Middle East Technical University

Department of Metallurgical and Material Engineering

Mete206 – Materials Processing Laboratory

Experiment 6: Charpy Impact Test

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ABSTRACT

In this experiment, 9 samples of the materials Aluminum, C-Steel and PVC was prepared and their impact energies at different temperatures were measured and recorded to find out how toughness changes with temperature. It was observed that C-Steel and PVC showed the characteristics of brittle structure at lower temperature meaning that they go through ductile to brittle transformation. For aluminum this was not observed. It was also observed that less amount of lateral expansion was observed for PVC and C-Steel as the temperature decreased and they showed characteristic behavior of a brittle material.

INTRODUCTION

In materials engineering it is very important to know the material that one is meaning that one should know how the material behaves in certain situations and environments. To know the materials properties certain tests are performed to make analysis. One of the important properties that must be known is how the material fractures where fracture is the material separating into one or pieces (Callister & Rethwisch, 2016). Moreover, fracture can be said to be categorized under two categories which are namely ductile and brittle fracture. Whether a material has underwent ductile or brittle fracture can be easily identified by examining the samples after a tensile test. A material that has had a ductile fracture can be identified from the plastic deformation that would have occurred at the fracture point where else for a brittle material after the fracture the surface would be relatively smoother and it would more look like a clean cut. As mentioned, it is an important to identify how a material fracture. A material that is ductile would be much more forgiving in case of a failure and it may save lives. Figure 1 illustrates the two types of fracture that might occur.

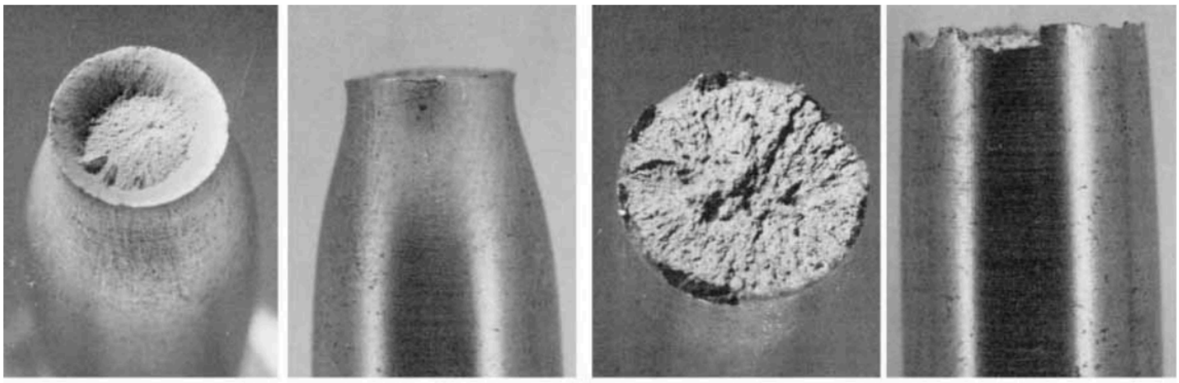


Figure 1. Images of two samples that fractured in a ductile and brittle manner (Becker, 2002)

The environment as well as the conditions that a materials life would be carried out is highly important during the engineering of a material for a certain application. The tensile test gives one certain information about the material however under certain different conditions a material can behave in a manner very different from what is requested. Toughness is one of the parameters that is used in design and it can be considered as the energy needed to break the material. It is a property that can be found from the area under the stress-strain curve which one can obtain after a tensile test (NDT resource center, n.d). However, as mentioned the temperature of the environment, the rate of loading and the notch effect (NDT resource center, n.d) will have an impact on the value of the toughness that is exhibited by a material. The temperature can lead to a ductile material acting as a brittle one which is defined as ductile to brittle transition (Callister & Rethwisch, 2016). The rate of loading, for example

with cyclic stresses can lead to fracture at a point where one would expect it to be still in elastic region in the stress-strain curve meaning that due to changing rates of loading exerted on a material the material can fracture below that of its tensile or yield strength. It is important to note that in every surface there would be a flaw which makes the notch effect very important. The geometry of the notch which is characterized by the stress concentration factor (Qu, Zhang, & ZhefengZhang, 2014) significantly impacts the toughness of a material. The stress concentration that can occur due to flaws can lead to the fracture of a material once again below that of its tensile or yield strength.
Now that what affects the toughness of a material is known, it is time to talk about how one can measure this toughness. There are multiple ways that impact testing can be done but, in this experiment, it was done using the Charpy V notch technique. It is a technique where a sample of specified size that has a notch with known dimensions getting hit by a pendulum and the energy is determined from the change in height of the pendulum (E.Hughes, 2009). The test can be done in different temperatures and the resulting temperature vs impact energy graph can give one an idea of the ductile to brittle transformation of the material. It has been mentioned that the area under the stress-strain curve obtained from the tensile test can also give one the toughness of the material however, there are some differences. In the tensile strength there is not a notch with known dimensions on the sample. In addition, in the life of a material generally it is exposed to an impact which is similar to that of the Charpy test and not like the tensile test where a force is suddenly applied on the material. This makes the Charpy test more accurate in most situations. Finally, with Charpy test it is possible to obtain a temperature vs impact energy graph which is very critical.

EXPERIMENTAL

Equipment

- Charpy Testing Machine 358J and 15J
- Tongs
- Tray
- Beakers
- Digital Thermometers
- Calipers
- Refrigerator

Materials

- Boiling Water
- Salt
- Standardized C-Steel for Charpy testing
- Standardized Aluminum for Charpy testing
- Standardized PVC for Charpy testing

Procedure

First it was checked that the samples are up par with the standards and they are ready for testing and to that the dimensions of the samples were measured by using a digital caliper. It was also double checked by using a “go - no go” sample. Now that the samples were known to fit the standards, the width of the sample just behind the notch was measured for each sample. To begin the Charpy test, the Charpy testing machine of 358 J was first used for C-Steel and Aluminum and a 15 j Charpy testing machine was used to determine the impact energy for PVC samples. While the test was done for different temperatures the -20 degrees sample was gotten from the refrigerator and 90 degrees sample was gotten from boiling water. The test for these two samples had to be done very quickly as to not skew the result obtained from the experiment. The testing was done for all temperatures and the impact energies were noted. After the experiment the width of the sample was once again measured and also the images of the fracture area were also taken.

RESULT

In this experiment, 9 samples of the same material were prepared and tested.

Table 1. The impact energy data of samples at certain temperature

Sample No	Material	Temperature (°C)	Impact Energy (J)	Average impact energy	Standar Deviation Of Impact Energy
1 2 3	Aluminium	90.00	35 35 37	35.67	1.15
4 5 6	Aluminium	90.00	32 33 32	32.33	0.58
7 8 9	Aluminium	90.00	31 33 31	31.67	1.15
10 11 12	C-Steel	20.00	64 65 61	63.33	2.08
13 14 15	C-Steel	20.00	22 21 21	21.33	0.58
16 17 18	C-Steel	20.00	13 9 13	11.67	2.31
19 20 21	PVC	-20.00	10.05 11.26 11.41	10.91	0.75
22 23 24	PVC	-20.00	0.56 0.63 0.83	0.67	0.14
25 26 27	PVC	-20.00	0.46 0.55 0.6	0.54	0.07

Table 1 shows the impact energies measured from the Charpy test at various temperatures and for three different materials. Three different measurements is done to get a more accurate result. The averages of the three measurements will be taken into account for the plotting of impact energies vs temperature graph and the standard deviation is also calculated and it is taken as the error for the measurements.

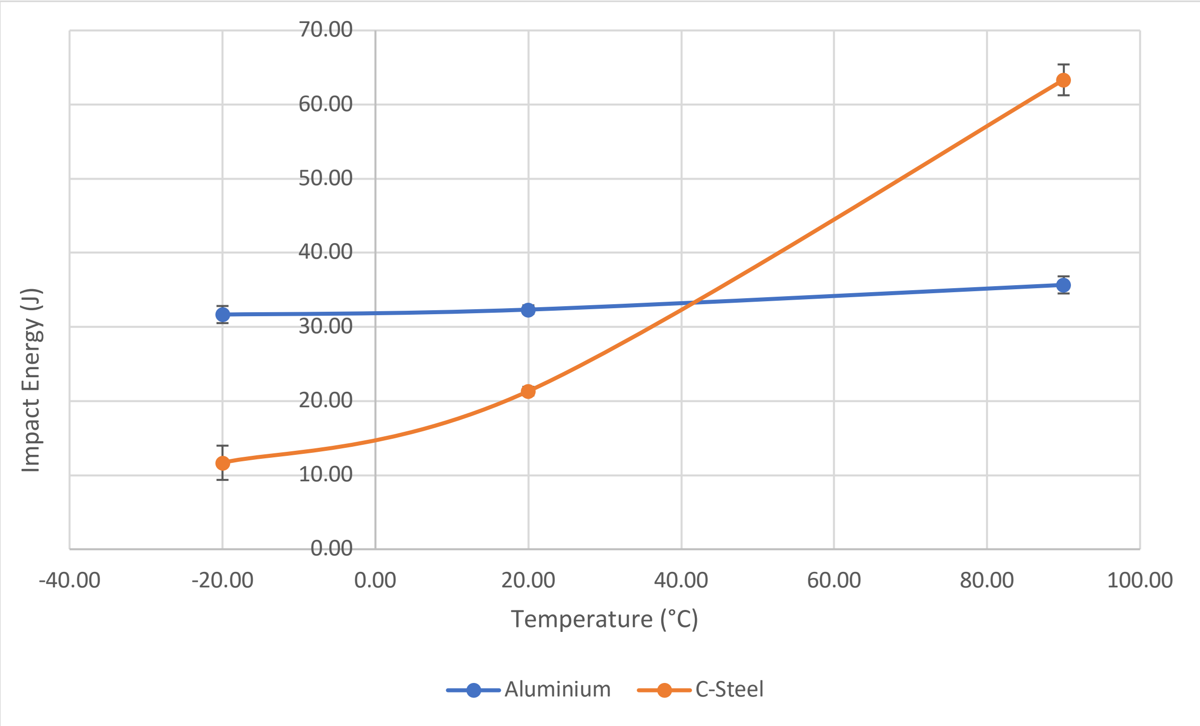


Figure 2. Temperature vs Impact energy graph for Aluminum and C-Steel

As mentioned by using the average values the temperature vs impact energy graph for aluminum and C-steel is plotted and it can be seen in figure 2.

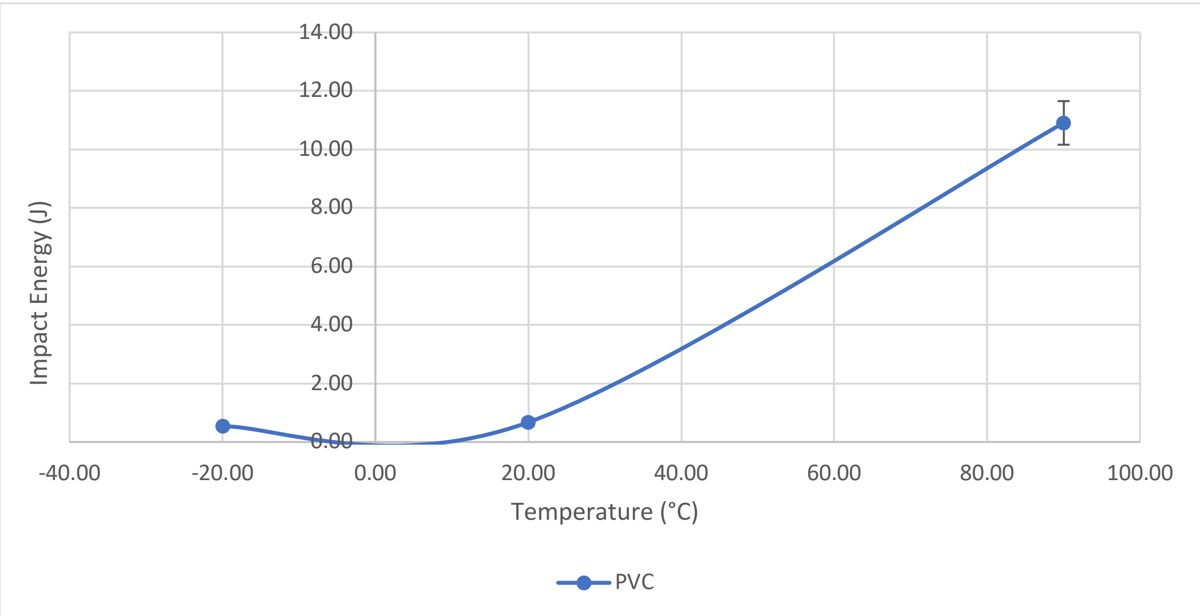


Figure 3. Temperature vs Impact energy graph for PVC

In figure 3, The average values taken of the three impact energies vs the temperature is once again observed.

Table 2. The lateral expansion data of samples at certain temperature

Sample No	Material	Temperature (°C)	Change in Length	Average Change in Length	Standar Deviation Of change in Length
1			0.77		
2	Aluminium	90.00	0.48	0.59	0.16
3			0.51		
4			0.13		
5	Aluminium	20.00	0.59	0.44	0.27
6			0.61		
7			0.64		
8	Aluminium	-20.00	0.48	0.54	0.09
9			0.5		
10			0.29		
11	C-Steel	90.00	0.75	0.63	0.30
12			0.84		
13			0.13		
14	C-Steel	20.00	0	0.08	0.07
15			0.1		
16			0.13		
17	C-Steel	-20.00	0.11	0.09	0.06
18			0.02		
19			0.52		
20	PVC	90.00	0.5	0.49	0.04
21			0.44		
22			0.29		
23	PVC	20.00	0.16	0.17	0.12
24			0.06		
25			0.36		
26	PVC	-20.00	0.13	0.17	0.18
27			0.01		

Table 2 gives the data on the lateral expansion for samples that underwent Charpy's test at different temperatures. The average values as well as the standard deviation of the samples were also computed and shown in table 2.

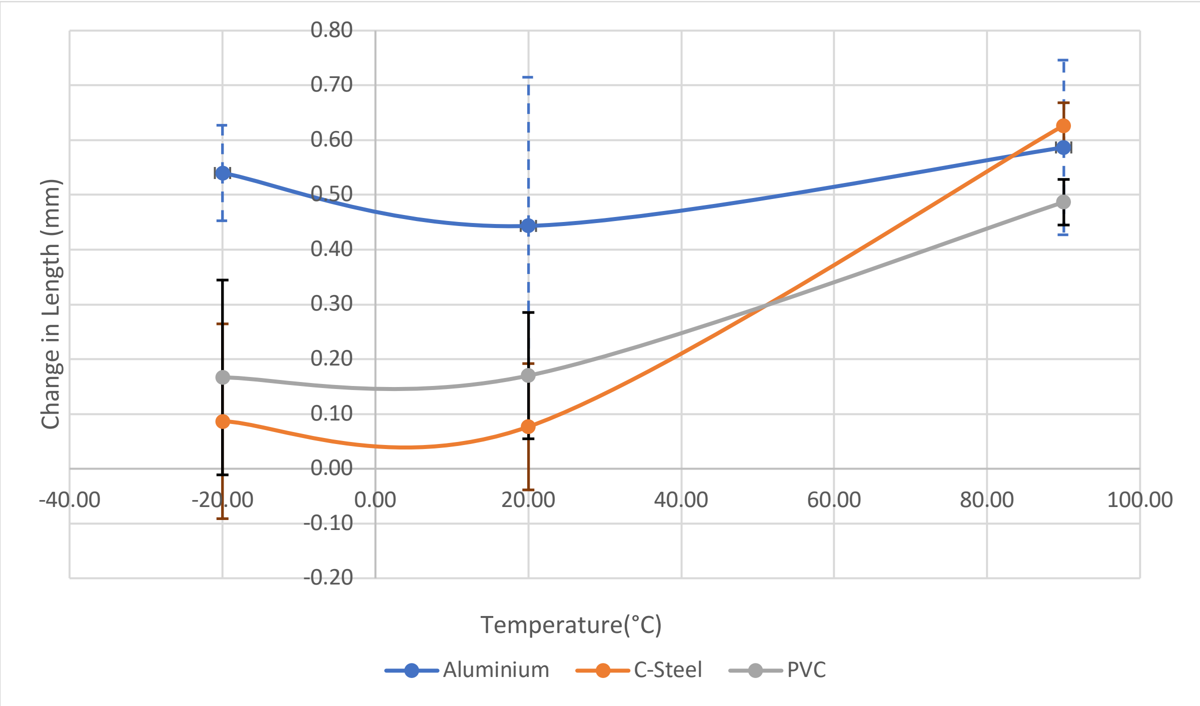
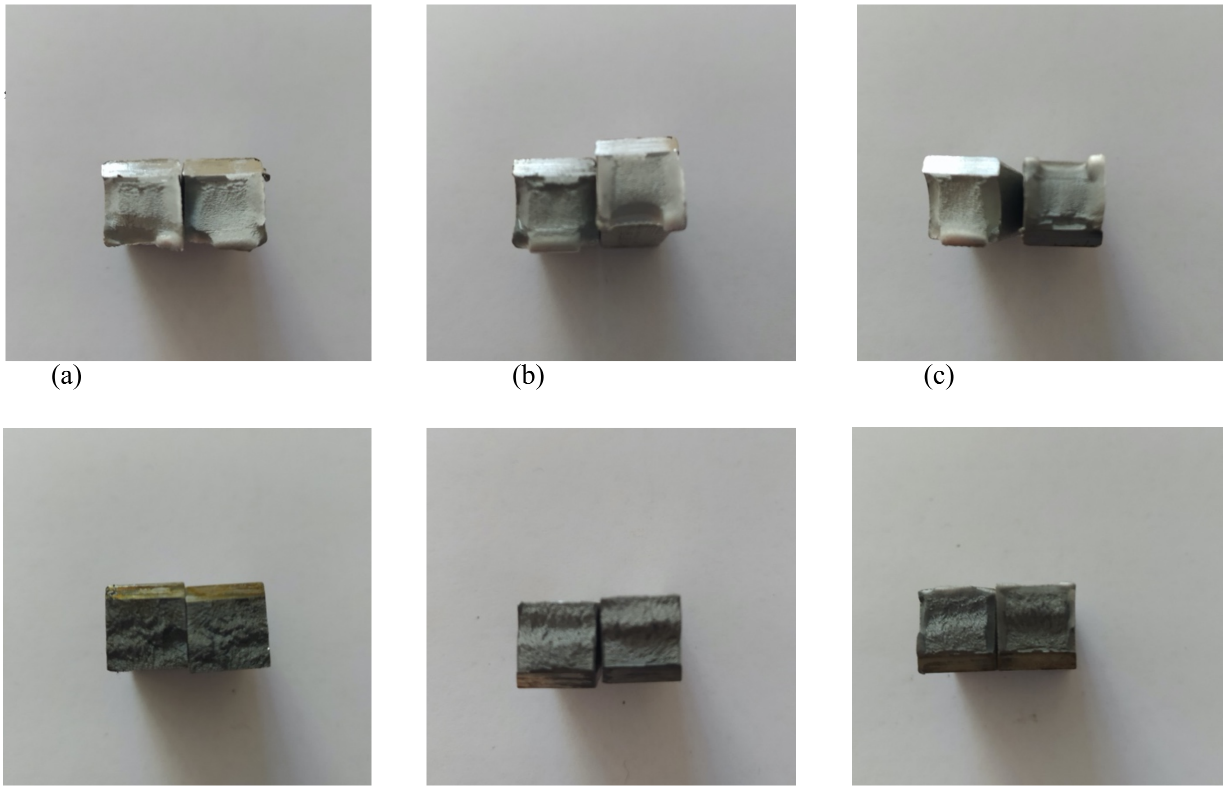


Figure 4. Temperature vs Δ*L* graph for PVC, C-Steel, Aluminum

Figure 4 is the plot of the data that can be found in table 2. It gives the lateral expansion of the samples at different temperatures after the Charpy test.



(a) (b) (c)

(d) (e) (f)

Figure 5. Samples after the Charpy testing where (a) is aluminum at -20 ℃ (b) aluminum at 20 ℃ (c) aluminum at 90 ℃ (d) C-Steel at -20 ℃ (e) C-Steel at 20 ℃ (f) C-Steel at 90 ℃

Figure 5 is the sample’s picture taken after the Charpy impact testing has been completed.

DISCUSSION

In this experiment, it was aimed to observe how the temperature would affect the impact testing for different kind of materials and the lateral expansion that would occur as a result of the testing.

First of all, it needs to be noted that all of the materials were in an equal standard state. This is very important as the geometry of the sample as well as the notch is critical on the toughness value of the material and it needs to be double checked whether the sample is up par with the standard that is wanted. In figure 2, the plot of temperature vs impact energy can be found for aluminum and C-steel. This graph allows one to examine the temperature dependency of the materials toughness and an analysis of the ductile to brittle transformation can be made. When it is looked at figure 2 it is seen that aluminum has a relatively constant impact energy change over temperature, where else the C-Steel show an increase in the impact energy as temperature increases. The reason can be corelated with their crystal structure as it is known that Aluminum has a FCC crystal structure and C-Steel has BCC type of crystal structure. It is also known that, Most FCC metals does not display ductile to brittle transformation along with high strength materials where they are also mostly independent of temperature for their impact energy (Callister & Rethwisch, 2016). Figure 3 is also a plot of the impact energy vs temperature graph but this time for the material, PVC. When this plot is examined once again a similar behavior to that of C-Steel is observed. It can be said that in figure 2 and 3 C-steel and PVC shows the characteristics of ductile to brittle transformation. At higher temperatures a relatively large toughness energy can be observed but as the temperature decreases the energy needed to fracture the material decreases. This means that at higher temperatures they may show the characteristics of a ductile material however, with the decrease in temperature they behave out of character and exhibit the properties of a brittle material.

It is true that PVC and C-Steel behave in a similar way but there are some differences between them. PVC is a thermoplastic polymer and it is seen that it behaves as brittle at low temperatures and ductile at high ones. It is due to the fact that when the temperature is above that of the glass transition temperature it is in a rubbery state and can behave in a ductile manner and if its lower than T_g Than it is in amorphous solid state and it will behave as brittle (Callister & Rethwisch, 2016). The ductile to brittle transformation for C-Steel however is related to its slip systems. Therefore, it is correct to say that PVC and C-Steel does exhibit similar ductile to brittle transformation however the mechanism behind them is different.

The crystal structure of a material is already determined as highly important for the toughness behavior that it exhibits at different temperatures. It was concluded that the BCC C-Steel is dependent of the temperature and can display ductile to brittle transformation and the FCC aluminum acts oppositely and it is independent of the temperature for the toughness that it displays.

One of the important ways to understand what happened to a material in its failure is by doing a visual inspection. There is a lot of information that can be obtained by analyzing the area that the fracture has occurred. In this experiment the photos of the samples were taken after the Charpy test and it can be found in figure 5. First, when the images of aluminum are examined after testing at various temperatures it can be seen that the surface went through some amount of plastic deformation which is the characteristic of a ductile fracture. This is true for all of the temperatures that the test is done for aluminum because it is said many times that FCC aluminum does not show any temperature dependency for the toughness it shows. Now, if C-steel is examined starting from the test done at 90 degrees, once again characteristics of a ductile fracture is observed which is expected from a C-Steel at high temperatures that hadn’t yet shown any transformation to being brittle. At 20 degrees the impact energy that it shows some decrease and this can also be observed from the specimen as the amount of plastic deformation that has occurred seems to look like it also lessened. Finally, at -20 degrees C-Steel shows a behavior of a brittle material. When the image is examined the plastic deformation seen on the other two cases seems to significantly decreased.

The Charpy test is very useful when comparing materials with each other for their impact energy values and also see the trend that they show for their ductile to brittle transformation. However, to get accurate results to use the Charpy test would be an error. They show little value on using the values of the test at very sensitive, engineering design. They are however, relatively cheap to conduct and also gives clue on the materials behavior therefore it is still a widely done test.

Apart from this test other tests such as Izod test and K_{Ic} tests are also done (E.Hughes, 2009). The difference between the Izod test and the Charpy test comes from the way that the sample is supported and it is also important to note that K_{Ic} tests is relative more expensive than these tests (Callister & Rethwisch, 2016).

Finally, when the values of lateral expansion is observed, which the data can be found in table 2 and a plot of temperature vs change in figure 4, it is seen that aluminum once again displays stable change in lateral expansion at all temperatures. PVC and C-Steel also display a relatively high amount of lateral expansion at 90 degrees where they both exhibit the behavior of a ductile material however with the decrease in temperature the lateral expansion also drastically decreases for both of them. This is due to the fact that they now behave in a brittle manner and in a brittle fracture plastic deformation does not occur as much. This further proves that they both displayed ductile to brittle transformation. It is also important to realize that there is a high amount of error for these measurements however the general trend is at is which does not change the conclusion.

CONCLUSION

To summarize this experiment, it was aimed to understand the impact energies of certain materials displayed and how this value changed with temperature. The impact energy was calculated by using one of the common tests that is done and that is the Charpy test. 9 different samples were for each material were used in the duration of the experiment and it was concluded that PVC and C-Steel exhibited the behavior of ductile to brittle transformation however on different mechanism and the FCC aluminum displayed no change in the impact energy values with the change in temperature. This was corelated to the importance of crystal structures. Some amount of error was also observed on the measurements which came from the equipment, sample, human flaws. In general, it can be said that the ductile to brittle transformation needs to be taken into very serious consideration as if not it very likely for a catastrophe to occur.

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