Designation: E92 – 17

Standard Test Methods for
Vickers Hardness and Knoop Hardness of Metallic Materials[1]

This standard is issued under the fixed designation E92; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope*

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

1.2 This standard includes additional requirements in annexes:

Verification of Vickers and Knoop Hardness Testing Machines	Annex A1
Vickers and Knoop Hardness Standardizing Machines	Annex A2
Standardization of Vickers and Knoop Indenters	Annex A3
Standardization of Vickers and Knoop Hardness Test Blocks	Annex A4
Correction Factors for Vickers Hardness Tests Made on Spherical and Cylindrical Surfaces	Annex A5

1.3 This standard includes nonmandatory information in an appendix which relates to the Vickers and Knoop hardness tests:

Examples of Procedures for Determining Vickers and Knoop Hardness Uncertainty	Appendix X1

1.4 This test method covers Vickers hardness tests made utilizing test forces ranging from 9.807×10^{-3} N to 1176.80 N (1 gf to 120 kgf), and Knoop hardness tests made utilizing test forces from 9.807×10^{-3} N to 19.613 N (1 gf to 2 kgf).

1.5 Additional information on the procedures and guidance when testing in the microindentation force range (forces ≤ 1 kgf) may be found in Test Method E384, Test Method for Microindentation Hardness of Materials.

1.6 *Units*—When the Vickers and Knoop hardness tests were developed, the force levels were specified in units of grams-force (gf) and kilograms-force (kgf). This standard specifies the units of force and length in the International System of Units (SI); that is, force in Newtons (N) and length in mm or μm. However, because of the historical precedent and continued common usage, force values in gf and kgf units are provided for information and much of the discussion in this standard as well as the method of reporting the test results refers to these units.

NOTE 1—The Vickers and Knoop hardness numbers were originally defined in terms of the test force in kilogram-force (kgf) and the surface area or projected area in millimetres squared (mm^2). Today, the hardness numbers are internationally defined in terms of SI units, that is, the test force in Newtons (N). However, in practice, the most commonly used force units are kilogram-force (kgf) and gram-force (gf). When Newton units of force are used, the force must be divided by the conversion factor 9.80665 N/kgf.

1.7 The test principles, testing procedures, and verification procedures are essentially identical for both the Vickers and Knoop hardness tests. The significant differences between the two tests are the geometries of the respective indenters, the method of calculation of the hardness numbers, and that Vickers hardness may be used at higher force levels than Knoop hardness.

NOTE 2—While Committee E28 is primarily concerned with metallic materials, the test procedures described are applicable to other materials. Other materials may require special considerations, for example see C1326 and C1327 for ceramic testing.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

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[1] These test methods are 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.

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

C1326 Test Method for Knoop Indentation Hardness of Advanced Ceramics

C1327 Test Method for Vickers Indentation Hardness of Advanced Ceramics

E3 Guide for Preparation of Metallographic Specimens

E6 Terminology Relating to Methods of Mechanical Testing

E7 Terminology Relating to Metallography

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

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

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

E175 Terminology of Microscopy

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E384 Test Method for Microindentation Hardness of Materials

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *ISO Standards:*[3]

ISO 6507-1 Metallic Materials—Vickers hardness Test— Part 1: Test Method

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

ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories

3. Terminology and Equations

3.1 *Definitions of Terms*—For the standard definitions of terms used in this test method, see Terminology E6 and Terminology E7.

3.1.1 *indentation hardness, n*—the hardness as evaluated from measurements of area or depth of the indentation made by forcing a specified indenter into the surface of a material under specified static loading conditions.

3.1.2 *Knoop hardness number, HK, n*—the calculated result from a Knoop hardness test, which is proportional to the test force applied to the Knoop indenter divided by the projected area of the permanent indentation made by the indenter after removal of the test force.

3.1.2.1 *Discussion*—The projected area of the permanent indentation made by the Knoop indenter is calculated based partly on the measured length of the long diagonal of the projected area of the indentation.

3.1.3 *Knoop hardness test, n*—an indentation test in which a Knoop rhombic-based pyramidal diamond indenter having specified edge angles, is forced under specified conditions into the surface of the test material, and, after removal of the test force, the length of the long diagonal of the projected area of the indentation is measured to calculate the Knoop hardness number.

3.1.4 *Vickers hardness number, HV, n*—the calculated result from a Vickers hardness test, which is proportional to the test force applied to the Vickers indenter divided by the surface area of the permanent indentation made by the indenter after removal of the test force.

3.1.4.1 *Discussion*—The surface area of the permanent indentation made by the Vickers indenter is calculated based partly on the measured mean length of the two diagonals of the projected area of the indentation.

3.1.5 *Vickers hardness test, n*—an indentation test in which a Vickers square-based pyramidal diamond indenter having specified face angles is forced under specified conditions into the surface of the test material, and, after removal of the test force, the lengths of the two diagonals of the projected area of the indentation are measured to calculate the Vickers hardness number.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *standardization, n*—to bring in conformance to a known standard through verification or calibration.

3.2.2 *microindentation hardness test, n*—a hardness test, normally in the Vickers or Knoop scales, using test forces in the range of 9.807×10^{-3} to 9.807 N (1 to 1000 gf).

3.2.3 *macroindention hardness test, n*—a hardness test using test forces normally higher than 9.807 N (1 kgf). Macroindentation tests include Vickers, Rockwell and Brinell.

Note 3—Use of the term microhardness should be avoided because it implies that the hardness, rather than the force or the indentation size, is very low.

3.2.4 *scale, n*—a specific combination of indenter (Knoop or Vickers) and the test force (kgf).

3.2.4.1 *Discussion*—For example, HV 10 is a scale defined as using a Vickers indenter and a 10 kgf test force and HK 0.1 is a scale defined as using a Knoop indenter and a 100 gf test force. See 5.10 for the proper reporting of the hardness level and scale.

3.2.5 *as-found condition, n*—the state of the hardness machine as reflected by the initial verification measurements made prior to performing any cleaning, maintenance, adjustments or repairs associated with an indirect verification.

3.2.6 *hardness machine, n*—a machine capable of performing a Vickers or Knoop hardness test.

3.2.7 *hardness testing machine, n*—a Vickers or Knoop hardness machine used for general testing purposes.

3.2.8 *hardness standardizing machine, n*—a Vickers or Knoop hardness machine used for the standardization of Vickers or Knoop hardness test blocks.

3.2.8.1 *Discussion*—A hardness standardizing machine differs from a hardness testing machine by having tighter tolerances on certain parameters.

3.3 *Equations:*

3.3.1 The average $\bar{d}$ of a set of n diagonal length measurements $d_1, d_2, ..., d_n$ is calculated as:

$$\bar{d} = \frac{d_1 + d_2 + ... + d_n}{n} \tag{1}$$

where each of the individual diagonal measurements d_1, d_2, ..., d_n is the mean of the two diagonal length measurements in the case of a Vickers indentation, or is the long diagonal length measurement in the case of a Knoop indentation.

3.3.2 The repeatability R in the performance of a Vickers or Knoop hardness machine at each hardness level, under the particular verification conditions, is determined from n diagonal measurements made on a standardized test block as part of a performance verification. The repeatability is estimated as the percent range of n diagonal measurements with respect to the measured average hardness value as:

$$R = 100 \times \left(\frac{d_{\max} - d_{\min}}{\bar{d}} \right) \qquad (2)$$

where:

$d_{\max}$ = the longest diagonal length measurement made on the standardized test block,

$d_{\min}$ = the shortest diagonal length measurement made on the standardized test block, and

$\bar{d}$ = the average (see 3.3.1) of the n diagonal length measurements made on the standardized test block.

3.3.3 The error E in the performance of a Vickers or Knoop hardness machine at each hardness level, relative to a standardized reference value, is calculated as a percent error determined as:

$$E = 100 \times \left(\frac{|\bar{d} - d_{ref}|}{d_{ref}} \right) \qquad (3)$$

where:

$\bar{d}$ = the average (see 3.3.1) of n diagonal length measurements made on a standardized test block as part of a performance verification, and

d_{ref} = the certified diagonal length reported for the standardized test block.

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

4. Significance and Use

4.1 Vickers and Knoop hardness tests have been found to be very useful for materials evaluation, quality control of manufacturing processes and research and development efforts. Hardness, although empirical in nature, can be correlated to tensile strength for many metals, and is an indicator of wear resistance and ductility.

4.2 Microindentation hardness tests extend testing to materials that are too thin or too small for macroindentation hardness tests. Microindentation hardness tests also allow specific phases or constituents and regions or gradients too small for macroindentation hardness testing to be evaluated. Recommendations for microindentation testing can be found in Test Method E384.

4.3 Because the Vickers and Knoop hardness will reveal hardness variations that may exist within a material, a single test value may not be representative of the bulk hardness.

4.4 The Vickers indenter usually produces essentially the same hardness number at all test forces when testing homogeneous material, except for tests using very low forces (below

25 gf) or for indentations with diagonals smaller than about 25 µm (see Test Method E384). For isotropic materials, the two diagonals of a Vickers indentation are equal in length.

4.5 The Knoop indenter usually produces similar hardness numbers over a wide range of test forces, but the numbers tend to rise as the test force is decreased. This rise in hardness number with lower test forces is often more significant when testing higher hardness materials, and is increasingly more significant when using test forces below 50 gf (see Test Method E384).

4.6 The elongated four-sided rhombohedral shape of the Knoop indenter, where the length of the long diagonal is 7.114 times greater than the short diagonal, produces narrower and shallower indentations than the square-based pyramid Vickers indenter under identical test conditions. Hence, the Knoop hardness test is very useful for evaluating hardness gradients since Knoop indentations can be made closer together than Vickers indentations by orienting the Knoop indentations with the short diagonals in the direction of the hardness gradient.

5. Principle of Test and Apparatus

5.1 *Vickers and Knoop Hardness Test Principle*—The general principle of the Vickers and Knoop indentation hardness test consists of two steps.

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

5.1.2 *Step 2*—For the Vickers hardness test, the lengths of the two diagonals are measured and the mean diagonal length is calculated, which is used to derive the Vickers hardness value. For the Knoop hardness test, the length of the long diagonal is measured, which is used to derive the Knoop hardness value.

5.1.3 Most materials will exhibit some elastic recovery when the indenter is removed after the loading cycle. However, for the purposes of calculating the hardness results from the indentation diagonal lengths, it is assumed that the indentation retains the shape of the indenter after the force is removed. In Knoop testing, it is assumed that the ratio of the long diagonal to the short diagonal of the indentation is the same as for the indenter.

5.2 *Testing Machine*—The testing machine shall support the test specimen and control the movement of the indenter into the specimen under a preselected test force, and should have a light optical microscope to select the desired test location and to measure the size of the indentation produced by the test. The plane of the surface of the test specimen should be perpendicular to the axis of the indenter which is the direction of the force application.

5.2.1 See the equipment manufacturer's instruction manual for a description of the machine's characteristics, limitations, and respective operating procedures.

5.3 *Indenters:*

5.3.1 Indenters for general Vickers or Knoop hardness testing shall comply with the requirements of a Class B indenter or better in accordance with Annex A3.

5.3.2 *Vickers Indenter*—The ideal Vickers indenter (see Fig. A3.1) is a highly polished, pointed, square-based pyramidal diamond with face angles of 136° 0'.

5.3.3 *Knoop Indenter*—The ideal Knoop indenter (see Fig. A3.2) is a highly polished, pointed, rhombic-based, pyramidal diamond. The included longitudinal edge angles are 172° 30' and 130° 0'.

NOTE 4—The user should consult with the manufacturer before applying macroindentation test forces (over 1 kgf) with diamond indenters previously used for microindentation testing. The diamond mount may not be strong enough to support the higher test forces and the diamond may not be large enough to produce the larger indentation sizes.

5.4 *Measurement Device*—The diagonals of the indentation are measured (see 7.9.2) using a light microscope equipped with a filar type eyepiece (see Terminology E175), or other type of measuring device. Additional guidance on measuring devices may be found in Test Method E384.

5.4.1 The testing machine's measuring device shall be capable of reporting the diagonal lengths to within the requirements of 7.9.2.

5.4.2 The measuring device may be an integral part of the tester or a stand-alone instrument, such as a high quality measuring microscope or measuring system. To obtain the highest quality image for measuring the indentation diagonal, the measuring microscope should have adjustable illumination intensity, adjustable alignment, aperture, and field diaphragms.

5.4.3 Magnifications should be provided so that the diagonal can be enlarged to greater than 25 % but less than 75 % of the field width. The device may be built with single or multiple magnifying objectives.

5.5 *Verifications*—All testing machines, indentation measuring devices and indenters used to perform Vickers and Knoop hardness tests shall be verified periodically in accordance with Annex A1 prior to performing hardness tests.

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

5.7 *Test Forces*—The standard hardness test forces are given in Table 1. Other non-standard test forces may be used by special agreement.

5.8 *Calculation of the Vickers Hardness Number*—The Vickers hardness number is based on the indentation test force F in kgf divided by the surface area A_S of the indentation in mm^2.

$$HV = \frac{Test\ force}{Surface\ Area} = \frac{F_{(kgf)}}{A_{S\ (mm^2)}} \tag{4}$$

The surface area (A_S) of the indentation is calculated as:

$$A_S = \frac{d_V^2}{2\sin\frac{\alpha}{2}} = \frac{d_V^2}{1.8544} \tag{5}$$

where:
α = face angle of the diamond indenter = 136°, and
d_V = mean Vickers indentation diagonal length (mm).

TABLE 1 Standard Hardness Scales and Test Forces

Vickers scale	Knoop scale[A]	Test force (N)	Approximate Test force (kgf)	Approximate Test force (gf)
HV 0.001	HK 0.001	0.009807	0.001	1
HV 0.01	HK 0.01	0.09807	0.01	10
HV 0.015	HK 0.015	0.1471	0.015	15
HV 0.02	HK 0.02	0.1961	0.02	20
HV 0.025	HK 0.025	0.2451	0.025	25
HV 0.05	HK 0.05	0.4903	0.05	50
HV 0.1	HK 0.1	0.9807	0.1	100
HV 0.2	HK 0.2	1.961	0.2	200
HV 0.3	HK 0.3	2.942	0.3	300
HV 0.5	HK 0.5	4.903	0.5	500
HV 1	HK 1	9.807	1	1000
HV 2	HK 2	19.61	2	2000
HV 3		29.41	3	
HV 5		49.03	5	
HV 10		98.07	10	
HV 20		196.1	20	
HV 30		294.1	30	
HV 50		490.3	50	
HV 100		980.7	100	
HV 120		1177	120	

[A] The user should consult with the manufacturer before applying macroindentation test forces (over 1 kgf) for Knoop hardness testing. The diamond may not be large enough to produce the larger indentation sizes (see Note 4).

Other units of force and length may be used; however, the reported Vickers hardness number shall be converted to the units of kgf and mm, as follows and given in Table 2.

5.8.1 Microindentation Vickers hardness is typically determined using indentation test forces in grams-force (gf) and indentation diagonals measured in micrometres (μm). The Vickers hardness number, in terms of gf and μm, is calculated as follows:

$$HV = 1000 \times 1.8544 \times \frac{F_{(gf)}}{d_{V\ (\mu m)}^2} = 1854.4 \times \frac{F_{(gf)}}{d_{V\ (\mu m)}^2} \tag{6}$$

5.8.2 Macroindentation Vickers hardness is typically determined using indentation test forces in kilograms-force (kgf) and indentation diagonals measured in millimetres (mm). The Vickers hardness number, in terms of kgf and mm, is calculated as follows:

$$HV = 1.8544 \times \frac{F_{(kgf)}}{d_{V\ (mm)}^2} \tag{7}$$

5.8.3 The Vickers hardness number, in terms of indentation test forces in Newtons (N) and indentation diagonals measured in millimetres (mm), is calculated as follows:

$$HV = \frac{1.8544}{9.80665} \times \frac{F_{(N)}}{d_{V\ (mm)}^2} = 0.1891 \times \frac{F_{(N)}}{d_{V\ (mm)}^2} \tag{8}$$

TABLE 2 Vickers and Knoop Formulae

Vickers hardness number		
Force (F) unit	Diagonal (d) unit	Formula
kgf	mm	$HV = 1.8544 \times F/d^2$
gf	μm	$HV = 1854.4 \times F/d^2$
N	mm	$HV = 0.1891 \times F/d^2$
Knoop hardness number		
Force (F) unit	Diagonal (d) unit	Formula
kgf	mm	$HK = 14.229 \times F/d^2$
gf	μm	$HK = 14229 \times F/d^2$
N	mm	$HK = 1.451 \times F/d^2$

5.9 *Calculation of the Knoop Hardness Number*—The Knoop hardness number is based on the indentation test force (kgf) divided by the projected area A_P of the indentation (mm²).

$$HK = \frac{Test\ force}{Projected\ Area} = \frac{F_{(kgf)}}{A_{P\ (mm^2)}} \tag{9}$$

The projected area (A_P) of the indentation is calculated as:

$$A_P = d_K^2 \times c_P \tag{10}$$

where:

d_K = Knoop indentation long diagonal length (mm), and
c_P = indenter constant relating the projected area of the indentation to the square of the length of the long diagonal, ideally 0.07028, where:

$$c_P = \frac{\tan\frac{\angle B}{2}}{2\tan\frac{\angle A}{2}} = 0.07028 \tag{11}$$

where:

$\angle A$ = the included longitudinal edge angle, 172° 30', and
$\angle B$ = included transverse edge angle, 130° 0'.

Other units of force and length may be used, however, the Knoop hardness number shall be converted to the units of kgf and mm, as follows and as given in Table 2.

5.9.1 Knoop hardness is typically determined using indentation test forces in grams-force (gf) and indentation long diagonal measured in micrometres (µm). The Knoop hardness number, in terms of gf and µm, is calculated as follows:

$$HK = 1000 \times 14.229 \times \frac{F_{(gf)}}{d_K^2\ (\mu m)} = 14229 \times \frac{F_{(gf)}}{d_K^2\ (\mu m)} \tag{12}$$

5.9.2 The Knoop hardness number, in terms of indentation test forces in kgf and the indentation long diagonal measured in mm, is calculated as follows:

$$HK = 14.229 \times \frac{F_{(kgf)}}{d_K^2\ (mm)} \tag{13}$$

5.9.3 The Knoop hardness number, in terms of indentation test forces in Newtons (N) and the indentation long diagonal measured in millimetres (mm), is calculated as follows:

$$HK = \frac{14.229}{9.80665} \times \frac{F_{(N)}}{d_K^2\ (mm)} = 1.451 \times \frac{F_{(N)}}{d_K^2\ (mm)} \tag{14}$$

5.10 *Hardness Number*—Vickers and Knoop hardness values are not designated by a number alone because it is necessary to indicate which force has been employed in making the test. The hardness numbers shall be followed by the symbol HV for Vickers hardness, or HK for Knoop hardness, and be supplemented by a value representing the test force in kgf.

5.10.1 For nonstandard dwell times, other than 10 to 15 s, the hardness shall be supplemented with the actual total force dwell time used in seconds separated by a "/".

5.10.2 The reported Vickers and Knoop hardness number shall be reported rounded to three significant digits in accordance with Practice E29.

5.10.3 *Examples:*

400 HK 0.5 = Knoop hardness of 400 determined with a 500 gf (0.5 kgf) indentation test force.
99.2 HV 0.1 = Vickers hardness of 99.2 determined with a 100 gf (0.1 kgf) indentation test force.
725 HV 10 = Vickers hardness of 725 determined with a 10 kgf indentation test force.
400 HK 0.1 /22. = Knoop hardness of 400 determined with a 100 gf (0.1 kgf) indentation test force and a 22 s total force dwell time.

6. Test Piece

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

6.2 *Preparation*—For optimum accuracy of measurement, the test should be performed on a flat specimen with a polished or otherwise suitably prepared surface. The quality of the required surface finish can vary with the forces and magnifications used. The lower the test force and the smaller the indentation size, the more critical is the surface preparation. In all tests, the preparation should be such that the indentation perimeter and the indentation tips in particular, can be clearly defined when observed by the measuring system. Surface preparation recommendations for low-force microindentation testing can be found in Test Method E384.

6.2.1 The test surface shall be free of any defects that could affect the indentation or the subsequent measurement of the diagonals. It is well known that improper grinding and polishing methods can alter test results either due to excessive heating or cold work. Some materials are more sensitive to preparation-induced damage than others; therefore, special precautions shall be taken during specimen preparation. Remove any damage introduced during specimen preparation.

6.2.2 The specimen surface should not be etched before making an indentation. Etched surfaces can obscure the edge of the indentation, making an accurate measurement of the size of the indentation difficult. There may be microindentation testing applications where a light etch may be appropriate (see Test Method E384).

6.3 *Alignment*—To obtain usable information from the test, the specimen should be prepared or mounted so that the test surface is perpendicular to the axis of the indenter. This can readily be accomplished by surface grinding (or otherwise machining) the opposite side of the specimen parallel with the side to be tested. Non-parallel test specimens can be tested using clamping and leveling fixtures designed to align the test surface properly to the indenter.

6.4 *Mounted Test Specimens*—In many instances, especially in microindentation testing, it is necessary to mount the specimen for convenience in preparation and to maintain a sharp edge when surface gradient tests are to be performed on the test specimen. When mounting is required, the specimen shall be adequately supported by the mounting medium so that the specimen does not move during force application, that is, avoid the use of polymeric mounting compounds that creep under the indenter force (see Test Method E384).

6.5 *Thickness*—The thickness of the specimen tested shall be such that no bulge or other marking showing the effect of the test force appears on the side of the piece opposite the

indentation. The thickness of the material under test should be at least ten times the depth of the indentation (see Note 5). Similarly, when testing a coating on a material, the minimum thickness of the coating should be at least ten times the depth of the indentation.

Note 5—The Vickers indentation depth h_V is approximately

$$h_V = 0.143 \times d_V \qquad (15)$$

or approximately 1/7 of the mean diagonal length d_V. The Knoop indentation depth h_K is approximately

$$h_K = 0.033 \times d_K \qquad (16)$$

or approximately 1/30 of the long diagonal length d_K.

6.6 *Radius of Curvature*—Due caution should be used in interpreting or accepting the results of tests made on spherical or cylindrical surfaces, particularly when using low test forces. Results will be affected even in the case of the Knoop test where the radius of curvature is in the direction of the short diagonal. Annex A5 provides correction factors that shall be applied to Vickers hardness values obtained when tests are made on spherical or cylindrical surfaces.

7. Test Procedure

7.1 *Verification*—A periodic verification procedure shall be performed in accordance with A1.5 within one week prior to making hardness tests. The periodic verification should be performed on a daily basis.

7.2 *Test Temperature*—Vickers and Knoop hardness tests should be carried out at a temperature within the limits of 10 to 35°C (50 to 95°F). Because variations within this temperature range may affect results, users may choose to control temperature within a tighter range.

7.3 *Indenter*—Select the indenter, either Knoop or Vickers, to suit the desired test to be performed. Refer to the manufacturer's instruction manual for the proper procedure if it is necessary to change indenters.

7.3.1 After each change, or removal and replacement, of the indenter, it is recommended that a periodic verification be performed as specified in A1.5.

7.3.2 Occasionally clean the indenter with a cotton swab and alcohol. Avoid creating static charges during cleaning. Indenting a piece of paper placed on top of the test specimen will often remove oil from the indenter. Do not touch the diamond tip with fingers.

7.3.3 Indenters should be examined periodically and replaced if they become worn, dulled, chipped, cracked or separated from the mounting material. Checks of the indenter by the user may be performed by visual inspection of the resulting indentations performed on test blocks.

7.4 *Magnitude of Test Force*—Set the desired test force on the tester by following the manufacturer's instructions.

7.4.1 After each change of a test force, it is recommended that the operation of the machine be checked by performing a periodic verification as specified in A1.5, particularly for machines where the weights that create test forces are changed manually or there is a chance of jamming occurring when weights are changed.

7.5 *Positioning the Test Specimen*—Place the test specimen in the appropriate fixture or on the tester stage so that the test surface is perpendicular to the indenter axis.

7.6 *Locate the Test Point*—Focus the measuring microscope with a low power objective so that the specimen surface can be observed. Adjust the light intensity and adjust the diaphragms for optimum resolution and contrast. Adjust the position of the test specimen so that the indentation will be made in the desired location on the test surface. Before applying the force, make a final focus using the measuring objective (see 7.9 and Table 3).

7.7 *Force Application*—Apply the selected test force as follows in a manner and in an environment that prevents shock or vibration during the indenting process.

7.7.1 For microindentation testing, the indenter shall contact the specimen at a velocity between 15 and 70 μm/s. For macroindentation testing, the contact velocity should not exceed 0.2 mm/s.

7.7.2 The time from the initial application of the force until the full test force is reached shall not be more than 10 s.

7.7.3 The full test force shall be applied for 10 to 15 s unless otherwise specified.

7.7.4 For some applications it may be necessary to apply the test force for longer times. In these instances the tolerance for the time of the applied force shall be ± 2 s. The application time shall be defined in the report.

7.7.5 Remove the test force without shock or vibration.

7.7.6 During the entire test cycle of force application and removal, the test machine should be protected from shock or vibration. To minimize vibrations, the operator should avoid contacting the machine in any manner during the entire test cycle.

7.8 *Test Location*—After the force is removed, switch to the measuring mode, and select the proper objective lens. Focus the image, adjust the light intensity if necessary, and adjust the diaphragms for maximum resolution and contrast.

7.8.1 Examine the indentation for its position relative to the desired location and for its symmetry.

7.8.2 If the indentation did not occur at the desired spot, the tester is out of alignment. Consult the manufacturer's instruction manual for the proper procedure to produce alignment. Make another indentation and recheck the indentation location. Readjust and repeat as necessary.

7.9 *Indentation Measurement*—Measure both diagonals of a Vickers indentation or the long diagonal of a Knoop indentation by operating the measuring device in accordance with the manufacturer's instruction manual.

7.9.1 When the indentation measuring device is a light microscope that requires the full indentation to be seen and measured in the field of view, the highest magnification that can image the full indentation shall be used. To stay within the flat field of the objective, the indentation length should not exceed 75% of the field width. The objective selected to measure the indentation should have an objective resolution (r_{obj}) that is ≤ 2% of the diagonal length to be measured. Objective resolution (r_{obj}) is a function of the numerical aperture (NA) of the objective, see Note 6. The minimum

recommended diagonal lengths to be measured by typical objectives are shown in Table 3.

NOTE 6—The objective's resolution (r_{obj}) is defined as:

$$r_{obj} = \lambda / (2 \times NA) \qquad (17)$$

where:
λ = the wave length of the light in µm (approx. 0.55 µm for green light), and
NA = the numerical aperture of the objective as defined by the manufacturer. (The NA is frequently marked on the side of each objective.) Example: For a 50× objective with a NA of 0.65 using green light, $r_{obj} = 0.55$ µm / (2 × 0.65) = 0.42 µm.

7.9.2 Determine the length of the diagonals to within 0.5 µm or less. For indentations less than 40 µm, determine the length of the diagonals to within 0.25 µm or less. For indentations less than 20 µm, the length of the diagonals should be determined to within 0.1 µm or less. In all cases, smaller measurement increments may be reported if the equipment is capable of displaying smaller measurement increments.

7.10 *Indentation Examination:*

7.10.1 *Vickers*—For a Vickers indentation, if one half of either diagonal is more than 5 % longer than the other half of that diagonal, or if the four corners of the indentation are not in sharp focus, the test surface may not be perpendicular to the indenter axis. Check the specimen alignment as described in 7.10.3.

7.10.2 *Knoop*—For a Knoop indentation, if one half of the long diagonal is greater than 10 % longer than the other, or if both ends of the indentation are not in sharp focus, the test specimen surface may not be perpendicular to the indenter axis. Check the specimen alignment as given in 7.10.3.

7.10.3 If the diagonal legs are unequal by an amount greater than the limits defined in 7.10.1 or 7.10.2, rotate the specimen 90° and make another indentation in an untested region. If the nonsymmetrical aspect of the indentations has rotated 90°, then the specimen surface may not be perpendicular to the indenter axis and may yield incorrect hardness results. If the nonsymmetrical nature of the indentation remains in the same orientation, check the indenter for damage or misalignment as described in 7.10.4.

7.10.4 The alignment of the indenter may be checked using a test specimen, such as a standardized test block, known to produce uniformly shaped indentations. Confirm that the test block surface is perpendicular to the indenter axis as described in 7.10.3. Make an indentation. If the indentation is not symmetrical, the indenter is misaligned, and the tester shall not be used until it meets the requirements of sections 7.10.1 or 7.10.2.

7.10.5 Some materials may have nonsymmetrical indentations even if the indenter and the specimen surface are perfectly aligned. Tests on single crystals or on textured materials may produce such results. When tests on these types of materials produce nonsymmetrical indents exceeding the limits of 7.10.1 or 7.10.2, it should be noted on the test report.

7.10.6 Brittle materials such as ceramics may crack as a result of being indented. Specific details for testing ceramics are contained in Test Methods C1326 and C1327.

7.11 *Spacing of Indentations*—Generally more than one indentation is made on a test specimen. It is necessary to ensure that the spacing between indentations is large enough so that adjacent tests do not interfere with each other.

7.11.1 For most testing purposes, the minimum recommended spacing between separate tests, and minimum distance between an indentation and the edge of the specimen are illustrated in Fig. 1.

7.11.2 For some applications, closer spacing of indentations than those shown in Fig. 1 may be desired. If closer indentation spacing is used, it shall be the responsibility of the testing laboratory to verify the accuracy of the testing procedure.

8. Conversion to Other Hardness Scales or Tensile Strength Values

8.1 There is no general method of accurately converting the Vickers or Knoop hardness numbers using one test force to hardness numbers using a different test force, or to other types of hardness numbers, or to tensile strength values. Such conversions are, at best, approximations and, therefore, should be avoided except for special cases where a reliable basis for the approximate conversion has been obtained by comparison tests. For homogeneous materials and test forces ≥ 100 gf, microindentation Vickers hardness numbers are in reasonable agreement with macroindentation Vickers hardness numbers. Refer to E140 for hardness conversion tables for metals.

NOTE 7—E140 gives approximate hardness conversion values for specific materials such as steel, nickel and high-nickel alloys, cartridge brass, copper alloys, alloyed white cast irons, and wrought aluminum products.

9. Report

9.1 Report the following information:

9.1.1 The results (see 5.10), the number of tests, and, where appropriate, the mean and standard deviation of the results,

9.1.2 Test force,

9.1.3 The total force application time if outside the limits of 10 to 15 s as defined in 7.7.3,

9.1.4 Any unusual conditions encountered during the test, and

9.1.5 The test temperature, when outside the recommended allowable range of 10°C to 35°C (50°F to 95°F).

TABLE 3 Recommended Indentation Diagonal Lengths for Commonly used Objectives and NA

Commonly used Objective Magnifications[A]	Typical NA (will vary by objective type)	Objective Resolution (r_{obj}) µm	Recommended Diagonal Lengths µm
2.5×	0.07	3.93	196.5 or longer
5×	0.10	2.75	137.5 or longer
10×	0.25	1.10	55 or longer
20×	0.40	0.69	34.5 or longer
20×	0.45	0.61	30.5 or longer
40×	0.55	0.50	25 or longer
40×	0.65	0.42	21 or longer
50×	0.65	0.42	21 or longer
60×	0.70	0.39	19.5 or longer
100×	0.80	0.34	17 or longer
100×	0.95	0.29	14.5 or longer

[A] This is the magnification of the objective and may not be the total magnification of the system. Many systems have a 10× eyepiece that increases the total magnification by a factor of 10 at the operator's eye. This additional magnification does not change the optical resolution (r_{obj}) or the recommended diagonal lengths.
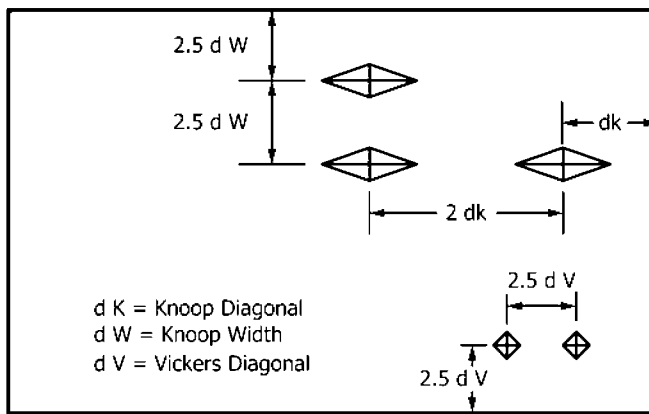
FIG. 1 Minimum Recommended Spacing for Vickers and Knoop Indentations

10. Precision and Bias

10.1 Four separate interlaboratory studies have been conducted in accordance with Practice E691 to determine the precision, repeatability, and reproducibility of this test method. The four studies are defined as follows:

(1) Vickers and Knoop tests, six test forces in the microindentation range, twelve laboratories, manual measurements, seven different hardness level test specimens. See Test Method E384.

(2) Vickers and Knoop tests, two test forces in the microindentation range, seven laboratories, image-analysis and manual measurements, four different hardness level test specimens. See Test Method E384.

(3) Vickers and Knoop tests, six test forces in the micro range, twenty-five laboratories, manual measurements, six different hardness level test specimens. See Test Method E384.

(4) Vickers tests, four test forces in the macro range, seven laboratories, manual measurements, three different hardness level test specimens. See 10.3.

10.2 *Studies 1 through 3*—The results and discussion of Studies 1 through 3 are given in Test Method E384.

10.3 *Study 4*—The macroindentation Vickers precision statement is based on an interlaboratory study of Test Methods E92, Standard Test Method for Vickers Hardness of Metallic Materials, conducted in 2001. Seven laboratories tested three different standard hardness test blocks using macro range test forces of 1, 5, 10, and 20 kgf. Only four laboratories were also able to provide results at 50 kgf test force. Every "test result" represents an individual determination of the Vickers hardness of the material. Each laboratory was asked to report triplicate test results in order to permit the estimation of intralaboratory precision. Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report No. RR: E04-1007.[4]

10.3.1 The precision statement was determined through statistical examination of 288 results, from seven laboratories, on three test blocks. The materials were described as the following:

Material 1: 200 HV
Material 2: 400 HV
Material 3: 800 HV

10.3.2 Repeatability and reproducibility limits are listed in Tables 4-8.

10.3.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

10.4 *Bias*—There is no recognized standard by which to estimate the bias of this test method.

11. Keywords

11.1 hardness; indentation; Knoop; macroindentation; microindentation; Vickers

TABLE 4 Vickers Hardness at 1 kgf Test Force (HV 1)

Test Block Nominal Hardness (HV)	Average (HV) $\bar{X}$	Bias %	Repeatability Standard Deviation (HV) s_r	Reproducibility Standard Deviation (HV) s_R	Repeatability Limit (HV) r	Reproducibility Limit (HV) R
200	209.2	N/A	4.1	7.1	11.5	19.9
400	413.8	N/A	8.1	15.6	22.8	43.7
800	812.9	N/A	21.8	21.8	61.1	61.1

TABLE 5 Vickers Hardness at 5 kgf Test Force (HV 5)

Test Block Nominal Hardness (HV)	Average (HV) $\bar{X}$	Bias %	Repeatability Standard Deviation (HV) s_r	Reproducibility Standard Deviation (HV) s_R	Repeatability Limit (HV) r	Reproducibility Limit (HV) R
200	199.0	N/A	1.7	5.2	4.7	14.5
400	421.8	N/A	4.8	7.3	13.3	20.5
800	828.0	N/A	8.9	19.5	25.0	54.6

TABLE 6 Vickers Hardness at 10 kgf Test Force (HV 10)

Test Block Nominal Hardness (HV)	Average (HV) $\bar{X}$	Bias %	Repeatability Standard Deviation (HV) s_r	Reproducibility Standard Deviation (HV) s_R	Repeatability Limit (HV) r	Reproducibility Limit (HV) R
200	198.1	N/A	2.1	3.0	6.0	8.5
400	398.5	N/A	2.9	9.1	8.2	25.4
800	800.2	N/A	2.3	11.7	6.6	32.7

TABLE 7 Vickers Hardness at 20 kgf Test Force (HV 20)

Test Block Nominal Hardness (HV)	Average (HV) $\bar{X}$	Bias %	Repeatability Standard Deviation (HV) s_r	Reproducibility Standard Deviation (HV) s_R	Repeatability Limit (HV) r	Reproducibility Limit (HV) R
200	197.1	N/A	1.8	3.5	4.9	9.9
400	415.7	N/A	2.5	5.1	7.0	14.2
800	811.5	N/A	8.3	16.6	23.3	46.6

TABLE 8 Vickers Hardness at 50 kgf Test Force (HV 50)

Test Block Nominal Hardness (HV)	Average (HV) $\bar{X}$	Bias %	Repeatability Standard Deviation (HV) s_r	Reproducibility Standard Deviation (HV) s_R	Repeatability Limit (HV) r	Reproducibility Limit (HV) R
200	191.2	N/A	0.5	1.5	1.4	4.3
400	399.9	N/A	1.1	2.0	3.1	5.7
800	814.4	N/A	2.8	12.0	7.7	33.6

ANNEXES

(Mandatory Information)

A1. VERIFICATION OF VICKERS AND KNOOP HARDNESS TESTING MACHINES

A1.1 Scope

A1.1.1 This Annex specifies three types of procedures for verifying Vickers and Knoop hardness testing machines: direct verification, indirect verification, and periodic verification.

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

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

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

A1.2 General Requirements

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

A1.2.2 All instruments used to make measurements required by this Annex shall be calibrated traceable to national standards when a system of traceability exists, except as noted otherwise.

A1.2.3 Direct verification of newly manufactured testing machines may be performed at the place of manufacture or the location of use. Direct verification of rebuilt testing machines may be performed at the place of rebuild or the location of use.

A1.2.4 The temperature at the verification site shall be measured with an instrument having an accuracy of at least

TABLE A1.1 Verification Schedule for a Vickers and Knoop Hardness Testing Machine

Verification Procedure	Schedule
Direct Verification	When a testing machine is new, or when adjustments, modifications or repairs are made that could affect the application of the test forces or the measuring system. When a testing machine fails an indirect verification.
Indirect Verification	Recommended every 12 months, or more often if needed. Shall be no longer than every 18 months. When a testing machine is installed or moved, [only a partial indirect verification is performed by following the procedure given in A1.4.5 for verifying the as-found condition]. Following a direct verification. To qualify an indenter that was not verified in the last indirect verification, (only a partial indirect verification is performed, see A1.4.8).
Periodic Verification	Required within a week prior to the machine being used. Recommended each day that the machine is used. Required whenever the machine is moved. Recommended whenever the indenter or test force is changed.

TABLE A1.2 Accuracy of Applied Forces

Applied Force, gf	Accuracy, %
$F < 200$	1.5
$F \geq 200$	1.0

± 2.0°C or ± 3.6°F. It is recommended that the temperature be monitored throughout the verification period, and significant temperature variations be recorded and reported. The temperature at the verification site does not need to be measured for a periodic verification or when qualifying additional user's indenters in accordance with A1.4.8.

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

NOTE A1.2—A valid and current certificate/scope of accreditation to conduct verifications of Vickers or Knoop hardness testing machines in accordance with Test Method E384 is considered equivalent to a certificate/scope of accreditation to conduct verifications of Vickers or Knoop hardness testing machines in accordance with this standard for the force levels listed on the certificate/scope.

A1.3 Direct Verification

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

NOTE A1.3—Direct verification is a useful tool for determining the sources of error in a Knoop or Vickers hardness testing machine.

A1.3.2 *Verification of the Test Forces*—Each Vickers and/or Knoop test force that will be used shall be measured. The test forces shall be measured by means of a Class A elastic force measuring instrument, as described in Practice E74, or an equivalent.

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

A1.3.2.2 Each test force F shall meet the requirements specified in Table A1.2.

A1.3.3 *Verification of the Indentation Measuring System*—Each magnification of the measuring device used to determine the diagonal of the indentation shall be verified at five evenly spaced intervals over the working range by comparison with an accurate scale such as a stage micrometer. The accuracy of the certified line interval of the stage micrometer shall be 0.1 μm or 0.05% of any interval, whichever is greater. Throughout the range covered, the difference between the reading of the device and of the stage shall not exceed 0.4 μm or 0.5%, whichever is greater.

A1.3.4 *Verification of the Testing Cycle*—The testing machine shall be verified to be capable of meeting the testing cycle tolerances specified in 7.7. Direct verification of the testing cycle is to be verified by the testing machine manufacturer at the time of manufacture, or when the testing machine is returned to the manufacturer for repair, or when a problem with the testing cycle is suspected. Verification of the testing cycle is recommended but not required as part of the direct verification at other times.

A1.3.4.1 Instruments that have timing controlled by software or other nonadjustable components do not have to be verified providing that the design has been proven to produce the correct testing cycle.

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

A1.3.6 *Indirect Verification*—Following a successful direct verification, an indirect verification according to A1.4 shall be performed.

A1.4 Indirect Verification

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

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

A1.4.3 Standardized test blocks used for the indirect verification shall meet the requirements of Annex A4.

NOTE A1.4—It is recognized that appropriate standardized test blocks are not available for all geometric shapes, materials, or hardness ranges.

A1.4.4 The indenter(s) to be used for the indirect verification shall meet the requirements of Annex A3.

A1.4.5 *As-found Condition*—It is recommended that the as-found condition of the testing machine be assessed as part of an indirect verification. This is important for documenting the historical performance of the machine. This procedure should be conducted by the verification agency prior to any cleaning, maintenance, adjustments, or repairs.

A1.4.5.1 The as-found condition of the testing machine shall be determined with the user's indenter that is normally used with the testing machine. One or more standardized test blocks in the range of normal testing should be used for each Vickers or Knoop hardness scale that will undergo indirect verification.

A1.4.5.2 On each standardized test block, make at least three measurements distributed uniformly over the test surface. Let d_1, d_2, …, d_n be the indentation diagonal measurement values, and $\bar{d}$ be the average of the measurements, see Eq.1.

NOTE A1.5—When testing at low forces it may be necessary to increase the number of tests in order to obtain more consistent results.

A1.4.5.3 Determine the repeatability R and the error E in the performance of the testing machine for each standardized test block that is measured using Eq 2 and Eq 3. The repeatability R and the error E shall be within the tolerances of the applicable Table A1.3 or Table A1.4.

A1.4.5.4 If the calculated values of the repeatability R or the error E fall outside the specified tolerances, this is an indication that the hardness tests made since the last indirect verification or periodic verification may be suspect.

A1.4.6 *Cleaning and Maintenance*—Perform cleaning and routine maintenance of the testing machine when required in accordance with the manufacturer's specifications and instructions.

A1.4.7 *Indirect Verification Procedure*—The indirect verification procedure is designed to verify that for all Vickers and Knoop hardness scales to be used, each test force is being accurately applied, each indenter is correct, and the measuring device is calibrated correctly for the range of indentation sizes that these test force and indenter combinations produce. This is accomplished by making hardness measurements on test blocks that have been calibrated using the same Vickers and Knoop hardness scales.

TABLE A1.4 Repeatability and Error of Testing Machines—Test Forces > 1 kgf[A]

Hardness Range of Standardized Test Blocks	Force, kgf	R Maximum Repeatability (%)	E Maximum Error (%)[B]
≥ 100 to < 240	> 1	4	2
> 240 to ≤ 600	> 1	3	2
> 600	> 1	2	2

[A] In all cases, the repeatability is satisfactory if $(d_{max}-d_{min})$ is equal to 1 µm or less.
[B] In all cases, the error is satisfactory if E from Eq 3 is equal to 0.5 µm or less.

A1.4.7.1 The testing machine shall be verified with the user's indenter(s) normally used for testing.

A1.4.7.2 A minimum of two standardized test blocks shall be used for the verification of the testing machine. The test blocks shall be chosen such that the following criteria are met:

(1) At least one hardness test block shall be used for each Vickers and Knoop hardness scale to be verified.

(2) At least two of the blocks shall be from different hardness ranges, low, mid or high hardness as specified in Table A1.5. The hardness difference between two blocks from different ranges shall be a minimum of 100 points. For example, if only one Vickers and Knoop hardness scale is to be verified, and one block having a hardness of 220 is used to verify the low range, then a block having a minimum hardness of 320 shall be used to verify the mid hardness range or high hardness range. See more examples below of the test blocks needed when performing multi-scale verifications.

(3) The highest test force shall be verified on a block from the lower of the chosen hardness ranges to produce the largest indentation size, and the lowest test force shall be used on the block from the higher of the chosen hardness ranges to produce the smallest indentation size. The two extremes of indentation size will verify the capability of the measuring device.

Example 1—A testing machine is to be verified for the HV 0.5 and HK 1 scales. Two test blocks are chosen for the verification: 450 HV 0.5 (mid-range) and 200 HK 1 (low-range). In this case, the highest test force (1000 gf) is used on a low-range hardness block, and the lowest test force (500 gf) is used on a mid-range test block, which is the higher of the two hardness ranges.

TABLE A1.3 Repeatability and Error of Testing Machines—Test Forces ≤ 1 kgf[A]

Hardness Range of Standardized Test Blocks		Force, gf	R Maximum Repeatability (%)	E Maximum Error (%)[B]
Knoop	Vickers			
HK > 0	HV > 0	1 ≤ F < 100	13	3
HK < 100	HV < 100	100 ≤ F ≤ 1000	13	3
100 ≤ HK ≤ 250	100 ≤ HV ≤ 240	100 ≤ F < 500	13	2
250 < HK ≤ 650	240 < HV ≤ 600		5	2
HK > 650	HV > 600		4	2
100 ≤ HK ≤ 250	100 ≤ HV ≤ 240	500 ≤ F ≤ 1000	8	2
250 < HK ≤ 650	240 < HV ≤ 600		4	2
HK > 650	HV > 600		3	2

[A] In all cases, the repeatability is satisfactory if $(d_{max}-d_{min})$ is equal to 1 µm or less.
[B] In all cases, the error is satisfactory if E from Eq 3 is equal to 0.5 µm or less.

TABLE A1.5 Hardness Ranges Used for Indirect Verification

Range	Knoop	Vickers
Low	< 250	< 240
Mid	250 to 650	240 to 600
High	> 650	> 600

Example 2—A testing machine is to be verified for the HK 0.1, HV 0.3 and HV 1 scales. Three test blocks are chosen for the verification: 720 HK 0.1 (high-range), 480 HV 0.3 (mid-range) and 180 HV 1 (low-range). In this case, the highest test force (1000 gf) is used on a low-range hardness block, and the lowest test force (100 gf) is used on the high-range test block. A mid-range block was chosen for the 300 gf test force although a block from any of the three hardness ranges would have complied with the requirements.

Example 3—A testing machine is to be verified for the HV 0.5 and HV 1 scales. Two test blocks are chosen for the verification: 150 HV 1 (low-range) and 450 HV 0.5 (mid-range). In this case, the highest test force (1000 gf) is used on a low-range hardness block, and the lowest test force (500 gf) is used on a mid-range test block, which is the higher of the two hardness ranges.

Example 4—A testing machine is to be verified for the HV 1, HV 3 and HV 5 scales. Three test blocks are chosen for the verification: 180 HV 5 (low-range), 480 HV 3 (mid-range) and 720 HV 1 (high-range). In this case, the highest test force (5 kgf) is used on a low-range hardness block, and the lowest test force (1 kgf) is used on the high-range test block. A mid-range block was chosen for the 3 kgf test force although a block from any of the three hardness ranges would have complied with the requirements.

A1.4.7.3 On each standardized test block, make five measurements distributed uniformly over the test surface. Let d_1, d_2,..., d_5 be the five indentation diagonal measurement values, and $\bar{d}$ be the average of the five measurements, calculated using Eq 1. Hardness measurements shall be made only on the calibrated surface of the test block. Determine the repeatability R and the error E in the performance of the testing machine using Eq 2 and Eq 3 for each hardness level of each Vickers and Knoop hardness scale to be verified. The repeatability R and the error E shall be within the tolerances of the applicable Table A1.3 or Table A1.4.

Example: Repeatability R Calculation—Assume that five Knoop indentations were made on a test block with a nominal hardness of 420 HK at the certified block test force of 300 gf and that the five diagonal measurements are 103.9, 104.8, 102.3, 102.8 and 100.2 μm. Therefore, $d_{max}-d_{min}$ = 104.8 – 100.2 = 4.6 μm and R = 100(4.6)/102.8 = 4.47 %. According to Table A1.3, the repeatability for a test block with a hardness >250 to 650 HK shall be ≤5 %. In this example, the testing machine met the repeatability requirement for this hardness test block and force. However, if these diagonals had been obtained using a test block with a nominal hardness of 700 HK and a certified test force of 300 gf, then the repeatability would be inadequate as Table A1.3 requires $R \leq 4$ % for a hardness >650 HK.

Example: Error E Calculation—The following example of an error calculation is based on the measurement data given in

the repeatability example above, and a certified mean diagonal length for the test block, d_{ref}, of 100.8 μm (420 HK 0.3). Since $\bar{d}$ =102.8 μm, $(\bar{d}-d_{ref})$ = 102.8 – 100.8 = 2.0 μm. Thus, E = 1.98 %. In this case, the percent error meets the maximum of ± 2 %, which is greater than 0.5 μm. For this example, $\bar{d}-d_{ref}$ must be > 2.016 μm for the error to be above the limit of 2 %.

A1.4.7.4 If the measurements of repeatability R or error E using the user's indenter fall outside of the specified tolerances, the indirect verification measurements may be repeated using a different indenter.

A1.4.7.5 The indirect verification shall be approved only when the testing machine measurements of repeatability and error meet the specified tolerances with the user's indenter.

A1.4.8 In cases where it is necessary to replace the indenter during the period between indirect verifications, the new indenter shall be verified for use with the specific testing machine. The user may perform the verification by following the as-found procedures given in A1.4.5. If the repeatability R and error E values fall within the tolerances in the applicable Table A1.3 or Table A1.4, the indenter can be used.

A1.4.9 When the combination of block hardness and test force produces indentations with diagonals less than 20 μm in length, indirect verification using standardized test blocks is not recommended. In these situations, the indentation measurement error represents a significant proportion of the diagonal length. This can lead to substantial deviations in hardness from the stated value. If possible, a block hardness should be used that produces indentations with diagonals at least 20 μm in length. Additional guidance when testing in the microindentation force range (forces ≤ 1 kgf) may be found in Test Method E384.

A1.5 Periodic Verification

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

A1.5.2 *Periodic Verification Procedures*—The procedures to use when performing a periodic verification are as follows:

A1.5.2.1 Periodic verification shall be done for each Vickers and Knoop hardness scale that will be used. At least one standardized test block that meets the requirements of Annex A4 shall be used for each Vickers and Knoop hardness scale to be verified. When test blocks are commercially available, the hardness level of the test blocks shall be chosen at approximately the same hardness value as the material to be measured.

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

A1.5.2.3 Before performing the periodic verification tests, ensure that the testing machine is working freely, the stage and test block are clean, and the measuring device is properly adjusted and zeroed.

A1.5.2.4 Make at least two hardness tests on each of the periodic verification test blocks adhering to the spacing requirements given in 7.11.1. Hardness measurements shall be made only on the calibrated surface of the test block.

A1.5.2.5 Let $\bar{d}$ be the average of the diagonal measurements. Determine the error E in the performance of the testing machine using Eq 3 for each standardized test block that is measured.

A1.5.2.6 If the error E calculated for each test block is within the tolerances given in the applicable Table A1.3 or Table A1.4, the testing machine with the indenter may be regarded as performing satisfactorily.

A1.5.2.7 Alternately to calculating the error E, it is acceptable to calculate the error range for the reference block in diagonal length units or hardness units. The testing machine with the indenter may be regarded as performing satisfactorily if the average measured diagonal length $\bar{d}$ or calculated average hardness value is within the error range.

Example—The test block has a certified average diagonal length of 35.2 µm and a certified value of 750 HV 0.5. From Table A1.4, the maximum error E is 2% of 35.2 µm or a range of 34.5 µm to 35.9 µm. This is equivalent to 719 HV 0.5 to 779 HV 0.5. The periodic verification is acceptable when the measured average diagonal length or equivalent HV value is within these ranges.

A1.5.2.8 If the error E calculated for any of the test blocks is outside the tolerances, follow the manufacturer's troubleshooting recommendations and repeat the test. If the average of the hardness measurements again falls outside of tolerances for any of the test blocks, an indirect verification shall be performed.

A1.5.2.9 Whenever a testing machine fails a periodic verification, the hardness tests made since the last valid indirect verification or periodic verification may be suspect.

Note A1.6—It is highly recommended that the results obtained from the periodic verification testing be recorded using accepted Statistical Process Control techniques, such as, but not limited to, X-bar (measurement averages) and R-charts (measurement ranges), and histograms.

A1.6 Verification Report

A1.6.1 A verification report is required for direct and indirect verifications. A verification report is not required for a periodic verification; however, it is recommended that records be kept of the periodic verification results, including the verification date, measurement results, certified value of the test block, test block identification, and the name of the person that performed the verification, etc. (see also Note A1.6). These records can be used to evaluate the performance of the hardness machine over time.

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

A1.6.2.1 Reference to this ASTM test method. Historical reports for verifications that reference Test Method E384 that occurred prior to the release of this edition of Test Methods E92 and continue to be within the verification schedule given in Table A1.1 are considered to meet this requirement.

A1.6.2.2 Method of verification (direct or indirect).

A1.6.2.3 Identification of the hardness testing machine and the indenters used.

A1.6.2.4 Means of verification (test blocks, elastic proving devices, etc.) with statements defining traceability to a national standard.

A1.6.2.5 The Vickers and Knoop hardness scale(s) verified.

A1.6.2.6 The individual or calculated results used to determine whether the testing machine meets the requirements of the verification performed. Measurements made to determine the as-found condition of the testing machine shall be included whenever they are made.

A1.6.2.7 Description of adjustments or maintenance done to the testing machine.

A1.6.2.8 Date of verification and reference to the verifying agency or department.

A1.6.2.9 Identification of the person performing the verification.

A2. VICKERS AND KNOOP HARDNESS STANDARDIZING MACHINES

A2.1 Scope

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

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

A2.2 Accreditation

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

indirect) and the Vickers and Knoop hardness scales that are covered by the accreditation.

A2.2.2 A laboratory that was accredited in accordance with A2.2.1 to conduct direct and/or indirect verifications of Vickers or Knoop hardness standardizing machines prior to the release of this edition of Test Methods E92 having a valid and current certificate/scope of accreditation that references Test Method E384 satisfies the accreditation requirements of this edition.

A2.3 Apparatus

A2.3.1 The standardizing machine shall comply with Annex A1 with the following additional requirements.

A2.3.2 *Direct Verification*—Direct verification shall be performed every 12 months according to A1.3.

A2.3.3 *Indirect Verification*—Indirect verification shall be performed according to A1.4, following the direct verification.

A2.3.3.1 Indirect verifications should be performed using test blocks traceable to national standards whenever they are available.

NOTE A2.1—Primary standardized test blocks are available as Standard Reference Material from NIST, Gaithersburg, MD 20899.

A2.3.4 *Periodic Verification*—Periodic verification shall be performed according to A1.5 with the following additional requirements.

A2.3.4.1 Periodic verification shall be performed before and after each lot of test blocks is standardized. When standardizations of a single lot of test blocks spans multiple days, the periodic verification procedures shall be performed at the end of the work day and at the start of the following day during the period that the lot is standardized.

A2.3.4.2 Periodic verification shall be performed whenever the indenter, anvil, or test force is changed.

A2.3.4.3 At least two test blocks shall be used in the appropriate hardness ranges that bracket the hardness level to be standardized.

A2.3.5 *Indenters*—Class A Vickers and Knoop indenters as specified in Annex A3 shall be used.

A2.3.6 *Testing Cycle*—The test force application time shall be between 5 and 7 seconds. The test force dwell time shall be between 13 and 15 seconds.

A2.3.7 The indentation measuring system shall be verified according to A1.3.3. The difference between the reading device and the stage micrometer shall not exceed 0.2 μm or 0.25 %, whichever is greater.

A2.4 Verification Report

A2.4.1 *Direct Verification:*

A2.4.1.1 Reference to this ASTM test method.

A2.4.1.2 Identification of the hardness standardizing machine, including the serial number, manufacturer and model number.

A2.4.1.3 Identification of all devices (elastic proving devices, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A2.4.1.4 Test temperature at the time of verification reported to a resolution of at least 1°C.

A2.4.1.5 The individual measurement values and calculated results used to determine whether the standardizing machine meets the requirements of the verification performed. It is recommended that the uncertainty in the calculated results used to determine whether the standardizing machine meets the requirements of the verification performed also be reported.

A2.4.1.6 Description of adjustments or maintenance done to the standardizing machine, when applicable.

A2.4.1.7 Date of verification and reference to the verifying agency or department.

A2.4.1.8 Identification of the person performing the verification.

A2.4.1.9 Accreditation certification number.

A2.4.2 *Indirect Verification:*

A2.4.2.1 Reference to this ASTM test method.

A2.4.2.2 Identification of the standardizing machine, including the serial number, manufacturer and model number.

A2.4.2.3 Identification of all devices (test blocks, indenters, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A2.4.2.4 Test temperature at the time of verification reported to a resolution of at least 1°C.

A2.4.2.5 The hardness scale(s) verified.

A2.4.2.6 The individual measurement values and calculated results used to determine whether the standardizing machine meets the requirements of the verification performed. Measurements made to determine the as-found condition of the standardizing machine shall be included whenever they are made. It is recommended that the uncertainty in the calculated results used to determine whether the standardizing machine meets the requirements of the verification performed also be reported.

A2.4.2.7 Description of maintenance done to the standardizing machine, when applicable.

A2.4.2.8 Date of verification and reference to the verifying agency or department.

A2.4.2.9 Identification of the person performing the verification.

A2.4.2.10 Accreditation certification number.

A2.4.3 *Periodic Verification:*

A2.4.3.1 No periodic verification report is required; however, it is required that records be kept of the periodic verification results.

A3. STANDARDIZATION OF VICKERS AND KNOOP INDENTERS

A3.1 Scope

A3.1.1 This Annex specifies the requirements and procedures to manufacture and standardize the Vickers and Knoop diamond indenters.

A3.1.2 The Annex covers two levels of diamond indenters, designated by this standard as Class B and Class A indenters. Class B indenters are intended for everyday use with hardness testing machines. Class A indenters are intended for the standardization of test blocks in accordance with Annex A4.

A3.1.3 Adherence to this standard and annex provides traceability to national standards, except as stated otherwise.

A3.1.4 Indenters that were standardized to Test Method E384 by a laboratory accredited in accordance with A3.2.1 prior to the release of this edition of Test Methods E92 may be used to satisfy the requirements of this edition provided that they meet all of the requirements of Test Method E384-09 or a later revision.

A3.2 Accreditation

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

A3.2.2 A laboratory that was accredited in accordance with A3.2.1 to standardize indenters prior to the release of this edition of Test Methods E92 having a valid and current certificate/scope of accreditation that references Test Method E384 is considered to satisfy the accreditation requirements of this edition.

A3.3 General Requirements

A3.3.1 *Vickers Indenter*—The ideal Vickers indenter is a highly polished, pointed, square-based pyramidal diamond with face angles of 136° 0'.

A3.3.2 *Knoop Indenter*—The ideal Knoop indenter is a highly polished, pointed, rhombic-based, pyramidal diamond. The included longitudinal edge angles are 172° 30' and 130° 0'.

A3.3.3 The four faces of the Vickers or Knoop indenter shall be equally inclined to the axis of the indenter and shall meet at a sharp point.

A3.3.4 All instruments used to make measurements required by this Annex shall be calibrated traceable to national standards where a system of traceability exists, except as noted otherwise.

A3.3.5 *Verification of Indenters*—The geometry of all classes of Vickers and Knoop diamond indenters shall be directly verified before placing into service. The instruments used to verify the geometrical features of the indenter shall have a maximum expanded uncertainty ($k=2$) as specified in Table A3.1.

A3.4 Class B Vickers Indenter

A3.4.1 The Class B Vickers diamond indenter, see Fig. A3.1, used for standard testing and indirect verifications shall have face angles of 136° 0' ± 30'. The four faces of the diamond shall be equally inclined to the axis of the indenter to within ± 30'.

A3.4.2 As an alternate, the 136° face angles may be verified by measuring the angles between the opposite edges rather than the faces. When measured, the edge angles shall be 148° 6' 36" ± 45' and equally inclined to the axis of the indenter within ± 30'.

A3.4.3 The face junction offset, see Fig. A3.1, shall not exceed 1 µm when testing with test forces of 1 kgf and greater. When testing with forces less than 1 kgf, the offset shall not exceed 0.5 µm.

A3.4.4 As an alternate, it is permissible to verify the face junction offset by using a microscope with at least 500× magnification to view an indentation created by the indenter and compare the offset length to a known dimension.

A3.5 Class A Vickers Indenter

A3.5.1 The Class A Vickers diamond indenter used for the standardization of test blocks shall have face angles of 136° 0' ± 6'. The face angles shall be equally inclined to the axis of the indenter within ± 15'.

A3.5.2 As an alternate, the 136° face angles may be verified by measuring the angles between the opposite edges rather than the faces. When measured, the edge angles shall be 148° 6' 36" ± 9', and equally inclined to the axis of the indenter within ± 30'.

A3.5.3 The face junction offset shall not exceed 0.3 µm.

A3.6 Class B Knoop Indenter

A3.6.1 The Class B Knoop diamond indenter, see Fig. A3.2, used for standard testing and indirect verifications shall have an included longitudinal edge angle A of 172° 30' ± 6', and a corresponding edge angle B of 130° ± 1°. The two angle A edges of the diamond shall be equally inclined to the axis of the

TABLE A3.1 Maximum Expanded Uncertainty of Instruments for Verifying the Geometrical Features of Knoop and Vickers Indenters

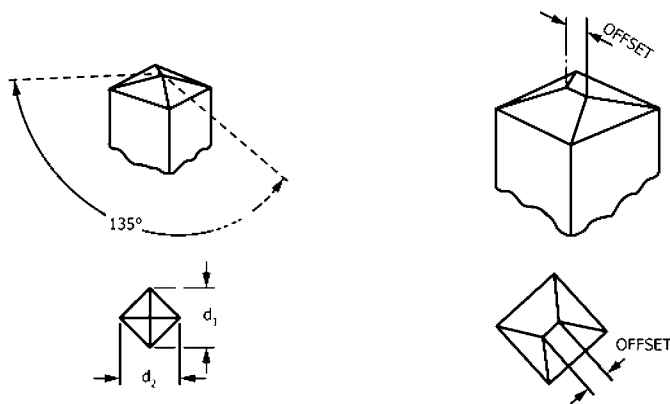| Geometrical Feature	Indenter Class	Maximum Expanded Uncertainty ($k=2$)
Angles	A and B	0.07°
Junction offset	B	0.5 µm
Junction offset	A	0.3 µm

FIG. A3.1 Vickers Indenter

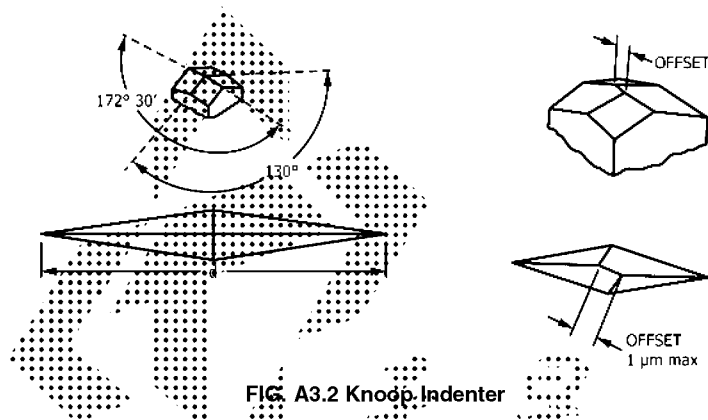FIG. A3.2 Knoop Indenter

indenter to within ± 30', and the two angle edges of the diamond shall be equally inclined to the axis of the indenter to within ± 30'.

A3.6.2 The indenter constant (c_P) shall be 0.07028 within ± 1 %.

A3.6.3 The face junction offset shall not be more than 1 μm in length for indentations greater than 15 μm in length, as shown in Fig. A3.2. For shorter indentations the offset should be proportionally less. (See A3.4.4.)

A3.7 Class A Knoop Indenter

A3.7.1 The Class A Knoop diamond indenter used for the standardization of test blocks shall meet the requirements of a Class B Knoop indenter as given in A3.6, and have an indenter constant of 0.07028 ± 0.5 %. The offset shall not exceed 0.5 μm.

A3.8 Marking

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

A3.9 Certificate

A3.9.1 Each class A or class B indenter shall have a calibration certificate with the following information (see A3.1.4).

A3.9.1.1 Reference to this ASTM test method.

A3.9.1.2 Serial number of the indenter.

A3.9.1.3 Date of standardization.

A3.9.1.4 Type (Vickers or Knoop) and class of the indenter (class A or class B).

A3.9.1.5 The results of all geometric verifications.

A3.9.1.6 For Class B Vickers indenter: lowest test force that can be used (1 gf or 1 kgf, dependent on junction offset value).

A3.9.1.7 For Class B Knoop indenter: smallest indentation allowed to be made (dependent on junction offset value).

A3.9.1.8 A statement declaring that the indenter meets all of the geometric requirements for the type and class of indenter.

A3.9.1.9 Accreditation agency certification number.

A4. STANDARDIZATION OF VICKERS AND KNOOP HARDNESS TEST BLOCKS

A4.1 Scope

A4.1.1 This Annex specifies the requirements and procedures for the standardization of Vickers and Knoop hardness test blocks that are traceable to specific hardness standards. These standardized test blocks are to be used for the verification of the performance of Vickers and Knoop testing machines by way of periodic verifications and indirect verifications as described in Annex A1.

A4.1.2 Test blocks that were standardized by a laboratory accredited in accordance with A4.2.1 to Test Methods E92 or Test Method E384 prior to the release of this edition of Test Methods E92 may be used to satisfy the requirements of this edition provided that they meet all of the requirements of Test Methods E92 (2003) or Test Method E384-09 or later revisions.

A4.2 Accreditation

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

A4.2.2 A laboratory that was accredited in accordance with A4.2.1 to standardize test blocks prior to the release of this edition of Test Methods E92 having a valid and current certificate/scope of accreditation that references Test Method E384 are considered to satisfy the accreditation requirements of this edition.

A4.3 Test Block Manufacture

A4.3.1 The test block thickness shall be greater than twenty times the depth of the indentation made with the certified test force.

A4.3.2 The test block material and manufacturing processes shall be chosen to produce the required degree of homogeneity, structural stability and uniformity of hardness at the prepared surface.

A4.3.3 Ferromagnetic test blocks shall be demagnetized by the manufacturer and shall be maintained in that condition by the user.

A4.3.4 The test block support surface shall have a finely ground surface finish. The maximum deviation from flatness of the test and support surfaces shall not exceed 5 μm. The maximum error in parallelism shall not exceed 15 μm in 30 mm.

A4.3.5 The test block test surface shall be polished according to the procedures in Methods E3 to yield the true microstructure, free from scratches that would interfere with production of the indentation or measurement of the indentation diagonal(s). The mean, centerline average, surface roughness height measurement of the test surface shall not exceed 0.1 μm (4 μin.).

A4.3.6 Repolishing of the test block will invalidate the standardization and is not recommended. Cleaning of the polished test block surface is often required in normal usage but must not alter the hardness or quality of the polished test surface.

A4.4 Standardizing Tester Requirements

A4.4.1 The standardization of the hardness test blocks shall be performed with a Knoop or Vickers hardness standardizing machine that meets all of the requirements of Annex A2.

A4.4.2 *Indenters*—Class A Vickers and Knoop indenters as specified in Annex A3 shall be used.

A4.4.3 *Testing Cycle*—The test force application time shall be between 5 and 7 seconds. The test force dwell time shall be between 13 and 15 seconds.

A4.5 Test Block Standardization Procedure

A4.5.1 Make a minimum of five hardness measurements arranged as follows on the surface of the test block- one indentation near the center of each of the four quadrants of the block and the fifth near the center of the test block. When more than five indents are done, they shall be arranged around the test surface in a similar manner.

A4.5.2 Adjust the illumination for the measuring system to produce uniform intensity over the field of view and optimum contrast between the indents and the block surface.

A4.5.3 Measure the length of the Knoop longitudinal diagonal, or the average length of the Vickers diagonals of each indentation. Record the data by location and by block.

A4.6 Repeatability of the Standardized Test Block

A4.6.1 Let d_1, d_2,..., d_5 be the five indentation diagonal measurement values, and $\bar{d}$ be the average of the five measurements calculated using Eq 1. Determine the repeatability R of the calibration measurements using Eq 2. The repeatability R is an indication of the hardness homogeneity of the test block, although R is influenced by all of the variables that affect the repeatability of test results. The repeatability R shall be within the tolerances of the applicable Table A4.1 or Table A4.2, which list the required maximum R values for test blocks by indenter type, test force range and hardness range. The measured R value shall be less than these limits for it to be considered sufficiently uniform enough in hardness to function as a standardized test block.

A4.7 Marking

A4.7.1 Each block shall be permanently marked with the name or identifying mark of the standardizing agency, an appropriate identifying serial number and a mark on the test surface that will be obliterated if the surface is repolished.

TABLE A4.1 Repeatability of Diagonal Measurements for Standardized Test Blocks Calibrated in the Microindentation Force Ranges (≤ 1 kgf)[A]

Hardness Range of Standardized Test Blocks		Force, gf	R, %, Less Than
Knoop	Vickers		
HK > 0	HV > 0	1 ≤ F < 100	12
HK < 100	HV < 100	100 < F ≤ 1000	12
100 ≤ HK ≤ 250	100 ≤ HV ≤ 240	100 ≤ F < 500	12
250 < HK ≤ 650	240 < HV ≤ 600		4
HK > 650	HV > 600		3
100 ≤ HK ≤ 250	100 ≤ HV ≤ 240	500 ≤ F ≤ 1000	7
250 < HK ≤ 650	240 < HV ≤ 600		3
HK > 650	HV > 600		2

[A] In all cases, the repeatability limit is the greater of the percentage given or 0.001 mm (1 µm).

TABLE A4.2 Repeatability of Diagonal Measurements for Standardized Test Blocks Calibrated in the Macroindentation Force Ranges (> 1 kgf)[A]

Hardness Range of Standardized Test Blocks	Force, kgf	Maximum R%
100 to 240 inclusive	> 1	3
Over 240 to 600 inclusive	> 1	2
Over 600	> 1	1.5

[A] In all cases, the repeatability limit is the greater of the percentage given or 0.001 mm (1 µm).

A4.7.2 When the test blocks are encapsulated in a mounting medium, the markings listed in A4.7.1 shall be permanently placed on the surface of the medium that contains the test surface.

A4.7.3 Each of the calibration measurements shall be identified so that they can be located by the user.

A4.8 Certification of Standardized Test Block

A4.8.1 At a minimum the certificate accompanying each standardized hardness test block shall include the following information. (See A4.1.2.)

A4.8.1.1 The mean diagonal length and location of each of the standardizing indentations.

A4.8.1.2 The average value of all the indentation mean diagonal lengths, and the corresponding hardness value.

A4.8.1.3 The test force.

A4.8.1.4 The serial number of the test block.

A4.8.1.5 The name of the manufacturer and standardizing organization.

A4.8.1.6 The magnification used to measure the standardizing indents.

A4.8.1.7 The date of standardization.

A4.8.1.8 Reference to this ASTM test method.

A4.8.1.9 Value of the uncertainty in the standardized value with an explanation of how the uncertainty was calculated.

A4.8.1.10 Accreditation agency certification number.

A5. CORRECTION FACTORS FOR VICKERS HARDNESS TESTS MADE ON SPHERICAL AND CYLINDRICAL SURFACES

A5.1 Tables A5.1-A5.3 provide correction factors that shall be applied to Vickers hardness values obtained when tests are made on spherical or cylindrical surfaces. The correction factors are tabulated in terms of the ratio of the mean diagonal d of the indentation to the diameter D of the sphere or cylinder. Examples of the use of these tables are given in Example A5.1 and A5.2.

Example A5.1
Convex Sphere
Diameter of sphere, D = 10 mm, Force, F = 10 kgf
Mean diagonal of impression, d = 0.150 mm
d/D = 0.150/10 = 0.015
From Eq 7 and Table 2, HV = 824
From Table A5.1, by interpolation, correction factor = 0.983
Hardness of sphere = 824 × 0.983 = 810 HV 10

Example A5.2
Concave Cylinder, One Diagonal Parallel to Axis
Diameter of cylinder, D = 5 mm, Force, F = 30 kgf
Mean diagonal of impression, d = 0.415 mm
d/D = 0.415/5 = 0.083
From Eq 7 and Table 2, HV = 323
From Table A5.3, correction factor = 1.075
Hardness of cylinder = 323 × 1.075 = 347 HV 30

NOTE A5.1—A method for correcting Vickers hardness readings taken on spherical or cylindrical surfaces can be found in the International Organization for Standardization (ISO) Vickers Hardness Standard (ISO 6507-1).

TABLE A5.1 Correction Factors for Use in Vickers Hardness Tests Made on Spherical Surfaces

Convex Surface		Concave Surface	
d/D^A	Correction Factor	d/D^A	Correction Factor
0.004	0.995	0.004	1.005
0.009	0.990	0.008	1.010
0.013	0.985	0.012	1.015
0.018	0.980	0.016	1.020
0.023	0.975	0.020	1.025
0.028	0.970	0.024	1.030
0.033	0.965	0.028	1.035
0.038	0.960	0.031	1.040
0.043	0.955	0.035	1.045
0.049	0.950	0.038	1.050
0.055	0.945	0.041	1.055
0.061	0.940	0.045	1.060
0.067	0.935	0.048	1.065
0.073	0.930	0.051	1.070
0.079	0.925	0.054	1.075
0.086	0.920	0.057	1.080
0.093	0.915	0.060	1.085
0.100	0.910	0.063	1.090
0.107	0.905	0.066	1.095
0.114	0.900	0.069	1.100
0.122	0.895	0.071	1.105
0.130	0.890	0.074	1.110
0.139	0.885	0.077	1.115
0.147	0.880	0.079	1.120
0.156	0.875	0.082	1.125
0.165	0.870	0.084	1.130
0.175	0.865	0.087	1.135
0.185	0.860	0.089	1.140
0.195	0.855	0.091	1.145
0.206	0.850	0.094	1.150

^{A} D = diameter of cylinder in millimetres; d = mean diagonal of indentation in millimetres.

TABLE A5.2 Correction Factors for Use in Vickers Hardness Tests Made on Cylindrical Surfaces (Diagonals at 45° to the axis)

Convex Surface		Concave Surface	
d/D^A	Correction Factor	d/D^A	Correction Factor
0.009	0.995	0.009	1.005
0.017	0.990	0.017	1.010
0.026	0.985	0.025	1.015
0.035	0.980	0.034	1.020
0.044	0.975	0.042	1.025
0.053	0.970	0.050	1.030
0.062	0.965	0.058	1.035
0.071	0.960	0.066	1.040
0.081	0.955	0.074	1.045
0.090	0.950	0.082	1.050
0.100	0.945	0.089	1.055
0.109	0.940	0.097	1.060
0.119	0.935	0.104	1.065
0.129	0.930	0.112	1.070
0.139	0.925	0.119	1.075
0.149	0.920	0.127	1.080
0.159	0.915	0.134	1.085
0.169	0.910	0.141	1.090
0.179	0.905	0.148	1.095
0.189	0.900	0.155	1.100
0.200	0.895	0.162	1.105
		0.169	1.110
		0.176	1.115
		0.183	1.120
		0.189	1.125
		0.196	1.130
		0.203	1.135
		0.209	1.140
		0.216	1.145
		0.222	1.150

^{A} D = diameter of cylinder in millimetres; d = mean diagonal of impression in millimetres.

TABLE A5.3 Correction Factors for Use in Vickers Hardness Tests Made on Cylindrical Surfaces (One diagonal parallel to axis)

Convex Surface		Concave Surface	
d/D^A	Correction Factor	d/D^A	Correction Factor
0.009	0.995	0.008	1.005
0.019	0.990	0.016	1.010
0.029	0.985	0.023	1.015
0.041	0.980	0.030	1.020
0.054	0.975	0.036	1.025
0.068	0.970	0.042	1.030
0.085	0.965	0.048	1.035
0.104	0.960	0.053	1.040
0.126	0.955	0.058	1.045
0.153	0.950	0.063	1.050
0.189	0.945	0.067	1.055
0.243	0.940	0.071	1.060
		0.076	1.065
		0.079	1.070
		0.083	1.075
		0.087	1.080
		0.090	1.085
		0.093	1.090
		0.097	1.095
		0.100	1.100
		0.103	1.105
		0.105	1.110
		0.108	1.115
		0.111	1.120
		0.113	1.125
		0.116	1.130
		0.118	1.135
		0.120	1.140
		0.123	1.145
		0.125	1.150

^{A} D = diameter of cylinder in millimetres; d = mean diagonal of impression in millimetres.
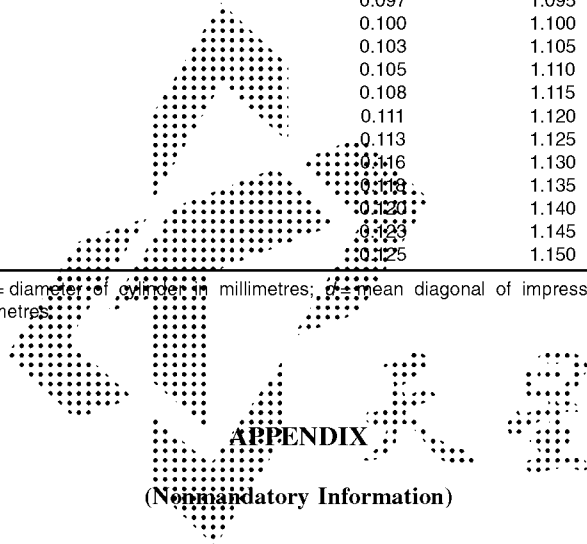
APPENDIX

(Nonmandatory Information)

X1. EXAMPLES OF PROCEDURES FOR DETERMINING VICKERS AND KNOOP HARDNESS UNCERTAINTY

X1.1 Scope

X1.1.1 The intent of this appendix is to provide a basic approach to evaluating the uncertainty of Vickers and Knoop hardness measurement values in order to simplify and unify the interpretation of uncertainty by users of Vickers and Knoop 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 hardness measurements are made on a reference test block. According to Annex A1, the error E is calculated as a percent (%) error based on diagonal lengths, and not hardness values (see Eq 3). Determining the uncertainty of this value is difficult since, in addition to the resolution of the indentation measuring system, the uncertainty depends on the force application, indenter geometry and other parameters, but it provides little information to the customer. A better indication of measurement uncertainty is the uncertainty of the difference, or hardness error E_H, between the average of

the hardness measurement values and the certified hardness value of the reference block. The procedure described in section X1.6 provides a method for determining the uncertainty in the hardness measurement error E_H of the hardness machine. The uncertainty value may be reported on the verification certificate and report, and is useful to users in determining their own measurement uncertainty.

X1.1.2.2 *Hardness Value Measured by a User (see X1.7)*—The procedure provides a method for determining the uncertainty in the hardness values measured by a user during the normal use of a hardness machine. The user may report the uncertainty value with the measurement value.

X1.1.2.3 *Certified Value of a Hardness Test Block (see X1.8)*—The procedure provides a method for determining the uncertainty in the certified value of standardized test blocks. The standardizing agency may report the uncertainty value on the test block certificate.

NOTE X1.1—When calculated, uncertainty values reported by a field calibration agency (see X1.6) are not the measurement uncertainties of the hardness machine in operation, but only that of the measurements made at

the time of verification to determine machine "error."

NOTE 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 Vickers and Knoop hardness users and standardizing agencies. The reader should be aware that there are other methods that may be employed to determine the same uncertainties, which may provide more accurate estimations of the uncertainty values.

NOTE X1.3—This standard states tolerances or limits on the acceptable repeatability and error of a Vickers or Knoop hardness machine (Table A1.3 and Table A1.4) and the nonuniformity of standardized blocks (Table A4.1 and Table A4.2). These limit values were originally established based on the testing experience of many users of the Vickers and Knoop hardness tests, and therefore reflect the normal performance of a properly functioning Vickers or Knoop 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 Vickers and Knoop hardness measurements. Consequently, when determining compliance with Table A1.3, Table A1.4, Table A4.1 and Table A4.2, the user's measurement uncertainty should not be subtracted from the tolerance limit values given in the tables, as is commonly done for other types of metrological measurements. The calculated values for repeatability, error or block nonuniformity should be directly compared to the tolerance limits given in the tables.

NOTE X1.4—Most product specification tolerances for Vickers and Knoop hardness were established based on testing and performance experience. The tolerance values reflect the normal performance of a properly functioning Vickers and Knoop hardness machines, 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 Vickers and Knoop hardness measurements. Consequently, when acceptance testing most products for Vickers or Knoop 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 $H_1, H_2, ..., H_n$ is calculated as:

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

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

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

where $\bar{H}$ is the average of the set of n hardness measurements $H_1, H_2, ..., H_n$ 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

X1.3 General Requirements

X1.3.1 The approach for determining uncertainty presented in this appendix considers only those uncertainties associated with the overall measurement performance of the Vickers or Knoop hardness machine with respect to reference standards. These performance uncertainties reflect the combined effect of the separate uncertainties associated with the numerous individual components of the machine, such as the force application system and indentation measuring system. Therefore, the uncertainties associated with the individual components of the machine are not included in the calculations. Because of this approach, it is important that the individual machine components are operating within tolerances. It is strongly recommended that this procedure be applied only after successfully passing a direct verification.

X1.3.2 The procedures given in this appendix are appropriate only when the Vickers or Knoop hardness machine has passed an indirect verification in accordance with the procedures and schedules of this test method standard.

X1.3.3 The procedures for calculating the uncertainty of Vickers and Knoop hardness measurement values are similar for both a standardizing machine and testing machine. The principal difference is in the hierarchy level of the reference test blocks normally used for the indirect verification. Generally, standardizing machines are verified using primary reference standards, and testing machines are standardized using secondary reference standards.

X1.3.4 To estimate the overall uncertainty of Vickers and Knoop 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.

X1.3.5 Uncertainty should be determined with respect to a country's highest level of reference standard or the national reference standard of another country. In some cases, the highest level of reference standard may be a commercial reference standard.

X1.4 General Procedure

X1.4.1 This procedure calculates a combined standard uncertainty u_c by combining the contributing components of uncertainty $u_1, u_2, ..., u_n$, such that:

$$u_c = \sqrt{u_1^2 + u_2^2 + \cdots + u_n^2} \quad (X1.3)$$

X1.4.2 Measurement uncertainty is usually expressed as an expanded uncertainty U which is calculated by multiplying the combined standard uncertainty u_c by a numerical coverage factor k, such that:

$$U = k \times u_c \quad (X1.4)$$

X1.4.3 A coverage factor is chosen that depends on how well the standard uncertainty was estimated (number of

measurements), and the level of uncertainty that is desired. For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

X1.4.4 The measurement bias B of the hardness machine is the difference between the expected hardness measurement values as displayed by the hardness machine and the "true" hardness of a material. Ideally, measurement biases should be corrected. When test systems are not corrected for measurement bias, as often occurs in Vickers and Knoop 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:

$$U = ku_c + ABS(B) \qquad (X1.5)$$

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

X1.4.5 Because several approaches may be used to evaluate and express measurement uncertainty, a brief description of what the reported uncertainty values represent should be included with the reported uncertainty value.

X1.5 Sources of Uncertainty

X1.5.1 This section describes the most significant sources of uncertainty in a Vickers or Knoop 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 hardness machine's lack of repeatability, (2) the non-uniformity in hardness of the material under test, (3) the hardness machine's lack of reproducibility, (4) the resolution of the hardness machine's indentation measurement display, and (5) the uncertainty in the certified value of the reference test block standards. An estimation of the measurement bias and its inclusion into the expanded uncertainty will also be discussed.

X1.5.3 *Uncertainty Due to Lack of Repeatability (u_{Repeat}) and when Combined with Non-uniformity ($u_{Rep\&NU}$)*—The repeatability of a hardness machine is an indication of how well it can continually produce the same hardness value each time a measurement is made. Imagine there is a material, which is perfectly uniform in hardness over its entire surface. Also imagine that hardness measurements are made repeatedly on this uniform material over a short period of time without varying the testing conditions, including the operator. Even though the actual hardness of every test location is exactly the same, it would be found that due to random errors each measurement value would differ from all other measurement values (assuming sufficient measurement resolution). Therefore, lack of repeatability prevents the hardness machine from being able to always measure the true hardness of the material, and hence contributes to the uncertainty in the measurement.

X1.5.3.1 The contribution that a hardness machine's lack of repeatability makes to the overall measurement uncertainty is determined differently depending on whether a single measurement value or an average of multiple measurements is to be reported. Additionally, in cases where the reported average measurement value is intended to be an estimate of the average hardness of the material tested, the uncertainty contributions due to the machine's lack of repeatability and the non-uniformity in the hardness of the test material are difficult to separate and must be determined together. The uncertainty contributions for each of these circumstances may be estimated as follows.

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 specimen as:

$$u_{Repeat} = STDEV(H_1, \quad H_2, \ldots, H_n) \qquad (X1.6)$$

where H_1, H_2, ..., H_n are the n hardness values. In general, the estimate of repeatability is improved as the number of hardness measurements is increased. Usually, the hardness values measured during an indirect verification will provide an adequate estimate of u_{Repeat}; however, the caution given in Note X1.6 should be considered. It may be more appropriate for the user to determine a value of u_{Repeat} by making hardness measurements close together (within spacing limitations) on a uniform material, such as a test block.

Note X1.5—The uncertainty u_{Repeat}, due to the lack of repeatability of a hardness machine as discussed above, should not be confused with the historically defined "repeatability" that is a requirement to be met as part of an indirect verification (see A1.4.7.3). The calculations of the uncertainty u_{Repeat} and of the historically defined repeatability do not produce the same value. The uncertainty u_{Repeat} is the contribution to the overall uncertainty of a hardness measurement value due to a machine's lack of repeatability, while the historically defined repeatability is the range of hardness values measured during an indirect verification.

Note X1.6—All materials exhibit some degree of hardness non-uniformity across the test surface. Therefore, the above evaluation of the uncertainty contribution due to the lack of repeatability will also include a contribution due to the hardness non-uniformity of the measured material. When evaluating repeatability as discussed above, any uncertainty contribution due to the hardness non-uniformity should be minimized as much as possible. The laboratory should be cautioned that if the measurements of repeatability are based on tests made across the surface of the material, then the repeatability value will likely include a significant uncertainty contribution due to the material's non-uniformity. A machine's repeatability is better evaluated by making hardness measurements close together (within spacing limitations).

X1.5.3.3 *Average of Multiple Measurements*—When the average of multiple hardness test values is to be due reported, the standard uncertainty contribution $u_{\overline{Repeat}}$ due to the lack of repeatability of the hardness machine, may be estimated by dividing the standard uncertainty contribution u_{Repeat} (previously calculated from a number of hardness measurements made on a uniform test specimen, see X1.5.3.1) by the square-root of the number of hardness test values being averaged, as:

$$u_{\overline{Repeat}} = \frac{u_{Repeat}}{\sqrt{n_T}} \qquad (X1.7)$$

where u_{Repeat} is calculated by Eq X1.6 and n_T is the number of individual hardness 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 in order to estimate the average hardness of the material as a whole. For example, this may be done when making quality control measurements during the manufacture of many types of products; when determining the machine error E as part of an indirect verification; and when calibrating a test block. Because all materials exhibit some degree of hardness non-uniformity across the test surface, the extent of a material's non-uniformity also contributes to the uncertainty in this estimate of the average hardness of the material. When the average of multiple hardness measurement values is calculated as an estimate of the average material or product hardness, it may be desired to state the uncertainty in this value with respect to the true hardness of the material. In this case, the combined uncertainty contributions due to the lack of repeatability in the hardness machine and the non-uniformity in the test material may be estimated from the "standard deviation of the mean" of the hardness measurement values. This is calculated as the standard deviation of the hardness values, divided by the square-root of the number of measurements as:

$$u_{Rep\&NU} = \frac{STDEV(H_{T1}, H_{T2}, \ldots, H_{Tn})}{\sqrt{n_T}} \qquad (X1.8)$$

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

X1.5.4 *Uncertainty Due to Lack of Reproducibility* (u_{Reprod})—The day-to-day variation in the performance of the hardness machine is known as its level of reproducibility. Variations such as different machine operators and changes in the test environment often influence the performance of the hardness machine. The level of reproducibility is best determined by monitoring the performance of the hardness machine over an extended period of time during which the hardness machine is subjected to the extremes of variations in the testing variables. It is very important that the test machine be in control during the assessment of reproducibility. If the machine is in need of maintenance or is operated incorrectly, the lack of reproducibility will be overestimated.

X1.5.5 An assessment of a hardness machine's lack of reproducibility should be based on periodic monitoring measurements of the hardness machine, such as periodic verification measurements made on the same test block over time. The uncertainty contribution may be estimated by the standard deviation of the average of each set of monitoring values, as:

$$u_{Reprod} = STDEV(M_1, M_2, \ldots, M_n) \qquad (X1.9)$$

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

NOTE X1.7—The uncertainty contribution due to the lack of reproducibility, as calculated in Eq X1.9, also includes a contribution due to the machine's lack of repeatability and the non-uniformity of the monitoring test block; however, these contributions are based on the average of multiple measurements and should not significantly overestimate the reproducibility uncertainty.

X1.5.6 *Uncertainty Due to the Resolution of the Indentation Measuring System* (u_{Resol})—The finite resolution of the indentation measuring system prevents the hardness machine from providing an absolutely accurate hardness value. The uncertainty contribution u_{Resol}, due to the influence of the measuring

system resolution r_H, may be described by a rectangular distribution and estimated as:

$$u_{Resol} = \frac{r_H / 2}{\sqrt{3}} = \frac{r_H}{\sqrt{12}} \qquad (X1.10)$$

where r_H is the resolution limit that a hardness value can be estimated from the indentation diagonal measurement system in hardness units. It is important to note that the resolution limit r_H will be dependent not only on the length resolution r_d of the indentation measurement system, but also on the hardness value $\bar{H}$ and the corresponding diagonal length d. The measurement resolution in diagonal length units may be converted to the resolution in hardness units as:

$$r_H = r_d \times \frac{2 \times \bar{H}}{d} \qquad (X1.11)$$

NOTE X1.8—The influence of measurement resolution can be a significant contribution to HV and HK measurement uncertainty, particularly for small indentations. Consider the case of measuring a small indentation, for example having a 25 µm diagonal length, with a measuring system having a resolution of 1 µm. It is probable that every measurement of the indentation would yield the same measurement value, indicating that the measurement uncertainty due to the (lack of) repeatability in the ability to measure the indentation diagonal length would be negligent or zero. However, this is probably not the case. The actual uncertainty in the measurement repeatability is likely much higher due to the measurement resolution.

Several factors should be considered when determining how resolution contributes to the overall hardness measurement uncertainty. The resolution contributions are also dependent on the type of measurement system used. In most cases, a Vickers or Knoop indentation diagonal length is measured by locating and resolving the indentation tips at each end of the diagonal. The ability of the measuring system to resolve the indentation tip is partly due to the incremental resolution of the system, but also due to the optical resolution of the microscope objective. In the case of video measurement systems, the incremental resolution may be based on the incremental length spacing observed on the sample corresponding to two adjacent video display pixels, or how the measurement software resolves the video image. In the case of using an optical microscope with a filar eyepiece, the incremental resolution may be based on the resolution of the measurement display or micrometre scale. The resolution of the measuring system is also dependent on the resolution of the microscope objective based on the wavelength of light used to observe the indentation and the numerical aperture of the lens (see 7.9.1).

To determine the overall measurement uncertainty due to the measurement resolution, both the uncertainties due to the incremental resolution of the system $u_{Resol(incr)}$ and the optical resolution of the microscope objective $u_{Resol(obj)}$ should be taken into account.

The hardness measurement uncertainty due to resolving the tip of one end of an indentation diagonal is $u_{Resol}^2 = u_{Resol(incr)}^2 + u_{Resol(obj)}^2$, calculating $u_{Resol(incr)}$ and $u_{Resol(obj)}$ using Eq X1.10 after converting r_d to r_H according to Eq X1.11. Since the measurement of a diagonal length usually involves resolving both tips of the diagonal, the uncertainty due to resolving both ends of an indentation diagonal is $u_{Resol}^2 = 2 \times (u_{Resol(incr)}^2 + u_{Resol(obj)}^2)$ which is the uncertainty due the resolution of measuring a single diagonal length. For a Knoop or Vickers hardness measurement, $u_{Resol} = \sqrt{2 \times (u_{Resol(incr)}^2 + u_{Resol(obj)}^2)}$.

X1.5.7 *Standard Uncertainty in the Certified Average Hardness Value of the Reference Test Block* (u_{RefBlk})—Reference test blocks provide the link to the Vickers and Knoop standards to which traceability is claimed. The certificate accompanying reference test blocks should provide an uncertainty in the stated certified value, and should state to which Vickers or Knoop standard the reference test block value is traceable. This uncertainty contributes to the measurement uncertainty of hardness machines calibrated or verified with the reference test blocks. Note that the uncertainty reported on reference test

block certificates is typically stated as an expanded uncertainty. As indicated by Eq X1.4, the expanded uncertainty is calculated by multiplying the standard uncertainty by a coverage factor (often 2). This analysis uses the standard uncertainty and not the expanded uncertainty value. Thus, the uncertainty value due to the uncertainty in the certified value of the reference test block usually may be calculated as:

$$u_{RefBlk} = \frac{U_{RefBlk}}{k_{RefBlk}} \qquad (X1.12)$$

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

X1.5.8 *Measurement Bias (B)*—The measurement bias is the difference between the hardness measurement values as displayed by the hardness machine and the "true" hardness of a material. The measurement bias B may be estimated by the error E determined as part of the indirect verification as:

$$B = \bar{H} - \bar{H}_{RefBlk} \qquad (X1.13)$$

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

X1.6 Procedure for Calculating Uncertainty: Indirect Verification

X1.6.1 As part of an indirect verification, the percent (%) error E of the hardness machine is determined from the average of diagonal length measurements made on a reference test block (see Eq 3 and A1.4). This value provides an indication of how well the hardness machine can measure the "true" hardness of a material; however, determining the uncertainty of this value is not useful to the user (see X1.1.2.1). This section provides a procedure that can be used, for example by a field calibration agency, to estimate the uncertainty U_{Mach} in the hardness measurement error E_H 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. 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.

X1.6.2 The contributions to the standard uncertainty of the hardness measurement error, u_{Mach}, are:

(1) $u_{Rep\&NU}$ (*Ref. Block*), the uncertainty due to the lack of repeatability of the hardness machine combined with the uncertainty due to the non-uniformity in the reference test block (Eq X1.8), which is determined from the hardness measurements made on a reference test block to determine the error E of the hardness machine. The notation (*Ref. Block*) is added to the term $u_{Rep\&NU}$ to clarify that the uncertainty is determined from measurements made on the reference block used for the indirect verification,

(2) u_{Resol}, the uncertainty due to the resolution of the indentation measuring system (Eq X1.10) in hardness units, and

(3) u_{RefBlk}, the standard uncertainty in the certified value of the reference test block (Eq X1.12).

X1.6.3 The combined standard uncertainty u_{Mach} and the expanded uncertainty U_{Mach} are calculated by combining the appropriate uncertainty components described above for each hardness level of each Vickers and Knoop hardness scale as:

$$u_{Mach} = \sqrt{u_{Rep\&NU}^2(Ref.\,Block) + u_{Resol}^2 + u_{RefBlk}^2} \qquad (X1.14)$$

and

$$U_{Mach} = k \times u_{Mach} \qquad (X1.15)$$

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 X1.9—The uncertainty contribution u_{Mach} as calculated in Eq X1.14 does not include a contribution due to the machine's lack of reproducibility. This is because it is assumed that the indirect verification is made while the hardness machine is operating at its optimal performance level with the best possible environmental conditions.

NOTE X1.10—The expanded uncertainty U_{Mach} will commonly be larger than the value of the hardness machine "error."

X1.6.5 *Reporting the Measurement Uncertainty*—This expanded uncertainty U_{Mach} may be reported by a calibration agency to its customer as an indication of the uncertainty in the hardness machine error E reported as part of the indirect verification of a Vickers or Knoop hardness machine. The value of U_{Mach} should be supplemented with a statement defining to what Vickers or Knoop hardness scale and hardness level the uncertainty is applicable, with an explanatory statement such as: "The expanded uncertainty of the hardness machine error E reported as part of the indirect verification for the stated hardness scale(s) and hardness level(s) is with respect to hardness reference standards maintained at _____ (for example, NIST), and was calculated in accordance with Appendix X1 of ASTM E92 with a coverage factor of 2 representing a confidence level of approximately 95 %."

X1.6.6 The standard uncertainty value u_{Mach} can be used as an uncertainty contribution when determining the measurement uncertainty of future measurements made with the hardness machine (see X1.7 and X1.8).

X1.6.7 *Example X1.1*—This example illustrates how to calculate the uncertainty U_{Mach} in the hardness measurement error E_H of the hardness machine determined as the difference between the average of the measurement values and the certified value of a reference block. An evaluation will only be made for measurements made on a Knoop reference block with a reported certified value of 420 HK 0.3 and an expanded uncertainty of $U_{RefBlk} = 6$ HK 0.3. The microscope used to measure the indentations has a resolution of 1 µm. The agency performs five verification measurements on the block. The five diagonal measurements are 103.9, 104.8, 102.3, 102.8 and 100.2 µm, which calculate to 395, 389, 408, 404, and 425 HK 0.3, resulting in an average value of 404 HK 0.3. Therefore:

$$u_{Rep\&NU}(Ref.\,Block) = \frac{STDEV(395\,,\,389\,,\,408\,,\,404\,,\,425)}{\sqrt{5}}$$

or

$$u_{Rep\&NU}(Ref.\,Block) = 6.18 \text{ HK } 0.3$$

$$r_d = 1 \text{ µm} = 0.001 \text{ mm}$$

$$r_H = r_d \times 2 \times \bar{H}/d = 0.001 \times 2 \times 404.2\,/\,0.1028$$

or

$$r_H = 7.86 \text{ HK } 0.3$$

$$u_{Resol} = \frac{r_H / 2}{\sqrt{3}} = \frac{r_H}{\sqrt{12}} = 2.27 \text{ HK } 0.3$$

$$u_{RefBlk} = \frac{6}{2} = 3 \text{ HK } 0.3$$

Thus,

$$u_{Mach} = \sqrt{6.18^2 + 2.27^2 + 3^2} = 7.24 \text{ HK } 0.3$$

$$U_{Mach} = 2 \times 7.24 = 14.5 \text{ HK } 0.3$$

Therefore, the uncertainty in the −16 HK 0.3 error E_H in the hardness machine is 14.5 HK 0.3. Although this evaluation was made on material having a hardness of approximately 420 HK 0.3, the uncertainty may be considered to apply to the entire mid-range of the HK 0.3 hardness scale. This calculation must be made for the low and high ranges of the HK 0.3 hardness scale, as well as for the ranges of the other Vickers and Knoop hardness scales that are verified.

Note X1.11—The reader should be aware that in computing the final uncertainty value in all examples in this appendix, no rounding of results was done between steps. Consequently, if individual equations are solved using the rounded values that are given at each step of this example, some computed results might differ in value in the last decimal place from the results stated.

X1.7 Procedure for Calculating Uncertainty: Vickers and Knoop Hardness Measurement Values

X1.7.1 The uncertainty U_{Meas} in a hardness value measured by a user may be thought of as an indication of how well the measured value agrees with the "true" value of the hardness of the material.

X1.7.2 *Single Measurement Value*—When measurement uncertainty for a single hardness measurement value is to be determined, the contributions to the standard uncertainty u_{Meas} are:

(1) u_{Repeat}, the uncertainty due to the machine's lack of repeatability (Eq X1.6),

(2) u_{Reprod}, the uncertainty contribution due to the lack of reproducibility (Eq X1.9),

(3) u_{Resol}, the uncertainty due to the resolution of the indentation measuring system (Eq X1.10), and

(4) u_{Mach}, the uncertainty in determining the error E of the hardness machine (Eq X1.14).

The combined standard uncertainty u_{Meas} is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Vickers or Knoop hardness scale as:

$$u_{Meas} = \sqrt{u_{Repeat}^2 + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach}^2} \qquad (X1.16)$$

X1.7.3 *Average Measurement Value*—In the case that measurement uncertainty is to be determined for an average value of multiple hardness measurements, made either on the same test piece or multiple test pieces, the contributions to the standard uncertainty u_{Meas} are:

(1) $u_{\overline{Repeat}}$, the uncertainty due to the machine's lack of repeatability based on the average of multiple measurements (Eq X1.7),

(2) u_{Reprod}, the uncertainty contribution due to the lack of reproducibility (Eq X1.9),

(3) u_{Resol}, the uncertainty due to the resolution of the indentation measuring system (Eq X1.10), and

(4) u_{Mach}, the uncertainty in determining the error E of the hardness machine (Eq X1.14).

The combined standard uncertainty u_{Meas} is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Vickers and Knoop hardness scale as:

$$u_{Meas} = \sqrt{u_{\overline{Repeat}}^2 + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach}^2} \qquad (X1.17)$$

X1.7.4 The measurement uncertainty discussed above for the single and average hardness values only represents the uncertainties of the measurement process and are independent of any test material non-uniformity.

X1.7.5 *Average Measurement Value as an Estimate of the Average Material Hardness*—Measurement laboratories and manufacturing facilities often measure the Vickers or Knoop hardness of a test specimen or product for the purpose of estimating the average hardness of the test material. Usually, multiple hardness measurements are made across the surface of the test piece, and then the average of the hardness values is reported as an estimation of the average hardness of the material. If it is desired to report the uncertainty as an indication of how well the average measurement value represents the true average hardness of the material, then the contributions to the standard uncertainty u_{Meas} are:

(1) $u_{Rep\&NU}$ (*Material*), the uncertainty due to the machine's lack of repeatability combined with the uncertainty due to the material's non-uniformity (Eq X1.8), which is determined from the hardness measurements made on the test material. The notation (*Material*) is added to the term $u_{Rep\&NU}$ to clarify that the uncertainty is determined from measurements made on the material under test.

(2) u_{Reprod}, the uncertainty contribution due to the lack of reproducibility (Eq X1.9),

(3) u_{Resol}, the uncertainty due to the resolution of the indentation measuring system (Eq X1.10), and

(4) u_{Mach}, the uncertainty in determining the error E of the hardness machine (Eq X1.14).

X1.7.6 The combined standard uncertainty u_{Meas} is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Vickers or Knoop hardness scale as:

$$u_{Meas} = \sqrt{u_{Rep\&NU}^2(Material) + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach}^2} \quad (X1.18)$$

X1.7.7 When reporting uncertainty as an indication of how well the average measurement value represents the true average hardness of the material, it is important to ensure that a sufficient number of measurements are made at the appropriate test locations to provide a representative sampling of any variations in the hardness of the material.

X1.7.8 The expanded uncertainty U_{Meas} is calculated for the three cases discussed above as:

$$U_{Meas} = k \times u_{Meas} + ABS(B) \qquad (X1.19)$$

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

X1.7.9 Reporting Measurement Uncertainty:

X1.7.9.1 *Single and Average Measurement Values*—When the reported measurement value is for a single hardness test or the average of multiple hardness tests, then the value of U_{Meas} should be supplemented with an explanatory statement such as, "The expanded measurement uncertainty of the reported hardness value (or average hardness value) is with respect to hardness reference standards maintained at _____ [for example, NIST], and was calculated in accordance with Appendix X1 of ASTM E92 with a coverage factor of 2 representing a confidence level of approximately 95 %."

X1.7.9.2 *Average Measurement Value as an Estimate of the Average Material Hardness*—When it is desired to report the uncertainty as an indication of how well the average measurement value represents the true average hardness of the material, then the value of U_{Meas} should be supplemented with an explanatory statement such as, "The expanded uncertainty of the reported average hardness of the material under test is based on uncertainty contributions from the measurement process and from the hardness non-uniformity of the material. The uncertainty is with respect to hardness reference standards maintained at _____ [for example, NIST], and was calculated in accordance with Appendix X1 of ASTM E92 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.

X1.7.9.3 *Example X1.2*—For this example, a laboratory examines its product by making six Vickers HV 0.5 hardness measurements across its surface as an estimate of the product hardness. The values of the hardness measurements of the product were 303, 310, 301, 312, 301 and 320, resulting in an average value of 308 HV 0.5. The microscope used to measure the indentations has a resolution of 1 μm. The laboratory would like to determine the measurement uncertainty in the average hardness value. A hardness of 308 HV 0.5 is in the mid-range of the HV 0.5 test range (see Table A1.3). The last indirect verification of the mid-range of the HV 0.5 test range reported U_{Mach} = 8.4 HV 0.5 and an error E of –6 HV 0.5. Therefore:

$$u_{Rep\&NU}(Material) = \frac{STDEV(303\,,\,310\,,\,301\,,\,312\,,\,301\,,\,320)}{\sqrt{6}}$$

$$u_{Rep\&NU}(Material) = 3.1 \text{ HV } 0.5$$

For this example, assume the hardness machine has been monitored for an extended period of time, and from Eq X1.9, it was determined that u_{Reprod} = 4.2 HV 0.5 for the mid-range of the HV 0.5 test range. Other uncertainty contributions are calculated as:

$$r_d = 1 \text{ μm} = 0.001 \text{ mm}$$

$$r_H = r_d \times 2 \times \bar{H}/d = 0.001 \times 2 \times 307.8 / 0.0549$$

or

$$r_H = 11.21 \text{ HV } 0.5$$

$$u_{Resol} = \frac{r_H/2}{\sqrt{3}} = \frac{r_H}{\sqrt{12}} = 3.24 \text{ HV } 0.5$$

$$u_{Mach} = \frac{9.2}{2} = 4.6 \text{ HV } 0.5$$

Thus,

$$u_{Meas} = \sqrt{3.1^2 + 4.2^2 + 3.24^2 + 4.6^2 +} = 7.68 \text{ HV } 0.5$$

and since B = –6 HV 0.5,

$$U_{Meas} = (2 \times 7.68) + ABS(-6)$$

or

$$U_{Meas} = 21.4 \text{ HV } 0.5$$

for the average value of the hardness measurements made on the single product item.

X1.8 Procedure for Calculating Uncertainty: Certified Value of Standardized Test Blocks

X1.8.1 Standardizing laboratories engaged in the calibration of reference test blocks must determine the uncertainty in the reported certified value. This uncertainty U_{Cert} provides an indication of how well the certified value would agree with the "true" average hardness of the test block.

X1.8.2 Test blocks are certified as having an average hardness value based on calibration measurements made across the surface of the test block. This analysis is essentially identical to the analysis given in X1.7.5 for measuring the average hardness of a product. In this case, the product is a calibrated reference test block. The contributions to the standard uncertainty U_{Cert} of the certified average value of the test block are:

(1) $u_{Rep\&NU}$ *(Calib.Block)*, the uncertainty due to the standardizing machines lack of repeatability combined with the uncertainty due to the calibrated blocks non-uniformity (Eq X1.8), which is determined from the calibration measurements made on the test block. The notation *(Calib.Block)* is added to the term $u_{Rep\&NU}$ to clarify that the uncertainty is determined from calibration measurements made on the calibrated block.

(2) U_{Reprod}, the uncertainty contribution due to the lack of reproducibility (Eq X1.9),

(3) U_{Resol}, the uncertainty due to the resolution of the standardizing machines indentation measuring system (Eq X1.10), and

(4) U_{Mach}, the uncertainty in determining the error E of the standardizing machine (Eq X1.14).

X1.8.3 The combined standard uncertainty uCert and the expanded uncertainty U_{Cert} are calculated by combining the appropriate uncertainty components described above for each hardness level of each Vickers or Knoop test force and indenter combination as:

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

(X1.20)

$$U_{Cert} = k \times u_{Cert} + ABS(B)$$

(X1.21)

X1.8.4 For this analysis, a coverage factor of $k = 2$ should be used. This coverage factor provides a confidence level of approximately 95 %.

X1.8.5 *Reporting the Measurement Uncertainty*—The value of U_{Cert} is an estimate of the uncertainty in the reported certified average hardness value of a reference test block. The reported value should be supplemented with a statement defining to what Vickers or Knoop test force and indenter combination and hardness level the uncertainty is applicable, with an explanatory statement such as, "The expanded uncertainty in the certified value of the test block is with respect to hardness reference standards maintained at _____ [for example, NIST], and was calculated in accordance with Appendix X1 of ASTM E92 with a coverage factor of 2 representing a confidence level of approximately 95 %."

X1.8.6 *Example X1.3*—A secondary level test-block standardizing laboratory has completed the calibration of a HV 5 test block in the high hardness range. The values of the calibration measurements of the block were 674, 674, 680, 682, and 670 HV 5, resulting in an average value of 676 HV 5. The laboratory must determine the uncertainty in the certified average hardness value of the block. A hardness of 676 HV 5 is considered within the high-range of the HV 5 test range (see Table A1.3). The last indirect verification of the high-range of the HV 5 test range reported $U_{Mach} = 6.4$ HV 5 and an error E of +5 HV 5. The microscope used to measure the indentations has a resolution of 1 μm. Therefore:

$$u_{Rep\&NU}(Calib.Block) = \frac{STDEV(674, 674, 680, 682, 670)}{\sqrt{5}}$$

$$u_{Rep\&NU}(Calib.Block) = 2.2 \text{ HV } 5$$

For this example, assume the hardness machine has been monitored for an extended period of time, and from Eq X1.9, it was determined that $u_{Reprod} = 3.8$ HV 5 for the high-range of the HV 5 test range. Other uncertainty contributions are calculated as:

$$r_d = 1 \text{ μm} = 0.001 \text{ mm}$$

$$r_H = r_d \times 2 \times \bar{H}/d = 0.001 \times 2 \times 676 / 0.1171$$

or

$$r_H = 11.55 \text{ HV } 5$$

$$u_{Resol} = \frac{r_H / 2}{\sqrt{3}} = \frac{r_H}{\sqrt{12}} = 3.33 \text{ HV } 5$$

$$u_{Mach} = \frac{6.4}{2} = 3.2 \text{ HV } 5$$

Thus,

$$u_{Meas} = \sqrt{2.2^2 + 3.8^2 + 3.33^2 + 3.2^2 +} = 6.37 \text{ HV } 5$$

and since $B = +5$ HV 5,

$$U_{Meas} = (2 \times 7.68) + ABS(5)$$

or

$$U_{Meas} = 17.7 \text{ HV } 5$$

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 (E92–16) that may impact the use of this standard.

(1) 3.3.3 was revised

(2) A1.6.2.9, A2.4.1.8, and A2.4.2.9 were revised.