



Standard Test Method for Brinell Hardness of Metallic Materials¹

This standard is issued under the fixed designation E 10; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

^{ε1} NOTE—The layout of Table 2 was editorially corrected in March 2007.

1. Scope*

1.1 This test method (Test Method A) covers the determination of the Brinell hardness of metallic materials, including methods for the verification of Brinell hardness testing machines (Test Method B) and the calibration of standardized hardness test blocks (Test Method C).

1.2 The values stated in SI units are to be regarded as the standard.

NOTE 1—In common terminology, the equivalent force in kgf is substituted for N.

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

2. Referenced Documents

2.1 ASTM Standards:²

- E 4 Practices for Force Verification of Testing Machines
- E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 74 Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines
- E 140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness

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. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *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.

$$HBW = 0.102 \times \frac{2F}{\pi D(D - \sqrt{D^2 - d^2})} \quad (\text{See Table 1}) \quad (1)$$

where:

D = diameter of the ball, mm,

F = test force, N, and

d = mean diameter of the indentation, mm.

The Brinell hardness is denoted by the symbol: HBW.

3.1.1.1 *Discussion*—In former standards, a steel ball was allowed for hardness values below 450. In cases when a steel ball was used, the Brinell hardness was denoted by HB or HBS.

3.1.1.2 *Discussion*—The symbol HBW is preceded by the hardness value. When conditions other than those specified in 11.1.2 are used, the hardness value is supplemented by an index indicating the test conditions in the order:

(1) Diameter of the ball, in mm,

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

(3) Duration of loading, in s.

Examples:

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 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.

3.1.1.3 *Discussion*—Brinell hardness numbers vary with the test force used; however, test results will generally be in agreement when the ratio of the test force to the square of the ball diameter is held constant (see Table 3).

3.1.1.4 *Discussion*—Table 2 lists the Brinell hardness numbers corresponding to various diameters of indentations for 29.4 kN (3000 kgf), 14.7 kN (1500 kgf), and 4.90 kN (500 kgf) test forces making it unnecessary to calculate for each test the value of the Brinell hardness number by the above equation in Table 1 when these forces are used with a 10-mm diameter ball.

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

TABLE 1 Symbols and Designations

NOTE 1—Constant = $\frac{1}{g_n} = \frac{1}{9.806\,65} = 0.102$

Symbol	Designation
D	Diameter of the ball, mm
F	Test force, N
d	Mean diameter of the indentation, mm
h	Depth of the indentation, mm
HBW	Brinell hardness
	= Constant $\times \frac{\text{Test force}}{\text{Surface area of indentation}}$
	= $0.102 \times \frac{2F}{\pi D(D - \sqrt{D^2 - d^2})}$

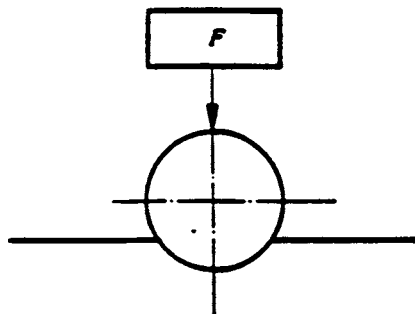


FIG. 1 Principle of Test

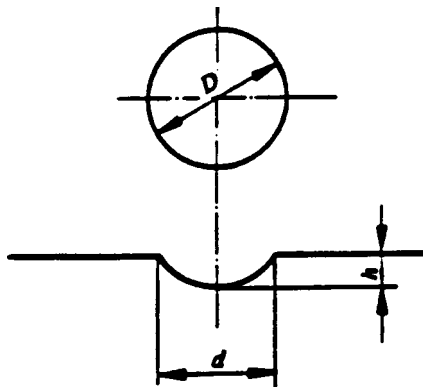


FIG. 2 Principle of Test

3.1.2 *Brinell hardness test*—an indenter (tungsten carbide ball with diameter D) is forced into the surface of a test piece and the diameter of the indentation d left in the surface after removal of the test force, F , is measured. (see Table 1 and Figs. 1 and 2.)

3.1.2.1 *Discussion*—The tungsten carbide ball may be used for materials with a Brinell hardness not exceeding 650.

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

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

4. Significance and Use

4.1 The Brinell hardness test is an empirical indentation hardness test. Brinell hardness tests 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. Brinell hardness testing at the specific location on a part may not represent the physical characteristics of the whole part or end product. Brinell hardness tests are considered satisfactory for acceptance testing of commercial shipments, and they have been used extensively in industry for this purpose.

TEST METHOD A—GENERAL DESCRIPTION AND TEST PROCEDURE FOR BRINELL HARDNESS TESTS

5. Apparatus

5.1 *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. The design of the testing machines 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 shall be 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. See equipment manufacturer's instruction manual for a description of the machine's characteristics, limitations, and respective operating procedure.

5.2 Brinell Balls:

5.2.1 The standard ball for Brinell hardness testing shall be 10.000 mm in diameter with a deviation from this value of not more than 0.005 mm in any diameter. The ball shall be polished and free of surface defects. Smaller balls having the diameters and tolerances indicated in Table 4 may be used also provided the precautions set forth in 8.1 are observed.

5.2.2 The tungsten carbide ball indenter shall have a minimum hardness of 1500 HV10.

NOTE 2—**Caution:** The Brinell test is not recommended for material having hardness over 650 HBW (see 8.1).

5.2.2.1 The chemical composition of tungsten carbide balls shall be:

Tungsten Carbide (WC)	Balance
Cobalt (Co)	5.0 to 7.0 %
Total other Carbides	2.0 % max

5.2.2.2 The use of hardened steel ball indenters has been eliminated from this test method. Only tungsten carbide balls may now be used for this test method.

5.2.3 If a ball is used to test a specimen which shows a Brinell hardness greater than 650, the result should be considered suspect and the ball inspected for damage. If there is any evidence of damage, the ball shall be replaced.

5.3 *Measuring Device*—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 direct measuring of the diameter to 0.1 mm and the estimation of the diameter to 0.05 mm.

NOTE 3—This requirement applies to the construction of the device only and is not a requirement for measurement of the indentation.

TABLE 2 Brinell Hardness Numbers^A
(Ball 10 mm in Diameter, Applied Forces of 500, 1500, and 3000 kgf)

NOTE 1—The values given in this table for Brinell hardness numbers are merely solutions of the equation given in the definition in 3.1.1, and include values for impression diameters outside the ranges recommended in 8.1. These values are indicated by italics.

Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number		
	500- kgf Force	1500- kgf Force	3000- kgf Force		500- kgf Force	1500- kgf Force	3000- kgf Force		500- kgf Force	1500- kgf Force	3000- kgf Force		500- kgf Force	1500- kgf Force	3000- kgf Force
2.00	158	473	945	2.60	92.6	278	555	3.20	60.5	182	363	3.80	42.4	127	255
2.01	156	468	936	2.61	91.8	276	551	3.21	60.1	180	361	3.81	42.2	127	253
2.02	154	463	926	2.62	91.1	273	547	3.22	59.8	179	359	3.82	42.0	126	252
2.03	153	459	917	2.63	90.4	271	543	3.23	59.4	178	356	3.83	41.7	125	250
2.04	151	454	908	2.64	89.7	269	538	3.24	59.0	177	354	3.84	41.5	125	249
2.05	150	450	899	2.65	89.0	267	534	3.25	58.6	176	352	3.85	41.3	124	248
2.06	148	445	890	2.66	88.4	265	530	3.26	58.3	175	350	3.86	41.1	123	246
2.07	147	441	882	2.67	87.7	263	526	3.27	57.9	174	347	3.87	40.9	123	245
2.08	146	437	873	2.68	87.0	261	522	3.28	57.5	173	345	3.88	40.6	122	244
2.09	144	432	865	2.69	86.4	259	518	3.29	57.2	172	343	3.89	40.4	121	242
2.10	143	428	856	2.70	85.7	257	514	3.30	56.8	170	341	3.90	40.2	121	241
2.11	141	424	848	2.71	85.1	255	510	3.31	56.5	169	339	3.91	40.0	120	240
2.12	140	420	840	2.72	84.4	253	507	3.32	56.1	168	337	3.92	39.8	119	239
2.13	139	416	832	2.73	83.8	251	503	3.33	55.8	167	335	3.93	39.6	119	237
2.14	137	412	824	2.74	83.2	250	499	3.34	55.4	166	333	3.94	39.4	118	236
2.15	136	408	817	2.75	82.6	248	495	3.35	55.1	165	331	3.95	39.1	117	235
2.16	135	404	809	2.76	81.9	246	492	3.36	54.8	164	329	3.96	38.9	117	234
2.17	134	401	802	2.77	81.3	244	488	3.37	54.4	163	326	3.97	38.7	116	232
2.18	132	397	794	2.78	80.8	242	485	3.38	54.1	162	325	3.98	38.5	116	231
2.19	131	393	787	2.79	80.2	240	481	3.39	53.8	161	323	3.99	38.3	115	230
2.20	130	390	780	2.80	79.6	239	477	3.40	53.4	160	321	4.00	38.1	114	229
2.21	129	386	772	2.81	79.0	237	474	3.41	53.1	159	319	4.01	37.9	114	228
2.22	128	383	765	2.82	78.4	235	471	3.42	52.8	158	317	4.02	37.7	113	226
2.23	126	379	758	2.83	77.9	234	467	3.43	52.5	157	315	4.03	37.5	113	225
2.24	125	376	752	2.84	77.3	232	464	3.44	52.2	156	313	4.04	37.3	112	224
2.25	124	372	745	2.85	76.8	230	461	3.45	51.8	156	311	4.05	37.1	111	223
2.26	123	369	738	2.86	76.2	229	457	3.46	51.5	155	309	4.06	37.0	111	222
2.27	122	366	732	2.87	75.7	227	454	3.47	51.2	154	307	4.07	36.8	110	221
2.28	121	363	725	2.88	75.1	225	451	3.48	50.9	153	306	4.08	36.6	110	219
2.29	120	359	719	2.89	74.6	224	448	3.49	50.6	152	304	4.09	36.4	109	218
2.30	119	356	712	2.90	74.1	222	444	3.50	50.3	151	302	4.10	36.2	109	217
2.31	118	353	706	2.91	73.6	221	441	3.51	50.0	150	300	4.11	36.0	108	216
2.32	117	350	700	2.92	73.0	219	438	3.52	49.7	149	298	4.12	35.8	108	215
2.33	116	347	694	2.93	72.5	218	435	3.53	49.4	148	297	4.13	35.7	107	214
2.34	115	344	688	2.94	72.0	216	432	3.54	49.2	147	295	4.14	35.5	106	213
2.35	114	341	682	2.95	71.5	215	429	3.55	48.9	147	293	4.15	35.3	106	212
2.36	113	338	676	2.96	71.0	213	426	3.56	48.6	146	292	4.16	35.1	105	211
2.37	112	335	670	2.97	70.5	212	423	3.57	48.3	145	290	4.17	34.9	105	210
2.38	111	332	665	2.98	70.1	210	420	3.58	48.0	144	288	4.18	34.8	104	209
2.39	110	330	659	2.99	69.6	209	417	3.59	47.7	143	286	4.19	34.6	104	208
2.40	109	327	653	3.00	69.1	207	415	3.60	47.5	142	285	4.20	34.4	103	207
2.41	108	324	648	3.01	68.6	206	412	3.61	47.2	142	283	4.21	34.2	103	205
2.42	107	322	643	3.02	68.2	205	409	3.62	46.9	141	282	4.22	34.1	102	204
2.43	106	319	637	3.03	67.7	203	406	3.63	46.7	140	280	4.23	33.9	102	203
2.44	105	316	632	3.04	67.3	202	404	3.64	46.4	139	278	4.24	33.7	101	202
2.45	104	313	627	3.05	66.8	200	401	3.65	46.1	138	277	4.25	33.6	101	201
2.46	104	311	621	3.06	66.4	199	398	3.66	45.9	138	275	4.26	33.4	100	200
2.47	103	308	616	3.07	65.9	198	395	3.67	45.6	137	274	4.27	33.2	99.7	199
2.48	102	306	611	3.08	65.5	196	393	3.68	45.4	136	272	4.28	33.1	99.2	198
2.49	101	303	606	3.09	65.0	195	390	3.69	45.1	135	271	4.29	32.9	98.8	198
2.50	100	301	601	3.10	64.6	194	388	3.70	44.9	135	269	4.30	32.8	98.3	197
2.51	99.4	298	597	3.11	64.2	193	385	3.71	44.6	134	268	4.31	32.6	97.8	196
2.52	98.6	296	592	3.12	63.8	191	383	3.72	44.4	133	266	4.32	32.4	97.3	195
2.53	97.8	294	587	3.13	63.3	190	380	3.73	44.1	132	265	4.33	32.3	96.8	194
2.54	97.1	291	582	3.14	62.9	189	378	3.74	43.9	132	263	4.34	32.1	96.4	193
2.55	96.3	289	578	3.15	62.5	188	375	3.75	43.6	131	262	4.35	32.0	95.9	192
2.56	95.5	287	573	3.16	62.1	186	373	3.76	43.4	130	260	4.36	31.8	95.5	191
2.57	94.8	284	569	3.17	61.7	185	370	3.77	43.1	129	259	4.37	31.7	95.0	190
2.58	94.0	282	564	3.18	61.3	184	368	3.78	42.9	129	257	4.38	31.5	94.5	189
2.59	93.3	280	560	3.19	60.9	183	366	3.79	42.7	128	256	4.39	31.4	94.1	188

TABLE 2 *Continued*

Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number		
	500- kgf Force	1500- kgf Force	3000- kgf Force		500- kgf Force	1500- kgf Force	3000- kgf Force		500- kgf Force	1500- kgf Force	3000- kgf Force		500- kgf Force	1500- kgf Force	3000- kgf Force
4.40	31.2	93.6	187	5.05	23.3	69.8	140	5.70	17.8	53.5	107	6.35	14.0	42.0	84.0
4.41	31.1	93.2	186	5.06	23.2	69.5	139	5.71	17.8	53.3	107	6.36	13.9	41.8	83.7
4.42	30.9	92.7	185	5.07	23.1	69.2	138	5.72	17.7	53.1	106	6.37	13.9	41.7	83.4
4.43	30.8	92.3	185	5.08	23.0	68.9	138	5.73	17.6	52.9	106	6.38	13.8	41.5	83.1
4.44	30.6	91.8	184	5.09	22.9	68.6	137	5.74	17.6	52.7	105	6.39	13.8	41.4	82.8
4.45	30.5	91.4	183	5.10	22.8	68.3	137	5.75	17.5	52.5	105	6.40	13.7	41.2	82.5
4.46	30.3	91.0	182	5.11	22.7	68.0	136	5.76	17.4	52.3	105	6.41	13.7	41.1	82.2
4.47	30.2	90.5	181	5.12	22.6	67.7	135	5.77	17.4	52.1	104	6.42	13.6	40.9	81.9
4.48	30.0	90.1	180	5.13	22.5	67.4	135	5.78	17.3	51.9	104	6.43	13.6	40.8	81.6
4.49	29.9	89.7	179	5.14	22.4	67.1	134	5.79	17.2	51.7	103	6.44	13.5	40.6	81.3
4.50	29.8	89.3	179	5.15	22.3	66.9	134	5.80	17.2	51.5	103	6.45	13.5	40.5	81.0
4.51	29.6	88.8	178	5.16	22.2	66.6	133	5.81	17.1	51.3	103	6.46	13.4	40.4	80.7
4.52	29.5	88.4	177	5.17	22.1	66.3	133	5.82	17.0	51.1	102	6.47	13.4	40.2	80.4
4.53	29.3	88.0	176	5.18	22.0	66.0	132	5.83	17.0	50.9	102	6.48	13.4	40.1	80.1
4.54	29.2	87.6	175	5.19	21.9	65.8	132	5.84	16.9	50.7	101	6.49	13.3	39.9	79.8
4.55	29.1	87.2	174	5.20	21.8	65.5	131	5.85	16.8	50.5	101	6.50	13.3	39.8	79.6
4.56	28.9	86.8	174	5.21	21.7	65.2	130	5.86	16.8	50.3	101	6.51	13.2	39.6	79.3
4.57	28.8	86.4	173	5.22	21.6	64.9	130	5.87	16.7	50.2	100	6.52	13.2	39.5	79.0
4.58	28.7	86.0	172	5.23	21.6	64.7	129	5.88	16.7	50.0	99.9	6.53	13.1	39.4	78.7
4.59	28.5	85.6	171	5.24	21.5	64.4	129	5.89	16.6	49.8	99.5	6.54	13.1	39.2	78.4
4.60	28.4	85.4	170	5.25	21.4	64.1	128	5.90	16.5	49.6	99.2	6.55	13.0	39.1	78.2
4.61	28.3	84.8	170	5.26	21.3	63.9	128	5.91	16.5	49.4	98.8	6.56	13.0	38.9	78.0
4.62	28.1	84.4	169	5.27	21.2	63.6	127	5.92	16.4	49.2	98.4	6.57	12.9	38.8	77.6
4.63	28.0	84.0	168	5.28	21.1	63.3	127	5.93	16.3	49.0	98.0	6.58	12.9	38.7	77.3
4.64	27.9	83.6	167	5.29	21.0	63.1	126	5.94	16.3	48.8	97.7	6.59	12.8	38.5	77.1
4.65	27.8	83.3	167	5.30	20.9	62.8	126	5.95	16.2	48.7	97.3	6.60	12.8	38.4	76.8
4.66	27.6	82.9	166	5.31	20.9	62.6	125	5.96	16.2	48.5	96.9	6.61	12.8	38.3	76.5
4.67	27.5	82.5	165	5.32	20.8	62.3	125	5.97	16.1	48.3	96.6	6.62	12.7	38.1	76.2
4.68	27.4	82.1	164	5.33	20.7	62.1	124	5.98	16.0	48.1	96.2	6.63	12.7	38.0	76.0
4.69	27.3	81.8	164	5.34	20.6	61.8	124	5.99	16.0	47.9	95.9	6.64	12.6	37.9	75.7
4.70	27.1	81.4	163	5.35	20.5	61.5	123	6.00	15.9	47.7	95.5	6.65	12.6	37.7	75.4
4.71	27.0	81.0	162	5.36	20.4	61.3	123	6.01	15.9	47.6	95.1	6.66	12.5	37.6	75.2
4.72	26.9	80.7	161	5.37	20.3	61.0	122	6.02	15.8	47.4	94.8	6.67	12.5	37.5	74.9
4.73	26.8	80.3	161	5.38	20.3	60.8	122	6.03	15.7	47.2	94.4	6.68	12.4	37.3	74.7
4.74	26.6	79.9	160	5.39	20.2	60.6	121	6.04	15.7	47.0	94.1	6.69	12.4	37.2	74.4
4.75	26.5	79.6	159	5.40	20.1	60.3	121	6.05	15.6	46.8	93.7	6.70	12.4	37.1	74.1
4.76	26.4	79.2	158	5.41	20.0	60.1	120	6.06	15.6	46.7	93.4	6.71	12.3	36.9	73.9
4.77	26.3	78.9	158	5.42	19.9	59.8	120	6.07	15.5	46.5	93.0	6.72	12.3	36.8	73.6
4.78	26.2	78.5	157	5.43	19.9	59.6	119	6.08	15.4	46.3	92.7	6.73	12.2	36.7	73.4
4.79	26.1	78.2	156	5.44	19.8	59.3	119	6.09	15.4	46.2	92.3	6.74	12.2	36.6	73.1
4.80	25.9	77.8	156	5.45	19.7	59.1	118	6.10	15.3	46.0	92.0	6.75	12.1	36.4	72.8
4.81	25.8	77.5	155	5.46	19.6	58.9	118	6.11	15.3	45.8	91.7	6.76	12.1	36.3	72.6
4.82	25.7	77.1	154	5.47	19.5	58.6	117	6.12	15.2	45.7	91.3	6.77	12.1	36.2	72.3
4.83	25.6	76.8	154	5.48	19.5	58.4	117	6.13	15.2	45.5	91.0	6.78	12.0	36.0	72.1
4.84	25.5	76.4	153	5.49	19.4	58.2	116	6.14	15.1	45.3	90.6	6.79	12.0	35.9	71.8
4.85	25.4	76.1	152	5.50	19.3	57.9	116	6.15	15.1	45.2	90.3	6.80	11.9	35.8	71.6
4.86	25.3	75.8	152	5.51	19.2	57.7	115	6.16	15.0	45.0	90.0	6.81	11.9	35.7	71.3
4.87	25.1	75.4	151	5.52	19.2	57.5	115	6.17	14.9	44.8	89.6	6.82	11.8	35.5	71.1
4.88	25.0	75.1	150	5.53	19.1	57.2	114	6.18	14.9	44.7	89.3	6.83	11.8	35.4	70.8
4.89	24.9	74.8	150	5.54	19.0	57.0	114	6.19	14.8	44.5	89.0	6.84	11.8	35.3	70.6
4.90	24.8	74.4	149	5.55	18.9	56.8	114	6.20	14.7	44.3	88.7	6.86	11.7	35.2	70.4
4.91	24.7	74.1	148	5.56	18.9	56.6	113	6.21	14.7	44.2	88.3	6.86	11.7	35.1	70.1
4.92	24.6	73.8	148	5.57	18.8	56.3	113	6.22	14.7	44.0	88.0	6.87	11.6	34.9	69.9
4.93	24.5	73.5	147	5.58	18.7	56.1	112	6.23	14.6	43.8	87.7	6.88	11.6	34.8	69.6
4.94	24.4	73.2	146	5.59	18.6	55.9	112	6.24	14.6	43.7	87.4	6.89	11.6	34.7	69.4
4.95	24.3	72.8	146	5.60	18.6	55.7	111	6.25	14.5	43.5	87.1	6.90	11.5	34.6	69.2
4.96	24.2	72.5	145	5.61	18.5	55.5	111	6.26	14.5	43.4	86.7	6.91	11.5	34.5	68.9
4.97	24.1	72.2	144	5.62	18.4	55.2	110	6.27	14.4	43.2	86.4	6.92	11.4	34.3	68.7
4.98	24.0	71.9	144	5.63	18.3	55.0	110	6.28	14.4	43.1	86.1	6.93	11.4	34.2	68.4
4.99	23.9	71.6	143	5.64	18.3	54.8	110	6.29	14.3	42.9	85.8	6.94	11.4	34.1	68.2
5.00	23.8	71.3	143	5.65	18.2	54.6	109	6.30	14.2	42.7	85.5	6.95	11.3	34.0	68.0
5.01	23.7	71.0	142	5.66	18.1	54.4	109	6.31	14.2	42.6	85.2	6.96	11.3	33.9	67.7
5.02	23.6	70.7	141	5.67	18.1	54.2	108	6.32	14.1	42.4	84.9	6.97	11.3	33.8	67.5
5.03	23.5	70.4	141	5.68	18.0	54.0	108	6.33	14.1	42.3	84.6	6.98	11.2	33.6	67.3
5.04	23.4	70.1	140	5.69	17.9	53.7	107	6.34	14.0	42.1	84.3	6.99	11.2	33.5	67.0

^A Prepared by the Engineering Mechanics Section, National Bureau of Standards.

TABLE 3 Test Conditions

Hardness Symbol	Ball Diameter D , mm	0.102 F D^2	Test Force F Nominal Value
HBW 10/3000	10	30	29.42 kN – (3000 kgf)
HBW 10/1500	10	15	14.71 kN – (1500 kgf)
HBW 10/1000	10	10	9.807 kN – (1000 kgf)
HBW 10/500	10	5	4.903 kN – (500 kgf)
HBW 10/250	10	2.5	2.452 kN – (250 kgf)
HBW 10/125	10	1.25	1.226 kN – (125 kgf)
HBW 10/100	10	1	980.7 N – (100 kgf)
HBW 5/750	5	30	7.355 kN – (750 kgf)
HBW 5/250	5	10	2.452 kN – (250 kgf)
HBW 5/125	5	5	1.226 kN – (125 kgf)
HBW 5/62.5	5	2.5	612.9 N – (62.5 kgf)
HBW 5/31.25	5	1.25	306.5 N – (31.25 kgf)
HBW 5/25	5	1	245.2 N – (25 kgf)
HBW 2.5/187.5	2.5	30	1.839 kN – (187.5 kgf)
HBW 2.5/62.5	2.5	10	612.9 N – (62.5 kgf)
HBW 2.5/31.25	2.5	5	306.5 N – (31.25 kgf)
HBW 2.5/15.625	2.5	2.5	153.2 N – (15.625 kgf)
HBW 2.5/7.8125	2.5	1.25	76.61 N – (7.8125 kgf)
HBW 2.5/6.25	2.5	1	61.29 N – (6.25 kgf)
HBW 2/120	2	30	1.177 kN – (120 kgf)
HBW 2/40	2	10	392.3 N – (40 kgf)
HBW 2/20	2	5	196.1 N – (20 kgf)
HBW 2/10	2	2.5	98.07 N – (10 kgf)
HBW 2/5	2	1.25	49.03 N – (5 kgf)
HBW 2/4	2	1	39.23 N – (4 kgf)
HBW 1/30	1	30	294.2 N – (30 kgf)
HBW 1/10	1	10	98.07 N – (10 kgf)
HBW 1/5	1	5	49.03 N – (5 kgf)
HBW 1/2.5	1	2.5	24.52 N – (2.5 kgf)
HBW 1/1.25	1	1.25	12.26 N – (1.25 kgf)
HBW 1/1	1	1	9.807 N – (1 kgf)

TABLE 4 Tolerances for Brinell Hardness Balls

Ball Diameter, mm	Tolerance, mm
10	±0.005
5	±0.004
2.5	±0.003
2	±0.003
1	±0.003

TABLE 5 Minimum Thickness Requirements for Brinell Hardness Tests

Minimum Thickness of Specimen		Minimum Hardness for Which the Brinell Test May Safely Be Made		
in.	mm	3000-kgf Force	1500-kgf Force	500-kgf Force
1/16	1.6	602	301	100
1/8	3.2	301	150	50
3/16	4.8	201	100	33
1/4	6.4	150	75	25
5/16	8.0	120	60	20
3/8	9.6	100	50	17

6. Test Specimen

6.1 There is no standard shape or size for a Brinell test specimen. The specimen upon which the indentation is made shall 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. As a general rule, the thickness of the specimen shall be at least ten times the depth of the indentation (Table 5).

TABLE 6 Standard Test Forces

Ball Diameter, mm	Force	Recommended Range, HBW
10	29.42 kN (3000 kgf)	96 to 600
10	14.7 kN (1500 kgf)	48 to 300
10	4.90 kN (500 kgf)	16 to 100

TABLE 7 Hardness Ranges Used by Standard Test Block Method

100 to 200 HBW
300 to 400 HBW
500 to 600 HBW

6.1.2 The minimum width shall conform with the requirements of 8.3.

6.1.3 *Finish*—When necessary, the surface on which the indentation is to be made shall be filed, ground, machined or polished with abrasive material so that the edge of the indentation shall be clearly defined to permit the measurement of the diameter to the specified accuracy (see 9.1). Care should be taken to avoid overheating or cold working the surface.

7. Verification of Testing Machine

7.1 *Verification Methods*—The hardness testing machine shall be verified in accordance with one of the two acceptable methods of verifying Brinell hardness testing machines as given in Test Method B.

7.2 *Test Force Range*—When direct verification is used, the Brinell hardness testing machine is acceptable for use over a test force range within which the error in test force does not exceed ±1 %. When indirect verification is used, the Brinell hardness machine is acceptable for use over a test force range within which the mean hardness value obtained is within ±3 % of the Brinell hardness of the standardized test blocks used.

8. Procedure

8.1 *Magnitude of Test Force*—Typically, the force in the standard Brinell test shall be 29.42 kN (3000 kgf), 14.7 kN (1500 kgf), or 4.90 kN (500 kgf). It is recommended that the diameter of the indentation be between 24 and 60 % of the ball diameter. A lower limit in indentation diameter is necessary because of the risk in damaging the ball and difficulty measuring the indentation. The upper limit is necessary because of a reduction in sensitivity as the diameter of the indentation approaches the ball diameter. The thickness and spacing requirements of 6.1.1, 6.1.2, and 8.3 may determine the maximum permissible diameter of indentation for a specific test. Table 6 gives standard test forces and approximate Brinell hardness numbers for the above range of indentation diameters. It is not mandatory that the Brinell test conform to these hardness ranges, but it should be realized that different Brinell hardness numbers may be obtained for a given material by using different forces on a 10-mm diameter ball. For the purpose of obtaining a continuous scale of values it may be desirable, however, to use a single force to cover the complete range of hardness for a given class of materials. For softer metals, forces of 2.45 kN (250 kgf), 1.23 kN (125 kgf), or

0.981 kN (100 kgf) are sometimes used. The force used shall be specifically stated in the test report (see 11.1.2).

8.1.1 For testing thin or small specimens, a ball less than 10 mm in diameter is sometimes used. Such tests, which are not to be regarded as standard tests, will approximate the standard tests more closely if the relation between the applied force, F , measured in N, and the diameter of the ball, D , measured in mm is the same as in the standard tests,

where:

$$0.102F/D^2 = 30 \text{ for } 29.42 \text{ kN (3000 kgf) force and 10-mm ball,}$$

$$0.102F/D^2 = 15 \text{ for } 14.72 \text{ kN (1500 kgf) force and 10-mm ball, and}$$

$$0.102F/D^2 = 5 \text{ for } 4.90 \text{ kN (500 kgf) force and 10-mm ball.}$$

8.1.1.1 *Example*—A 1.23-kN (125-kgf) test force on a 5-mm diameter ball would approximate a standard 4.90-kN (500-kgf) test force on a 10-mm diameter ball.

8.1.2 Tests for soft metals often are made with the following force-diameter ratios:

$$0.102F/D^2 = 2.5 \quad (2)$$

$$0.102F/D^2 = 1.25$$

$$0.102F/D^2 = 1.0$$

8.1.3 When balls smaller than 10 mm in diameter are used, both the test force and ball size shall be specifically stated in the test report (see 3.1.1, 3.1.1.1, and 11.1.2).

8.2 *Radius of Curvature*—When indentations are made on a curved surface, the minimum radius of curvature of the surface shall be not less than $2\frac{1}{2}$ 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.

8.3 *Spacing of Indentations*—The distance of the center of the indentation from the edge of the specimen or edge of another indentation shall be at least two and one half times the diameter of the indentation.

8.4 *Application of Test Force*—Apply the force to the specimen uniformly taking precautions to prevent a momentary overload of the system. Apply the full test force for 10 to 15 s.

8.4.1 If a duration of test force application other than 10 to 15 s is used, results of the test shall be reported using the nomenclature outlined in 3.1.1.2 and 11.1.2.

8.5 *Alignment*—The angle between the indenter force line and the surface of the specimen should be $90 \pm 2^\circ$ (see 9.1).

9. Measurement of Indentation

9.1 *Diameter*—In the Brinell hardness test, two diameters of the indentation at right angles to each other shall be measured and their mean value used as a basis for calculation of the Brinell hardness number for flat specimens. If the largest and smallest diameters for two readings of the same indentation differ by 0.1 mm or more, refer to the material specifications for further guidance. For routine tests and for tests to determine compliance with a material or product specification, the diameter of the indentation shall be estimated to 0.05 mm (0.0020 in.).

NOTE 4—These measurements are usually made with a low-magnification portable measuring device (approximately 20 $\times$) having a fixed scale in the eyepiece. If a more accurate determination is needed, as in referee or standardization tests, a laboratory comparator such as a micrometer measuring device is required.

10. Conversion to Other Hardness Scales or Tensile Strength Values

10.1 There is no general method for accurately converting Brinell hardness numbers to other hardness scales or tensile strength values. Such conversion are, at best, approximations and, therefore, should be avoided except for special cases where a reliable basis for the approximate conversion has been obtained by comparison tests.

NOTE 5—Hardness Conversion Tables E 140 for Metals give approximate hardness conversion values for specific materials such as steel, austenitic stainless steel, nickel and high-nickel alloys, and cartridge brass.

11. Report

11.1 Whenever a Brinell hardness number is used, provide the following information:

11.1.1 The Brinell hardness number, which shall be reported rounded to three significant digits in accordance with rounding method in Practice E 29 (for example, 125 HBW, 99.2 HBW).

11.1.2 The test conditions when the Brinell hardness number is determined from forces other than 29.42 kN (3000 kgf), ball diameters other than 10 mm, and test force applications other than 10 to 15 s (see 3.1.1 and 8.4).

12. Precision and Bias

12.1 *Precision*—An interlaboratory comparison program is now in progress which, when completed, will be the basis of a statement on precision.

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

TEST METHOD B—VERIFICATION OF BRINELL HARDNESS TESTING MACHINES

13. Scope

13.1 Test Method B covers two procedures for the verification of Brinell hardness testing machines. These are as follows:

13.1.1 *Direct Verification*—Separate verification of force application, indenter, and the measuring device for measuring the diameter of the indentation.

13.1.2 *Indirect Verification*—Verification by the standardized test block method.

13.2 New or rebuilt machines shall be initially checked by the direct verification method (see 13.1.1) before being placed in service.

13.3 Machines used for routine testing may be checked by either verification method.

14. General Requirements

14.1 Before a Brinell hardness testing machine is verified, the machine shall be examined to ensure that:

14.1.1 The machine is set up properly.

14.1.2 The ball holder, with a new ball whose nominal diameter has been checked (see 15.1.2), is mounted firmly in the plunger.

14.1.3 The force will be applied and removed without shock or vibration.

14.2 If the measuring device is integral with the machine, the machine shall be examined to ensure the following:

14.2.1 The change from test force application to measuring does not influence the readings.

14.2.2 The method of illumination does not affect the readings.

14.2.3 The center of the indentation is in the center of the field of view.

15. Verification

15.1 *Direct Verification*—Separate verification of force application, indenter, and measuring device:

15.1.1 *Force Application*—Brinell hardness testing machines shall be verified at the test force(s) at which it is used. The test forces will be checked periodically with a force measuring device traceable to national standards (in the United States, National Institute of Standards and Technology) in the manner described in Practices E 4. A Brinell hardness testing machine is acceptable for use when the test force error does not exceed $\pm 1\%$.

15.1.2 *Indenter*—The indenter to be verified shall be a new ball selected at random from a lot meeting the hardness requirements specified in 5.2. The diameter of each ball shall be verified at not less than three positions and the mean of these readings shall not differ from the nominal diameter by more than the tolerance specified in Table 4.

15.1.3 *Measuring Device*—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. The adjustment of the device shall be such that, throughout the range covered, the difference between the scale divisions of the device and of the calibrating scale does not exceed 0.01 mm (0.0004 in.).

15.1.4 The verification is incomplete if a verification report is not issued.

15.2 *Indirect Verification*—Verification by standardized test block method.

15.2.1 A Brinell hardness testing machine also may be checked by making a series of at least five indentations on standardized hardness test blocks (Test Method C).

15.2.2 If the machine is to be used at conditions other than 10/29.42 kN (3000 kgf)/15, the machine also shall be verified at those other conditions.

15.2.3 The testing machine shall be verified for each test force and for each size of ball used. For each test force, standardized blocks within the hardness ranges given in Table 7, shall be used.

NOTE 6—When the hardness test in question makes it impossible to reach the higher hardness range defined in Table 7 (for $0.102/F/D^2 = 5$ or 10), the verification may be carried out with two blocks from the lower hardness range.

15.2.3.1 Verification shall be carried out using a tungsten carbide ball and this verification will be valid for hardnesses ≤ 650 HBW.

15.2.4 *Repeatability*—For each standardized block, let $d_1, d_2, \dots, d_n$ be the mean values of the measured diameter of the indentations, arranged in increasing order of magnitude. The repeatability of the testing machine under the particular verification conditions is determined by the following quantity:

$$d_n - d_1 \quad (3)$$

The repeatability of the testing machine verified is not considered satisfactory unless it satisfies the conditions given in Table 8.

15.2.5 *Error*—The error of the testing machine under the particular verification conditions is characterized by the following quantity:

$$\bar{H} - H \quad (4)$$

where:

$$\text{error} = \bar{H} - H$$

$$\bar{H} = \frac{H_1 + H_2 + \dots + H_n}{n} \quad (5)$$

$H_1, H_2, \dots, H_n$ = the hardness values corresponding to $d_1, d_2, \dots, d_n$, and

H = specified hardness of the standardized block.

15.2.6 The Brinell hardness testing machine shall be considered verified if the mean hardness differs by no more than 3 % from the hardness value of the standardized hardness test block.

15.2.7 The verification is incomplete if a verification report is not issued.

15.3 *Verification Report*—The test report shall include the following information:

15.3.1 Reference to this ASTM test method,

15.3.2 Method of verification (direct or indirect),

15.3.3 Identification of the hardness testing machine,

15.3.4 Means of verification (test blocks, elastic proving devices, etc.),

15.3.5 Diameter of indenter ball and test force,

15.3.6 The result obtained,

15.3.7 Date of verification and reference to the calibration institution, and

15.3.8 Identity of person performing the verification.

16. Procedure for Periodic Checks by the User

16.1 Verification by the standardized test block method (15.2) is too lengthy for daily use. Instead, the following is recommended:

16.1.1 Make at least one routine check in accordance with 16.1.2 each day that the testing machine is used.

TABLE 8 Repeatability of Testing Machine

Hardness of Standardized Block HBW	Repeatability of the Testing Machine, max	HBW	
		H	$H_1 - H_{15}, \text{max}$
<225	0.04 $\bar{d}^A$	100	9
		200	17
		300	12
>225	0.02 $\bar{d}^A$	400	17
		500	20
		600	24

$$^A \bar{d} = (d_1 + d_2 + \dots + d_n)/n$$

16.1.2 Consult the machine manufacturer's start-up procedures. Select the force, indenter, and measuring device that will be used for the routine testing. Make at least two indentations on a standardized hardness test block. If the mean of these two values falls within the tolerances required (see 15.2.6), the hardness machine may be regarded as producing satisfactory hardness results. If not, the hardness machine shall be verified as described in 15.2.

TEST METHOD C—CALIBRATION OF STANDARDIZED HARDNESS TEST BLOCKS FOR BRINELL HARDNESS TESTING MACHINES

17. Scope

17.1 This test method covers the calibration of standardized hardness test blocks for the verification of Brinell hardness testing machines as described in Test Method B.

18. Manufacture

18.1 Each metal block to be calibrated shall be not less than 16 mm (5/8 in.) in thickness for 10-mm balls, 12 mm (1/2 in.) thick for 5-mm balls, and 6 mm (1/4 in.) thick for smaller balls.

18.1.1 The maximum surface area of the test block shall be 40 cm² (6 in.²) for balls less than 5 mm in diameter, and 150 cm² (24 in.²) for balls equal to or greater than 5 mm in diameter.

18.2 Each block shall be specially prepared and heat treated to give the necessary homogeneity and stability of structure.

18.3 The maximum error in parallelism shall not exceed 0.0008 mm/mm (in./in.) for blocks when used with balls having a diameter greater than or equal to 5 mm and 0.0002 mm/mm (in./in.) for blocks when used with balls having a diameter less than 5 mm. The maximum deviation in flatness of the block surfaces shall not exceed 0.02 mm (0.0008 in.) and 0.005 mm (0.0002 in.) for balls having diameters equal to or greater than 5 mm and less than 5 mm, respectively.

18.4 The supporting surface of the test block shall have a ground finish and shall have a mean surface roughness height rating that shall not exceed 0.0008-mm (32-μin.) centerline average.

18.5 The test surface shall be free of scratches which would interfere with measurements of the diameters of the indentation.

18.5.1 The mean surface roughness height of the test surface rating shall not exceed 0.0003-mm (12-μin.) center line average for the standard 10-mm ball. For smaller balls a maximum mean test surface roughness height rating of 0.00015 mm (6 μin.) is recommended.

18.6 To permit checking that no material is subsequently removed from the standardized block, its thickness at the time of standardization shall be marked on it to the nearest 0.1 mm (0.004 in.), or an identifying mark shall be made on the test surface. (See Section 24.)

18.7 Each block, if of steel, shall be demagnetized by the manufacturer and maintained demagnetized by the user.

18.8 Each block must be uniquely serialized by the manufacturer for traceability.

19. Standardizing Procedure

19.1 The standardized blocks shall be calibrated on a Brinell hardness testing machine which was verified in accordance with the requirements of 15.1.

19.2 The mechanism that controls the application of the force shall ensure that the speed of approach immediately before the ball touches the specimen and the speed of penetration does not exceed 1 mm/s (0.040 in./s).

19.3 The test force shall be within 0.25 % of the nominal force. Use of a Practice E 74 Class AA device will be required to verify the force.

19.4 The test force shall be applied for 10 to 15 s.

19.5 The standardized blocks shall be calibrated at a temperature of 23 ± 5°C, using the general procedure described in Test Method A.

20. Indenter

20.1 A ball conforming to the requirements of 15.1.2 shall be used for calibrating standardized hardness test blocks.

21. Number of Indentations

21.1 At least five uniformly distributed indentations shall be made on the test surface of the block.

22. Measurement of the Diameters of the Indentation

22.1 The illuminating system of the measuring device shall be adjusted to give uniform intensity over the field of view and maximum contrast between the indentations and the undisturbed surface of the block.

22.2 The measuring device shall be graduated to read 0.002 mm (0.00008 in.) for indentations made with balls of 5-mm diameter or larger and 0.001 mm (0.00004 in.) for indentations made with balls of smaller diameter.

22.3 The measuring device shall be checked by a stage micrometer, or by other suitable means to ensure that the difference between readings corresponding to any two divisions of the instrument is within ±0.001 mm (0.00004 in.) for balls of less than 5-mm diameter and within ±0.002 mm (0.00008 in.) for balls of larger diameter.

23. Uniformity of Hardness

23.1 If $d_1, d_2, \dots, d_n$ are the mean values of the measured diameters as determined by one observer and arranged in increasing order of magnitude, the range of the hardness readings, measured from the last block, is defined as $d_n - d_1$ where $n =$ at least five indentations.

23.2 The range of hardness readings shall be equal to or less than 2 % of the mean diameter for Brinell hardness numbers equal to or less than 225 and 1 % for Brinell hardness number values greater than 225.

24. Marking

24.1 Each standardized block shall be marked with the following:

24.1.1 The arithmetic mean of the hardness values found in the standardizing test and the type of ball used.

24.1.2 The name or mark of the supplier.

24.1.3 The serial number or other unique identification of the block.

24.1.4 Name or mark of the calibrating agency if different from supplier.

24.1.5 The thickness of the block or an official mark on the test surface (see 18.6).

24.1.6 The year of calibration. It is sufficient that the year of calibration be incorporated into the serial number of the block.

24.2 All of the markings except the official mark should be placed outside of the test area or on the side of the block. When the markings are on the side of the block, the markings shall be upright when the test surface is the upper face.

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

24.3.1 Date of standardization,

24.3.2 Serial number of block, and

24.3.3 Name of manufacturer or mark of supplier.

25. Keywords

25.1 Brinell hardness; metallic

APPENDIX

(Nonmandatory Information)

X1. BRINELL HARDNESS UNCERTAINTY

X1.1 Scope

X1.1.1 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.

X1.1.2 This appendix provides basic procedures for determining the uncertainty of the following values of hardness:

X1.1.2.1 *The Hardness Machine “Error” Determined as Part of an Indirect Verification (see X1.6)*—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 15.2.5) of the hardness machine. The procedure described in section X1.6 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.

X1.1.2.2 *The Hardness Machine “Error” Determined from Measurements Made as Part of a Direct Verification (see X1.7)*—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 X1.7 provides a method for determining the uncertainty in this measurement “error” of the hardness machine.

X1.1.2.3 *Brinell Hardness Value Measured by a User (see X1.8)*—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.

X1.1.2.4 *Certified Value of a Brinell Hardness Test Block (see X1.9)*—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 X1.1—When calculated, uncertainty values reported by a field calibration agency (see X1.5.7 and X1.7) 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 X1.2—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 X1.3—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 X1.4—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.

X1.1.3 This appendix does not address uncertainties at the primary reference standardizing level.

X1.2 Equations

X1.2.1 The *average (AVG)*, $\bar{H}$, of a set of n hardness measurements $H_1, H_2, \dots, H_n$ is calculated as:

$$AVG(H_1, H_2, \dots, H_n) = \bar{H} = \frac{H_1 + H_2 + \dots + H_n}{n} \quad (X1.1)$$

X1.2.2 The *standard deviation (STDEV)* of a set of n hardness measurements $H_1, H_2, \dots, H_n$ is calculated as:

$$STDEV(H_1, H_2, \dots, H_n) = \sqrt{\frac{(H_1 - \bar{H})^2 + \dots + (H_n - \bar{H})^2}{n - 1}} \quad (X1.2)$$

where:

$\bar{H}$ = average of the set of n hardness measurements $H_1, H_2, \dots, H_n$ as defined in Eq X1.1.

X1.2.3 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

$$ABS(-0.12) = 0.12$$

X1.2.4 An incremental change in hardness ΔH resulting from an incremental change in indentation diameter Δd may be calculated as:

$$\Delta H = -\Delta d \times \left(\frac{H \times (D + \sqrt{D^2 - d^2})}{d \times \sqrt{D^2 - d^2}} \right) \quad (X1.3)$$

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.

X1.2.5 An incremental change in indentation diameter Δd resulting from an incremental change in hardness ΔH may be calculated as:

$$\Delta d = -\Delta H \times \left(\frac{d \times \sqrt{D^2 - d^2}}{H \times (D + \sqrt{D^2 - d^2})} \right) \quad (X1.4)$$

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.

X1.2.6 An incremental change in hardness ΔH resulting from an incremental change in the applied force ΔF may be calculated as:

$$\Delta H = \Delta F \times \left(\frac{H}{F} \right) \quad (X1.5)$$

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).

X1.2.7 Combining equations Eq X1.3 and Eq X1.5, an incremental change in indentation diameter Δd resulting from an incremental change in applied force ΔF may be calculated as:

$$\Delta d = -\frac{\Delta F}{F} \times \left(\frac{d \times \sqrt{D^2 - d^2}}{D + \sqrt{D^2 - d^2}} \right) \quad (X1.6)$$

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 X1.5—Equations Eq X1.3, Eq X1.4, and Eq X1.6 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.

X1.3 General Requirements

X1.3.1 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.

X1.3.2 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.

X1.3.3 Uncertainty should be determined with respect to a country's national reference standards.

X1.4 General Procedure

X1.4.1 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.

X1.4.2 This procedure calculates a *combined* standard uncertainty u_c by combining the contributing components of uncertainty $u_1, u_2, \dots, u_n$, such that:

$$u_c = \sqrt{u_1^2 + u_2^2 + \dots + u_n^2} \quad (X1.7)$$

X1.4.3 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:

$$U = k \times u_c \quad (\text{X1.8})$$

X1.4.4 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 %.

X1.4.5 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:

$$U = ku_c + ABS(B) \quad (\text{X1.9})$$

where:

$ABS(B)$ = absolute value of the bias.

X1.4.6 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.

X1.5 Sources of Uncertainty

X1.5.1 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 X1.1.2.

X1.5.2 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.

X1.5.3 *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.

X1.5.3.1 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.

X1.5.3.2 *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:

$$u_{Repeat} = STDEV(d_1, d_2, \dots, d_n) \quad (\text{X1.10})$$

where:

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

NOTE X1.6—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 X1.8 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 X1.7—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 15.2.4). 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 X1.8—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).

X1.5.3.3 *Average of Multiple Measurements*—When the average of multiple hardness measurements is to be reported,

the standard uncertainty contribution u_{Repeat} , due to the lack of repeatability of the hardness machine, may be estimated by dividing the standard uncertainty contribution u_{Repeat} (previously calculated from a number of indentations made on a uniform test sample, see X1.5.3.2) by the square-root of the number of hardness test values being averaged, as:

$$u_{Repeat} = \frac{u_{Repeat}}{\sqrt{n_T}} \quad (X1.11)$$

where:

u_{Repeat} = calculation by Eq X1.10, and
 n_T = number of individual test values being averaged.

X1.5.3.4 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:

$$u_{Rep\&NU} = \frac{STDEV(d_{T1}, d_{T2}, ..., d_{Tn})}{\sqrt{n_T}} \quad (X1.12)$$

where:

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

X1.5.4 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.

X1.5.4.1 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:

$$u_{Reprod} = STDEV(\overline{d_{M1}}, \overline{d_{M2}}, ..., \overline{d_{Mn}}) \quad (X1.13)$$

where:

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

NOTE X1.9—The uncertainty contribution due to the lack of reproducibility, as calculated in Eq X1.13, 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.

X1.5.4.2 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.

X1.5.4.3 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:

$$u_{Resol} = \frac{r/2}{\sqrt{3}} = \frac{r}{\sqrt{12}} \quad (X1.14)$$

where:

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

X1.5.5 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.

X1.5.5.1 Note that the uncertainty reported on reference test block certificates is typically stated as an *expanded uncertainty*. As indicated by Eq X1.9, 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:

$$u_{RefBlk(mm)} = \frac{U_{RefBlk(mm)}}{k_{RefBlk(mm)}} \quad (X1.15)$$

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).

X1.5.5.2 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 X1.4, 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:

$$u_{RefBlk(mm)} = u_{RefBlk(HBW)} \times \left(\frac{d \times \sqrt{D^2 - d^2}}{H \times (D + \sqrt{D^2 - d^2})} \right) \quad (X1.16)$$

X1.5.6 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.

X1.5.6.1 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.

X1.5.6.2 The measurement bias $B_{(mm)}$, in terms of indentation diameter, may be calculated as:

$$B_{(mm)} = \bar{d} - \bar{d}_{RefBlk} \quad (X1.17)$$

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 X1.10—The measurement bias $B_{(mm)}$ is in length units (mm).

X1.5.6.3 The measurement bias $B_{(HBW)}$, in terms of Brinell hardness numbers, may be calculated as:

$$B_{(HBW)} = \bar{H} - \bar{H}_{RefBlk} \quad (X1.18)$$

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 X1.3, where $B_{(mm)}$ is substituted for Δd . The calculated value of ΔH then becomes the new value of $B_{(HBW)}$ as:

$$B_{(HBW)} = B_{(mm)} \times \left(\frac{H \times (D + \sqrt{D^2 - d^2})}{d \times \sqrt{D^2 - d^2}} \right) \quad (X1.19)$$

NOTE X1.11—The measurement bias $B_{(HBW)}$ is in Brinell hardness units (HBW).

X1.5.6.4 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.

X1.5.6.5 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 $E_{Force(kgf \text{ or } N)}$ must be converted to an error in indentation diameter using Eq X1.6, where $E_{Force(kgf \text{ or } N)}$ is substituted for ΔF . The calculated value of Δd then becomes a new value of $E_{Force(mm)}$, in mm as:

$$E_{Force(mm)} = - \frac{E_{Force(kgf \text{ or } N)}}{F} \times \left(\frac{d \times \sqrt{D^2 - d^2}}{D + \sqrt{D^2 - d^2}} \right) \quad (X1.20)$$

X1.5.6.6 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:

$$B_{(mm)} = E_{Indentation} + E_{Force(mm)} \quad (X1.21)$$

X1.5.7 To determine the measurement “error” or bias in terms of Brinell hardness units $B_{(HBW)}$ the bias, as calculated in Eq X1.21 in terms of indentation diameter, must be converted using Eq X1.19.

X1.6 Procedure for Calculating Uncertainty: Measurement Error Determined by Indirect Verification

X1.6.1 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 15.2.5). 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.

X1.6.2 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 X1.12], 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 X1.14], and (3) u_{RefBlk} , the standard uncertainty in the certified value of the reference test block in terms of indentation diameter [Eq X1.15 and X1.16]. 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.

X1.6.3 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:

$$u_{Mach(mm)} = \sqrt{u_{Rep\&Nu}^2(Ref. Block) + u_{Resol}^2 + u_{RefBlk}^2} \quad (X1.22)$$

and

$$U_{Mach(mm)} = k u_{Mach(mm)} \quad (X1.23)$$

X1.6.4 For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

NOTE X1.12—The uncertainty contribution $u_{Mach(mm)}$, as calculated in Eq X1.22, 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.

X1.6.5 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 X1.23 in terms of indentation diameter, must be converted using Eq X1.3, 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:

$$U_{Mach(HBW)} = U_{Mach(mm)} \times \left(\frac{H \times (D + \sqrt{D^2 - d^2})}{d \times \sqrt{D^2 - d^2}} \right) \quad (X1.24)$$

NOTE X1.13—The first minus sign in Eq X1.3 has been deleted when using Eq X1.24 since uncertainty values are always positive.

NOTE X1.14—The expanded uncertainty U_{Mach} , will commonly be larger than the value of the hardness machine “error” (bias).

X1.6.6 *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 E 10 with a coverage factor of 2 representing a confidence level of approximately 95 %.”

X1.6.7 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 X1.8 and X1.9).

X1.6.8 *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:

$$u_{Rep\&Nu}(Ref. Block) = \frac{STDEV(4.25, 4.25, 4.30)}{\sqrt{3}} \text{ [Eq X1.12], or}$$

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

$$u_{Resol} = \frac{0.05}{\sqrt{12}} = 0.0144 \text{ mm [Eq X1.14], and}$$

$$u_{RefBlk} = \frac{0.04}{2} = 0.02 \text{ mm [Eq X1.15]}$$

Thus:

$$u_{Mach(mm)} = \sqrt{0.0167^2 + 0.0144^2 + 0.02^2} = 0.0298 \text{ mm [Eq X1.22], and}$$

$$U_{Mach(mm)} = (2 \times 0.0298) = 0.0596 \text{ mm [Eq X1.23]}$$

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

In terms of Brinell hardness units:

$$U_{Mach(HBW)} = 0.0596 \times \left(\frac{199.8 \times (10 + \sqrt{10^2 - 4.267^2})}{4.267 \times \sqrt{10^2 - 4.267^2}} \right) \text{ [Eq X1.24], or}$$

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

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.

X1.7 Procedure for Calculating Uncertainty: Measurement Error Determined by Direct Verification

X1.7.1 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.

X1.7.2 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.

X1.7.3 As done previously in X1.5.6.4, 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 X1.6 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:

$$u_{Force(mm)} = \frac{u_{Force(kgf\ or\ N)}}{F} \times \left(\frac{d \times \sqrt{D^2 - d^2}}{D + \sqrt{D^2 - d^2}} \right) \quad (X1.25)$$

X1.7.4 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 X1.14], as:

$$u_{Mach(mm)} = \sqrt{u_{Indentation}^2 + u_{Force(mm)}^2 + u_{Resol}^2} \quad (X1.26)$$

and

$$U_{Mach(mm)} = k u_{Mach(mm)} \quad (X1.27)$$

X1.7.5 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 X1.27 in terms of indentation diameter, must be converted in accordance with X1.6.5.

X1.7.6 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 X1.8 and X1.9).

X1.7.7 *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

$$E_{Force(mm)} = -\frac{15}{3000} \times \left(\frac{4.265 \times \sqrt{10^2 - 4.265^2}}{10 + \sqrt{10^2 - 4.265^2}} \right) \quad [\text{Eq X1.20}], \text{ or}$$

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

Thus:

$$B_{(mm)} = E_{Indentation} + E_{Force(mm)} = 0 + 0.0101 = 0.0101 \text{ mm} \quad [\text{Eq X1.21}]$$

To calculate the uncertainty in the machine “error” or bias:

$$u_{Indentation} = 0.002 \text{ mm, and}$$

$$u_{Force(mm)} = \frac{2.5}{3000} \times \left(\frac{4.265 \times \sqrt{10^2 - 4.265^2}}{10 + \sqrt{10^2 - 4.265^2}} \right) \quad [\text{Eq X1.25}], \text{ or}$$

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

$$u_{Resol} = \frac{0.05}{\sqrt{12}} = 0.0144 \text{ mm} \quad [\text{Eq X1.14}]$$

Thus:

$$u_{Mach(mm)} = \sqrt{0.002^2 + 0.0017^2 + 0.0144^2} \\ = 0.01464 \text{ mm} \quad [\text{Eq X1.26}], \text{ and}$$

$$U_{Mach(mm)} = (2 \times 0.01464) = 0.0293 \text{ mm} \quad [\text{Eq X1.27}]$$

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:

$$B_{(HBW)} = -(0.0101) \times \left(\frac{200 \times (10 + \sqrt{10^2 - 4.265^2})}{4.265 \times \sqrt{10^2 - 4.265^2}} \right) \quad [\text{Eq X1.19}], \text{ or}$$

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

$$U_{Mach(HBW)} = 0.0293 \times \left(\frac{200 \times (10 + \sqrt{10^2 - 4.265^2})}{4.265 \times \sqrt{10^2 - 4.265^2}} \right) \quad [\text{Eq X1.24}], \text{ or}$$

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

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.

X1.8 Procedure for Calculating Uncertainty: Brinell Hardness Measurement Values

X1.8.1 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.

X1.8.2 *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 X1.10], (2) u_{Reprod} , the uncertainty contribution due to the lack of reproducibility [Eq X1.13], (3) u_{Resol} , the uncertainty due to the resolution of the indentation measurement system [Eq X1.14], and (4) u_{Mach} , the uncertainty

in determining the “error” of the hardness machine [Eq X1.22 or Eq X1.26]. 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:

$$u_{Meas(mm)} = \sqrt{u_{Repeat}^2 + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach(mm)}^2} \quad (X1.28)$$

X1.8.3 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_{Repeat} , the uncertainty due to the machine’s lack of repeatability based on the average of multiple measurements [Eq X1.11], (2) u_{Reprod} , the uncertainty contribution due to the lack of reproducibility [Eq X1.13], (3) u_{Resol} , the uncertainty due to the resolution of the indentation measurement system [Eq X1.14], and (4) u_{Mach} , the uncertainty in determining the “error” of the hardness machine [Eq X1.22 or Eq X1.26]. 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:

$$u_{Meas(mm)} = \sqrt{u_{Repeat}^2 + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach(mm)}^2} \quad (X1.29)$$

X1.8.4 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.

X1.8.5 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 X1.12], 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 X1.13], (3) u_{Resol} , the uncertainty due to the resolution of the indentation measurement system [Eq X1.14], and (4) $u_{Mach(mm)}$, the uncertainty in determining the “error” of the hardness machine [Eq X1.22 or Eq X1.26]. 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:

$$u_{Meas(mm)} = \sqrt{u_{Rep\&NU}(Material)^2 + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach(mm)}^2} \quad (X1.30)$$

X1.8.6 When reporting uncertainty as an indication of how well the average measurement value represents the true aver-

age 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.

X1.8.7 The expanded uncertainty $U_{Meas(mm)}$ is calculated for the three cases discussed above as:

$$U_{Meas(mm)} = k u_{Meas(mm)} + ABS(B_{(mm)}) \quad (X1.31)$$

X1.8.8 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 X1.31, in terms of indentation diameter, must be converted using Eq X1.3, 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:

$$U_{Meas(HBW)} = U_{Meas(mm)} \times \left(\frac{H \times (D + \sqrt{D^2 - d^2})}{d \times \sqrt{D^2 - d^2}} \right) \quad (X1.32)$$

NOTE X1.15—The first minus sign in Eq X1.3 has been deleted when using Eq X1.32 since uncertainty values are always positive.

X1.8.9 For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

X1.8.10 Reporting Measurement Uncertainty:

X1.8.10.1 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 E 10 with a coverage factor of 2 representing a confidence level of approximately 95 %.”

X1.8.10.2 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 E 10 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.

X1.8.10.3 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 X1.13, it was determined that:

u_{Reprod} = 0.040 mm

Other uncertainty contributions are calculated as:

$$u_{Resol} = \frac{0.05}{\sqrt{12}} = 0.0144 \text{ mm [Eq X1.14]}$$

Therefore:

$$u_{Meas(mm)} = \sqrt{0.032^2 + 0.040^2 + 0.0144^2 + 0.054^2} \text{ [Eq X1.30], or}$$

$$u_{Meas(mm)} = 0.0758 \text{ mm}$$

and since $B = -0.029$ mm,

$$U_{Meas(mm)} = (2 \times 0.0758) + ABS(-0.029) \text{ [Eq X1.31], or}$$

$$U_{Meas(mm)} = 0.1806 \text{ mm}$$

In terms of Brinell hardness units:

$$U_{Meas(HBW)} = 0.1806 \times \left(\frac{103 \times \left(10 + \sqrt{10^2 - 4.20^2} \right)}{4.20 \times \sqrt{10^2 - 4.20^2}} \right) \text{ [Eq X1.32], or}$$

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

X1.9 Procedure for Calculating Uncertainty: Certified Value of Standardized Test Blocks

X1.9.1 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.

X1.9.2 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 X1.8.5 for measuring the average hardness of a product. In this case, the product is a calibrated reference test block.

X1.9.3 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.

X1.9.4 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 X1.12], 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 X1.13], (3) u_{Resol} , the uncertainty due to the resolution of the indentation measurement system [Eq X1.14], and (4) $u_{Mach(mm)}$, the uncertainty in determining the “error” of the standardizing machine [Eq X1.22 or Eq X1.26]. 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*.

X1.9.5 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:

$$u_{Cert(mm)} = \sqrt{u_{Rep\&NU}^2(Calib. Block) + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach(mm)}^2} \quad (X1.33)$$

and

$$U_{Cert} = k u_{Cert} + ABS(B) \quad (X1.34)$$

X1.9.6 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 X1.34, in terms of indentation diameter, must be converted using Eq X1.3, 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:

$$U_{Cert(HBW)} = U_{Cert(mm)} \times \left(\frac{H \times \left(D + \sqrt{D^2 - d^2} \right)}{d \times \sqrt{D^2 - d^2}} \right) \quad (X1.35)$$

NOTE X1.16—The first minus sign in Eq X1.3 has been deleted when using Eq X1.35 since uncertainty values are always positive.

X1.9.7 For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

X1.9.8 *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 E 10 with a coverage factor of 2 representing a confidence level of approximately 95 %.”

X1.9.9 *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:

$$u_{Rep\&NU}(Calib. Block) = \frac{STDEV(2.53, 2.50, 2.50, 2.51, 2.51)}{\sqrt{5}} \text{ [Eq X1.12], or}$$

$$u_{Rep\&NU}(Calib. Block) = 0.0055 \text{ mm}$$

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 X1.13, 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:

$$u_{Resol} = \frac{0.01}{\sqrt{12}} = 0.0029 \text{ mm [Eq X1.14]}$$

Therefore:

$$u_{Cert(mm)} = \sqrt{0.0055^2 + 0.004^2 + 0.0029^2 + 0.015^2} \text{ [Eq X1.33], or}$$

$$U_{\text{Cert}(mm)} = 0.167 \text{ HBW } 10/500$$

and since $B = -0.004 \text{ mm}$,

$$U_{\text{Cert}(mm)} = (2 \times 0.0167) + \text{ABS}(-0.004) \text{ [Eq X1.34], or}$$

$$U_{\text{Cert}(mm)} = 0.0374 \text{ mm}$$

In terms of Brinell hardness units:

$$U_{\text{Cert}(HBW)} = 0.0374 \times \left(\frac{99.4 \times (10 + \sqrt{10^2 - 2.51^2})}{2.51 \times \sqrt{10^2 - 2.51^2}} \right) \text{ [Eq X1.35], or}$$

$U_{\text{Cert}(HBW)} = 3.0 \text{ HBW } 10/500$ 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 (E 10–01^{€1}) that may impact the use of this standard.

(1) **Appendix X1** was added.

(2) Table footnote^A was added to **Table 8**.

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