CONCORDIA UNIVERSITY
ENGR 244 – Mechanics of Materials

Experiment 1: Brinell Hardness Test

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Experiment Date:

Mai 16th, 2024

Lab Section:

ENGR 244 AJ-X

Objective:

In this experiment, Brinell hardness test has been deployed to measure different materials specimens to permanent deformation under controlled loading.

Introduction:

Hardness is an important material's property. There exist different hardness testing techniques that provide the designer with valuable information related to the material's mechanical properties. Testing metals particularly for hardness allow engineers to quantify their resistance to deformation due to compressive loads, as well as their wear properties.

The Brinell Hardness test consists of a testing structure that applies a localised controlled load using an indenter in contact with the sample for a specific amount of time. Through microscopic observation of the sample, a designer can extract the dimensions of the test indentation and use the appropriate equations to formulate the results [1].

The Brinell's Hardness test was first introduced by the Swedish engineer Johan Brinell in 1900 and has been widely used and standardized hardness test in engineering since then [2].

There exist various quantitative hardness testing methods including but not limited to, Rockwell, Vickers, and Knoop with most of the techniques using different indenters but relying on similar methods [3].

The Brinell's hardness test has been chosen for this experiment due to its reliability as well as the availability of the testing material.

Prior to the experiment, certain assumptions are to be noted:

- The machine used has been properly calibrated to output the exact loading shown digitally but hasn't been ASTM certified.
- The testing samples contain only steel for the first, and aluminum for the second.
- The surface of the samples has been properly machined to a flat surface and have not been subjected to high temperatures or chemical substances that might alter their inherent mechanical properties.

The Brinell Hardness test has potential value and practical outcomes since it will allow us to define an essential mechanical property of materials, hardness, that can therefore be used in determining the utility of a material in a design and help the designer in their selection of materials depending on the application. Another practical implication would be in quality control of the material produced in an industrial setting. Hardness is a property that could inform the service life expectancy of a part made of a known material.

Procedure:

In this experiment, we used the Brinell Hardness test through a fixture locally made to measure the hardness of two metal specimens, a steel sample and an aluminum sample, see figure 1.

The fixture used is comprised of 4 vertically standing rods fixed at the work bench and holds a stationary upper platform that houses the indenter, see figure 2. The indenter consists of a ball with a 10mm diameter. Through a hydraulic pump actuated by a simple hand lever, a single axes moving platform is moved vertically, pushing the sample into the indenter, therefore applying a controlled load.

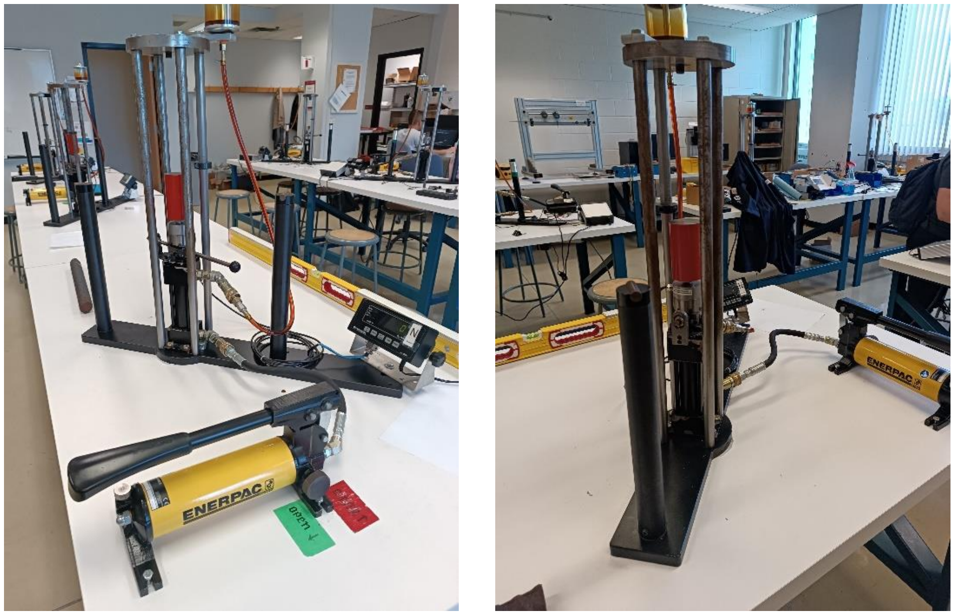

Figure 1: Hardness testing fixture.

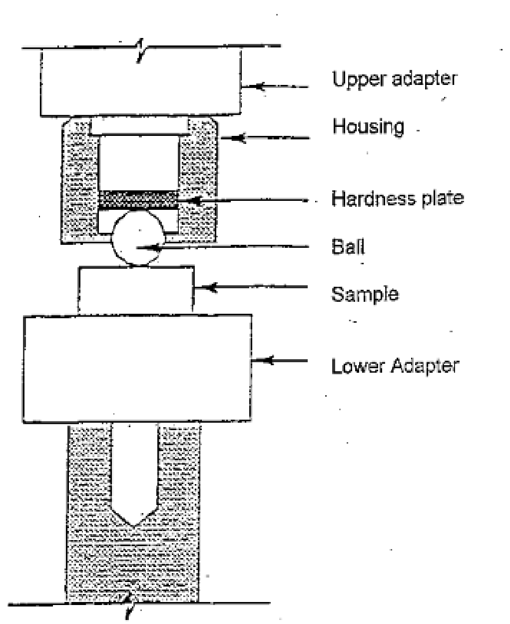

Figure 2: Schematic of Hardness testing fixture.[4]

The testing starts by properly setting the sample on top of the moving platform, then pumping down on the lever to apply the pressure while keeping a close eye on the digital gauge. The pump then exerts the pressure on the fluid in the system pushing the piston up, and therefore moving the platform to displace the sample vertically and into the indenter. The pressure on the lever is applied in such a way to increase the load by roughly 100N per second until we get to the desired value.

Once the testing value is reached, we start a timer to complete 15 seconds of the constant following loading:

- The steel specimen was subjected to a load $P = 10 \times 10^3 N$.
- The aluminum specimen was subjected to a load $P = 5 \times 10^3 N$.

The test has been repeated on the same samples at different locations to average the results, each of the sample was successfully tested three times.
It is important to note that the constant load has been averaged since during the static loading cycle of 15 seconds, there may have been slight variations resulting from the inconsistency of the force applied by the tester on the lever.

Results:

After a visual microscopic observation, the results have been extracted related to each of the three attempts, refer to Table 1. Using a microscope, we measure the diameter along the two main axes of the indentation, along the X axes and the Y axes of the outline of the circle to the nearest 0.1mm.

Sample	Test #	Diameter in X (mm)	Diameter in Y (mm)	Load F (N)		Load P (Kg)
Steel	1	3.0	3.0	Max	10063	1022.88
				Min	10006	
	2	2.9	2.9	Max	10058	1023.14
				Min	10016	
	3	3.1	3.1	Max	10311	1035.42
				Min	10004	
Aluminum	1	2.4	2.4	Max	5037	512.18
				Min	5012	
	2	2.4	2.4	Max	5041	512.54
				Min	5015	
	3	2.4	2.4	Max	5065	513.20
				Min	5004	

Table 1 : Diameters of the indentation

The extracted values are then used to calculate Brinell's Hardness using the following equation (1):

$$\mathbf{HB} = \frac{\mathbf{P}}{\mathbf{A}}$$

HB = Brinell's Hardness
P = applied load (kg)
A = Area of the indentation (mm^2)

The area of the indentation can further be expanded into the following equation (2):

$$\mathbf{A = \pi Dt = [(\frac{\pi}{2}D)(D - (D^2 - d^2)^{\frac{1}{2}}]}$$

D = diameter of the ball (mm)
d = mean diameter of the impression (mm)
t = depth of the indentation (mm)

The testing fixture displays the load in Newtons on it's digital monitor, in order to use the values in equation (2), we had to convert it to Kg by using the following equation (3):

$$\mathbf{P = \frac{F}{g}}$$

P = load (Kg)
F = load (N)
g = gravitational constant ($\frac{N.m^2}{Kg^2}$)

We use equation (2) to get the area of the indentation, here is an example of its use for test #1 for the steel sample:

$$\mathbf{A = [(\frac{\pi}{2}D)(D - (D^2 - d^2)^{\frac{1}{2}}]}$$

$$\mathbf{A = [(\frac{\pi}{2} \times (10)\left(10 - \sqrt{10^2 - 3^2}\right)]}$$

$$\mathbf{A = 7.2352\ mm^2}$$

To determine the Brinell Hardness, we use the area calculated in equation (1):

$$\mathbf{HB = \frac{P}{A}}$$

$$\mathbf{HB = \frac{1022.88}{7.2352}}$$

$$\mathbf{HB = 141.38\,\frac{Kg}{mm^2}}$$

We used the same method to calculate the Brinell Hardness for the rest of the steel sample tests, and the aluminum sample tests, the results are shown in Table 2.

Sample	Test #	Depth of indentation t (mm)	Area of indentation A (mm)	Brinell Hardness HB (Kg/mm^2)	Average Brinell Hardness HB (Kg/mm^2)
Steel	1	0.2303	7.2352	141.38	138.68
	2	0.2303	7.2352	141.41	
	3	0.2463	7.7383	133.80	
Aluminum	1	0.1461	4.5910	111.56	111.66
	2	0.1461	4.5910	111.64	
	3	0.1461	4.5910	111.78	

Table 2: Brinell Hardness data and calculations table.

Discussion:

The Brinell Hardness test has allowed us to deduce the hardness of the two metal samples.
We note some slight variations in the results due to the variation in the load applied during the test. During the 15 seconds of the tests, there were variations in the load applied to the indenter as showed by the parameter F in Table 1. We've used an average in the results to account for those variations.
There are direct implications we can utilize in multiple engineering applications based on the results of this test. For example, in the automotive industry, we can use hardness tests to test high load, high localised impact components such as camshafts or pistons to predict their resistance, durability and life cycle.
With an approximative load of about 1000Kg for steel sample, steel has an intermediate hardness, unlike the aluminum sample, that's been subjected to about 500Kg of load during the test, the results show that it's a soft metal based on the ASTM specifications. Since the equipment isn't ASTM certified, we can only use these results as a reference to base our deductions.
We can clearly note that the HB of steel is higher than that of aluminum in all the tests.
During the third steel test, the load applied has exceeded the threshold of the digital reader, a peak of 10311N has been recorded, therefore the indentation was larger, and the area calculated was bigger, since we took and average of all three tests, we don't expect this value to have a very large impact of the results.
As for the aluminum sample, the load applied on all tests was within a reasonable range, so the results were almost identical, and the measured area as well.
It is important to note that during the test, the placement of the sample within the testing fixture could have a considerable effect on the results, for example if the indentation was made too close to the edge, then the data would be erroneous since the there would be less material on one axes to support the localised load applied on the surface of the sample. If the indentations are made too close to each other, the results might not be accurate due the compressive effect that has been applied at the neighboring region of the indentation, the indentation creates a compressed localised region that has its mechanical properties slightly modified.
We could have opted for a different method to test our samples, such as the Rockwell Hardness test, which consists of a similar machine that applies a localized load through an indenter. Different indenters could be used, such as diamond cones and steel balls based on the hardness of the material being tested, then based on the observed dimensions of the indentation, we can calculate the Rockwell hardness. [5]
There are some considerations to be taken regarding this experiment that could generate erroneous results, the machine used for this experiment is locally made, and hasn't been tested under ASTM standards, and the calibration of the fixture could generate false data if not done properly as well.

Conclusions:

The Brinell Hardness test is a useful experiment to evaluate the hardness of materials, the test allowed us to determine the hardness of steel and aluminum using a simple fixture in a reasonable amount of time.

Based on the results we deduced that the hardness of steel is higher than that of aluminum. The test is a reliable way to determine the hardness of the samples despite some sources of errors that must be considered during the interpretation of the results. In our report, we have enumerated other methods of testing materials for hardness that could be considered as alternatives to the Brinell's Hardness test.

Reference:

[1] R. Hill, B. Storåkers, and A. B. Zdunek, 'A theoretical study of the Brinell hardness test', *Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences*, vol. 423, no. 1865, pp. 301–330, 1989.

[2] G. Leyi, Z. Wei, Z. Jing, and H. Songling, 'Mechanics analysis and simulation of material Brinell hardness measurement', *Measurement*, vol. 44, no. 10, pp. 2129–2137, 2011.

[3] W. D. Callister 1940- and D. G. Rethwisch, *Materials science and engineering : an introduction*, 10th edition. Hoboken, NJ: Wiley, 2018.

[4] 'ENGR 244 Lab manual_2020'. Departement of Building, Civil and Enviromental Engineering.

[5] G. Revankar, 'Introduction to hardness testing', 2000.