Washington University in St. Louis

MEMS 205 Mechanics and Materials Science Laboratory

Lab 1: Impact Test

Section: Group D (Tuesday 12 PM)

Lab Instructor: Dr. Sellers

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We hereby certify that the lab report herein is our original academic work, completed in accordance to the McKelvey School of Engineering and Undergraduate Student academic integrity policies, and submitted to fulfill the requirements of this assignment.

Aidan Murphy	Team Leader
Matthew Donaldson	Data Acquisition Manager
Isaac Sasser	Test Engineer
Andrew Brown	Quality Control Engineer

Abstract

This report looks into the ductile-to-brittle transition temperature of two materials by measuring the impact energy to determine the appropriateness of the material to be used in Yaktrax LLC new ice cleats. The impact energy of each material was tested with the Charpy test across a range of temperatures between -200 and 200 ℃. The results of this test are plotted with impact energy as a function of temperature. We found that Specimen A had a ductile to brittle transition temperature between 0℃ and -50℃, specifically at 0℃ based on our conservative estimation, with a low impact energy of 10 (Ft*Lb). While Specimen B did not have a ductile-to-transition temperature consistent impact energy of about 20 (Ft*Lb). From our data, we concluded that material B should be used for Yaktrax LLC new ice cleats due to its ductility throughout the temperature range and its superior impact energy in comparison to material A. This ductility is desired for two reasons. First, ductile failure gives a warning before failure, which is desirable for both ease of use and safety of the consumer. Second, over the course of the operating range, the ductile fracture of material B yields to a higher strength within the operating region.

Introduction

Our purpose is to select the most appropriate material, of unknown metals A and B, to[] construct new ice cleats for Yaktrax LLC. The cleats are intended to operate in temperatures between 0 °C and -50 °C. Therefore, we must determine which material, A or B, is more durable in these temperatures.

The durability comparison will be based on a study of each material's performance during fracture. There are two main modes of fracture in metals: ductile and brittle. Visually, the fracture surface of a ductile material is fibrous or dull and the fracture surface of a brittle material is granular or shiny. Ductile fracture is characterized by a high degree of plastic deformation before fracture while minimal to no plastic deformation develops before brittle fracture. As a result, ductile materials tend to be tougher than brittle materials, absorbing more energy than brittle materials prior to fracturing [1]. Therefore, a ductile material should be chosen to make the cleats if at all possible.

However, many metals undergo a ductile to brittle transition at a temperature known as the Ductile to Brittle Transition Temperature (DBTT). Figure 1 represents a graphical depiction of the ductile-to-brittle transition of metal as it related to impact energy. A metal deforms plastically when dislocations travel along slip planes in its lattice [2]. During slip, the atoms along a slip plane break their bonds and form new bonds farther along in the direction of slip. Thermal vibrations add energy to atoms, allowing them to break their bonds more easily, increasing the likelihood the material will slip before it fractures. As temperature increases, thermal vibrations increase, increasing the ductility of a material. As temperature decreases thermal vibration decreases, increasing the brittleness of a material [3]. When brittle fracture occurs, every bond on the boundary of the fracture breaks at once, causing the material to fail without plastic deformation.

However, not all metals undergo a ductile to brittle transition. For example, in FCC metals, which have a high number of slip planes because their lattice is close-packed [4], the amount of stress necessary to cause brittle failure is almost always lower than the stress needed to cause slip. Therefore, in many FCC materials, ductility is temperature independent, and plastic deformation will always occur before failure [3].

To determine our materials' failure characteristics, we will perform a Charpy test on samples of each material. The Charpy test measures the impact energy necessary to cause a sample to fracture. The sample is placed so that it spans two anvils as depicted in Fig. 2. A striker on the end of a pendulum (Fig. 3) is released from above the specimen, rupturing the specimen as the pendulum swings between the anvils. The rectangular specimen (Fig. 2) has a notch cut into the face opposite the striker (Fig 2.). When the specimen is contacted by the striker, the stress is greatest at the tip of the notch, causing the fracture to begin at the tip of the notch [1] and propagate toward the plane contacted by the striker. The “absorbed energy” or “impact energy” of specimen failure is measured as:

$$\Delta E = E_i - E_f \tag{1}$$

ΔE is the impact energy required to break the specimen, E_i is the potential energy of the striker before it is released, and E_f is the maximum potential energy of the striker after connecting with the specimen plus the energy lost by the pendulum due to friction [5]. An indicator of the Charpy impact machine records the ΔE of each impact test.

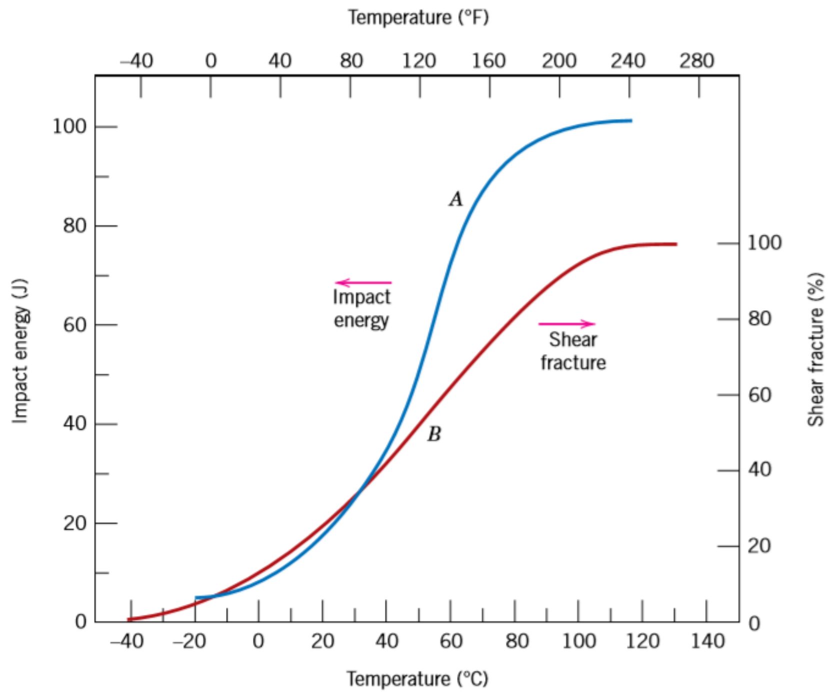

Fig. 1 Temperature dependence of the Charpy V-notch impact energy (curve A) for A283 steel [1].

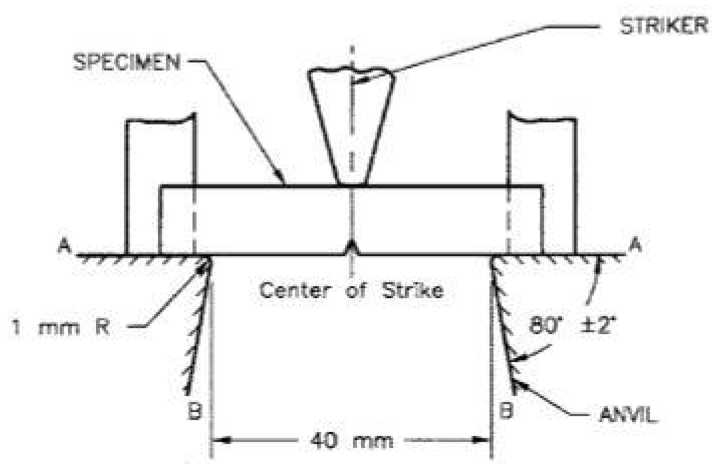

Fig. 2 Striker contracting type A V-notch specimen which is spanning anvils [5].

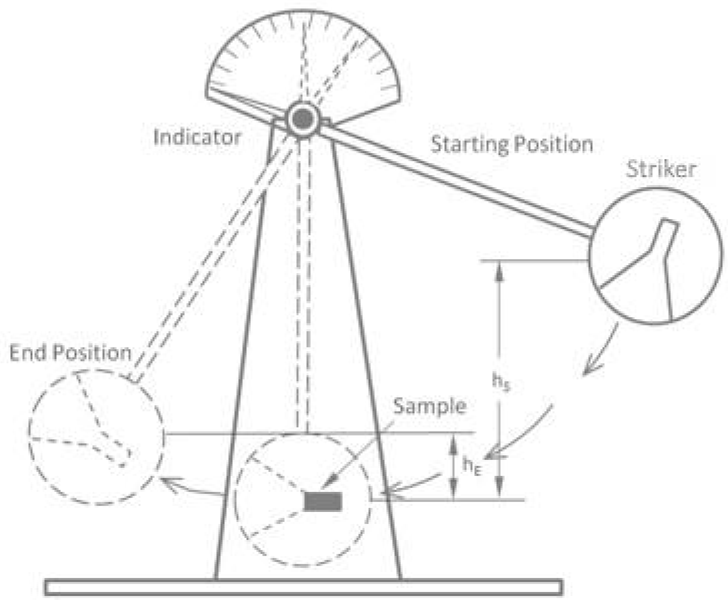

Fig. 3 Charpy test diagram with sample inserted and swing positions outline with dotted lines [6]

By performing the Charpy test on samples of material A and B across a broad range of temperatures, we will learn the fracture characteristics of each sample, determining if and when each material goes through a ductile to brittle transition. The material that is most ductile between 0 °C and -50 °C will be used to construct the Yaktrax LLC cleats because this material will be able to absorb the most energy before failing when operating in the specified temperature range.

Experimental Methods

To measure the impact energy of material A and B, we put eight pieces of each material at different temperatures. Each piece was Type A sample (center notch with a length of 55 mm and width and thickness of 10 mm) according to ASTM standards [5]. In order to control the temperature of the materials, samples of each material were placed in different environments. One sample of each material was placed in liquid nitrogen. Another pair of samples were placed in dry ice and ethanol, another placed in a freezer, another in a refrigerator, another at room temperature, and three pairs in electric furnaces set to different temperatures. The liquid nitrogen was in a dewar, and the dry ice with ethanol was in a styrofoam container under a hood. When the specimen was put into these containers they were submerged under the liquid. The pendulum was then placed in its holder a set distance, h_s, from the base of the machine seen in Fig. 3. We first did a dry run to see if there was any loss of energy due solely to the swing. After at least five minutes has passed with the specimen in test condition we then placed the specimen onto the base of the Charpy machine while someone was holding the pendulum. We tried to take no more than 5 seconds between the time it was in its controlled environment and the Charpy Machine. The specimen was arranged at the base with the notch centered and facing inwards. After the dial was set between 210-220 ft-lb, and no one was in the path of the pendulum or fragment zone, the Test Engineer yelled clear before the lever was pulled and the pendulum hit the specimen. The Test Engineer then caught the pendulum on its upswing and set it back in the holder before the fragments of the specimen were collected and put into a bag.

Table 1 below lists the equipment used in the lab. The Charpy machine measures the energy absorbed from the impact of the pendulum and the specimen through a dial at the top of the machine.

Table 1 Equipment used to measure impact energy.

Equipment	Serial Number	Quantity	Description	Tolerances
Charpy Machine	R13485	1	American Machine and Metal INC, RIEHLE Testing Machine Division	+/- 1
Electric Furnace	**01509106001130503** **0150913201130506** **01529080011105909**	3	Thermolyne, Thermo Scientific Model #: FB1315M	None
Styrofoam container	N/A	1	Insulated container	None
Dewar	N/A	1	Insulated container	None

Table 2 below lists the different testing conditions needed for the experiment with their temperature values.

Table 2 Testing Condition and their Temperature used in Experiment.

Conditions	Temperature (℃)
Liquid nitrogen	-200
Dry ice and ethanol (200 proof)	-60
Freezer	-12
Refrigerator	7
Room temperature	24
Variable Temperature Electric Furnace	50
	100
	200

Results and Discussion

Table 3 below lists the measured impact energies for both material A and material B depending on the exposed temperature were calculated using Eq.1, as well as the fractured surface appearance following each test.

Table 3 Impact energy and fracture surface appearance for both specimens at different temperatures.

Temperature (℃)	Impact Energy (Ft * lb)		Fracture Surface Appearance	
	Specimen A	Specimen B	Specimen A	Specimen B
-200	5	24	Brittle	Ductile
-60	10	23	Brittle	Ductile
-12	79	22	Ductile	Ductile
7	93	19	Ductile	Ductile
24	75	21	Ductile	Ductile
50	63	21	Ductile	Ductile
100	70	22	Ductile	Ductile
200	68	25	Ductile	Ductile

Figure 4 below shows the different fracture surface appearance for A36 steel at different temperatures, where the most brittle fracture is shown on the left and the most ductile fracture surface is on the right.

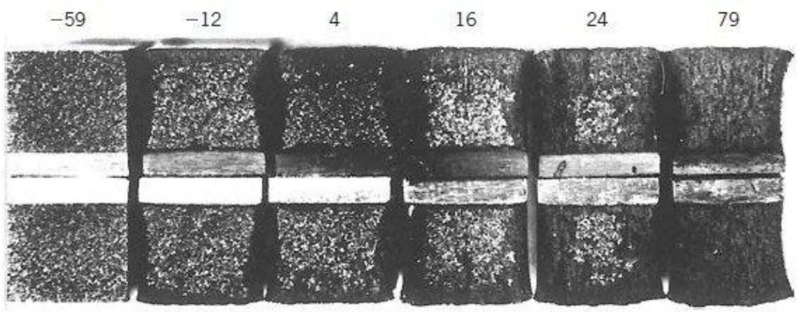

Fig. 4 Charpy test fracture surfaces of A36 steel at varying temperatures (°C) with fracture surface appearances shifting from brittle on the left to ductile on the right [1].

The following images, Fig. 5 depicts the different fracture surfaces of material A under two different temperature conditions. The image on the left is the sample of material A that was exposed to the refrigerator and the image on the right is the sample of material A that was immersed in liquid nitrogen. The left fracture surface appears to be the most brittle of our test and the right fracture surface appeared to be the most ductile.

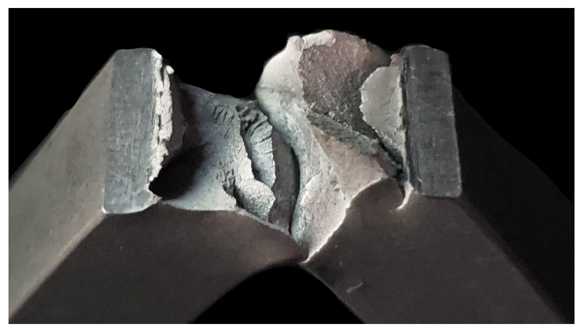

Fig. 5 Specimen A fracture surface under two separate conditions. The image on the left shows the brittle fracture of material A (-200 °C). This fracture is characterized by sharp edges and the absence of plastic deformation. The image on the right shows plastic deformation (7 °C), seen by the reduction in the diameter of the specimen.

Figure 6 below shows the Charpy test fracture surface the dry ice/ethanol exposed test for material B. This surface appears brittle at the center with some ductile attributes at the edges of the specimen.

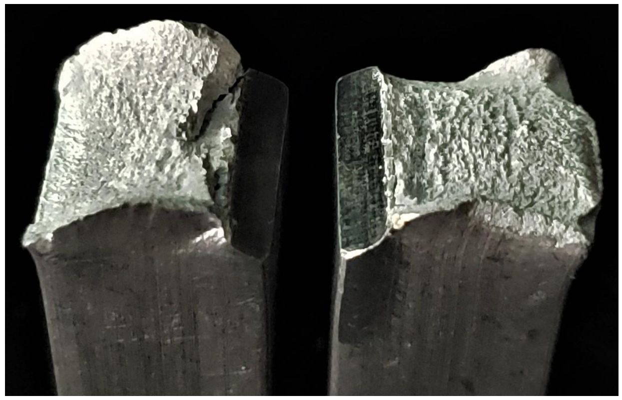

Fig. 6 Material B fracture surface for the dry ice/ethanol test sample. Plastic deformation can be seen in the pulling apart at the edges of the sample and a reduction in diameter.

Figure 7 below graphically represents the numerical data from Table 3, showing the linear behavior of material B and the transitional behavior of Specimen A. The transition from larger to smaller impact energies for Specimen A somewhere between -50 and 0°C.

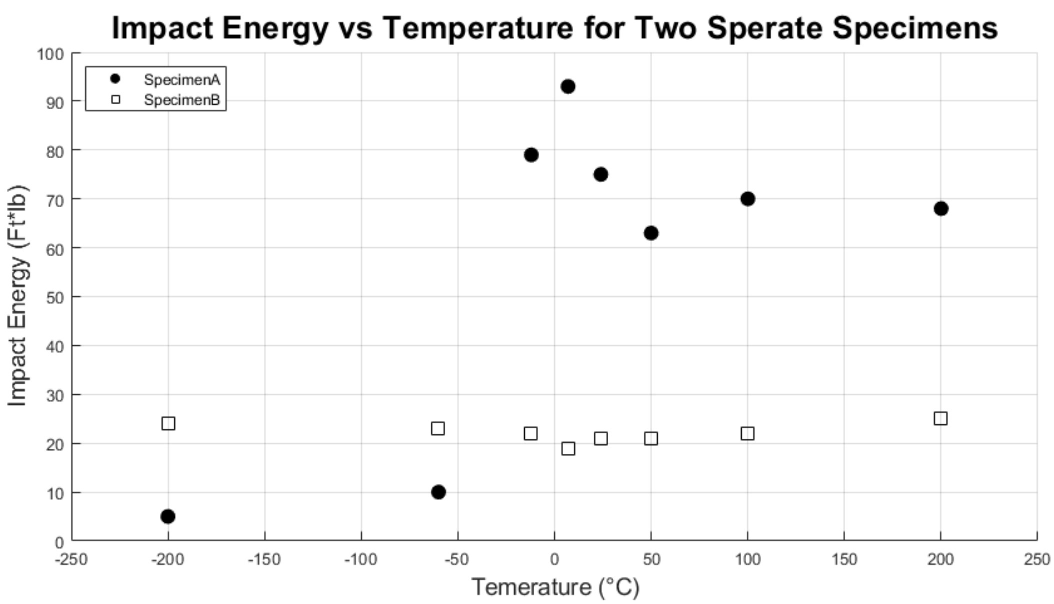

Fig. 7 Impact energy of both material A and material B for different temperatures that the specimens were exposed to. Material B shows a decrease in impact energy within the operating range as it undergoes ductile to brittle transition. Material B does not undergo a ductile to brittle transition and exhibits no temperature dependence.

When determining which of the proprietary materials is better suited for the task at hand, creation of Ice cleats, we must first attempt to define what better means. “Better” will be defined by analyzing properties of ductile versus brittle materials and the overall strength of the materials within the context of the given operating conditions.

The initial dry swing, with no inserted specimen, had an average impact energy of 3 ft*lb for to separate dry swings. The theoretical impact energy of the Charpy should be zero since all of the pendulum’s potential energy should be conserved throughout the swing, however, experimentally some of the potential energy is lost due to various factors. Friction within the pendulum’s joint is likely the largest contributing factor to this loss of potential energy.

We will first consider material A. In Fig. 5, the reader will see the relationship of impact energy and temperature for material A. From this figure, conclusions about the dependance of impact energy on the temperature of the specimen. What is seen in Fig. 5 is that the amount of energy absorbed by material A before fracture, which is directly proportional to the impact energy [5], depends heavily upon the temperature at which the impact occurs. Armed with this knowledge of the temperature dependence of material A, the reader may refer to Table 3 to see a comparison of impact to the visual observation of the type of fracture, ductile or brittle. Figure 5 shows a clear transition (namely a decrease) in the amount of energy absorbed as the temperature decreases. That decrease is typically associated with a ductile to brittle transition in the material [1]. With both the visual information in Table 3 and Fig. 3**,** and the data in Fig. 5, one can see that material A undergoes a ductile to brittle transition within the 0 °C to-50 °C operating range, specifically at 0°C. This transition temperature was determined by taking a conservative estimate of the DBTT by looking at the point at which material A starts to become brittle. This can be seen from both from Fig 5, looking at the change in the impact energy, and from Table 3 where the fracture surface becomes brittle [1]. While above material A has a significantly higher ability to absorb energy, strength, the transition within the operating range of 0 °C to-50 °C leads to two important implications. First, the decrease in strength previously mentioned. Second, a characteristic of brittle materials is they fail without warning [1]. Meaning, one second your ice cleats are doing great, and the next they fail without any signs even if you had just inspected them.

Next, we will consider material B. One can see from Fig. 5, that over the course of the entire testing range, there is a very small deviation from the mean value of impact energy. In addition, Fig. 3 shows a visual relationship of material B and temperature marked with triangles. As evidenced by both approaches, material B's strength does not depend upon the testing temperature. Materials with an FCC crystal structure generally do not undergo a ductile to brittle transition, as observed with material A, rather, FCC materials generally stay ductile at low temperatures [3]. Figure 3 shows the fracture surfaces of the two materials. As seen in the images, material B undergoes plastic deformation before fracture. This deformation can been seen in the reduction of diameter of each specimen at the fracture site. This reduction is known a phenomenon known as necking and it is characteristic feature of ductile fracture. Knowing that material B does not undergo a ductile to brittle transition as evidenced in Fig. 5 and Table 3 (which is common in FCC materials that remain ductile without temperature dependence), and from the images in Fig. 3, the team concluded that material B remains ductile over the entire testing range.

Conclusion

The Charpy test over the range testing temperatures -200 °C to 200 °C allowed the team to obtain a relationship of impact energy to temperature for the entire testing range. To answer the question of which material is "better," we recommend that Yaktrax LLC make their ice cleats out of material B. This recommendation is based on two main pieces of evidence. First, material A will undergo a ductile to brittle transition under the conditions for intended use. Despite a significantly higher strength at higher temperatures, under the conditions at which the ice cleats will be in use material A is brittle with a lower impact energy, strength, than material B. Furthermore, under the usage conditions, material A will fail without warning or indication of failure. This sudden failure is not a desirable trait, it is the belief of the team that a failure warning would be a desirable trait for both ease of use and safety of the consumer. Thus, because of the better strength within the operating range and the failure warning the team recommends that Yaktrax LLC make their ice cleats out of material B.

References

[1] Callister, W. D. and Rethwisch, D. G., 2018, *Fundamentals of Materials Science and Engineering: An Integrated Approach*, 5th ed. John Wiley & Sons Inc., NJ, chap 9.

[2] Callister, W. D. and Rethwisch, D. G., 2018, *Fundamentals of Materials Science and Engineering: An Integrated Approach*, 5th ed. John Wiley & Sons Inc., NJ, chap 8.

[3] Sutar, S. S., Kale, G. S., and Merad, S. H., 2014, "Analysis of Ductile-to-Brittle Transition Temperature of Mild Steel," International Journal Of Innovations In Engineering Research And Technology, **1**(1), pp. 1-10.

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[6] Zhang, W., 2016, "Technical Problems Identifications for the Failures of the Liberty Ship", MPDI AG, **7**(20), pp. 6. From https://www.researchgate.net/publication/310374263_Technical_Problem_Identification_for_the_Failures_of_the_Liberty_Ships

Appendix A

Test numbers, temperatures, and impacte energy raw data for the Charpy test results

Test Number	Temperature Source	Temperature (℃)	Impact Energy (Ft * lb)	
			Specimen A	Specimen B
3	Dry Ice/ Ethanol	-60	9.5	23
2	Freezer	-12	79	21.5
8	Refrigerator	7	93	19
1	Room Temperature	24	75	21
5	Variable Temperature Electric Furnace	50	63	21
7		100	70	22
6		200	68	25