بسم الله الرحمن الرحيم

Benha University
Shoubra Faculty of Engineering

Mechanical Department
1st year Mech.

31.03.2019 – Week 8

Hardness test

Prof. Farida Sayed Ahmed
Dr. Mahmoud Khedr

Outline

- Introduction.
- Advantages of Indentation Hardness.
- Hardness testing machine.
- Brinell Hardness.
- Vickers Hardness.
- Rockwell Hardness.
- Comparison.

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Introduction

Prof. Farida Sayed Ahmed
Dr. Mahmoud Khedr

Introduction

What is Hardness?

Hardness is defined as "*Resistance of metal to plastic deformation, usually by indentation, or resistance to scratching, abrasion, or cutting*".

Principle of any hardness test method is "forcing an indenter into the sample surface followed by measuring dimensions of the indentation i.e. depth or actual surface area of the indentation".

It is the property to the metal surface. The greater the hardness of the metal is, the greater its surface resistance has to deformation.

In ***mineralogy*** the property of matter commonly described as the resistance of a substance to being *scratched* by another substance. In metallurgy hardness is defined as the ability of a material to resist plastic deformation.

Introduction

Indentation Hardness

Indentation hardness as the resistance of a material surface to indentation. This is the usual type of hardness test, in which a pointed or rounded ***indenter*** is pressed into a surface under a substantially ***static load***.

There are three types of tests used with accuracy by the metals industry;

*The **Brinell** hardness test,*
*The **Vickers** hardness test, and*
*The **Rockwell** hardness test.*

It can generally be assumed that a ***strong metal*** is also a ***hard metal***.

The way the three of these hardness tests measure a metal's hardness is to determine the metal's resistance to the ***penetration*** of a non-deformable ***ball or cone***. The tests determine the ***depth*** which such a ball or cone will sink into the metal, under a given load, within a specific period of time.

Advantages of Indentation Hardness

1. Most standard specifications dictates that indentation hardness may be used as acceptance test to accept or reject metal products.

2. Indentation hardness method is one of the primary and important test methods to determine and to compare metal hardness.

3. It is a primary method in quality control for metal products quality assurance.

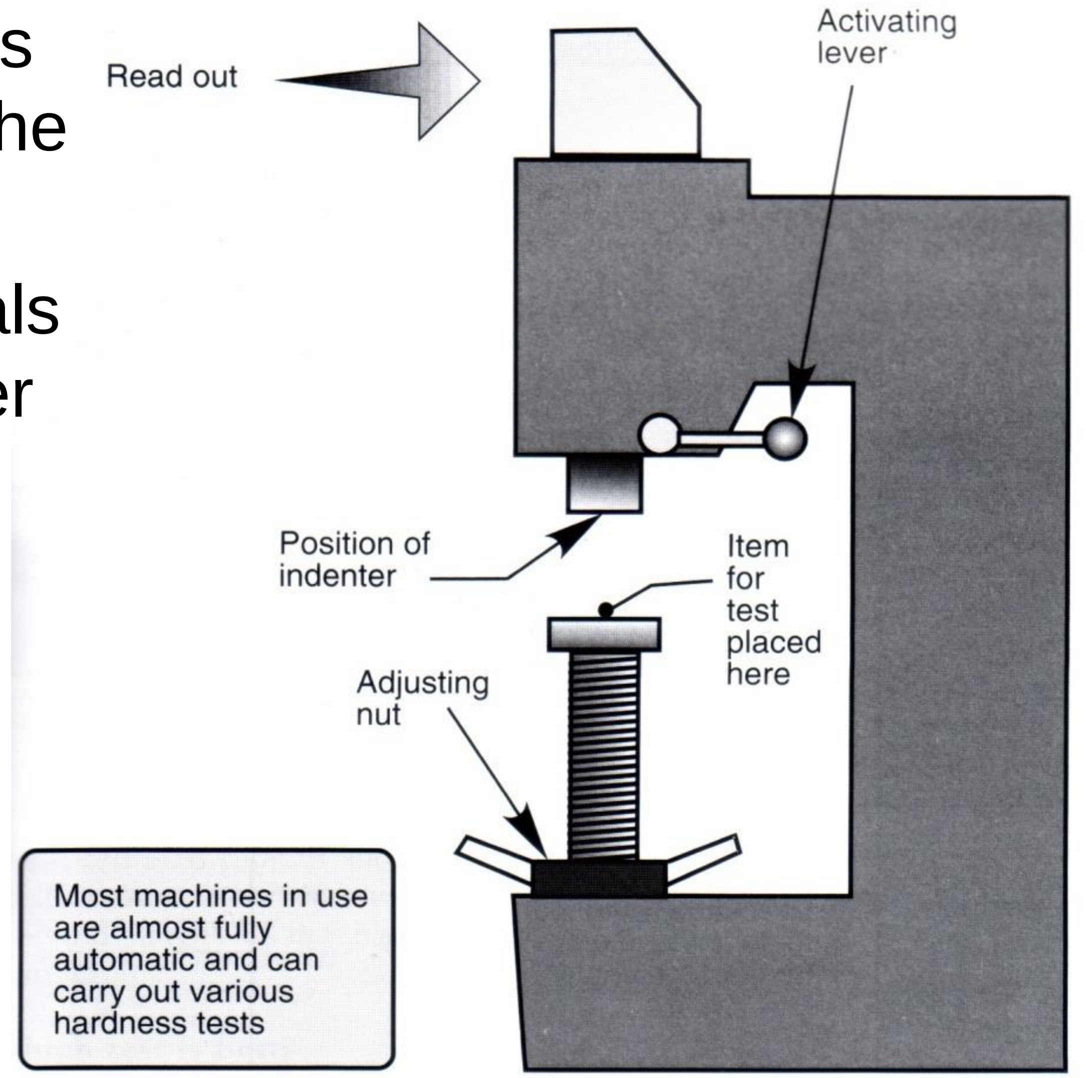
4. Indentation hardness method is an easy to perform method accompanied with high accuracy and low cost.

5. Indentation hardness method is a non destructive testing method NDT.

6. Easy, Inexpensive , Quick, Non-destructive , May be applied to the samples of various dimensions and shapes, May be performed in-situ

Hardness testing machine

- The indenter is pressed into the metal
- Softer materials leave a deeper indentation



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Brinell Hardness

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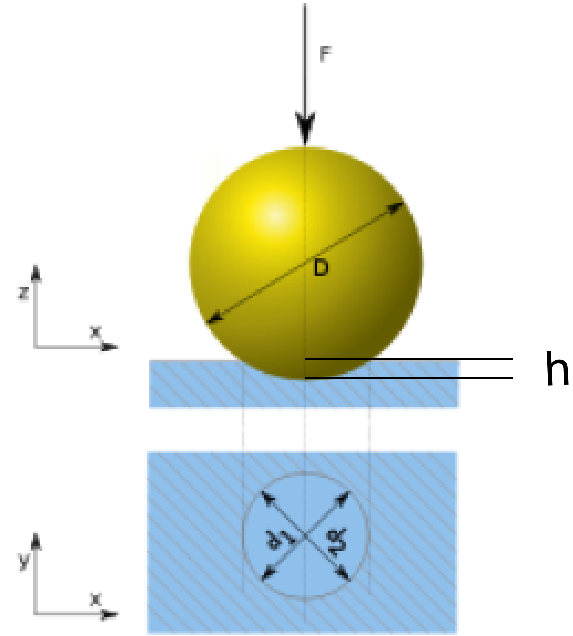
Brinell Hardness

A hardened steel ball of 1, 2.5, 5 or 10 mm in diameter <u>*hardened steel*</u> or <u>*tungsten carbide*</u> is used as indenter.

The loading force is in the range of :

- 30 kg for testing lead alloys,
- 500 kg for testing aluminum alloys,
- 1000 kg for copper alloys, and
- 3000 kg for testing steels



The indentation is measured and the Brinell Hardness Number (HB) is calculated by the formula:

BHN = F/ (π * D* h)

$$\mathrm{BHN} = \frac{2P}{\pi D\left(D - \sqrt{(D^2 - d^2)}\right)}$$

where:

P = applied force (kg),

h = depth of indentation (mm),

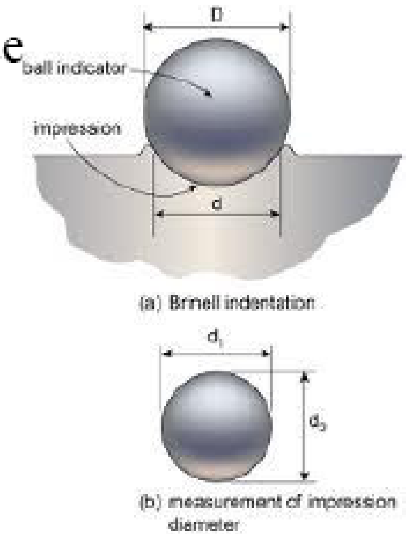
D = diameter of indenter (mm), and

d = diameter of indentation (mm).

Brinell Hardness

Precautions for Brinell Hardness tests:

1. The indentation diameter should be measured in two perpendicular directions.
2. The large size of indentation and possible damage to test-piece limits its usefulness.
3. Plastic deformations are not allowed around the indentation.
4. The ratio between d/D = (1/4 – ½) $\underline{=}$ 3/8 where D is the diameter of indenter (mm) and d is the diameter of indentation (mm).
5. Brinell hardness test may not be performed on thin plates where t < 10 h where: t is the plate thicness and h is the indentation depth.
6. Test piece may be leveled, smooth, free of loose particles, debris, oil or grease.
7. Test piece may not suffer any bulging or indentation on the opposite side.
8. Min edge distance is *2.5 d*



Brinell Hardness

Brinell Hardness Testing Machines

Brinell Hardness Manual C-Clamp tester

Optics Digital Brinell hardness tester

Portable Brinell hardness tester

Automatic Brinell Hardness Tester

Brinell Hardness

Relation between Loading and Indenter diameter:

The indenter diameter should be picked up carefully not to make any permanent deformation to the ball or flatten.

If BHN is greater than 500 the steel ball is deformed, if BHN is over 733, then steel ball will flatten.

The relation between P/D^2 is given as:

$P/D^2 = 30$ for steel

$P/D^2 = 10$ for brass and aluminum alloys

$P/D^2 = 5$ for cupper and aluminum, and

$P/D^2 = 1$ for lead, tin and wood.

Brinell Hardness

Brielnell Hardness Number:

When quoting a Brinell hardness number (BHN), the conditions of the test used to obtain the number must be specified.

The standard format for specifying tests can be seen in the example:

"HBW 10/3000". "HBW" means that a tungsten carbide (from the chemical symbol for tungsten) ball indenter was used.

"HBS 10/3000", which means a hardened steel ball.

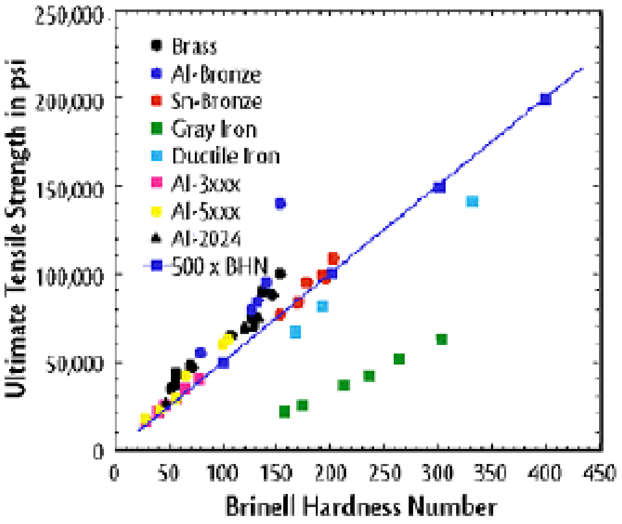
The "10" is the ball diameter in millimeters. The "3000" is the force in kilograms force.

Brinell Hardness

BHN & UTS

There is no definite relationship between BHN and UTS for the metal. BHN can NOT be used instead of "static tensile test".
Yet, for ferrous metals, there is an approximate "imperical" relation beteen BHN and UTS .
This relation is useful in determining an approximate value for the insitu UTS if the portable Brinell Hardness tester is used.

UTS = 36% BHN.



Brinell Hardness

The Brinell Hardness Test

Brinell hardness testing: Surface preparation

This image shows sample preparation for Brinell hardness testing experiment. Using a small hand grinder with a 600 mesh abrasive disc a flat area in the centre of the raised boss is lightly polished. A great care has to be taken by using light pressure to ensure that the surface is not deformed or overheated. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell hardness testing: Calibration block

This image shows how to do calibration during Brinell hardness testing. The check that the machine is giving accurate results is done by making a hardness test on a standard block. The hardness value measured is compared against the certified hardness of the standard block. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell Hardness

The Brinell Hardness Test

Brinell hardness test: Ready for the test

This image shows the casting located on the support anvil, ready to commence the Brinell hardnes test. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell hardness test: Load limits

This image shows how to apply load during Brinell hardness testing. By winding the hand wheel we raise the test piece up until the indenter just touches the casting surface. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell Hardness

The Brinell Hardness Test

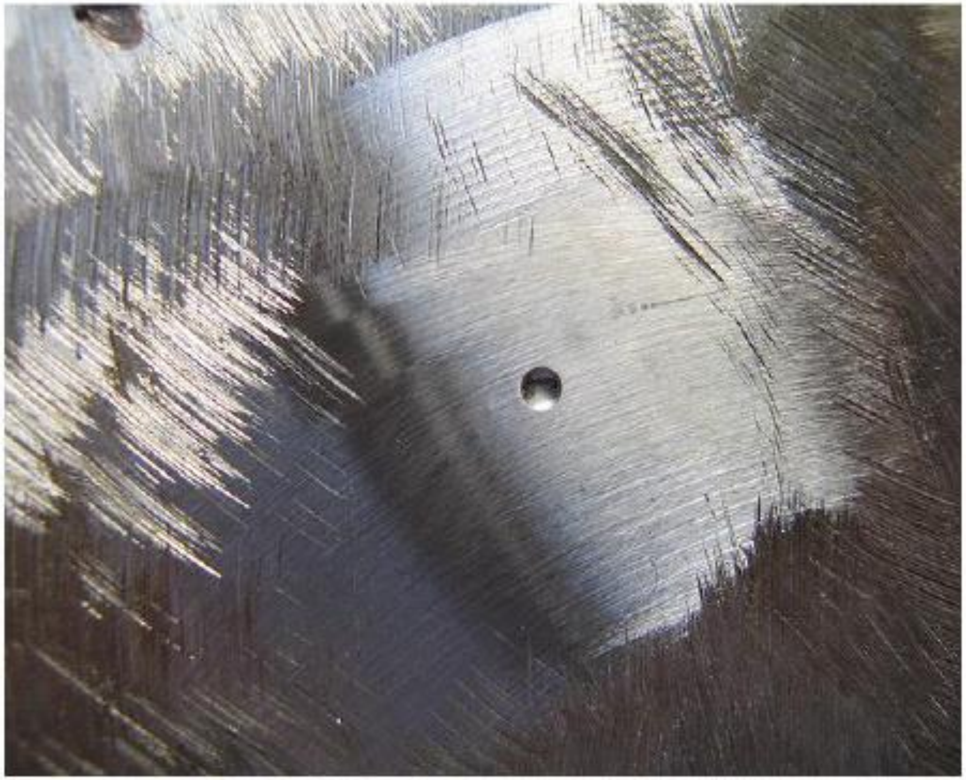
Brinell hardness test: Set position

This image shows a set position for Brinell hardness testing. As the indenter touches the metal surface the display window of the machine indicates that the start position is "SET". Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell hardness test: Applying load

This image shows how to apply load during Brinell hardness testing by depressing the actuating lever. The display screen indicates when the load application is complete. A standard test is of 15 seconds duration. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell Hardness



Brinell hardness test: Ball impression

This image shows the impression on the prepared area of the casting in Brinell hardness testing. You can see that it is circular and the edges are sharply defined. Courtesy of Roger White and Derrick Hurley, Bradford College.

Brinell hardness test: Reading ball impression

This image shows how to read ball impression during Brinell hardness testing. A hand held microscope is used to measure the diameter of the impression in two directions at right angles. Courtesy of Roger White and Derrick Hurley, Bradford College

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Vickers Hardness

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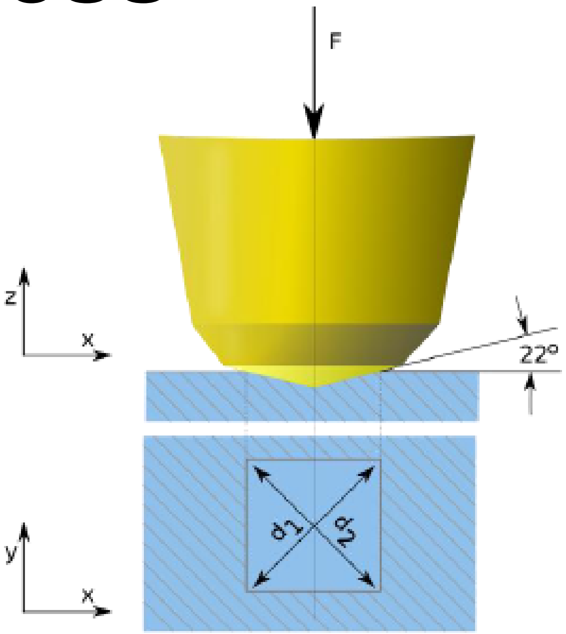
Vickers Hardness



The **Vickers hardness test** was developed as an alternative to the Brinell method to measure the hardness of materials.

The Vickers test is often easier to use than other hardness tests as the indenter can be used for all materials irrespective of hardness.

The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the **Vickers Pyramid Number** (**HV**) or **Diamond Pyramid Hardness** (**DPH**).

The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force.

Vickers Hardness

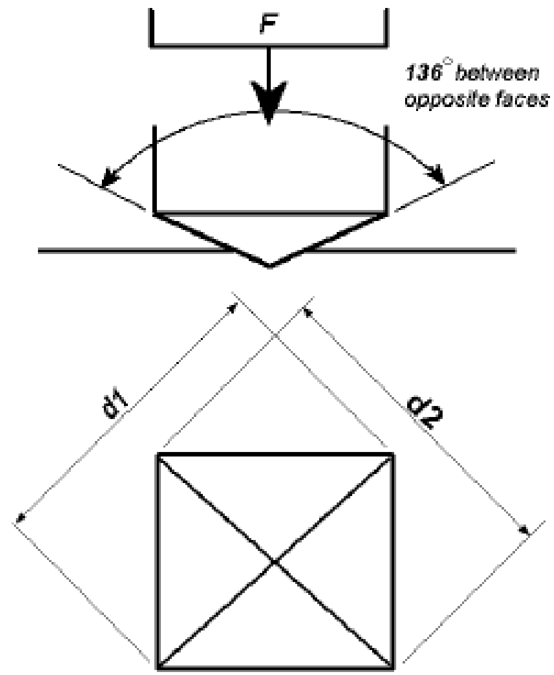
Advantages of VHT: Irrespective of specimen size;

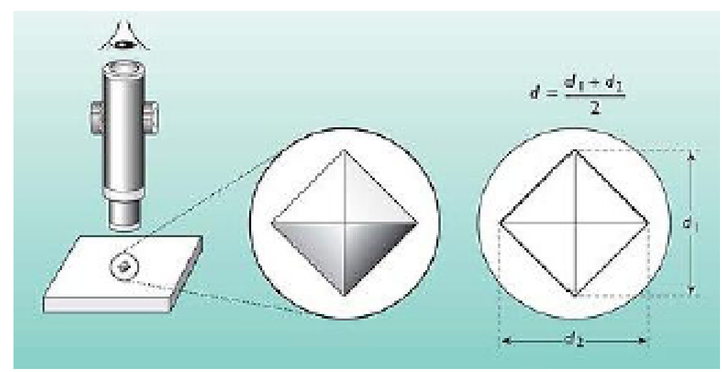
- The indenter shape is capable of producing geometrically similar impressions.
- The impression have well-defined points of measurement;
- The indenter have high resistance to self-deformation.

A diamond in the form of a square-based pyramid is used.

*It had been established that the ideal size of a **Brinell** impression was 3/8 of the ball diameter. As two tangents to the circle at the ends of a chord 3d/8 long intersect at 136°, it was decided to use this as the included angle of the indenter.*

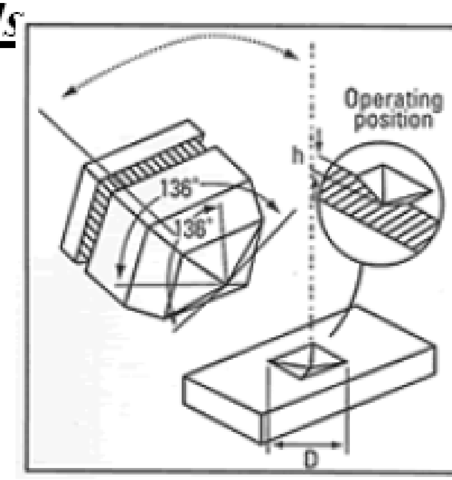
The hardness value obtained on a homogeneous piece of material remained constant, irrespective of load.





Vickers Hardness

1. The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for ***<u>10 to 15 seconds</u>***
2. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated.
3. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.



4. Accordingly, loads of various magnitudes are applied to a flat surface, depending on the hardness of the material to be measured. The HV number is then determined by the ratio *F/A* where

F is the force applied to the diamond in kilograms-force and
A is the surface area of the resulting indentation in mm^2.
The area A can be determined by the formula

$$A = \frac{d^2}{2\sin(136°/2)}$$

Vickers Hardness

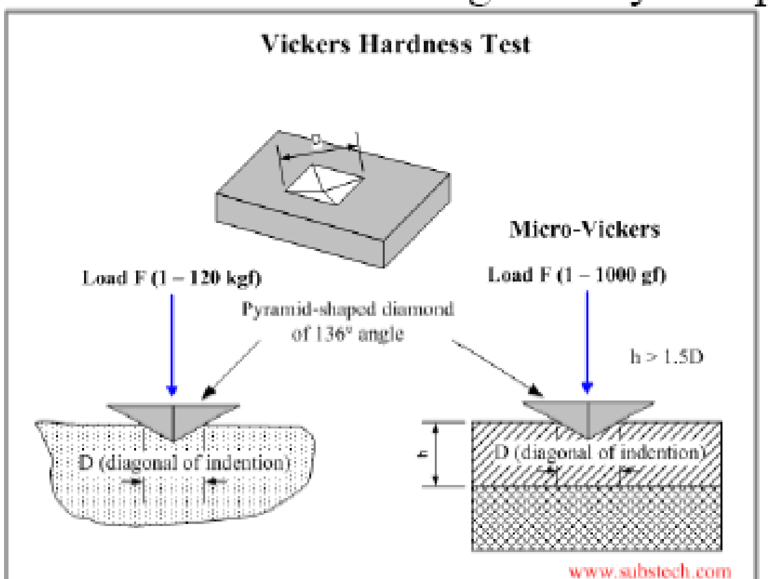
$$HV = \frac{F}{A} \approx \frac{1.8544F}{d^2}$$

HV = Vickers hardness

F= Load in kgf

d= Arithmetic mean of the two diagonals, d_1 and d_2 (mm)

Vickers hardness numbers are reported as **xxxHVyy**, e.g. **440HV30**, or **xxxHVyy/zz** if duration of force differs from 10 s to 15 s, e.g. 440Hv30/20, where: **440** is the hardness number, **HV** gives the hardness scale (Vickers), **30** indicates the load used in kg, **20** indicates the loading time if it differs from 10 s to 15 s. Vickers values are generally independent of the test force.



Examples of HV values for various materials

Material	Value
316L stainless steel	140HV30
347L stainless steel	180HV30
Carbon steel	55–120HV5
Iron	30–80HV5

Vickers Hardness

The Vickers hardness test

Vickers diamond indentor: the end

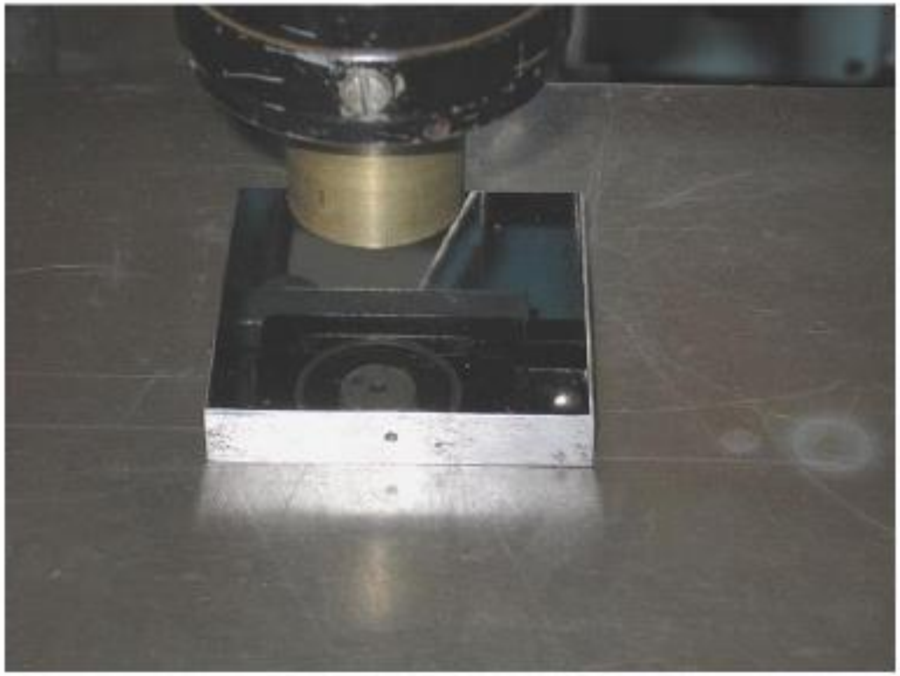
This image shows the end on view of the Vickers diamond indenter. The condition of the diamond indenter is extremely important to ensure that the test result is accurate. Courtesy of Roger White and Derrick Hurley, Bradford College.

Vickers diamond indentor: the mount

This image shows the mount of a Vickers diamond indenter. The condition of the diamond indenter is extremely important to ensure that the test result is accurate. Courtesy of Roger White and Derrick Hurley, Bradford College.

Vickers Hardness

The calibration



Vickers hardness test: Calibration block

This image shows the beginning of the calibration of the measuring device during Vickers hardness test. In order to check that the measuring device is calibrated an impression on a standard test block is made. It then checked that the measured result lies within the acceptance range of the block. Courtesy of Roger White and Derrick Hurley, Bradford College.

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Rockwell Hardness

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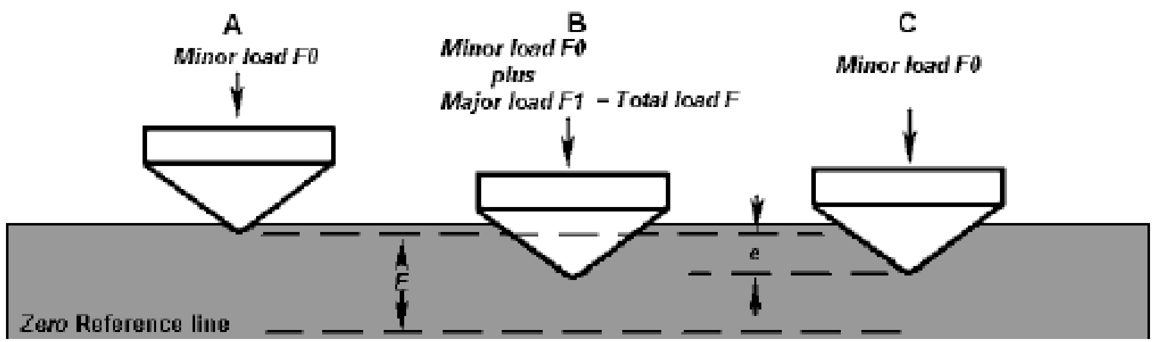
Rockwell Hardness

- Gives direct reading.
- Rockwell B (ball) used for soft materials.
- Rockwell C (cone) uses diamond cone for hard materials.
- Flexible, quick and easy to use.

Two most common indenters are
Ball – B and
Cone – C

Rockwell Hardness

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter.
The indenter is forced into the test material under a preliminary minor load *F0* (Fig. 1A) usually 10 kg.
When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter is set to a datum position.
While the preliminary minor load is still applied an additional major load (50 or 90 or 150 kg) is applied with resulting increase in penetration (Fig. 1B).
When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained.
Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Fig. 1C).
The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number: HR = $E - e$



Rockwell Hardness

Rockwell hardness tester

Rockwell hardness tester
Close up

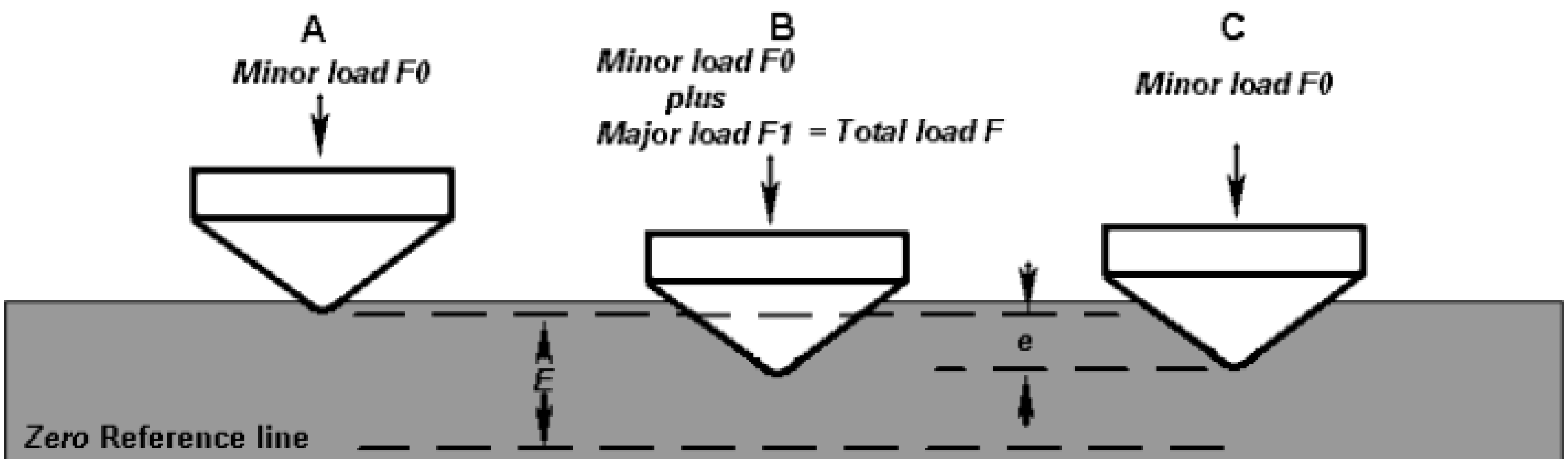
Digital
Rockwell hardness tester

Rockwell Hardness

F0 = preliminary minor load in kgf
F1 = additional major load in kgf
F = total load in kgf
e = permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm
E = a constant depending on form of indenter:

100 units for diamond indenter, ***HRC = 100 – e / 0.002***
130 units for steel ball indenter ***HRB = 130 – e / 0.002***

HR = Rockwell hardness number, that is inversely proportional to the distance e i.e. as e increases HR decreases.



Rockwell Hardness

Rockwell Hardness Scales

Scale	Indenter	Minor Load *F0* kgf	Major Load *F1* kgf	Total Load *F* kgf	Value of *E*
A	Diamond cone	10	50	60	100
B	**1/16" steel ball**	**10**	**90**	**100**	**130**
C	**Diamond cone**	**10**	**140**	**150**	**100**

HRA Cemented carbides, thin steel and shallow case hardened steel.

HRB Copper alloys, soft steels, aluminum alloys, malleable irons, etc.

HRC Steel, hard cast irons, case hardened steel and other materials harder than 100 HRB.

Advantages of the Rockwell hardness method:

The direct Rockwell hardness number readout and rapid testing time.

The small amount or load required.

It gives the metal hardness and not only the surface hardness.

May be used for thin sheets.

Comparison

Hardness-testing Methods and Formulas

Test	Indenter	Shape of indentation: Side view	Shape of indentation: Top view	Load, P	Hardness number
Brinell	10-mm steel or tungsten carbide ball	D, d	d	500 kg 1500 kg 3000 kg	$HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$
Vickers	Diamond pyramid	136°	L	1–120 kg	$HV = \frac{1.854P}{L^2}$
Knoop	Diamond pyramid	$L/b = 7.11$ $b/t = 4.00$ t	b, L	25 g–5 kg	$HK = \frac{14.2P}{L^2}$
Rockwell					
A C D	Diamond cone	120° t = mm		60 kg 150 kg 100 kg	HRA HRC HRD } $= 100 - 500t$
B F G	$\frac{1}{16}$- in. diameter steel ball	t = mm		100 kg 60 kg 150 kg	HRB HRF HRG } $= 130 - 500t$
E	$\frac{1}{8}$- in. diameter steel ball			100 kg	HRE

Minimum distance from edge