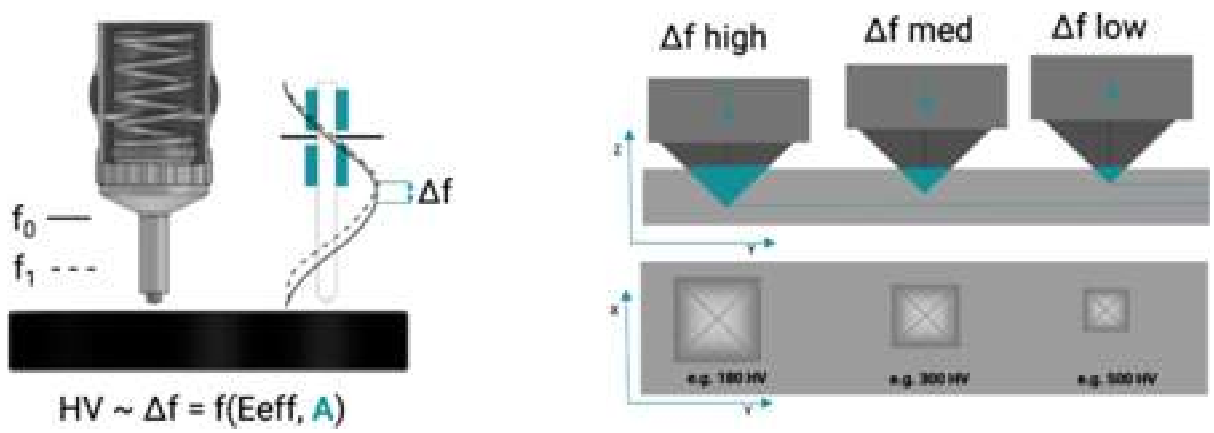
Diamonds are not forever: Diamonds in Ultrasonic Contact Impedance (UCI) Probes for Accurate Measurements

Introduction

The Vickers diamond used in Ultrasonic Contact Impedance (UCI) measurements is of pyramid shape and is precisely defined in the ISO 6507-2 & ASTME92-17 standards. The quality of the diamond and its geometry impacts the measurement accuracy.

Adapted from the bench-top, provides much faster readouts

The usage of the UCI diamond has been adopted from conventional bench-top devices, where the users set up a load to the indenter, which then penetrates the material and creates an indentation. The indentation depth reflects the hardness of a test piece. The user then uses a microscope to evaluate the diagonals of the imprint and due to well-known (defined by the standard) and precise geometry of the diamond it can evaluate the indentation depth and hence the hardness in Vickers units.



caption

- Oscillation of resonating rod at ULTRASONIC prequency
- Vickers Indenter forced CONTACTS test piece (Surface A exposure)
- Measured frequency shift converted to hardness (IMPEDANCE)

In UCI devices the same diamond is mounted onto the tip of the resonator that vibrates with a specific frequency. Upon the indentation – id est. pressing the diamond into the test piece, the frequency changes and is related to the E modulus of the material, and to the diamond's surface exposed. It is correct to say that: the lower the indentation depth the lower the contact (surface) of the diamond with the material and the smaller the frequency shift. This is also true for various test forces, if an inspector uses 1N load, its indentation into the material will be much shallower than it would be with 100N test force. The frequency shift is then converted into hardness values based on pre-defined frequency shift – Vickers hardness conversion curves, by default created for materials with E modulus of 210 GPa. Because of this, the user has no need to measure the indentation under the microscope, as it is automatically computed by the probe firmware/device software.

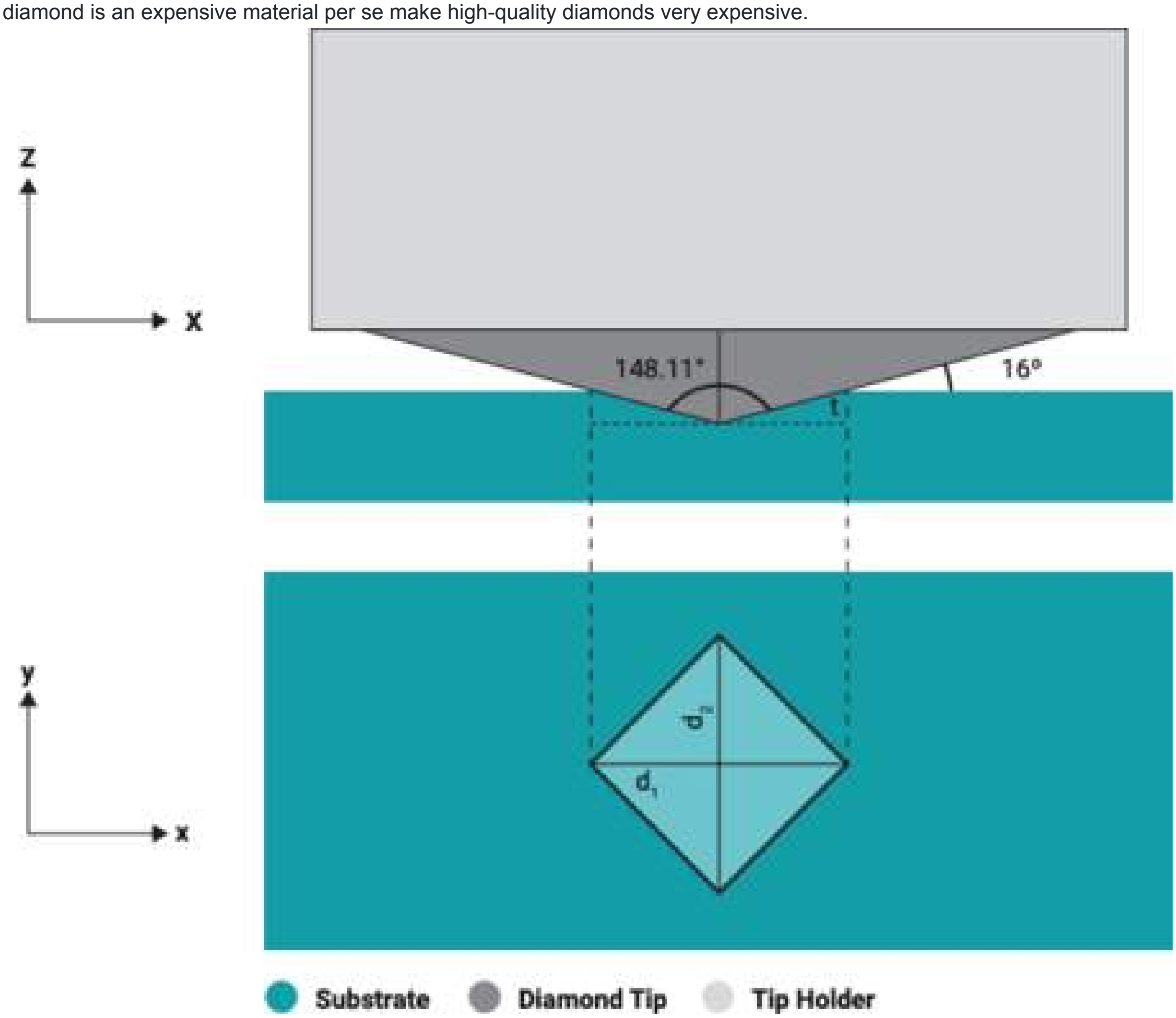
Hence this tiny, precisely fabricated diamond is an interface between the UCI measuring device and a test piece – it is the element that “amplifies” the contact with the test piece. Imperfect and damaged diamonds will lead to measurements of low accuracy and precision.

ISO 6507-2 defines the “true” diamond

The true Vickers 6507-2 compliant diamond has a very narrow tolerances, which varies depending on the applied test force. As mentioned above, measurements with HV1 (10N) or lower will have much less contact with the test piece and those require even higher tolerances than those used for HV5 or HV10 (50N and 100N respectively). The correct geometry is given in the image below and can be measured twofold:

- By measuring the angle between the opposite faces, which is determined by the angle between the opposite edges and must be equal to 148.11° ±0.76°, and additionally "a" parameter (line of conjunction) to be within the tolerance for the specific force (See table below)
- By measuring directly the angle between the opposite faces at the vertex of the diamond pyramid, which must be 136° ±0.5°, and additionally "a" parameter (line of conjunction) to be within the tolerance for the specific force (See table below)

One needs to highlight that the tolerances for such a diamond must be checked with adequate equipment, that can measure with high resolution, accuracy and uncertainty. A diamond suitable for HV1 is suitable for HV5, but HV5 diamonds may not be suitable for HV1 due to the wrong line of the conjunction "a" parameter (See table below). All of the above and the fact that a diamond is an expensive material per se make high-quality diamonds very expensive.



caption

Schematic representation of Vickers test indenter displaying the relevant measurement distances (d1 and d2) and angles for measuring Vickers hardness and the depth of the indent (t). The angle between the opposite faces is determined by the angle between the opposite edges and must be equal to 148.11° ±0.76°. X- magnification on the line of conjunction on the top of the indenter (schematic).

Force denotation in "HV load"	Ranges of test force, F in N	Maximum permissible length of the line of conjunction "a" in µm
HV0.1 ≤ F < HV 0.2	0.009 ≤ F < 1.961	0.5
HV 0.2 ≤ F < HV5	1.961 ≤ F < 49.03	1
≥ HV5	F ≥	2

Table.1. Line of conjunction tolerances for a specific test load applied.

This is for instance particular advantage of the 3-in-1 probe users, where a diamond with more demanding parameters must be used in order to satisfy the criteria for HV1 Load.

Diamond quality and UCI standard compliance

Is a device with lower quality of the diamond (e.g. larger than allowed a parameter, or faces of the diamonds are out of tolerance) but measurement accuracy (and repeatability also required for DIN 50159 and GB/T 34205 standard) compliant to ASTM A1038, DIN 50159 or GB/T 34205 standard?

Short answer: No.

How do measurement deviations and repeatability are adjusted to the test force?

Scale / Range	Max. measurement deviation (E) in % DIN 50159, ASTM A1038, and GB/T 34205								Repeatability (R) / %			
	DIN & GB/T	ASTM	DIN & GB/T	ASTM	DIN & GB/T	ASTM	DIN & GB/T	ASTM	DIN & GB/T	ASTM	DIN & GB/T	ASTM
	<250 HV		250 -500 HV		500 – 800 HV		>800 HV		≤ 250 HV		> 250 HV	
HV 0.1	5	6	6	7	7	8	8	9	8	Not required	6	Not required
HV 0.3	5	6	6	7	7	8	8	9	8		6	
HV 0.8	4	6	4	7	5	8	6	9	8		6	
HV 1	4	5	4	5	5	7	6	7	8		6	
HV 5	4	5	4	5	4	7	4	7	5		5	
HV 10	4	5	4	5	4	7	4	7	5		5	

Table 2. The summary of maximum tolerable errors for measurement deviation and repeatability from DIN 50157-2, ASTM A1038 and GB/T 34205, used but the calibration laboratories.

Lower indentation depths and hence the resolutions are taken into account in all UCI-related standards, whereby the maximum permissible measurement deviation and coefficient of variation vary depending on the test load. In simple words, those max permissible tolerances reflect the measurement resolution that comes from the indentation depth (surface exposure of the diamond). For example, for very low loads and hard materials (e.g. >800 HV) the maximum permissible measurement deviation in the case of DIN 50159 is equal to 8% (please note that ASTM standard allows higher measurement deviations than DIN and GB/T standards) while for HV10 this requirement is narrowed to 4%. The same can be seen when comparing the same load for various hardness regimes, whereby for softer materials lower measurement deviation is allowed than in case of hard ones (e.g. HV1 <250 HV demands 4%, while HV1 >800 HV demands max 6%). If your application allows it, consider using higher loads of the probe, especially if harder materials are tested - this increases the indentation depth and measurement resolution.

What about the diamond parameters over time?

Diamond is the hardest natural material known to mankind, but can it be damaged by improper usage of equipment? Lateral movements of the probe upon indentation (Figure 2.a) and impacting the surface of the test piece with momentum (Figure 2.b) instead of slow and controlled material penetration can cause diamond fractures and wear. The movement of the probe shall be always controlled with both hands.

Figure.2. Schematic illustrations of potential probe applications that may lead to damage of the indenter. a) Lateral movements of the probe during the indentation. b) strong impact of the p

Can a fractured diamond be repaired?

Short answer: Yes.

However, the process requires almost a complete dismantling of the device, diamond or resonator replacement, followed by re-assembly, quality assurance of the new built and subsequent calibration. The costs of reparation is always a non-series-production process, and it is not much lower than purchasing a new device, where the user receives all new and pristine components.

What is the best practice?

Before You purchase:

- Make sure that your device has a true, ISO 6507-2 Vickers-compliant diamond that matches your measurement expectation and quality and that warrants the standard compliance of your choice
- Consider what load you want to use. Using higher loads may be more exhausting for the inspectors but may provide higher measurement resolution and can also be executed on higher surface roughness, thus saving time.
- Reliable test results require indentation size to be larger in comparison to the materials' microstructure / grain size distribution. Consider the indentation size of the diamond to understand what test load you require.

After You purchase:

- Make sure you do not unintentionally damage the diamond through lateral movements upon the indentation (scratching the surface) or impacting the surface with your probe.
- Service and calibrate your devices regularly to be certain of your equipment.
- Protect your indenter with a safety cap for storage and transportation to avoid accidental damage (e.g. suddenly drop).
- Train your staff adequately, informing them about potential equipment damages due to unintentional and improper usage.

References

Metallische Werkstoffe – Härteprüfung nach dem UCI-Verfahren – Teil 2: Prüfung und Kalibrierung der Härteprüfgeräte, DIN 50159-2:2015-01, 2015

Standard Test Method for Portable Hardness Testing by the Ultrasonic Contact Impedance Method, ASTM A1038-19, 2019

Metallic materials – Hardness testing – Ultrasonic contact impedance method, GB/T 34205-2017, 2017

Portable Hardness Testing. Theory practice, Applications, guidelines. Burnat, D., Raj, L., Frank, S., Ott, T. Schwerzenbach, Screening Eagle Technologies AG, 2022.

Metallic materials — Vickers hardness test —Part 2: Verification and calibration of testing machines. ISO 6507-2:2018