CERTIFICATION OF APPROVAL

Effects of Curvature on Impact Testing of Mild Steel SS400

by

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

The main objective of this project is to study the effects of pipe curvature on the results of impact tests. Impact test on pipes are typically performed on curved samples, and subsequent materials comparison are frequently conducted against results obtained from impact tests performed using flat samples. The main result that is compared is the ductile-to-brittle transition temperature. Previous work has suggested that the impact test results for flat and curved samples are not similar. In this work, the specimens were prepared according to ASTM standard E23 and the same standard was also used for laboratory testing. The steel evaluated in this study was mild steel SS400. Both flat and curved samples were fabricated and the pipe curvatures chosen were comparable to pipe sizes of NPS 4, NPS 6, NPS 12 and NPS 20. Testing of the samples was conducted at various temperatures ranging from -60^{o}C to 80^{o}C. The results from this work confirmed that the transition temperature for flat and curved samples of mild steel SS400 are different.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Steel is an alloy that consists mostly of iron and has carbon content between 0.2% and 2.1% by weight, depending on the grade. The brittle fracture of steels is the main cause of several historical accidents, like those with the Liberty ships in World War II [1]. Since the 1950's, brittle fracture have been intensively studied, and nowadays the Charpy impact test, regulated by ASTM E23-96 and in Brazil by NBR 6157, is one of the most important methods used to study the brittle behavior of metals and alloys.

The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test, which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent brittle-ductile transition. It is widely applied in industry, since it is easy to prepare and conduct, and results can be obtained quickly and cheaply. But a major disadvantage is that all results are only comparative [1].

The four most common impact test procedures in use around the world are probably ISO 148 - “Steel-Charpy impact test (V-notch)", ASTM E 23 - “Standard Test Methods for Notched Bar Impact Testing of Metallic Materials”, EN - 10045 “Charpy Impact Test for Metallic Materials”, and JIS Z2242 - “Method for Impact Test for Metallic Materials”. While these four methods have some similarities, they also have differences in the details of the procedures. Much current research is directed toward both improving these (and other) standardized procedures, trying to understand the effect of their differences, and moving toward harmonization [2].

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With the inclusion of transverse impact toughness requirements in the American Petroleum Institute (API) specifications as well as various companies' specifications, the need arose for evaluating the effects of curvature and flat sample to determine the degree of influence of these effects [3].

Basically the normal impact test uses a flat specimen, however in this study, a curved sample, which reflects the curvature of a pipe will be used to observe the impact energies at different temperatures in tests conducted using mild steel SS400. The results from the curved samples will be compared to results obtained from flat samples. It is initially anticipated that although the impact energy values might be different between flat and curved samples, the ductile-to-brittle-transition temperature were expected to be the same, since sample geometry was not considered to have any effects on the transition temperature.

1.2 Problem Statement

Typical impact test on pipes are performed on curved samples, and subsequent materials comparison are frequently conducted against results obtained from flat samples. Although many studies have been conducted concerning non-standard Charpy V-Notched specimens, none have addressed the influence of specimen curvature on impact test results.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The objective of this project is to study the effects of pipe curvature on impact tests. Four different curvatures that reflect various pipe sizes will be tested, and the ductile-to-brittle transition temperature will be observed.

1.3.2 Scope of Study and Work

The material used for this study is mild steel SS400. The test standard used throughout the project is ASTM E 23. The samples produced for the Charpy Impact Test reflect pipe sizes of NPS 4, NPS 6, NPS 12 and NPS 20. They were produced using EDM wire cut machine and the thickness of these samples is 10 mm. Temperatures between -60°C to 80°C was chosen for the impact tests to determine the ductile-to-brittle transition temperature.

CHAPTER 2
LITERATURE REVIEW

2.1 Impact Tests (Izod versus Charpy)

Basically there are two types of impact test, which are Charpy Impact Test and Izod Test. Both of these tests are not the same. One of the criteria that differ is their specimen and loading configuration (see Figure 1). The Izod test involved the striker, the testing material, and the pendulum. The striker was fixed at the end of the pendulum. The test material was fastened in a vertical position at the bottom, and the notch is facing the striker. The striker swings downward, hitting the test material in the middle, at the bottom of its swing, and is left free at the top. The notch is placed to concentrate the stress, and provoke delicate failure. It lowers distortion and decreases the ductile fracture. The test was done easily and quickly to examine the quality of the materials, and test whether it meets the specific force of collision properties. It is also used to evaluate the materials for overall hardiness. It is not applicable to compound materials because of the influence of complicated and inconsistent failure modes.

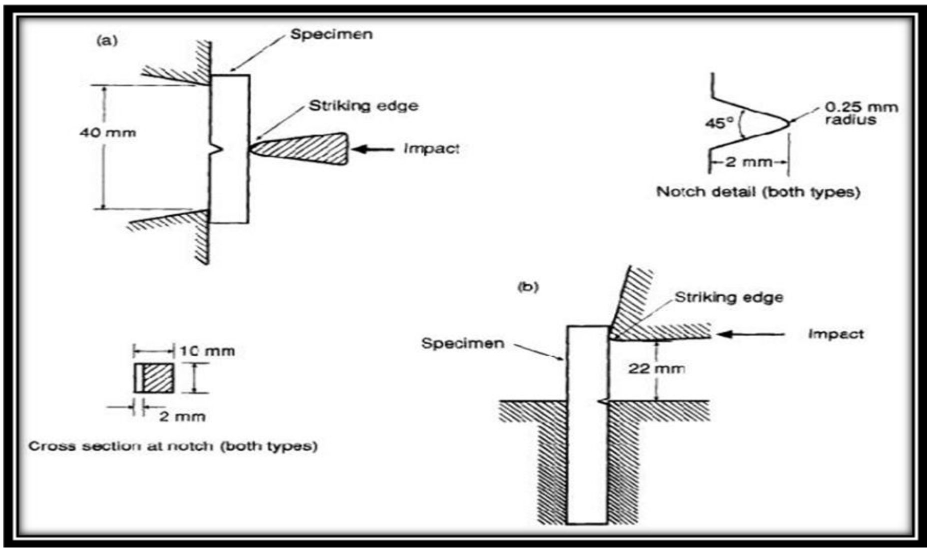


Figure 1: Specimens and Loading Configurations for (a) Charpy V-Notch and (b) Izod Tests

The Charpy method involves striking an appropriate test material with a striker fastened at the end of a pendulum. The test material is secured horizontally in place at both ends, and the striker hits the center of the test material, behind a machined notch. The notch is positioned away from the striker, fastened in a pendulum. The test material usually measures 55×10x10 millimeters (see Figure 2). The Charpy method has a machined notch across one of the larger faces. There are two types of charpy notch, a V-notch or a U-notch. The V-notch, or the AV-shaped notch, measures 2 millimeters deep, with a 45 degree angle and 0.25 millimeter radius, parallel to the base. The U-notch, or keyhole notch, is 5 millimeters deep notch, with a 1 millimeter radius at the bottom of the notch. Higher speeds and collision energy could be achieved in a vertical style fall. This method proved to be reliable, and gave qualitative collision data [2, 4]. Figure 2 below shows the Charpy Test Specimen that was usually used in industry.

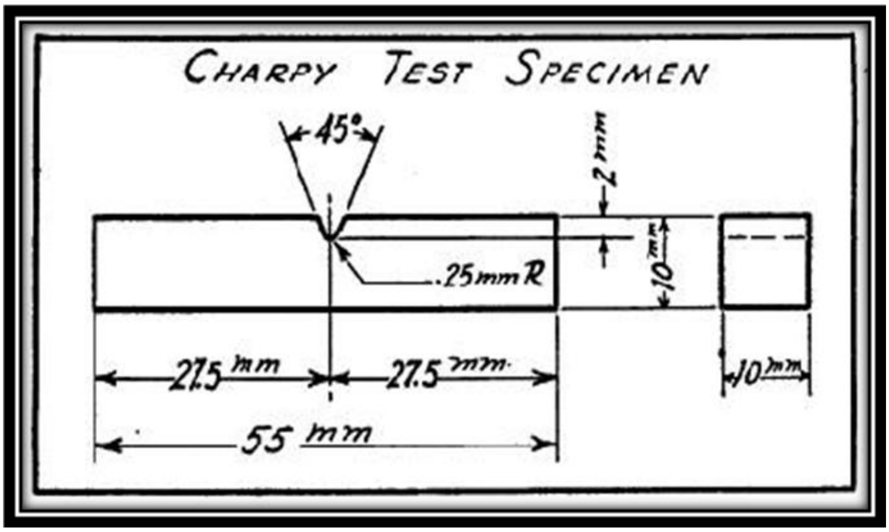


Figure 2: Charpy Test Specimen

2.2 Sample of tapers specimen by George M. Waid and Harry Zantopulos [3]

Charpy impact tests were conducted on specimens having various amounts of curvature and on flattened sample to determine the degree of influence of these effects. Tapering the specimens by as much as 75% or this much curvature did not have significant effect on the CVN energy. Flattening of the tubes before testing reduced the CVN energy by about 4%. The test specimens used in the curvature study were taken from the mid-wall location of 243.1 mm(9.571")OD x 24.5 mm (0.963") wall tubing made from a modified 4130(4130M7) alloy steel which was developed for the oil and gas industry where high impact toughness properties and sulfide stress cracking resistance was needed for deep wells. The Charpy specimens were machined to various sizes to simulate different tubing and pipe diameters. Figure 3, taken from the API 5CT specification, shows the curvature allowances permitted. The tapers, machined for this study, ranged from no taper to 1/4 the original thickness, which is greater taper than specified by API 5CT [3].

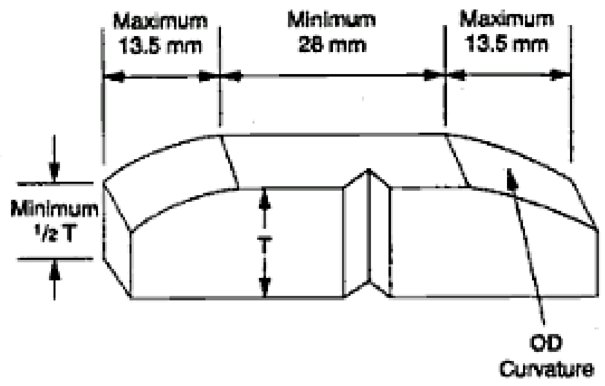


Figure 3: Charpy V-Notch Impact Test Specimens OD Curvature Allowance

2.3 Ductile to Brittle Transition Temperature

The ductile-brittle transition (Figure 4) is exhibited in body-centered cubic (BCC) metals, such as low carbon steel, which become brittle at low temperature or at very high strain rates. Face-Centered Cubic (FCC) metals, however generally remain ductile at low temperatures. In metals, plastic deformation at room temperature occurs by dislocation motion. The stress required to move a dislocation depends on the atomic bonding, crystal structure and obstacles such as solute atoms, grain boundaries, precipitate particles and other dislocations. If the stress required to move the dislocation is too high, the metal will fail by the propagation of cracks and the failure will be brittle [5].

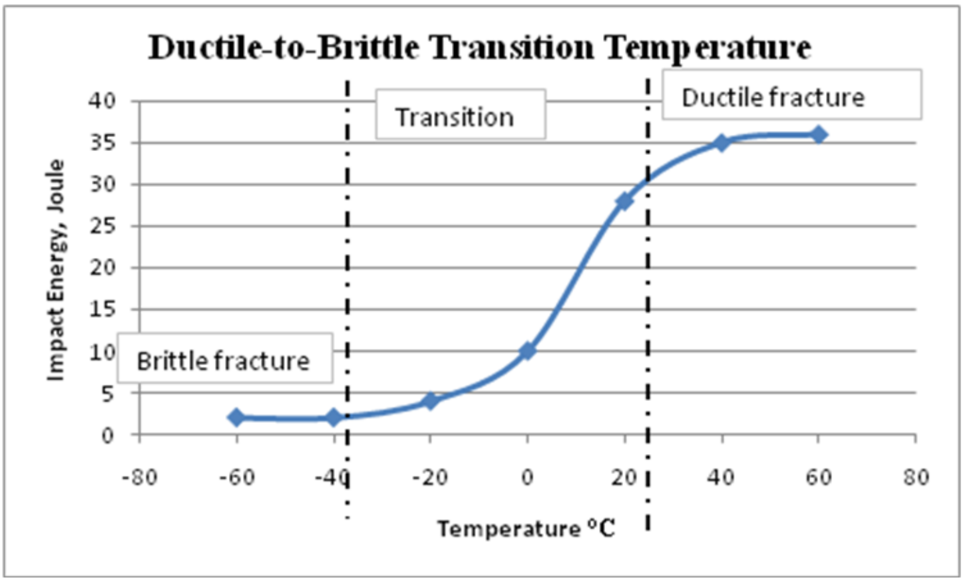


Figure 4: Ductile to Brittle Transition Temperature

The brittle fracture macroscopic behavior is related to the absence of plastic deformation, and the most usual microscopic fracture mechanism is cleavage, which is the separation of the lowest density planes in a crystallographic structure, and it occurs when there are no active slip systems capable to promote plastic deformation. Considering plastic deformation in metals and alloys as a thermally activated process, at "low" temperatures cleavage will occur. For carbon and low-alloy steels, cleavage is usually the fracture mechanism at temperatures below 25°C.

The simplest way to characterize a brittle fracture is by quantifying how much energy it absorbs to fracture: generally speaking, brittle fractures absorb low energy. On the other hand, ductile fractures, which are related to large amounts of plastic deformation, absorb high-energy values. This energy is called the toughness of the material, and its measurement as a temperature function is the fundamental of Charpy impact test. The absorbed energy is plotted against the test temperature and a "ductile-to-brittle transition temperature" (DBTT) could be determined as the maximum temperature where the cleavage fracture is the most important fracture mechanism. One way to determine the DBTT is by assuming that it happens at the mean energy value between the maximum energy value (at the upper shelf energy in the energy *vs.* temperature diagram) and minimum energy value (at the lower shelf energy in the energy *vs.* temperature diagram). Not only cleavage could impose a brittle fracture to steel. The presence of brittle inclusions and carbides, or weak interfaces between them and the metallic matrix, associated with mechanical "layering" imposed by metalworking (as in rolling), could reduce the total absorbed energy and promote brittle fractures. Large grain sizes are another occurrence that could reduce the total absorbed energy, considering that fracture (specially the cleavage one) has to be nucleated at each grain boundary, and this nucleation is a process that absorbs energy [6].

2.4 Mild Steel SS400

For this project, the material chosen for the specimen was mild steel (SS400).The reason that this material was chosen because it is a body-centered cubic (BCC) metal. This is important since the ductile-brittle transition is exhibited in body-centered cubic (BCC) metals as stated previously. Moreover it is easy to machine and it fits the purpose of this project. Table 1 and Table 2 show the chemical composition and the mechanical properties of SS400 steel [7].

Table 1: Chemical composition of the SS400 steel (wt %)

C	Mn	Si	P	S	Al	N
0.085~0.12	**1.14~1~17**	**0.18~0.19**	**0.0015**	**0.060**	**0.038**	**0.006**

Table 2: Typical Mechanical properties of the SS400 steel

Yield strength, σ_s/MPa	Tensile strength, σ_b/MPa	σ_s / σ_b	Elongation, δ_s /%	Cold bending
420~450	**520~550**	**0.81~0.82**	**28~36**	**qualified**

CHAPTER 3
METHODOLOGY

3.1 Process Flow

This project is a lab-based project. The results can only be gained by doing the lab experiment. The project contains several important steps such as problem definition and identification, literature review, designing of samples, processing of the material, fabricating of samples, testing, data analysis and result. These steps can be seen in the flow chart below (Figure 5).

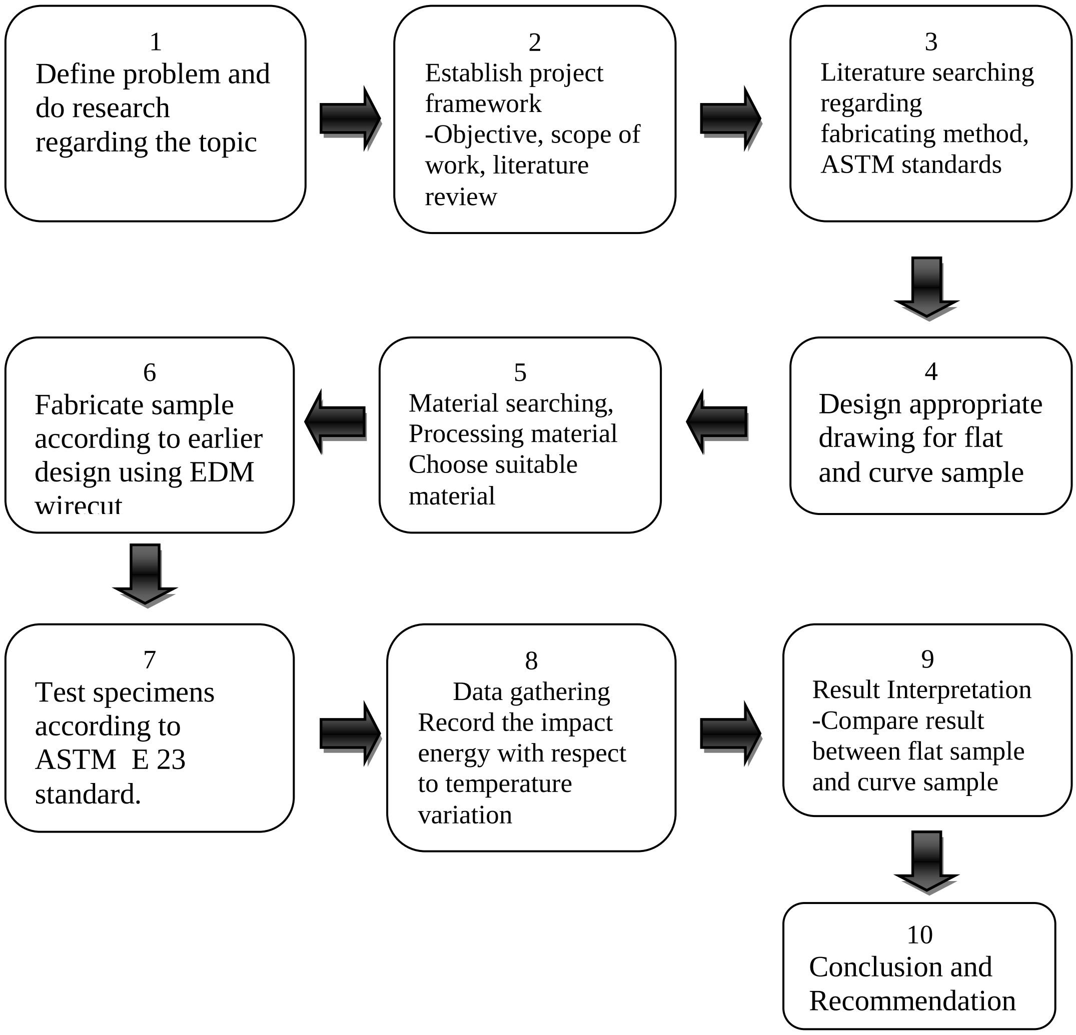


Figure 5: Project Flow

3.2 Lab Experiment Methodology

<u>Design sample</u>

The design for the samples was made using AutoCAD software in lab. Dimensions for the samples reflect the pipe curvatures of NPS 4”, 6”, 12” and 20” (see Figures 6-9).

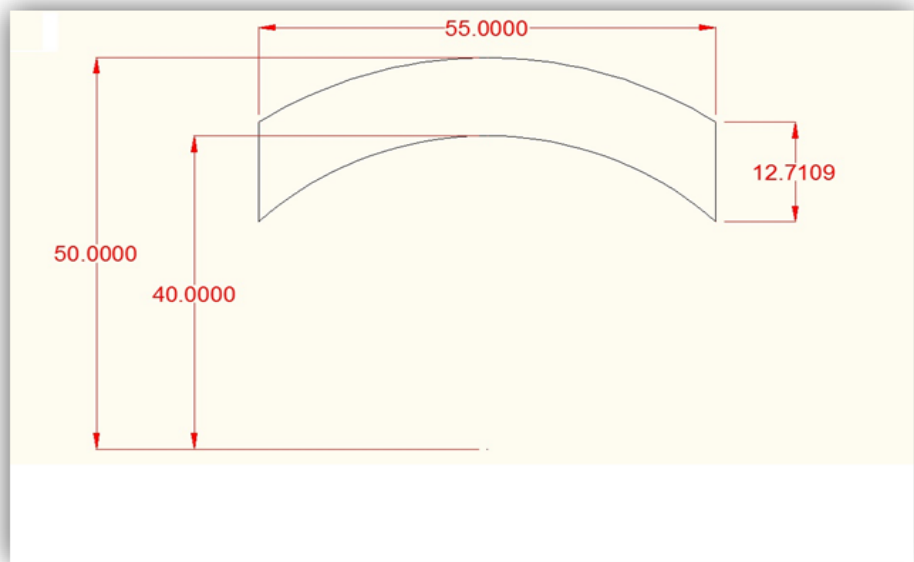


Figure 6: NPS 4 Curve Specimen

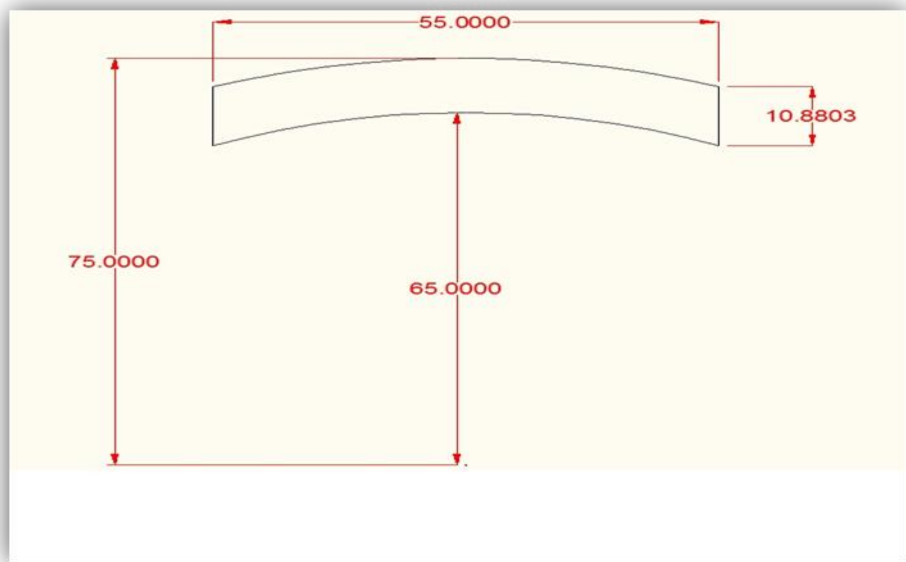


Figure 7: NPS 6 Curve Specimen

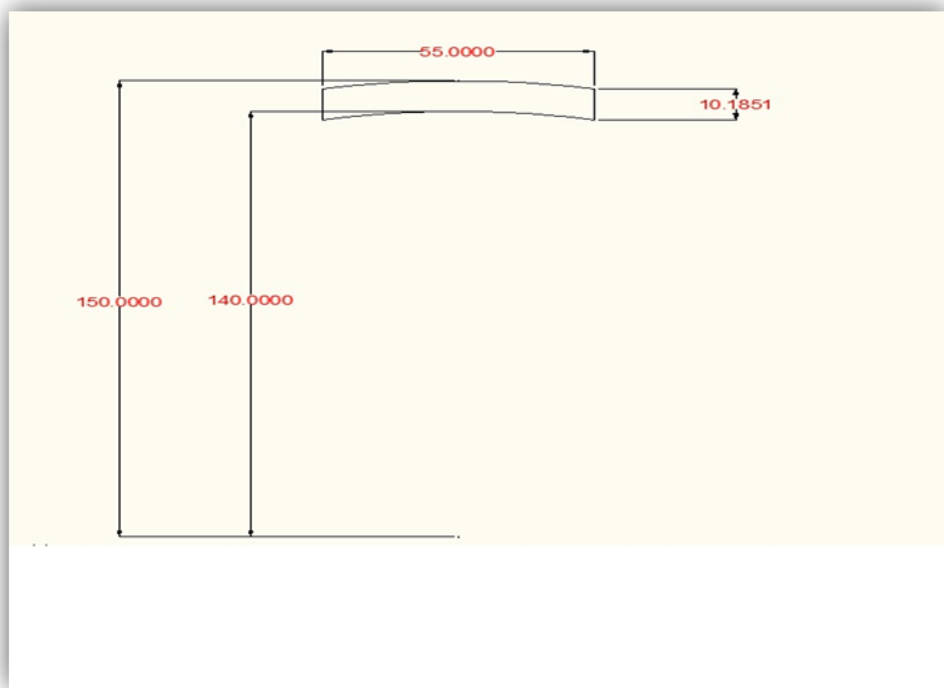


Figure 8: NPS 12 Curve Specimen

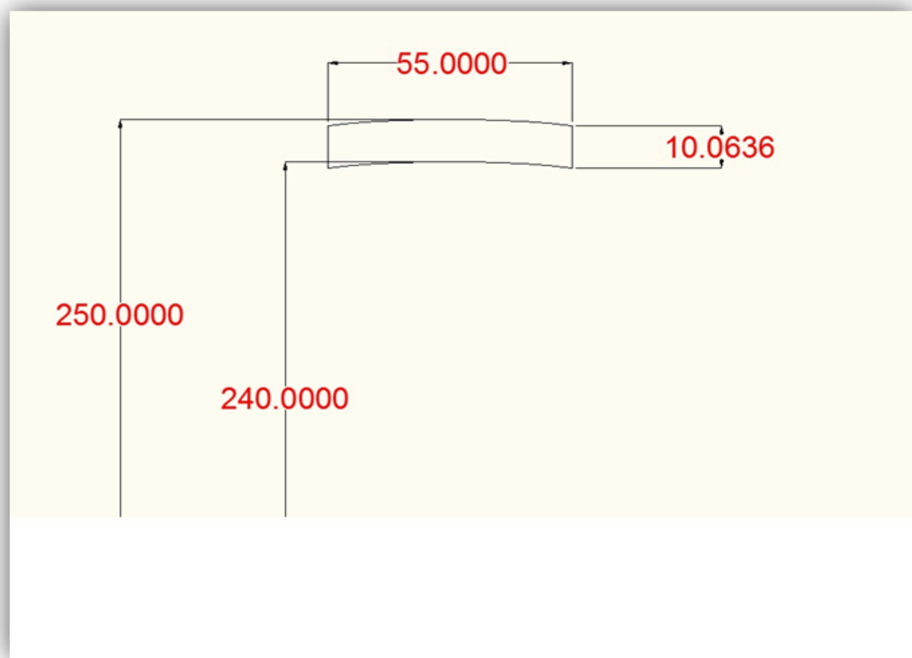


Figure 9: NPS 20 Curve Specimen

Material Selection

In this work, Mild Steel SS400 was selected because it is body-centered cubic (BCC) which is expected to exhibit a ductile-brittle transition temperature. The material stock is shown in Figure 10.

Figure 10: Mild Steel SS400 (63mm x 63mm x 110mm)

Sample Fabrication

The SS400 stock was sent to the lab to be fabricated. In order to get an accurate dimension, EDM wire cut was used in the process of fabricating the samples. The incomplete 12” and 20” samples are shown in Figures 11 and 12. The completed 4” samples are shown in Figure 13.

Figure 11: Incomplete 12” specimen

Figure 12: Incomplete 20” specimen

Figure 13: Completed 4 inch specimens.

Impact Testing Procedure

Impact tests are conducted according to ASTM E 23 standard. The testing was done at various temperatures °C: -60,-40, -20, 0, 20, 40, 60 and lastly 80°C. The cold temperature was achieved by using dry ice and ethanol mixture while the heating can be done using a water bath. Each sample was immerse in the ethanol mixture or water bath and maintained for 5 minutes at each designated temperature. A digital thermometer was used to measure the desired temperature (Figure 14). Both flat and curve samples will undergo the same testing procedure. The specimen that was stabilized at the desired temperature was transferred to the impact test machine and placed in its position within 5 seconds. The impact energy, in Joule was recorded after each test was complete.

Figure 14: Digital Thermometer

<u>Data gathering</u>

The impact energy versus temperature data obtained during the test will be tabulated as below.

Table 3: Sample Data Collection Table

Temperature °C	Impact Energy, Joule				
	Flat Samples	Curve Samples			
		4”	6”	12”	20”
-60					
-40					
-20					
0					
20					
40					
60					

<u>Result interpretation</u>

The results for the flat and curved samples will be compared. Graphical interpretation will be done by plotting impact energy versus temperature for both flat and curved samples. Ductile-brittle transition temperature will be calculated and identified within the graph plotted. Ductile-brittle transition temperature will be observed and compared between the flat and curved samples.

3.3 Project Gantt chart (FYP II)

The project work for semester II is summarized in Figure 15.

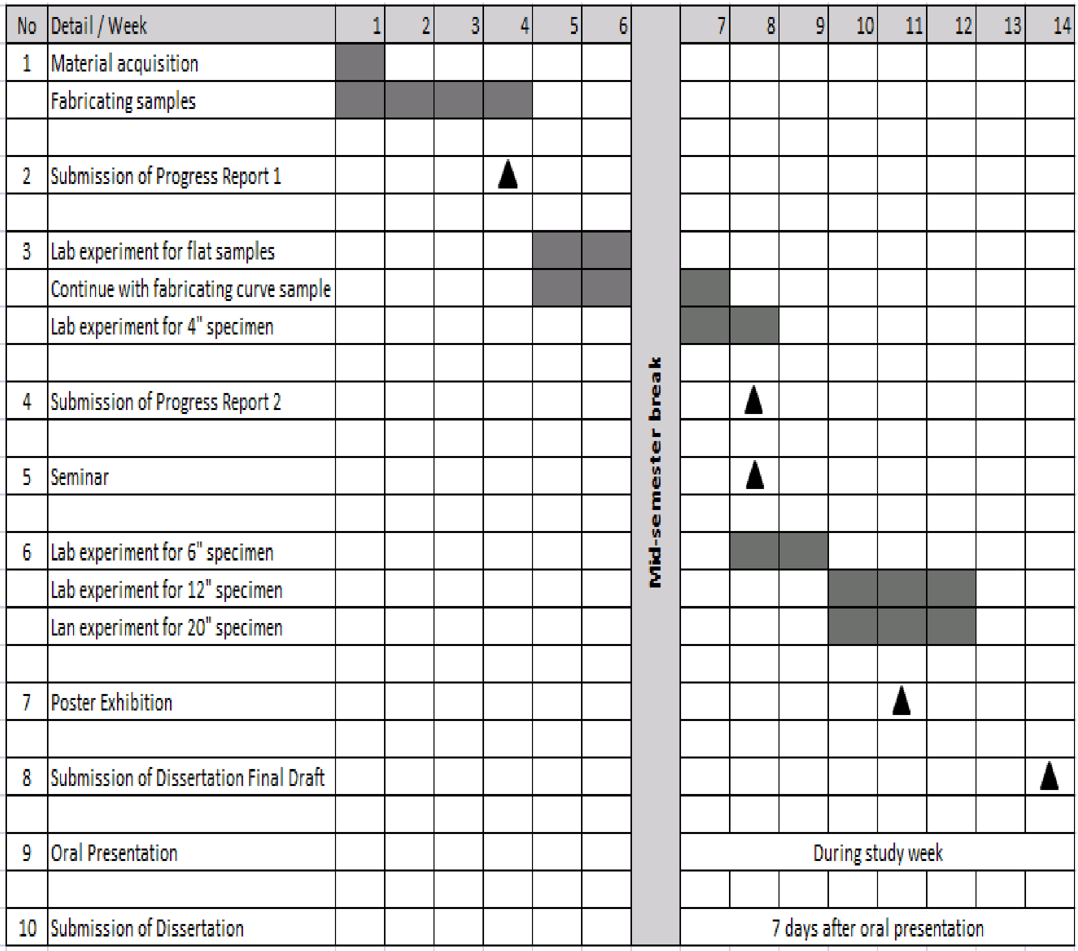


Figure 15: Gantt Chart for Semester II

CHAPTER 4
RESULT AND DISCUSSION

4.1 Tabulated Data of Impact Energy

Table 4 shows the data recorded during testing in the laboratory. The specimens were tested using Charpy Impact Test machine and the impact energy for each sample were recorded respectively.

Table 4: Tabulated data recorded from the testing of flat sample, NPS 4, NPS 6, NPS 12 and NPS 20 curve sample.

Temperature °C	Impact Energy, Joule				
	Flat Samples	Curved Samples			
		4”	6”	12”	20”
-60	12.321	6.179	3.967	3.348	3.320
-40	19.005	6.405	4.184	5.327	3.549
-20	33.882	11.340	8.710	7.317	4.862
0	41.051	13.817	10.855	10.417	20.350
20	44.923	36.027	31.867	27.821	29.783
40	45.497	59.829	54.569	52.519	58.083
60	45.597	72.057	71.904	70.723	65.531
80	45.700	72.387	72.014	71.088	66.745

4.2 Impact Energy versus Temperature Plot

Figure 15 shows the impact energy versus temperature for flat sample, while Figures 16 – 19 shows the impact energy versus temperature for NPS 4”, 6”, 12”, and 20” curved samples.

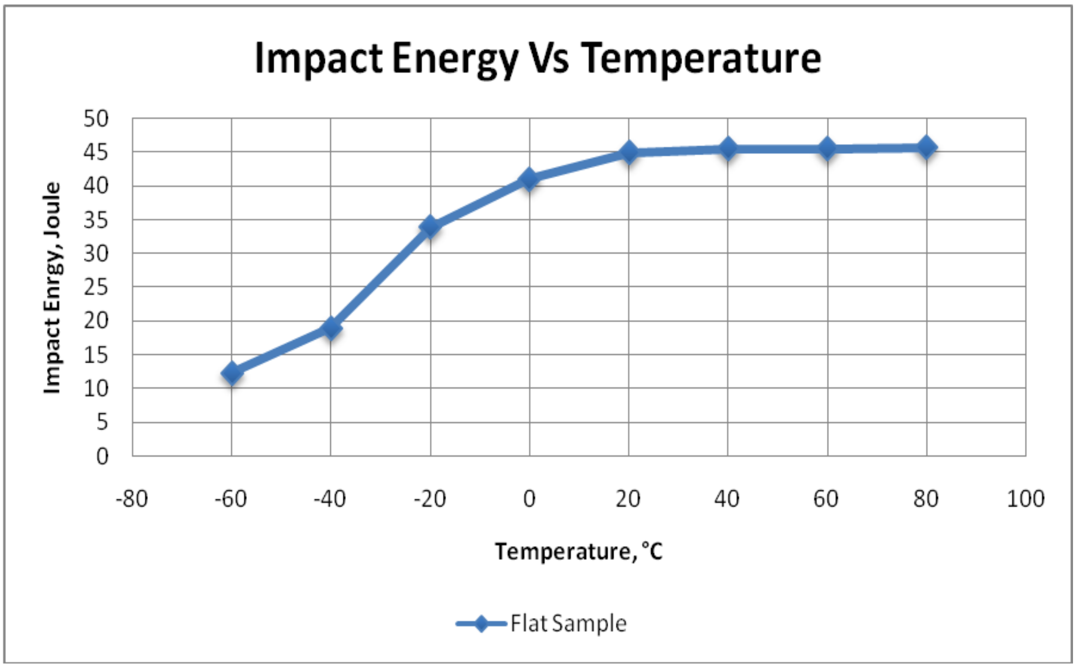


Figure 16: Impact Energy Versus Temperature (Flat sample)

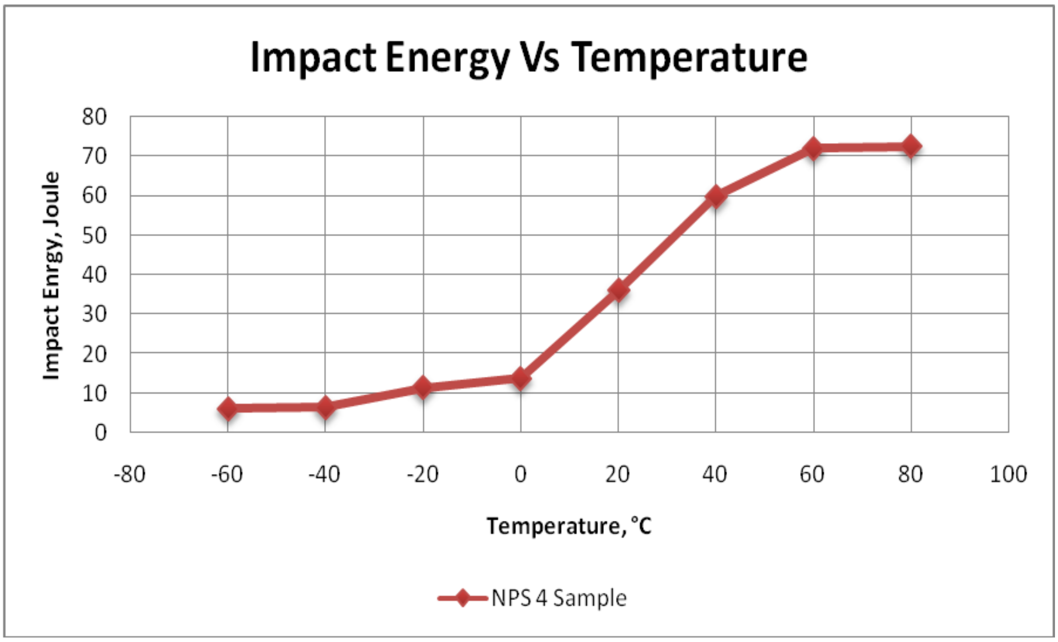


Figure 17: Impact Energy versus Temperature (NPS 4 sample)

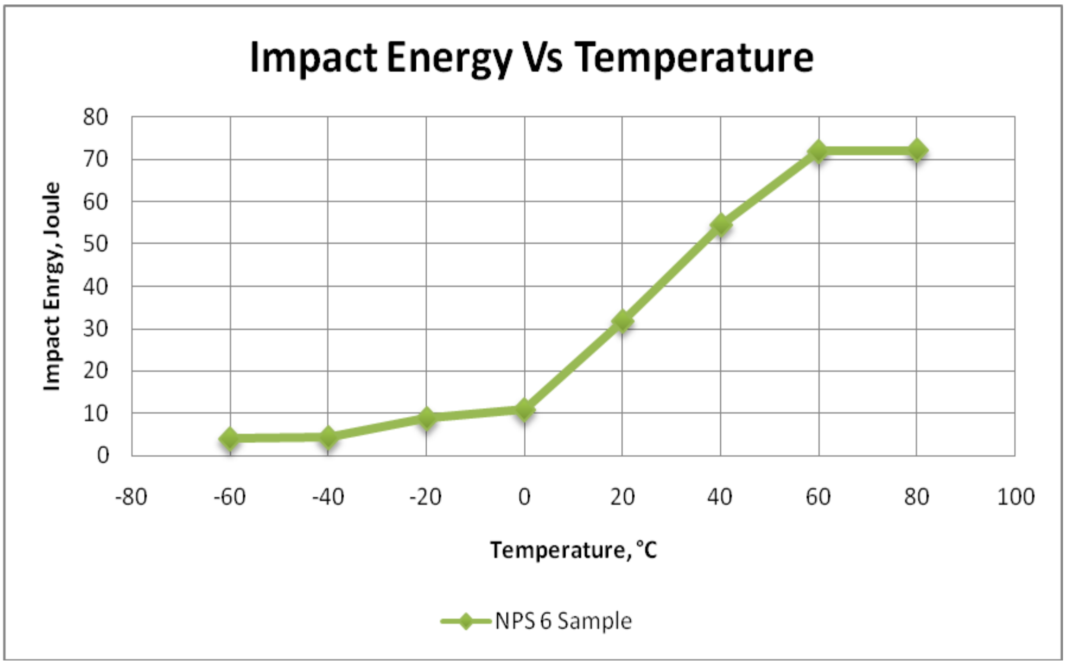


Figure 18: Impact Energy versus Temperature (NPS 6 sample)

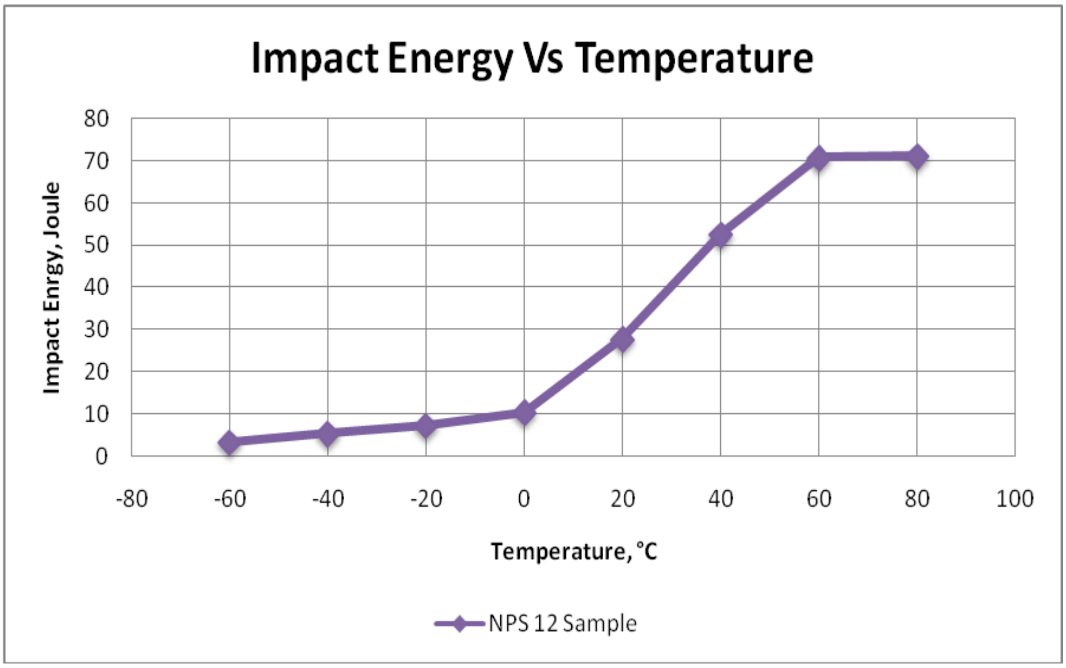


Figure 19: Impact Energy versus Temperature (NPS 12 sample)

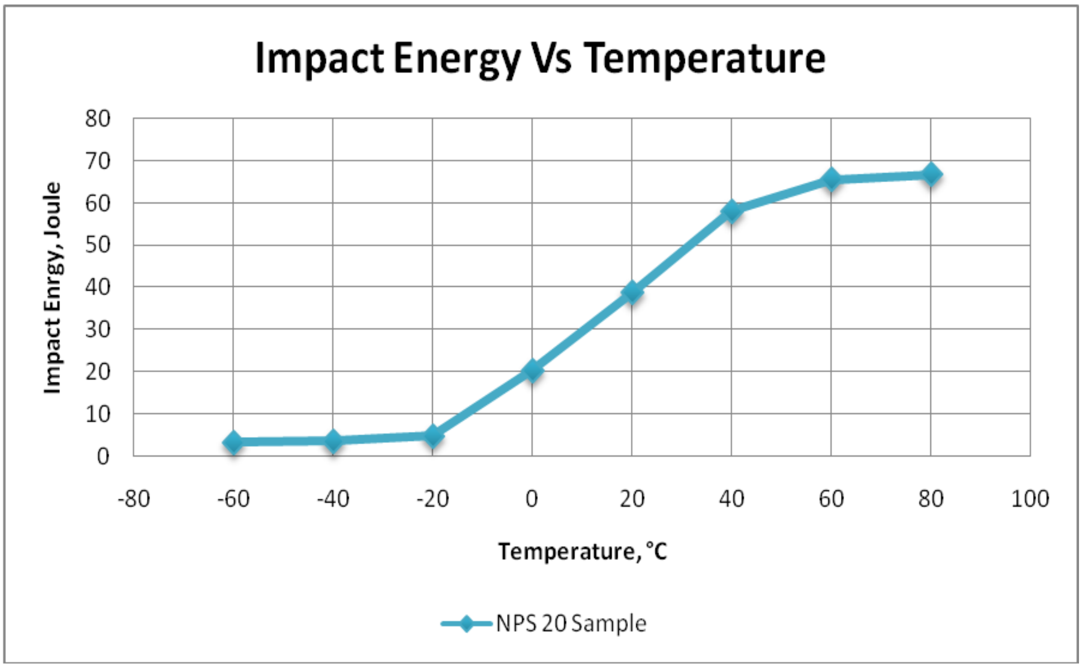


Figure 20: Impact Energy versus Temperature (NPS 20 sample)

Figure 21 below shows the combined impact energy versus temperature for flat, NPS 4, NPS 6, NPS 12 and NPS 20 samples along with the determination of the ductile-to-brittle transition temperature (DBTT).

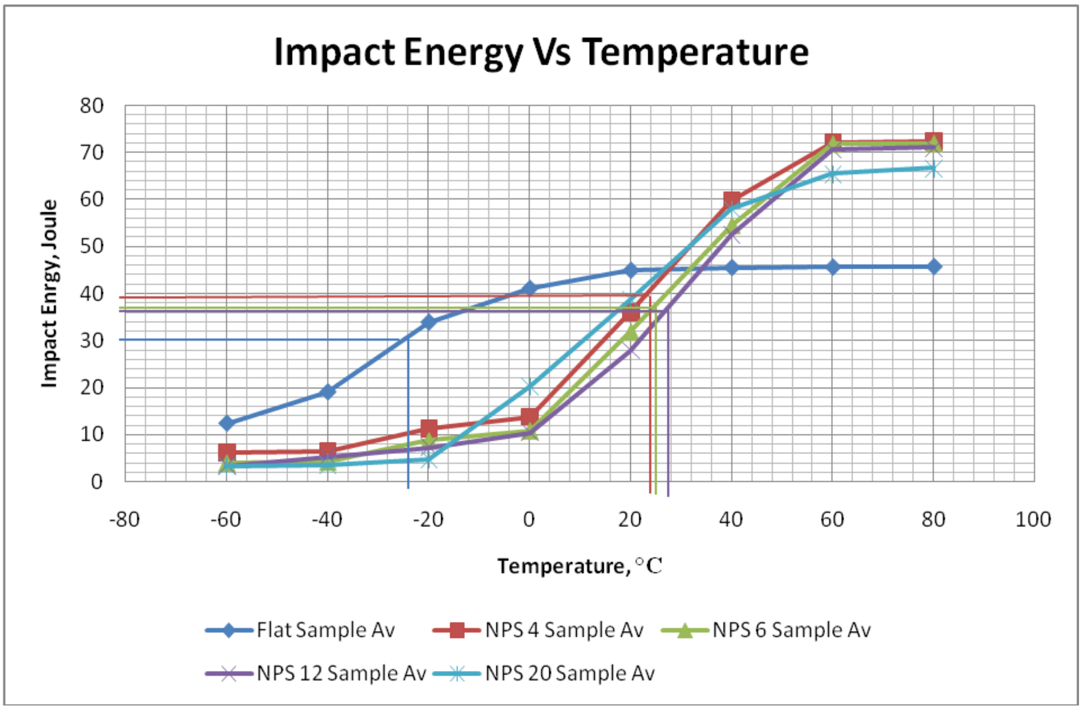


Figure 21: Combined Impact Energy versus Temperature and Determination of DBTT.

The DBTT obtained from Figure 21 is tabulated in Table

Table 5: DBTT versus Curvature Data

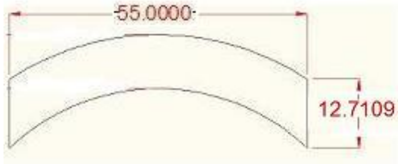
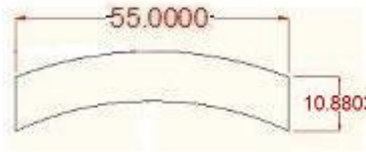
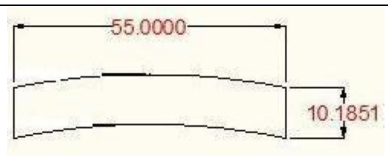
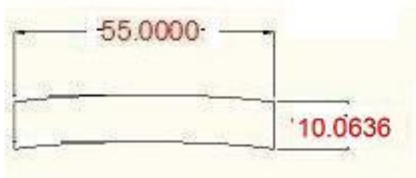
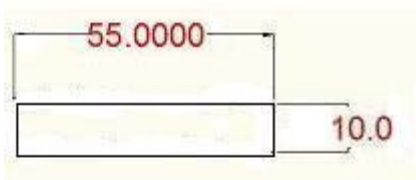
Specimen Curvature	Ductile to Brittle Transition Temperature (DBTT)	Curvature Data
NPS 4	24°C	
NPS 6	26°C	
NPS 12	28°C	
NPS 20	16°C	
Flat	-24°C	

Table 6: Impact Energy at Room Temperature (27°C)

Specimen	Impact Energy at 27°C	% Deviation |Flat-NPS |/Flat x 100%
Flat	46 J	-
NPS 4	44 J	4.3%
NPS 6	40 J	13%
NPS 12	38 J	17.4%
NPS 20	46 J	0%

4.3Result Interpretation

The absorbed energy was plotted against the test temperature and the "ductile-to-brittle transition temperature" (DBTT) for both the flat and curved samples were found to be different. It was found that the DBTT for flat samples, NPS 4, NPS 6, NPS 12 and NPS 20 to be -24°C, 24°C, 26°C, 28°C and 16°C respectively. The DBTT tends to increase when the curvature increases from NPS 4 to NPS 12. Further observing shows that DBTT is lowest at NPS 20 compared with other curved samples. It is believe that from this point onwards as the curvature increases, the behavior reverts back to that of the flat sample. This is shown in Table 5 previously and can be observed from the graph in Figure 21. From the graph, it is also shown that at very low temperature, the impact energy for all the curves sample was significantly lower than the flat sample. However at high temperature their impact energy is higher than the flat samples.

Tapering the specimens by as much as 75% or this much curvature did not have significant effect on the impact energy [3]. This statement is nearly accurate when there is no temperature variation involved in the experiment. From the graph, the impact energy at room temperature or 27°C for both flat specimen and curve specimen was found out to be about the same with percent deviation of 4%-17%. Table 5 previously shows the impact energy value for each sample at 27°C. The percent deviation is likely affected due to the shape of the sample. In Waid and Zantopulos study, the sample was tapered only at the upper side of the sample but in this study the sample considered both OD and ID curvature. Figure 22 illustrate the differences between tapered sample and NPS 4 sample.

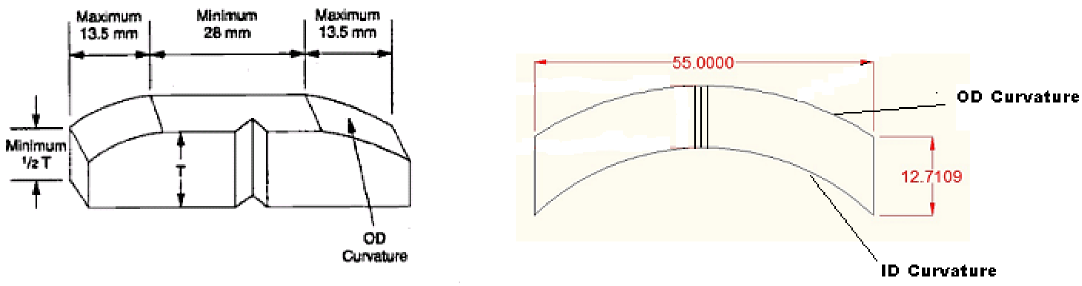


Figure 22: Differences between Waid tapered sample with NPS 4 sample.

In addition, the way the sample was prepared also contribute to the differences. The tapered sample was from tubing whereas the NPS 4 sample was fabricated from a block of steel. Thus the mechanical properties for both samples will not be the same. The number of samples tested also contributes to the end result. Due to time constraint and machine availability to fabricate the samples, only one sample was prepared for each temperature. It was preferred if more samples were tested for each temperature and an average or mean value of the samples were taken. By doing so, it will decrease the error and improve reliability of the results.

CHAPTER 5
CONCLUSION

5.1 Conclusion

It can be conclude that the objective of the project was achieved by successfully comparing and observing the ductile-to-brittle transition temperature (DBTT) of all the samples. At 27°C, it was found out that the curvature do not have significant effect on the impact energy. The impact energy for flat and curve samples were about the same at this temperature. At high temperature (80°C), the impact energy for the curve specimen was much higher compared to flat specimen but at very low temperature (-60°C), the impact energy for curve specimen was lower than the flat specimen. The transition temperature was found to be 24°C, 26°C, 29°C, 16°C and -24°C for NPS 4, NPS 6, NPS 12, NPS 20 and flat specimen respectively. It was conclude that the DBTT for both flat and curve samples differ from each other.

5.2 Recommendation for future work

It is suggested that the micro structure of the NPS sample which was tested at very high temperature and very low temperature to be further studied. Scanning Electron Microscope (SEM) method should be included in determining the microstructure of the specimen in the future for better reasoning.

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