Standard Test Method for Portable Hardness Testing by the Ultrasonic Contact Impedance Method[1]

This standard is issued under the fixed designation A1038; 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.

ε^1 NOTE—Table 3 heading was corrected editorially in April 2016.

1. Scope*

1.1 This test method covers the determination of comparative hardness values by applying the Ultrasonic Contact Impedance Method (UCI Method).

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A370 Test Methods and Definitions for Mechanical Testing of Steel Products

E10 Test Method for Brinell Hardness of Metallic Materials

E18 Test Methods for Rockwell Hardness of Metallic Materials

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

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

3. Terminology

3.1 *Definitions:*

3.1.1 *calibration*—determination of the specific values of the significant operating parameters of the UCI instrument by comparison with values indicated by a standardized workbench hardness tester or by a set of certified reference test pieces.

3.1.2 *surface finish*—all references to surface finish in this test method are defined as surface roughness (that is, *Ra* = average roughness value).

3.1.3 *UCI hardness test*—a hardness testing method using a calibrated instrument by pressing a resonating rod with a defined indenter, for example, a Vickers diamond, with a fixed force against the surface of the part to be tested.

3.1.4 *UCI method*—Ultrasonic Contact Impedance, a hardness testing method developed by Dr. Claus Kleesattel in 1961 based on the measurement of the frequency shift of a resonating rod caused by the essentially elastic nature of the finite area of contact between the indenter and the test piece during the penetration.

3.1.5 *verification*—checking or testing the UCI instrument to ensure conformance with this test method.

4. Significance and Use

4.1 The hardness of a material is a defined quantity having many scales and being dependent on the way the test is performed. In order to avoid the creation of a new method involving a new hardness scale, the UCI method converts into common hardness values, for example, HV, HRC, etc.

4.2 The UCI hardness test is a superficial determination, only measuring the hardness condition of the surface contacted. The results generated at a specific location do not represent the part at any other surface location and yield no information about the material at subsurface locations.

4.3 The UCI hardness test may be used on large or small components at various locations. It can be used to make hardness measurements on positions difficult to access, such as tooth flanks or roots of gears.

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[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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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.

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

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A. GENERAL DESCRIPTION OF INSTRUMENTS AND TEST PROCEDURE FOR UCI HARDNESS TESTING

5. Apparatus

5.1 Instruments used for UCI hardness testing generally consist of *(1)* a probe containing a rod with a defined indenter, for example, a Vickers diamond, attached to the contacting end per Test Method E384 (see Fig. 1), *(2)* vibration generating means, *(3)* vibration detecting means, *(4)* electronic means for the numerical evaluation, and *(5)* a digital display, indicating the measured hardness number.

5.2 *UCI Probes*—There are different probes available for UCI hardness testing. They typically cover static loads ranging from 1 N to 98 N. See also Appendix X1. They come also in different sizes with longer and shorter sensor rods for specials applications. And they are developed in two versions, that is, manually operated or equipped with a servo-motor for automatic testing.

5.3 *Summary of Test Method*—In conventional workbench hardness testing like Brinell or Vickers testing according to Test Methods E10 and E384, the hardness value is determined optically by the size of the indentation in the material generated by a certain test load, after the indenter has been removed. In the mobile hardness test under applied load according to the UCI method, however, the size of the produced indents are not determined optically. Instead the contact area is derived from the electronically measured shift of an ultrasonic resonance frequency. To carry out the UCI test, a probe containing the rod with the indenter is excited into a longitudinal ultrasonic oscillation of about 70 kHz by piezoelectric ceramics—the so-called zero frequency, which occurs when the indenter is vibrating in air.

5.3.1 A spring inside the probe applies the specified test load, the vibrating tip penetrates into the material creating an elastic contact, which results in a positive frequency shift of the resonating rod. This shift is related to the size of the indent area (contact area of the indenter with the material). The size, in turn, is a measure for the hardness of the test material at a given modulus of elasticity, for example, HV(UCI) according to Eq 1.

5.3.2 Therefore, the frequency shift is relatively small for hard materials, because the indenter penetrates not very deep into the test material leaving only a small indent.

5.3.3 The frequency shift becomes larger if the indenter penetrates deeper into the material, indicating medium hardness, in accordance with the larger test indentations. Analogously, the frequency shift becomes largest when soft materials are tested (see Fig. 2).

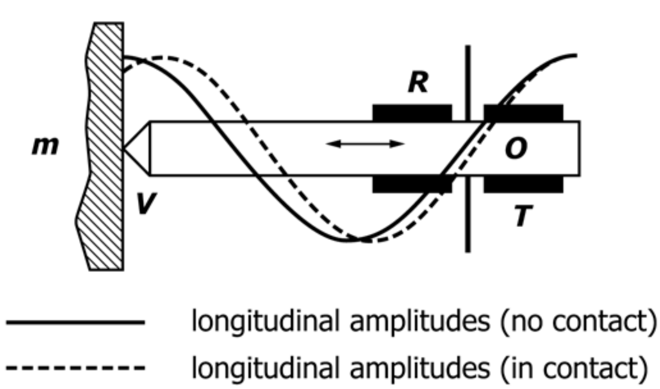
5.3.4 The instrument constantly monitors the resonance frequency, calculates the frequency shift when the specified test load has been reached either after the internal switch has triggered the corresponding measurement frequency in the case of handheld probes or after a specific dwell time has been elapsed in the case of motor driven probes. The instrument carries out the evaluation and calculations, and displays instantaneously the hardness value, for example, HV(UCI).

$$\begin{array}{ccc} \text{UCI} & & \text{Vickers} \\ \Delta f = f(E_{eff} \cdot A) & \text{and} & HV = \dfrac{F}{A} \\ \uparrow & \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_} & \uparrow \end{array} \quad (1)$$

5.3.5 The frequency shift is a function of the indentation size of a defined indenter, for example, a Vickers diamond, at a given modulus of elasticity of the measurement system.

5.3.6 Eq 1 describes the basic relation in comparison to the definition of the Vickers hardness value: Δf = Frequency shift, A = indentation area, E_{eff} = effective elastic modulus (contains the elastic constants of both the indenter and the test piece), HV = Vickers hardness value, F = Force applied in the hardness test.

5.4 *The Influence of the Elastic Constants*—As can be seen in Eq 1, the frequency shift not only depends on the size of the contact area but also on the elastic moduli of the materials in contact. To allow for differences in Young's modulus, the



Legend:
T = Piezo Transducer
R = Receiver
O = Oscillating rod
V = indenter, for example, Vickers diamond
m = test material

FIG. 1 Schematic Description of the UCI Probe

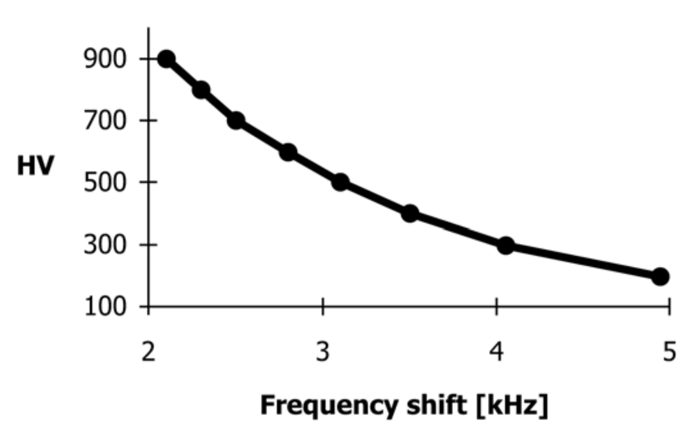


FIG. 2 Hardness Value versus Frequency Shift of the Oscillating Rod

instrument has to be calibrated for different groups of materials. After calibration, the UCI method can be applied to all materials, which have the corresponding Young's modulus.

5.4.1 As manufactured, the UCI instrument usually has been calibrated on non-alloyed and low-alloyed steel, that is, certified hardness reference blocks according to Test Method E384. Besides this, some instruments may be calibrated quickly, also at the test site, for metals such as high-alloyed steels, aluminum or titanium.

6. Calibration to Other Materials

6.1 A test piece of the particular material is needed. The hardness value should then be determined with a standardized workbench hardness tester like one for Vickers, Brinell or Rockwell according to Test Methods and Definitions A370. It is recommended to take at least five readings and calculate the average hardness value. Now carry out a set of at least five single UCI measurements on your test material according to instructions in 10.6, adjust the displayed average value to the before measured hardness of the material and thus find the calibration value which is necessary for further measurements on this particular material in the desired hardness scale and range.

6.1.1 Some instruments allow storing all calibration data and adjustment parameters for hardness testing of different materials. They can be recalled to the instrument as needed.

7. Comparison with Other Hardness Testing Methods

7.1 As opposed to conventional low load hardness testers, the UCI instruments do not evaluate the indentation size microscopically but electronically according to the UCI method. The UCI method yields comparative hardness measurements when considering the dependency on the elastic modulus of the test piece.

7.2 After removing the test force, an indentation generated by the UCI probe using a Vickers diamond as indenter and mounted in a test stand is practically identical to a Vickers indentation produced by a workbench tester of the same load. The indentation can be measured optically according to the standard Vickers test if care is taken to apply the force according to Test Method E384 and if a Vickers indenter is used in the UCI probe. In this case special arrangements or probe attachments have to be used to provide verification of the actual test force of the UCI probe.

8. Test Piece

8.1 *Surface Preparation*—The applied test force (that is, the selected UCI probe) must not only match the application but also the surface quality and roughness of the material. While smooth, homogeneous surfaces can be tested with low test loads, rougher and coarse-grained surfaces require test loads as high as possible. However, the surface must always be free of any impurities (oil, dust, etc.) and rust.

8.1.1 The surface roughness should not exceed ≈30 % of the penetration depth ($Ra \leq 0.3 \times$ h) with:

$$\mathrm{h}[\mathrm{mm}] = 0.062 \times \sqrt{\frac{\mathrm{Force}\,[\mathrm{N}]}{\mathrm{Hardness}\,[\mathrm{HV}]}} \tag{2}$$

8.1.2 Penetration depth of the Vickers diamond pyramid for a certain hardness (in HV) and test load (in N) id is shown in Eq 2.

8.1.3 Table 1 provides the recommended minimal surface roughness for certain UCI probes that use a Vickers indenter. If surface preparation is necessary, care must be taken not to alter the surface hardness by overheating or cold working. Any paint, scale or other surface coatings shall be completely removed. Failure to provide adequate surface finish will produce unsteady readings. Coarse finishes will tend to lower the measured value.

8.2 *Minimum Thickness*—Thin coatings or surface layers on bulk material must have a minimum thickness of at least ten times of the indentation depth of the indenter used (see Fig. 3 for a Vickers indenter) corresponding to the Bueckle's rule: S_{min} = 10 × h.

8.3 *Minimum Wall Thickness*—Distinct reading variations may especially occur with a specimen thickness of less than about 15 mm if the test material is excited to resonance or sympathetic oscillations (for example, thin blocks, tubes, pipes, etc.). Most disturbing are flexural vibrations excited by the vibrating tip. These should be suppressed by suitable means. Sometimes attaching the test piece to a heavy metal block by means of a viscous paste, grease or oil film suffices to quench the flexural waves. Nevertheless, a minimum wall thickness of 2 to 3 mm is recommended.

8.4 *Influence of the Oscillation*—The UCI method is based on measuring a frequency shift. Parts less than about 300 g can go into self-oscillating causing erroneous or erratic readings. Test pieces of weights less than the minimum or pieces of any weight with sections less than the minimum thickness require rigid support and coupling to a thick, heavier non-yielding surface to resist the oscillation of the UCI probe. Failure to provide adequate support and coupling will produce test results lower or higher than the true hardness value.

8.5 *Surface Curvature*—Test pieces with curved surfaces may be tested on either the convex or concave surfaces providing that the radius of curvature of the specimens is matched to the appropriate probe and probe attachment in order to ensure a perpendicular positioning of the probe.

8.6 *Temperature*—The temperature of the test piece may affect the results of the UCI hardness test. However, if the probe is exposed to elevated temperature for only the time of measurement, measurements are possible at temperatures higher than room temperature, without influencing the performance of the UCI instrument.

9. Verification of the Apparatus

9.1 *Verification Method*—Prior to each shift or work period the instrument shall be verified as specified in Part B. Any UCI hardness testing instrument not meeting the requirements of Part B shall not be used for the acceptance testing of products.

TABLE 1 Surface Finish for Different Test Loads

Test Load	98 N	50 N	10 N	3 N
Ra	≤ 15 µm	≤ 10 µm	≤ 5 µm	≤ 2.5 µm

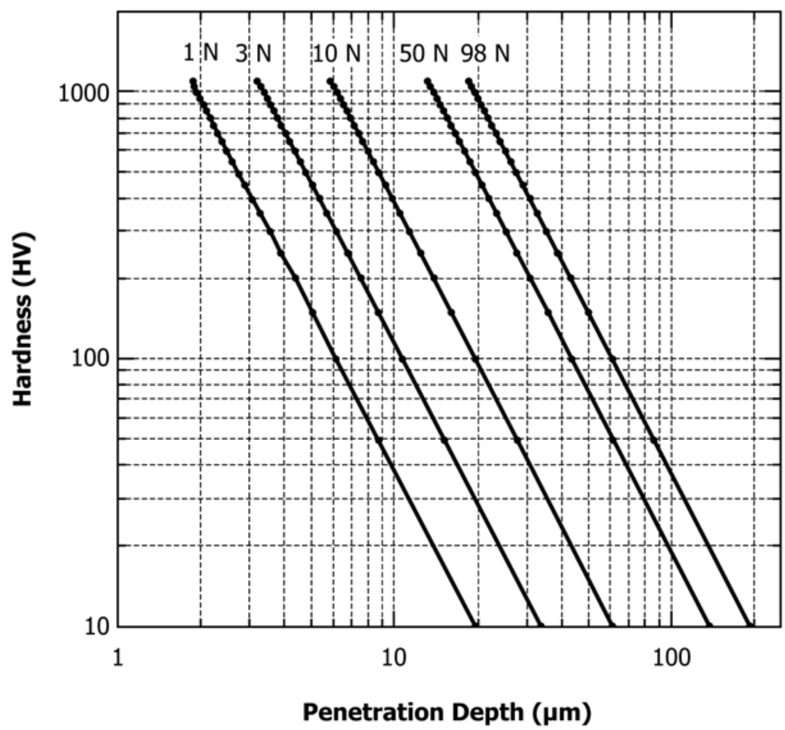


FIG. 3 Vickers Diamond Penetration Depth for Different Test Loads from 1 N to 98 N

10. Procedure

10.1 *Test Procedure*—To perform a hardness test, the probe is connected to the indicating unit and the instrument is turned on. The probe is held firmly (using a probe grip if needed) with its axis in a perpendicular position relative to the test piece surface. Hold the probe with both hands to achieve the best possible result. Carefully exert steady pressure against the test piece during the loading phase. Make sure that the vertical probe position is maintained as long as the load is effective. Some instruments indicate the end of the measurement by an acoustic signal and display the hardness value instantaneously.

10.2 *Alignment*—To prevent errors from misalignment move the UCI probe with slow and steady speed. The probe should be perpendicular with respect to the surface. The maximum angular deviation from the perpendicular position should be less than 5 degrees. Avoid twisting of the probe housing. There should be no lateral forces on the indenter. Therefore, avoid slip.

10.3 *Test Direction*—Hardness testing according to the UCI method generally can be carried out in any direction, without the necessity of corrections depending on the loading. There may be an effect of the measurement direction on the hardness measurement depending on the manufacturer and the test load of an UCI probe. This is due to the mass of the vibrating rod, which may influence the test load in dependence on the direction of measurement; that is, the mass of the rod will increase the load when measuring top to bottom and vice versa. This should be considered especially for test loads below 10 N. In this case the user has to verify the influence of test orientation on the hardness reading depending on test load and hardness of material.

10.4 *Spacing Indentation*—As per Test Method E384 the center distance between two adjacent indents in relation to the mean length of the diagonals must be *(1)* at least 3 times the amount for steel, copper and copper alloys, and *(2)* at least 6 times the amount for light metals, lead, tin and their alloys. If two neighboring indents vary in size then the mean indent diagonal of the larger indent must be used for calculation of the minimum distance. No point shall be measured more than once.

10.5 *Reading of UCI Instruments*—Hardness values can be read directly off the electronic display of the instrument. On some instruments, they can be displayed either as single figure showing the actual reading, or as average figure showing the average of the hardness readings taken so far. Equivalent hardness numbers on other scales can be obtained by using a hardness conversion table (see also Section 12) or by calibration according to Section 6.

10.6 *Number of Measurements*—Five measurements taken in an area of approximately 650 mm^2 shall constitute one test. If the material being tested is considered to be inhomogeneous, ten measurements or more shall be made to constitute one test.

NOTE 1—650 mm^2 is an area approximately equal to 1 $in.^2$.

10.7 *Reporting*—The numerical hardness value shall be followed by the symbol for the UCI test, HV(UCI) in the case of a Vickers reading with a suffix number denoting the test force in kgf. Example: 446 HV(UCI) 10 = UCI hardness number of 466 under a force of 10 kgf. If numerical hardness values are presented in other scales by calibration according to Section 6, they should analogously be reported as 45 HR-C(UCI) or 220 HBW(UCI) etc. Reporting of converted values, see Section 12.

11. Precision and Bias[3,4]

11.1 The precision of this test method is based on an interlaboratory study conducted in 2009. Each of 13 laboratories tested five different materials. Every "test result" represents the average of five individual measurements per Paragraph 10.6 of A1038. Laboratories reported two replicate test results (from a single operator) for each of two different analysis configurations (hand held and test stand). Practice E691 was followed for the design and analysis of the data.

11.1.1 *Repeatability limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "*r*" value for that material; "*r*" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

11.1.1.1 Repeatability limits are listed in Table 2 and Table 3.

11.1.2 *Reproducibility limit (R)*—Two test results shall be judged not equivalent if they differ by more than the "*R*" value for that material; "*R*" is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

11.1.2.1 Reproducibility limits are listed in Table 2 and Table 3.

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

11.1.4 Any judgment in accordance with statements 11.1.1 and 11.1.2 would have an approximate 95 % probability of being correct.

11.2 *Bias*—See Table 4.

11.3 The precision statement was determined through statistical examination of 258 results, from 13 laboratories, on five materials. These five materials were identified as follows:

	Certified Brinell Hardness	Certified Brinell Diameter (3000 kg load - 10 mm indenter)
Test Block 1: 0300142	143	4.985 mm
Test Block 2: 0729385	194	4.325 mm
Test Block 3: 0800213	242	3.897 mm
Test Block 4: 0722420	312	3.446 mm
Test Block 5: 0723157	377	3.144 mm

11.4 To judge the equivalency of two test results, it is recommended to choose the test block closest in characteristics to the test material.

12. Hardness Scale Conversions

12.1 *Conversion of Hardness Numbers*—Some instruments allow also an automatic conversion of measured hardness numbers into other hardness scales. Such conversion into other hardness values or also into tensile strength, measured in N/mm^2, is made according to Hardness Conversion Tables E140. Therefore, reporting of converted values and all limitations specified in Hardness Conversion Tables E140 do apply.

12.1.1 Conversion between hardness numbers is only possible with certain limitations. Hardness values, measured by different methods cannot be correlated by established mathematical relationships. The form and material of the indenter, the size of the indent and the measured number depend on the type of hardness test that is used.

12.1.2 Conversion of one hardness number either into another hardness number or a unit of tensile strength may be inaccurate or inadmissible, depending on the material, its preparation and its surface finish.

12.2 *Conversion to Tensile Strength*—The conversion into the stress unit N/mm^2 is limited to loads equal to or greater than 98 N.

B. VERIFICATION OF UCI HARDNESS TESTING INSTRUMENTS

13. Scope

13.1 Part B covers the verification procedure for UCI hardness testing instruments by using suitable hardness reference blocks. Direct verification has to be done by the manufacturer.

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:A01-1002. Contact ASTM Customer Service at service@astm.org.

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:A01-1003. Contact ASTM Customer Service at service@astm.org.

TABLE 2 Test Stand: HV (UCI)

Test Block	Average[A]		Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	$S_{\bar{x}}$	S_r	S_R	r	R
0300142[B]	745.13					
0729385	192.39	5.45	1.68	5.57	4.71	15.61
0800213	220.61	7.14	1.91	7.27	5.33	20.35
0722420	306.91	9.67	1.26	9.71	3.54	27.18
0723157	377.20	6.55	4.03	7.15	11.29	20.01

[A] The average of the laboratories' calculated averages.

[B] Test Block 1 data was deleted from consideration when it was realized that it was fabricated from aluminum while blocks 2, 3, 4, and 5 were fabricated from steel. The differing materials require individual calibration.

TABLE 3 Hand Held Probe: HV (UCI)†

Test Block	Average[A]		Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	$S\bar{x}$	S_r	S_R	r	R
0300142[B]	723.608					
0729385	189.915	6.398	1.868	6.532	5.229	18.291
0800213	219.277	8.135	2.105	8.270	5.894	23.156
0722420	305.654	10.357	8.093	11.833	22.660	33.132
0723157	370.285	10.469	7.632	11.778	21.370	32.978

† Editorially corrected.

[A] The average of the laboratories' calculated averages.

[B] Test Block 1 data was deleted from consideration when it was realized that it was fabricated from aluminum while blocks 2, 3, 4, and 5 were fabricated from steel. The differing materials require individual calibration.

TABLE 4 Comparative Vickers Hardness

Test Block	Calculated "True" Hardness Value[A]	ILS #358 Determined Hardness Value[B] (Test Stand)	ILS #358 Determined Hardness Value[C] (Hand Held)	Bias (Test Stand)	Bias (Hand Held)
0300142	143.06	NR	NR	NR	NR
0729385	189.70	197.40	196.14	+4.06	+3.39
0800213	240.32	228.44	227.98	-4.94	-5.13
0722420	321.75	311.20	314.22	-3.28	-2.34
0723157	388.78	382.46	372.28	-1.63	-4.24

[A] The average of the three testing laboratories' calculated averages (obtained using an actual Vickers hardness tester – 5 kg test force) from ILS #619. Testing performed in accordance with Test Method E384.

[B] The average of five testing laboratories' calculated averages (obtained using UCI (*ultrasonic contact impedance*) hardness testing equipment with the data expressed in Vickers hardness numbers) from ILS #358. All included labs utilized 5 kg test force.

[C] The average of five testing laboratories' calculated averages (obtained using UCI (*ultrasonic contact impedance*) hardness testing equipment with the data expressed in Vickers hardness numbers) from ILS #358. All included labs utilized 5 kg test force.

14. General Requirements

14.1 *Instrument*—Before a UCI instrument is verified, the instrument shall be examined to ensure that: *(1)* the batteries in the indicating unit are not discharged, and *(2)* the indenter is clean, that is, free from foreign matter like dust, grit, grease or oil.

15. Hardness Reference Block

15.1 In order to avoid perturbing vibrations in the reference blocks caused by the ultrasonic sensor, they should be sufficiently large. Recommended is to use steel blocks with dimensions not less than 80 mm in diameter and 16 mm in thickness.

15.2 Each block shall be specifically prepared and heat-treated to give a specific hardness and the necessary homogeneity, such as in Test Methods E18, and stability of the surface hardness distribution.

15.3 The test surface shall be polished or fine ground and free of scratches and other discontinuities, which would influence the UCI measurement. The surface finish of the test surface shall not exceed 0.4 µm maximum.

15.4 To ensure that no material is subsequently removed from the test surface of the reference block, an official mark or the thickness to an accuracy of ±0.025 mm at the time of calibration shall be marked on the test surface.

15.5 The hardness reference block shall be calibrated using a standard and certified hardness testing device per Test Method E10, Test Methods E18, or Test Method E384. Make at least five randomly distributed hardness measurements on the test surface of the reference block and take the arithmetic mean of all of the readings as the mean hardness of the block.

15.6 Each block shall be marked with *(1)* the arithmetic mean of the hardness values found in the standardization test suffixed by the scale designation letter (for example HV, HRC, HRB, HBW, HBS, etc.), and *(2)* with the name or mark of the supplier. If edge of block is marked, the lettering shall be upright when the test surface is upward.

16. Verification

16.1 Check the UCI hardness-testing instrument by making at least two measurements on a standard reference block of the selected hardness scale.

16.2 The instrument shall be considered verified if each hardness reading falls within ±3 % of the reference block hardness value. Unverified instruments must not be used for testing. They should be repaired, if necessary, and be verified subsequently.

17. Keywords

17.1 portable hardness testing; superficial hardness; ultrasonic contact impedance (UCI); vickers diamond indenter

APPENDIX

(Nonmandatory Information)

X1. GUIDELINES FOR SELECTION AND USE OF UCI INSTRUMENTS

TABLE X1.1

Load	Model	Features	Typical Applications
98 N	standard length (manual)	relatively large indentation; requires minimal surface preparation	small forgings, cast material, weld inspection, HAZ
49 N	standard length (manual)	for general use	induction hardened or carburized machine parts, for example, camshafts, turbine weld inspection, HAZ
	extended length (manual)	30 mm extended length	measurement in grooves, on gear tooth flanks and roots
	short probe (manual)	reduced length (90 mm); electronics in separate housing	turbine blades, inside wall of pipes with Ø >90 mm
9.8 N	standard length (manual)	load is easy to apply and provides control to test on sharp radii	ion-nitrided stamping dies and molds, forms, presses, thin walled parts
	extended length (manual)	30 mm extended length	bearings, tooth flanks
	short probe (manual)	reduced length (90 mm); electronics in separate housing	turbine blades, inside wall of pipes with Ø >90 mm
7.8 N	motor probe style	load is applied by servomotor	finished precision parts, gears, bearing raceways
3 N	motor probe style	load is applied by servomotor; rather small indentations	thin layers, for example, copper or chromium on steel cylinders; copper rotogravure cylinders; coatings, case hardened parts
1 N	motor probe style	load is applied by servomotor; rather small indentations	thin layers and coatings

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A1038 – 10a) that may impact the use of this standard. (Approved Nov. 1, 2013.)

(1) Added new bias information in 11.2.

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