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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.

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

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~~safety, health, and environmental 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]

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 Practices for Calibration and Verification for Force-Measuring Instruments
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 (Withdrawn 2019)[3]
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:*[4]

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.

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

[3] The last approved version of this historical standard is referenced on www.astm.org.

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

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 $d_1, d_2, \ldots, d_n$ is calculated as:

$$\bar{d} = \frac{d_1 + d_2 + \ldots + d_n}{n} \quad (1)$$

where each of the individual diagonal measurements $d_1, d_2, \ldots, d_n$ 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:

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

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:

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

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.

$$HV = \frac{Testforce}{SurfaceArea} = \frac{F_{(kgf)}}{A_{S(mm^2)}} \tag{4}$$

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).

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:

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

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:

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

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).

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	$HK = 1.451 \times F/d^2$

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

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

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 (mm^2).

$$HK = \frac{Testforce}{ProjectedArea} = \frac{F_{(kgf)}}{A_{P(mm^2)}} \tag{9}$$

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:

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

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:

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

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:

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

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~~10 s 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

$$h_V = 0.143 \times d_V \tag{15}$$

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

$$h_K = 0.033 \times d_K \tag{16}$$

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. Additional requirements are specified in 9.3 and 9.4 when reporting corrected hardness values.

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~~10 °C to 35°C ~~(50 to 95°F).~~(50 °F 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 µm/s 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~~10 s 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%~~75 % of the field width. The objective selected to measure the indentation should have an objective resolution (r_{obj}) that is ≤ ~~2%~~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:

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

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.

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.

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.

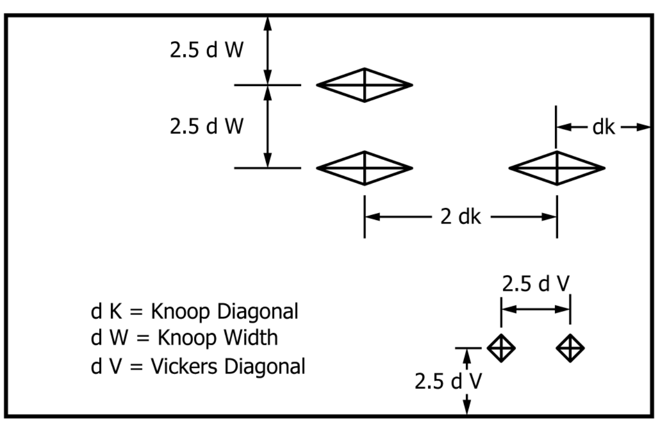

FIG. 1 Minimum Recommended Spacing for Vickers and Knoop Indentations

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. Additional requirements are specified in 9.2 and 9.4 when reporting converted hardness values.

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~~10 s 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).~~10 °C to 35 °C (50 °F to 95 °F).

9.2 *Reporting Converted Hardness Values*—When reporting hardness values that have been converted from one type of hardness test or hardness scale to another type of hardness test or hardness scale, the original measurement number and test scale shall also be reported (see E140).

9.2.1 A common historical practice is to report the converted hardness value followed by the measured hardness value given in parentheses. For example: 353 HBW (372 HV), where 353 HBW is the converted hardness value and 372 HV is the original measurement value.

9.2.2 Other formats for reporting converted hardness values, such as data tables, may be used, however, the original measurement number and test scale shall also be reported and clearly identified.

9.3 *Reporting Curvature Corrected Hardness Values*—When reporting Vickers or Knoop hardness test values that have been corrected for testing on cylindrical or spherical surfaces (see 6.6), the following information shall be indicated in the test report or documented in the test lab/customer contract or agreement:

–the test values are corrected due to testing on a curved surface,
–the source of correction value, if other than the correction tables given in Annex A5 for convex cylindrical surfaces.

9.4 Since all converted or curvature-corrected hardness values are considered approximate, the reported hardness values shall be rounded in accordance with the Rounding Method of Practice E29 and should have no more significant digits than is given for the data in the applicable conversion or correction table.

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.[5]

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

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E04-1007. Contact ASTM Customer Service at service@astm.org.