1. **Objective**

The objective of this lab is experimenting one of the hardness testing techniques which is the Brinell hardness test on specimens of different carbon content and different materials. This technique let us measure the diameter of indentation on these materials which is used to calculate the resistance of the materials to indentation: hardness. Moreover, another objective is the calculation of the tensile strength using the Brinell hardness and comparing these mechanical properties changes with the changes of carbon content on one side and the microstructure of the materials on the other side.

1. **Introduction**
2. **Background on hardness and hardness testing techniques**

Hardness is a measure of a material’s resistance to localized plastic deformation and indentation (e.g., a small dent or a scratch). Resistance to indentation is a function of the mechanical properties of the material, primarily its elastic limit and to a lesser extent, its work-hardening tendency, and the modulus of elasticity.

Early hardness tests were based on natural minerals with a scale constructed solely on the ability of one material to scratch another that was softer. A qualitative and somewhat arbitrary hardness indexing scheme was devised, termed the Mohs scale, which ranged from 1 on the soft end for talc to 10 for diamond.

Quantitative hardness techniques have been developed over the years in which a small indenter is forced into the surface of a material to be tested, under controlled conditions of load and rate of application.

The depth or size of the resulting indentation is measured, which in turn is related to a hardness number; the softer the material, the larger and deeper the indentation, and the lower the hardness index number. Measured hardness are only relative (rather than absolute), and care should be exercised when comparing values determined by different techniques.

Hardness tests are performed more frequently than any other mechanical test for several reasons:

**1.** They are simple and inexpensive—ordinarily no special specimen need be prepared, and the testing apparatus is relatively inexpensive.

**2.** The test is nondestructive—the specimen is neither fractured nor excessively deformed; a small indentation is the only deformation.

**3.** Other mechanical properties often may be estimated from hardness data, such as tensile strength.

There exist three different hardness-testing techniques:

a) **Rockwell hardness test:** the indenter includes spherical hardened steel balls and conical diamonds.

b) **Brinell hardness test:** uses a hardened spherical ball as indenter.

c) **Knoop and Vickers micro hardness test** uses a small pyramidal shaped indenter.

*Find a table showing the details of the shape of the indenter and different characteristics of the different hardness testing techniques in Appendix A.*

Between all these different techniques to test hardness of different materials chosen, we have performed in our third lab the Brinell hardness test on different specimens.

1. **Brinell hardness test apparatus and specimens**

**Apparatus Settings:**

* Brinell Testing machine: consists of a test bed able to support the specimen and apply the indenting force to it via the indenter ball. The machine allows only vertical motion of the ball to avoid rocking and lateral sliding of the ball on the test specimen. The force applied is 500 Kg, 1500 Kg, or 3000 Kg according on the material to be tested. However, in this experiment we only used the 3 ton force( and every specimen was put under the action of that 3 ton force for about 30 sec)
* Brinell ball: the ball that transmits the indenting force is 10.000 mm in diameter. It is to be made of Tungsten Carbide and to be free of surface defects.
* Measuring device: used to measure the diameter of the indentation.

**Test specimen:**

There is no standard shape or size for a Brinell test specimen. The test specimen, however, must be thick enough not to bulge under the load (no signs of the load must appear on the opposite side). The test specimen is to be polished and cleaned to ensure accurate reading of the diameter.

1. **Problem Approach**

In this lab, we operated the Brinell hardness test on five types of specimens:

1. Cast iron specimen
2. Low carbon steel specimen
3. High carbon specimen
4. Heat treated carbon steel specimen
5. Brass specimen

**Procedure:**

1. set the required load on top of the machine (the 3 ton load in this case)
2. place the specimen on the flat surface below the brinell ball
3. Apply the load on the specimen for about 30 seconds.
4. Remove the specimen and measure the indentation diameter (d) using the microscope (two readings are taken at right angle and their average is to be used to determine the hardness of material).



Procedure of Brinell hardness test

**Theory and Measurements:**

After finding the indentation diameter 2 methods are used to find the hardness either through tables or through the following formula:



F: Applied load in Kg

D: Indenter diameter mm

d: Indentation diameter mm

Both tensile strength and hardness are indicators of a metal’s resistance to plastic deformation. Consequently they are roughly proportional.

**For most steels, TS (psi) = 500 x HB or TS (MPa) = 3.45 x HB**

To find the tensile strength of brass and cast iron we will use the graph showing the tensile strength versus the Brinell hardness number shown in Appendix B.

The obtained diameters of indentation by the Brinell testing technique for the five specimens with an indenter of 10 mm in diameter and load of 3000Kg are in the following table.

Table showing the measurements of the indentation diameters of the specimens

1. **Analysis and calculations**

Calculations:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | measure1  (d1 mm) | measure2 (d2 mm) | Average (mm) | Calculated HBW | Table Value for HBW | TS (MPa) | % of carbon |
| 1-Cast Iron | 4.45 | 4.5 | 4.475 | 180.65 | 185 | 525.5 | - |
| 2-Low Carbon Steel | 4.5 | 4.5 | 4.5 | 178.539 | 179 | 615.96 | 0.43 |
| 3-High Carbon Steel | 4.5 | 4.45 | 4.15 | 211.786 | 212 | 731.4 | 0.58 |
| 4-Heat-Treated High Carbon Steel | 3 | 2.9 | 2.95 | 429.16 | 566 | 1480.58 | 1.5 |
| 5-Brass | 5.35 | 5.4 | 5.375 | 121.852 | 123 | 423.388 | - |

As discussed in the theory section, we found the average of the two values of each specimen then:

* **For metals**

We calculated the Brinell hardness by the formula before HBW=2F/( pi\*D\*( D-sqrt(D^2-d^2) ) ) and the tensile strength from : Tensile strength (MPa)=3.45\*HBW. Using the graph in appendix C we also found the carbon content of each specimen analyzed.

* **For cast iron and brass**

We calculated the Brinell hardness by the formula before HBW=2F/( pi\*D\*( D-sqrt(D^2-d^2) ) ) and we calculated tensile strength of the cast iron from graph in appendix B : y=4.9x-380. For a 185 HBW, tensile strength will be 525.5 MPA. We calculated tensile strength of the brass from graph in appendix B: y=2.9x+70. For a 123 HBW, tensile strength will be 423.7 MPA.

Analysis:

In this experiment we measured the Brinell hardness of five different specimens. The choice of these five specimen is to analyze the effect of two important parameters on the hardness of a material:

1. **The carbon content:**

In metals, we find many dislocations which if numerous make the material easily fractured and ductile: atoms are free. However when we add carbon these dislocations are hardened and bonds are made harder between the atoms thus the hardness of the material increases and becomes more brittle.

Heat treated steel has the highest percentage of carbon and as the percent of carbon increases the hardness of material increase. After quenching the layers of materials will cool down rapidly, this will make the distribution of carbon homogenous, thus making the material harder.

As we notice the Brinell hardness of high carbon steel is higher than low carbon steel as well as the tensile strength (table of calculations) so the carbon addition increased the resistance of the material to indentation and it can handle more stress.

1. **The microstructure of the material**

Cast iron has a lower hardness than low carbon steel but almost the same. Also it has a lower hardness than high carbon steel and heat treated steel. Cast iron has many impurities which weaken the material.

Low carbon steel has a small hardness number and is less brittle than the other materials. In fact, in low carbon steel layers of ferrite and cementite are formed, consequently weakening the material.

High carbon steel has a high hardness number and is more brittle than the low carbon steel. In fact, high carbon steel has fine pearlite formed which hardens the material.

Brass has the lowest hardness and is therefore the most ductile specimen between the five and therefore does not withstand high tensile strengths.

**5. Observations:**

We first tried manually to test the hardness of the different specimens. The material which has been scratched is therefore less ductile than the one by which it is scratched.

Different indentations were observed for the different specimens, thus, each specimen has hardness different from the other.

After the material in removed from the Brinell hardness machine we could classify the specimens at naked eye from the most ductile to the most brittle by the depth of the indentation. The more it is deep and large the more the material is ductile.

**6.Conclusion:**

Hardness of the material is affected by its composition (especially the composition of carbon) and method of manufacturing (the heated treated steel was the hardest of the 5 specimens).

When the carbon content in the steel increases, the hardness of the material increases as well as its tensile strength. The microstructure also affects the hardness, low carbon steel has ferrite and cementite which weakens the material, and high carbon steel contains pearlite which makes it hard. The method of manufacturing affects the hardness of the material. In fact when it is heated and quenched at low temperature the material becomes harder and more brittle.

The ascending order of hardness of the 5 given specimens is as following: brass, cast iron, low carbon steel, high carbon steel, heat treated carbon.



**7. References**

1. Materials Science and Engineering: An Introduction, by W.D. Callister, 8th Ed., Wiley.
2. The structure and properties of materials, Vol III, *Mechanics of behavior.*

**Appendix A**



Appendix B Appendix C

