**American University of Beirut**

Faculty of Engineering & Architecture

Mechanical Engineering

**Charpy (Notched) Bar Impact Testing of Metallic Material**

**(Lab04)**

MECH 341 – Engineering Materials Lab

Section 4

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**I. Objective:**

The experiment that we did this week consists of performing a series of impact tests on different specimens. We are interested to study the behavior of materials under impact loading and at certain conditions. The impact test is done through a sudden applied force over a relatively short period of time.

We want to know how the material acts since we want to predict what material is best for specific applications. There are two main tests to measure impact energy: the Charpy Impact Test and the Izod Impact test. The difference between the two is that the Charpy test specimen is gripped from each end while the Izod test specimen is gripped from only one end.

In our experiment we are going to use the Charpy V-notch test since it is inexpensive and easy to use. The impact energies that we get are not used numerically to find related values, instead they are used relatively to other impact energies found. Therefore, they are used for comparisons, and there quantity has no use.

The behavior of materials is not always consistent and spontaneous. On the contrary, materials’ behaviour varies with respect to different conditions, some of which are:

• Deformation at a low temperature

• High strain rate

• Tri axial stress state

Impact testing serves us whenever we want to choose some material for a special application.

**II. Introduction**

**Charpy Testing Machine:**

 One can view the simulation of the Charpy test for both ductile and brittle materials at: ***http://www.binaryblue.com.au/05\_charpy\_test.html***

The Charpy V-notch test consists of the machine used and the specimen to be studied. The specimen must have a V-notch, hence the test’s name. The V-notch makes it easier for the specimen to be fractured.

The notch serves as a stress concentration zone and some materials are more sensitive towards notches than others. The notch depth and tip radius are therefore very important.

The specimen should be uniform in its material and not include any fractures or differences in composition of material since test results will be altered. It should also be of standard dimensions. Several dimensions can be used.

After the specimen is chosen and fixed to standard dimensions it’s ready for testing. We place the specimen at the bottom of the machine and grip it from both ends. A hammer, mass pendulum, will drop freely from a certain height from which it was fixed, impact the specimen breaking it, and rise back to another height at opposite ends. The machine would have measured the difference in height and calculated the corresponding impact energy. This energy would be the energy absorbed by the specimen.

*It is calculated as follows:*

***Cv : the energy of hammer (measured in lbf).***

***m: mass of hammer***

***g: gravitational acceleration (9.81 m/s2 or its equivalent in British units)***

***h0: initial vertical height of hammer***

***h1: final vertical height of hammer***

Since h1 is less than h0, then C v will be negative so the hammer loses energy giving it to the specimen. Therefore, we denote C v (positive value) as the energy that the specimen absorbed. C v is also the measure of toughness of a material under impact loading.

Hence, Charpy Impact test gives us a certain review for a number of properties of a material along with the effect of some factors on this material, especially when we consider different samples with different carbon content, heat treatment, and temperature

**Note:** For more accurate results we need to measure the friction in the machine. To do so, we have to test our machine with no specimen placed between the grips. We get a certain Cv-friction and subtract that amount from the Cv that we read from the machine when each specimen was tested. In our case, we got energy of 1 lbf-ft lost due to friction (lost as heat).

**III. Problem Approach**

In this experiment, we want to perform the Charpy (V-notched) impact test in order to find and compare the impact energies of different steel metals (low carbon steels, high carbon steels, and high carbon heat treated steels) at different temperature which is directly related to the toughness.

* *Materials & Equipment Used:*
	+ 3 specimens of low carbon steels.
	+ 3 specimens of high carbon steels.
	+ 3 specimens of high carbon heat treated steels.
	+ Liquid Nitrogen.
	+ Riehle, American Machine & Metals inc. (Charpy Testing machine)
	+ Digital thermometer.
	+ Digital caliber
* *Specimen’s Dimension & Geometry:*

Each steel bar must have the following :

 Length: 55 mm or 64 mm long

 Width: 10mm

 Depth: 10 mm

 Specimen’s Notch

 45o V notch centered at the middle.

 2 mm depth.

* *Procedure:*

1- Leave a set of each specimen at room temperature, and place a set in ice water and another in liquid nitrogen.

2- Using the digital thermometer, measure the specimen’s temperature (since we are engineers, we must be meticulous with all measurements).

3- In order to eliminate the effect of friction in the machine on our measurements, we release the pendulum without placing any bar and then subtract the measured value from each value taken.

4- Elevate the weight arm to its initial position.

5- Place the specimen horizontally in its appropriate position.

6- Release the weight arm and record using the scale on the machine the impact energy of the specimen (ft-lb).

7- Measure the specimen’s smooth shinny surface in order to calculate the shear lip percentage.

8- Repeat the procedure till all the 9 bars are tested.

**IV. Measurement**

The quantity Cv is a measure of the toughness of the material under impact loading, i.e the energy absorbed in fracturing the specimen. The measured values computed in the lab for each specimen at different temperatures are shown below:



|  |  |
| --- | --- |
| Temperature | Impact Energy (lb-ft) |
| Low Carbon Steel | High Carbon Steel | Heat Treated High Carbon Steel |
| 25 oC | 117 | 36 | 20 |
| 0 oC | 116.5 | 37 | 22 |
| -50 oC | 24 | 30 | 23 |

However, we have measured in the lab energy loss due to friction and it turned out to be 11 lb-ft. Therefore the actual values of impact energy are those in the previous table from which we subtract the energy from friction. The new values will be presented in the following table:

|  |  |
| --- | --- |
| Temperature | Impact Energy (lb-ft) |
| Low Carbon Steel | High Carbon Steel | Heat Treated High Carbon Steel |
| 25 oC | 99 | 18 | 2 |
| 0 oC | 98.5 | 19 | 4 |
| -50 oC | 6 | 12 | 5 |

The shear lip is:

%shear lip= (AB –xy/AB)x100

Computed values for shear lip for all specimens are shown in the following table:

|  |  |  |
| --- | --- | --- |
| Temperature | Shear Lip Dimensions (mm) | Shear lip percentage(%) |
| Low Carbon Steel | High Carbon Steel | Heat Treated High Carbon Steel | Low Carbon Steel | High Carbon Steel | Heat Treated High Carbon Steel |
| 25 oC | 5x3 | 6x10 | 8x10 | 81.25 | 25 | 0 |
| 0 oC | 4x3 | 6x10 | 8x10 | 85 | 25 | 0 |
| -50 oC | 8x10 | 8x10 | 8x10 | 0 | 0 | 0 |

**V. Analysis**

The fracture toughness calculated for low carbon steel shows that it has the highest impact energy with Cv=117 lb-ft at 25. On the other hand shear lip for low carbon steel turned out to be 81 % indicating a high ductility. This result shows obviously how a material with high toughness is relatively ductile.

Furthermore, when the impact energy decreased for high carbon steel to 36 lb-ft at 25, we noticed a similar decrease in shear lip to 25%. This shows that decreasing impact energy leads to a decrease in ductility.

And finally, a very low impact energy of 20 lb-ft at 25 for heat treated high carbon steel correlates with a zero shear lip percentage as expected illustrating the 100 % brittleness of heat treated high carbon .

**VI. Correlation between impact energy and modulus of toughness from the first two labs.**

|  |  |  |
| --- | --- | --- |
|  | Low carbon steel | High carbon steel |
| Modulus of toughness from Labs 1&2(MPa) | 181.5 | 45.84 |
| Fracture toughness(lb-ft) | 117 | 36 |

It is expected that the modulus of toughness and fracture toughness are related in the following sense: higher modulus of toughness corresponds to a higher fracture toughness considering that both indicate toughness and the ability to absorb energy in the plastic range under dynamic loading. We can see that high carbon steel that is less ductile than low carbon steel has a smaller modulus of toughness.

**VII. Correlation between fracture toughness and Brinell hardness from Lab 3**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Low carbon steel | High carbon steel | Heat treated high carbon steel |
| Brinell Hardness from Lab3 | 63.96 | 69.5 | 181.5 |
| Fracture toughness | 117 | 36 | 20 |

 A harder material is expected to have less ductility and less toughness since it will be able to resist more plastic deformation having fewer slip planes. As Brinell hardness increases from low carbon steel to high carbon steel and from high carbon steel to heat treated high carbon steel, we notice how fracture toughness decreases in the same order.

**VIII. Temperature effect**

The shear lip percentage shows that there is a relation between brittleness of the material and the temperature. In this experiment, it appears that low carbon steel has experienced a ductile fracture at both temperatures 25 and 0 0C since shear lip that shows percentage of ductile surface is 99.7%, which shows that decreasing the temperature from 25 to 0 did not affect much the ductility of low carbon steel. However, at -50 the shear lip became zero which shows that low carbon steel experienced a brittle fracture with 0 % ductile surface and therefore 100 % brittle surface. These results correlate to the ductile-to-brittle transition temperature where steel below a certain temperature becomes brittle. As deduced from our experiment, this transition temperature for low carbon steel is below 0 since above this temperature it was still revealing a ductile behavior, and above - 50 since at this temperature it was revealing a brittle behavior.

A similar result was obtained for high carbon steel: At 25 the percent shear lip was 69.2% and decreasing the temperature to 0 also decreased a little bit the shear lip to 61.5%, thus showing how a decrease in temperature decreases ductility by a little amount. However, at -50 the shear lip was zero which also proves that the ductile-to-brittle transition temperature is also above -50 as for low carbon steel. Nevertheless, an interesting result is how the effect of temperature on ductility decreased with increasing carbon content from high to low carbon steel. This is obvious in the impact energy versus temperature graph in figure 5. This graph shows that when carbon content increases, varying the temperature becomes less affecting on impact energy as the slope of the curve drastically decreases with increasing carbon content .

As for heat treated high carbon steel, the shear lip shows that for all temperatures heat treated high carbon steel has a brittle behavior having zero shear lip and therefore 100 % brittle fracture. Moreover, temperature does not affect brittleness since shear lip remains zero.

**IX. Conclusion**

This experiment allows us to find fracture toughness for three specimens: low carbon steel, high carbon steel and heat treated high carbon steel. It also permits us to calculate percent shear lip which gives us an idea about ductility of these specimens. With these two properties, we were able to determine the effect of temperature on ductility and brittleness since we conducted the experiment with three different temperatures. Other than ductility, we were able to correlate fracture toughness to hardness and modulus of toughness from previous labs and determine how these three properties change with respect to each other. All these calculations and correlations reveal the importance of impact tests since they allow us to have an overview about many properties such as fracture toughness, modulus of toughness, ductility and hardness for different types of metals. Its importance also appears in our knowledge about ductile-to brittle transition which gives us information about operating temperatures and design criteria for materials of different applications.

**X. Appendix**

|  |  |
| --- | --- |
|  | Figure 1: Brittle to ductile transition curve. |
| More ductileMore brittle | Figure 2: effect of temperature fracture surface, at -59oC we have 100% shiny smooth surface (pure brittle), and at 79 oC 100% dull rough surface (pure ductile) |
|  | Figure 3: Effect of carbon percentage on the temperature transition and impact energy. |
|  | Figure 4: Schematic curves for the three general types of impact energy vs. temperature behavior. |
|  | Figure 5: Schematic drawing of the hammer striking the specimen opposite to the notch’s surface. |
|  | Figure 6: Material plane stain fracture toughness |
|  | Figure 7: Materials plane stain fracture toughness ranges |
|  |  |

**XI. References:**

1- [www.azom.com](http://www.azom.com)

2- "Deformation and Fracture Mechanics of Engineering Materials", (4th ed.) Fig. 7.1(b), p. 262, John Wiley and Sons, Inc., 1996. (Orig. source: Earl R. Parker, "Behavior of Engineering Structures", Nat. Acad. Sci., Nat. Res. Council, John Wiley and Sons, Inc., NY, 1957.)

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