Laboratory 9

Hardness Testing

Contents

1. Objectives:

Students are required to: understand the principles of hardness testing and its importance in engineering, learn how to use Rockwell hardness tester.

2. Introduction:

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. It is not an intrinsic material property. It is a characteristic deriving from the composition, the thermal and mechanical history of the material, and essentially from the structure (or more properly the microstructure) of the specimen involved. The present guide highlights the measurement procedure of this property.

The device used in this laboratory session is a Rockwell (Brinell) hardness tester with test forces ranging from 2.5kgf to 187.5kgf (depending on model), closed loop, load cell, force feedback technology for a reliable fast measurement procedure. Adding to this, this device features:

- Superior test control
- Superior accuracy
- Automatic testing procedure
- Superior gauge repeatability & reproducibility
- Superior productivity
- Superior flexibility

The Rockwell (Brinell) hardness testers combine a practical design with universal specifications. It assures fast test results at the highest possible accuracy.

3. Equipment description:

The Figure below shows the individual parts of the main tester body

1. Front panel
2. 6.5 " LCD touch panel
3. Adjustable clamping attachment
4. Large round work piece stage
5. Spindle protection cover
6. Elevator spindle screw
7. Tester house
8. Emergency switch
9. USB connection
10. Adjustable vibration damper

Fig.1 Main Rockwell (Brinell) hardness tester body

4. Safety Instructions

ATTENTION	ATTENTION Do not turn the elevator spindle hardly Do not change the machine configuration, the machine is already configured.

5. Formula Symbols and Units Used

Symbol	Mathematical/physicalquantity	Unit
HRX	Rockwell Hardness	
P	applied load	kgf
D	diameter of the steel ball	mm
d	diameter of the indentation	mm
t	depth of impression	mm
BHN	Brinell hardness	$kgf.mm^{-2}$

6. Basic principles

Hardness is one of the most basic mechanical properties of engineering materials. Hardness test is practical and provide a quick assessment and the result can be used as a good indicator for material selections. This is for example, the selection of materials suitable for metal-forming dies or cutting tools. Hardness test is also employed for quality assurance in parts which require high wear resistance such as gears.

The nomenclature of hardness comes in various terms depending on the techniques used for hardness testing and also depends on the hardness levels of various types of materials. A scratch hardness test is generally used for minerals, giving a wide range of hardness values in a Moh's scale at minimum and maximum values of 1 and 10 respectively. For example, talcum provides the lowest value of 1 while diamond gives the highest of 10. The basic principle is that the harder material will leave a scratch on a softer material. Hardness values of metals generally fall in a range of 4-8 in Moh's scale, which is not practical to differentiate hardness properties for engineering applications.

Therefore, indentation hardness measurement is conveniently used for metallic materials. A deeper or wider indentation indicates a less resistance to plastic deformation of the material being tested, resulting in a lower hardness value.

The indentation techniques involve Brinell, Rockwell, Vickers and Knoop. Different types of indenters are applied for each type. The standard test methods according to the American Society Testing and Materials (ASTM) available are, for instance, ASTM E10-07a (Standard test method for Brinell hardness of metallic materials), ASTM E18-08 (Standard test method for Rockwell hardness of metallic materials) and ASTM E92-41 (Standard test method for Vickers hardness of metallic materials). These hardness testing techniques are selected in relation to specimen dimensions, type of materials and the required hardness information.

a. Brinell Hardness Test

Brinell hardness test was invented by J.A. Brinell in 1900 using a steel ball indenter with a 10 mm diameter. The steel ball is pressed on a metal surface to provide an impression as demonstrated in figure 2. This impression should not be distorted and must not be too deep since this might cause too much of plastic deformation, leading to errors of the hardness values.

Different levels of material hardness result in impression of various diameters and depths. Therefore different loads are used for hardness testing of different materials as listed in table 1. Hard metals such as steels require a 3,000 kgf load while brass and aluminium involve the loads of 2,000 and 1,000 or 500 kgf respectively. For materials with very high hardness, a tungsten carbide ball is utilized to avoid the distortion of the ball.

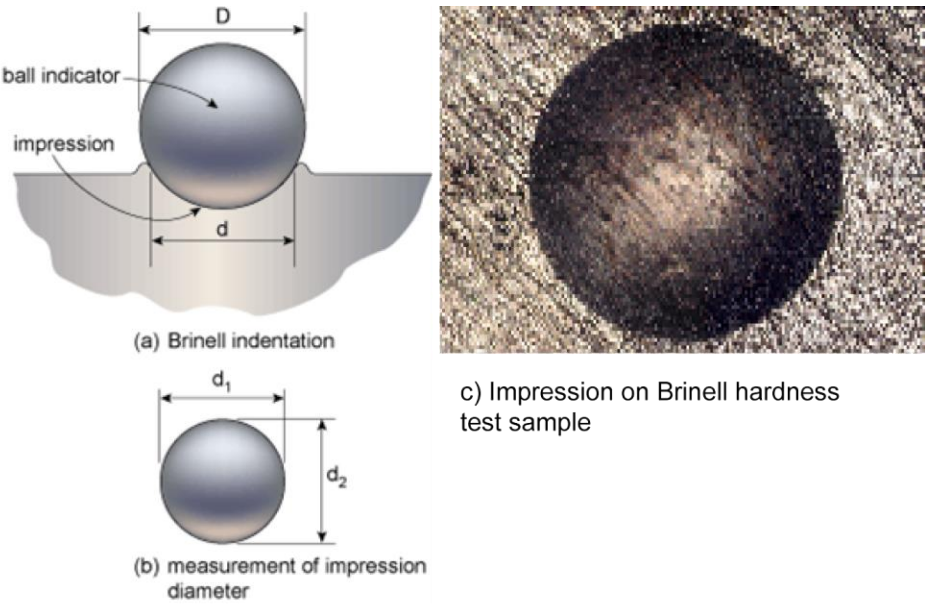


Fig 2 (a) Brinell indentation (b) measurement of impression diameter and c)Impression on Brinell hardness test sample.

In practice, pressing of the steel ball on the metal surface is carried out for 30 seconds, followed by measuring two values of impression diameters normal to each other using a low magnification macro-scope. An average value is used for the calculation according to equation (1)

$$\mathbf{BHN}=\frac{P}{\left(\frac{\pi D}{2}\right)\left(D-\sqrt{D^2-d^2}\right)}=\frac{P}{\pi D t} \qquad \mathbf{(1)}$$

Where:

P : The applied load, kg

D : The diameter of the steel ball, mm

d : The diameter of the indentation, mm

t : The depth of impression, mm

Note: This BHN values has a unit of $kgf.mm^{-2}$ $(1kgf.mm^{-2} = 9.8\,MPa)$ which cannot be compared to the average mean pressure on the impression.

Generally, the metal surface should be flat without oxide scales or debris because these will significantly affect the hardness values obtained. A good sampling size due to a large steel ball diameter is advantageous for materials with highly different microstructures or microstructural heterogeneity. Scratches or surface roughness have very small effects on the hardness values measured. However, there are some disadvantages of Brinell hardness test. These are errors arising from the operator themselves (from diameter measurement) and the limitation in measuring of too small samples.

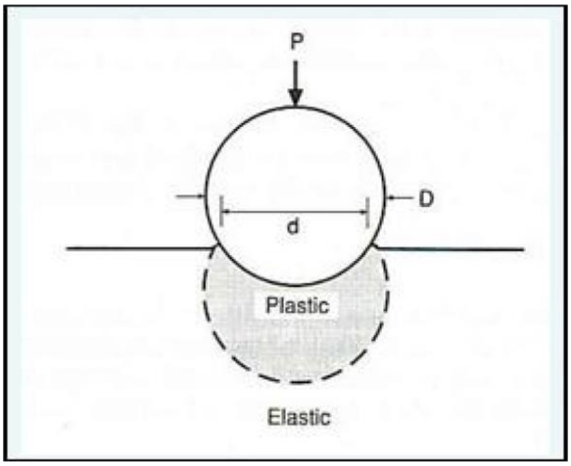


Fig 3 Plastic deformation surrounded by elastic material underneath a Brinell indenter

If we considered the plastic zone beneath the Brinell indenter, this plastic region is surrounded by elastic material which obstructs the plastic flow. This condition is said to be plane strain compressive where plastic deformation is limited. If the metal is very rigid, the metal flow upwards surrounding the indenter is possible as illustrated in figure 6.2.a). However this situation is rarely seen because the metal displaced by the indenter is accounted for by the reduced volume of elastic material.

b. Rockwell Hardness Test

Rockwell hardness test is commonly used among industrial practices because the Rockwell testing machine offers a quick and practical operation and can also minimize errors arising from the operator. The depth of an indentation determines the hardness values. There are two types of indenters, Brale and steel ball indenters. The former is a round-tip cone with an included angle of 120^o whereas the latter is a hardened steel ball with their sizes ranging from 1.6-12.7 mm. Therefore different combinations of indenters and loads selected are suitable for hardness testing of various materials. This is for example; the R scale is employed for soft materials such as polymers while the A scale is suitable for hardness testing of hard materials such as tool materials according to table 1.

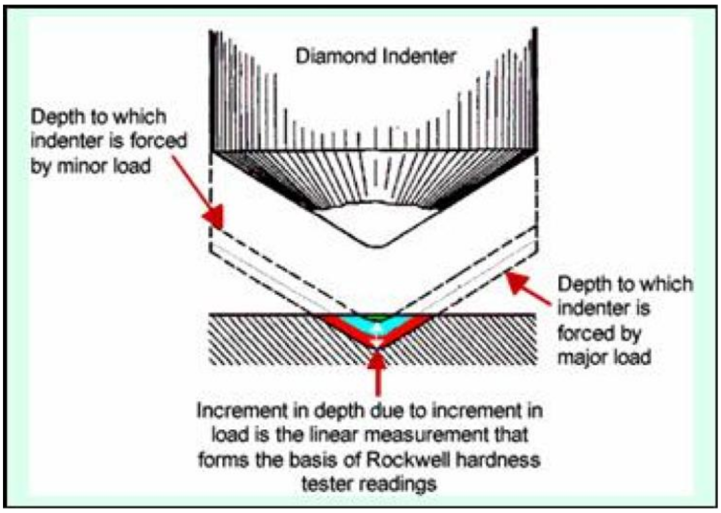


Figure 4: Rockwell hardness measurement showing positions to apply the minor and major loads.

The testing procedure starts with indenting a flatly ground metal surface with a diamond or hardened steel ball with a minor load of 10 kgf to position the metal surface as shown in figure 4. The depth of the impression caused by the minor load will be recorded as H_1 onto the machine before applying a major load level according to a standard and is recorded as H_2. The difference of the depths ($\Delta H = H_1 - H_2$) when applying the minor and the major loads indicates the hardness value of the material. If the depth difference is small, the deformation resistance of the metal is high, resulting in a high Rockwell hardness value. The hardness value will be displayed on a dial or a screen, having 100 divisions and each division represents a depth of 0.002 mm. Therefore the hardness value can be determined from a relationship as follows.

$$\mathbf{HRX= M-}\frac{\Delta H}{0.002}$$

Table 1 Rockwell hardness scale for various materials

Scale symbol and prefix letter	Indenter	Total load (kg)	Dial Numerals	Typical applications of scales
A	Diamond cone	60	Black	Cemented carbides, thin steel, shallow depth case-hardened steel.
B	1.588 mm dia. steel ball	100	Red	Copper alloys, soft steels, aluminium alloys, malleable iron.
C	Diamond cone	150	Black	Steel, hard cast iron, pearlitic malleable iron, high depth case-hardened steel.
D	Diamond cone	100	Black	Thin steel, medium depth case-hardened steel.
E	3.175 mm dia. steel ball	100	Red	Cast iron, aluminium and magnesium alloys, bearing metals.
F	1.588 mm dia. steel ball	60	Red	Annealed copper alloys, thin soft sheet metals.
G	1.588 mm dia. steel ball	150	Red	Phosphor bronze, beryllium copper, malleable iron.
H	3.175 mm dia. steel ball	60	Red	Aluminium, lead, zinc.
K	3.175 mm dia. steel ball	150	Red	Soft bearing metals.

Where M is the maximum scale which equals 100 in general for testing with the diamond indenter (scale A, C and D). The M value equals 130 when testing with a steel ball for Rockwell scales B, E, M, and R.

There are several considerations for Rockwell hardness test

- ✓ Require clean and well positioned indenter and anvil

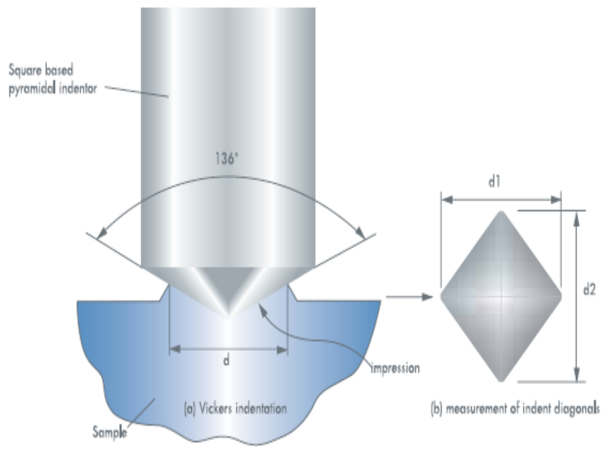
- ✓ The test sample should be clean, dry, smooth and oxide-free surface
- ✓ The surface should be flat and perpendicular to the indenter
- ✓ Low reading of hardness value might be expected in cylindrical surfaces
- ✓ Specimen thickness should be 10 times higher than the depth of the indenter
- ✓ The spacing between the indentations should be 3 to 5 times of the indentation diameter
- ✓ Loading speed should be standardized.

c. Vickers hardness test:

Vickers Hardness is a very popular test, which is characterized by a square based diamond pyramid indenter, exactly ground to a standard form with 136 degrees between opposite faces and used to leave a mark in metal under a precisely applied force. It was developed in 1924 by Smith and Sandland at Vickers Ltd as an alternative to the Brinell method to measure the hardness of materials.

The basic principle, as with all common measures of hardness, is to observe the questioned material’s ability to resist plastic deformation from a standard source.

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, and is therefore not a pressure.

The hardness number is not really a true property of the material and is an empirical value that should be seen in conjunction with the experimental methods and hardness scale used.

When doing the hardness tests the distance between indentations must be more than 2.5 indentation diameters apart to avoid interaction between the work-hardened regions.

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 square millimeters.

A can be determined by the formula:

$$A = \frac{d^2}{2\sin(136^\circ/2)}, \quad \text{Thus:} \quad HV = \frac{F}{A} \approx \frac{1.8544F}{d^2}$$

Examples of HV values for various materials:

Material	Value
316L stainless steel	140HV30
347L stainless steel	180HV30
Carbon steel 55	120HV5

Vickers hardness numbers are reported as **xxxHVyy**, For example:

440Hv30/20, where:

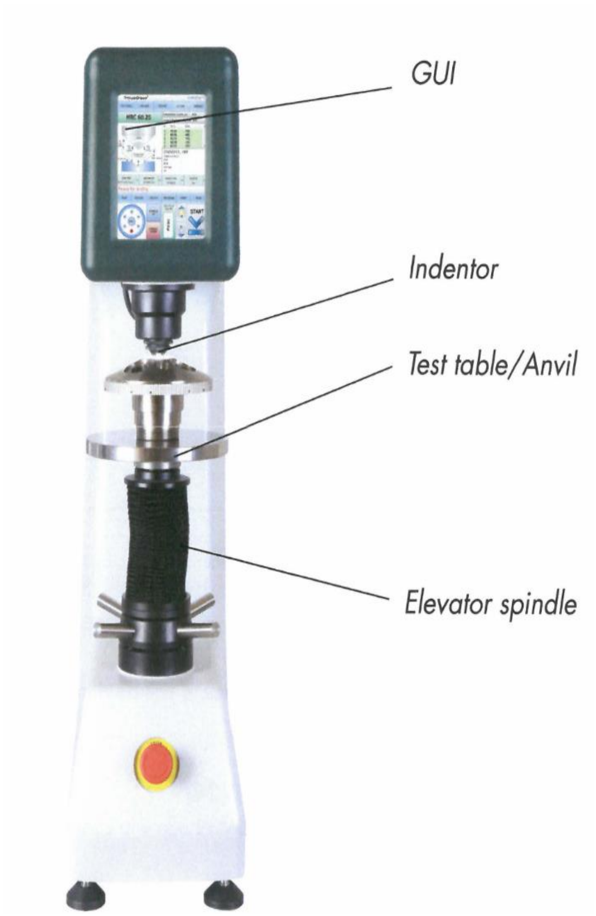
440 is the hardness number,

HV gives the hardness scale (Vickers),

30 indicates the load used in kg.

20 indicates the loading time if it differs from 10s to 15s

7. Experimental Procedure



Performing a Rockwell test

1. Setup the tester for the required Rockwell scale (scale selection).

2. Make sure the correct indentor is installed.

3. Put a work piece on the test table or anvil.

4. Turn the elevator spindle in this direction ⟵ until the work piece moves slowly upwards.

5. Keep turning upward (without interruption) until work piece gently touches the indenter.

6. On the tester's GUI (graphical user interface) the animated workpiece move slowly upward, keep turning upward (without interruption) until the animated indenter shows START (**in green**), then release the elevator screw (stop turning upward). If the indenter is in red, it means that the speed of turning is very high or very low.

7. The tester will now first apply the pre-load, following your selected setting automatically apply the main load.

8. After the pre-load has been applied, the tester will automatically apply the main load

9. The message in the GUI will change accordingly.

10. The LIVE animation leads you through the entire force application process.

11. After the main load has been applied the tester will pause according to the selected dwell time. When the dwell time has passed, the tester will unload the main force automatically and return to the start position.

11. The hardness value measured will be displayed on the GUI.

12. Remove the workpiece from the indenter by turning elevator spindle courter clockwise and move the workpiece into a new position to repeat the test.

NOTICE

If too much manual force is applied while performing a test, the user interface will give a clear warning, Remove pre-load, move the workpiece and restart the procedure.

8. Questions

Do the experiment as described in paragraph 7 for two materials with five points of measurements for each one and compare the obtained values

9. Results

	Test 1	Test 2	Test 3	Test 4	Test 5	Average
Material A						
Material B						