°) to each other. Additional measurements of the indentation diameter may also be made. The arithmetic mean of the measurements shall be used for the calculation of the Brinell hardness number.

7.6.2 For routine testing, the diameter of the indentation shall be measured to the resolution of the measuring device when using a Type A device, or one-half the graduation spacing when using a Type B device.

7.6.3 For tests on flat surfaces, the difference between the largest and smallest measured diameters for the same indentation shall not exceed 1% of the indenter ball diameter unless it is specified in the product specification, such as for an anisotropic grain structure.

7.6.3.1 *Example*—For indentations made using ball indenters having 10 mm, 5 mm, 2.5 mm and 1 mm diameters, the maximum differences between the largest and smallest measured diameters are 0.1 mm, 0.05 mm, 0.025 mm and 0.01 mm, respectively.

7.6.4 When indentations are made on a curved surface, the minimum radius of curvature of the surface shall be two and a half times the diameter of the ball. Indentations made on curved surfaces may be slightly elliptical rather than circular in shape. The measurements of the indentation shall be taken as the mean of the major and minor axes.

7.7 *Indentation Spacing*—The distance between the centers of two adjacent indentations shall be at least three times the diameter of the mean indentation.

7.7.1 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 mean indentation.

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

8. Conversion to Other Hardness Scales or Tensile Strength Values

8.1 There is no general method of accurately converting the Brinell hardness numbers on one scale to Brinell 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 4—The Standard Hardness Conversion Tables for Metals, E140,

TABLE 5 Summary of Statistical Information

Test Block	$\bar{X}$	$S\bar{X}$	Sr	SR	r_{PB}	R_{PB}
100 HBW 5/500	101.71	2.31	0.91	2.42	2.56	6.78
170 HBW 10/1500	175.42	2.08	0.89	2.21	2.49	6.18
225 HBW 10/1500	221.83	4.00	2.20	4.38	6.16	12.28
300 HBW 10/1500	284.63	5.48	2.64	5.89	7.39	16.48
500 HBW 10/3000	502.21	11.78	4.74	12.40	13.28	34.71
300 HBW 10/3000	291.25	6.72	2.08	6.93	5.83	19.42
200 HBW 10/3000	197.71	5.64	4.47	6.72	12.51	18.80

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.

9. Report

9.1 At a minimum, the test report shall include the following information:

9.1.1 The Brinell hardness value $\bar{H}$ of the test results rounded to three significant digits, including all zero digits, in accordance with Practice E29, for example, 225 HBW, 100 HBW 10/500, 95.9 HBW or 9.10 HBW 5/62.5.

9.1.2 The test conditions, when other than a 3000 kgf (29.42 kN) applied force, a 10 mm ball diameter, and a 10 s to 15 s application of test force are used (see 5.6.1).

9.1.3 A statement that the indentation measuring device was Type A, when such a device is used. When a Type B indentation measuring device is used, no statement is required.

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

10. Precision and Bias

10.1 The precision of this test method is based on an interlaboratory study of Test Method E10 conducted in 2006. This replaces a previous study which used steel ball indenters. Each of eight laboratories tested the Brinell hardness of metallic materials. Three analyses were performed on a total of seven different materials of varying levels of hardness. Three replicates of each analysis were performed. The results from this study are filed in an ASTM Research Report.[5]

10.2 *Repeatability*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the r_{PB} value for that material; r_{PB} is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

10.3 *Reproducibility*—Two test results should be judged not equivalent if they differ by more than the R_{PB} value for that material; R_{PB} is the interval representing the difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

10.4 Any judgment in accordance with statements 10.2 or 10.3 would have an approximate 95 % probability of being correct.

10.5 Results from the interlaboratory study are summarized in Table 5.

10.6 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias can be made.

11. Keywords

11.1 Brinell; hardness; mechanical test; metals

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E28-1023.

ANNEXES

(Mandatory Information)

A1. VERIFICATION OF BRINELL HARDNESS TESTING MACHINES

A1.1 Scope

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

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

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

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

A1.2 General Requirements

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

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

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

A1.2.4 Indirect verification of the testing machine shall be performed at the location where it will be used.

A1.2.5 Direct verification of newly manufactured or rebuilt testing machines may be performed at the place of manufacture, rebuild, repair or the location of use.

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

A1.3 Direct Verification

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

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

TABLE A1.1 Verification Schedule for a Brinell Testing Machine

Verification Procedure	Schedule
Direct verification	When a testing machine is new, or when adjustments, modifications or repairs are made that could affect the application of the test forces or the measuring system. When a testing machine fails an indirect verification.
Indirect verification	Recommended every 12 months, or more often if needed. Shall be no longer than every 18 months. When a test machine is installed, [only the procedure for verifying the as-found condition is required, (see A1.4.4). When a test machine is moved, [only the procedure for verifying the as-found condition is required, (see A1.4.4). This does not apply to machines that are designed to be moved or that move prior to each test, when it has been previously demonstrated that such a move will not affect the hardness result. Following a direct verification.
Daily verification	Required each day that hardness tests are made. Recommended whenever the indenter or test force is changed.

A1.3.2 *Verification of the Test Forces*—For each Brinell scale that will be used, the corresponding test force shall be measured. The test forces shall be measured by means of a Class A elastic force measuring instrument having an accuracy of at least 0.25 %, as described in Practice E74.

A1.3.2.1 Make three measurements of each force. The forces shall be measured as they are applied during testing; however, longer dwell times are allowed when necessary to enable the measuring device to obtain accurate measurements.

A1.3.2.2 Each test force F shall be accurate to within ±1 % of the nominal test force as defined in Table 3.

A1.3.3 *Verification of the Indentation Measuring System*—The measuring device used to determine the diameter of the indentation shall be verified at five intervals over the working range by comparison with an accurate scale such as a stage micrometer. The accuracy of the stage micrometer used to verify both Type A and Type B devices shall be at least 0.005 mm for 5 mm and 10 mm ball tests and at least 0.001 mm for 2.5 mm and 1 mm ball tests.

A1.3.3.1 For Type A devices, the error between the stage micrometer and the measuring device over each interval shall not exceed the Type A minimum indicator resolution shown in Table 2 for the size of ball to be used.

A1.3.3.2 For Type B devices, it is not possible to determine a quantitative error value. Position the measuring device such that the lines of the measuring device line-up with the lines of the stage micrometer as closely as possible. If any lines of the measuring device do not, at least partially, overlap the corresponding lines of the stage micrometer, then the measuring device shall be adjusted.

A1.3.4 *Verification of the Testing Cycle*—The testing machine shall be verified to be capable of meeting the testing cycle tolerances specified in 7.5. Direct verification of the testing cycle is to be verified by the testing machine manufacturer at the time of manufacture, or when the testing machine is returned to the manufacturer for repair, or when a problem with the testing cycle is suspected. Verification of the testing cycle is recommended but not required as part of the direct verification at other times.

A1.3.5 *Direct Verification Failure*—If any of the direct verifications fail the specified requirements, the testing machine shall not be used until it is adjusted or repaired. If the test forces, indentation measuring system or testing cycle may have been affected by an adjustment or repair, the affected components shall be verified again by a direct verification.

A1.4 Indirect Verification

A1.4.1 An indirect verification of the testing machine shall be performed in accordance with the schedule given in Table A1.1 Indirect verifications may be required more frequently than stated in Table A1.1 and should be based on the usage of the testing machine.

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

A1.4.3 Standardized test blocks used for the indirect verification shall meet the requirements of Annex A4. Hardness measurements shall be made only on the calibrated surface of the test block.

NOTE A1.3—It is recognized that appropriate standardized test blocks are not available for all geometric shapes, materials, or hardness ranges.

A1.4.4 *As-found Condition*—It is recommended that the as-found condition of the testing machine be assessed as part of an indirect verification. This is important for documenting the historical performance of the machine. This procedure should be conducted by the verification agency prior to any cleaning, maintenance, adjustments, or repairs.

A1.4.4.1 When the as-found condition of the testing machine is assessed, the assessment shall be made using the user's indenter ball that is normally used with the testing machine.

A1.4.4.2 One or more standardized test blocks in the range of normal testing should be tested for each Brinell scale that will undergo indirect verification.

A1.4.4.3 On each standardized test block, make at least two Brinell hardness tests distributed uniformly over the test surface. Determine the repeatability *R* and the error *E* (Eq 3 and Eq 5) in the performance of the testing machine for each standardized test block that is measured.

A1.4.4.4 The repeatability *R* and the error *E* should be within the tolerances of Table A1.2. If the calculated values of the repeatability *R* or the error *E* fall outside the specified tolerances, this is an indication that the hardness tests made since the last indirect verification may be suspect.

A1.4.5 *Cleaning and Maintenance*—Perform cleaning and routine maintenance of the testing machine (when required) in accordance with the manufacturer's specifications and instructions.

A1.4.6 *Indirect Verification Procedure*—The indirect verification procedure is designed to verify that for all of the Brinell hardness scales to be used, each test force is being accurately applied, each indenter-ball size is correct, and the measuring device is calibrated correctly for the range of indentation sizes that these scales produce. This is accomplished by making Brinell hardness tests on test blocks that have been calibrated for appropriate Brinell hardness scales that employ each of the corresponding test forces and indenter ball sizes.

A1.4.6.1 The calibrated values and Brinell hardness scales of the test blocks shall be chosen such that the following criteria are met:

(1) For each test force that will be used, at least one block shall be tested.

(2) For each indenter-ball size that will be used, at least two blocks shall be tested, one from a low hardness level and one from a high hardness level. As best as practical, choose the low and high hardness levels from the range of commercially available test blocks. In cases where more than one of the Brinell hardness scales to be verified employs the same ball size, then the Brinell scale using the highest test force shall be verified on a low hardness level block to produce the largest indentation size, and the Brinell scale using the lowest test force shall be verified on a high hardness level block to produce the smallest indentation size. The two extremes of indentation size will verify the capability of the measuring device. The blocks need not be from scales of the same force/diameter ratio.

(3) Each test block's calibrated Brinell scale is one of the scales to be verified.

(4) In cases where a Brinell scale should be verified using a low level and high level test block, but test blocks are commercially available for only one hardness level, perform the indirect verification using the one block, and directly verify the measuring device according to A1.3.3.

(5) In cases where no test blocks are commercially available for a specific Brinell scale that requires verification, directly verify the force level employed by the scale according to A1.3.2 and the measuring device according to A1.3.3.

Example 1—A testing machine is to be verified for the HBW 10/3000 and HBW 5/750 scales. At a minimum, two blocks for each of the two ball sizes are required for the verification, for a total of four test blocks: one block from a low hardness level of the HBW 10/3000 scale, one block from a high hardness level of the HBW 10/3000 scale, one block from a low hardness level of the HBW 5/750 scale, and one block from a high hardness level of the HBW 5/750 scale. Note that both test forces are also tested.

Example 2—A testing machine is to be verified for the HBW 10/3000, HBW 10/1500 and HBW 10/1000 scales. At a minimum, one block for each of the force levels are required for the verification, for a total of three test blocks: one block from a low hardness level of the HBW 10/3000 scale, one block from a high hardness level of the HBW 10/1000 scale, and one block from any hardness level of the HBW 10/1500 scale. In this case, although there is only one ball size, there are three test forces that must be verified. The highest test force (29420 N, 3000 kgf) scale is tested on a low hardness level hardness block, and the lowest test force (9807 N, 1000 kgf) scale is tested on a high hardness level test block. The middle test force (14710 N, 1500 kgf) scale may be tested on either a low or high hardness level test block.

Example 3—A testing machine is to be verified for only the HBW 10/3000 scale. At a minimum, two test blocks are required for the verification: one block from a low hardness level of the HBW 10/3000 scale, and one block from a high hardness level of the HBW 10/3000 scale. In this case, although there is only one Brinell scale to be verified, two test blocks of different hardness levels are required for the verification.

A1.4.6.2 Prior to making the indirect verification hardness tests, the measuring device shall be indirectly verified by measuring the diameters of two reference indentations (see A4.5.6) chosen from the reference blocks to be used for the indirect verification. Locate the reference indentation on each

TABLE A1.2 Repeatability and Error of the Testing Machine

Reference Block Hardness HBW	Maximum Permissible Repeatability, *R* % of $\bar{d}$ (See Eq 3)	Maximum Permissible Error, *E* % of H (See Eq 5)
HBW ≤ 125	3	3
125 < HBW ≤ 225	2.5	3
HBW > 225	2	3

reference block. The two reference indentations to be measured shall be the indentation having the smallest diameter and the indentation having the largest diameter. For Type A devices, the measured dimensions shall agree with the certified diameter values within 0.5 %. For Type B devices, the measured dimensions shall be estimated to agree with the certified diameter values within ±0.02 mm for 10 mm ball indentations and ±0.01 mm for 5 mm ball indentations. If any of the differences is larger, the measuring device shall be directly verified in accordance with A1.3.3. As an alternative to measuring reference indentations, the measuring device may be directly verified in accordance with A1.3.3.

A1.4.6.3 The testing machine shall be verified with the user's indenter ball(s) that will normally be used for testing.

A1.4.6.4 On each standardized test block, make three tests when using a 5 mm or 10 mm ball, or make five tests when using a 2.5 mm or 1 mm ball distributed uniformly over the test surface. Determine the repeatability *R* and the error *E* (Eq 3 and Eq 5) in the performance of the testing machine for each hardness level of each Brinell scale to be verified. The repeatability *R* and the error *E* shall be within the tolerances of Table A1.2.

A1.4.6.5 If the measurements of error *E* or repeatability *R* using the user's indenter fall outside of the specified tolerances, the indirect verification tests may be repeated using a different ball.

A1.4.6.6 The indirect verification shall be approved only when the testing machine measurements of repeatability and error meet the specified tolerances with the user's indenter ball.

A1.4.7 In cases where it is necessary to replace the indenter ball during the period between indirect verifications, the new indenter ball shall be verified for use with the specific testing machine. The user may perform the verification by following the verification procedures for the as-found condition given above in A1.4.4.

A1.5 Daily Verification

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

A1.5.2 *Daily Verification Procedure*—The procedure to use when performing a daily verification are as follows.

A1.5.2.1 At least one standardized test block that meets the requirements of Annex A4 shall be tested for each Brinell scale to be used prior to its use. When test blocks are commercially available, the hardness level of the test blocks should be chosen at approximately the same hardness value as the material to be measured.

A1.5.2.2 The indenter ball to be used for the daily verification shall be the indenter ball that is normally used for testing.

A1.5.2.3 Make at least two hardness tests on each of the daily verification test blocks adhering to the spacing requirements given in 7.7.

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

A1.5.2.4 Determine the error *E* in the performance of the testing machine (Eq 5) for each standardized test block that is measured. If the difference between any of the hardness test values and the certified value of the test block is outside the maximum permissible error tolerances given in Table A1.2, then also determine the repeatability *R* (Eq 3).

A1.5.2.5 If the error *E* and the repeatability *R* (if calculated) for each test block are within the tolerances given in Table A1.2, then the testing machine with the indenter may be regarded as performing satisfactorily.

A1.5.2.6 If the error *E* or the repeatability *R* (if calculated) for any of the test blocks is outside the tolerances, the daily verification may be repeated with a different ball or indenter. If the error *E* or the repeatability *R* again falls outside of tolerances for any of the test blocks, an indirect verification shall be performed. Whenever a testing machine fails a daily verification, the hardness tests made since the last valid daily verification may be suspect.

A1.5.2.7 If the Brinell testing machine fails daily verification using test blocks, the measuring device should be verified by measuring a reference indentation (see A4.5.6) on the standardized test block. The measured dimension should agree with the certified diameter value within the tolerances given in A1.4.6.2. If the difference is larger, the measuring device should be directly verified in accordance with A1.3.3.

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

A1.6 Verification Report

A1.6.1 A verification report is required for direct and indirect verifications. A verification report is not required for a daily verification.

A1.6.2 The verification report shall be produced by the person performing the verification and include the following information when available as a result of the verification performed.

A1.6.3 *Direct Verification:*

A1.6.3.1 Reference to this ASTM test method.

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

A1.6.3.3 Identification of the indentation measuring device(s), including the serial number, model number, and whether it is a Type A or B device.

A1.6.3.4 Identification of all devices (elastic proving devices, etc.) used for the verification, including serial numbers, and identification of standards to which traceability is made.

A1.6.3.5 Test temperature at the time of verification reported to a resolution of at least 1°C. The temperature at the verification site does not need to be recorded for a daily verification unless the temperature is outside recommended limits or can be shown to affect the test results.

A1.6.3.6 The individual measurement values and calculated results used to determine whether the testing machine meets the requirements of the verification performed. It is recommended that the uncertainty in the calculated results used to determine whether the testing machine meets the requirements of the verification performed also be reported.

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

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

A1.6.3.9 Identification of the person performing the verification.

A1.6.4 *Indirect Verification:*

A1.6.4.1 Reference to this ASTM test method.

A1.6.4.2 Identification of the hardness testing machine, including the serial number and model number.

A1.6.4.3 Identification of all devices (test blocks, indenters, etc.) used for the verification, including serial numbers, and identification of standards to which traceability is made.

A1.6.4.4 Test temperature at the time of verification reported to a resolution of 1°C.

A1.6.4.5 The Brinell hardness scale(s) verified.

A1.6.4.6 The individual test values and calculated results used to determine whether the testing machine meets the requirements of the verification performed. Measurements made to determine the as-found condition of the testing machine shall be included whenever they are made. It is recommended that the uncertainty in the calculated results used to determine whether the testing machine meets the requirements of the verification performed also be reported.

A1.6.4.7 Description of maintenance done to the testing machine, when applicable.

A1.6.4.8 Date of verification and reference to the verifying agency or department.

A1.6.4.9 Identification of the person performing the verification.

A1.6.5 *Daily Verification:*

A1.6.5.1 No verification report is required; however, it is recommended that records be kept of the daily verification results, including the verification date, measurement results, certified value of the test block, test block identification, and the name of the person that performed the verification, etc. (see also Note A1.5). These records can be used to evaluate the performance of the hardness machine over time.

A2. BRINELL HARDNESS STANDARDIZING MACHINES

A2.1 Scope

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

A2.2 Accreditation

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

NOTE A2.1—Accreditation is a new requirement starting with this edition of the standard.

A2.3 Apparatus

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

A2.3.2 The standardizing machine shall be designed such that each test force can be selected by an operator without their ability to adjust away from the value set at the time of verification.

A2.3.3 *Measurement Device*—The measuring device shall be a Type A device as described in 5.2.5. The divisions of the micrometer scale of the microscope or other measuring devices used for the measurement of the diameter of the indentations shall be such as to permit the estimation of the diameter to within the tolerances given in Table A2.1.

A2.3.4 *Indenters*—Indenters as specified in Annex A3 shall be used.

TABLE A2.1 Resolution of Indentation Measuring Device

Ball Indenter Diameter mm	Minimum Resolution mm
10	±0.002
5	±0.002
2.5	±0.001
1	±0.001

A2.3.5 *Testing Cycle*—The standardizing machine shall be capable of meeting a desired test cycle parameter value within the tolerances specified in Table A2.2 for each part of the test cycle.

A2.4 Laboratory Environment

A2.4.1 The standardizing machine shall be located in a temperature and relative-humidity controlled room with tolerances for these conditions given in Table A2.3. The accuracy of the temperature and relative-humidity measuring instruments shall be as given in Table A2.3.

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

A2.4.3 The standardizing machine, indenter(s), and test blocks to be standardized must be in an environment meeting the tolerances of Table A2.3 for at least one hour prior to standardization.

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

A2.5 Standardizing Machine Verifications

A2.5.1 The standardizing machine shall undergo direct verification at periodic intervals and when circumstances occur that may affect the performance of the standardizing machine, according to the schedule given in Table A2.4.

NOTE A2.2—Periodic direct verification (every 12 months) is a new requirement starting with this edition of the standard. In previous editions of this standard, direct verification was used only as an alternative to indirect verification (which is no longer required) for machine verification.

A2.5.2 The standardizing machine shall undergo monitoring verifications each day that standardizations are made, according to the schedule given in Table A2.4.

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

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

A2.6 Direct Verification Procedures

A2.6.1 Perform a direct verification of the standardizing machine in accordance with the schedule given in Table A2.4. The test forces, indentation measuring system and the testing cycle shall be verified.

A2.6.2 *Perform Cleaning and Maintenance*—If required, cleaning and routine maintenance of the standardizing machine shall be made before conducting direct or indirect verifications in accordance with the manufacturer's specifications and instructions.

A2.6.3 *Verification of the Test Forces*—For each Brinell scale that will be used, the associated test force shall be measured. The test forces shall be measured by means of a Class AA elastic force measuring instrument having an accuracy of at least 0.05 %, as described in Practice E74.

A2.6.3.1 Make three measurements of each force. The forces shall be measured as they are applied during testing. The extension of dwell times to obtain force measurements is not permitted. No adjustments are allowed between measurements.

A2.6.3.2 Each test force F shall be accurate to within 0.25 % of the nominal test force as defined in Table 3.

A2.6.4 *Verification of the Indentation Measuring System*—The measuring device used to determine the diameter of the indentation shall be verified at five intervals over the working range by the use of an accurate scale such as a stage micrometer or by other suitable means to ensure that the accuracy of the measurements is within the tolerances given in Table A2.5 for the size of indentation to be measured. The accuracy of the stage micrometer shall be 0.00025 mm.

A2.6.5 *Verification of the Testing Cycle*—The standardizing machine shall be verified to be capable of meeting the testing cycle tolerances specified in Table A2.2.

A2.6.6 *Indenter Balls*—At the time of the direct verification, all indenter balls that have been used shall be replaced by new unused indenter balls meeting the requirements of Annex A3.

TABLE A2.2 Testing Cycle Requirements

Testing Cycle Parameter	Tolerance
Indenter contact velocity	≤1 mm/s
Time for application of test force	2.0 to 8.0 s
Dwell time for test force	10 to 15 s

TABLE A2.3 Standardization Laboratory Environmental Requirements

Environmental Parameter	Tolerance	Accuracy of Measuring Instrument
Temperature	23 ± 2°C (73 ± 5°F)	±1°C (2°F)
Relative humidity	≤70 %	±10 %

TABLE A2.4 Verification Schedule for a Brinell Hardness Standardizing Machine

Verification	Schedule
Direct Verification	At a maximum, shall be within 12 months prior to standardization testing. When a standardizing machine is new, moved, or when adjustments, modifications or repairs are made that could affect the application of the test forces, the indentation measuring system, or the testing cycle.
Monitoring	Each day that test blocks are to be calibrated. Either a direct verification or performance.

TABLE A2.5 Maximum Error of Indentation Measuring Device

Ball Indenter Diameter mm	Maximum Error mm
10	±0.004
5	±0.004
2.5	±0.002
1	±0.002

A2.6.7 *Direct Verification Failure*—If any of the direct verifications fail the specified requirements, the standardizing machine shall not be used until it is adjusted or repaired. Any parameter that may have been affected by an adjustment or repair shall be verified again by direct verification.

A2.7 Monitoring Verification Procedures

A2.7.1 This section describes the monitoring procedures for the standardizing hardness machine.

A2.7.2 The standardizing laboratory shall monitor the standardizing machine by performing monitoring verifications each day that test block calibrations are made, according to the schedule given in Table A2.4. Monitoring verifications shall be performed prior to the test block calibrations, and may be made either by direct verification or by performance verification using test blocks.

A2.7.3 *Monitoring Direct Verification*—When the monitoring verification is to be made by direct verification, it shall be in accordance with the requirements of A2.6 for the force level and ball size of the Brinell scale to be used that day.

A2.7.4 *Monitoring Performance Verifications*—When the monitoring verification is to be made by performance verification, the following monitoring procedures shall be performed.

A2.7.4.1 Depending on the Brinell scales for which test blocks will be calibrated on that day, monitoring tests shall be performed on at least one monitoring test block for each force level that will be used and on at least one monitoring test block for each ball size that will be used. The monitoring test blocks shall meet the requirements of Annex A4. The hardness level of each monitoring block should be chosen that is in the mid range of the hardness scale.

A2.7.4.2 Make at least two hardness tests distributed uniformly over the surface of the test block. Determine the error E (Eq 5) and the repeatability R (Eq 3) in the performance of the standardizing machine for each monitoring test block that is measured. If the error E and the repeatability R for each test block are within the tolerances given in Table A2.6, then the standardizing machine with the indenter may be regarded as performing satisfactorily.

A2.7.4.3 If any of the error E or repeatability R measurements fall outside of the specified tolerances, the standardizing machine shall not be considered to have passed the monitoring verification, and shall not be used for standardizations. Whenever a standardizing machine fails a monitoring verification, the standardizations made since the last valid monitoring verification may be suspect.

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

Reference Block Hardness HBW	Maximum Permissible Repeatability, R % of $\bar{d}$ (See Eq 3)	Maximum Permissible Error, E % of H (See Eq 5)
HBW ≤ 125	2	2
125 < HBW ≤ 225	2	2
HBW > 225	1.5	1.5

A2.7.5 *Monitoring Methods*—Control charts or other comparable methods should be used to monitor the performance of the standardizing machine between direct verifications. Control charts provide a method for detecting lack of statistical control. There are many publications available that discuss the design and use of control charts, such as the ASTM "Manual on Presentation of Data and Control Chart Analysis: 6th Edition," prepared by Committee E11 on Quality and Statistics. The standardizing laboratory should develop and use control charts that best apply to their specific needs.

NOTE A2.3—Control chart data should be interpreted by the laboratory based on past experience. The need for corrective action does not depend solely on data falling outside the control limits, but also on the prior data leading to this occurrence. As a general rule, however, once the standardizing machine is determined to be in control, a single occurrence of data falling outside the control limits should alert the laboratory to a possible problem. The level of action that is required depends on the history of the machine performance. It may be precautionary such as increasing the monitoring frequency, or corrective such as performing new direct and indirect verifications.

A2.8 Verification Report

A2.8.1 *Direct Verification:*

A2.8.1.1 Reference to this ASTM test method.

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

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

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

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

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

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

A2.8.1.8 Identification of the person performing the verification.

A2.8.1.9 Accreditation certification number.

A2.8.2 *Indirect Verification:*

A2.8.2.1 Reference to this ASTM test method.

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

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

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

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

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

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

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

A2.8.2.9 Identification of the person performing the verification.

A2.8.2.10 Accreditation certification number.

A2.8.3 *Monitoring Verification:*

A2.8.3.1 No verification report is required; however, it is required that records be kept of the monitoring verification results, see A2.7.5.

A3. STANDARDIZATION OF BRINELL HARDNESS INDENTERS

A3.1 Scope

A3.1.1 Annex A3 specifies the requirements for Brinell hardness indenter balls. The Annex covers the Brinell tungsten-carbide ball indenters for use with all Brinell scales.

A3.2 Accreditation

A3.2.1 The agency conducting the standardizations of indenters shall be accredited to the requirements of ISO 17025 (or an equivalent) by an accrediting body recognized by the International Laboratory Accreditation Cooperation (ILAC) as operating to the requirements of ISO/IEC 17011. The standardizing laboratory shall have a certificate of accreditation stating the class and types of indenters that are covered by the accreditation.

NOTE A3.1—Accreditation is a new requirement starting with this edition of the standard.

A3.3 General Requirements

A3.3.1 The standard indenters are tungsten carbide balls of four specified diameters (10 mm, 5 mm, 2.5 mm, and 1 mm) to be used for the Brinell hardness scales as given in Table 3.

A3.3.2 All instruments used to make measurements required by this Annex shall be calibrated traceable to national standards where a system of traceability exists, except as noted otherwise.

A3.3.3 Ball indenters frequently consist of a holder, a cap and a ball. The ball may be changed without affecting the assembly's verification provided the ball conforms to all the requirements in this section.

A3.4 Indenter Balls

A3.4.1 Indenter balls are verified for correct geometry, hardness, density, and chemical composition in accordance with the schedule specified in Table A3.1.

A3.4.2 The hardness of the ball shall be not less than 1500 HV10 when measured on the spherical surface of the ball in accordance with ASTM E92, or not less than 1500 HV 1 when measured on the flat surface of a sectioned ball in accordance with ASTM E92 or Test Method E384. When testing on the spherical surface of the ball, the hardness result must be corrected due to the curved surface as specified in ASTM E92.

A3.4.3 The material of the balls shall have a density of 14.8 $g/cm^3 \pm 0.2\ g/cm^3$ and the following chemical composition:

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

A3.4.4 The diameter, when measured at not less than three positions, shall not differ from the nominal diameter by more than the tolerances given in Table A3.2.

A3.4.5 The mean surface roughness of the ball shall not exceed 0.00005 mm (2 µin.).

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

A3.4.6 For the purpose of verifying the density, size, finish and hardness of the ball, it is considered sufficient to test a sample selected at random from a batch. The balls verified for hardness shall be discarded.

A3.4.7 To meet the above requirements for indenter balls, the ball-standardizing laboratory may either verify that the balls meet the requirements, or obtain a certificate of verification from the ball manufacturer.

A3.5 Certificate

A3.5.1 At a minimum, each indenter ball shall have a test certificate with the following information:

A3.5.1.1 Reference to this ASTM test method.

A3.5.1.2 Identification of the lot or batch.

A3.5.1.3 Date.

A3.5.1.4 A statement declaring that the indenter meets all of the geometrical, density and hardness requirements for a Brinell hardness indenter.

A3.5.1.5 Accreditation certification number.

TABLE A3.1 Indenter Ball Verification Schedule

Verification	Schedule
Geometrical features, density, chemical composition, and hardness	When an indenter is new

TABLE A3.2 Diameter Tolerances for Indenter Balls

Ball Diameter, mm	mm
10	±0.005
5	±0.004
2.5	±0.003
1	±0.003

A4. STANDARDIZATION OF BRINELL HARDNESS TEST BLOCKS

A4.1 Scope

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

A4.2 Accreditation

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

NOTE A4.1—Accreditation is a new requirement starting with this edition of the standard.

A4.3 Manufacture

A4.3.1 The attention of the manufacturer of test blocks is drawn to the need to use material and a manufacturing process, which will give the necessary homogeneity, stability of structure, and uniformity of surface hardness.

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

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

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

TABLE A4.1 Physical Requirements of Standardized Test Blocks

Test Block Parameter	Tolerance
Thickness	≥16.0 mm for 10 mm ball tests ≥12.0 mm for 5 mm ball tests ≥6.0 mm for smaller ball tests
Test surface area	≤150 cm^2 for ≥ 5 mm ball tests ≤40 cm^2 for < 5 mm ball tests
Deviation from surface flatness (test & bottom)	≤0.02 mm for ≥ 5 mm ball tests ≤0.005 mm for < 5 mm ball tests
Deviation from surface parallelism (test & bottom)	≤0.0008 mm per mm for ≥ 5 mm ball tests ≤0.0002 mm per mm for < 5 mm ball tests
Mean test surface roughness	≤0.0003 mm R_a for 10 mm ball tests ≤0.00015 mm R_a for smaller ball tests

A4.4 General Requirements

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

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

A4.5 Standardization Procedure

A4.5.1 A test block is standardized by calibrating the average hardness of the test surface. Only one surface of the test block shall be calibrated. The Brinell standard to which the test blocks are traceable shall be stated in the certification.

A4.5.2 The standardization procedure involves making hardness tests on the test block surface using the forces and type of indenter that are appropriate for the hardness scale. Make at least five hardness tests distributed uniformly over the test surface.

A4.5.3 Calculate the diameter values for d_1, d_2, ... d_n for each indentation (see Table 1) and the average of the diameter values $\bar{d}$ using Eq 2.

A4.5.4 Determine the percent range d_R for the measurements as:

$$d_R = 100 \times \frac{d_{max} - d_{min}}{\bar{d}} \tag{A4.1}$$

where:

d_{max} = diameter value of the largest measured indentation, and

d_{min} = diameter value of the smallest measured indentation.

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

A4.5.5 The standardized value of the test block is defined as the average of the standardization measurements $\bar{H}$ (Eq 4).

A4.5.6 *Reference Indentation*—In addition to calibrating the average hardness of the test surface, one or more of the calibration indentations shall be certified for the measurement of the diameter and will be known as a *reference indentation*. The reference indentation will be measured as part of the indirect and daily verifications.

TABLE A4.2 Maximum Nonuniformity for Standardized Test Blocks

Reference Block Hardness HBW	Maximum Range, d_R % of $\bar{d}$ (see Eq A4.1)
HBW ≤ 225	2
HBW > 225	1

A4.6 Marking

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

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

A4.6.2.1 The standardized hardness value $\bar{H}$ of the test block rounded to no better than three significant digits in accordance with Practice E29, for example, 125 HBW, 99 HBW, or 99.2 HBW.

A4.6.2.2 Identification of the reference indentation(s).

A4.6.2.3 A mark identifying the test surface, which will be obliterated if the surface is reground.

A4.6.2.4 Unique serial number.

A4.6.2.5 Year of standardization. It is sufficient that the year of standardization be incorporated into the serial number of the block.

A4.7 Certificate

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

A4.7.1.1 Reference to this ASTM test method.

A4.7.1.2 Serial number of the test block.

A4.7.1.3 The results of the individual standardizing tests, including:

(1) The diameter values $d_1, d_2, ..., d_n$ of the n indentations (see Table 1).

(2) The average of the diameter values $\bar{d}$ (see Eq 2).

(3) The calculated hardness values $H_1, H_2, ..., H_n$.

(4) The average hardness value $\bar{H}$ rounded to three significant digits in accordance with Practice E29, for example, 125 HBW, 99.2 HBW.

A4.7.1.4 Information about the location of the reference indentation(s), the orientation of the measured diameter(s), and the certified value of the reference indentation(s) diameter (see A4.5.6).

A4.7.1.5 The body that maintains the Brinell hardness scale to which the test block is traceable.

A4.7.1.6 Date of standardization.

A4.7.1.7 Accreditation agency certification number.

APPENDIXES

(Nonmandatory Information)

X1. TABLE OF BRINELL HARDNESS NUMBERS

TABLE X1.1 Brinell Hardness Numbers

NOTE 1—The values given in the table for Brinell numbers are merely solutions of the equation for Brinell hardness, and include values for indentation diameters outside the recommended ranges. These values are indicated by italics.

Diameter of Indentation, *d* (mm)				Brinell Hardness Number						
				HBW 10/3000	HBW 10/1500	HBW 10/1000	HBW 10/500	HBW 10/250	HBW 10/125	HBW 10/100
10 mm	5 mm	2.5 mm	1 mm	HBW 5/750		HBW 5/250	HBW 5/125	HBW 5/62.5	HBW 5/31.25	HBW 5/25
ball	ball	ball	ball	HBW 2.5/187.5		HBW 2.5/62.5	HBW 2.5/31.25	HBW 2.5/15.625	HBW 2.5/7.8125	HBW 2.5/6.25
				HBW 1/30		HBW 1/10	HBW 1/5	HBW 1/2	HBW 1/1.25	HBW 1/1
2.00	1.000	0.5000	0.200	*945*	*473*	*315*	*158*	*78.8*	*39.4*	*31.5*
2.01	1.005	0.5025	0.201	*936*	*468*	*312*	*156*	*78.0*	*39.0*	*31.2*
2.02	1.010	0.5050	0.202	*926*	*463*	*309*	*154*	*77.2*	*38.6*	*30.9*
2.03	1.015	0.5075	0.203	*917*	*459*	*306*	*153*	*76.4*	*38.2*	*30.6*
2.04	1.020	0.5100	0.204	*908*	*454*	*303*	*151*	*75.7*	*37.8*	*30.3*
2.05	1.025	0.5125	0.205	*899*	*450*	*300*	*150*	*74.9*	*37.5*	*30.0*
2.06	1.030	0.5150	0.206	*890*	*445*	*297*	*148*	*74.2*	*37.1*	*29.7*
2.07	1.035	0.5175	0.207	*882*	*441*	*294*	*147*	*73.5*	*36.7*	*29.4*
2.08	1.040	0.5200	0.208	*873*	*437*	*291*	*146*	*72.8*	*36.4*	*29.1*
2.09	1.045	0.5225	0.209	*865*	*432*	*288*	*144*	*72.1*	*36.0*	*28.8*
2.10	1.050	0.5250	0.210	*856*	*428*	*285*	*143*	*71.4*	*35.7*	*28.5*
2.11	1.055	0.5275	0.211	*848*	*424*	*283*	*141*	*70.7*	*35.3*	*28.3*
2.12	1.060	0.5300	0.212	*840*	*420*	*280*	*140*	*70.0*	*35.0*	*28.0*
2.13	1.065	0.5325	0.213	*832*	*416*	*277*	*139*	*69.4*	*34.7*	*27.7*
2.14	1.070	0.5350	0.214	*824*	*412*	*275*	*137*	*68.7*	*34.4*	*27.5*
2.15	1.075	0.5375	0.215	*817*	*408*	*272*	*136*	*68.1*	*34.0*	*27.2*
2.16	1.080	0.5400	0.216	*809*	*405*	*270*	*135*	*67.4*	*33.7*	*27.0*
2.17	1.085	0.5425	0.217	*802*	*401*	*267*	*134*	*66.8*	*33.4*	*26.7*
2.18	1.090	0.5450	0.218	*794*	*397*	*265*	*132*	*66.2*	*33.1*	*26.5*
2.19	1.095	0.5475	0.219	*787*	*393*	*262*	*131*	*65.6*	*32.8*	*26.2*
2.20	1.100	0.5500	0.220	*780*	*390*	*260*	*130*	*65.0*	*32.5*	*26.0*
2.21	1.105	0.5525	0.221	*772*	*386*	*257*	*129*	*64.4*	*32.2*	*25.7*
2.22	1.110	0.5550	0.222	*765*	*383*	*255*	*128*	*63.8*	*31.9*	*25.5*

TABLE X1.1 *Continued*

Diameter of Indentation, *d* (mm)				Brinell Hardness Number						
				HBW 10/3000	HBW 10/1500	HBW 10/1000	HBW 10/500	HBW 10/250	HBW 10/125	HBW 10/100
10 mm	5 mm	2.5 mm	1 mm	HBW 5/750		HBW 5/250	HBW 5/125	HBW 5/62.5	HBW 5/31.25	HBW 5/25
ball	ball	ball	ball	HBW 2.5/187.5		HBW 2.5/62.5	HBW 2.5/31.25	HBW 2.5/15.625	HBW 2.5/7.8125	HBW 2.5/6.25
				HBW 1/30		HBW 1/10	HBW 1/5	HBW 1/2	HBW 1/1.25	HBW 1/1
2.23	1.115	0.5575	0.223	*758*	*379*	*253*	*126*	*63.2*	*31.6*	*25.3*
2.24	1.120	0.5600	0.224	*752*	*376*	*251*	*125*	*62.6*	*31.3*	*25.1*
2.25	1.125	0.5625	0.225	*745*	*372*	*248*	*124*	*62.1*	*31.0*	*24.8*
2.26	1.130	0.5650	0.226	*738*	*369*	*246*	*123*	*61.5*	*30.8*	*24.6*
2.27	1.135	0.5675	0.227	*732*	*366*	*244*	*122*	*61.0*	*30.5*	*24.4*
2.28	1.140	0.5700	0.228	*725*	*363*	*242*	*121*	*60.4*	*30.2*	*24.2*
2.29	1.145	0.5725	0.229	*719*	*359*	*240*	*120*	*59.9*	*29.9*	*24.0*
2.30	1.150	0.5750	0.230	*712*	*356*	*237*	*119*	*59.4*	*29.7*	*23.7*
2.31	1.155	0.5775	0.231	*706*	*353*	*235*	*118*	*58.8*	*29.4*	*23.5*
2.32	1.160	0.5800	0.232	*700*	*350*	*233*	*117*	*58.3*	*29.2*	*23.3*
2.33	1.165	0.5825	0.233	*694*	*347*	*231*	*116*	*57.8*	*28.9*	*23.1*
2.34	1.170	0.5850	0.234	*688*	*344*	*229*	*115*	*57.3*	*28.7*	*22.9*
2.35	1.175	0.5875	0.235	*682*	*341*	*227*	*114*	*56.8*	*28.4*	*22.7*
2.36	1.180	0.5900	0.236	*676*	*338*	*225*	*113*	*56.3*	*28.2*	*22.5*
2.37	1.185	0.5925	0.237	*670*	*335*	*223*	*112*	*55.9*	*27.9*	*22.3*
2.38	1.190	0.5950	0.238	*665*	*332*	*222*	*111*	*55.4*	*27.7*	*22.2*
2.39	1.195	0.5975	0.239	*659*	*330*	*220*	*110*	*54.9*	*27.5*	*22.0*
2.40	1.200	0.6000	0.240	653	327	218	109	54.5	27.2	21.8
2.41	1.205	0.6025	0.241	648	324	216	108	54.0	27.0	21.6
2.42	1.210	0.6050	0.242	643	321	214	107	53.5	26.8	21.4
2.43	1.215	0.6075	0.243	637	319	212	106	53.1	26.5	21.2
2.44	1.220	0.6100	0.244	632	316	211	105	52.7	26.3	21.1
2.45	1.225	0.6125	0.245	627	313	209	104	52.2	26.1	20.9
2.46	1.230	0.6150	0.246	621	311	207	104	51.8	25.9	20.7
2.47	1.235	0.6175	0.247	616	308	205	103	51.4	25.7	20.5
2.48	1.240	0.6200	0.248	611	306	204	102	50.9	25.5	20.4
2.49	1.245	0.6225	0.249	606	303	202	101	50.5	25.3	20.2
2.50	1.250	0.6250	0.250	601	301	200	100	50.1	25.1	20.0
2.51	1.255	0.6275	0.251	597	298	199	99.4	49.7	24.9	19.9
2.52	1.260	0.6300	0.252	592	296	197	98.6	49.3	24.7	19.7
2.53	1.265	0.6325	0.253	587	294	196	97.8	48.9	24.5	19.6
2.54	1.270	0.6350	0.254	582	291	194	97.1	48.5	24.3	19.4
2.55	1.275	0.6375	0.255	578	289	193	96.3	48.1	24.1	19.3
2.56	1.280	0.6400	0.256	573	287	191	95.5	47.8	23.9	19.1
2.57	1.285	0.6425	0.257	569	284	190	94.8	47.4	23.7	19.0
2.58	1.290	0.6450	0.258	564	282	188	94.0	47.0	23.5	18.8
2.59	1.295	0.6475	0.259	560	280	187	93.3	46.6	23.3	18.7
2.60	1.300	0.6500	0.260	555	278	185	92.6	46.3	23.1	18.5
2.61	1.305	0.6525	0.261	551	276	184	91.8	45.9	23.0	18.4
2.62	1.310	0.6550	0.262	547	273	182	91.1	45.6	22.8	18.2
2.63	1.315	0.6575	0.263	543	271	181	90.4	45.2	22.6	18.1
2.64	1.320	0.6600	0.264	538	269	179	89.7	44.9	22.4	17.9
2.65	1.325	0.6625	0.265	534	267	178	89.0	44.5	22.3	17.8
2.66	1.330	0.6650	0.266	530	265	177	88.4	44.2	22.1	17.7
2.67	1.335	0.6675	0.267	526	263	175	87.7	43.8	21.9	17.5
2.68	1.340	0.6700	0.268	522	261	174	87.0	43.5	21.8	17.4
2.69	1.345	0.6725	0.269	518	259	173	86.4	43.2	21.6	17.3
2.70	1.350	0.6750	0.270	514	257	171	85.7	42.9	21.4	17.1
2.71	1.355	0.6775	0.271	510	255	170	85.1	42.5	21.3	17.0
2.72	1.360	0.6800	0.272	507	253	169	84.4	42.2	21.1	16.9
2.73	1.365	0.6825	0.273	503	251	168	83.8	41.9	20.9	16.8
2.74	1.370	0.6850	0.274	499	250	166	83.2	41.6	20.8	16.6
2.75	1.375	0.6875	0.275	495	248	165	82.6	41.3	20.6	16.5
2.76	1.380	0.6900	0.276	492	246	164	81.9	41.0	20.5	16.4
2.77	1.385	0.6925	0.277	488	244	163	81.3	40.7	20.3	16.3
2.78	1.390	0.6950	0.278	485	242	162	80.8	40.4	20.2	16.2
2.79	1.395	0.6975	0.279	481	240	160	80.2	40.1	20.0	16.0
2.80	1.400	0.7000	0.280	477	239	159	79.6	39.8	19.9	15.9
2.81	1.405	0.7025	0.281	474	237	158	79.0	39.5	19.8	15.8
2.82	1.410	0.7050	0.282	471	235	157	78.4	39.2	19.6	15.7
2.83	1.415	0.7075	0.283	467	234	156	77.9	38.9	19.5	15.6
2.84	1.420	0.7100	0.284	464	232	155	77.3	38.7	19.3	15.5
2.85	1.425	0.7125	0.285	461	230	154	76.8	38.4	19.2	15.4
2.86	1.430	0.7150	0.286	457	229	152	76.2	38.1	19.1	15.2
2.87	1.435	0.7175	0.287	454	227	151	75.7	37.8	18.9	15.1
2.88	1.440	0.7200	0.288	451	225	150	75.1	37.6	18.8	15.0
2.89	1.445	0.7225	0.289	448	224	149	74.6	37.3	18.6	14.9

TABLE X1.1 *Continued*

Diameter of Indentation, *d* (mm)				Brinell Hardness Number						
				HBW 10/3000	HBW 10/1500	HBW 10/1000	HBW 10/500	HBW 10/250	HBW 10/125	HBW 10/100
10 mm	5 mm	2.5 mm	1 mm	HBW 5/750		HBW 5/250	HBW 5/125	HBW 5/62.5	HBW 5/31.25	HBW 5/25
ball	ball	ball	ball	HBW 2.5/187.5		HBW 2.5/62.5	HBW 2.5/31.25	HBW 2.5/15.625	HBW 2.5/7.8125	HBW 2.5/6.25
				HBW 1/30		HBW 1/10	HBW 1/5	HBW 1/2	HBW 1/1.25	HBW 1/1
2.90	1.450	0.7250	0.290	444	222	148	74.1	37.0	18.5	14.8
2.91	1.455	0.7275	0.291	441	221	147	73.6	36.8	18.4	14.7
2.92	1.460	0.7300	0.292	438	219	146	73.0	36.5	18.3	14.6
2.93	1.465	0.7325	0.293	435	218	145	72.5	36.3	18.1	14.5
2.94	1.470	0.7350	0.294	432	216	144	72.0	36.0	18.0	14.4
2.95	1.475	0.7375	0.295	429	215	143	71.5	35.8	17.9	14.3
2.96	1.480	0.7400	0.296	426	213	142	71.0	35.5	17.8	14.2
2.97	1.485	0.7425	0.297	423	212	141	70.5	35.3	17.6	14.1
2.98	1.490	0.7450	0.298	420	210	140	70.1	35.0	17.5	14.0
2.99	1.495	0.7475	0.299	417	209	139	69.6	34.8	17.4	13.9
3.00	1.500	0.7500	0.300	415	207	138	69.1	34.6	17.3	13.8
3.01	1.505	0.7525	0.301	412	206	137	68.6	34.3	17.2	13.7
3.02	1.510	0.7550	0.302	409	205	136	68.2	34.1	17.0	13.6
3.03	1.515	0.7575	0.303	406	203	135	67.7	33.9	16.9	13.5
3.04	1.520	0.7600	0.304	404	202	135	67.3	33.6	16.8	13.5
3.05	1.525	0.7625	0.305	401	200	134	66.8	33.4	16.7	13.4
3.06	1.530	0.7650	0.306	398	199	133	66.4	33.2	16.6	13.3
3.07	1.535	0.7675	0.307	395	198	132	65.9	33.0	16.5	13.2
3.08	1.540	0.7700	0.308	393	196	131	65.5	32.7	16.4	13.1
3.09	1.545	0.7725	0.309	390	195	130	65.0	32.5	16.3	13.0
3.10	1.550	0.7750	0.310	388	194	129	64.6	32.3	16.2	12.9
3.11	1.555	0.7775	0.311	385	193	128	64.2	32.1	16.0	12.8
3.12	1.560	0.7800	0.312	383	191	128	63.8	31.9	15.9	12.8
3.13	1.565	0.7825	0.313	380	190	127	63.3	31.7	15.8	12.7
3.14	1.570	0.7850	0.314	378	189	126	62.9	31.5	15.7	12.6
3.15	1.575	0.7875	0.315	375	188	125	62.5	31.3	15.6	12.5
3.16	1.580	0.7900	0.316	373	186	124	62.1	31.1	15.5	12.4
3.17	1.585	0.7925	0.317	370	185	123	61.7	30.9	15.4	12.3
3.18	1.590	0.7950	0.318	368	184	123	61.3	30.7	15.3	12.3
3.19	1.595	0.7975	0.319	366	183	122	60.9	30.5	15.2	12.2
3.20	1.600	0.8000	0.320	363	182	121	60.5	30.3	15.1	12.1
3.21	1.605	0.8025	0.321	361	180	120	60.1	30.1	15.0	12.0
3.22	1.610	0.8050	0.322	359	179	120	59.8	29.9	14.9	12.0
3.23	1.615	0.8075	0.323	356	178	119	59.4	29.7	14.8	11.9
3.24	1.620	0.8100	0.324	354	177	118	59.0	29.5	14.8	11.8
3.25	1.625	0.8125	0.325	352	176	117	58.6	29.3	14.7	11.7
3.26	1.630	0.8150	0.326	350	175	117	58.3	29.1	14.6	11.7
3.27	1.635	0.8175	0.327	347	174	116	57.9	29.0	14.5	11.6
3.28	1.640	0.8200	0.328	345	173	115	57.5	28.8	14.4	11.5
3.29	1.645	0.8225	0.329	343	172	114	57.2	28.6	14.3	11.4
3.30	1.650	0.8250	0.330	341	170	114	56.8	28.4	14.2	11.4
3.31	1.655	0.8275	0.331	339	169	113	56.5	28.2	14.1	11.3
3.32	1.660	0.8300	0.332	337	168	112	56.1	28.1	14.0	11.2
3.33	1.665	0.8325	0.333	335	167	112	55.8	27.9	13.9	11.2
3.34	1.670	0.8350	0.334	333	166	111	55.4	27.7	13.9	11.1
3.35	1.675	0.8375	0.335	331	165	110	55.1	27.5	13.8	11.0
3.36	1.680	0.8400	0.336	329	164	110	54.8	27.4	13.7	11.0
3.37	1.685	0.8425	0.337	326	163	109	54.4	27.2	13.6	10.9
3.38	1.690	0.8450	0.338	325	162	108	54.1	27.0	13.5	10.8
3.39	1.695	0.8475	0.339	323	161	108	53.8	26.9	13.4	10.8
3.40	1.700	0.8500	0.340	321	160	107	53.4	26.7	13.4	10.7
3.41	1.705	0.8525	0.341	319	159	106	53.1	26.6	13.3	10.6
3.42	1.710	0.8550	0.342	317	158	106	52.8	26.4	13.2	10.6
3.43	1.715	0.8575	0.343	315	157	105	52.5	26.2	13.1	10.5
3.44	1.720	0.8600	0.344	313	156	104	52.2	26.1	13.0	10.4
3.45	1.725	0.8625	0.345	311	156	104	51.8	25.9	13.0	10.4
3.46	1.730	0.8650	0.346	309	155	103	51.5	25.8	12.9	10.3
3.47	1.735	0.8675	0.347	307	154	102	51.2	25.6	12.8	10.2
3.48	1.740	0.8700	0.348	306	153	102	50.9	25.5	12.7	10.2
3.49	1.745	0.8725	0.349	304	152	101	50.6	25.3	12.7	10.1
3.50	1.750	0.8750	0.350	302	151	101	50.3	25.2	12.6	10.1
3.51	1.755	0.8775	0.351	300	150	100	50.0	25.0	12.5	10.0
3.52	1.760	0.8800	0.352	298	149	99.5	49.7	24.9	12.4	9.95
3.53	1.765	0.8825	0.353	297	148	98.9	49.4	24.7	12.4	9.89
3.54	1.770	0.8850	0.354	295	147	98.3	49.2	24.6	12.3	9.83
3.55	1.775	0.8875	0.355	293	147	97.7	48.9	24.4	12.2	9.77
3.56	1.780	0.8900	0.356	292	146	97.2	48.6	24.3	12.1	9.72

TABLE X1.1 *Continued*

Diameter of Indentation, *d* (mm)				Brinell Hardness Number						
				HBW 10/3000	HBW 10/1500	HBW 10/1000	HBW 10/500	HBW 10/ 250	HBW 10/ 125	HBW 10/100
10 mm	5 mm	2.5 mm	1 mm	HBW 5/750		HBW 5/250	HBW 5/125	HBW 5/62.5	HBW 5/31.25	HBW 5/25
ball	ball	ball	ball	HBW 2.5/187.5		HBW 2.5/62.5	HBW 2.5/31.25	HBW 2.5/ 15.625	HBW 2.5/ 7.8125	HBW 2.5/6.25
				HBW 1/30		HBW 1/10	HBW 1/5	HBW 1/2	HBW 1/1.25	HBW 1/1
3.57	1.785	0.8925	0.357	290	145	96.6	48.3	24.2	12.1	9.66
3.58	1.790	0.8950	0.358	288	144	96.1	48.0	24.0	12.0	9.61
3.59	1.795	0.8975	0.359	286	143	95.5	47.7	23.9	11.9	9.55
3.60	1.800	0.9000	0.360	285	142	95.0	47.5	23.7	11.9	9.50
3.61	1.805	0.9025	0.361	283	142	94.4	47.2	23.6	11.8	9.44
3.62	1.810	0.9050	0.362	282	141	93.9	46.9	23.5	11.7	9.39
3.63	1.815	0.9075	0.363	280	140	93.3	46.7	23.3	11.7	9.33
3.64	1.820	0.9100	0.364	278	139	92.8	46.4	23.2	11.6	9.28
3.65	1.825	0.9125	0.365	277	138	92.3	46.1	23.1	11.5	9.23
3.66	1.830	0.9150	0.366	275	138	91.8	45.9	22.9	11.5	9.18
3.67	1.835	0.9175	0.367	274	137	91.2	45.6	22.8	11.4	9.12
3.68	1.840	0.9200	0.368	272	136	90.7	45.4	22.7	11.3	9.07
3.69	1.845	0.9225	0.369	271	135	90.2	45.1	22.6	11.3	9.02
3.70	1.850	0.9250	0.370	269	135	89.7	44.9	22.4	11.2	8.97
3.71	1.855	0.9275	0.371	268	134	89.2	44.6	22.3	11.2	8.92
3.72	1.860	0.9300	0.372	266	133	88.7	44.4	22.2	11.1	8.87
3.73	1.865	0.9325	0.373	265	132	88.2	44.1	22.1	11.0	8.82
3.74	1.870	0.9350	0.374	263	132	87.7	43.9	21.9	11.0	8.77
3.75	1.875	0.9375	0.375	262	131	87.2	43.6	21.8	10.9	8.72
3.76	1.880	0.9400	0.376	260	130	86.8	43.4	21.7	10.8	8.68
3.77	1.885	0.9425	0.377	259	129	86.3	43.1	21.6	10.8	8.63
3.78	1.890	0.9450	0.378	257	129	85.8	42.9	21.5	10.7	8.58
3.79	1.895	0.9475	0.379	256	128	85.3	42.7	21.3	10.7	8.53
3.80	1.900	0.9500	0.380	255	127	84.9	42.4	21.2	10.6	8.49
3.81	1.905	0.9525	0.381	253	127	84.4	42.2	21.1	10.6	8.44
3.82	1.910	0.9550	0.382	252	126	83.9	42.0	21.0	10.5	8.39
3.83	1.915	0.9575	0.383	250	125	83.5	41.7	20.9	10.4	8.35
3.84	1.920	0.9600	0.384	249	125	83.0	41.5	20.8	10.4	8.30
3.85	1.925	0.9625	0.385	248	124	82.6	41.3	20.6	10.3	8.26
3.86	1.930	0.9650	0.386	246	123	82.1	41.1	20.5	10.3	8.21
3.87	1.935	0.9675	0.387	245	123	81.7	40.9	20.4	10.2	8.17
3.88	1.940	0.9700	0.388	244	122	81.3	40.6	20.3	10.2	8.13
3.89	1.945	0.9725	0.389	242	121	80.8	40.4	20.2	10.1	8.08
3.90	1.950	0.9750	0.390	241	121	80.4	40.2	20.1	10.0	8.04
3.91	1.955	0.9775	0.391	240	120	80.0	40.0	20.0	10.0	8.00
3.92	1.960	0.9800	0.392	239	119	79.5	39.8	19.9	9.94	7.95
3.93	1.965	0.9825	0.393	237	119	79.1	39.6	19.8	9.89	7.91
3.94	1.970	0.9850	0.394	236	118	78.7	39.4	19.7	9.84	7.87
3.95	1.975	0.9875	0.395	235	117	78.3	39.1	19.6	9.79	7.83
3.96	1.980	0.9900	0.396	234	117	77.9	38.9	19.5	9.73	7.79
3.97	1.985	0.9925	0.397	232	116	77.5	38.7	19.4	9.68	7.75
3.98	1.990	0.9950	0.398	231	116	77.1	38.5	19.3	9.63	7.71
3.99	1.995	0.9975	0.399	230	115	76.7	38.3	19.2	9.58	7.67
4.00	2.000	1.0000	0.400	229	114	76.3	38.1	19.1	9.53	7.63
4.01	2.005	1.0025	0.401	228	114	75.9	37.9	19.0	9.48	7.59
4.02	2.010	1.0050	0.402	226	113	75.5	37.7	18.9	9.43	7.55
4.03	2.015	1.0075	0.403	225	113	75.1	37.5	18.8	9.38	7.51
4.04	2.020	1.0100	0.404	224	112	74.7	37.3	18.7	9.34	7.47
4.05	2.025	1.0125	0.405	223	111	74.3	37.1	18.6	9.29	7.43
4.06	2.030	1.0150	0.406	222	111	73.9	37.0	18.5	9.24	7.39
4.07	2.035	1.0175	0.407	221	110	73.5	36.8	18.4	9.19	7.35
4.08	2.040	1.0200	0.408	219	110	73.2	36.6	18.3	9.14	7.32
4.09	2.045	1.0225	0.409	218	109	72.8	36.4	18.2	9.10	7.28
4.10	2.050	1.0250	0.410	217	109	72.4	36.2	18.1	9.05	7.24
4.11	2.055	1.0275	0.411	216	108	72.0	36.0	18.0	9.01	7.20
4.12	2.060	1.0300	0.412	215	108	71.7	35.8	17.9	8.96	7.17
4.13	2.065	1.0325	0.413	214	107	71.3	35.7	17.8	8.91	7.13
4.14	2.070	1.0350	0.414	213	106	71.0	35.5	17.7	8.87	7.10
4.15	2.075	1.0375	0.415	212	106	70.6	35.3	17.6	8.82	7.06
4.16	2.080	1.0400	0.416	211	105	70.2	35.1	17.6	8.78	7.02
4.17	2.085	1.0425	0.417	210	105	69.9	34.9	17.5	8.74	6.99
4.18	2.090	1.0450	0.418	209	104	69.5	34.8	17.4	8.69	6.95
4.19	2.095	1.0475	0.419	208	104	69.2	34.6	17.3	8.65	6.92
4.20	2.100	1.0500	0.420	207	103	68.8	34.4	17.2	8.61	6.88
4.21	2.105	1.0525	0.421	205	103	68.5	34.2	17.1	8.56	6.85
4.22	2.110	1.0550	0.422	204	102	68.2	34.1	17.0	8.52	6.82
4.23	2.115	1.0575	0.423	203	102	67.8	33.9	17.0	8.48	6.78

TABLE X1.1 *Continued*

Diameter of Indentation, *d* (mm)				Brinell Hardness Number						
				HBW 10/3000	HBW 10/1500	HBW 10/1000	HBW 10/500	HBW 10/ 250	HBW 10/ 125	HBW 10/100
10 mm	5 mm	2.5 mm	1 mm	HBW 5/750		HBW 5/250	HBW 5/125	HBW 5/62.5	HBW 5/31.25	HBW 5/25
ball	ball	ball	ball	HBW 2.5/187.5		HBW 2.5/62.5	HBW 2.5/31.25	HBW 2.5/ 15.625	HBW 2.5/ 7.8125	HBW 2.5/6.25
				HBW 1/30		HBW 1/10	HBW 1/5	HBW 1/2	HBW 1/1.25	HBW 1/1
4.24	2.120	1.0600	0.424	202	101	67.5	33.7	16.9	8.44	6.75
4.25	2.125	1.0625	0.425	201	101	67.1	33.6	16.8	8.39	6.71
4.26	2.130	1.0650	0.426	200	100	66.8	33.4	16.7	8.35	6.68
4.27	2.135	1.0675	0.427	199	100	66.5	33.2	16.6	8.31	6.65
4.28	2.140	1.0700	0.428	198	99.2	66.2	33.1	16.5	8.27	6.62
4.29	2.145	1.0725	0.429	198	98.8	65.8	32.9	16.5	8.23	6.58
4.30	2.150	1.0750	0.430	197	98.3	65.5	32.8	16.4	8.19	6.55
4.31	2.155	1.0775	0.431	196	97.8	65.2	32.6	16.3	8.15	6.52
4.32	2.160	1.0800	0.432	195	97.3	64.9	32.4	16.2	8.11	6.49
4.33	2.165	1.0825	0.433	194	96.8	64.6	32.3	16.1	8.07	6.46
4.34	2.170	1.0850	0.434	193	96.4	64.2	32.1	16.1	8.03	6.42
4.35	2.175	1.0875	0.435	192	95.9	63.9	32.0	16.0	7.99	6.39
4.36	2.180	1.0900	0.436	191	95.4	63.6	31.8	15.9	7.95	6.36
4.37	2.185	1.0925	0.437	190	95.0	63.3	31.7	15.8	7.92	6.33
4.38	2.190	1.0950	0.438	189	94.5	63.0	31.5	15.8	7.88	6.30
4.39	2.195	1.0975	0.439	188	94.1	62.7	31.4	15.7	7.84	6.27
4.40	2.200	1.1000	0.440	187	93.6	62.4	31.2	15.6	7.80	6.24
4.41	2.205	1.1025	0.441	186	93.2	62.1	31.1	15.5	7.76	6.21
4.42	2.210	1.1050	0.442	185	92.7	61.8	30.9	15.5	7.73	6.18
4.43	2.215	1.1075	0.443	185	92.3	61.5	30.8	15.4	7.69	6.15
4.44	2.220	1.1100	0.444	184	91.8	61.2	30.6	15.3	7.65	6.12
4.45	2.225	1.1125	0.445	183	91.4	60.9	30.5	15.2	7.62	6.09
4.46	2.230	1.1150	0.446	182	91.0	60.6	30.3	15.2	7.58	6.06
4.47	2.235	1.1175	0.447	181	90.5	60.4	30.2	15.1	7.55	6.04
4.48	2.240	1.1200	0.448	180	90.1	60.1	30.0	15.0	7.51	6.01
4.49	2.245	1.1225	0.449	179	89.7	59.8	29.9	14.9	7.47	5.98
4.50	2.250	1.1250	0.450	179	89.3	59.5	29.8	14.9	7.44	5.95
4.51	2.255	1.1275	0.451	178	88.9	59.2	29.6	14.8	7.40	5.92
4.52	2.260	1.1300	0.452	177	88.4	59.0	29.5	14.7	7.37	5.90
4.53	2.265	1.1325	0.453	176	88.0	58.7	29.3	14.7	7.34	5.87
4.54	2.270	1.1350	0.454	175	87.6	58.4	29.2	14.6	7.30	5.84
4.55	2.275	1.1375	0.455	174	87.2	58.1	29.1	14.5	7.27	5.81
4.56	2.280	1.1400	0.456	174	86.8	57.9	28.9	14.5	7.23	5.79
4.57	2.285	1.1425	0.457	173	86.4	57.6	28.8	14.4	7.20	5.76
4.58	2.290	1.1450	0.458	172	86.0	57.3	28.7	14.3	7.17	5.73
4.59	2.295	1.1475	0.459	171	85.6	57.1	28.5	14.3	7.13	5.71
4.60	2.300	1.1500	0.460	170	85.2	56.8	28.4	14.2	7.10	5.68
4.61	2.305	1.1525	0.461	170	84.8	56.5	28.3	14.1	7.07	5.65
4.62	2.310	1.1550	0.462	169	84.4	56.3	28.1	14.1	7.03	5.63
4.63	2.315	1.1575	0.463	168	84.0	56.0	28.0	14.0	7.00	5.60
4.64	2.320	1.1600	0.464	167	83.6	55.8	27.9	13.9	6.97	5.58
4.65	2.325	1.1625	0.465	167	83.3	55.5	27.8	13.9	6.94	5.55
4.66	2.330	1.1650	0.466	166	82.9	55.3	27.6	13.8	6.91	5.53
4.67	2.335	1.1675	0.467	165	82.5	55.0	27.5	13.8	6.88	5.50
4.68	2.340	1.1700	0.468	164	82.1	54.8	27.4	13.7	6.84	5.48
4.69	2.345	1.1725	0.469	164	81.8	54.5	27.3	13.6	6.81	5.45
4.70	2.350	1.1750	0.470	163	81.4	54.3	27.1	13.6	6.78	5.43
4.71	2.355	1.1775	0.471	162	81.0	54.0	27.0	13.5	6.75	5.40
4.72	2.360	1.1800	0.472	161	80.7	53.8	26.9	13.4	6.72	5.38
4.73	2.365	1.1825	0.473	161	80.3	53.5	26.8	13.4	6.69	5.35
4.74	2.370	1.1850	0.474	160	79.9	53.3	26.6	13.3	6.66	5.33
4.75	2.375	1.1875	0.475	159	79.6	53.0	26.5	13.3	6.63	5.30
4.76	2.380	1.1900	0.476	158	79.2	52.8	26.4	13.2	6.60	5.28
4.77	2.385	1.1925	0.477	158	78.9	52.6	26.3	13.1	6.57	5.26
4.78	2.390	1.1950	0.478	157	78.5	52.3	26.2	13.1	6.54	5.23
4.79	2.395	1.1975	0.479	156	78.2	52.1	26.1	13.0	6.51	5.21
4.80	2.400	1.2000	0.480	156	77.8	51.9	25.9	13.0	6.48	5.19
4.81	2.405	1.2025	0.481	155	77.5	51.6	25.8	12.9	6.46	5.16
4.82	2.410	1.2050	0.482	154	77.1	51.4	25.7	12.9	6.43	5.14
4.83	2.415	1.2075	0.483	154	76.8	51.2	25.6	12.8	6.40	5.12
4.84	2.420	1.2100	0.484	153	76.4	51.0	25.5	12.7	6.37	5.10
4.85	2.425	1.2125	0.485	152	76.1	50.7	25.4	12.7	6.34	5.07
4.86	2.430	1.2150	0.486	152	75.8	50.5	25.3	12.6	6.31	5.05
4.87	2.435	1.2175	0.487	151	75.4	50.3	25.1	12.6	6.29	5.03
4.88	2.440	1.2200	0.488	150	75.1	50.1	25.0	12.5	6.26	5.01
4.89	2.445	1.2225	0.489	150	74.8	49.8	24.9	12.5	6.23	4.98
4.90	2.450	1.2250	0.490	149	74.4	49.6	24.8	12.4	6.20	4.96

TABLE X1.1 *Continued*

Diameter of Indentation, *d* (mm)				Brinell Hardness Number						
				HBW 10/3000	HBW 10/1500	HBW 10/1000	HBW 10/500	HBW 10/ 250	HBW 10/ 125	HBW 10/100
10 mm	5 mm	2.5 mm	1 mm	HBW 5/750		HBW 5/250	HBW 5/125	HBW 5/62.5	HBW 5/31.25	HBW 5/25
ball	ball	ball	ball	HBW 2.5/187.5		HBW 2.5/62.5	HBW 2.5/31.25	HBW 2.5/ 15.625	HBW 2.5/ 7.8125	HBW 2.5/6.25
				HBW 1/30		HBW 1/10	HBW 1/5	HBW 1/2	HBW 1/1.25	HBW 1/1
4.91	2.455	1.2275	0.491	148	74.1	49.4	24.7	12.4	6.18	4.94
4.92	2.460	1.2300	0.492	148	73.8	49.2	24.6	12.3	6.15	4.92
4.93	2.465	1.2325	0.493	147	73.5	49.0	24.5	12.2	6.12	4.90
4.94	2.470	1.2350	0.494	146	73.2	48.8	24.4	12.2	6.10	4.88
4.95	2.475	1.2375	0.495	146	72.8	48.6	24.3	12.1	6.07	4.86
4.96	2.480	1.2400	0.496	145	72.5	48.3	24.2	12.1	6.04	4.83
4.97	2.485	1.2425	0.497	144	72.2	48.1	24.1	12.0	6.02	4.81
4.98	2.490	.2450	0.498	144	71.9	47.9	24.0	12.0	5.99	4.79
4.99	2.495	1.2475	0.499	143	71.6	47.7	23.9	11.9	5.97	4.77
5.00	2.500	1.2500	0.500	143	71.3	47.5	23.8	11.9	5.94	4.75
5.01	2.505	1.2525	0.501	142	71.0	47.3	23.7	11.8	5.91	4.73
5.02	2.510	1.2550	0.502	141	70.7	47.1	23.6	11.8	5.89	4.71
5.03	2.515	1.2575	0.503	141	70.4	46.9	23.5	11.7	5.86	4.69
5.04	2.520	1.2600	0.504	140	70.1	46.7	23.4	11.7	5.84	4.67
5.05	2.525	1.2625	0.505	140	69.8	46.5	23.3	11.6	5.81	4.65
5.06	2.530	1.2650	0.506	139	69.5	46.3	23.2	11.6	5.79	4.63
5.07	2.535	1.2675	0.507	138	69.2	46.1	23.1	11.5	5.76	4.61
5.08	2.540	1.2700	0.508	138	68.9	45.9	23.0	11.5	5.74	4.59
5.09	2.545	1.2725	0.509	137	68.6	45.7	22.9	11.4	5.72	4.57
5.10	2.550	1.2750	0.510	137	68.3	45.5	22.8	11.4	5.69	4.55
5.11	2.555	1.2775	0.511	136	68.0	45.3	22.7	11.3	5.67	4.53
5.12	2.560	1.2800	0.512	135	67.7	45.1	22.6	11.3	5.64	4.51
5.13	2.565	1.2825	0.513	135	67.4	45.0	22.5	11.2	5.62	4.50
5.14	2.570	1.2850	0.514	134	67.1	44.8	22.4	11.2	5.60	4.48
5.15	2.575	1.2875	0.515	134	66.9	44.6	22.3	11.1	5.57	4.46
5.16	2.580	1.2900	0.516	133	66.6	44.4	22.2	11.1	5.55	4.44
5.17	2.585	1.2925	0.517	133	66.3	44.2	22.1	11.1	5.53	4.42
5.18	2.590	1.2950	0.518	132	66.0	44.0	22.0	11.0	5.50	4.40
5.19	2.595	1.2975	0.519	132	65.8	43.8	21.9	11.0	5.48	4.38
5.20	2.600	1.3000	0.520	131	65.5	43.7	21.8	10.9	5.46	4.37
5.21	2.605	1.3025	0.521	130	65.2	43.5	21.7	10.9	5.43	4.35
5.22	2.610	1.3050	0.522	130	64.9	43.3	21.6	10.8	5.41	4.33
5.23	2.615	1.3075	0.523	129	64.7	43.1	21.6	10.8	5.39	4.31
5.24	2.620	1.3100	0.524	129	64.4	42.9	21.5	10.7	5.37	4.29
5.25	2.625	1.3125	0.525	128	64.1	42.8	21.4	10.7	5.34	4.28
5.26	2.630	1.3150	0.526	128	63.9	42.6	21.3	10.6	5.32	4.26
5.27	2.635	1.3175	0.527	127	63.6	42.4	21.2	10.6	5.30	4.24
5.28	2.640	1.3200	0.528	127	63.3	42.2	21.1	10.6	5.28	4.22
5.29	2.645	1.3225	0.529	126	63.1	42.1	21.0	10.5	5.26	4.21
5.30	2.650	1.3250	0.530	126	62.8	41.9	20.9	10.5	5.24	4.19
5.31	2.655	1.3275	0.531	125	62.6	41.7	20.9	10.4	5.21	4.17
5.32	2.660	1.3300	0.532	125	62.3	41.5	20.8	10.4	5.19	4.15
5.33	2.665	1.3325	0.533	124	62.1	41.4	20.7	10.3	5.17	4.14
5.34	2.670	1.3350	0.534	124	61.8	41.2	20.6	10.3	5.15	4.12
5.35	2.675	1.3375	0.535	123	61.5	41.0	20.5	10.3	5.13	4.10
5.36	2.680	1.3400	0.536	123	61.3	40.9	20.4	10.2	5.11	4.09
5.37	2.685	1.3425	0.537	122	61.0	40.7	20.3	10.2	5.09	4.07
5.38	2.690	1.3450	0.538	122	60.8	40.5	20.3	10.1	5.07	4.05
5.39	2.695	1.3475	0.539	121	60.6	40.4	20.2	10.1	5.05	4.04
5.40	2.700	1.3500	0.540	121	60.3	40.2	20.1	10.1	5.03	4.02
5.41	2.705	1.3525	0.541	120	60.1	40.0	20.0	10.0	5.01	4.00
5.42	2.710	1.3550	0.542	120	59.8	39.9	19.9	10.0	4.99	3.99
5.43	2.715	1.3575	0.543	119	59.6	39.7	19.9	9.93	4.97	3.97
5.44	2.720	1.3600	0.544	119	59.3	39.6	19.8	9.89	4.95	3.96
5.45	2.725	1.3625	0.545	118	59.1	39.4	19.7	9.85	4.93	3.94
5.46	2.730	1.3650	0.546	118	58.9	39.2	19.6	9.81	4.91	3.92
5.47	2.735	1.3675	0.547	117	58.6	39.1	19.5	9.77	4.89	3.91
5.48	2.740	1.3700	0.548	117	58.4	38.9	19.5	9.73	4.87	3.89
5.49	2.745	1.3725	0.549	116	58.2	38.8	19.4	9.69	4.85	3.88
5.50	2.750	1.3750	0.550	116	57.9	38.6	19.3	9.66	4.83	3.86
5.51	2.755	1.3775	0.551	115	57.7	38.5	19.2	9.62	4.81	3.85
5.52	2.760	1.3800	0.552	115	57.5	38.3	19.2	9.58	4.79	3.83
5.53	2.765	1.3825	0.553	114	57.2	38.2	19.1	9.54	4.77	3.82
5.54	2.770	1.3850	0.554	114	57.0	38.0	19.0	9.50	4.75	3.80
5.55	2.775	1.3875	0.555	114	56.8	37.9	18.9	9.47	4.73	3.79
5.56	2.780	1.3900	0.556	113	56.6	37.7	18.9	9.43	4.71	3.77
5.57	2.785	1.3925	0.557	113	56.3	37.6	18.8	9.39	4.70	3.76

TABLE X1.1 *Continued*

Diameter of Indentation, *d* (mm)				Brinell Hardness Number						
				HBW 10/3000	HBW 10/1500	HBW 10/1000	HBW 10/500	HBW 10/250	HBW 10/125	HBW 10/100
10 mm	5 mm	2.5 mm	1 mm	HBW 5/750		HBW 5/250	HBW 5/125	HBW 5/62.5	HBW 5/31.25	HBW 5/25
ball	ball	ball	ball	HBW 2.5/187.5		HBW 2.5/62.5	HBW 2.5/31.25	HBW 2.5/15.625	HBW 2.5/7.8125	HBW 2.5/6.25
				HBW 1/30		HBW 1/10	HBW 1/5	HBW 1/2	HBW 1/1.25	HBW 1/1
5.58	2.790	1.3950	0.558	112	56.1	37.4	18.7	9.35	4.68	3.74
5.59	2.795	1.3975	0.559	112	55.9	37.3	18.6	9.32	4.66	3.73
5.60	2.800	1.4000	0.560	111	55.7	37.1	18.6	9.28	4.64	3.71
5.61	2.805	1.4025	0.561	111	55.5	37.0	18.5	9.24	4.62	3.70
5.62	2.810	1.4050	0.562	110	55.2	36.8	18.4	9.21	4.60	3.68
5.63	2.815	1.4075	0.563	110	55.0	36.7	18.3	9.17	4.59	3.67
5.64	2.820	1.4100	0.564	110	54.8	36.5	18.3	9.14	4.57	3.65
5.65	2.825	1.4125	0.565	109	54.6	36.4	18.2	9.10	4.55	3.64
5.66	2.830	1.4150	0.566	109	54.4	36.3	18.1	9.06	4.53	3.63
5.67	2.835	1.4175	0.567	108	54.2	36.1	18.1	9.03	4.51	3.61
5.68	2.840	1.4200	0.568	108	54.0	36.0	18.0	8.99	4.50	3.60
5.69	2.845	1.4225	0.569	107	53.7	35.8	17.9	8.96	4.48	3.58
5.70	2.850	1.4250	0.570	107	53.5	35.7	17.8	8.92	4.46	3.57
5.71	2.855	1.4275	0.571	107	53.3	35.6	17.8	8.89	4.44	3.56
5.72	2.860	1.4300	0.572	106	53.1	35.4	17.7	8.85	4.43	3.54
5.73	2.865	1.4325	0.573	106	52.9	35.3	17.6	8.82	4.41	3.53
5.74	2.870	1.4350	0.574	105	52.7	35.1	17.6	8.79	4.39	3.51
5.75	2.875	1.4375	0.575	105	52.5	35.0	17.5	8.75	4.38	3.50
5.76	2.880	1.4400	0.576	105	52.3	34.9	17.4	8.72	4.36	3.49
5.77	2.885	1.4425	0.577	104	52.1	34.7	17.4	8.68	4.34	3.47
5.78	2.890	1.4450	0.578	104	51.9	34.6	17.3	8.65	4.33	3.46
5.79	2.895	1.4475	0.579	103	51.7	34.5	17.2	8.62	4.31	3.45
5.80	2.900	1.4500	0.580	103	51.5	34.3	17.2	8.59	4.29	3.43
5.81	2.905	1.4525	0.581	103	51.3	34.2	17.1	8.55	4.28	3.42
5.82	2.910	1.4550	0.582	102	51.1	34.1	17.0	8.52	4.26	3.41
5.83	2.915	1.4575	0.583	102	50.9	33.9	17.0	8.49	4.24	3.39
5.84	2.920	1.4600	0.584	101	50.7	33.8	16.9	8.45	4.23	3.38
5.85	2.925	1.4625	0.585	101	50.5	33.7	16.8	8.42	4.21	3.37
5.86	2.930	1.4650	0.586	101	50.3	33.6	16.8	8.39	4.20	3.36
5.87	2.935	1.4675	0.587	100	50.2	33.4	16.7	8.36	4.18	3.34
5.88	2.940	1.4700	0.588	100	50.0	33.3	16.7	8.33	4.16	3.33
5.89	2.945	1.4725	0.589	100	49.8	33.2	16.6	8.30	4.15	3.32
5.90	2.950	1.4750	0.590	99.2	49.6	33.1	16.5	8.26	4.13	3.31
5.91	2.955	1.4775	0.591	98.8	49.4	32.9	16.5	8.23	4.12	3.29
5.92	2.960	1.4800	0.592	98.4	49.2	32.8	16.4	8.20	4.10	3.28
5.93	2.965	1.4825	0.593	98.0	49.0	32.7	16.3	8.17	4.09	3.27
5.94	2.970	1.4850	0.594	97.7	48.8	32.6	16.3	8.14	4.07	3.26
5.95	2.975	1.4875	0.595	97.3	48.7	32.4	16.2	8.11	4.05	3.24
5.96	2.980	1.4900	0.596	96.9	48.5	32.3	16.2	8.08	4.04	3.23
5.97	2.985	1.4925	0.597	96.6	48.3	32.2	16.1	8.05	4.02	3.22
5.98	2.990	1.4950	0.598	96.2	48.1	32.1	16.0	8.02	4.01	3.21
5.99	2.995	1.4975	0.599	95.9	47.9	32.0	16.0	7.99	3.99	3.20
6.00	3.000	1.5000	0.600	95.5	47.7	31.8	15.9	7.96	3.98	3.18
6.01	3.005	1.5025	0.601	*95.1*	*47.6*	*31.7*	*15.9*	*7.93*	*3.96*	*3.17*
6.02	3.010	1.5050	0.602	*94.8*	*47.4*	*31.6*	*15.8*	*7.90*	*3.95*	*3.16*
6.03	3.015	1.5075	0.603	*94.4*	*47.2*	*31.5*	*15.7*	*7.87*	*3.93*	*3.15*
6.04	3.020	1.5100	0.604	*94.1*	*47.0*	*31.4*	*15.7*	*7.84*	*3.92*	*3.14*
6.05	3.025	1.5125	0.605	*93.7*	*46.9*	*31.2*	*15.6*	*7.81*	*3.91*	*3.12*
6.06	3.030	1.5150	0.606	*93.4*	*46.7*	*31.1*	*15.6*	*7.78*	*3.89*	*3.11*
6.07	3.035	1.5175	0.607	*93.0*	*46.5*	*31.0*	*15.5*	*7.75*	*3.88*	*3.10*
6.08	3.040	1.5200	0.608	*92.7*	*46.3*	*30.9*	*15.4*	*7.72*	*3.86*	*3.09*
6.09	3.045	1.5225	0.609	*92.3*	*46.2*	*30.8*	*15.4*	*7.69*	*3.85*	*3.08*
6.10	3.050	1.5250	0.610	*92.0*	*46.0*	*30.7*	*15.3*	*7.67*	*3.83*	*3.07*
6.11	3.055	1.5275	0.611	*91.7*	*45.8*	*30.6*	*15.3*	*7.64*	*3.82*	*3.06*
6.12	3.060	1.5300	0.612	*91.3*	*45.7*	*30.4*	*15.2*	*7.61*	*3.80*	*3.04*
6.13	3.065	1.5325	0.613	*91.0*	*45.5*	*30.3*	*15.2*	*7.58*	*3.79*	*3.03*
6.14	3.070	1.5350	0.614	*90.6*	*45.3*	*30.2*	*15.1*	*7.55*	*3.78*	*3.02*
6.15	3.075	1.5375	0.615	*90.3*	*45.2*	*30.1*	*15.1*	*7.53*	*3.76*	*3.01*
6.16	3.080	1.5400	0.616	*90.0*	*45.0*	*30.0*	*15.0*	*7.50*	*3.75*	*3.00*
6.17	3.085	1.5425	0.617	*89.6*	*44.8*	*29.9*	*14.9*	*7.47*	*3.74*	*2.99*
6.18	3.090	1.5450	0.618	*89.3*	*44.7*	*29.8*	*14.9*	*7.44*	*3.72*	*2.98*
6.19	3.095	1.5475	0.619	*89.0*	*44.5*	*29.7*	*14.8*	*7.42*	*3.71*	*2.97*
6.20	3.100	1.5500	0.620	*88.7*	*44.3*	*29.6*	*14.8*	*7.39*	*3.69*	*2.96*
6.21	3.105	1.5525	0.621	*88.3*	*44.2*	*29.4*	*14.7*	*7.36*	*3.68*	*2.94*
6.22	3.110	1.5550	0.622	*88.0*	*44.0*	*29.3*	*14.7*	*7.33*	*3.67*	*2.93*
6.23	3.115	1.5575	0.623	*87.7*	*43.8*	*29.2*	*14.6*	*7.31*	*3.65*	*2.92*
6.24	3.120	1.5600	0.624	*87.4*	*43.7*	*29.1*	*14.6*	*7.28*	*3.64*	*2.91*

TABLE X1.1 *Continued*

Diameter of Indentation, *d* (mm)				Brinell Hardness Number						
				HBW 10/3000	HBW 10/1500	HBW 10/1000	HBW 10/500	HBW 10/250	HBW 10/125	HBW 10/100
10 mm	5 mm	2.5 mm	1 mm	HBW 5/750		HBW 5/250	HBW 5/125	HBW 5/62.5	HBW 5/31.25	HBW 5/25
ball	ball	ball	ball	HBW 2.5/187.5		HBW 2.5/62.5	HBW 2.5/31.25	HBW 2.5/15.625	HBW 2.5/7.8125	HBW 2.5/6.25
				HBW 1/30		HBW 1/10	HBW 1/5	HBW 1/2	HBW 1/1.25	HBW 1/1
6.25	3.125	1.5625	0.625	87.1	43.5	29.0	14.5	7.25	3.63	2.90
6.26	3.130	1.5650	0.626	86.7	43.4	28.9	14.5	7.23	3.61	2.89
6.27	3.135	1.5675	0.627	86.4	43.2	28.8	14.4	7.20	3.60	2.88
6.28	3.140	1.5700	0.628	86.1	43.1	28.7	14.4	7.18	3.59	2.87
6.29	3.145	1.5725	0.629	85.8	42.9	28.6	14.3	7.15	3.57	2.86
6.30	3.150	1.5750	0.630	85.5	42.7	28.5	14.2	7.12	3.56	2.85
6.31	3.155	1.5775	0.631	85.2	42.6	28.4	14.2	7.10	3.55	2.84
6.32	3.160	1.5800	0.632	84.9	42.4	28.3	14.1	7.07	3.54	2.83
6.33	3.165	1.5825	0.633	84.6	42.3	28.2	14.1	7.05	3.52	2.82
6.34	3.170	1.5850	0.634	84.3	42.1	28.1	14.0	7.02	3.51	2.81
6.35	3.175	1.5875	0.635	84.0	42.0	28.0	14.0	7.00	3.50	2.80
6.36	3.180	1.5900	0.636	83.7	41.8	27.9	13.9	6.97	3.49	2.79
6.37	3.185	1.5925	0.637	83.4	41.7	27.8	13.9	6.95	3.47	2.78
6.38	3.190	1.5950	0.638	83.1	41.5	27.7	13.8	6.92	3.46	2.77
6.39	3.195	1.5975	0.639	82.8	41.4	27.6	13.8	6.90	3.45	2.76
6.40	3.200	1.6000	0.640	82.5	41.2	27.5	13.7	6.87	3.44	2.75
6.41	3.205	1.6025	0.641	82.2	41.1	27.4	13.7	6.85	3.42	2.74
6.42	3.210	1.6050	0.642	81.9	40.9	27.3	13.6	6.82	3.41	2.73
6.43	3.215	1.6075	0.643	81.6	40.8	27.2	13.6	6.80	3.40	2.72
6.44	3.220	1.6100	0.644	81.3	40.6	27.1	13.5	6.77	3.39	2.71
6.45	3.225	1.6125	0.645	81.0	40.5	27.0	13.5	6.75	3.37	2.70
6.46	3.230	1.6150	0.646	80.7	40.3	26.9	13.4	6.72	3.36	2.69
6.47	3.235	1.6175	0.647	80.4	40.2	26.8	13.4	6.70	3.35	2.68
6.48	3.240	1.6200	0.648	80.1	40.1	26.7	13.4	6.68	3.34	2.67
6.49	3.245	1.6225	0.649	79.8	39.9	26.6	13.3	6.65	3.33	2.66
6.50	3.250	1.6250	0.650	79.6	39.8	26.5	13.3	6.63	3.31	2.65
6.51	3.255	1.6275	0.651	79.3	39.6	26.4	13.2	6.61	3.30	2.64
6.52	3.260	1.6300	0.652	79.0	39.5	26.3	13.2	6.58	3.29	2.63
6.53	3.265	1.6325	0.653	78.7	39.4	26.2	13.1	6.56	3.28	2.62
6.54	3.270	1.6350	0.654	78.4	39.2	26.1	13.1	6.54	3.27	2.61
6.55	3.275	1.6375	0.655	78.2	39.1	26.1	13.0	6.51	3.26	2.61
6.56	3.280	1.6400	0.656	77.9	38.9	26.0	13.0	6.49	3.24	2.60
6.57	3.285	1.6425	0.657	77.6	38.8	25.9	12.9	6.47	3.23	2.59
6.58	3.290	1.6450	0.658	77.3	38.7	25.8	12.9	6.44	3.22	2.58
6.59	3.295	1.6475	0.659	77.1	38.5	25.7	12.8	6.42	3.21	2.57
6.60	3.300	1.6500	0.660	76.8	38.4	25.6	12.8	6.40	3.20	2.56
6.61	3.305	1.6525	0.661	76.5	38.3	25.5	12.8	6.38	3.19	2.55
6.62	3.310	1.6550	0.662	76.2	38.1	25.4	12.7	6.35	3.18	2.54
6.63	3.315	1.6575	0.663	76.0	38.0	25.3	12.7	6.33	3.17	2.53
6.64	3.320	1.6600	0.664	75.7	37.9	25.2	12.6	6.31	3.15	2.52
6.65	3.325	1.6625	0.665	75.4	37.7	25.1	12.6	6.29	3.14	2.51
6.66	3.330	1.6650	0.666	75.2	37.6	25.1	12.5	6.26	3.13	2.51
6.67	3.335	1.6675	0.667	74.9	37.5	25.0	12.5	6.24	3.12	2.50
6.68	3.340	1.6700	0.668	74.7	37.3	24.9	12.4	6.22	3.11	2.49
6.69	3.345	1.6725	0.669	74.4	37.2	24.8	12.4	6.20	3.10	2.48
6.70	3.350	1.6750	0.670	74.1	37.1	24.7	12.4	6.18	3.09	2.47
6.71	3.355	1.6775	0.671	73.9	36.9	24.6	12.3	6.16	3.08	2.46
6.72	3.360	1.6800	0.672	73.6	36.8	24.5	12.3	6.13	3.07	2.45
6.73	3.365	1.6825	0.673	73.4	36.7	24.5	12.2	6.11	3.06	2.45
6.74	3.370	1.6850	0.674	73.1	36.5	24.4	12.2	6.09	3.05	2.44
6.75	3.375	1.6875	0.675	72.8	36.4	24.3	12.1	6.07	3.04	2.43
6.76	3.380	1.6900	0.676	72.6	36.3	24.2	12.1	6.05	3.02	2.42
6.77	3.385	1.6925	0.677	72.3	36.2	24.1	12.1	6.03	3.01	2.41
6.78	3.390	1.6950	0.678	72.1	36.0	24.0	12.0	6.01	3.00	2.40
6.79	3.395	1.6975	0.679	71.8	35.9	23.9	12.0	5.99	2.99	2.39
6.80	3.400	1.7000	0.680	71.6	35.8	23.9	11.9	5.97	2.98	2.39
6.81	3.405	1.7025	0.681	71.3	35.7	23.8	11.9	5.94	2.97	2.38
6.82	3.410	1.7050	0.682	71.1	35.5	23.7	11.8	5.92	2.96	2.37
6.83	3.415	1.7075	0.683	70.8	35.4	23.6	11.8	5.90	2.95	2.36
6.84	3.420	1.7100	0.684	70.6	35.3	23.5	11.8	5.88	2.94	2.35
6.85	3.425	1.7125	0.685	70.4	35.2	23.5	11.7	5.86	2.93	2.35
6.86	3.430	1.7150	0.686	70.1	35.1	23.4	11.7	5.84	2.92	2.34
6.87	3.435	1.7175	0.687	69.9	34.9	23.3	11.6	5.82	2.91	2.33
6.88	3.440	1.7200	0.688	69.6	34.8	23.2	11.6	5.80	2.90	2.32
6.89	3.445	1.7225	0.689	69.4	34.7	23.1	11.6	5.78	2.89	2.31
6.90	3.450	1.7250	0.690	69.2	34.6	23.1	11.5	5.76	2.88	2.31
6.91	3.455	1.7275	0.691	68.9	34.5	23.0	11.5	5.74	2.87	2.30

TABLE X1.1 *Continued*

Diameter of Indentation, *d* (mm)				Brinell Hardness Number						
				HBW 10/3000	HBW 10/1500	HBW 10/1000	HBW 10/500	HBW 10/ 250	HBW 10/ 125	HBW 10/100
10 mm	5 mm	2.5 mm	1 mm	HBW 5/750		HBW 5/250	HBW 5/125	HBW 5/62.5	HBW 5/31.25	HBW 5/25
ball	ball	ball	ball	HBW 2.5/187.5		HBW 2.5/62.5	HBW 2.5/31.25	HBW 2.5/ 15.625	HBW 2.5/ 7.8125	HBW 2.5/6.25
				HBW 1/30		HBW 1/10	HBW 1/5	HBW 1/2	HBW 1/1.25	HBW 1/1
6.92	3.460	1.7300	0.692	*68.7*	*34.3*	*22.9*	*11.4*	*5.72*	*2.86*	*2.29*
6.93	3.465	1.7325	0.693	*68.4*	*34.2*	*22.8*	*11.4*	*5.70*	*2.85*	*2.28*
6.94	3.470	1.7350	0.694	*68.2*	*34.1*	*22.7*	*11.4*	*5.68*	*2.84*	*2.27*
6.95	3.475	1.7375	0.695	*68.0*	*34.0*	*22.7*	*11.3*	*5.66*	*2.83*	*2.27*
6.96	3.480	1.7400	0.696	*67.7*	*33.9*	*22.6*	*11.3*	*5.64*	*2.82*	*2.26*
6.97	3.485	1.7425	0.697	*67.5*	*33.8*	*22.5*	*11.3*	*5.63*	*2.81*	*2.25*
6.98	3.490	1.7450	0.698	*67.3*	*33.6*	*22.4*	*11.2*	*5.61*	*2.80*	*2.24*
6.99	3.495	1.7475	0.699	*67.0*	*33.5*	*22.3*	*11.2*	*5.59*	*2.79*	*2.23*

X2. EXAMPLES OF PROCEDURES FOR DETERMINING BRINELL HARDNESS UNCERTAINTY

X2.1 Scope

X2.1.1 The intent of this appendix is to provide a basic approach to evaluating the uncertainty of Brinell hardness measurement values in order to simplify and unify the interpretation of uncertainty by users of Brinell 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 Brinell hardness measurements are made on a reference test block. The average of the measurement values is compared to the certified value of the reference block to determine the "error" (see 3.2.5) 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 *The Hardness Machine "Error" Determined from Measurements Made as Part of a Direct Verification (see X2.7)*—As part of a direct verification, errors in separate components of the hardness machine are determined. These are the force application system, the indentation measuring system, and the indenter. In addition to these, there are other potential sources of error that should be considered. The measurement "error" of the hardness machine can be estimated by determining how each of the errors in these components contributes to the overall error of the hardness measurement. Although the measurement "error" of the hardness machine estimated in this way is not reported on the verification certificate and report, this value and its uncertainty are needed to calculate measurement uncertainties when verification of the hardness machine is only made by the direct verification method. The procedure described in section X2.7 provides a method for determining the uncertainty in this measurement "error" of the hardness machine.

X2.1.2.3 *Brinell Hardness Value Measured by a User (see X2.8)*—The procedure provides a method for determining the uncertainty in the hardness values measured by a user during the normal use of a Brinell hardness machine. The user may report the uncertainty value with the measurement value.

X2.1.2.4 *Certified Value of a Brinell Hardness Test Block (see X2.9)*—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 X2.5.7 and X2.7) 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 Brinell hardness users and standardizing agencies. The reader should be aware that there are other methods that may be employed to determine the same uncertainties.

NOTE X2.3—This standard states tolerances or limits on the acceptable repeatability and error of a Brinell hardness machine and the nonuniformity of standardized blocks. These limit values were originally established based on the testing experience of many users of the Brinell hardness test, and therefore reflect the normal performance of a properly functioning Brinell 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 Brinell hardness measurements. Consequently, when determining compliance with the stated tolerances, 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 Brinell hardness were established based on testing and performance experience. The tolerance values reflect the normal performance of a properly functioning Brinell 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 Brinell hardness measurements. Consequently, when acceptance testing most products for Brinell 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, …, H_n is calculated as:

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

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

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

where:

$\bar{H}$ = average of the set of n hardness measurements H_1, H_2, …, 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

$$ABS(-0.12) = 0.12$$

X2.2.4 An incremental change in hardness ΔH resulting from an incremental change in indentation diameter Δd may be calculated as:

$$\Delta H = -\Delta d \times \left(\frac{H \times \left(D + \sqrt{D^2 - d^2}\right)}{d \times \sqrt{D^2 - d^2}} \right) \quad (X2.3)$$

where:

H = Brinell hardness value prior to the incremental change in hardness ΔH,
d = mean diameter of the indentation in mm prior to the incremental change in diameter Δd, and
D = diameter of the indenter ball in mm.

X2.2.5 An incremental change in indentation diameter Δd resulting from an incremental change in hardness ΔH may be calculated as:

$$\Delta d = -\Delta H \times \left(\frac{d \times \sqrt{D^2 - d^2}}{H \times \left(D + \sqrt{D^2 - d^2}\right)} \right) \quad (X2.4)$$

where:

H = Brinell hardness value prior to the incremental change in hardness ΔH,
d = mean diameter of the indentation in mm prior to the incremental change in diameter Δd, and
D = diameter of the indenter ball in mm.

X2.2.6 An incremental change in hardness ΔH resulting from an incremental change in the applied force ΔF may be calculated as:

$$\Delta H = \Delta F \times \left(\frac{H}{F} \right) \quad (X2.5)$$

where:

H = Brinell hardness value prior to the incremental change in hardness ΔH, and
F = applied force prior to the incremental change in applied force ΔF (F and ΔF having the same units).

X2.2.7 Combining equations [Eq X2.3] and [Eq X2.5], an incremental change in indentation diameter Δd resulting from an incremental change in applied force ΔF may be calculated as:

$$\Delta d = -\frac{\Delta F}{F} \times \left(\frac{d \times \sqrt{D^2 - d^2}}{D + \sqrt{D^2 - d^2}} \right) \quad (X2.6)$$

where:

F = applied force prior to the incremental change in applied force ΔF (F and ΔF having the same units),
d = mean diameter of the indentation in mm prior to the incremental change in diameter Δd, and
D = diameter of the indenter ball in mm.

NOTE X2.5—Equations [Eq X2.3], [Eq X2.4], and [Eq X2.6] should only be used for small values of ΔH and Δd. These equations are suitable for use with the typical values of ΔH and Δd used by the procedures in this appendix; however, the equations produce significant errors as the values of ΔH and Δd become large.

X2.3 General Requirements

X2.3.1 The main approach for determining uncertainty presented in this appendix considers only those uncertainties associated with the overall measurement performance of the Brinell hardness machine with respect to reference standards. 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 To estimate the overall uncertainty of Brinell 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.

X2.3.3 Uncertainty should be determined with respect to a country's national reference standards.

X2.4 General Procedure

X2.4.1 All uncertainty calculations are initially based on indentation diameter values in mm units. These uncertainties, in terms of indentation diameter, may also be converted to uncertainties in terms of Brinell hardness numbers.

X2.4.2 This procedure calculates a *combined* standard uncertainty u_c by combining the contributing components of uncertainty u_1, u_2, …, u_n, such that:

$$u_c = \sqrt{u_1^2 + u_2^2 + \ldots + u_n^2} \quad \text{(X2.7)}$$

X2.4.3 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:

$$U = k \times u_c \quad \text{(X2.8)}$$

X2.4.4 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 %.

X2.4.5 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 Brinell 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:

$$U = ku_c + ABS(B) \quad \text{(X2.9)}$$

where:

ABS(B) = absolute value of the bias.

X2.4.6 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 Brinell 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 lack of repeatability of the hardness machine and measuring system, *(2)* the non-uniformity in hardness of the material under test, *(3)* the long-term lack of reproducibility of the hardness machine and measuring system, *(4)* the resolution of the hardness machine's measurement system, and *(5)* the uncertainty in the certified value of 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 *lack of repeatability* is an indication of how well the Brinell hardness machine and indentation measuring system 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 the lack of repeatability of a hardness machine and indentation measurement system 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:

$$u_{Repeat} = STDEV(d_1, d_2, \ldots, d_n) \quad \text{(X2.10)}$$

where:

$d_1, d_2, \ldots, d_n$ = measured average indentation diameters in mm of the n indentations.

NOTE X2.6—In general, the estimate of repeatability is improved as the number of hardness measurements is increased. Usually, the hardness measurements made during an indirect verification (as indentation diameters) will provide an adequate estimate of u_{Repeat}; however, the caution given in Note X2.8 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 X2.7—The uncertainty u_{Repeat}, due to the lack of repeatability of a hardness machine as discussed above, should not be confused with the historically defined "repeatability" that is a requirement to be met as part of an indirect verification (see 3.2.3). The calculations of the uncertainty u_{Repeat} and of the historically defined repeatability do not produce the same value. The uncertainty u_{Repeat} is the contribution to the overall uncertainty of a hardness measurement value due to a machine's lack of repeatability, while the historically defined repeatability is the range of hardness values measured during an indirect verification.

NOTE X2.8—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 measurements is to be reported, the standard uncertainty contribution $u_{\overline{Repeat}}$, due to the lack of repeatability of the hardness machine, may be estimated by dividing the standard uncertainty contribution u_{Repeat} (previously calculated from a number of indentations made on a uniform test sample, see X2.5.3.2) by the square-root of the number of hardness test values being averaged, as:

$$u_{\overline{Repeat}} = \frac{u_{Repeat}}{\sqrt{n_T}} \quad \text{(X2.11)}$$

where:

u_{Repeat} = calculation by [Eq X2.10], and
n_T = number of individual 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 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 indentation measurement system and due to 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:

$$u_{Rep\&NU} = \frac{STDEV(d_{T1}, d_{T2}, \ldots, d_{Tn})}{\sqrt{n_T}} \quad \text{(X2.12)}$$

where:

$d_{T1}, d_{T2}, ..., d_{Tn}$ = the n_T average diameter measurement values.

X2.5.4 *Uncertainty Due to Lack of Reproducibility* *(u_{Reprod})*—Lack of reproducibility is the day-to-day variation in the performance of the hardness measurement system. 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 overestimated.

X2.5.4.1 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:

$$u_{Reprod} = STDEV\left(\overline{d_{M1}}, \overline{d_{M2}}, \ldots, \overline{d_{Mn}}\right) \quad \text{(X2.13)}$$

where:

$d_{M1}, d_{M2}, ..., d_{Mn}$ = the n sets of the average of each day's set of multiple monitoring measurement values.

NOTE X2.9—The uncertainty contribution due to the lack of reproducibility, as calculated in [Eq X2.13], 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 overestimate the reproducibility uncertainty.

X2.5.4.2 *Uncertainty Due to the Resolution of the Indentation Measurement System (u_{Resol})*—The finite resolution of the indentation diameter measurement system prevents the determination of an absolutely accurate hardness value. This uncertainty may be significant when some types of hand-held measuring scopes are used.

X2.5.4.3 The uncertainty contribution u_{Resol}, due to the influence of the resolution of the indentation measurement system, may be described by a rectangular distribution and estimated as:

$$u_{Resol} = \frac{r/2}{\sqrt{3}} = \frac{r}{\sqrt{12}} \quad \text{(X2.14)}$$

where:

r = resolution limit that a indentation diameter can be estimated from the indentation measurement system in mm.

X2.5.5 *Standard Uncertainty in the Certified Value of the Reference Test Block (u_{RefBlk})*—The certificate accompanying reference test blocks should provide an uncertainty in the stated certified value. This uncertainty contributes to the measurement uncertainty of hardness machines calibrated or verified with the blocks.

X2.5.5.1 Note that the uncertainty reported on reference test block certificates is typically stated as an *expanded uncertainty*. As indicated by [Eq X2.9], 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 in the certified average indentation diameter value of the reference test block usually may be calculated as:

$$u_{RefBlk(mm)} = \frac{U_{RefBlk(mm)}}{k_{RefBlk(mm)}} \quad \text{(X2.15)}$$

where:

$U_{RefBlk(mm)}$ = reported expanded uncertainty of the certified value of the reference test block in terms of indentation diameter (mm), and
$k_{RefBlk(mm)}$ = coverage factor used to calculate the uncertainty in the certified value of the reference standard (usually 2).

X2.5.5.2 For this analysis, the uncertainty in the stated certified value of the reference block must be in terms of indentation diameter (mm). In the case that the reference test block certificate only provides uncertainty in terms of the Brinell hardness value, then this uncertainty must be converted using [Eq X2.4], where $u_{RefBlk(HBW)}$ is substituted for ΔH. The calculated value of Δd then becomes the new value of $u_{RefBlk(mm)}$, in mm, as:

$$u_{RefBlk(mm)} = u_{RefBlk(HBW)} \times \left(\frac{d \times \sqrt{D^2 - d^2}}{H \times \left(D + \sqrt{D^2 - d^2}\right)} \right) \tag{X2.16}$$

X2.5.6 *Measurement Bias (B)*—The verification section of this test method provides two acceptable procedures for determining measurement bias of a Brinell hardness machine: *(1)* by indirect verification through the use of reference blocks, and *(2)* by direct verification of components of the machine, including the applied forces and the indentation measuring system. The measurement bias is the difference between the "true" hardness of a material and the hardness measurement values as measured by the hardness machine.

X2.5.6.1 *Indirect Verification*—In the case that the hardness machine is verified by indirect verification, the measurement error of the hardness machine is estimated by performing Brinell hardness measurements on reference standards. The measurement bias *B* may be estimated by the "error" determined as part of the indirect verification, either in terms of indentation diameter or in terms of Brinell hardness numbers.

X2.5.6.2 The measurement bias $B_{(mm)}$, in terms of indentation diameter, may be calculated as:

$$B_{(mm)} = \bar{d} - \bar{d}_{RefBlk} \tag{X2.17}$$

where:

$\bar{d}$ = average indentation diameter as measured during the indirect verification, and

$\bar{d}_{RefBlk}$ = certified average indentation diameter of the reference test block standard used for the indirect verification.

NOTE X2.10—The measurement bias $B_{(mm)}$ is in length units (mm).

X2.5.6.3 The measurement bias $B_{(HBW)}$, in terms of Brinell hardness numbers, may be calculated as:

$$B_{(HBW)} = \bar{H} - \bar{H}_{RefBlk} \tag{X2.18}$$

where:

$\bar{H}$ = mean hardness value as measured by the hardness machine during the indirect verification, and

$\bar{H}_{RefBlk}$ = certified average hardness value of the reference test block standard used for the indirect verification.

The measurement bias $B_{(HBW)}$ may also be calculated from $B_{(mm)}$ using [Eq X2.3], where $B_{(mm)}$ is substituted for Δd. The calculated value of ΔH then becomes the new value of $B_{(HBW)}$ as:

$$B_{(HBW)} = B_{(mm)} \times \left(\frac{H \times \left(D + \sqrt{D^2 - d^2}\right)}{d \times \sqrt{D^2 - d^2}} \right) \tag{X2.19}$$

NOTE X2.11—The measurement bias $B_{(HBW)}$ is in Brinell hardness units (HBW).

X2.5.6.4 *Direct Verification*—In the case that the hardness machine is verified only by direct verification, the measurement error of the hardness machine is estimated by combining the individual errors of the components of the machine. Although there are potentially many contributing sources of error for a Brinell hardness machine, typically the most significant sources of error are in the force application system E_{Force} and the indentation measuring system $E_{Indentation}$. Other sources may include error in the indenter ball diameter, error in the timing of the stated hold time, error in the rate of indentation, etc. It is recommended that an analysis of all error sources be done to determine the significance of these errors. For simplicity, only the two errors E_{Force} and $E_{Indentation}$ will be considered.

X2.5.6.5 These contributing sources of error are calculated in terms of their units of measurement, for example, $E_{Indentation}$ and E_{Force} are determined in units of length (mm) and force (kgf or N), respectively. Procedures for calculating $E_{Indentation}$ and E_{Force} are not presented here. To calculate the measurement bias *B*, these errors must be determined in terms of indentation diameter. The error in the indentation measuring system $E_{Indentation}$ is already in the correct units; however, the error $E_{Force(kgf\ or\ N)}$ must be converted to an error in indentation diameter using [Eq X2.6], where $E_{Force(kgf\ or\ N)}$ is substituted for ΔF. The calculated value of Δd then becomes a new value of $E_{Force(mm)}$, in mm as:

$$E_{Force(mm)} = -\frac{E_{Force(kgf\ or\ N)}}{F} \times \left(\frac{d \times \sqrt{D^2 - d^2}}{D + \sqrt{D^2 - d^2}} \right) \tag{X2.20}$$

X2.5.6.6 The measurement bias *B* may be estimated by combining the individual errors determined as part of the direct verification while maintaining the correct sign (positive or negative) for each of the individual errors:

$$B_{(mm)} = E_{Indentation} + E_{Force(mm)} \tag{X2.21}$$

X2.5.7 To determine the measurement "error" or bias in terms of Brinell hardness units $B_{(HBW)}$ the bias, as calculated in [Eq X2.21] in terms of indentation diameter, must be converted using [Eq X2.19].

X2.6 Procedure for Calculating Uncertainty: Measurement Error Determined by Indirect Verification

X2.6.1 As part of an indirect verification, the "error" of the hardness machine is determined from the average value of measurements made on a reference test block (see 3.2.5). 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 All uncertainty calculations are initially based on indentation diameter values in mm. The contributions to the standard uncertainty of the measurement "error," $u_{Mach(mm)}$, 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 X2.12], 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 indentation measurement system [Eq X2.14], and *(3)* u_{RefBlk}, the standard uncertainty in the certified value of the reference test block in terms of indentation diameter [Eq X2.15 and X2.16]. The notation (*Ref. Block*) is added to the term $u_{Rep\&Nu}$ to signify that the uncertainty is determined from measurements made on the *reference block* used for the indirect verification.

X2.6.3 The combined standard uncertainty $u_{Mach(mm)}$ and the expanded uncertainty $U_{Mach(mm)}$ are calculated by combining the appropriate uncertainty components described above for each hardness level of each Brinell scale in terms of indentation diameter in mm:

$$u_{Mach(mm)} = \sqrt{u^2_{Rep\&Nu}(Ref.\ Block) + u^2_{Resol} + u^2_{RefBlk}} \quad \text{(X2.22)}$$

and

$$U_{Mach(mm)} = k u_{Mach(mm)} \quad \text{(X2.23)}$$

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 X2.12—The uncertainty contribution $u_{Mach(mm)}$, as calculated in [Eq X2.22], 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.

X2.6.5 To determine the uncertainty in the measurement "error" of the hardness machine in terms of Brinell hardness units $U_{Mach(HBW)}$, then the uncertainty, as calculated in [Eq X2.23] in terms of indentation diameter, must be converted using [Eq X2.3], where $U_{Mach(mm)}$ is substituted for Δd. The calculated value of ΔH then becomes the new value of $U_{Mach(HBW)}$, in Brinell hardness units, as:

$$U_{Mach(HBW)} = U_{Mach(mm)} \times \left(\frac{H \times \left(D + \sqrt{D^2 - d^2}\right)}{d \times \sqrt{D^2 - d^2}} \right) \quad \text{(X2.24)}$$

NOTE X2.13—The first minus sign in [Eq X2.3] has been deleted when using [Eq X2.24] since uncertainty values are always positive.

NOTE X2.14—The expanded uncertainty U_{Mach}, will commonly be larger than the value of the hardness machine "error" (bias).

X2.6.6 *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 Brinell hardness machine. The value of U_{Mach} should be supplemented with a statement defining to what Brinell 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 Brinell scale(s) and hardness level(s) was calculated in accordance with Appendix X1 of ASTM E10 with a coverage factor of 2 representing a confidence level of approximately 95 %."

X2.6.7 The standard uncertainty value $u_{Mach(mm)}$ can be used as an uncertainty contribution when determining the measurement uncertainty of future measurements made with the hardness machine (see X2.8 and X2.9).

X2.6.8 *Example*—As part of an indirect verification of a Brinell hardness machine, a verification agency may need 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 mid hardness range of the HBW 10/3000 scale. The indentation measuring device is a portable hand-held scope with a resolution of 0.05 mm. The agency performs three verification measurements on a HBW 10/3000 hardness block with a reported certified average indentation diameter value of 4.24 mm with an expanded uncertainty of $U_{RefBlk(mm)} = \pm 0.04$ mm. The hardness block certificate also stated a certified average Brinell hardness value of 202 HBW 10/3000 with an expanded uncertainty of $U_{RefBlk(HBW)} = \pm 4$ HBW 10/3000. The results of the three verification measurements are:

Diameter length (average) of indentations: 4.25, 4.25 and 4.30 mm
Average indentation diameter: 4.267 mm
Indentation diameter error (bias) value: 0.027 mm
Calculated average hardness value: 199.8 HBW 10/3000
Hardness error (bias) value: –2.3 HBW 10/3000
Therefore:

$$u_{Rep\&NU}(Ref.\ Block) = \frac{STDEV(4.25, 4.25, 4.30)}{\sqrt{3}}$$ [Eq X2.12], or

$$u_{Rep\&NU}(Ref.\ Block) = 0.0167 \text{ mm}$$

$$u_{Resol} = \frac{0.05}{\sqrt{12}} = 0.0144 \text{ mm}$$ [Eq X2.14], and

$$u_{RefBlk} = \frac{0.04}{2} = 0.02 \text{ mm}$$ [Eq X2.15]

Thus:

$$u_{Mach(mm)} = \sqrt{0.0167^2 + 0.0144^2 + 0.02^2} = 0.0298 \text{ mm}$$ [Eq X2.22], and

$$U_{Mach(mm)} = (2 \times 0.0298) = 0.0596 \text{ mm}$$ [Eq X2.23]

Therefore, the uncertainty in the 0.027 mm "error" in the hardness machine is 0.060 mm.

In terms of Brinell hardness units:

$$U_{Mach(HBW)} = 0.0596 \times \left(\frac{199.8 \times \left(10 + \sqrt{10^2 - 4.267^2}\right)}{4.267 \times \sqrt{10^2 - 4.267^2}} \right)$$ [Eq X2.24], or

$$U_{Mach(HBW)} = 5.9 \text{ HBW } 10/3000$$

Therefore, the uncertainty in the –2.3 HBW 10/3000 "error" in the hardness machine is 5.9 HBW 10/3000. Although this evaluation was made on material having a hardness of approximately 200 HBW 10/3000, the uncertainty may be considered to apply to the entire mid range of the HBW 10/3000 scale. This calculation must be made for the low and high ranges of the HBW 10/3000 scale, as well as for the ranges of the other Brinell scales that are verified.

X2.7 Procedure for Calculating Uncertainty: Measurement Error Determined by Direct Verification

X2.7.1 As part of a direct verification, errors in separate components of the hardness machine are determined. The uncertainty of the hardness machine measurement "error" is estimated by combining the uncertainties of the individual verification measurements of each of the machine components.

X2.7.2 For each of the sources of error in a Brinell hardness machine and indentation measurement system, a value of error and the uncertainty of the error must be determined. Some of these error values and uncertainties are not determined in terms of indentation diameter. To estimate the uncertainty U_{Mach} in the measurement "error" of the hardness machine, the effect that each of these errors has on the hardness measurement in terms of indentation diameter must be determined.

X2.7.3 As done previously in X2.5.6.4, for simplicity only the uncertainty in the error of the force application system u_{Force} and the uncertainty in the error of the indentation measuring system $u_{Indentation}$ will be considered. Procedures for calculating the errors $E_{Indentation}$ and E_{Force} are not presented here. The uncertainty u_{Force} is usually determined in units of force (kgf or N), rather than in terms of indentation diameter (mm). The uncertainty in the error of the indentation measuring system $u_{Indentation}$ is already in the correct units; however, the uncertainty in the error of the force $u_{Force(kgf\ or\ N)}$ must be converted to an uncertainty in terms of indentation diameter $u_{Force(mm)}$ using [Eq X2.6] where $u_{Force(kgf\ or\ N)}$ is substituted for ΔF. The calculated value of Δd then becomes a new value of $u_{Force(mm)}$, in terms of indentation diameter as:

$$u_{Force(mm)} = \frac{u_{Force(kgf\ or\ N)}}{F} \times \left(\frac{d \times \sqrt{D^2 - d^2}}{D + \sqrt{D^2 - d^2}} \right) \qquad (X2.25)$$

X2.7.4 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 Brinell scale and u_{Resol}, the uncertainty due to the resolution of the indentation measurement system [Eq X2.14], as:

$$u_{Mach(mm)} = \sqrt{u^2_{Indentation} + u^2_{Force(mm)} + u^2_{Resol}} \qquad (X2.26)$$

and

$$U_{Mach(mm)} = k u_{Mach(mm)} \qquad (X2.27)$$

X2.7.5 To determine the uncertainty in the measurement "error" of the hardness machine in terms of Brinell hardness units $U_{Mach(HBW)}$, then the uncertainty, as calculated in [Eq X2.27] in terms of indentation diameter, must be converted in accordance with X2.6.5.

X2.7.6 Although the standard uncertainty value u_{Mach}, determined in this way, is not usually reported by a verification agency to its customer, it can be used as an uncertainty contribution when determining the measurement uncertainty of future measurements made with the hardness machine (see X2.8 and X2.9).

X2.7.7 *Example*—In cases where a Brinell hardness machine is verified by direct verification, a verification agency is not required to report an estimate of the uncertainty of the hardness machine "error;" however, an estimate of this uncertainty may be determined from the direct verification measurements. For this example, an evaluation will only be made for the mid hardness range of the HBW 10/3000 scale at 200 HBW 10/3000 (4.265 mm indentation diameter). The indentation measuring device is a portable hand-held scope with a resolution of 0.05 mm. The agency performs direct verification measurements of the 3000 kgf force application and of the indentation measuring device. The results of the verification measurements are:

Force error (bias) value, $E_{Force(kgf\ or\ N)}$: −15 kgf
Uncertainty in the force error, $u_{Force(kgf\ or\ N)}$: 2.5 kgf
Indentation measuring system error, $E_{Indentation(mm)}$: 0 mm
Uncertainty in the measuring system error, $u_{Indentation(mm)}$: 0.002 mm (stage micrometer uncertainty)

Therefore, for a hardness level of 200 HBW 10/3000, to calculate the machine bias in terms of indentation diameter:

$E_{Indentation} = 0$ mm, and

$$E_{Force(mm)} = -\frac{-15}{3000} \times \left(\frac{4.265 \times \sqrt{10^2 - 4.265^2}}{10 + \sqrt{10^2 - 4.265^2}} \right)$$ [Eq X2.20], or

$E_{Force(mm)} = 0.0101$ mm

Thus:

$B_{(mm)} = E_{Indentation} + E_{Force(mm)} = 0 + 0.0101 = 0.0101$ mm [Eq X2.21]

To calculate the uncertainty in the machine "error" or bias:

$u_{Indentation} = 0.002$ mm, and

$$u_{Force(mm)} = \frac{2.5}{3000} \times \left(\frac{4.265 \times \sqrt{10^2 - 4.265^2}}{10 + \sqrt{10^2 - 4.265^2}} \right)$$ [Eq X2.25], or

$u_{Force(mm)} = 0.0017$ mm, and

$$u_{Resol} = \frac{0.05}{\sqrt{12}} = 0.0144 \text{ mm}$$ [Eq X2.14]

Thus:

$u_{Mach(mm)} = \sqrt{0.002^2 + 0.0017^2 + 0.0144^2} = 0.01464$ mm [Eq X2.26], and

$U_{Mach(mm)} = (2 \times 0.01464) = 0.0293$ mm [Eq X2.27]

Therefore, the uncertainty in the 0.0101 mm "error" in the hardness machine at 200 HBW 10/3000 is 0.0293 mm.

In terms of Brinell hardness units:

$$B_{(HBW)} = -(0.0101) \times \left(\frac{200 \times (10 + \sqrt{10^2 - 4.265^2})}{4.265 \times \sqrt{10^2 - 4.265^2}} \right)$$ [Eq X2.19], or

$B_{(HBW)} = -0.997$ HBW 10/3000, and

$$U_{Mach(HBW)} = 0.0293 \times \left(\frac{200 \times (10 + \sqrt{10^2 - 4.265^2})}{4.265 \times \sqrt{10^2 - 4.265^2}} \right)$$ [Eq X2.24], or

$U_{Mach(HBW)} = 2.89$ HBW 10/3000

Therefore, the uncertainty in the –0.997 HBW 10/3000 "error" in the hardness machine is 2.89 HBW 10/3000. Although this evaluation was made for material having a hardness of 200 HBW 10/3000, the uncertainty may be considered to apply to the entire mid range of the HBW 10/3000 scale. This calculation must be made for the low and high ranges of the HBW 10/3000 scale, as well as for the ranges of the other Brinell scales that are verified.

X2.8 Procedure for Calculating Uncertainty: Brinell Hardness Measurement Values

X2.8.1 The uncertainty U_{Meas} in a measurement value measured by a user may be thought of as an indication of how well the measured value agrees with the "true" value for the material under test. For this procedure, all uncertainty calculations are initially based on indentation diameter values in mm units. The combined standard uncertainty $u_{Meas(mm)}$ and the expanded uncertainty $U_{Meas(mm)}$, are both in terms of indentation diameter. The uncertainty $U_{Meas(mm)}$ can then be converted to an expanded uncertainty $U_{Meas(HBW)}$ in terms of Brinell hardness numbers.

X2.8.2 *Single Measurement Value*—When measurement uncertainty for a single hardness measurement value is to be determined, the contributions to the standard uncertainty $u_{Meas(mm)}$ are *(1)* u_{Repeat}, the uncertainty due to the machine's lack of repeatability [Eq X2.10], *(2)* u_{Reprod}, the uncertainty contribution due to the lack of reproducibility [Eq X2.13], *(3)* u_{Resol}, the uncertainty due to the resolution of the indentation measurement system [Eq X2.14], and *(4)* u_{Mach}, the uncertainty in determining the "error" of the hardness machine [Eq X2.22 or Eq X2.26]. The combined standard uncertainty u_{Meas} is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Brinell scale as:

$$u_{Meas(mm)} = \sqrt{u^2_{Repeat} + u^2_{Reprod} + u^2_{Resol} + u^2_{Mach(mm)}} \qquad (X2.28)$$

X2.8.3 *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 $u_{Meas(mm)}$ are *(1)* $u_{\overline{Repeat}}$, the uncertainty due to the machine's lack of repeatability based on the average of multiple measurements [Eq X2.11], *(2)* u_{Reprod}, the uncertainty contribution due to the lack of reproducibility [Eq X2.13], *(3)* u_{Resol}, the uncertainty due to the resolution of the indentation measurement system [Eq X2.14], and *(4)* u_{Mach}, the uncertainty in determining the "error" of the hardness machine [Eq X2.22 or Eq X2.26]. The combined standard uncertainty u_{Meas} is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Brinell scale as:

$$u_{Meas(mm)} = \sqrt{u^2_{\overline{Repeat}} + u^2_{Reprod} + u^2_{Resol} + u^2_{Mach(mm)}} \tag{X2.29}$$

X2.8.4 The measurement uncertainty discussed above for the single and average measurement values only represents the uncertainties of the measurement process and are independent of any test material non-uniformity.

X2.8.5 *Average Measurement Value as an Estimate of the Average Material Hardness*—Measurement laboratories and manufacturing facilities often measure the Brinell 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 $u_{Meas(mm)}$ 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 X2.12], 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 X2.13], *(3)* u_{Resol}, the uncertainty due to the resolution of the indentation measurement system [Eq X2.14], and *(4)* $u_{Mach(mm)}$, the uncertainty in determining the "error" of the hardness machine [Eq X2.22 or Eq X2.26]. The notation (*Material*) is added to the term $u_{Rep\&NU}$ to signify that the uncertainty is determined from measurements made on the *material* under test. The combined standard uncertainty $u_{Meas(mm)}$ is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Brinell scale as:

$$u_{Meas(mm)} = \sqrt{u^2_{Rep\&NU}(Material) + u^2_{Reprod} + u^2_{Resol} + u^2_{Mach(mm)}} \tag{X2.30}$$

X2.8.6 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.

X2.8.7 The expanded uncertainty $U_{Meas(mm)}$ is calculated for the three cases discussed above as:

$$U_{Meas(mm)} = ku_{Meas(mm)} + ABS(B_{(mm)}) \tag{X2.31}$$

X2.8.8 To determine the uncertainty of a Brinell hardness measurement in terms of Brinell hardness units $U_{Mach(HBW)}$, then the uncertainty, as calculated in [Eq X2.31], in terms of indentation diameter, must be converted using [Eq X2.3], where $U_{Meas(mm)}$ is substituted for Δd. The calculated value of ΔH then becomes the new value of $U_{Meas(HBW)}$, in Brinell hardness units, as:

$$U_{Meas(HBW)} = U_{Meas(mm)} \times \left(\frac{H \times \left(D + \sqrt{D^2 - d^2}\right)}{d \times \sqrt{D^2 - d^2}} \right) \tag{X2.32}$$

NOTE X2.15—The first minus sign in [Eq X2.3] has been deleted when using [Eq X2.32] since uncertainty values are always positive.

X2.8.9 For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

X2.8.10 *Reporting Measurement Uncertainty:*

X2.8.10.1 *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) was calculated in accordance with Appendix X1 of ASTM E10 with a coverage factor of 2 representing a confidence level of approximately 95 %."

X2.8.10.2 *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 was calculated in accordance with Appendix X1 of ASTM E10 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.

X2.8.10.3 *Example*—For this example, a company tests its product by making one Brinell hardness measurement on its surface and measures the indentation with a portable hand-held scope having a resolution of 0.05 mm. The measurement value of the average indentation diameter is 4.20 mm or a Brinell hardness value of 103 HBW 10/1500. The testing facility would like to determine the measurement uncertainty in the single hardness value. A hardness of 104 HBW 10/1500 is in the mid range of the HBW 10/1500 scale.

For this example, assume the last verification of the mid range of the HBW 10/1500 scale reported:

u_{Repeat}:0.032 mm

$u_{Mach(mm)}$:0.054 mm

Bias, $B_{(mm)}$: −0.029 mm
For this example, assume the hardness machine has been monitored for an extended period of time, and from [Eq X2.13], it was determined that:
u_{Reprod} = 0.040 mm
Other uncertainty contributions are calculated as:

$$u_{Resol} = \frac{0.05}{\sqrt{12}} = 0.0144 \text{ mm} \quad \text{[Eq X2.14]}$$

Therefore:

$$u_{Meas(mm)} = \sqrt{0.032^2 + 0.040^2 + 0.0144^2 + 0.054^2} \quad \text{[Eq X2.30], or}$$

$u_{Meas(mm)}$ = 0.0758 mm
and since B = –0.029 mm,

$$U_{Meas(mm)} = (2 \times 0.0758) + ABS(-0.029) \quad \text{[Eq X2.31], or}$$

$U_{Meas(mm)}$ = 0.1806 mm
In terms of Brinell hardness units:

$$U_{Meas(HBW)} = 0.1806 \times \left(\frac{103 \times \left(10 + \sqrt{10^2 - 4.20^2}\right)}{4.20 \times \sqrt{10^2 - 4.20^2}} \right) \quad \text{[Eq X2.32], or}$$

$U_{Meas(HBW)}$ = 9.3 HBW 10/1500 for the single value of the hardness measurement made on the single product item.

X2.9 Procedure for Calculating Uncertainty: Certified Value of Standardized Test Blocks

X2.9.1 Standardizing laboratories engaged in the calibration of reference test blocks must determine the uncertainty in the reported certified average hardness value of the block. This uncertainty U_{Cert} provides an indication of how well the certified value would agree with the "true" average hardness of the test block.

X2.9.2 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 X2.8.5 for measuring the average hardness of a product. In this case, the product is a calibrated reference test block.

X2.9.3 For this procedure, all uncertainty calculations are initially based on indentation diameter values in mm units. The combined standard uncertainty $u_{Cert(mm)}$ and the expanded uncertainty $U_{Cert(mm)}$, are both in terms of indentation diameter. The uncertainty $U_{Cert(mm)}$ can then be converted to an expanded uncertainty $U_{Cert(HBW)}$ in terms of Brinell hardness numbers.

X2.9.4 The contributions to the standard uncertainty $u_{Cert(mm)}$ 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 X2.12], 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 X2.13], *(3)* u_{Resol}, the uncertainty due to the resolution of the indentation measurement system [Eq X2.14], and *(4)* $u_{Mach(mm)}$, the uncertainty in determining the "error" of the standardizing machine [Eq X2.22 or Eq X2.26]. The notation (*Calib. Block*) is added to the term $u_{Rep\&NU}$ to signify that the uncertainty is determined from calibration measurements made on the *calibrated block*.

X2.9.5 The combined standard uncertainty $u_{Cert(mm)}$ and the expanded uncertainty $U_{Cert(mm)}$ are calculated by combining the appropriate uncertainty components described above for each hardness level of each Brinell scale as:

$$u_{Cert(mm)} = \sqrt{u^2_{Rep\&NU}(Calib.\ Block) + u^2_{Reprod} + u^2_{Resol} + u^2_{Mach(mm)}} \quad (X2.33)$$

and

$$U_{Cert} = ku_{Cert} + ABS(B) \quad (X2.34)$$

X2.9.6 To determine the uncertainty of the certified average hardness value of the block in terms of Brinell hardness units $U_{Cert(HBW)}$, then the uncertainty, as calculated in [Eq X2.34], in terms of indentation diameter, must be converted using [Eq X2.3], where $U_{Cert(mm)}$ is substituted for Δd. The calculated value of ΔH then becomes the new value of $U_{Cert(HBW)}$, in Brinell hardness units, as:

$$U_{Cert(HBW)} = U_{Cert(mm)} \times \left(\frac{H \times \left(D + \sqrt{D^2 - d^2}\right)}{d \times \sqrt{D^2 - d^2}} \right) \quad (X2.35)$$

NOTE X2.16—The first minus sign in [Eq X2.3] has been deleted when using [Eq X2.35] since uncertainty values are always positive.

X2.9.7 For this analysis, a coverage factor of k = 2 should be used. This coverage factor provides a confidence level of approximately 95 %.

X2.9.8 *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 Brinell 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 was calculated in accordance with Appendix X1 of ASTM E10 with a coverage factor of 2 representing a confidence level of approximately 95 %."

X2.9.9 *Example*—A test-block standardizing laboratory has completed the calibration of a test block in the hardness range of 100 HBW 10/500, and measures the indentation with a measuring system having a resolution of 0.01 mm. The laboratory must determine the uncertainty in the certified average hardness value of the block. A hardness of 100 HBW 10/500 is considered within the high range of the HBW 10/500 scale. The results of the five calibration measurements are:

Average diameter lengths: 2.53, 2.50, 2.50, 2.51, and 2.51 mm
Calculated average indentation diameter: 2.51 mm
Calculated hardness values 97.8, 100, 100, 99.4 and 99.4 HBW 10/500
Calculated average hardness value: 99.4 HBW 10/500
Therefore:

$$u_{Rep\&NU}(Calib.\ Block) = \frac{STDEV(2.53, 2.50, 2.50, 2.51, 2.51)}{\sqrt{5}} \quad \text{[Eq X2.12], or}$$

$u_{Rep\&NU}(Calib.\ Block)$ = 0.0055 mm
For this example, assume the last direct verification of the high range of the HBW 10/500 scale reported:
$u_{Mach(mm)}$: 0.015 mm
Bias, $B_{(mm)}$: −0.004 mm
Also assume the hardness machine has been monitored for an extended period of time, and from [Eq X2.13], it was determined that:
u_{Reprod} = 0.004 mm for the high range of the HBW 10/500 scale
Other uncertainty contributions are calculated as:

$$u_{Resol} = \frac{0.01}{\sqrt{12}} = 0.0029 \text{ mm} \quad \text{[Eq X2.14] Therefore:}$$

$$u_{Cert(mm)} = \sqrt{0.0055^2 + 0.004^2 + 0.0029^2 + 0.015^2} \quad \text{[Eq X2.33], or}$$

$u_{Cert(mm)}$ = 0.167 HBW 10/500
and since B = –0.004 mm,

$$U_{Cert(mm)} = (2 \times 0.0167) + ABS(-0.004) \quad \text{[Eq X2.34], or}$$

$U_{Cert(mm)}$ = 0.0374 mm
In terms of Brinell hardness units:

$$U_{Cert(HBW)} = 0.0374 \times \left(\frac{99.4 \times \left(10 + \sqrt{10^2 - 2.51^2}\right)}{2.51 \times \sqrt{10^2 - 2.51^2}} \right)$$ [Eq X2.35], or

$U_{Cert(HBW)} = 3.0$ HBW 10/500 for the certified hardness value of the single calibrated test block.

SUMMARY OF CHANGES

Committee E28 has identified the location of selected changes to this standard since the last issue (E10 – 15a) that may impact the use of this standard. (Approved April 1, 2017.)

(1) Added Note A1.4.
(2) Revised A1.6.3.8, A1.6.4.9, and A2.8.1.8.
(3) Revised Table 1.
(4) Added 3.2.2.
(5) Revised 3.2.3.
(6) Revised 3.2.5.
(7) Revised Table A1.2 and Table A2.6.
(8) Revised A4.5.3, A4.5.4, A4.5.1, A4.5.5 and A4.7.1.3.

Committee E28 has identified the location of selected changes to this standard since the last issue (E10–15) that may impact the use of this standard. (Approved December 1, 2015)

(1) 7.6.3 was revised.

Committee E28 has identified the location of selected changes to this standard since the last issue (E10–14) that may impact the use of this standard. (Approved May, 1 2015)

(1) A1.5.2.3 was revised.

Committee E28 has identified the location of selected changes to this standard since the last issue (E10–12) that may impact the use of this standard. (Approved May 1, 2014)

(1) 9.1.1 was revised.