Comparison between Mechanical Properties of Schedule 40 Steel Pipe and Structural Steel Tube

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Abstract

In this experiment, samples of schedule 40 steel pipe and Hot Rolled Electric Welded (HREW) tubing, which are both made from a similar mild carbon steel and undergo similar manufacturing processes under different conditions, were put through tensile and impact tests to find and compare their mechanical properties. These properties include hardness, elastic modulus, yield strength, ultimate strength, strain to fracture, ductility, and fracture toughness. Two tensile test specimens and two impact test specimens were fabricated from each sample of material. These specimens were loaded into an Instron #6025 Universal Tester and an Instron Dynatup Impact Tester to carry out tensile tests and impact tests, respectively. The collected data was analyzed using Microsoft Excel and the pipe was found to have a hardness of 16.1 HRC, and elastic modulus of 225 GPa, a yield strength of 423 Mpa, an ultimate strength of 470 MPa, a strain to failure of 0.25, a ductility of 67.4 %RA, and a fracture toughness of 353 Mpa sqr(m). The tube had a hardness of 13.4 HRC, elastic modulus of 288 GPa, yield strength of 426 MPa, ultimate strength of 446 MPa, strain to failure of 0.22, ductility of 52.6 %RA, and a fracture toughness of 335.2 Mpa sqr(m).

Background

Schedule 40 steel pipe and Hot Rolled Electric Welded (HREW) tube are two materials commonly used in the off-roading community for fabrication of various items such as bumpers and roll cages. The use of pipe for such items is heavily debated due to the fact that it was manufactured to transport water and gas, not for taking structural loads like tube.

Both of these materials are manufactured from a mild carbon steel and undergo similar manufacturing processes in which strips of steel are passed through rollers until they form the desired shape, then the seam is electrically welded[1]. This process is seen in Figure 1, below.

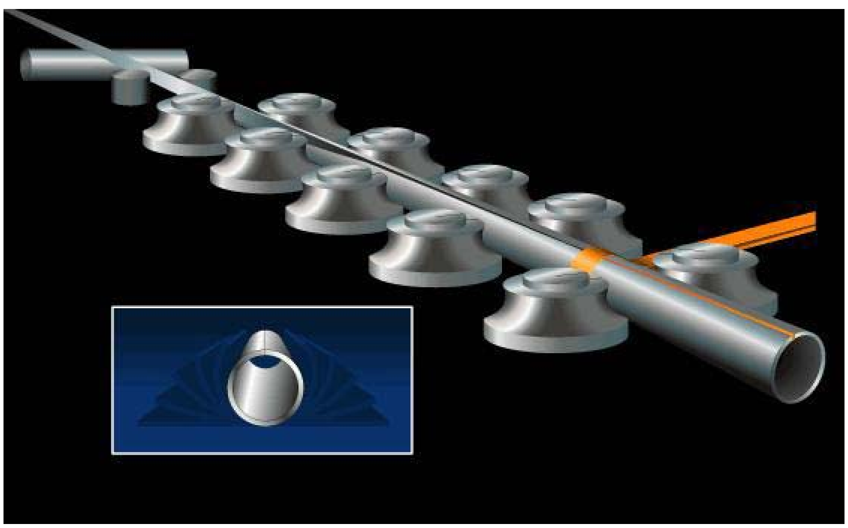

Figure 1: Basic manufacturing process for pipe and tube.

The difference is in the way they are rolled and finished. The tube is rolled at a high temperature, while the pipe is cold rolled and galvanized to protect it from corrosion. According to MatWeb[2], 1020 mild carbon steel should have the following values for mechanical properties displayed in Table 1.

Table 1: Properties of 1020 Mild Carbon Steel

Property	Cold Rolled	Hot Rolled
Elastic Modulus (Gpa)	205	205
Yield Strength (Mpa)	350	205
Ultimate Strength (Mpa)	420	380
Elongation (%)	15	25
%RA	40	50

The purpose of this experiment was to find, and most importantly, to compare the mechanical properties of the schedule 40 pipe and HREW tube using tensile and impact test procedures.

Procedure

Samples of pipe and tube were obtained from a local steel supplier in one-foot sections to custom fabricate the test specimens. From each material, two dog-bone shaped tensile specimens and two notched impact test specimens were fabricated. Tensile specimens were cut lengthwise from the pipe and tube, shown in Figure 2.

Figure 2: Tensile test specimen fabricated from round pipe.

Because of the small change of angle across the width of the test regions, the cross sectional areas used in the calculation of stress were approximated to be rectangular in shape. Dimensions of the tensile specimens are listed in Table 2.

Table 2: Dimensions of Tensile Specimens

Specimen	Thickness (mm)	Width (mm)	Area (mm^2)	Gage Length (mm)
Pipe 1	3.82	6.18	23.61	31.59
Pipe 2	3.83	6.52	24.97	31.20
Tube 1	3.10	6.30	19.53	31.59
Tube 2	3.36	6.43	21.60	31.33

Six hardness readings were taken for each material from the wide ends of the tensile specimens so not to interfere with the results of the tensile test.

In order to clamp the specimens in the tensile tester, the ends of the specimens, which had a curve to them from the shape of the pipe, had to be sent through a roller until they were flat and able to be gripped by the test machine. The rollers were stopped at the end of the wide sections so that no cold working would occur in the test region, allowing the samples to be clamped in the machine and tested with accurate results.

All four specimens were tested in an Instron #6025 Universal Tester (Appendix A; i) capable of applying a load of 20 kN. Load was applied until fracture, as seen in Figure 3, and an extensometer measured strain to plot the stress-strain behavior of each sample. The data was analyzed using Microsoft Excel.

Figure 3: Fractured test specimen loaded in Instron Tester.

The impact test specimens were fabricated by cutting strips of material from the round pipe and tube, then making a notch in the middle, shown in Figure 4.

Figure 4: Impact test specimen fabricated from round pipe.

Specimens were tested in an Instron Dynatup Impact Tester (Appendix A; ii) and the results allowed the fracture toughness of each specimen to be calculated.

Results

All data from testing was analyzed and compiled into a table of results in Table 3.

Table 3: Mechanical Properties of Tested Materials

Property	Pipe 1	Pipe 2	Tube 1	Tube 2		Pipe Ave	Tube Ave
Hardness (HRC)						16.1 +/- 0.1	13.4 +/- 1.7
Elastic Modulus (Gpa)	132	255	288	240		255	288
Yield Strength (Mpa)	421	425	412	440		423 +/- 2	426 +/- 14
Ultimate Strength (Mpa)	470	471	422	470		470.5 +/- 0.5	446 +/- 24
Fracture Strength (Mpa)	308	414	274	319		361 +/- 53	296.5 +/- 22.5
Strain to Failure	0.27	0.25	0.22	0.07		0.25	0.22
Ductility (%RA)	71.3	63.4	53.9	51.3		67.4 +/- 3	52.6 +/- 1.3
Fracture Toughness (Mpa sqr(m))	365.4	340.7	326.5	343.8		353 +/- 12.3	335.2 +/- 8.6

The hardness for each material was taken as the average of six hardness tests. The pipe was found to have a hardness of 16.1 +/- 0.1 HRC and the tube resulted in a hardness of 13.4 +/- 1.7 HRC.

Ductility was calculated in terms of % Reduction of Area using the equation:

$$\text{Percent reduction of area (RA)} = \frac{A_o - A_{min}}{A_o} = \frac{\text{decrease in area}}{\text{original area}} \times 100$$

The original area was the cross sectional area calculated in Table 1 before specimens were tested. Dimensions were measured again after fracture to determine the reduction of cross sectional area caused by necking as shown in Figure 5. The final dimensions and area are displayed in Table 4.

Table 4: Final Dimensions of Tensile Specimens

Specimen	Thickness (mm)	Width (mm)	Area (mm^2)
Pipe 1	1.82	3.72	6.77
Pipe 2	2.42	3.78	9.15
Tube 1	2.04	4.42	9.02
Tube 2	2.36	4.48	10.57

Figure 5: Cross section of specimen after necking and fracture.

Figures 6-13 display the results of tensile tests for each test specimen.

Figure 6, Figure 8, Figure 10, and Figure 12 show the stress vs. strain plots collected by the Instron Tester and Figure 7, Figure 9, Figure 11, and Figure 13 zoom in on the elastic regions of each test with a trend line added to approximate the elastic modulus.

Due to an uncontrollable error, the fracture during tensile testing occurred outside the range of the extensometer while testing samples “Pipe 1” and “Tube 2” which makes the readings for modulus of elasticity and strain to failure inaccurate for those two tests. However, the stresses and general shape of the plots still allow the graphs to be accurately analyzed for yield strength, ultimate strength, and fracture strength.

Because of this error during testing, the results of elastic modulus and strain to failure found in tests “Pipe 2” and “Tube 1” have been taken as the final values for pipe and tube in the table of results.

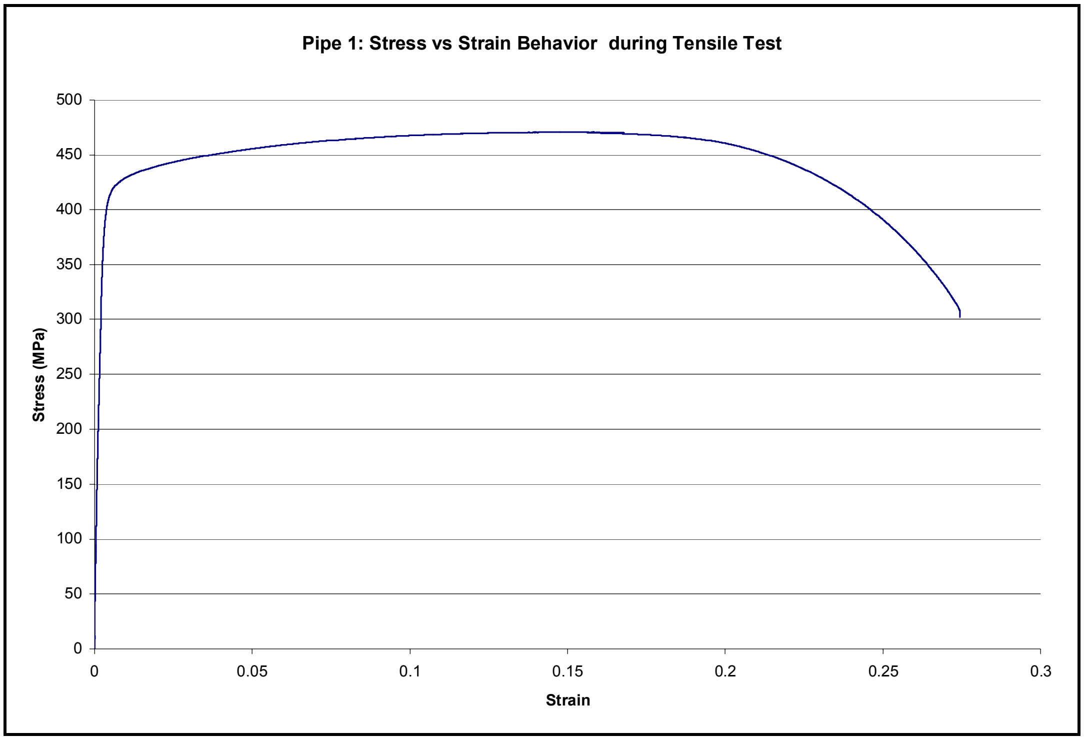

Figure 6: Stress vs. Strain plot for first pipe specimen, “Pipe 1”.

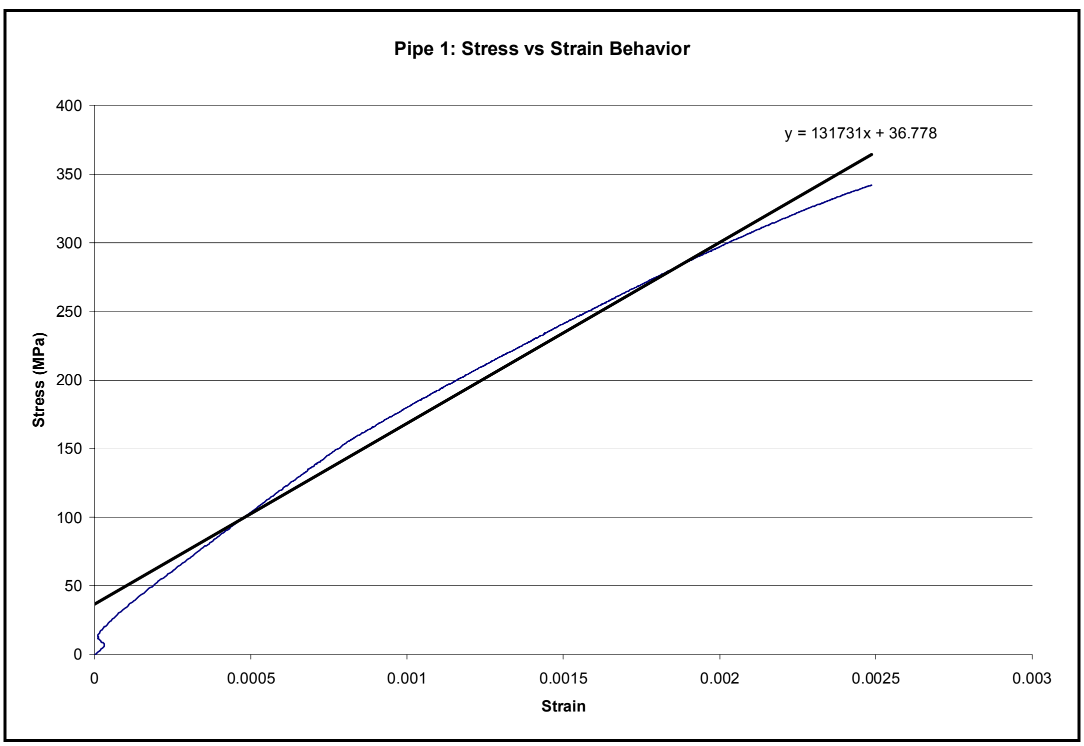

Figure 7: Elastic region of “Pipe 1” in tensile test.

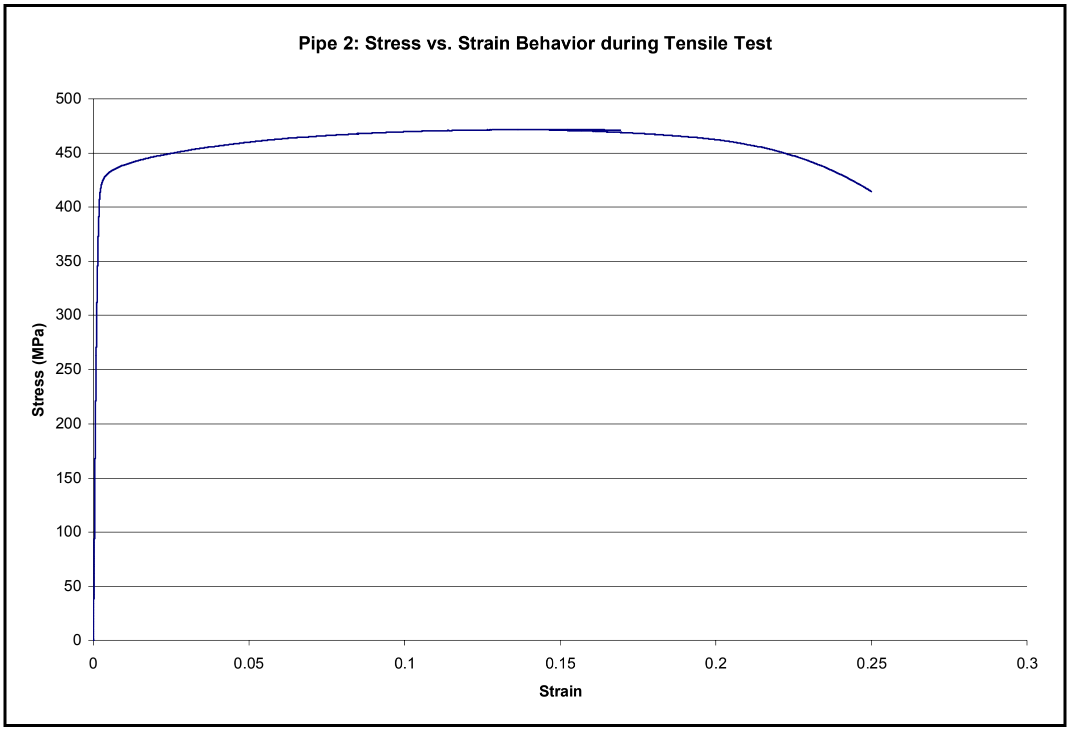

Figure 8: Tensile test results of “Pipe 2.”

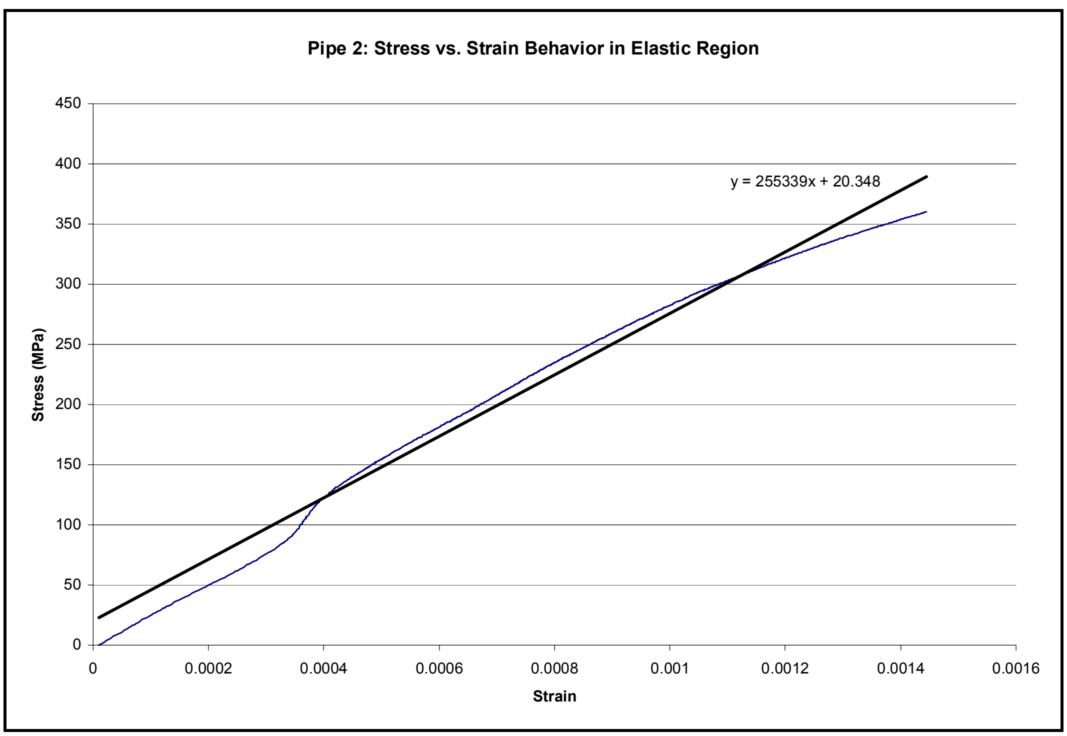

Figure 9: Elastic region of tensile test for “Pipe 2” specimen.

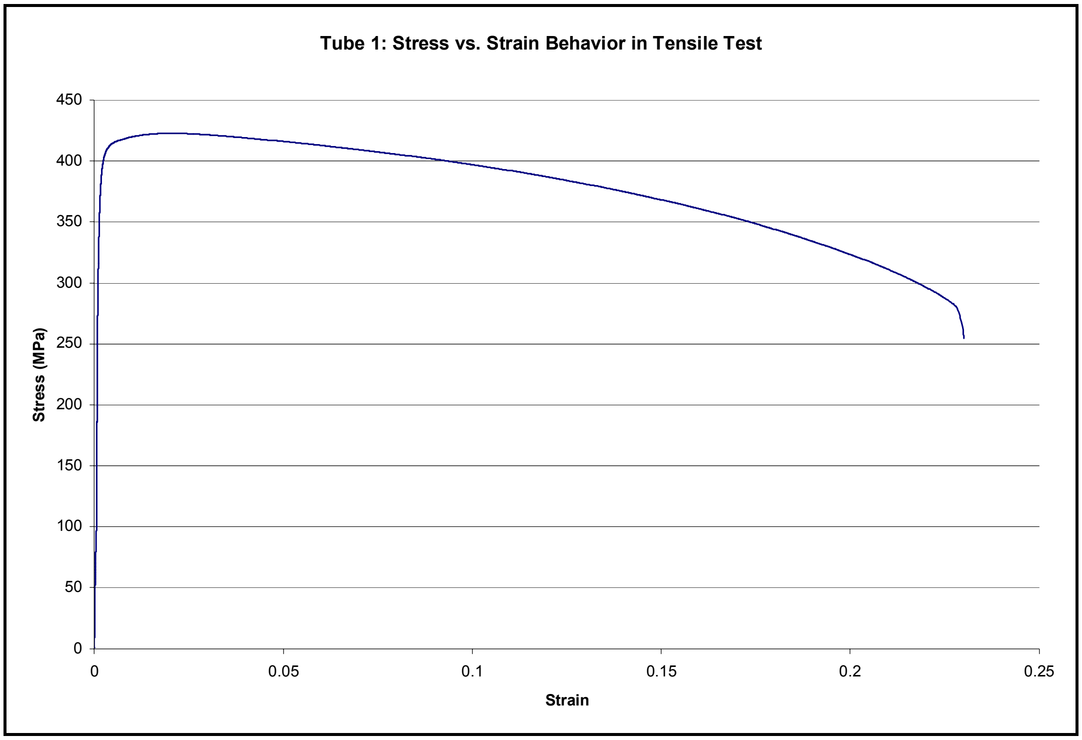

Figure 10: Tensile test results for “Tube 1” specimen.

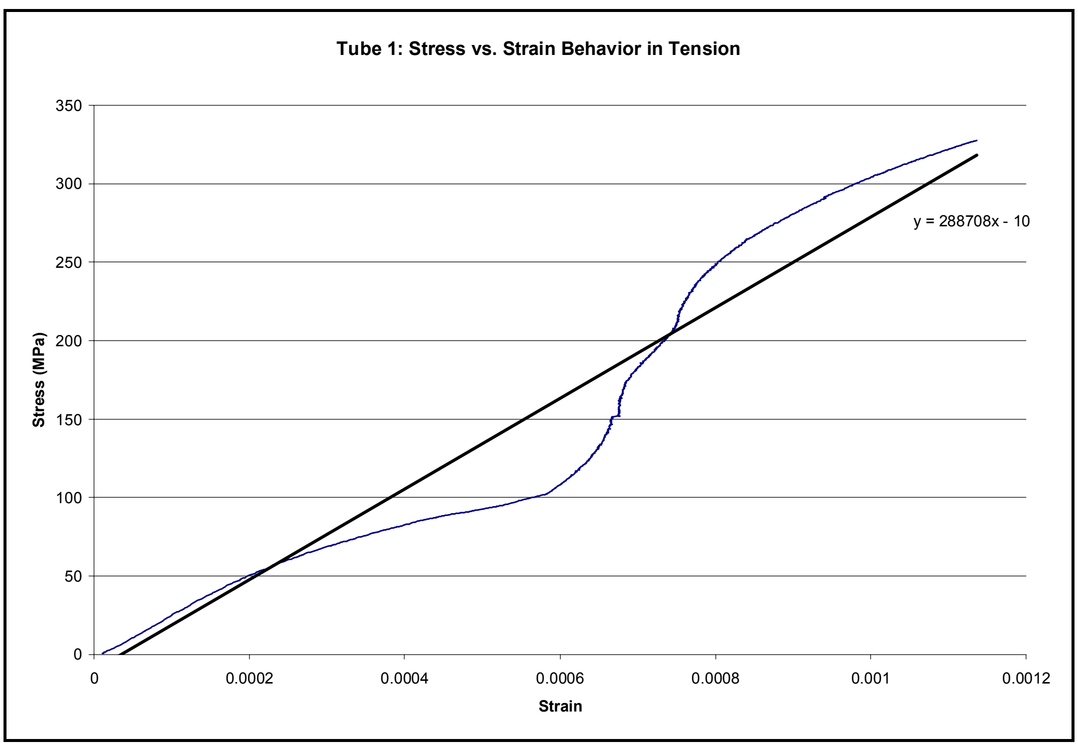

Figure 11: Elastic region of “Tube 1” during tensile test.

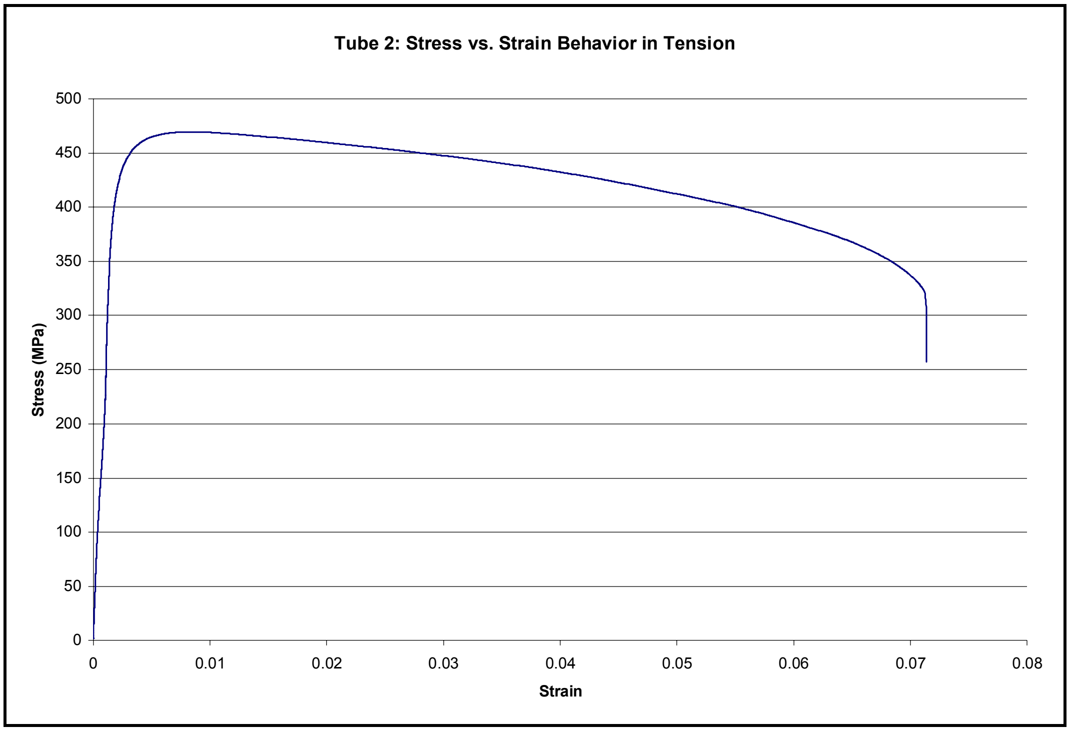

Figure 12: Tensile test results for “Tube 2.”

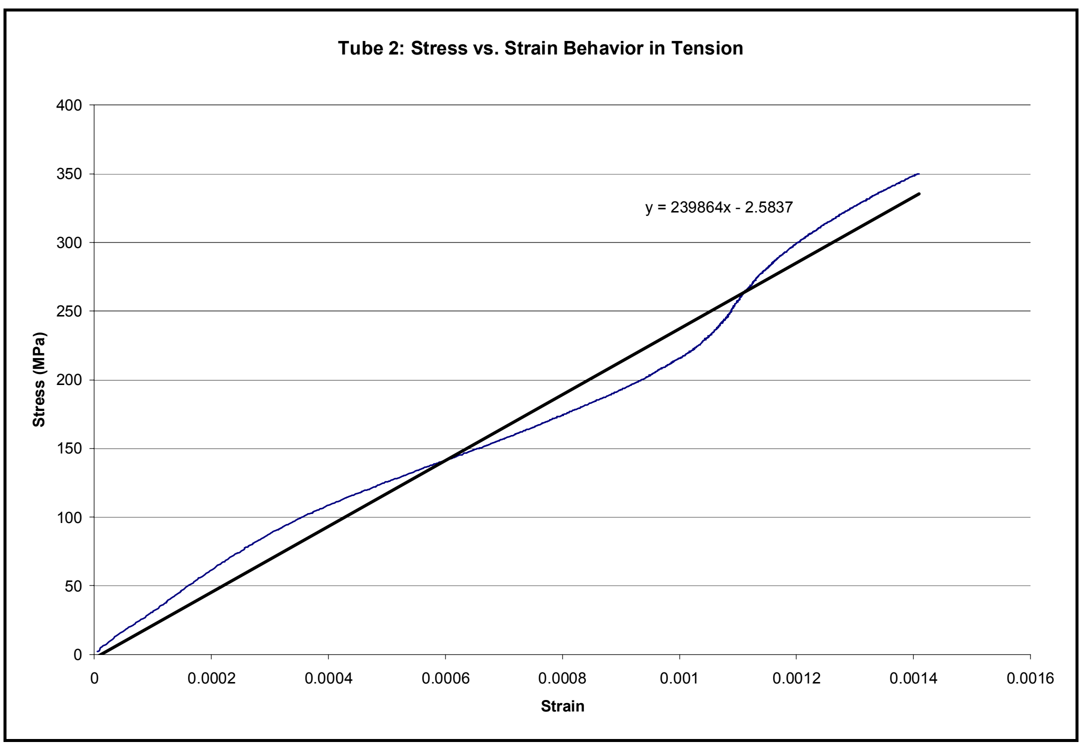

Figure 13: Elastic Region of “Tube 2” during tensile test.

The Instron Dynatup Impact Tester recorded the load and energy during the impact test and that data was plotted against time. The specimens tested did not completely break, but rather they bent at the notch as seen in Figure 14.

Figure 14: Appearance of impact specimens after testing.

When load is plotted against time for the pipe samples, a second peak is formed after the fracture occurs during which the tup is pushing the bent samples, seen above, through the opening in which the tup and carriage fall. Both samples of pipe followed similar load patterns seen in Figure 15. The value for the energy of “Pipe 1” in Figure 16, used to calculate the fracture toughness, is therefore taken at the point where it begins to flatten out in the middle, just after the first load peak. This value is taken to be approximately 10.9 J. Figure 17 displays the energy plot for “Pipe 2” during the impact test and when analyzed, the energy value used in calculations is taken as 11.1 J.

As seen in Figure 18, the tube samples did not experience the problem that the pipe samples did. Figure 19 shows the energy absorbed by “Tube 1” and Figure 20 displays the energy absorbed by “Tube 2.” Their energy values used for calculations are 9.9 J and 10.1 J, respectively.

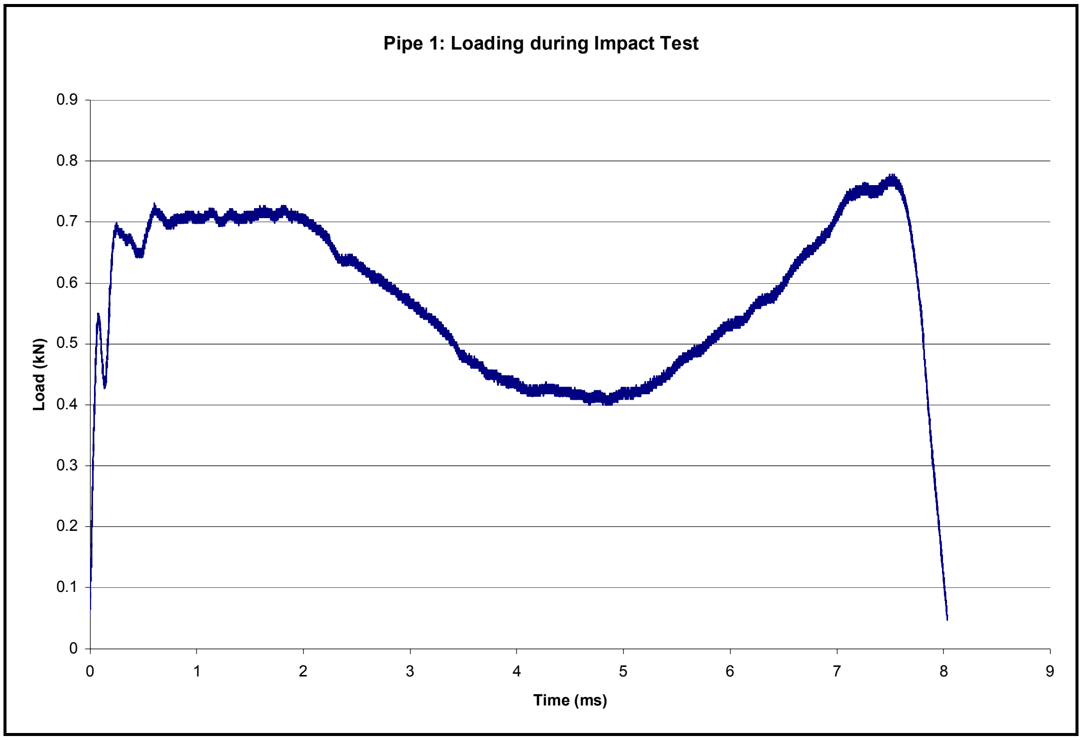

Figure 15: Load plotted against time during impact test of "Pipe 1."

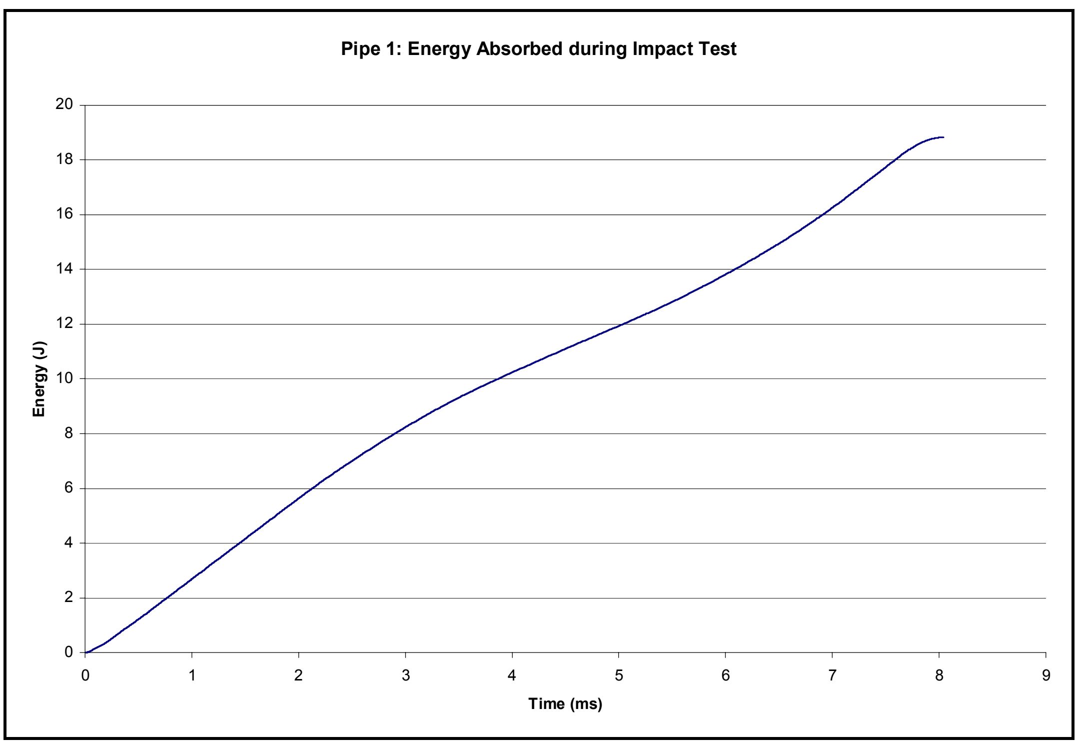

Figure 16: Energy vs. Time during impact test of "Pipe 1"

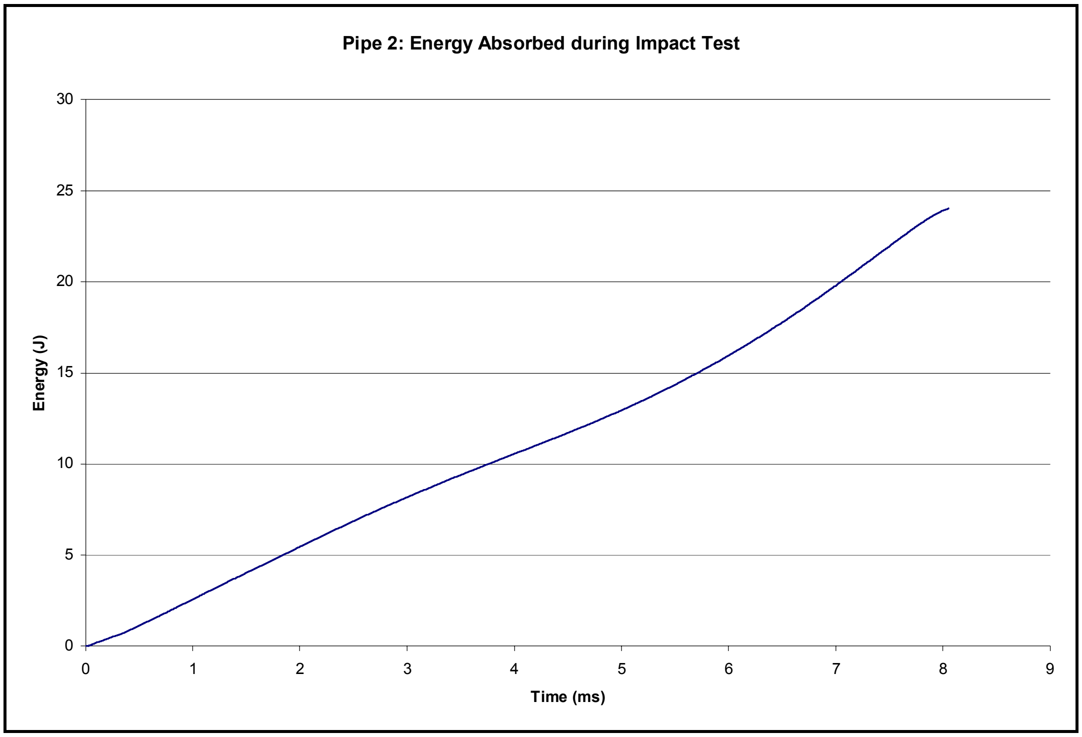

Figure 17: Energy vs. time plot of "Pipe 2" during impact testing.

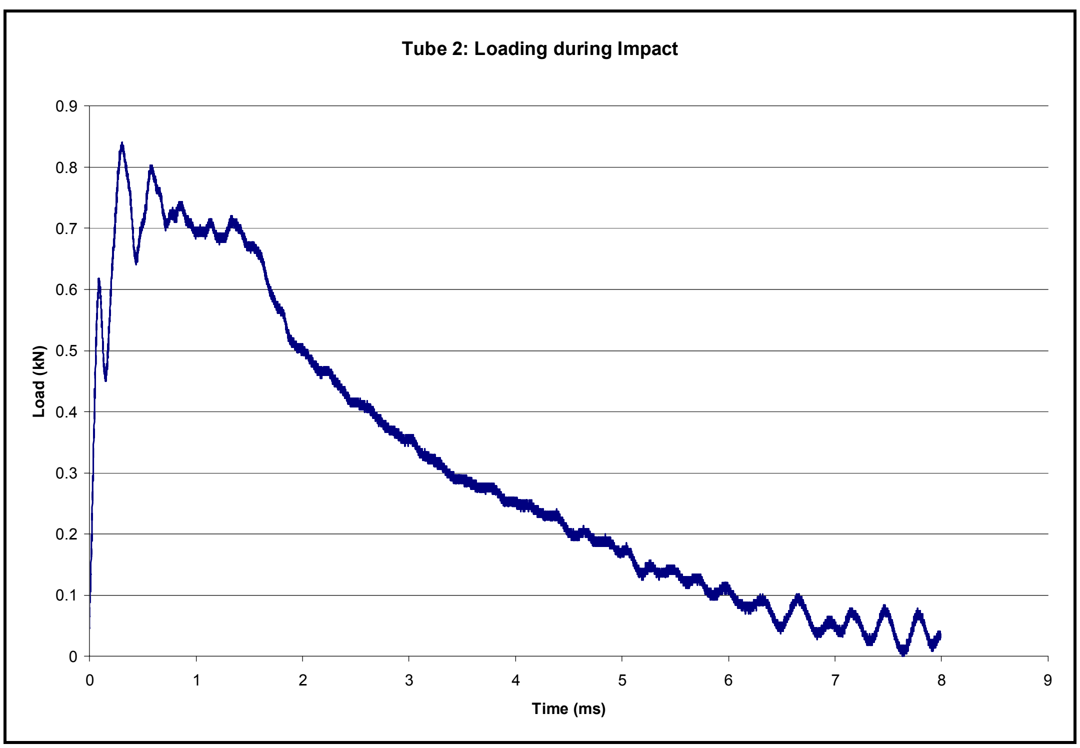

Figure 18: Loading of "Tube 1" specimen during impact testing.

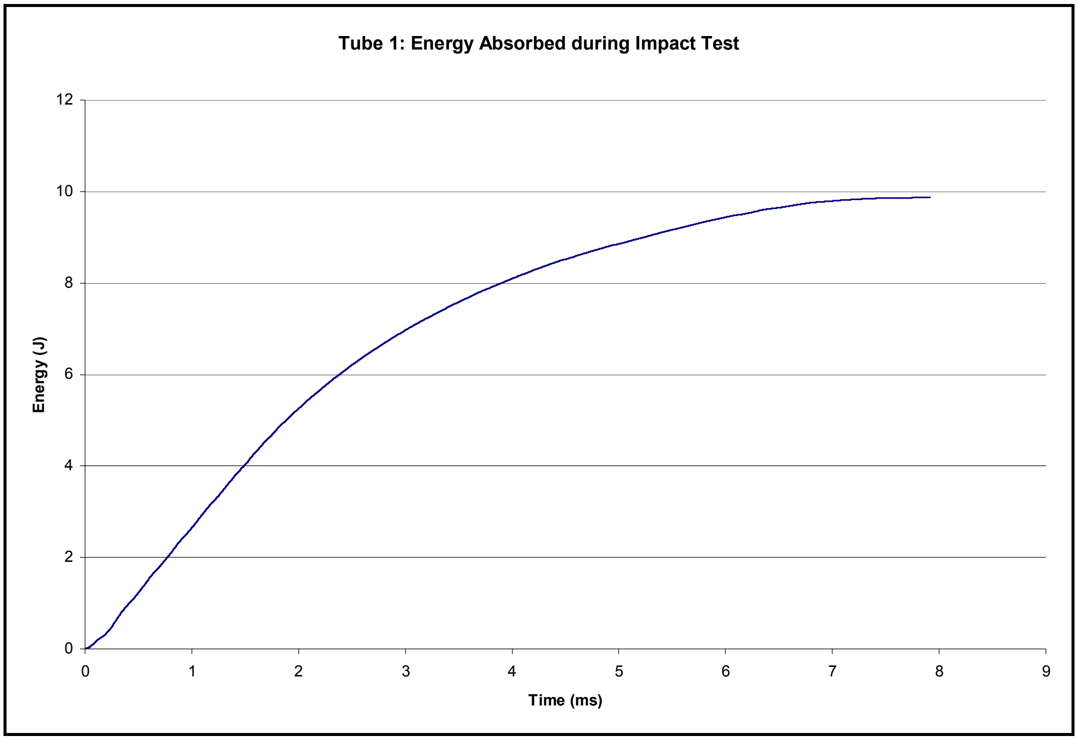

Figure 19: Energy plotted against time for “Tube 1” during impact testing.

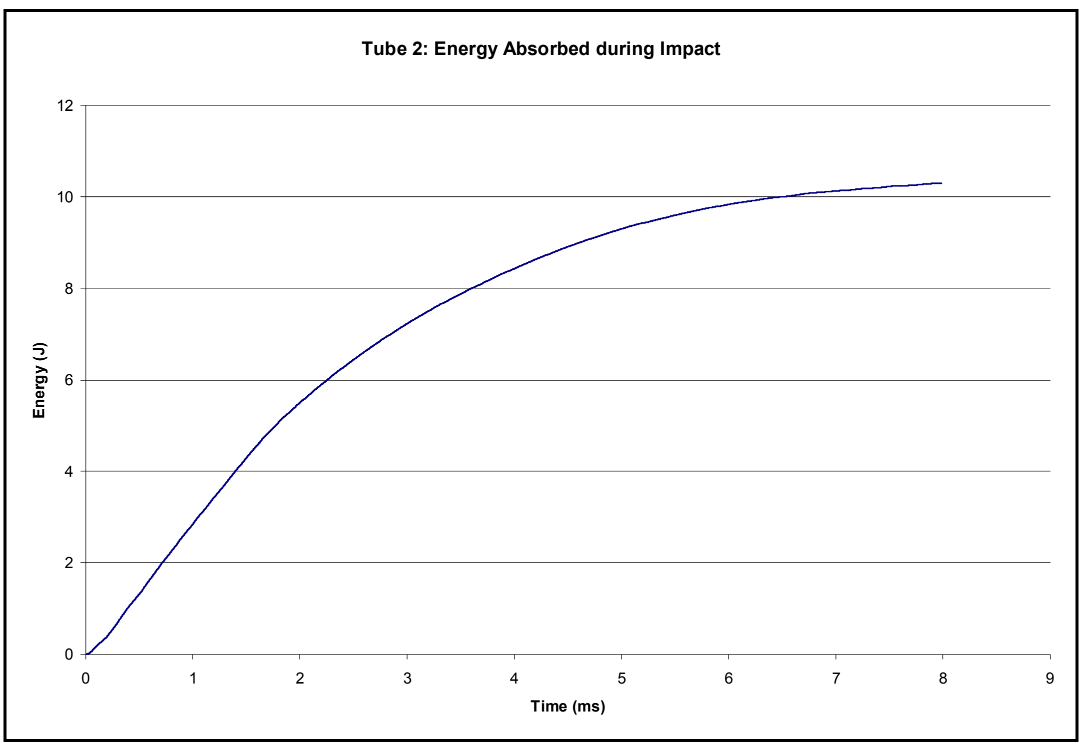

Figure 20: Energy vs. time for “Tube 2” during impact testing.

To calculate fracture toughness, the cross sectional areas of fracture had to be measured. The dimensions are listed in Table 5.

Table 5: Cross Sectional Areas of Impact Specimens

Specimen	Thickness (mm)	Width (mm)	Area (mm^2)
Pipe 1	1.75	10.82	18.94
Pipe 2	2.00	11.06	22.12
Tube 1	1.78	11.70	20.83
Tube 2	1.62	12.00	19.44

The cross sectional areas and the energy values found from testing were used along with known values of Poisson's ratio and the elastic modulus of steel to find fracture toughness. Poisson's ratio was taken as 0.3 and the elastic modulus used was 205 Gpa. Toughness was found using the equation:

$$K_{Ic} = \sqrt{\frac{J_{tot} \cdot E}{(1-\nu^2) A_f}}$$

Discussion

The results that were found during this experiment do not match up very well with the values for properties found in the background research, but that was expected to happen considering the exact values for such specific applications such as pipe and tube are not available on MatWeb. The slight differences in manufacturing processes caused mild discrepancies between the mechanical properties of both materials, but they are both comparable in terms of strength and toughness.

For values such as the modulus of elasticity, it was expected for that value to be closer to 205 GPa which is a typical value for steels. The higher values resulting from these tests might be attributed to the fact that the cross sectional areas of the tensile specimens cut from round tube were assumed to be rectangular in shape, which would cause the calculated areas to be smaller than actual, hence the stress would be higher. While these values might be higher than expected, the same discrepancy occurred on tests for both materials, so they were still able to be compared to each other with some confidence.

It is interesting to look at the stress vs. strain behavior of the tube after it yields. It is uncommon for a steel to reach ultimate stress so soon after yielding, but it still continued to strain to 0.25 which is a typical strain to fracture value for steel and it reached normal values for yield strength and ultimate strength.

Conclusion

Looking back at the objective, this experiment was successful in the sense that values of mechanical properties were found for both materials and they were able to easily be compared to each other. However, if more time was permitted, having at least 3 tensile and impact tests for each material would have offered a chance to better understand how accurate the results were. Redesigned impact test specimens would also help since the ones tested did not completely fracture which could have affected the resulting data.

References

1. http://www.steeltubeinstitute.org/pipe.htm

   http://www.steeltubeinstitute.org/mechanical.htm

2. http://www.matweb.com

Appendix A

i) Instron #6025 Universal Tester

ii) Instron Dynatup Impact Tester