Determination of the Hardness and Other Characteristic Materials Parameters Using the Instrumented Indentation Test

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Part 1: Fundamentals

1. Introduction

Hardness testing is widely used for quality control of high volume components after heat treatment or coating. It often enables access to the properties of very small areas such as structural components, coatings or micro-components even without extracting/building a sample.

The evaluation of the mechanical properties of coatings reached a new level of quality with the continued development of the load/indentation depth method and the continuous, high-resolution recording of the load and indentation depth for the complete test cycle (loading and unloading).

The hardness value determined for the selected test load using conventional hardness test methods according to Brinell, Rockwell or Vickers does not take into account the elastic deformation of the indentation. These values also always characterize, as an integral characteristic, the material resistance of the entire indentation area. In contrast, the continuous acquisition of the test load and the indentation depth under load has the advantage that the elastic and plastic deformations are measured. In addition, the hardness can be measured quantitatively for every indentation point and presented as a function of the indentation depth, the test load or the effective load duration. This results in additional capabilities, for example, the analysis of coatings or of hardened or softened surfaces. Aside from the hardness under load, additional material characteristics that allow for an in-depth evaluation of the specimen can be derived from the load/indentation depth curve. Compared to the methods using optical evaluation, the measurement of the indentation depth offers the additional advantage that it can be performed automatically (operator-independent).

The application of the instrumented indentation test is supported by its extensive information content, by the availability of a powerful test technology and by worldwide standards.

This article shall provide a brief overview of the foundations of the instrumented indentation test (load/indentation depth method), taking into account the current standards. Influencing factors that need to be observed, whether stemming from the test method or specific to the specimen, will be examined. The bibliographical references support a rapid entry into an efficient utilization of the test method.

2. The instrumented indentation test

In the technical literature, the instrumented indentation test is often referred to as load/indentation depth method or as recording hardness test [1, 2, 5]. The test method is based on the concept – following the definition of the technical hardness according to Martens – of determining the hardness under test load through measuring the elastic and plastic deformation. Taking the overall deformation into account leads to a physically sensible hardness value and to a comparable evaluation of the hardness among the materials. If one were to ignore the elastic deformation, rubber, for example, would be a very hard material.

2.1 The test procedure

In the instrumented indentation test, an indenter, e.g., a diamond pyramid, is pressed vertically into the surface of the specimen (**Fig. 1**). During the test procedure, the load F and the indentation depth h are measured during both loading and unloading.
The result of the test procedure is the correlation between test load F and the corresponding indentation depth h as illustrated in **Fig. 2**. The start of the test is defined as the moment of contact between the indenter and the surface of the specimen. The indentation depth h that has been measured under test load includes the elastic and the plastic deformations.
The load or the indentation depth shall control the test procedure. The type of control used must be specified in the test report.

With the **test load controlled method,** the test load is applied steadily or incrementally **(**Fischerscope H100 and H100C) and then maintained over a specified time span, i.e., the material is strained uniformly

over a defined period. The variable indentation depth at a uniform test load is measured in relation to the holding time of the test load (**Fig. 3**).
With the **indentation depth controlled method,** the desired indentation depth is reached and then maintained over a specified period. The variable test load at a constant indentation depth is measured in relation to the holding time.

2.2 Field of applications

The load/indentation depth method distinguishes itself through a large field of applications. Essentially, all materials and material coatings can be tested (**Fig. 4**).
One only needs to observe that the thickness of the specimen or the coating does not drop below 10 times the amount of the indentation depth. The latter is dependent on the hardness and the test load. The test load is variable over a big range. Thus, even very thin samples, micro-components or coatings can be tested by lowering the test load. Small test loads, in turn, constitute higher demands on the instrument technology.
Corresponding to the test load or the indentation depth, the recording indentation test according to DIN EN ISO 14577 -1 is divided into 3 application ranges [2]:

- Macro range $2\ N \leq F \leq 30\,000\ N$
- Micro range $2\ N > F$ and $h > 0.000\,2\ mm$
- Nano range $h \leq 0.000\,2\ mm$

The micro range is defined by 2 N at the top and an indentation depth of 0.0002 mm at the bottom.

DIN 50359-1 specifies the application range as follows [5]:

- Macro range $2\ N \leq F \leq 1000\ N$
- Micro range $2\ N > F$ and $h > 0.000\,2\ mm$

Compared to DIN EN 50359, the ISO Standard provides a wider spectrum of application options from the smallest indentation depths (coating tests) to large test loads (closer to conventional hardness test methods). Furthermore, selecting different indenters according to the ISO Standard provides the ability of selecting indenters specific for test applications.

2.3 Indenters

While German Standards specify for the Universal Hardness Test [5, 8] the square diamond pyramid with an opening angle of 136° according to Vickers as the indenter, DIN EN ISO 14577-1 [2] also allows hard metal spheres, spherical diamond indenters and diamond pyramids with a triangular base (e.g., Berkovich Pyramid) as indenters, corresponding to the test application. In this case, only the statement for the calculation of the surface area of the indentation changes for the determination of the hardness value (**Table 1**). If the Pyramid according to Vickers is not used, the indenter that is being used must be identified with the test results. The Standard does not exclude the use of other indenters.

The condition of the indenter is to be checked regularly. Due to production conditions, the shape of the indenter in use will often deviate from the "ideal" shape. For example, the tip roundness and the pyramid edge may be different between the Vickers Pyramids in use. Deviations from the nominal value of the opening angle, or the sphere diameter, respectively, may occur as well. Deviations of the shape inevitably will lead to different hardness values. In order to measure comparable hardness values on the same samples in different test labs, the geometric influences of the indenter in use must be taken into account for indentation depths of ≤ 6 μm.

According to [2] and [5], the diamond pyramid must meet the following conditions:

- The angle between opposite surfaces must be (136 ± 0.3) °
- The angle between the axis of the diamond pyramid and the axis of the holder may not exceed 0.5 °

- The four side surfaces of the pyramids must meet in one point at the tip of the pyramid. For indentation depths > 30 µm, the pyramid edge may be max. 1 µm, and for indentation depths between 30 and 6 µm, it may not exceed 0.5.

  For indentation depths ≤ 6 µm, the pyramid edge may not exceed 0.5 µm as well. An indenter shape correction always needs to be performed for this indentation depth range.
- For measurements in the micro range, the radius of the tip roundness may not exceed 0.5 µm.

The test results in **Fig. 5,** measured on a BK7 glass sample with homogeneous hardness, underline the necessity of an indenter shape correction. Without taking into account the actual indenter geometry, the measurement will provide a non-existent distinctive hardness gradient.
Regular checks of the indenters in use are, therefore, crucial. A suitable microscope must be used to check the shape of an indenter. An atomic force microscope (AMF) should be used for the measurement if the indenter is used in the micro range.
Another significantly simpler method for checking the geometry of the indenter is to measure the hardness on a material that exhibits a hardness that is independent of the indentation depth. With otherwise comparable test conditions, hardness differences are caused by deviations in the indenter condition. Using the Fischerscope H100 or H100C, the correction factor can be determined automatically when using such a reference measurement. This factor is then available for subsequent evaluations. Glass BK 7 or silica glass are suitable reference materials.

During the test, the distance changes of the indenter tip are measured as the indentation depth, that is, the distance measurement also includes the elastic deformations of components of the indenter and of the load transfer elements that are in the flow of the load. The elastic deformations from the embedding material are added as well.

Thus, typical commercial Vickers indenters should not be used for the determination of the hardness under load.

The indenter die should be made of hard metal and the indenter itself should rest plainly on the holder [3, 6]. Conventional embedding of the diamond using sinter bronze should be avoided. For accurate measurements at small indentation depths, it is necessary to determine the flexibility (elastic deformation) of the test system and to take it into account during the evaluation. The flexibility must be determined for at least five different test loads. A reference material with a certified hardness value or a certified indentation modulus must be used to verify the flexibility.
The minimum test load that results at an indentation depth of 0.006 mm and the maximum possible test load of the test device define the test load range.

2.4 Zero point determines the precision and repeatability of the test

For the recording hardness test, the start of the test is defined as the moment of contact between the indenter and the surface of the specimen. Thus, the accuracy of the test method is to a large degree determined by the resolution of the employed measurement technology and the precise determination of the zero point of the load/indentation depth curve. The zero point must be determined for each individual test sequence. Two methods are permissible to determine the zero point:

Method 1: The zero point is determined through extrapolation of a compensation function (e.g., polynomial of the second order) for the beginning region of the load/indentation depth curve.

Method 2: The contact point determined with the aid of the first load increase is set as the zero point. The load at the contact point may not exceed $1 \cdot 10^{-4}$ F_{max} (e.g., 0.0002 N for a nominal load of 2N) for the macro range and 5 µN for the micro and nano ranges.

The beginning region of three load/indentation depth curves obtained with the measuring head H100SMC on acrylic glass and presented in **Fig. 6** underlines that the zero point can be accurately determined to a few nanometers via the calculation of the compensation parable (polynomial of the second order) with the measured value pairs of the load/indentation depth curve. For a test load of 1N and a zero point deviation of 5 nm, the measurement error is less than 1%, even for hard materials.

However, it should be noted that for small indentation depths, the progress of the load/indentation depth curves is also influenced by the roughness of the test surface. When testing metallic materials, the indentation depth h must be at least 20 times the arithmetic mean roughness R_a ($h \geq 20\ R_a$ [2, 5]) to ensure that the measurement uncertainty of the indentation depth due to sample roughness does not exceed 5%.

2.5 Influencing factors specific to the test sequence

Parameters characteristic to the test sequence are the approach speed / contact speed of the indenter, the indentation speed, the load application method (steady or incremental) and the effective period of the test load.
Since these may affect the determination of the characteristics very differently, uniform test conditions must be selected for comparable measurements and the test results must be identified clearly.
It must be noted that materials react differently to test conditions, which can result in very different influences on the test results.

The following test conditions must be met:

- The test cycle (loading and unloading) must be carried out jolt-free and vibration-free.
- The test load must be applied without overshooting and vertical to the surface / test area
- The approach speed of the indenter should be as slow as possible and < 0.002 mm/ s for measurements in the micro range.
- The period from the start of applying the test load to the time the maximum test load is reached should be consistent within a test series.
- If the test load is applied incrementally, the increments should be spaced equally on the F scale.
  If the test sequence is controlled in incremental indentation depth steps, these steps should be spaced equally.
- Loading and unloading times should be equal if an additional evaluation of the load/indentation depth curve is intended.

The load/indentation depth curves in **Fig. 7** underline the significant influence of the load application speed on the characteristic values of soft coatings or soft materials. The load application speed affects the hardness, the creep amount at Fmax and the progress of the unloading curve. In both cases, the unloading speed corresponds to the loading speeds. With very small unloading speeds, the material will initially continue to creep, which may affect the determination of the elastic indentation modulus.

3. Characteristic material parameters that can be derived from the measurements

Table 2 offers an overview of the standardized designations and symbols for the characteristic material parameters that can be derived from the recording load/indentation depth curve. When using the Standards for testing metallic materials [2, 5], it should always be noted that the definitions for the hardness after unloading (plastic hardness / indentation hardness) are different and, therefore, lead to different hardness values.

3.1 Hardness under test load – Universal Hardness / Martens Hardness

In Germany, standardization procedures for the load/indentation depth method for testing metallic materials as well as paint and similar coating materials commenced some time ago and has swiftly been brought to a conclusion. The quotient of the test load F and the indentation surface generated under that load received the designation **Universal Hardness *HU*** (Univeralhärte in German) and the method received the short form designation Universal Hardness Test –**Chart 1** and [5, 8].

Within the scope of international standardization procedures, it was recently agreed upon to use the designation **Martens Hardness *HM*** – with reference to Martens, the “father” for the definition of the technical hardness as the resistance of an object to the indentation by another (harder) object – for the hardness under test load for metallic materials –**Charts 1** and [2]. The test method itself is called Instrumented Indentation Test for Determining the Hardness and Other Materials Parameters.

The hardness under test load includes the plastic and elastic portions of the deformation and is determined from the measurements of the load/indentation depth curve during loading, preferably after reaching a specified test load.

3.2 Hardness under test load, determined from the slope of the load/indentation depth curve

For homogeneous materials (at the surface, inhomogeneity is small in relation to the indentation depth), the equation for the load/indentation depth curve, preferably between 50% Fmax and 90% Fmax, is

$$h = m \cdot \sqrt{F} \qquad (3.2 - 1)$$

The slope m can be determined through a linear regression of the equation 3.2 –1, for example **(Chart 2).**

This calculation method has the advantage that the hardness under test load is independent of the uncertainty of the zero point determination and the roughness of the test surface. With greater loads and indentation depths, vibrations/jolts have less of an effect as well.

Note

With specimen, where the hardness changes with the indentation depth, hardness values were determined using this evaluation method that deviate from the HU or *HM* values that were determined according to 3.1.

The slope can also be obtained from measurement point to measurement point, such that the determined hardness values can also be presented as a function of the indentation depth. This type of presentation finds its application in particular for the characterization of coatings or hardened surfaces, or for the detection of inhomogeneities in the direction of the depth.

3.3 Hardness after unloading

Another hardness value can be determined from the load/indentation depth curve that is based on the lasting indentation after unloading, similar to the classic quasi-static method. The fictitious bounced back indentation depth h_r is used for the calculation of this hardness (**Chart 3**). It is assumed that a purely elastic recovery occurs. To determine h_r, a tangent is placed at the upper linear part of the curve during unloading and the intersection of the tangent with the axis of the indentation depth is determined.

Indentation hardness and plastic hardness are based on the evaluation of the lasting impression and a correlation to the Vickers Hardness *HV* can be expected. The available analysis results / 9, 10 / confirm a correlation of the plastic hardness HU_{plast} with the Vickers Hardness. It has been found that the hardness that has been determined with the depth h_r of the lasting impression is greater than the hardness calculated with the lasting diagonal, that is $HV < HU_{plast}$.

The conversion should only be used as estimation and not as a replacement for an actual Vickers value.

When correlating the indentation hardness H_{IT} with the Vickers Hardness, it should also be noted that the indentation hardness refers to the projected contact area of the indenter. The following applies to an ideal Vickers indenter:

Impression surface area A_s = 1.08 x projected contact area Ap and $HV = 0.0925 \times H_{IT}$

3.4 Indentation modulus

The elastic indentation modulus is determined from the rise of the tangents that are used for the calculation of the plastic hardness or the indentation hardness. It can be compared to the modulus of elasticity of the sample material (**Chart 4**).

3.5 Creep and Relaxation

The test procedure can be designed such that the measurements of the load/indentation depth curve can also be used to determine the characteristic parameters for evaluating the creep and relaxation behavior.

The relative indentation depth changes can be used as a measure for the creep of the material if the indentation depth changes are measured at a uniform and maintained test load.

$$C_{HU} \text{ after / 5 / and } C_{IT} \text{ after / 2 /} = \frac{h_2 - h_1}{h_1} x 100\,\% \qquad (3.5 - 1)$$

h_2 = indentation depth for the hold time t_2

h_1= indentation depth for the hold time t_1

The relative test load change can be used as a parameter for the evaluation of the relaxation of the material if the test load change is measured at a uniform and maintained indentation depth.

$$R_{HU} \text{ after / 2 / and } R_{IT} \text{ after / 5 /} = \frac{F_2 - F_1}{F_1} x 100\,\% \qquad (3.5 - 2)$$

F_2= for the hold time t_2

F_1= test load for the hold time t_1

3.6 Plastic and elastic portions of the indentation work

The mechanical work W_{total} expended during the indentation of the indenter is only partially consumed as plastic deformation work W_{plast}. The remainder is released upon unloading as elastic recovery work W_{elast}.

The total work W = $\int F \, d\, h$ (within the limits h = 0 mm and h = hmax) expended at the indentation procedure is the area under the load/indentation depth curve during load increase (Fig**. 2**).

The elastic indentation work corresponds to the area under the load/indentation depth curve during load reduction.

The elastic portion of the indentation work of a sample is:

$$\eta_{HU} \,;\, \eta_{IT} = \frac{W_{elast}}{W_{total}} \; 100\,\% \qquad (3.6 - 1)$$

Where: $W_{total} = W_{elast} + W_{plas}$

Thus, the plastic portion of the indentation work of a sample is:

$$\eta_{plast} = \frac{W_{plast}}{W_{total}} \; 100\,\% \qquad (3.6 - 2)$$

$$\eta_{plast} = 100\,\% - \eta_{HU} \,;\, \eta_{IT} \qquad 5/ \qquad (3.6 - 3)$$

η_{HU}, η_{IT} and η_{plast} contain measurement information that is suitable for the characterization of the material.
While the elastic portion of the deformation work characterizes the elastic recovery of the impression at load reduction, the plastic portion provides information about the ductility, sensitivity to percussion or sensitivity to brittle fracture of the materials or material coatings.

4. Hardness test device – requirements and inspections

The inspection of hardness test devices for instrumented indentation tests is specified in [3, 6]. A direct method is to be used for the inspection of the main functions of the test device and an indirect method for determining the deviation of the test device. The latter is favorably employed for regular routine inspections at the user's site.

Direct inspection

The direct inspection should be performed at a temperature of 23 ± 5°C. It includes:

- *The inspection of the test load*
- *The inspection of the indentation die*
  The verification that the indenter meets the requirements of the standard is to be provided through an accredited calibration lab and is to be documented with a calibration certificate. The inspection must be repeated after no more than 2 years.

  Re-ground or otherwise repaired indenters may not be used without a new inspection.
- *The inspection of the depth measurement device*
  Suitable measures must ensure that temperature-related longitudinal expansions do not invalidate the measurement result. During a test cycle, the temperature may not change by more than 0.5 °C in the micro range and 1 °C in the macro range.
- *The inspection of the test cycle*
  In this case, the time sequence of the test – test load increase, holding the maximum test load and load reduction – is inspected.

  The times selected for the test cycle may not deviate by more than 0.5 s.

The direct inspection must be performed:

a) Prior to the first start-up and after a repair
b) When the results of an indirect inspection are not satisfactory
c) At least within a period that does not exceed 12 months.

An indirect inspection must be carried out after every direct inspection.

Indirect inspection

The indirect inspection must be performed at a temperature of 23 ± 5°C using calibrated hardness reference plates for at least two of the typically employed test loads.

If the test device is used only for one test load, then it only needs to be inspected at this test load as well.

Two different hardness reference plates from differing hardness ranges must be used for each test load:

HU / *HM* / < 2 500 N / mm_
2 500 N / mm_ ≥ *HU* / *HM* / ≥ 7 000 N / mm_
HU / *HM* / > 7 000 N / mm_

When using the hardness test device in the micro range, the indirect inspection should be carried out at least once per month.

5. Bibliography

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Deutscher Verlag für Grundstoffindustrie- Leipzig-Stuttgart 1994
S. 195-198

[2] DIN EN ISO 14 577-1 — Metallische Werkstoffe - Instrumentierte Eindringprüfung zur Bestimmung der Härte und anderer Werkstoffparameter
Teil 1: Prüfverfahren

[Metallic materials – instrumented indentation test to determine the hardness and other material parameters

Part 1: Test methods]

[3] DIN EN ISO 14 577-2 — Metallische Werkstoffe - Instrumentierte Eindringprüfung zur Bestimmung der Härte und anderer Werkstoffparameter
Teil 2: Prüfung und Kalibrierung der Härteprüfmaschine

[Metallic materials – instrumented indentation test to determine the hardness and other material parameters

Part 2: Inspection and calibration of the test device]

[4] DIN EN ISO 14 577-3 — Metallische Werkstoffe - Instrumentierte Eindringprüfung zur Bestimmung der Härte und anderer Werkstoffparameter
Teil 3 : Kalibrierung von Härtevergleichsplatten

[Metallic materials – instrumented indentation test to determine the hardness and other material parameters

Part 3: Calibration of hardness reference plates]

[5] DIN 50359-1 — Prüfung metallischer Werkstoffe - Universalhärteprüfung
Teil 1: Prüfverfahren

[Testing metallic materials – Universal Hardness test

Part 1: Test method]

[6] DIN 50359-2 — Prüfung metallischer Werkstoffe - Universalhärteprüfung
Teil 2: Prüfung und Kalibrierung der Härteprüfmaschine

[Testing metallic materials – Universal Hardness test

Part 2: Inspection and calibration of the test device]

[7] DIN 50359-3 — Prüfung metallischer Werkstoffe - Universalhärteprüfung
Teil 3 : Kalibrierung von Härtevergleichsplatten

[Testing metallic materials – Universal Hardness test

Part 3: Calibration of hardness reference plates]

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Härterei -Technische Mitteilungen 48.Jahrgang, Heft 5 (1993)

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[10] Heermant, C. Universalhärteprüfung im Mikrobereich -
Dissertation TU Berlin 1998
[Universal Hardness in the micro range]

Figures

Fig. 1: Schematic presentation of the test principle

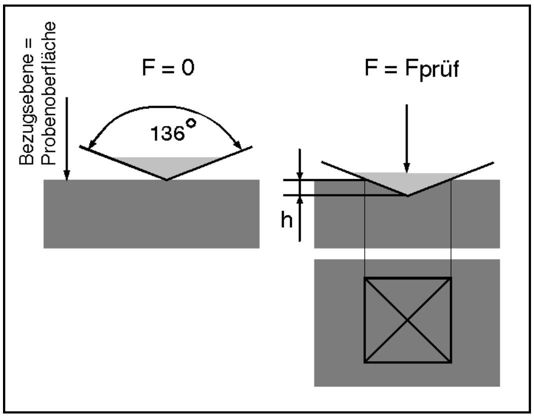


Fig. 2: Load/indentation depth curve for loading and unloading

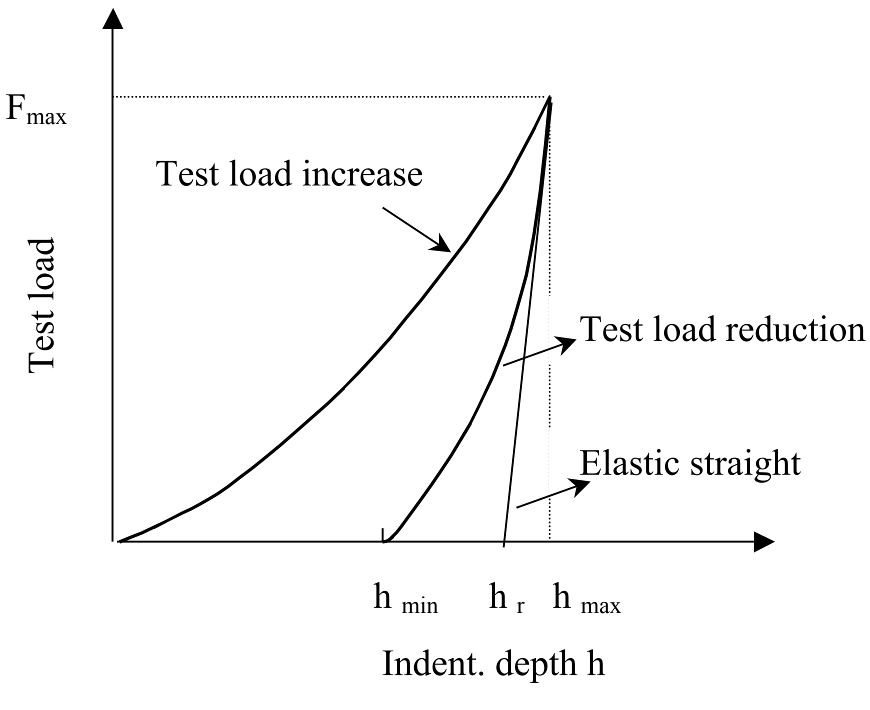


Fig. 3: Schematic presentation of the indentation procedure controlled via the test load dependent on the time

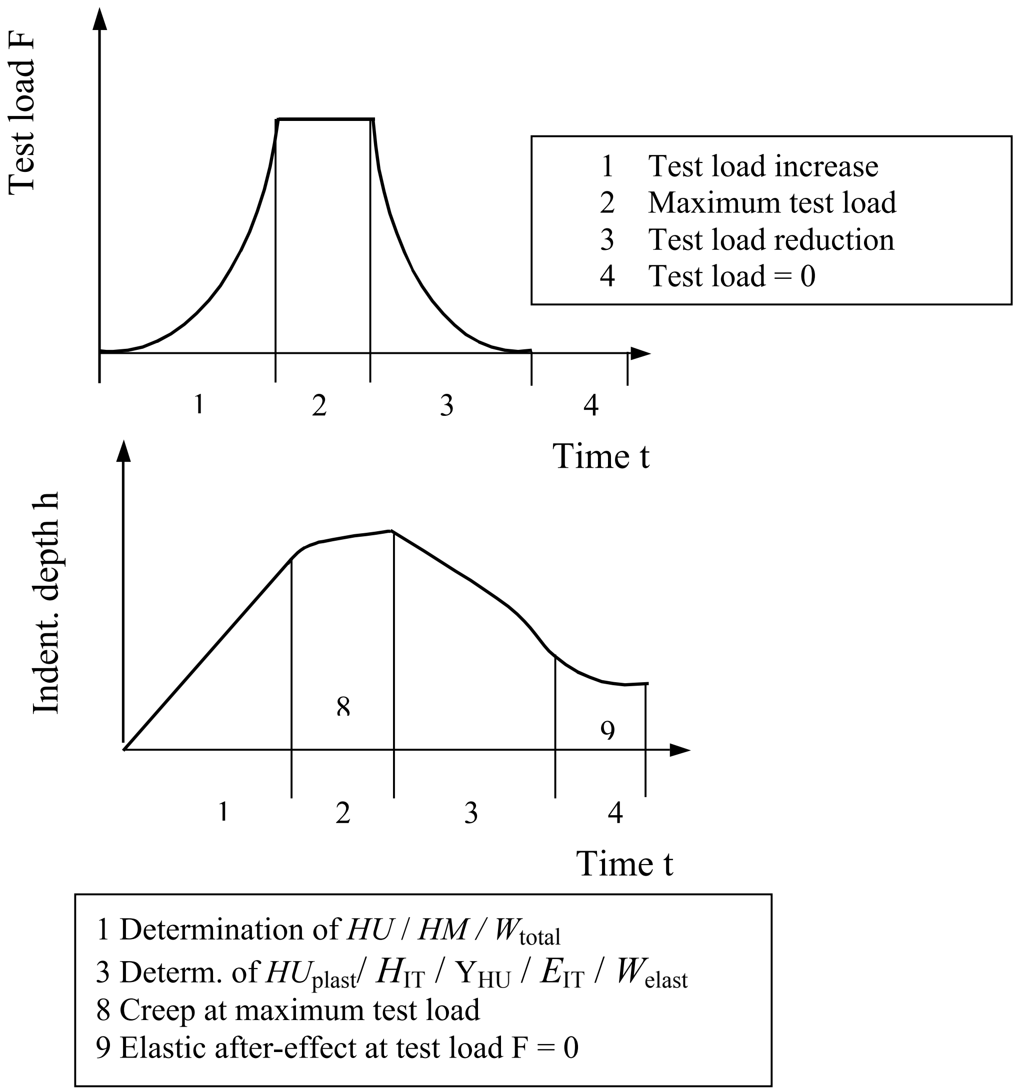


Fig. 4: Indentation depth under test load dependent on the test load and hardness

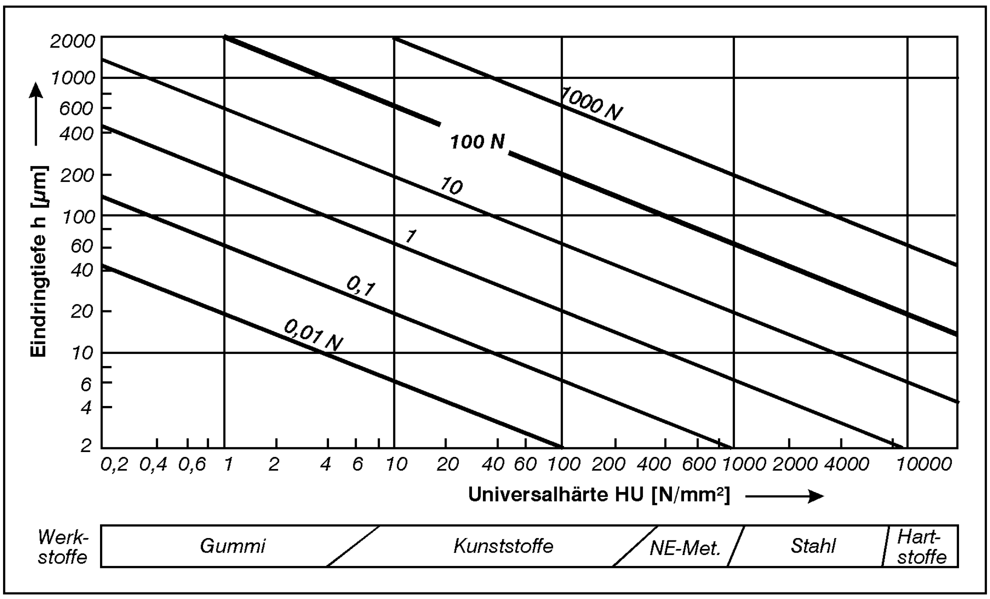


Fig.5: Universal hardness (upper curve) and corrected
Universal hardness (lower curve) of Glass BK7

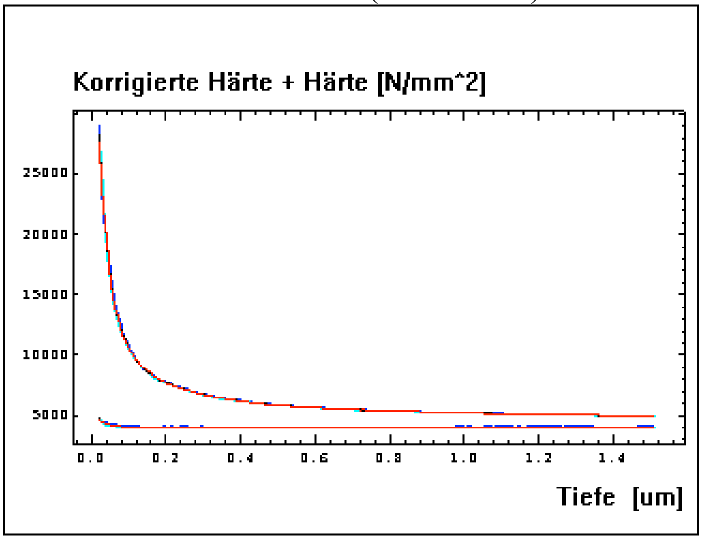


Fig. 6 : Load/indentation depth curves for the determination of the zero point using acryl glass

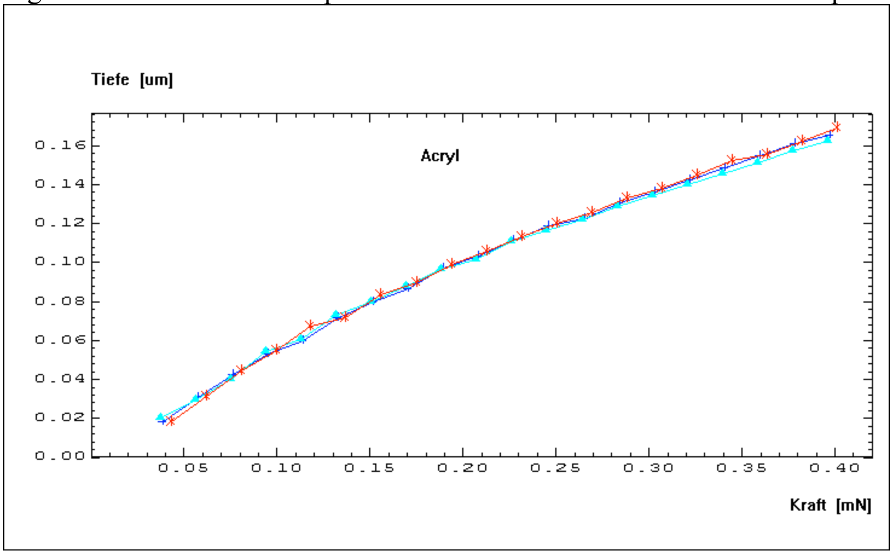
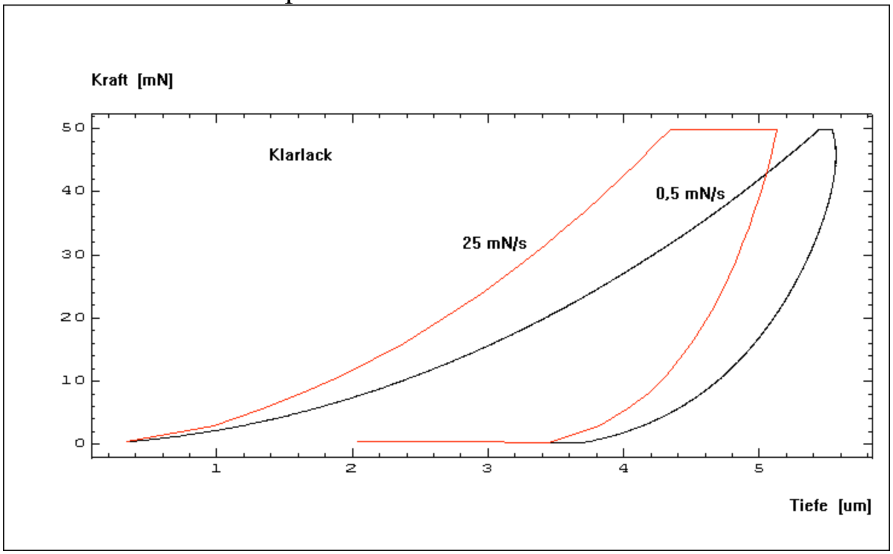


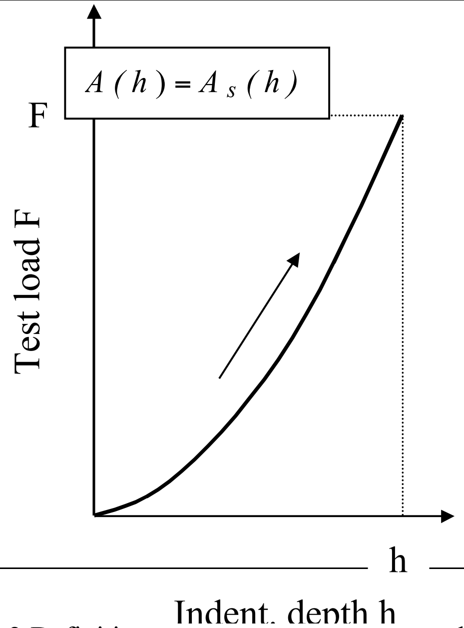
Fig. 7: Load/indentation depth curves of clear lacquer for various load application speeds – test instrument Fischerscope H100 C



Charts

Chart 1: Definition of the hardness under test load according to [2] and [5]

Hardness under test load / N/mm_ /



Universal hardness *HU* accdng to [5]

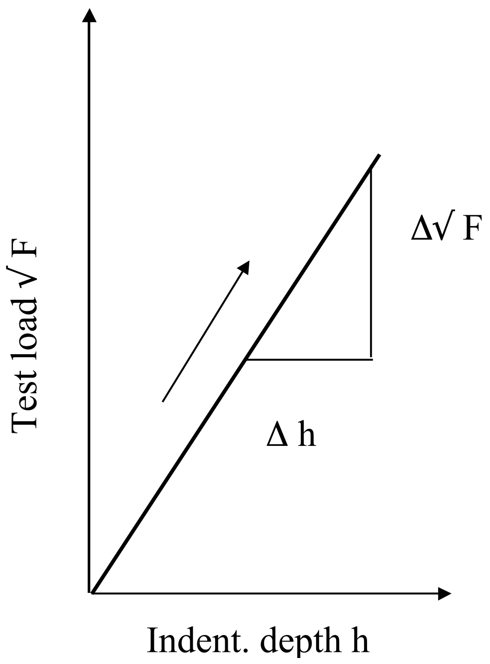
$$HU = \frac{Test\,load}{Indentation\,area} = \frac{F}{A(h)}$$

Martens hardness *HM* accdng to [2]

$$HM = \frac{Test\,load}{Indentation\,area} = \frac{F}{A_S(h)}$$

Chart 2:Definition of the hardness under test load determined from the rise of the F/h curve according to [2] and [5]

Hardness under test load determined from the rise of the F/h curve / N/mm_ /



Universal hardness HU_S accdng to [5]

$$HU_S = \frac{1}{m^2 A\ (h)/h^2}$$

Martens hardness HM_S accdng to [2]

$$HM_S = \frac{1}{m^2 A_S(h)/h^2}$$

with $A(h)/h^2$ or $A_S(h)/h^2$

= 26,43 for the Vickers indenter

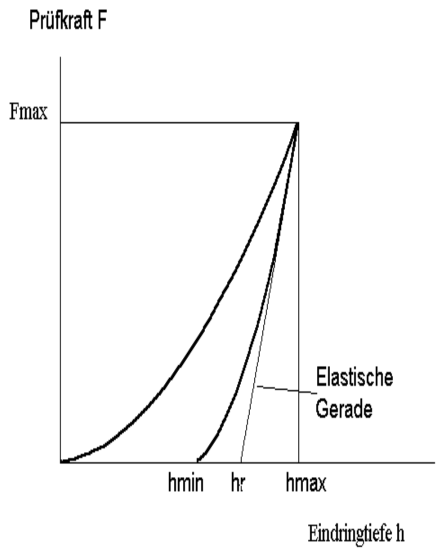
= 26,44 for the Berkovich indenter

A(h) = depth-dependent impression surface

$A_S(h)$ = depth-dependent impression surface

Chart 3: Definition of the hardness after unloading the test load according to [2] and [5]

Hardness after unloading the test load   / N/mm_ /



Plastic hardness *HU* plast accdng to [5]

$$HU_{\text{plast}} = \frac{F_{\max}}{A(h_r)}$$

$F_{\max}$ = max. effective test load
$A(h_r)$ = Indentation surface for the bounced back indentation depth h_r

Indentation hardness *H* IT   accdng to [2]

$$H_{\text{IT}} = \frac{F_{\max}}{A_p}$$

$F_{\max}$ = max. effective test load
A_p = projected contact area between the indenter and the sample, determined taking into account the actual indenter shape

Chart 4: Determination of the elastic indentation modulus from the load/indentation depth curve according to [2] and [5]

<table>
<tr><th colspan="2">Elastic indentation modulus / kN/mm_ /</th></tr>
<tr><td>

Elastic indent. modulus Y_{HU} accdng to [5]

$$Y_{HU} = \frac{1}{5{,}586 \cdot h_r \cdot \Delta h/\Delta F\,(h_{max}) - 7.813 \cdot 10^{-7}}$$

Where:

h_r is the intersection of the tangent f the load/indentation depth curve at max. load (area of unloading of the test load) with the indentation depth axis in mm (s. Chart 3)

$\Delta h/\Delta F\,(h_{max})$ reciprocal rise of the tangent at the load/indentation depth curve at max. load in mm/N (area of unloading of the test load)

</td><td>

Elastic indent. Modulus E_{IT} accdng to [2]

$$E_{IT} = \frac{1-(\nu_S)^2}{\frac{1}{E_r} - \frac{1-(\nu_i)^2}{E_i}}$$

$$E_r = \frac{\sqrt{\pi}}{2C\sqrt{A_p}}$$

Where:

C Flexibility of the contact

ν_s Poisson number of the sample

ν_i Poisson number of the indenter (for diamond 0,07)

E_i E-Modulus of the indenter (for diamond 1.14x 10^6 N/mm_)

E_r reduced modulus of the indenter contact

A_p projected contact area

</td></tr>
</table>

Table 1 : Instrumented indentation test – indenters and correlations
For calculating the impression area

Indenter	**Impression area A(h)**
Vickers Diamond pyramid with a square base area and with an angle of α = 136° between opposite surfaces	A (h) = 26,43 · h_ / mm_ /
Berkovich Diamond pyramid with a triangular base area	A (h) = 26,44 · h_ / mm_ /
Knoop Rhombic diamond pyramid Longitudinal edge angle 172° 30 ′ Cross edge angle 130°	A (h) = 72,33 · h_ / mm_ /
Hard metal sphere Diameter D 0.4 ; 1.0 ; 2.0 mm 2.5 ; 5.0 ; 10.0 mm	A (h) = π · D · h / mm_ /

Table 2 : Instrumented indentation test – hardness and other characteristic material parameters
- designations, symbols, units

Designation	Symbol	Unit	DIN EN ISO 14577	DIN 50359	DIN 55676
Universal hardness	HU	N/mm_		x	x
Universal hardness, determined from the rise of the load/indentation depth curve	HU_{S}	N/mm_		x	
Martens hardness	HM	N/mm_	x		
Martens hardness, determined from the rise of the load/indentation depth curve	HM_{S}	N/mm_	x		
Indentation hardness *Load is referenced to the <u>projected contact area</u> of the impression*	H_{IT}	N/mm_	x		
Plastic hardness *Load is referenced to the <u>impression surface</u>*	HU_{plast}	N/mm_		x	
Universal hardness after unloading *Load is referenced to the <u>impression surface</u>*	HU_{b}	N/mm_			x
Elastic indentation modulus	E_{IT}	N/mm_	x		
Elastic indentation modulus	Y_{HU}	N/mm_		x	
Derived modulus of elasticity	E_{HU}	N/mm_			x
Creep	C_{IT}	%	x		
Relaxation	R_{IT}	%	x		
Creep	C_{HU}	%		x	
Relaxation	R_{HU}	%		x	
Creep under effective test load	cr	%			x
Creep after unloading the test load	cr_{R}	%			x
Expended mechanical work	W_{total}	Nm	x	x	
Elastic recovery work	W_{elast}	Nm	x	x	
Elastic portion of the indentation work (W_{elast} / W_{total}) x 100	_ $_{IT}$	%	x		
Elastic portion of the indentation work (W_{elast} / W_{total}) x 100	_ $_{HU}$	%		x	
Plastic portion of the indentation work W_{plast} $W_{plast} = W_{total} - W_{elast}$ = 100 % - W_{elast} (_ $_{IT}$; _ $_{HU}$)	W_{plast}	%	x	x	
Elastic portion of the total deformation energy (100 x E_{e}) / E_{t}	W_{e}	%			x
Remaining portion of the total deformation energy 100 - W_{e}	W_{b}	%			x