Penetration Testing for Material Hardness

Purpose

The hardness of various materials, ranging from metals to plastics to rubber, can be an important design property. Consider, for instance, a camshaft in an automobile. The camshaft should be very carefully evaluated from the viewpoint of its ability to resist wear and the ease of production. A rubber tire should also perform a careful balancing act between the need for durability, governed largely by hardness, and traction. Hardness testing is used to quantify this important material characteristic.

Hardness testing methods have also been heavily utilized as a non-destructive testing method offering a quick evaluation of production quality and tensile strength of various metals. This strength evaluation is accomplished through the plastic deformation of a small volume of metal at the surface of a given sample.

Experimental Methods

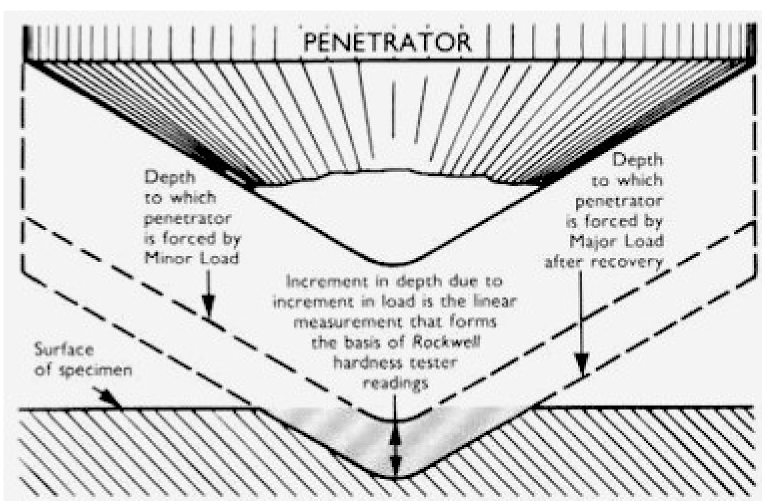
In this laboratory session, we will be using the *Rockwell*, and the *Brinell* Hardness Tests to measure the hardness of three metals, some of which you tested in the Tension Testing lab. These are: Aluminum, Cold-Formed Steel, Hot-Rolled steel

ROCKWELL HARDNESS

For Rockwell hardness tests we use two main penetrators the B (ball) and the C (cone) penetrator. The C penetrator is only used when HRB (Rockwell Hardness on the B Scale) exceeds 100.

An indentation mass of 60 kg should be applied when using the B penetrator (for F scale), an indentation mass of **100 kg should be applied when using the B penetrator (for B scale**), and **150 kg when using the B penetrator (for G scale**).

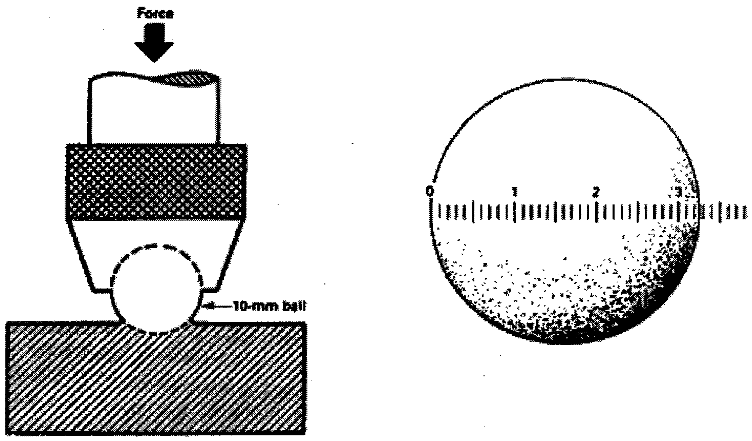
The following procedure details a given test:



1. Place the on the test bed and apply the minor load by raising the sample against the penetrator.
2. Apply the major load and wait 8 seconds for the dial reading to stabilize.
3. Remove the major load and read the dial gage.

BRINELL HARDNESS

This test determines the hardness of a material by forcing a hard steel or carbide ball of specified diameter into it under a specified load.



Brinell hardness number, HB, is a number related to the applied load and to the surface area of the permanent impression made by a ball indenter computed from the equation

$$HB = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

where P is applied load in kgf, D is diameter of ball in mm, and d is mean diameter of the impression in mm.

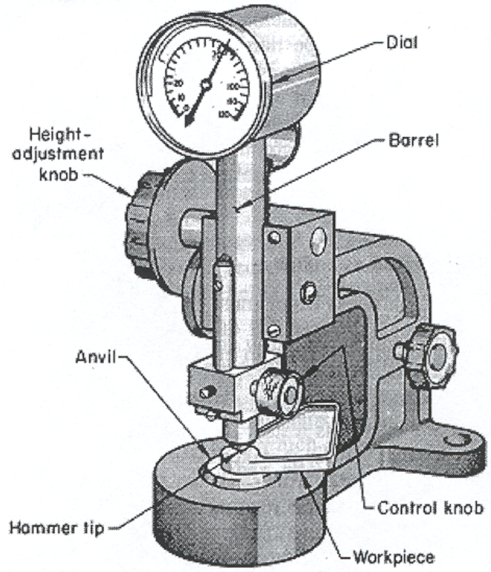
1 Place the sample on the test bed and raise the sample against the penetrator (simply make contact).

2 Apply the appropriate load (alluminum 500kgr, steel 2,000 kgr). Retain the load for 5 secs and unload.

3 Use the Brinell microscope to measure the diameter of the indentation and calculate the hardness from the equation above.

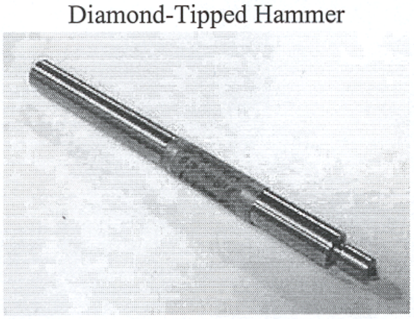
SCLEROSCOPE HARDNESS TEST

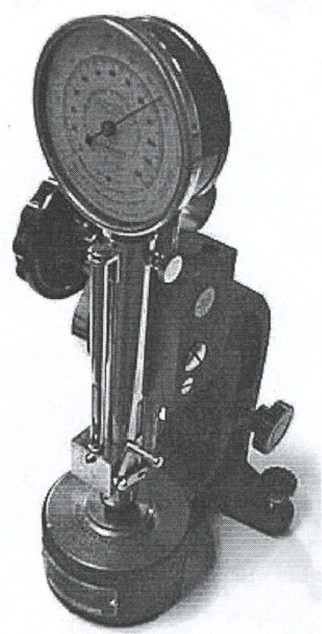
This is a dynamic indentation hardness test, which uses a calibrated instrument that drops a diamond-tipped hammer from a fixed height onto the surface of the material being tested.



Scleroscope hardness number, **HSc** or **HSd**, is a number related to the height of rebound of the hammer. It is measured on a scale determined by dividing the average rebound of the hammer from a quenched (to maximum hardness) and untempered high-carbon water-hardening tool steel test block of AISI W-5 into 100 units .

Diamond-Tipped Hammer





Theory

This test causes a plastic failure of limited extent in the region surrounding the penetrator. As the material becomes harder, the extent of the failure becomes smaller and smaller, leaving a decreasingly deep indentation (see figure above). It is important to note that this failure is confined solely to the surface of the specimen, and thus penetration tests have the very significant disadvantage of testing only a limited volume of the specimen, perhaps leading to error in evaluation.

Using the extent of the yielded zone as a guide, a rough guess of the rupture tensile strength of the material can be made from published charts. If extensive hardness data related to a particular alloy of a metal are available, a very accurate evaluation of the rupture strength can be made.

Analysis

Please include the following analysis in your *short report*:

1. Please tabulate summary data from the hardness testing within the body of the report text. Please include a statistical summary with this data. Attach any detailed data as needed.
2. From the chart of hardness results found on the Web, please estimate the tensile rupture strength of the cold and hot rolled steel samples. Compare these to the strength found in the Tension Testing lab of the previous laboratory.
3. Comment on the relation of the hardness from the Rockwell, and Brinell tests.

Main Assignment

Big Bob's Super Carnivals Inc. is designing a new Tilt and Whirl, a high-speed ride intended to spin its passengers around at previously unheard-of velocities. The design engineers propose a main shaft of ASTM A36 with replaceable bearings made from the 1045 steel. Big Bob, unhappy about the difficulty and expense of machining a steel shaft, thinks it would be OK to use the 1045 bearings, but wants to make the shaft out of aluminum, which "my cousin can machine at his shop in his garage, like we did with all the other rides". Think carefully about the hardness, strength and ductility of the two materials available and write a one-page report to Big Bob's Super Carnivals explaining your proposed solution to the shaft and bearing problem.

APPENDICES

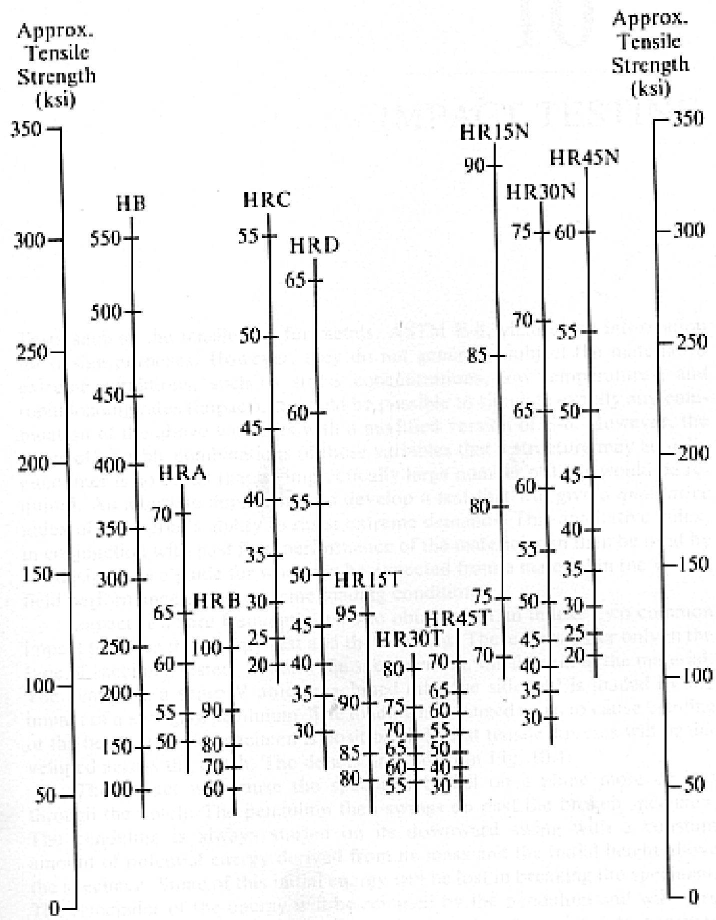


FIGURE 9.1
Hardness conversions for ferrous materials

Sample Name	***Hardness***		**Sample Name**	***Hardness***

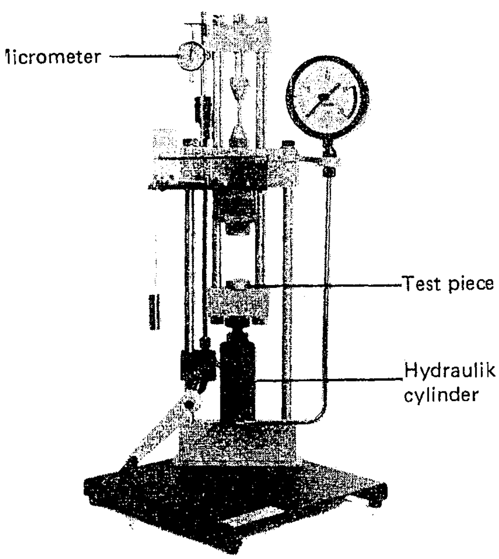
HARDNESS TESTING

The hardness of a material is defined as its capacity to withstand indentation from another body. There are many methods used in hardness testing and the results are difficult to compare as the indenting body and pressures applied are so unlike.

The most common tests are: Brinell
Vickers
Rockwell

Brinell Test

Fig. 3:1 and 3:2 show two types of hardness tester, by hydraulic pressure or by a special tester, durometer.



1. 3:1. Hydraulic Press.

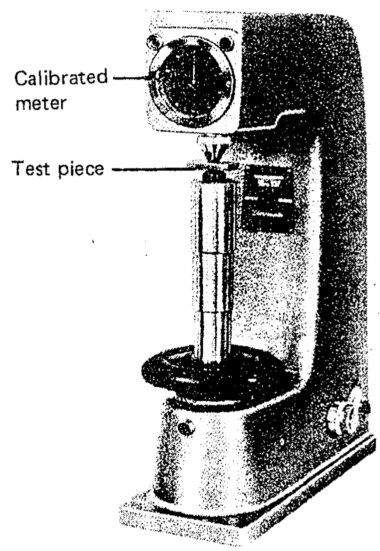
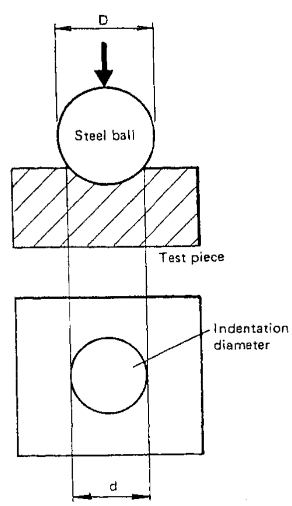


Fig. 3:2. Durometer.



A steel ball of diameter 2,5 mm, 5 mm or 10 mm is pressed into the surface of the material under a pressure of 1.25 to 30 kN. The load is sustained for a certain period, depending on the material. (Steel —15 secs.) The diameter of the indentation is measured using a measuring microscope, see fig. 3:3. The Brinell hardness HB is then taken from tables of indentation diameters. HB is defined as load divided by the spherical indentation area. The Brinell test can be completed on soft and half hard materials. The indentation is relatively large,

Fig. 3:3. Measurement of indentation.

Test piece requirements:

In order to obtain a distinct identation, the test piece must be flat and well polished. The thickness must be at least 8 times that of the depth of the impression. The centre of the impression must be at least twice the diameter of the indentation from the edge.

Material	Loading
Cast iron — steel	30 · D²
Copper and aluminium alloys (HB over 55)	10 · D²
Copper and aluminium alloys (HB under 55)	10 ·D²
Softer metals	2 ·5 D² or D²
Sintered metals	10 · D²

Fig. 3:4. Hardness table.

Selection of steel ball and loading

The reading accuracy is highest if the diameter of the indentation is 0.2—0.5 times the diameter of the ball. The constant should be slightly higher for harder materials. The hardness of the material will also govern the applied load. See fig. 3:4.

Complete Experiment 1 on page 39.

Vickers Test

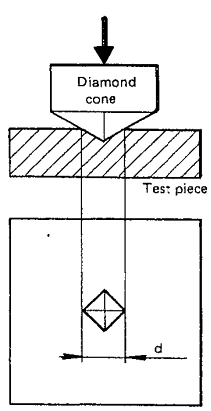


Fig. 3:5. Vickers diamond.

A diamond in the form of a quadratic cone is used in this test. See fig. 3:5. The shape of the cone is such that lower pressures are required (50—1200 N). The indentations are so small that the test piece is undamaged.
A measuring microscope is used to determine the diameter of the small impression and the HV hardness selected from the tables.

HV (Vickers hardness) is defined as the quotient of the load and the area of the pyramidic indentation.

As the load is so low, tests can be carried out on thin materials and materials having thin surface layers.
HV can be completed with both soft and hard materials.

Read the technical description on the durometer, see pages 47—51 and complete Experiment 2 on page 42.

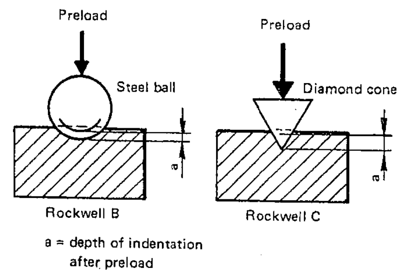


Fig. 3:6.

Rockwell Test

The two Rockwell tests are Rockwell B (Ball) which utilises a steel ball and Rockwell C (Cone) in which a diamond cone is used. See fig. 3:6.

HRB and HRC are defined as the quotient of the load and the depth of the indentation. Rockwell B test is used on soft and medium hard materials whilst Rockwell C is best suited for medium hard and hard materials

Method

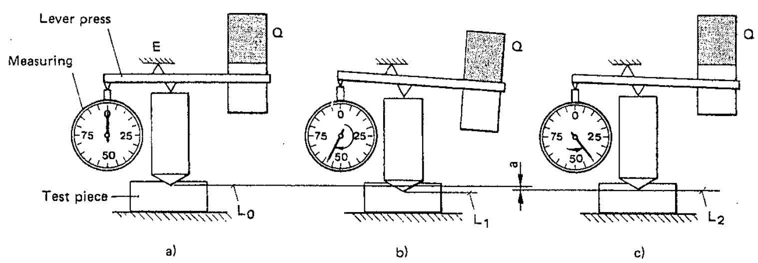


Fig. 3:7. Preload.

The test piece is placed on the anvil table and loaded to 100 N, see fig. 3:7 a. This preloading eliminates looseness in the settings between the test piece and the measuring instrument. Set the measuring instrument to zero. Increase the load on the test piece to 1000 N for test HRB and 1500 N for test HRC, see fig. 3:7 b. Release the loading until only the preloading remains, see fig. 3:7 c. The material will spring back slightly. Take a reading of this value. The hardness can be read off directly or by reference to tables.

Rockwell hardness defines infinite hardness to a theoretical value HRD = 130 and HRC = 100. The indentations caused by this test are so small that it can be categorized as non-destructive testing.

Complete Experiment 3 on page 44.

Complete Experiment 4 on page 46.

Summary

To complete an accurate hardness test, the measuring instrument must be calibrated against a standard hardness block. It is not possible to compare the different types of hardness tests. The selection of test method is dependent on the hardness of the material, see fig. 3:8.

Material test	Soft	Medium Hard	Hard
Brinell	X	X	
Vicker	X	X	X
Rockwell B	X	X	
Rockwell C		X	X

Fig. 3:8. Selection of test.