Mechanical Testing

1. Hardness Testing

Hardness has already been defined as the resistance of a material to indentation or abrasion by another hard body (good hardness generally means that the material is resistant to scratching and wear) . A **hard indenter** is pressed into the specimen by a standard load, and the magnitude of the **indentation** (either area or depth) is taken as a measure of hardness.

Hardness tests are commonly used for calculating material properties because they are **quick** and convenient **(suitable)**. However, a variety of testing methods is appropriate (suitable) due to differences in hardness among different materials. The most well-known hardness tests are Brinell, and Rockwell.

1.1 The Brinell Hardness Test

In this test, hardness is measured by pressing a hard steel, tungsten and cemented carbide ball (usually 10 mm in diameter) into the surface of the test piece, using a known load. It is important to choose the combination of **load** and **ball size** carefully so that the indentation is free from distortion and suitable for measurement. The relationship of the Brinell hardness [**H$_B$**] which is between load **P** (kg), the diameter **D** (mm) of the hardened ball indenter and the diameter **d** (mm) of the indentation on the surface is given by the expression:

$$H_B = \frac{Load\ (Kg)}{Area\ of\ curved\ surface\ of\ indentation}$$

$$H_B = \frac{P(Kg)}{\frac{1}{2}\Pi \times D[D - \sqrt{D^2 - d^2}](mm^2)}$$
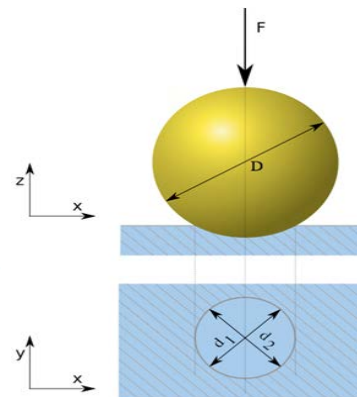
For different materials, the ratio (**P/D^2**) has been standardized in order to obtain accurate and comparative results such as :

$$K = P / D^2$$

Where **K** is. a constant; typical values of **K** are:

Ferrous metals	$K = 30$
Copper and copper alloys	$K = 10$
Aluminum and aluminum alloys	$K = 5$
Lead, tin and white-bearing metals	$K = 1$

Figure 1 shows how the Brinell hardness value is determined. The diameter of the indentation is measured in two directions at right angles and the average taken. The diameter is measured either by using a **microscope scale**, or by a **projection screen** with micrometer adjustment.
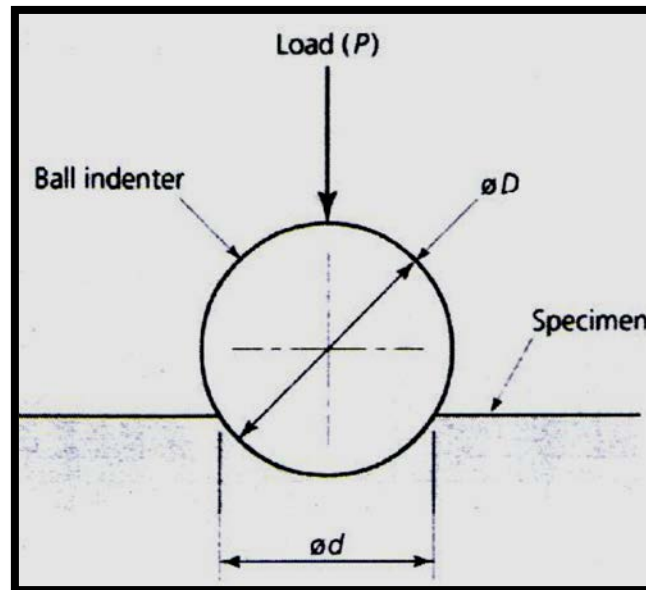
Figure 1. Principle of the Brinell hardness test.

To ensure consistent (dependable) results, the following precautions should be observed.

1. The **thickness** of the **specimen** should be at least **seven times** the **depth of the indentation** to allow unrestricted plastic flow below the indenter.

2. The **edge of the indentation** should be at least **three times** the **diameter of the indentation** from the edge of the test piece.

3. The test is **unsuitable** for materials whose hardness exceeds **500 H_B**, as the ball indenter tends to flatten.

There are a definite relationship between strength and hardness so it is possible to measure the tensile strength from the hardness test.

Advantages and dis-advantages of Brinell hardness test

1. Large indentation averages (covers) out local heterogeneities of microstructure.

2. Different loads are used to cover a wide range of hardness of commercial metals.

3. Brinell hardness test is less influenced by surface scratches and roughness than other hardness tests.

4. The test has limitations on small specimens or in critically stressed parts where indentation could be a possible site of failure.

1.2 The Vickers Hardness Test

This test is preferable to the Brinell test where hard materials are concerned, as it uses a diamond indenter. **Diamond** is the hardest material known - approximately **6000 H_B**. The diamond indenter is in the form of a square-based pyramid with an angle of **136°** between opposite faces.

Since only one type of indenter is used, the load has to be varied for different hardness ranges. Standard loads are (**5, 10, 20. 30, 50** and **100**) **kg**. It is necessary to state the load when specifying a Vickers hardness number. For example, if the hardness number is found to be **200** when using a **50 kg** load, then the hardness number is written as **H_V (50) = 200**.

Figure 2 shows the measuring screen for determining the distance across the corners of the indentation. The screen can be rotated so that two readings at right angles can be taken and the average is used to determine the hardness number (H_V). This is calculated by dividing the load by the projected area of the indentation:

$$H_v = \frac{Load\ (Kg)}{Surface\ area\ of\ indentation\ (mm^2)}$$

$$H_v = \frac{P(Kg)}{[d^2/2\sin\frac{1}{2}(136°)](mm^2)}$$

$$= \frac{2P\sin 68°}{d^2} = 1.854\frac{P}{d^2}$$

where **P** is the load in Kg and **d** (mm) is the diagonal of the impression made by the indenter made by the diamond.
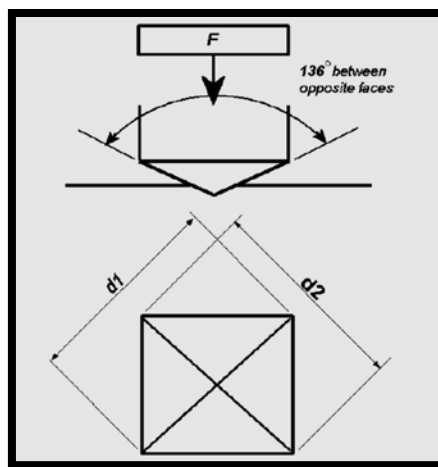

Figure 2. The Vickers hardness test method

1.3 The Rockwell Hardness Test

The Rockwell hardness test uses a small-diameter steel ball for soft materials and a diamond cone, or Brale, for harder materials. The depth of penetration of the indentor is automatically measured by the testing machine and converted to a Rockwell hardness number, hardness Rockwell (H_R). Since an optical measurement of the indention dimensions is not needed, the Rockwell test tends to be more popular (common) than the Brinell test. Therefore it is widely used in industry as it is:
1. Quick and simple.
2. Direct reading.
3. Freedom from personal error (require no special skills).
4. Ability to distinguish small hardness difference.
5. Small size of indentation, and
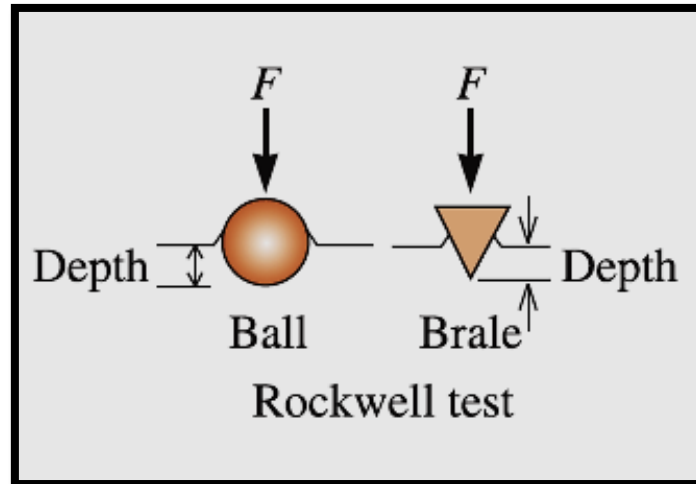**6.** They are so simple to perform.

Figure 3. The Rockwell hardness test.

In principle, the Rockwell hardness test compares the difference in depth of penetration of the indenter when using forces of two different values. That is, a minor force is first applied (to take up the backlash and pierce (penetrate) the surface of the component) and the scale are set to read zero. Then a major force is applied over and above the minor force and the increased depth of penetration is shown on the scales of the machine as a direct reading of hardness without the need for calculation or conversion tables.
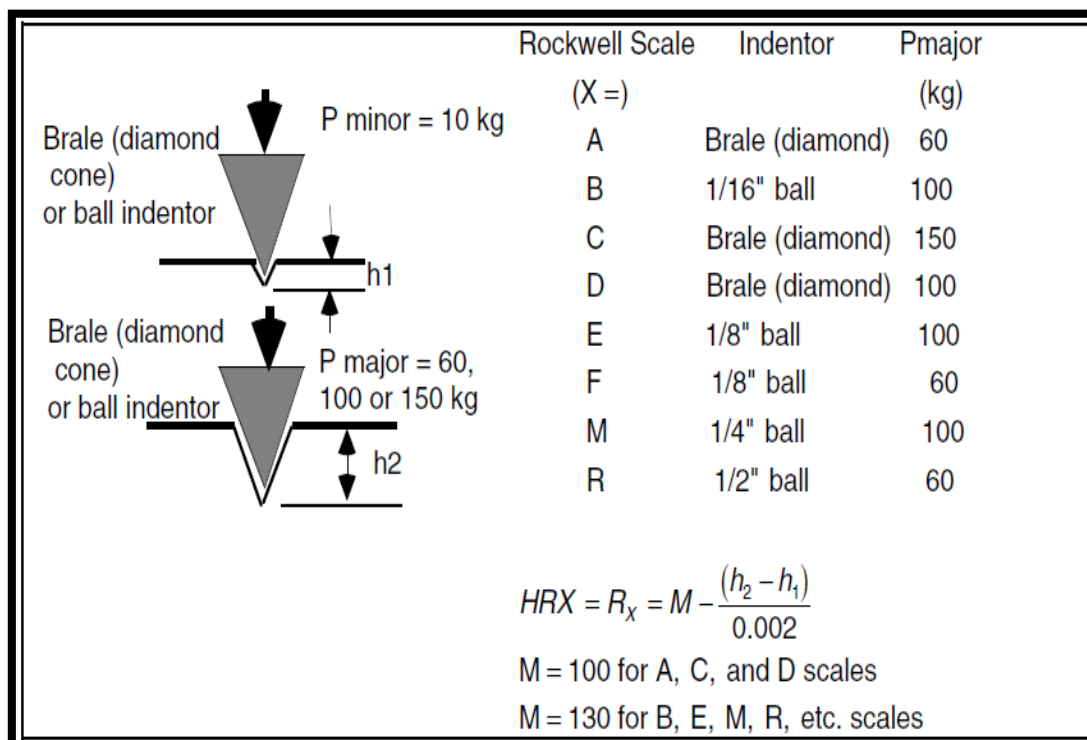

Rockwell Scale (X =)	Indentor	Pmajor (kg)
A	Brale (diamond)	60
B	1/16" ball	100
C	Brale (diamond)	150
D	Brale (diamond)	100
E	1/8" ball	100
F	1/8" ball	60
M	1/4" ball	100
R	1/2" ball	60

$$HRX = R_X = M - \frac{(h_2 - h_1)}{0.002}$$

M = 100 for A, C, and D scales

M = 130 for B, E, M, R, etc. scales

Figure 4. Rockwell Principle.