Material Science – ENGG*2120: Fall 2017
LAB SUBMISSION COVER SHEET
(Must be included for all group submissions)

Lab Performed: Impact Testing of Materials

Date Performed: Friday, November 3rd, 2017

Date Submitted: Friday, November 17th, 2017

Group Number: K1

GTA Name: Richard Chen

GROUP PARTICIPATION EVALUATION FORM

*****ALL GROUP MEMBERS MUST SIGN TO RECEIVE THEIR MARKS*****

By signing the cover sheet each member is stating that they made a significant contribution to the writing of this lab report and that the distribution of sections completed is accurate.

One form is required for each group report submitted. One report is to be submitted **per group.**

All submissions to be submitted electronically to the dropbox in Courselink by **NO LATER THAN** 4:00 p.m., two (2) weeks after the assigned experiment is performed (unless otherwise indicated in the course outline).

Group Members		Sections Completed
Name (Printed)	Signature	
Noah Montag		Summary, Experimental Procedures & Apparatus
Melissa Hardy	MHardy	Introduction, Conclusion
Daniel Sherman		Discussion Question #6, Results
Bilal Ayacche		Discussion Questions #1-4

IMPACT TESTING OF MATERIALS

November 17th, 2017

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*ENGG*2120*

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Summary

The purpose of this lab is to examine how different materials absorb impact energy when at different temperatures. To do this, Aluminum and Steel Charpy specimens were impact tested at several different temperatures. Steel has a BCC packing structure where as Aluminum has a FCC packing structure, so only the steel specimens were the only ones to have their ductility/brittleness change with temperature.

The Aluminum Absorbed 33.7J of energy when it was at approximately -190 °C, 23.4J of energy at 0 °C, 19.4J of energy at 75 °C, and 23.1J of energy at 120 °C. The absorbed energy didn't change much or follow a pattern because of its FCC packing structure. The Steel absorbed 3.1J, 14.2J, 132.3J, and 139.2J, respectively. Since steel has a BCC packing structure, its ductility/brittleness does change with temperature. The fracture surface for all of the Aluminum specimens showed ductile failure. The fracture surface for the -190 °C and 0 °C steel specimens showed brittle failure and the 75 °C and 120 °C fracture surfaces showed ductile failure.

This experiment showed that metals with an FCC packing structure do not have a ductile to brittle transition and that metals with a BCC packing structure do. If there were enough data points it would clearly show on the graphs that aluminum doesn't follow a ductile to brittle transition and absorbs around the same amount no matter what temperature it's at.

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INTRODUCTION

Charpy's impact test is used to evaluate the toughness of materials and resistance to high-rate loading, which is often directly related to the service life of a part. These values can often be used to determine the suitability for the application of a material and is an advantage in product liability and safety (Total Materia 2014). In this experiment, Charpy samples with square cross-sections of 10x10 mm, and 2mm deep, 45°, "V-shaped" notches, of steel and aluminum were used; steel has a body-centered cubic crystal structure (BCC), while aluminum's cubic crystal structure is face-centered (FCC). The ductility of BCC materials is variant as temperature changes, transitioning from ductile to brittle nature as temperature decreases. This ductile-to-brittle transition occurs across a range of temperatures, including a "transition temperature", at which the specimen fractures with a half-brittle and half-ductile fracture surface and the energy absorbed is half of the difference between that needed to fracture an entirely brittle specimen and an entirely ductile specimen (ENGG*2120 2012). FCC materials, on the other hand, maintain their ductility independent of temperatures, including at marginal temperatures. This invariance of ductility results in a lack of transition temperature in FCC materials and thus greater suitability for applications in which atmospheric temperature is not controlled or unpredictable.

The fracture surface of a V-notch sample can be used to determine at what point in the ductile-to-brittle transition curve a material had reached before an impact was applied. If a material is at the lower end of its transition state (brittle nature), the fracture surface of the sample will be considerably smooth and square-shaped, since the crack propagates very fast and perpendicular to the direction of the applied stress. In comparison, specimens on the higher end of the transition curve demonstrate a large distortion on their fracture surfaces as a result of necking, the formation of microvoids, and crack propagation by shear deformation (University of Virginia).

Material properties of the specimens also affect their ductility and thus their transition curve, such as carbon content and heat treatment; increased carbon content results in decreased ductility, whereas annealing results in increased ductility (ENGG*2120 2012). The AISI-1050 steel sample used in the experiment has a significantly high carbon content of 50%, and thus had a mostly brittle nature. The 6061-T6 Aluminum samples used, however, were annealed prior to the experiment and thus were predominantly ductile.

Experimental Apparatus & Procedures

Equipment

- 4 AISI-1050 steel Charpy specimens
- 4 Aluminum Charpy specimens (6061-T6 annealed at 440˚C for 3 hours and air cooled)
- Impact testing machine
- 2 furnaces
- Ice bath
- Liquid nitrogen bath

Experiment Procedures

1. Place all specimens in furnaces, ice baths, or liquid nitrogen baths to get them to their required temperatures as stated in the ENGG 2120 lab manual.
2. Pick up a material with gloves on and tongs and walk it over to the impact testing machine quickly.
3. Place material in the machine with the tongs sliding into the impact machine and carefully let go of the piece, making sure it is straight and evenly on the supports.
4. Close the door and push the red button on the handle to start the test.
5. Once completed, look at the digital reading left of the machine of the energy required to fracture the specimen and copy it down into a table.
6. Open the door and remove the broken metal specimen.
7. Push in the black circle on the analogue reading and rotate it counter clockwise to reset it.
8. Repeat steps 2-7 until all of the specimens have been tested.

Note: Lab manual instructions and all safety precautions were strictly followed and no additional changes were made to either.

RESULTS

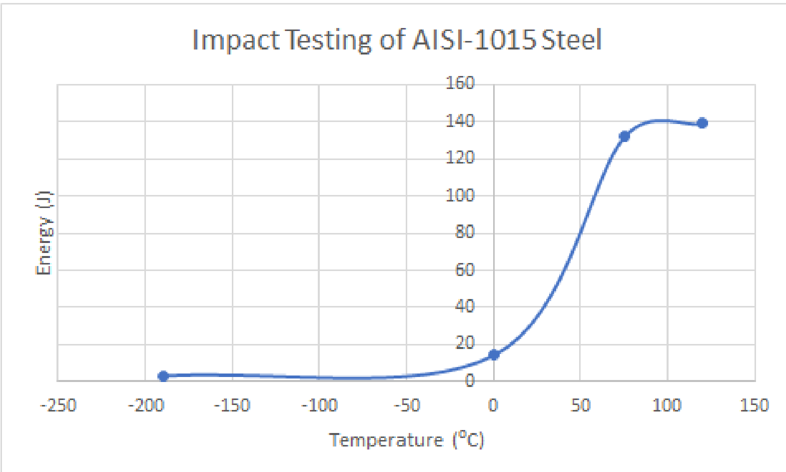

Figure 1: Energy Absorbed-Temperature Curve for AISI-1015 Steel

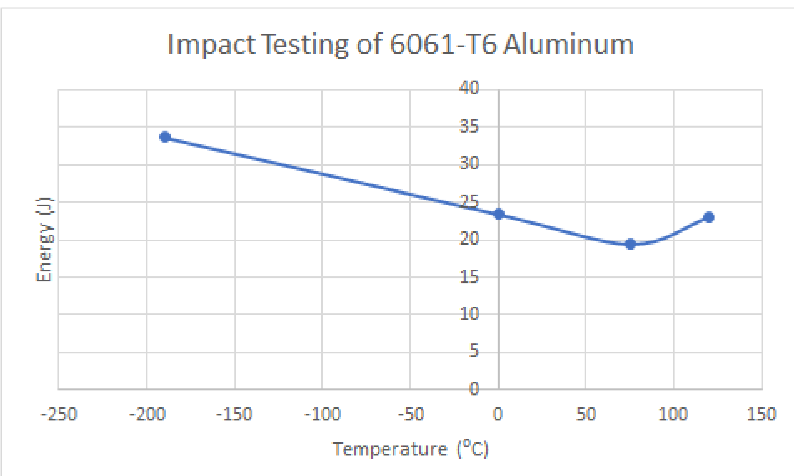

Figure 2: Energy Absorbed-Temperature Curve for 6061-T6 Aluminum

Metal Temperature (°C)	*Energy Absorbed for Steel (J)*	*Energy Absorbed for Aluminum (J)*
-190	3.1	33.7
0	14.2	23.4
75	132.3	19.4
120	139.2	23.1

Table 1: Energy Absorption for Steel & Aluminum (in Joules)

The Ductile-Brittle Transition Temperature for the AISI-1015 Steel is approximately 70˚C. The 6061-T6 Aluminum has no Ductile-Brittle Transition Temperature because it has an FCC crystal structure.

Metal Temperature (°C)	*Fracture Surface for Steel*	*Fracture Surface for Aluminum*
-190	Brittle failure. Fracture surfaces are smooth and snapped right apart. Pieces can fit together with very miniscule gaps	Ductile failure. Fracture pieces are deformed and do not fit together smoothly and are rough to the touch.
0	Brittle failure. Pieces are not completely separated, but fracture surfaces are smooth to the touch.	Ductile failure. Fracture pieces are deformed and do not fit together smoothly and are rough to the touch.
75	Ductile failure. Pieces fracture surfaces are very rough to the touch. Pieces no not fit smoothly together.	Ductile failure. Fracture pieces are deformed and do not fit together smoothly and are rough to the touch.
120	Ductile failure. Fracture surfaces are more rough than the 75℃. Pieces do not fit together	Ductile failure. Fracture pieces are deformed and do not fit together smoothly and are rough to the touch.

Table 2: Fracture Surface for Steel & Aluminum at Different Temperatures

Figure 3: Fractured Samples for Steel and Aluminum

Discussion

The brittle-to-ductile transition temperature can be determined by identifying the temperature at which a half brittle and half-ductile fracture forms on the surface of the material. Analyzing the shape of the fracture can give more information about the material being dealt with. Material surfaces that are rough or fibrous indicates that the specimen is completely ductile. On the other hand, completely brittle samples result in negligible plastic deformation. The surface of the specimen contains an irregular array of small bright facets, each correspond to the surface of a cleaved crystal. Referencing back to the graphs in the results section, it was observed that the impact surfaces of the aluminum samples tested at all temperatures appeared to have ductile characteristics. For steel samples, it was observed that the tested samples at -190ºC, 0ºC, and 25ºC have impact surfaces that suggest the material is brittle. Based on this information/data , it was determined that the transition temperature of steel must be approximately 70ºC. Another method of determining transition temperature is called the “average energy criterion”. This occurs when there is a drop in the energy absorbed by the specimen’s jump under a region of the graph . The transition temperature is represented by the midpoint of the area. Using this method to compare the values obtained from the results section, the transition temperature of the aluminum was found to be approximately -30ºC, but in practicality, aluminum has an FCC crystal structure, so it has no ductile-to-brittle transition temperature. Using the average energy criterion method, it was determined that the ductile to brittle transition temperature for steel was approximately 70ºC. Referring back to the average energy criterion method, it was found that the values obtained using this method fell in the temperature range determined in the first method.

The steel samples acquired a lower shelf energy value of 3.1J at -190ºC and an upper shelf energy value of 139.2J at 120ºC. This correlates with the transition temperature that was found to be approximately 60ºC using the average energy criterion method. At values above 60ºC, the steel becomes ductile. This increases the amount of energy absorbed by the material. At values below 60ºC, the steel is brittle which decreases the amount of energy absorbed prior to failure. There are some metals that do not show low temperature embrittlement, for example FCC metals such as nickel. This is due to the packing structure of these metals which causes the metals to respond differently to a change in temperature. Body-centered cubic (BCC) structures tend to obtain a higher transition temperatures range whereas face-centered cubic (FCC) structures tend to obtain no transition temperature range. The atomic packing factor can be defined as the ratio between the volume of the basic atoms of the unit cell. The higher the atomic packing factor is, the higher number of atoms per unit volume. FCC structures have the highest atomic packing factor of all crystal structures, being 0.74. This means that there is a higher number of atoms compared to other crystal structures. FCC crystals have close packed planes which act as glide planes for dislocations. The movement of dislocations allows atoms in crystal planes to slip past one another at a much lower stress level. The aluminum samples in the lab were found to share the previously mentioned properties.

Elements such as manganese and nickel can be added with Steels to make them less brittle under low temperatures. Nickel and Manganese are elements that have FCC crystal structures with 4 non-parallel closed backed planes. The orientation of these planes increases the coordination number which indicates how efficiently atoms are packed together. The lower the packing number the worse the material responds to a drop in temperature. Moreover, steels with lower carbon contents are generally less brittle and are more ductile at low temperatures. Additionally, by eliminating impurities like phosphorous, the ductility of steel may also be increased.

When using metal in the design process, the designer needs to know that it is very important to consider the transition temperature of the metal before building a design, because the user of the product assumes that it will function properly under any condition, not just ideal conditions. This is not always the case because material properties can differ under different environments. For example, the transition temperature of the metal used in the design of snow plough blades is important because they will be used in temperature conditions between 0 and -20℃ and be subject to heavy loads, and as a result, need to be ductile to absorb the energy. The combination of high stresses and low temperature create an increased risk for brittle fracture of the blade. As a method of prevention, the designer must choose a metal that has an appropriate ductile to brittle transition temperature (DBTT), or use a metal with FCC structure that will not undergo brittle failure. Given the choice of low carbon content or high carbon content steel, a designer would want to choose a metal with a lower carbon content because metals with high carbon content are more liable to fracture. Based on the results of this experiment, aluminum would be the better choice for a snow plough blade because it exhibits ductile behavior at low temperatures at which the plough would be operating.

The embrittlement of steels at room temperature can be a major issue. This is because the probability of failure occurrence for that specific steel is high under ideal conditions. The DBTT of 1015 Steel found in this lab was 70°C, which results in the steel acting brittle at room temperature. During the design process, the selected steel to be used in a design requires good toughness and high strength, designer must consider the acidic and temperature conditions that the steel will perform in. Plain carbon steel is not corrosion resistant, this means that rust can occur under acidic conditions. The temperature needs to also be considered because depending on the temperature, the properties of steel varies greatly and the BCC structure of the material is affected by the temperature. Steel is brittle at temperatures below 70°C, and ductile on temperatures above 70°C. This can cause the material to have drastically different properties.

The results of this lab were fairly inaccurate. Firstly, only four temperatures were studied. This reduces the accuracy of the Energy-Temperature graph because a lot of approximations need to be made to interpolate the information. Having a larger sample size of data would make the information more reliable. After plotting in the points, to get a curve, Excel needs to pretty much completely guess the slope and the curvature between the points, which it would not have to do if more data points (and therefore, more tested temperatures) were present. Another source of error was the time it takes between the removal of a sample from its temperature-controlled container and the time it takes for the actual impact to happen. The ATSM standard for the Charpy impact test states that it should take no longer than 5 seconds for an impact test to happen after the removal from a temperature-controlled container. Due to the setup of the lab, the ovens containing the samples were set far away from the impact machine and as a result, the samples were most likely out of the ovens for more than 5 seconds before the impact test, skewing the temperatures. The many sources of inaccuracy in this lab were due to extraneous factors that cannot be controlled, without the renovation of the lab, or the investment of an additional significant amount of time

CONCLUSION

In conclusion, the experiment proved that aluminum, and presumably all FCC metals, do not undergo a ductile-to-brittle transition, unlike steel and other BCC metals (as seen in Figures 1 & 2). Yet, Figure 2 displays a transition curve, however this can be attributed to the lack of multiple data points (since materials were only tested at 4 temperatures) and other sources of experimental error. These conclusions were deduced by qualitative analysis of the sample fracture surfaces, as well as a quantitative analysis of the energy recorded during impact testing. Since the fracture cross-section of the steel -190°C and 0°C specimens were fairly smooth and low energy amounts of energy were required, it was deduced that steel was brittle at temperatures lower than 70°C. In contrast, the fracture cross-section of steel at temperatures about 70°C were rough and required significantly more energy, as did all of the aluminum samples, indicating that steel had transitioned to a ductile state and aluminum maintained its high ductility at all temperatures.

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APPENDIX

Ductile to Brittle Transition Temperature

$$DBTT_E = \frac{E_{max} + E_{min}}{2}$$

The above equation gives an energy value for where the Ductile to Brittle Transition Temperature is, for BCC metals. After calculations, the graph is then looked at and the corresponding temperature value is found using the energy value.