Designation: A 1038 – 05

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

This standard is issued under the fixed designation A 1038; 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.

1. Scope

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

1.2 *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]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

E 10 Test Method for Brinell Hardness of Metallic Materials

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

E 92 Test Method for Vickers Hardness of Metallic Materials

E 140 Test Method for Hardness Conversion Tables for Metals

E 384 Test Method for Microindentation Hardness of Materials

3. Terminology

3.1 *Definitions:*

3.1.1 *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.

3.1.2 *UCI hardness test*—a hardness testing practice 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.

3.1.3 *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.

3.1.4 *verification*—checking or testing the UCI instrument to ensure conformance with this practice.

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

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 practice 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.

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 E 92 and Test Method E 384, *(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

[1] This practice 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.

Current edition approved Jan. 1, 2005. Published February 2005.

[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.

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.

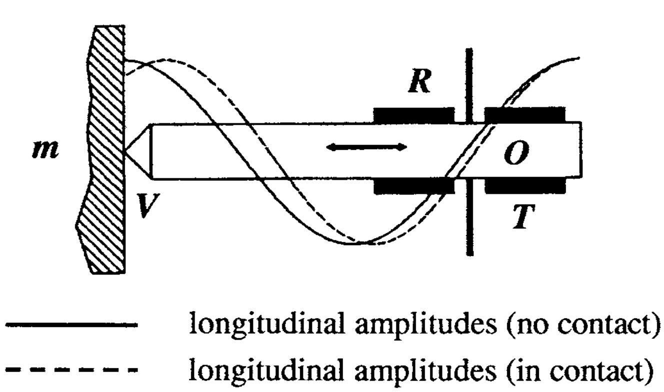
5.3 *Summary of Practice*—In conventional workbench hardness testing like Brinell or Vickers testing according to Test Methods E 10, E 92 and E 384, the hardness value is determined optically by the size of the indentation in the material generated by a certain test load, after the indenter has been 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.

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.

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.

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).

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).



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

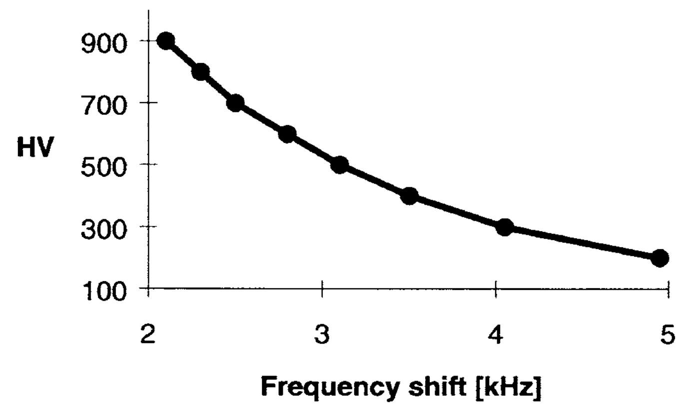


FIG. 2 Hardness Value versus Frequency Shift of the Oscillating Rod

$$\underset{\text{UCI}}{\Delta f = f(E_{eff} \cdot A)} \quad \text{and} \quad \underset{\text{Vickers}}{HV = \frac{F}{A}} \qquad (1)$$

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.

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 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.

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 E 92. 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 than be determined with a standardized workbench hardness tester like one for Vickers, Brinell or Rockwell according to Test Methods and Definitions A 370. It is recommended to take at least 5 readings and calculate the average hardness value. Now carry out a set of at least 5 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.

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.

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 E 92 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.

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

$$\text{h[mm]} = 0.062 \times \sqrt{\frac{\text{Force [N]}}{\text{Hardness [HV]}}} \quad (2)$$

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

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: $S_{min} = 10 \times \text{h}$.

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.

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

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.

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