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PORTABLE HARDNESS TESTING – PRINCIPLES AND APPLICATIONS

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Abstract

Conventional hardness testers, like Rockwell, Brinell or Vickers machines, require the test piece be brought to the testing device; but this is not always possible. Portable testing devices have been developed that permit in-situ hardness measurements thus offering quick and economical supplements to conventional, stationary testing machines. There are two different physical methods particularly recognized in the practical field and which are accepted tools for many applications.

This paper explains the basic principles of both test methods and compares, using examples from the practical field, the application possibilities of both methods. The subjects critically discussed are the factors of influence on hardness testing, such as surface preparation or the wall thickness of parts to be tested, e.g. pipelines.

In addition to these successfully applied methods, Krautkramer now introduces a completely new technique: The Through Diamond Technique. This optical mobile hardness tester measures, for the first time, real Vickers hardness under load.

Introduction

What is "hardness"?
With regard to metals, hardness has always been a subject of much discussion among technical people, resulting in a wide range of definitions. Hardness properties include such varied attributes as resistance to abrasives, resistance to plastic deformation, high modulus of elasticity, high yield point, high strength, absence of elastic damping, brittleness or lack of ductility.

To a metallurgist, hardness is a material's resistance to penetration. In general, an indenter is pressed into the surface of the material to be tested under a specific load for a definite time interval, and a measurement is made of the size or depth of the indentation.

Hardness is not a fundamental property of a material, but a response to a particular test method. Basically hardness values are arbitrary, and there are no absolute standards for hardness. Hardness has no quantitative value, except in terms of a given load applied in a specific, reproducible manner and with a specified indenter shape.

Static indentation tests in which a ball, cone or pyramid penetrates into the surface of the material being tested are widespread. The relationship of load to the area or depth of indentation is a measure of hardness, such as that found in common bench-top Brinell, Rockwell, Vickers or Knoop hardness testers.

The different methods and differently shaped indenters used by, for example, Brinell (HB) and

Rockwell (HRC) produce dissimilar responses of the material under test. Conversion tables relating to e.g. HRC and HB values have to be determined empirically by experimental evaluation of a specific material's hardness with the different test methods. There exists no mathematical equation to transfer measurements from one scale to another. To compare the hardness of two different samples, both must be measured using the same hardness scale, or a scale must be developed to convert from one measurement to the other.

Why hardness testing?
In manufacturing applications, materials are primarily tested for two reasons: either to research the characteristics of a new material or as a quality check to ensure that the sample meets a particular specification.

How to measure hardness on-site?
Conventional hardness testing machines require the test piece be brought to the testing device; but this is not always possible. Portable testing devices have been developed that permit in-situ hardness measurements.

One popular device measures the frequency shift of a resonating rod with a Vickers- diamond tip, which occurs when the diamond penetrates into the test material by applying a specific test load. The frequency shift is evaluated and electronically converted to a hardness value displayed on the LCD. The MICRODUR instruments (Krautkramer) work according this method, the so-called UCI (Ultrasonic Contact Impedance) method.

Another well-known principle for portable hardness testers is the rebound method. The DynaMIC and DynaPOCKET (Krautkramer), for example, measure the velocity of a propelled impact body directly before and after the impact onto the test material's surface. The ratio between both velocities indicates the hardness of the material, which can be converted into different scales by using conversion tables stored in the instrument for different materials.

UCI and Rebound hardness testing with just one instrument!

The brand-new Krautkramer MIC 20 combines the two most successfully applied portable hardness testing principles in one instrument. Whether you want to use the UCI principle or the dynamic Rebound testing method – the MIC 20 offers both possibilities. All you need is just one instrument and all current UCI probes and impact devices can be plugged in and used.

The UCI Method

As in standard Vickers or Brinell hardness testing, the question as to the size of the test indentation in the material generated by a certain test load also arises in Vickers hardness testing according to the UCI (Ultrasonic Contact Impedance) method. However, the diagonals of the test indentation, which have to be known in order to determine the Vickers Hardness value, are not evaluated optically as usual, but the indentation area is electronically detected by measuring the shift of an ultrasonic frequency

A UCI probe typically consists of a Vickers diamond attached to the end of a metal rod (Fig. 1). This rod is excited into longitudinal oscillation at about 70 kHz by piezoelectric transducers.

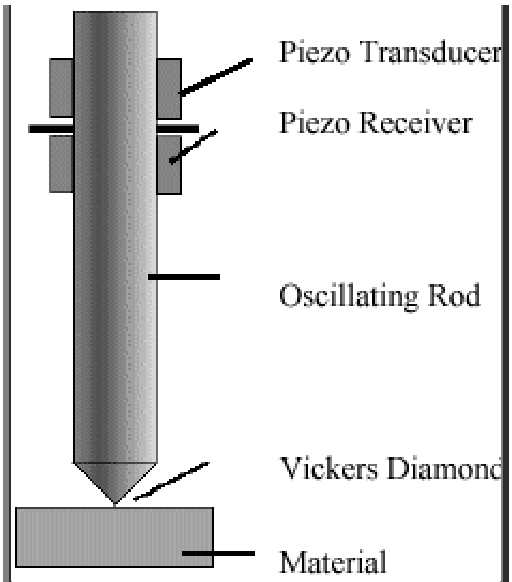

Fig 1: Schematic description of the UCI probe.

When the test load is applied, a frequency shift occurs as the diamond penetrates into the material. This frequency shift will become greater when the test indentation becomes larger, that means when the diamond penetrates deeper into "soft" material. Analogously, the smallest frequency shift is produced by hard test materials; the diamond penetrates only slightly into the material and leaves a small indentation.

This is the secret of UCI hardness testing: the frequency shift is proportional to the size of the test indentation produced by the Vickers diamond. Equation (1) describes this basic relation in comparison to the definition of the Vickers hardness value.

$$\Delta f = f(E_{eff}, A) \quad \text{and} \quad HV = F/A \qquad (1)$$

Equation 1: The Frequency shift as a function of the indentation size of a Vickers indenter. Δf= frequency shift, A = area of indentation, E_{eff} = effective elastic modulus (contains the elastic constants of both the indenter and the test piece), HV = Vickers hardness value, and F= Force applied in the Vickers hardness test.

To carry out the UCI principle, a probe containing a rod with a Vickers diamond attached to the contact end is resonated by piezoelectric ceramics at an ultrasonic frequency. A spring applies the load and the frequency of the rod changes in proportion to the contact area of the indentation produced by the Vickers diamond. Therefore, the hardness value is not visually determined by the diagonals of the indent, but by an electronic measurement of the frequency shift within seconds.

The instrument constantly monitors the frequency, performs the calculation and instantaneously displays the hardness value.

The frequency shift, nevertheless, also depends on the Young's modulus of elasticity, which is a material constant. For the practical application of the UCI-method, the Young's modulus therefore has to be considered. The instrument has to be calibrated when the hardness of different materials with different values of the Young's modulus has to be determined.

After completing the calibration, the UCI method can be used for all materials showing this modulus of elasticity. When being manufactured, the probes are calibrated on low- alloyed or unalloyed steels; however, modern test instruments can be calibrated quickly, also at the test location, to other materials as well, such as titanium or copper.

The Rebound method

Hardness testers using the Rebound method operate in a slightly different manner. Although the size of the test indentation generated is connected with the material hardness even in this case, it is indirectly measured via the loss of energy of a so-called impact body. A mass is accelerated to the surface of the test object and impinges on it at a defined speed, i.e. kinetic energy. The impact creates a plastic deformation of the surface, i.e. an indentation, due to which the impact body loses part of its original speed - or energy. It will lose more velocity when creating a bigger indentation on softer material. Technically, this principle of measurement is implemented by means of an impact body which has a spherical tungsten carbide tip and which is accelerated onto the test surface by spring force. The velocities after and before the impact are each measured in a non-contact mode.

This is done by a small permanent magnet within the impact body (Fig. 2) which generates an induction voltage during its passage through a coil, with this voltage being proportional to the speed.

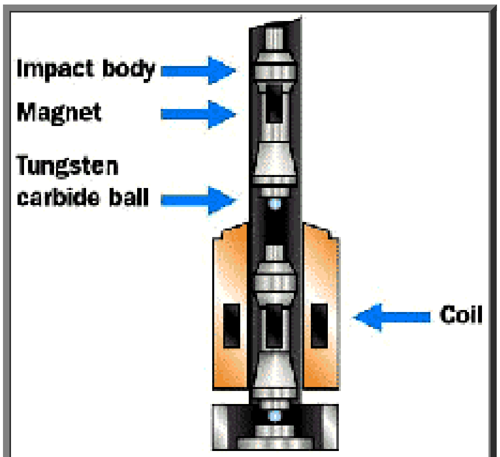

Fig 2: Cross-cut of a typical impact device.

The inventor of this method, D. Leeb, defined “his own” hardness value, the Leeb hardness value. The Leeb hardness value, HL, is calculated from the ratio of the impact and rebound speed according to:

$$HL = \frac{v_R}{v_I} \cdot 1000 \qquad (2)$$

Equation 2: The Hardness value according to Leeb (HL) is defined as the ratio between the rebound velocity (v_R) after and the impact velocity (v_I) before the impact of the tungsten carbide ball onto the test piece surface.

You might ask yourself: "Who wants to measure the hardness value in Leeb?" The answer is: as a matter of fact, anybody who uses the rebound hardness testing method does it, because the Leeb hardness value is, by definition in the equation (2), the actual physical measurement value behind this method. However, nearly no user indicates the Leeb hardness value HL in his specifications or test reports. We mostly convert into the required hardness scales (HV, HB, HS, HRC, HRB, N/mm^2). For this reason, only conversion brings the rebound hardness method to life. Empirically determined conversion tables for different material groups are stored in the Krautkramer hardness testing instruments.

To apply the principle, an impact device uses a spring to propel an impact body through a guide tube towards the test piece. As it travels towards the test piece, a magnet contained within the impact body generates a signal in a coil encircling the guide tube. After the impact, it rebounds from the surface inducing a second signal into the coil. The Krautkramer instrument calculates the hardness value using the ratio of the voltages and analyzes their phases to automatically compensate for changes in orientation. Due to the patented signal processing, there is no need for any manual correction for the impact direction. Only Krautkramer hardness testers offer this autobalancing feature.

Application solutions are determined by the force and ball size of the impact body. The operator can select between different impact devices for the DynaMIC hardness testers (Dyna D, Dyna E and Dyna G) as well as the DynaPOCKET instrument.

The Through-Diamond-Technique

While both methods – UCI- and Rebound – are successfully used in the field and solve many on-site hardness testing applications, there are limitations concerning the kind of material under test and its size and weight, respectively. Furthermore, because of the influence of Youngs-Modulus, most conventional testing methods do not allow to measure different materials without firstly calibrating or adjusting the instrument.

What are the advantages of the TDT method?

With Transpyramidal Indenter Viewing, or also known as Through Diamond Technique, we overcome this “handicap”: practically all kinds of material from steel to rubber and from aluminum to plastics can be tested without the necessity of instrument calibration. With this instrument we developed an optical mobile hardness tester, allowing real Vickers hardness measurement under load without having to face the disturbing influence of the elastic properties of the test material, i.e. Youngs-Modulus.

The system consists of the portable base instrument including a graphical LCD display and the TDT probe (see Figure 3).

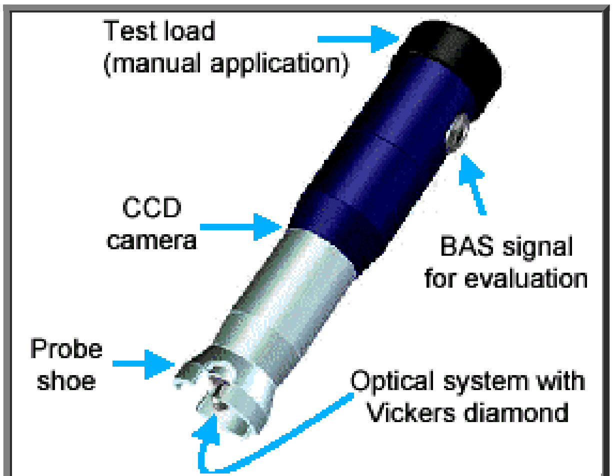

Fig 3: Schematic description of the TDT probe.

By applying a certain test load (e.g. 50 N) the diamond penetrates into the material. The indentation size of the Vickers diamond, i. e. the lengths of the diagonals, is automatically measured under load by viewing through the diamond with an optical system having a CCD camera. Data evaluation is then made in the instrument. As Vickers hardness is simply defined as the ratio between test load and indentation size (the diagonals of the indentation), the TDT-measurement of the diagonal length immediately produces a Vickers hardness value for the applied test load. The live picture of the indentation displayed on the instrument's LCD also allows immediate characterization of measurement reliability, i.e. the quality of the Vickers diamond indentation.

The physical method of TDT hardness testing – traced back to Vickers hardness – allows mobile testing of different materials without the necessity of calibrating the instrument. By viewing through the diamond under load, TDT opens up mobile hardness testing not only to new applications like coils, thin layers and coatings but also to different materials like plastics, glass and high-tech materials such as ceramics or intermetallics.

While testing under load by viewing through the diamond, the TDT instruments even allow to measure the hardness of elastic or soft materials. Other types of tests, such as Brinell, Vickers or Knoop tests, have their difficulties. The problem with trying to apply some of the "older types" of tests, is that the indentations themselves can at times almost completely recover, and there is no permanent impression left, thus making measurements impossible. The TDT method eliminates that problem. It involves pressing a diamond punch of known geometry into the surface of a material. The indentation size will be monitored under load during the test.

In some industries, aluminum or soft metal alloys such as solder would be considered "soft" materials. But as the testing of rubbers, plastics, and polymers becomes more commonplace, even the softest metals will seem comparatively hard. It is a relative term. Applications for testing soft materials are nonetheless widespread. The automotive industry tests the hardness of paints and tires. The microelectronics and photonics industries test low-dielectric constant films, chemical and mechanical polishing pads, bond pads, solders, and electronic packaging materials. The biomaterials industry tests polymer joint-implant materials, nail polish and drug particles. The medical field even tests biological samples such as liver, cartilage, and arterial tissues. Determining meaningful hardness values for soft materials has always been challenging, and despite recent advances in methods and instruments, continues to be so.

The Through Diamond Technique (TDT)

The innovation with this technique is the evaluation of the Vickers diamond indentation, which takes place by viewing through the Vickers diamond using a CCD camera. For that purpose it is necessary to light up the inner surfaces of the diamond using light-emitting diodes (LED) geometrically arranged.

In order to obtain the highest resolution of the indentation picture it is necessary to match the wavelength of the LED light and the spectral sensitivity characteristics of the CCD chip. A special lens system was developed and adjusted to the LED to ensure maximum resolution. Computer assisted evaluation of the indentation and determination of the diagonal's length occurs in three steps. A first step locates the approximate position of the indentation. After that the exact course of the indentation's border is determined in local vicinities (so-called Areas of Interest) by applying suitable "transition filters" for determination of any grey scale transition. Finally the indentation surface and the diagonals are determined using the intersections of the calculated borders and the edges of the Vickers diamond. According to the definition of Vickers, the HV value is calculated for the applied test load.

Practical application

The PC-based TDT system consists of a hand-held PC and the TDT probe. The interface between instrument and probe serves as power supply for the probe as well as connector for all control functions. The interface also feeds the BAS signal from the CCD camera to the frame grabber. With special software the data can be evaluated, the diagonals measured and the hardness value calculated. The live picture through the diamond can be displayed, enabling the diamond's indentation process to be viewed, i.e. the growth of the indentation by applying the test load. It also allows an in situ quality characterization of the diamond and the diamond's indentation, respectively.

Depending on the resolution and the test load, different hardness ranges can be analyzed. The standard TDT probe with a test load of 50 N allows a measurement range from about 100 HV5 to 900 HV5. For softer materials a lower test load has to be applied.

In principle, all kind of materials can be tested as long as the hardness value is in the range of the TDT probe used for the measurement.

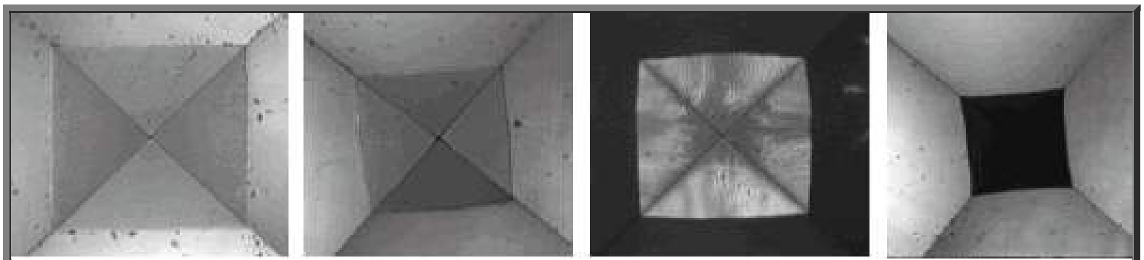

Fig 4: Typical Vickers diamond indentations obtained by TDT measurements on a) steel b) coiled steel c) Teflon and d) ceramics (Al_2O_3).

Figure 4 shows some typical Vickers diamond indentations obtained by the TDT instrument on different materials under test. TDT – for example – allows to determine the hardness of bulk material

a. enables to measure the hardness on coils
b. and also opens up hardness testing to new applications like high-tech materials
c. ceramics
d. or rubber and plastics.

Summary

By viewing through the diamond under load the Through Diamond Technique opens up new applications for hardness testing. The portable instrument not only allows for on-site measurements but also enables hardness measurements on all kind of materials. The obtained hardness value corresponds to Vickers testing, with the exception that TDT measures under load, thus also enabling measurement of elastic materials where usual indentation hardness fails.

Conclusion

Mobile hardness testing instruments will not replace the conventional bench-top machines, but nevertheless, they became an indispensable addition for hardness testing units. During the last decades several portable instruments based on different physical methods were developed. Today portable units are widespread and accepted tools for portable, on-site hardness testing applications.

Those instruments solve plenty of mobile hardness testing tasks, but however, each method is limited – more or less – to a specific application area and, therefore, the decision as to which method and instrument to use strongly depends on the testing application.

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