Understanding the Importance of Young's Modulus of non-standard materials in Ultrasonic Contact Impedance (UCI) Hardness Testing

Overview

- The Ultrasonic Contact Impedance (UCI) method is an adaptation of the conventional Vickers hardness test.
- UCI method measures hardness through the change of the frequency of the resonator before and after the indentation and is strongly corelated to Youngs modulus
- Measuring materials with a significantly different Young's modulus from standard steel can lead to inaccurate results unless appropriate corrections are applied. Even small differences in Young's modulus between the default calibration and the test material can introduce systematic bias, so adjustments are recommended.

Introduction

Measuring the hardness of non-standard materials—those that differ significantly from standard steel with an elastic modulus (Young's modulus) of 210 GPa—can lead to inaccurate results when using the Ultrasonic Contact Impedance (UCI) method. This is because the UCI technique relies on the elastic properties of the material being tested. In this article, we'll explain the fundamentals of both the conventional benchtop Vickers method and the UCI method. We'll also discuss why caution is necessary when conducting measurements on materials other than standard steel. By understanding and applying appropriate corrections, you can obtain reliable results quickly and efficiently. So, if you've ever measured, for example, 600 HV on aluminum with a UCI device, this article is for you.

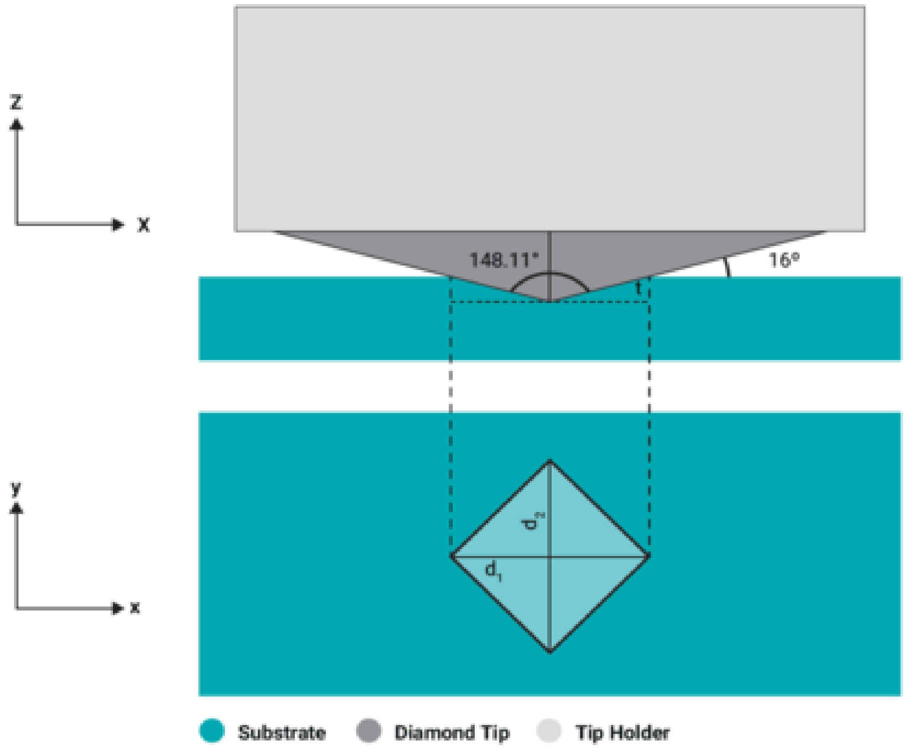
How does Ultrasonic Contact Impedance work compared to the benchtop method?

Benchtop Vickers Method

In the benchtop Vickers hardness test, a diamond indenter with a precise pyramid geometry (136° between the opposite facets or 148.11° between opposite edges) is pressed into the material under a specific load. This action creates a square-shaped indentation. The size of this indentation is then measured under a microscope by determining the lengths of the two diagonals. The Vickers hardness number (HV) is calculated by dividing the applied force by the surface area of the indentation.

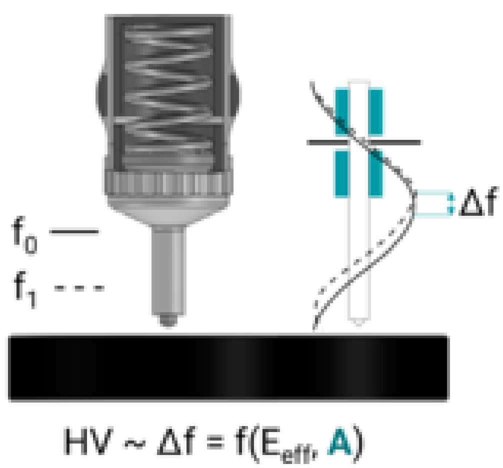
- **Softer materials** result in larger, deeper indentations with longer diagonals.
- **Harder materials** produce smaller, shallower indentations with shorter diagonals.

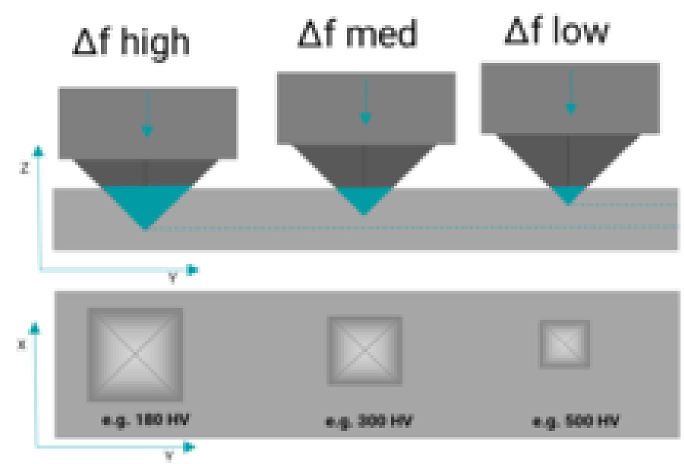
This method relies on optical measurements and can be time-consuming due to the need for microscopic analysis.



$$HV = \frac{F}{A} = 0,1891 \cdot \frac{F}{d^2}$$

The **UCI method** uses the same diamond indenter but mounted on a vibrating rod that resonates at an ultrasonic frequency. When the diamond indenter is pressed into the material, the surface contact between the indentation and diamond alters the resonating frequency. The larger the indentation, the greater the frequency change. Rather than measuring the diagonal of the indentation optically, the UCI method uses the frequency shift to instantly calculate the hardness value.





The resonation frequency, however is also strongly dependent of he elastic properties of the material, and standard calibrations for all devices on the market are set to steel and cast steel with Young's modulus (E, also called Elastic modulus) of 210 GPa. This means, that if you measure any materials with E modulus different than 210 GPa, while your device "believes" it is the standard material, you will get erroneous measurements. The higher the difference in E modulus, the larger the error. So if you had measured aluminum with UCI method and received 500-600 HV, this is most likely the issue. The following table summarizes most important measurement features between the both methods.

	Stationary (bench top) Vickers	Ultrasonic Contact Impedance
Indenter	Pyramid 136° indenter	Pyramid 136° indenter
Test load	HV1-HV100	HV0.1-HV10
Load application time	10-15s	0.5-2s
Scale	e.g. HV5	e.g. HV5 (UCI)
Computation	HV=F/A	HV ~ $\Delta f = f(E_{eff}, A)$
Material depencendy	Material-Independent	Material-Dependent!

What are the Youngs modulus tolerances to use the default material calibration? P91 steel case study.

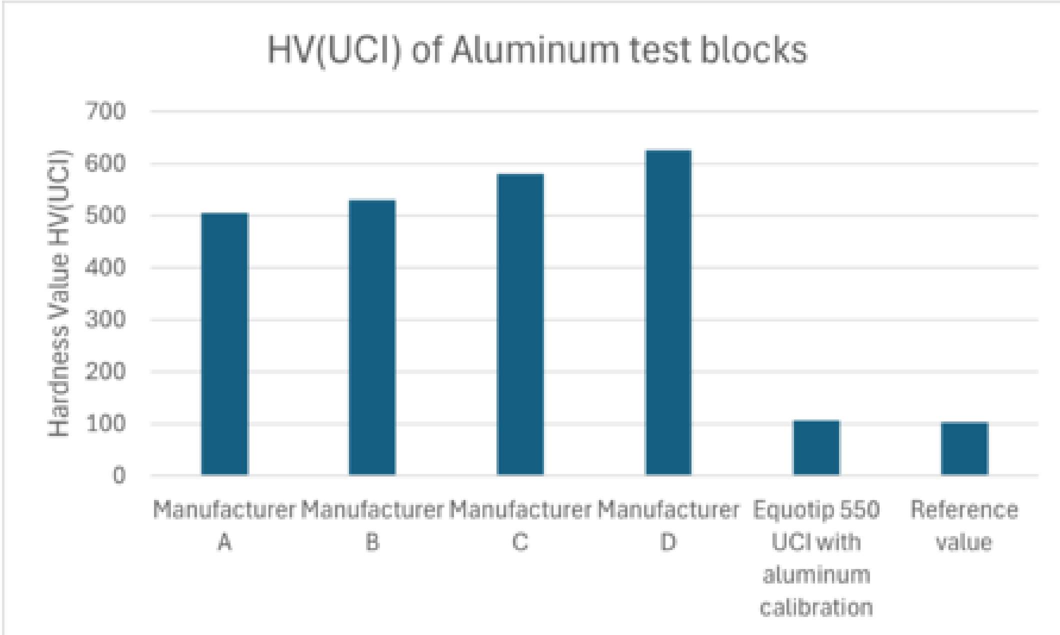
A general rule of thumb is to limit testing materials to those with a **Young's modulus** deviation of no more than **±10 GPa** from the calibrated material. However, this doesn't guarantee bias-free measurements. Take **T/P91 steel**, which has an average Young's modulus of **212- 218 GPa (in this example 218 GPa)**. This falls within the acceptable range, yet a stationary Vickers test might give a hardness of **185 HV**, while UCI probes could show **165-170 HV d**epending on the manufacturer. At first glance, this seems acceptable, but a deviation of up to **11%** is possible—far exceeding all standard tolerances.

It's essential to account for these deviations, as overlooking them can lead to underestimating or overestimating the hardness, potentially compromising the safety or quality of the material being tested; this lack of adjustment can make a brittle material looking safe and the other way around. Take into account that this bias does not yet account for user error (e.g. perpendicularity of the measurement) surface preparation bias and measurements conducted in the field.

It is therefore a good practice to always account even for minor bias sources and eliminate them whenever possible. Below is a field example of the user measuring P91 with predefined by the manufacturer correction.

What about other materials with much different Young's modulus?

Lets have a look on a more extreme example. Consider an aluminum engine block, with a standard hardness of **103 HV** using a benchtop Vickers test. When tested using UCI without proper calibration, results could vary wildly depending on the manufacturer. The key takeaway here is that without the correct calibration, you could end up with misleading results. This may be obvious in the case of aluminum since such hard aluminum does not exist, but smaller discrepancies may go unnoticed, leading to inaccurate assessments.



To ensure accurate measurements, special calibrations accounting for different Young's moduli are required. Manufacturers often provide these, or users can create their own through external calibration.

What is the best practice?

Understand the Material

- **Identify Young's Modulus**: Know the elastic properties of the material you're testing.
- **Check Manufacturer Options**: Many devices offer preset calibrations for different materials.

Apply Corrections

- **Use Manufacturer Calibrations**: Select the appropriate material calibration if available.
- **Create Custom Corrections**: Most modern UCI devices often allow users to generate their own correction curves.

Methods for Generating Correction Curves

1. **One-Point Shift**
    - **Usage**: Simple, quick adjustments.
    - **Limitations**: Best for minor corrections over a narrow hardness range.
2. **Two-Point Curve**
    - **Usage**: Accounts for non-linearity over a broader range.
    - **Advantages**: More accurate than one-point shift for materials with significant differences.
3. **Polynomial Curve**
    - **Usage**: Defines the correction using mathematical coefficients.
    - **Advantages**: Offers the highest accuracy over a wide range of hardness values.

Implementing corrections:

With modern devices generation of correction can be really easy to be executed, below the instructional video, demonstrating how easy it is with the Equotip 550 UCI.

The UCI method offers significant advantages over the conventional benchtop Vickers method, including faster measurements and greater portability. However, because UCI results are influenced by the material's elastic properties, it's crucial to apply appropriate corrections when testing non-standard materials.

By understanding the impact of Young's modulus on UCI measurements and following best practices for calibration, you can achieve accurate and reliable hardness measurements across a wide range of materials.