The measuring of the hardness

In the field of mechanics one often meets with the notion of "hardness", and in fact the hardness is a fundamental characteristic to determine whether a certain material is suitable or not to perform certain functions and to have a certain performance.
Need only think all the materials subject to wear, that is, everything that moves within an automobile or any machinery, or thinking of cutting tools, where the hardness is certainly an index that indicates where and how it should be used a certain material.
Hardness is a numeric value that represents an index of "*resistance to permanent deformation*."
The hardness test can be done in different ways, but in any case is to determine the resistance of the materials in letting oneself be penetrated by another, apparently harder, which can be called "*penetrator*" or "*indenter*" that has different forms.
Based on these different forms of the indenter and the test method can distinguish the following hardness scales:

- *Brinell*
- *Vickers*
- *Knoop*
- *Rockwell*
- *Nano-hardness*

<u>*Brinell Hardness*</u>
The Brinell hardness, created by J. A. Brinell in 1900, was the first standardized hardness scale.
The indenter has a spherical shape of diameter D and now constructed normally in sintered carbide, it is pressed on the surface of the sample with a load P. Called d the diameter of the mark, the hardness is essentially defined as the ratio between the load and the surface of the mark, that is:

$$HB = \frac{2 \cdot P \cdot 0{,}102}{\pi \cdot D \cdot \left(D - \sqrt{D^2 - d^2}\right)}$$

The conversion factor of 0.102 is used to compare the values of HB based on the Technical System in which the load was expressed in kg with the SI system in which the load is expressed in N, (1N = 0.102 kg).
The comparison of different measures with different parameters is not always reliable, it is only possible if the ratio between the diameter of the mark and the ball diameter satisfies the following condition:

$$\frac{d}{D} = \cos\frac{\omega}{2} = 0{,}375 \quad \text{that is:} \quad \omega = 136°$$

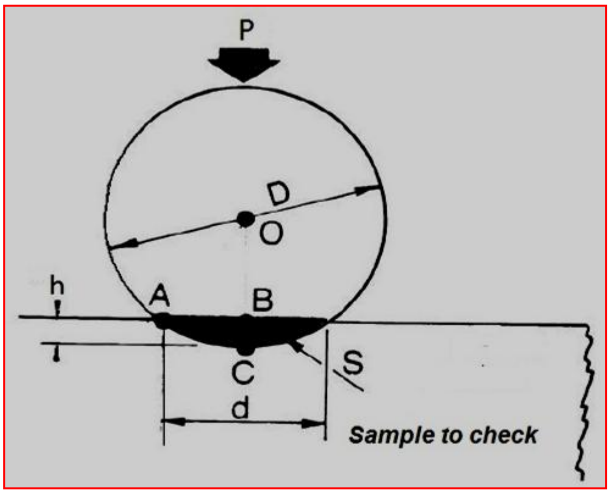


Figure N°1- *Control scheme of the Brinell hardness*

The test is valid if the following conditions are satisfied:

- *Distance from the edge of the mark a> 2.252 d*
- *Distance between the marks b> 4d*
- *Thickness of the sample to be tested S> 8D*
- $\frac{d}{D} = cos\frac{\omega}{2}$ *between from 0,24 to 0,6 ie* $(106° \leq \omega \leq 150°)$

The force applied can vary from 10 to 50,000 N and must specify it.

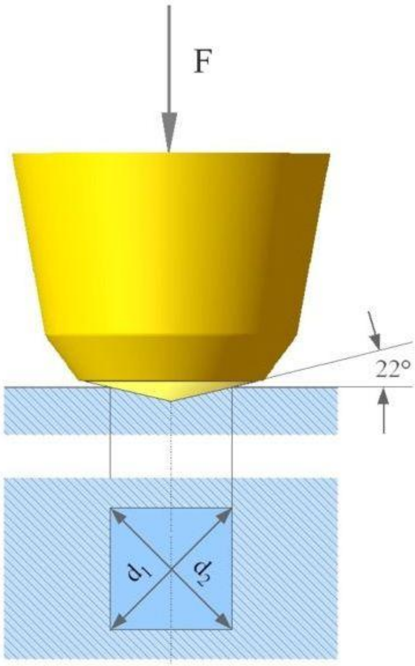
Vickers Hardness

Is calculated from the area of the mark made by the indenter that in this case has a pyramidal shape with a square base.
By microscope with graduated lenses is measured the diagonal $\mathbf{d_1}$ and $\mathbf{d_2}$ of the mark fron these values we can obtain the average:

$$t = \frac{d_1+d_2}{2}$$ and then:

$$HV = \frac{2 \cdot P \cdot 0,102 \cdot \sin\frac{\omega}{2}}{t^2}$$

Angle of the faces of the pyramid: ω = 136 °
The loads are smaller than the Brinell test and the conditions are less restrictive. In fact, the distance from the edge of the sample can be a> 2t and the distance between the marks b> 1.5 t.



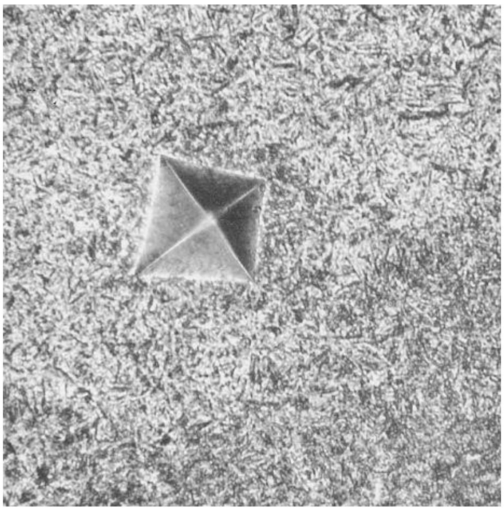


Figure N°2 - *Scheme of Vickers hardness testing and typical mark of the Vickers indenter*

Knoop Hardness

The Knoop hardness test is similar to the Vickers test. The difference is in the shape of the indenter that in this case is a pyramid with base rhomboid (not square) and the mark has a depth of about 60% of the mark Vickers, with the same force applied.
Whether in this test of hardness than in the previous the loads normally used are between 50 and 250 N.

Rockwell Hardness
It measures the depth of the mark made by an indenter that can have different forms depending on the scales used, as shown in the following table.

Type of test	Shape of indenter	Load	Hardness
D	Sferico	98 N	130 depth of the mark (μm)
C	Conico	98 N	100 depth of the mark (μm)
T	Sferico	29,4 N	130 depth of the mark (μm)
N	Conico	29,4 N	100 depth of the mark (μm)

This measure is widely used but is just conventional index.
For example, a tool in HSS, whose hardness is 63 HRC, the mark will have a depth of 0.63 mm. The equipment automatically measures this depth and gives on the display the hardness value.
The hardness of different scales (Brinell, Vickers, Knoop and Rockwell) cannot be compared, except in an approximate way, because they use different measurement units.

Nano-hardness
For control of the hardness of thin films, ie the thickness of a few micrometer, the above methods are not suitable, even at low loads.
This is known as measurement nano-hardness expressed in GPa (Giga Pascal)
This is based on the measurement of the mark made by an indenter pyramid-shaped in diamond (the type used for measuring Vickers), which penetrates the film for a few nm.
In particular it refers to the analysis of the curve of the loading / unloading in which the value of the applied load is plotted according to the corresponding area of the mark.
After reaching a predetermined maximum load (or a maximum depth) the load is reduced and the depth of penetration decreases because the material recovers elasticity.
It's just from the inclination of the unload that the elastic properties are determined. The hardness is derived from the residual depth of the unload.
The nano-hardness, as has been said, is measured in GPa and is derived from the following formula:

$$H_{IT} = \frac{F}{A(h_c)}$$

Where A (hc) is the area of the permanent mark , that is what remains after the release of the load F.

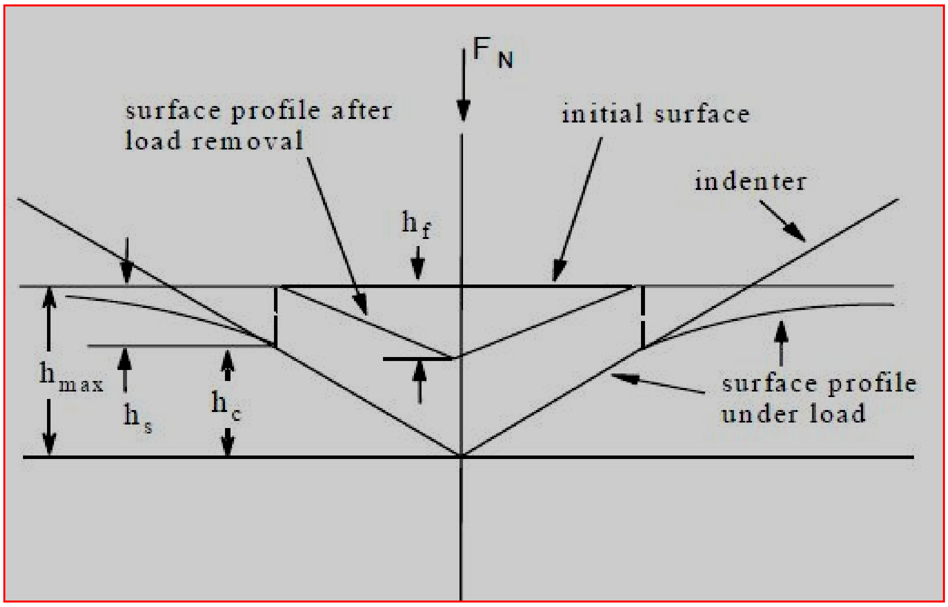


Figure N°3 – *Scheme of control of nano-hardness*

F_N is the normal component of the applied force; h_{max} the maximum depth reached by indenter during the measurement, h_f is the permanent depth of the mark after each measurement; h_c is the height to which the material follows the shape of indenter, in practice is excluded the deformation of the edges of the mark ; $h_s = h_{max} - h_c$,

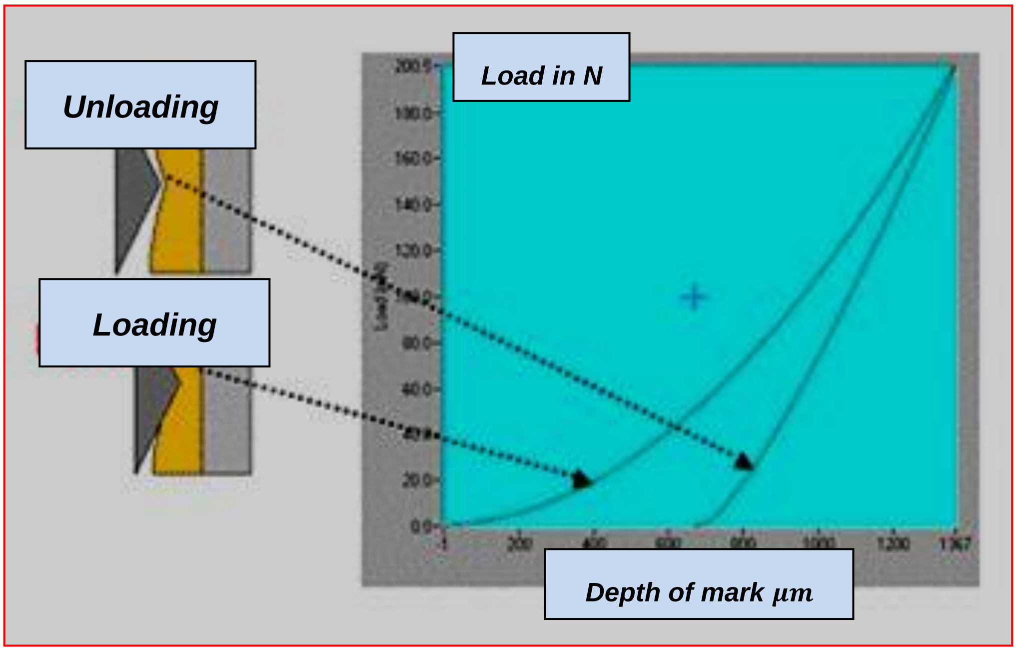


Figure N°4- *Loading and unloading curves of depth of the mark*

As you can see the permanent depth in the above case, is about 600 nanometers (0.6 micrometers).
As an example, the following table shows the values of nano-hardness of some materials.
But let's see what it is, intuitively, a Giga Pascal.
Literally it means one billion of Pascal.
The Pascal is a unit of measure of the pressure, namely a Newton per square meter.
Pa = N/m^2 .
It's a very little pressure, just to realize, it's the pressure that would carry a hectogram of sugar spread uniformly over a square meter.
If we transform the N to the kg (weight force) and the m^2 mm^2 we have:

$$GPa = 10^9 N = 10^9 \cdot \frac{1}{10} \cdot \frac{1}{10^6} \frac{Kg}{mm^2} = 100 \frac{Kg}{mm^2}$$

So 1 Newton (N) corresponds to 100 Kg/mm^2 .

Material	*Nano-hardness GPa*
Stainless steel	*3*
DLC in various combinations	*9 - 30*
Natural Diamond	*60 - 80*
DLC pure	*60 - 130*
TiN (titanium nitride)	*24*
TiCN (titanium carbonitride)	*31*
TiAlN (Titanium aluminum nitride)	*35 - 40*
TiAlCN (Titanium aluminum nitride)	*28*

<u>Mohs scale</u>

Even the Mohs scale is a method to estimate the hardness of various materials. Essentially consists of a ranking of hardness of materials in which one who is able to scratch a material with a lower index, but not the a material with index higher.

The following table compares the Mohs scale of hardness with Knoop hardness.

Mineral	Mohs scale	Knoop hardness	Mineral	Mohs scale	Knoop hardness
Talc	1	1	Orthoclase	6	560
Gypsum	2	32	Quartz	7	800 - 900
Calcite	3	135	Topaz	8	1300 - 1400
Fluorite	4	163	Corundum	9	2000
Apatite	5	430	Diamond	10	8000 - 8500