Experiment 3

Hardness Testing

Aim: To determine Rockwell hardness number and Brinell hardness number of different materials (metals and alloys).

Apparatus Required:

1. Rockwell hardness tests
2. Brinell hardness tests
3. Travelling microscope

Theory: *Hardness* is one of the most important mechanical properties. It can be defined in various ways. From our common sense, we know that one can scratch on wood with the help of a pointed steel pin but to put a scratch on a steel plate with the help of a wooden pin is not possible. The property which is mainly responsible for this is hardness. We can easily understand that steel being harder, it can scratch on wood. This type of hardness is often known as scratch hardness or resistance to scratching.

Now let us consider another practical situation. In any mechanical workshop, we come across cutting tools. The fundamental property which a cutting tool must possess is its hardness. Without hardness, a cutting tool cannot cut other jobs or materials. If the material to be cut is also very hard, it becomes very difficult for the cutting tool. So, hardness can be defined as resistance to cutting.

Naturally the question arises whether we will measure resistance to scratching or resistance to cutting while doing *Rockwell* or *Brinell* tests. We will not do any of those two, rather we would follow a third method of measuring hardness. What is that? This is resistance to indentation or resistance to localised plastic deformation. How can we achieve that? Just think about a block of mud and imagine what will happen if you try to penetrate it with a small force using your finger. If the force is small, there will be a small impression after you remove your finger. Now if the block is made of wood, can you put a similar impression with a similar force? Certainly not, because this block has higher hardness than the previous one. So, what is hardness? Hardness is the mechanical property by virtue of which a material can resist indentation or localised plastic deformation, scratching or cutting.

The hardness tests can be divided into two major groups: (a) macrohardness tests and (b) microhardness tests. Generally, *Rockwell*, *Brinell* and *Vicker's* tests are *macrohardness tests*, while *Micro-Vicker's* tests and *Knoop* tests are *microhardness tests*. For macrohardness tests, the load of indentation is larger (often more than 1 kg) while for microhardness tests, the load of indentation is in the order of grams or even lower. In recent times, nanohardness testers are also being used.

1. **Rockwell Hardness Test:** This is a simple hardness testing method. It is widely used method where hardness is determined through an *indentation* produced under static load. The indenter which is generally used consists of a *hardened steel ball* with 1/16 inch diameter or a diamond cone called

brale indentor. Depending on the material to be tested (if prior information about it is available), the suitable indenter can be selected for those materials which are supposed to be hard; diamond brate is used as the indenter. For soft metals and alloys, hardened steel ball is used. The basic principle of operation involves the following steps:

(a) The sample to be tested should have good polish. It should be flat, parallel and placed on the anvil.

(b) The anvil to be moved upward and brought in contact with the indenter such that a 'minor' load of 10 kg develops between the sample and the penetrator.

(c) The indicator of the dial of the tester (refer Figure 1) is to be set to 0 – the null point.

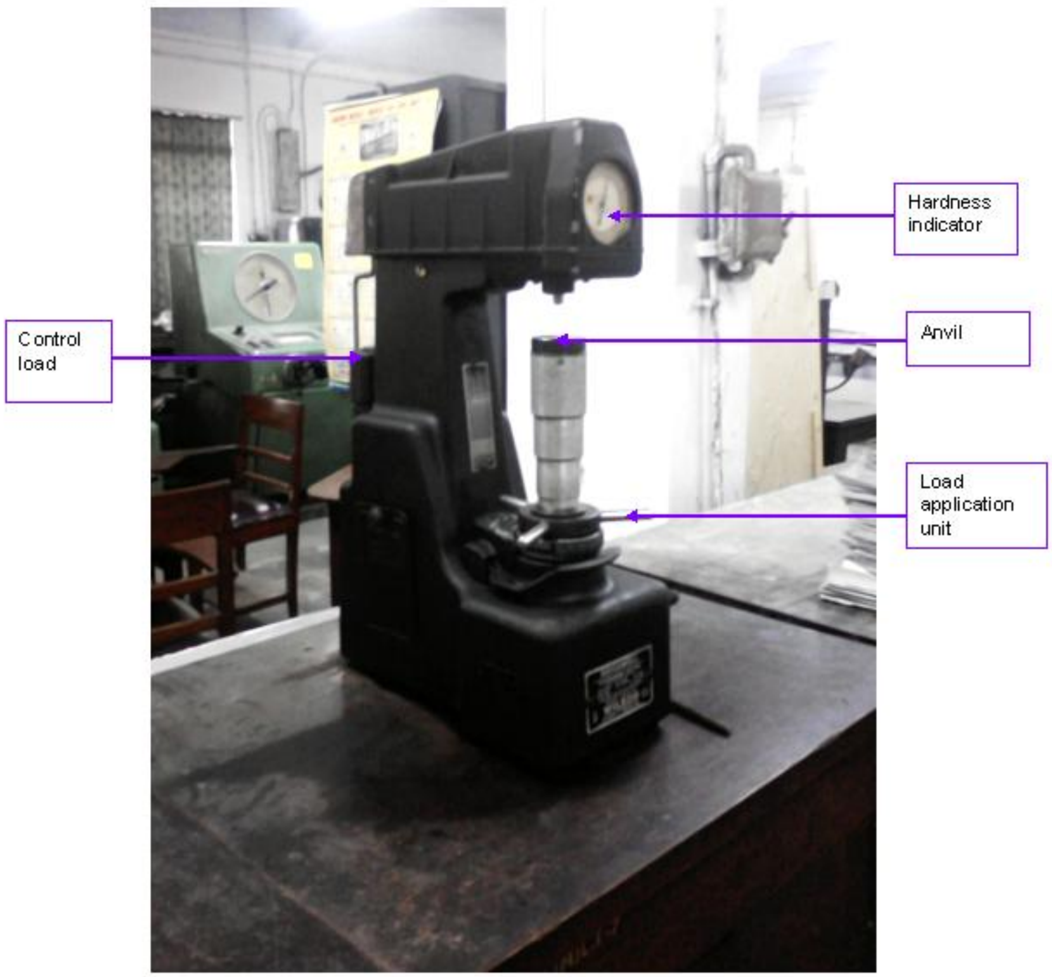

Figure 1 Rockwell hardness tester.
(*Photo Courtesy*: Applied Mechanics Laboratory, Mechanical Engineering Department, Jadavpur University, Kolkata)

(d) A major load of 100 kg (in case of hardened steel ball indenter) or 150 kg (for diamond brate) is then applied to the indenter to produce permanent deformation or impression.

(e) After the pointer comes to rest, the major load is removed.

(f) With the minor load still applied, the dial indicates the Rockwell hardness number in proper scale (B or C). In fact depending on materials, different other scales are also possible.

Any particular scale involves a typical set of major and minor loads and a typical indenter. A partial list of available Rockwell harness scales is provided in Table 1. The Rockwell hardness number is an indication of the depth of plastic or permanent penetration produced on the surface by the applied major load.

Precautions:

(a) The specimens should be flat and parallel.

(b) The surface should be free from undulations, scratches or cracks.

(c) The standard Rockwell test should be done only with sufficiently thick (5 to 10 times the diameter of the indenter) specimens.

(d) The impressions should not be made towards the edges of the sample to avoid stress concentration.

(e) While quoting the hardness of any material, the temperature during the test should be mentioned because with the rise in temperature, hardness decreases.

(f) Before each test run, machine is to be calibrated with standard piece.

(g) In Rockwell hardness test, it is possible to determine the depth of penetration. By using simple empirical relationship, the depth of penetration can be found out and it is higher for softer materials.

(h) The general practice of denoting Rockwell hardness number is to use a typical notation like 'RC 65' for one grade of martensitic steel where 'R' stands for Rockwell, 'C' stands for C-scale (that involves diamond brate as indenter, 150 kg as the major load) and 60 is the value in that scale. For one particular scale, higher the value, higher is the hardness.

Table 1 Major loads and hardness for different Rockwell scales

Scale	***Major Load (kg)***	***Indenter Type***
A	60	Brale
B	100	1/16 inch hardened steel ball

C	50	Brale
D	100	Brale
F	60	1/16 inch hardened steel ball
G	150	1/16 inch hardened steel ball

2. **Superficial Rockwell Hardness Test:** This is a special type of Rockwell Hardness Test. This is used for those material specimens which are less than 1/16 inch thick or not homogeneous, such as gray cast iron. In this type of test, the basic principle is same but as the size of indentation is very small, slight variation in surface contour roughness, composition, etc., can affect the results. So there must be special care for the sample preparation. Here the major and minor loads are very small and the penetration depth measuring device is very sensitive.

   This process is used for thin metallic sheets and for those materials that have been subjected to surface treatments such as *carburising*, *nitriding*, *cyaniding*, etc.

3. **Brinell Hardness Test:** In Rockwell hardness test, the parameter that is measured accurately is the depth of penetration, whereas in *Brinell hardness test*, the parameter to be measured is surface area of indentation. This test is one of the age old methodology. The indenter used in this method is a hardened steel ball 10 mm in diameter (Figure 2). It is pressed against a polished surface of the specimen. The standard loads used for the penetration are 500 kg, 1500 kg, 3000 kg. After this load is removed, the impression is observed under microscope and measured with the help of a grid. The *Brinell hardness number* (*BHN*) is equal to the load divided by spherical surface area of the indentation expressed in kg/mm^2. BHN can also be obtained in a chart where diameter of impression is shown against BHN for a particular load. It is given by

$$\begin{aligned}\text{BHN} &= \frac{\text{Load in kilogram}}{\text{Spherical area of indentation in mm}^2}\\ &= \frac{P}{\frac{\pi D}{2}\left[D-\sqrt{D^2-d^2}\right]}\end{aligned}$$

   where *D* is diameter of penetrator, *P* the load and *d* is the diameter of the impression. (See at the end, for the derivation of the above equation)

Figure 2 Brinell hardness tester.
(*Photo Courtesy*: Applied Mechanics Laboratory, Mechanical Engineering Department, Jadavpur University, Kolkata)

The relationships between RHN and BHN for ferrous and non-ferrous alloys are shown as follows:

$$\begin{aligned}
\text{BHN} &= \frac{7300}{130 - R_B} \qquad \text{for } R_B \text{ from 34 to 100} \\
&= \frac{25000}{100 - R_C} \qquad \text{for } R_C > 40 \\
&= \frac{1420000}{(100 - R_C)^2} \qquad \text{for } R_C \text{ from 20 to 40}
\end{aligned}$$

Proof of Brinell Hardness equation: Let us consider the following indentation geometry made on a surface by a hardened steel ball (i.e. the penetrator) of diameter *D* which creates a spherical impression of diameter *d* under the application of the load *P* on the penetrator.

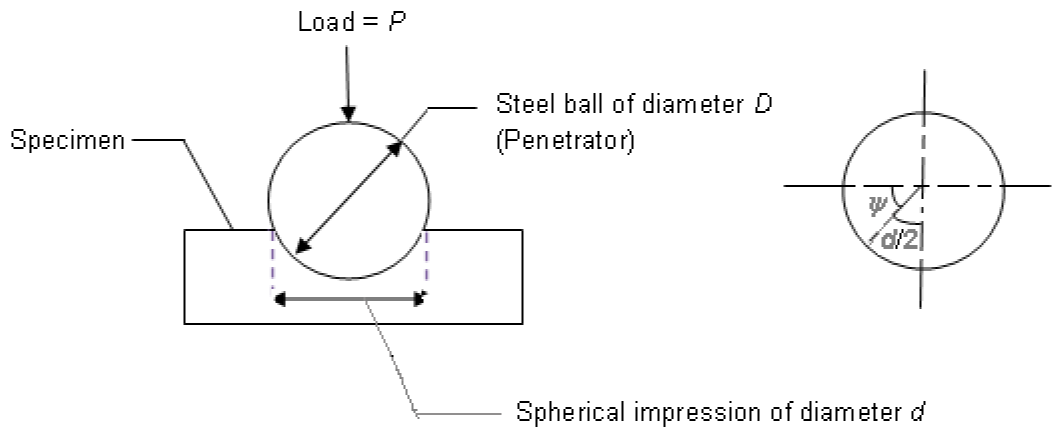

Figure 4 Geometry of Brinell hardness test.

Now from the adjoining geometry, the area of the indented surface is clearly given by:

$$
\begin{aligned}
A &= \int_{\theta=0}^{\theta=2\pi}\int_{\psi}^{2}\frac{D^2}{4}\cos\psi\,\mathrm{d}\psi\,\mathrm{d}\theta \quad \text{where}\cos\psi=\frac{d}{D}\\
&=(2\pi)\frac{D^2}{4}[\sin\psi]_{\psi}^{\pi/2}\\
&=\frac{\pi D^2}{2}[1-\sin\psi]\\
&=\frac{\pi D}{2}\left[D-\sqrt{D^2-d^2}\right]
\end{aligned}
$$

Thus, BHN is finally defined as:

$$\text{BHN}=P/A=\frac{P}{\frac{\pi D}{2}\left[D-\sqrt{D^2-d^2}\right]}$$

4. **Vicker's Hardness Test:** This is also a macrohardness test. This is particularly useful for ceramic materials where indentation hardness is measured. In this test, the indenter is a square-based diamond pyramid (Figure 3). Like Brinell test, Vicker's Harness number (VHN) is defined as the indentation load divided by the surface area of the indentation. In case of Vicker's test, even with a small load, permanent deformation can be produced. The apex angle at the tip of the diamond pyramid is 136°. Vickers hardness is given by

$$H_{\text{V}}=2\sin 68°\cdot\frac{P}{d^2}=\frac{1.8544P}{d^2}$$

where P is the load and d is the average diagonal of the impression. If P is in Newton and d in mm, the unit is Mega-Pascal. For steel, the value can be in the range 1.5×10^3–2.5×10^3 MPa while for hard ceramics like alumina, it is 16×10^3–20×10^3 MPa. We can also express Vickers hardness in *VHN*.

Like Brinell and Rockwell tests, Vicker's hardness test is also quite easy to perform, involves less time, is inexpensive and provides lot of data from a single specimen. Particularly Vickers and Rockwell tests make very small impressions on the surface concerned and hence can be easily used for assessing product quality.

Figure 3 Vicker's hardness test.
(*Photo Courtesy*: Applied Mechanics Laboratory, Mechanical Engineering Department, Jadavpur University, Kolkata)

From the discussions made so far, it is evident that although all the tests involve indentation technique, they differ from one another because they tend to evaluate somewhat different material phenomena. Hence, there is no simple relationship between different hardness numbers of the same material. However, some appropriate relationships are there and depending on them, it is possible to construct a conversion table of Hardness (Table 1).

5. **Durometer:** This is another test device by which soft materials such as rubber, polymer, non-rigid plastics can be tested. The machine consists of a spring-loaded conical steel indenter. The indenter is pressed against the surface and the dial indicator can give the hardness directly.

6. **Scleroscope:** There is another method known as Scleroscope test where hardness is measured by the rebound of a small diamond tipped hammer which is dropped from a fixed height on the surface of the material that is to be tested. This test measures the resilience of the body being tested.

7. **Microhardness Test:** Microhardness tests are done on very small areas. This type of test involves indentation with Vickers indenter using very small load. The penetrator is also small in size, however, the apex angle is the same as Vicker. It may be noted that this Micro-Vickers tests can also provide upstream information about other properties like stiffness of the material if the loading–unloading

curves are available. Knoop hardness testing involves similar methodology; only the indenter geometry is slightly different and the load varies between 25 g to 3600 g.

In the recent times, nanohardness and ultrananohardness testers are also in use for different scientific purposes. However, from engineering point of view, macro and micro tests are good enough.

Relationship of Hardness with Other Mechanical Properties

For various ferrous and non-ferrous alloys, there exist some empirical relationships between hardness (Brinell hardness number) and tensile strength. For plain carbon steel and low alloy steels, tensile strength in psi may be determined by multiplying BHN by a factor of 500. In this way, for this type of steel we can find out tensile strength quite easily. For non-ferrous alloys like duraluminium, the factor is 600 whereas for brass it is around 800.

Hardness often bears a simple relation with the yield point too. If both can be expressed in the dimensions of pressure, hardness is quite often considered to be three times the yield point stress. This does not hold for all metals and alloys.

Although in many practical situations, hardness was found to be inversely related to toughness, it should not be treated as a rule. In various grades of steel, increase in percentage of carbon makes the alloy harder and also brittle, it should be kept in mind that hardness is more or less a surface response while toughness or ductility is a bulk property.