Materials 2360

Lab #1 Tensile Test

Group 6

Team Leader: Allison Procher (8597789)

Samantha Boucher (8592418)

Jacob Green (8730554)

Alexanna Hawkins (8669997)

Peter Daginis (8624009)

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Abstract

The objective of the experiment was to determine the stress strain relationship in regards to both steel and aluminium. This was conducted using a tensile test on both metals, the data was then catalogued and graphed in order to analyze the following values. The tensile strength for steel and aluminium were 429.298 MPa and 312.8 MPa, respectively. Yield strength values for steel and aluminium were 265 MPa and 287 MPa. The values acquired for the modulus of elasticity were 18200 MPa and 10648.56 MPa. Percent reduction area for steel and aluminium was 67.58% and 16.58%, while percent elongation was 35.20% and 7.00%. Also, the toughness' calculated were 151.8 kJ/m^3 and 50.45 kJ/m^3 . Lastly, the resilience values of steel and aluminum were respectively 2.274 and 3.868 kJ/m^3 . By comparing steel and aluminium it was concluded that steel can withstand more plastic deformation than aluminium, as shown on the stress strain curves, and is therefore a stronger metal of the two.

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Introduction

The goal of this experiment was to collect and compare experimental data from 1018 steel and 6061 aluminium samples to determine their mechanical properties using a stress-strain curve. Stress-strain curves graph ∂, the tensile stress, as a function of Ɛ, the strain (deformation) of the material. Tensile stress is the pressure resulting from the applied load; strain is the response of the material to the applied stress (Ourdjini, 2017). From these curves other mechanical properties can be determined, including toughness, resilience, yield strength, elastic limit, ultimate tensile strength, percent elongation, and percent reduction in area. Ultimate tensile strength (UTS) is the maximum amount of force the sample can undergo before fracturing. Elastic limit is the point in which the materials begins to deform plastically (Ourdjini, 2017). This point is represented on the graph through the change of slope from linear to curved. Previous experimental data has shown that 1018 steel typically has a UTS of 485 MPa, yield strength of 415 MPa, percent elongation and reduction in area of 18% and 40% respectively, and a modulus of elasticity of 200 GPa (www.matweb.com). Similarly, 6061 aluminium has a UTS of 310 MPa, yield strength of 276 MPa, percent elongation and reduction in area of 12% and 17% respectively, and a modulus of elasticity of 68.9 GPa (www.asm.matweb.com).

In this experiment, the tensile stress of a material can be calculated using the equation

$$\sigma = \frac{F}{A}$$

where "∂" represents the tensile strength, "F" is the tensile force applied and "A" represents the are the load was applied on. Stress is measured in MPa.

The strain, or response of the material to the applied stress, a sample experiences is calculated using the equation

$$\varepsilon = \frac{lf - lo}{lo}$$

where “Ɛ” represents the strain, “Lo” represents the original length of the sample, and “L” represents the final length of the sample. Strain is a unitless measurement.

Young’s Modulus, or the modulus of elasticity, can be calculated from the slope of the linear portion of a stress-strain curve. This is determined using Hooke’s law, and uses the following equation

$$E = \frac{\sigma}{\varepsilon}$$

where “E” represents Young’s modulus, “Ɛ” represents the strain and “∂” represents the stress. Young’s modulus is typically measured in MPa.

The percent elongation is determined using the equation

$$\textbf{\% Elongation} = \frac{lf - lo}{lo} \times 100\%$$

where “Lo” represents the original length of the sample, and “Lf” represents the length at fracture.

Percent reduction in area is calculated using the equation

$$\textbf{\% Reduction in Area} = \frac{Af - Ao}{Ao} \times 100\%$$

where “Ao” is original area and “Af” is the area at fracture.

The toughness of a material is determined by finding the entire area under the stress-strain curve. While resilience is determined by finding the area under the linear section of the graph. Elastic deformation occurs in a material when small loads allow the atomic bonds to stretch out but return to their original length should the load be removed. After the elastic limit of a material is reached, it begins to deform plastically. This is where larger loads stretch bonds to the point that planes shear and the bonds cannot return to their original lengths. Elastic properties are independent of the materials microstructure but instead depend on the atoms crystal structure and bonding (Ourdjini, 2017).

Methodology

The steel and aluminium samples underwent axial tension using the Instron testing machine. The steel sample was placed into the testing machine and a load was placed on the sample pulling the two ends in opposite directions. The load was increased until the sample fractured and was then removed from the machine. A graphing software tracked the amount of force placed on the sample and graphed it resulting in a stress/strain curve. This process is then repeated with the aluminium sample. Once the process was complete the individual groups took images and measurements of the original and fractured sample. These measurements included the length and diameter of both samples, they can be found in table 1.

Experimental Apparatus

- Aluminium Sample
- Steel Sample
- Instron Testing Machine
- Data Collection Program
- Digital Vernier Calliper

Results

<u>Graphs</u>

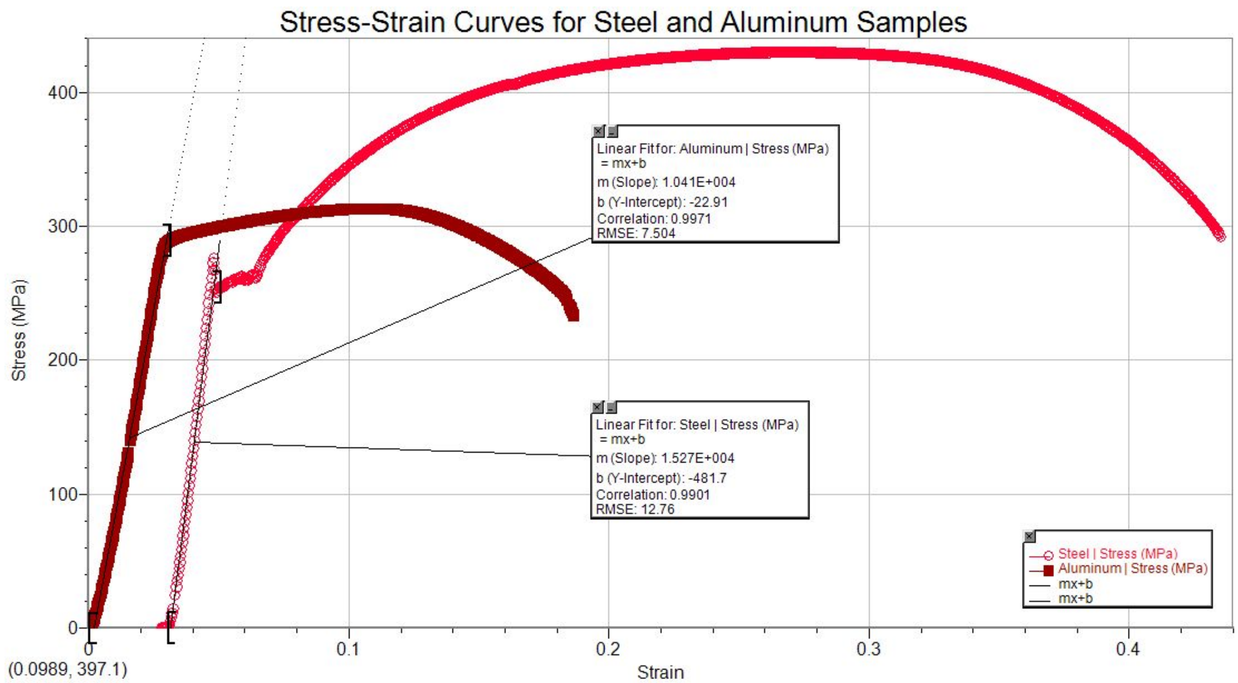

Figure 1: Comparison between the stress strain curves for the steel and aluminum samples

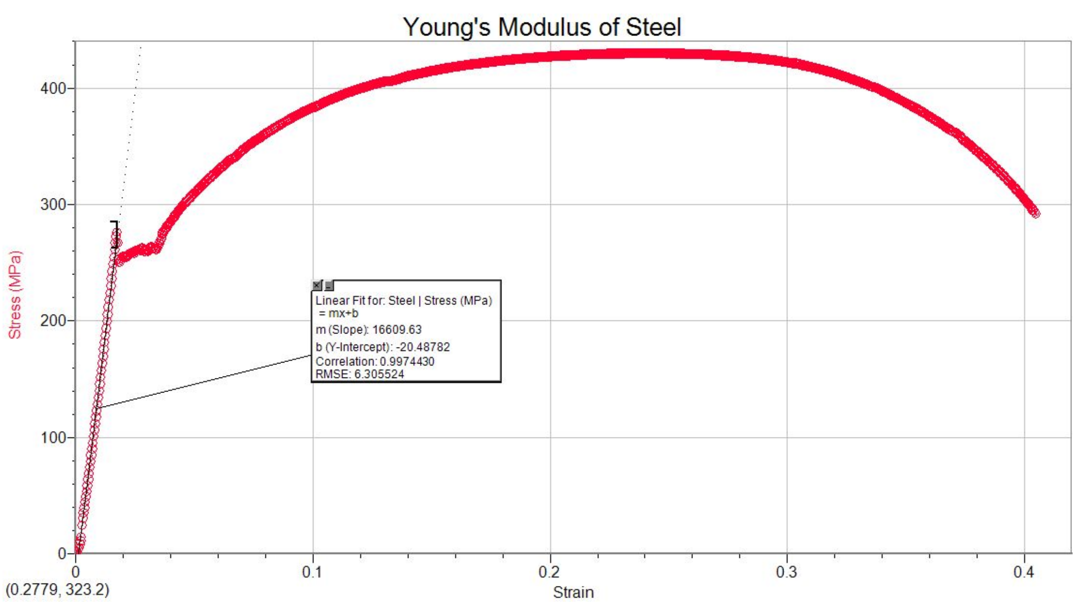

Figure 2: Slope of the linear portion of the steel graph showing Young's Modulus

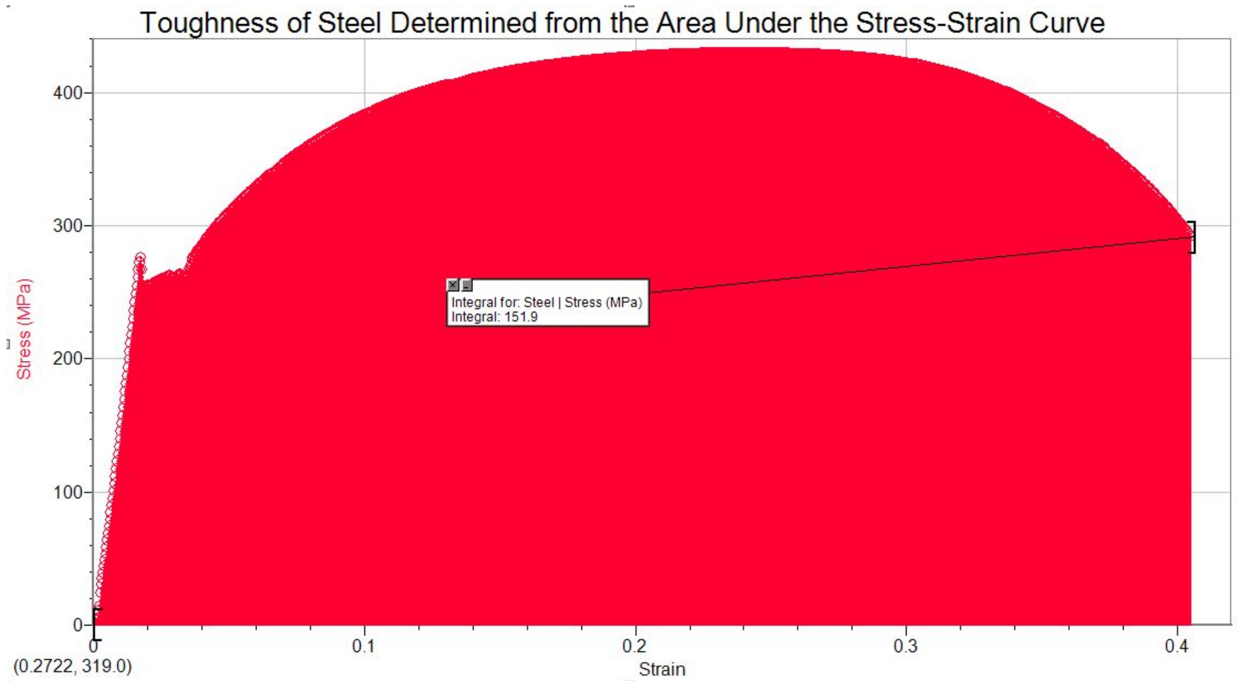

Figure 3: The area under the curve showing the toughness of steel

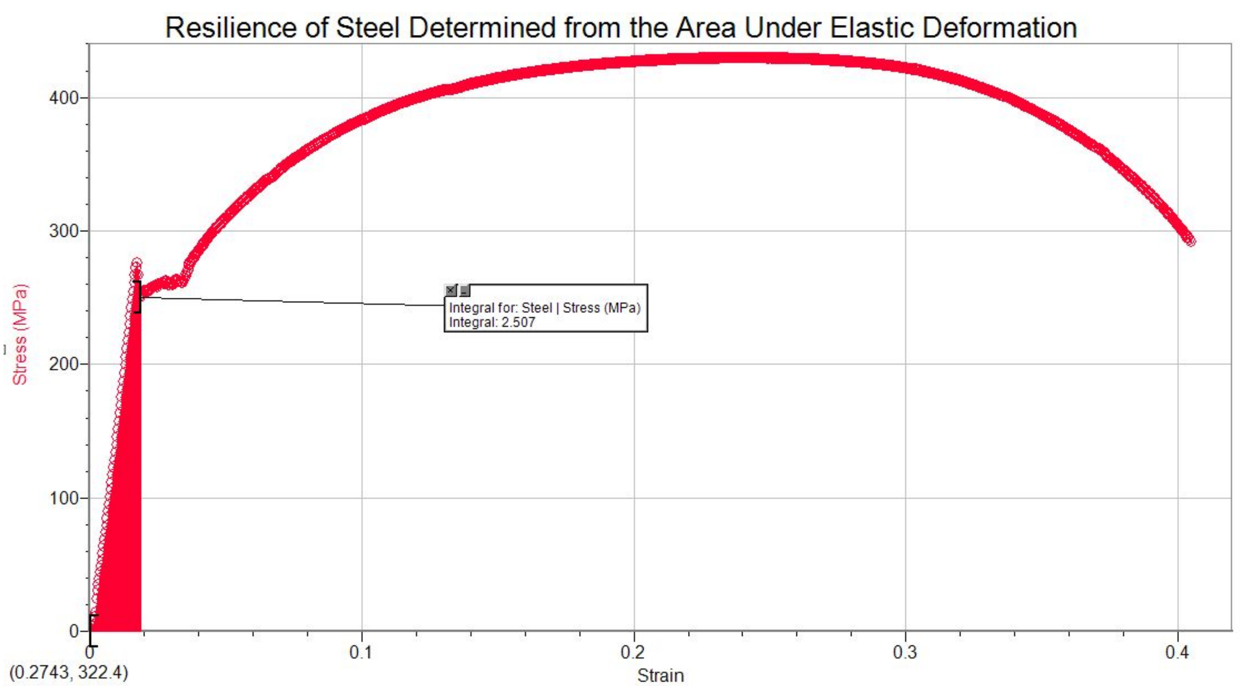

Figure 4: The area under the linear portion of the curve showing resilience

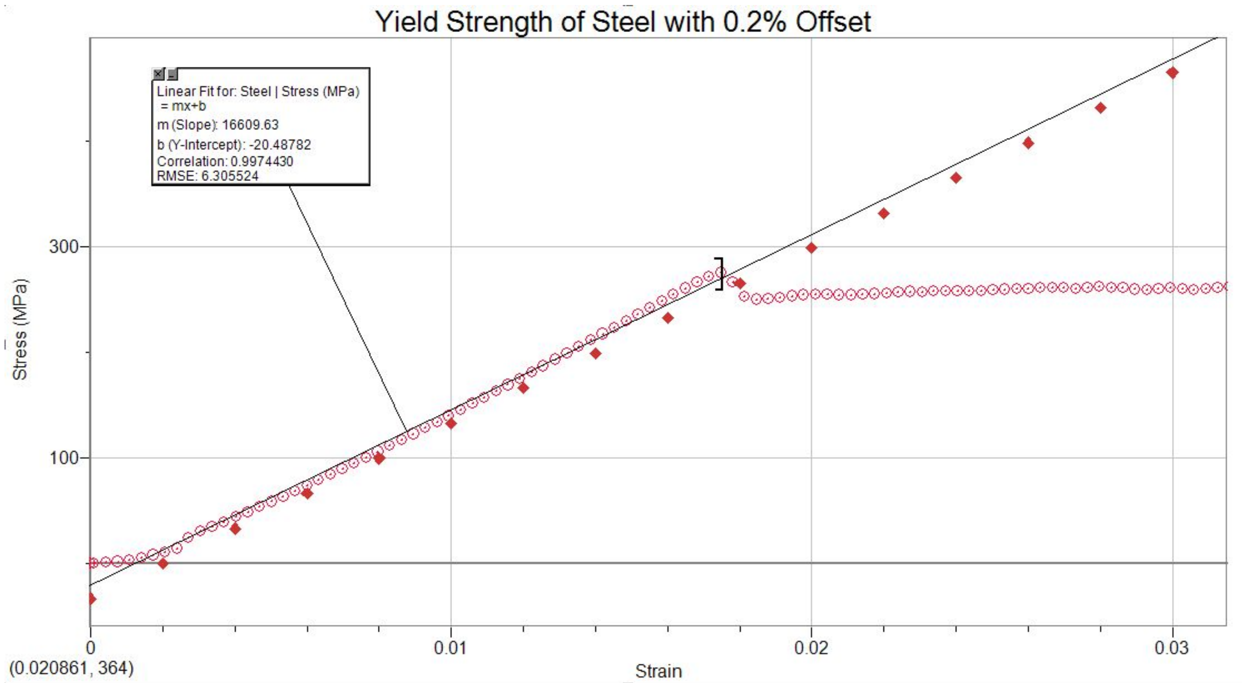

Figure 5: The slope of the steel graph showing the yield strength with a 0.2%

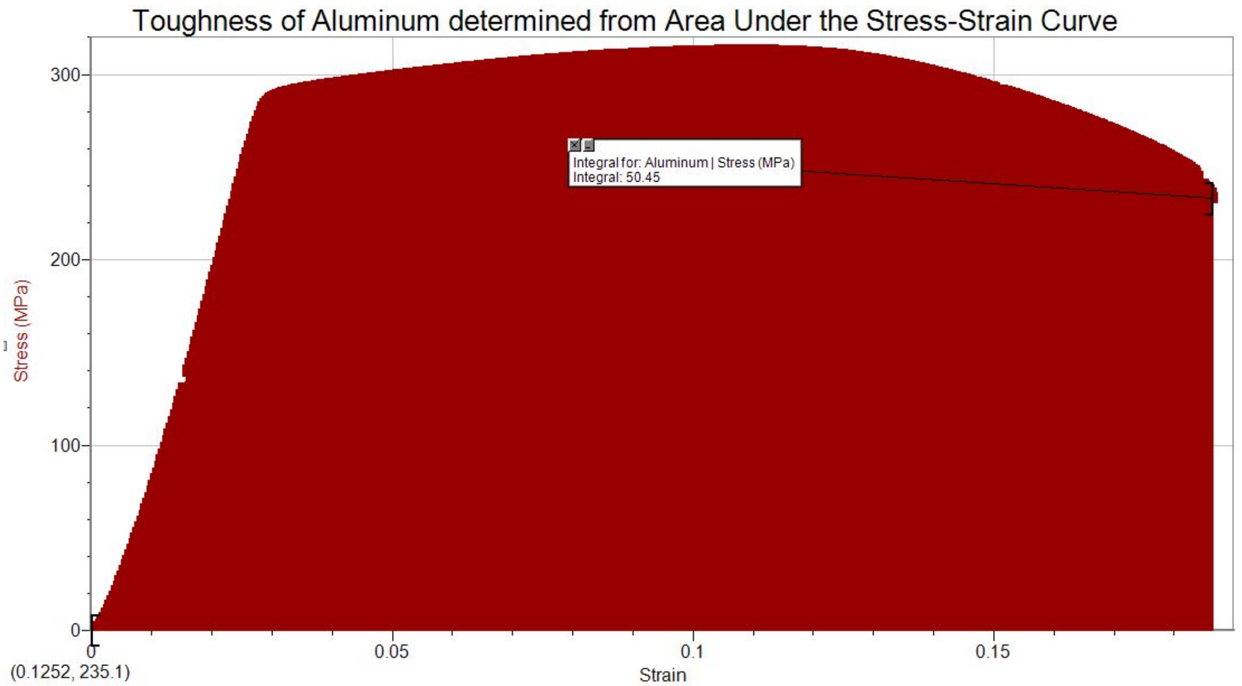

Figure 6: The area under the curve of aluminum showing the toughness

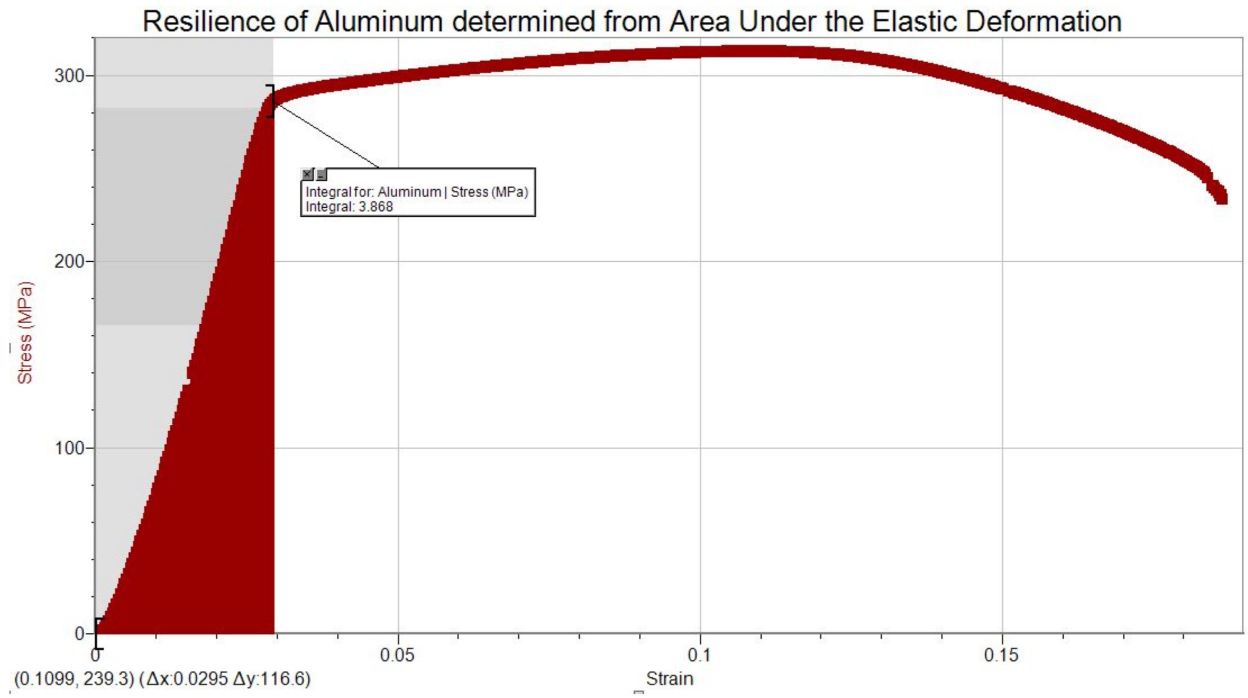

Figure 7: The area under the linear portion of the aluminum graph showing the resilience

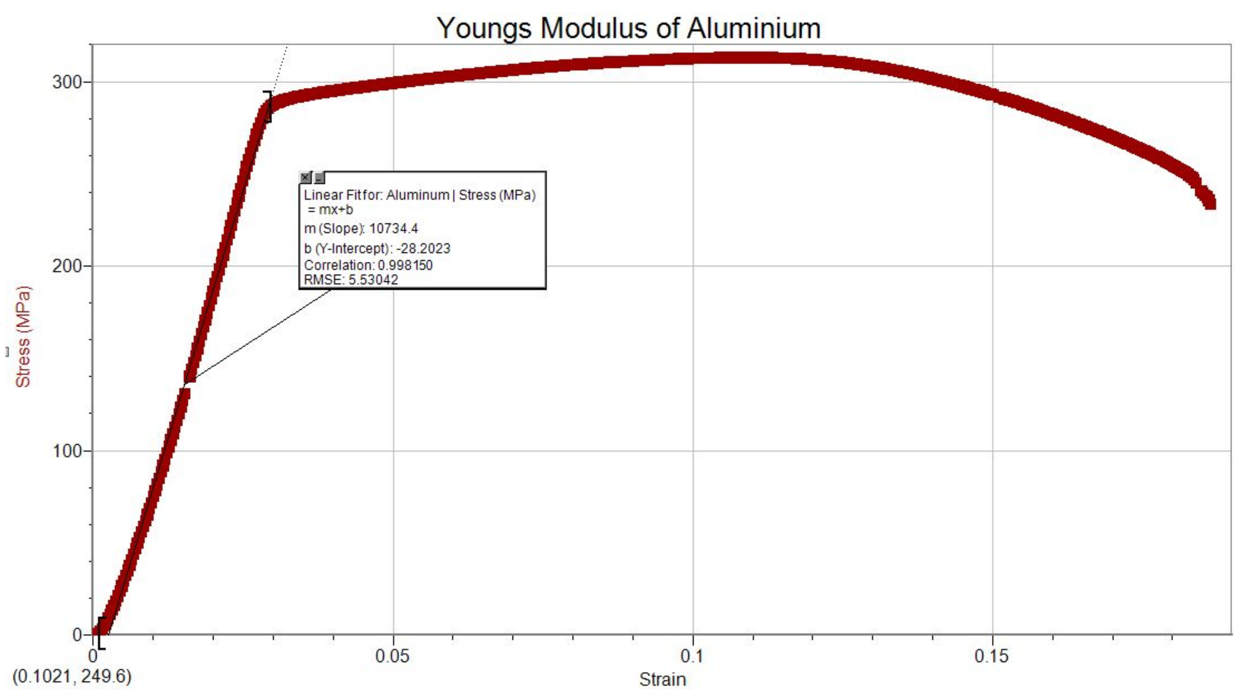

Figure 8: The slope of the linear portion of the aluminum graph showing Young's Modulus

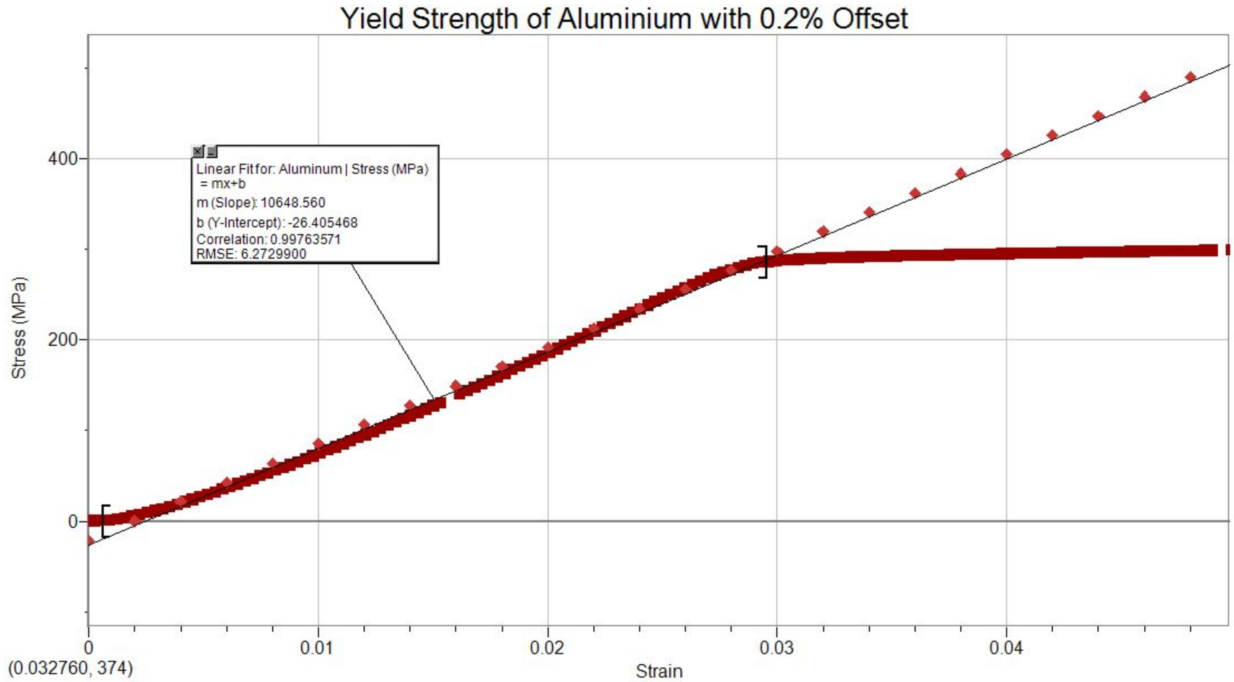

Figure 9: The slope of the aluminum graph showing the yield strength with a 0.2% offset

Table 1: Raw Data Recorded During Experiment

	Steel	Aluminium
Initial Length (in)	2.000	2.000
Initial Length (cm)	5.080	5.080
Final Length (in)	2.704	2.140
Final Length (cm)	6.868	5.436
Initial Diameter (in)	0.502	0.503
Initial Diameter (cm)	1.275	1.278
Final Diameter (in)	0.286	0.458
Final Diameter (cm)	0.726	1.163

Sample Calculations - Steel

Young's Modulus

$E = 1,820\ MPa$

$As\ determined\ using\ Figure\ 2\ by\ finding\ the\ slope\ of\ the\ linear\ portion\ of\ the\ graph$

Yield Strength

$\sigma y = 272.6\ MPa$

$As\ determined\ using\ Figure\ 5\ by\ finding\ the\ intersection\ point\ of\ a\ line\ offset\ by\ 0.002\ with\ the\ same\ E\ slope$

Ultimate Tensile Strength

$UTS = 429.298\ MPa$

Reduction in Area

$$\%RA = \frac{Ao - Af}{Ao} * 100\%$$

$$= \frac{0.198 - 0.0642}{0.01979} * 100$$

$$= 67.58\%$$

Elongation Length

$$\%El = \frac{lf - lo}{lo} * 100\%$$

$$= \frac{2.704 - 2.000}{2.000} * 100$$

$$= 35.20\%$$

Resilience

$Resilience = 2.274\ MPa$

$As\ determined\ using\ figure\ 4\ by\ finding\ the\ area\ under\ the\ linear\ portion\ of\ the\ graph.$

Toughness

$Toughness = 151.8$

$As\ determined\ by\ the\ area\ under\ the\ entire\ curve\ using\ Figure\ 5$

Sample Calculations - Aluminium

Young's Modulus

$E = 10648.56\ MPa$

As determined using figure 8 by finding the slope of the linear portion of the graph

Yield Strength

$\sigma y = 287\ MPa$

As determined using Figure 9 by finding the last point on the linear section of the graph

Ultimate Tensile Strength

$UTS =$ 312.8 MPa

Reduction in Area

$\%RA = \frac{Ao-Af}{Ao} * 100\%$

$= \frac{0.199-0.166}{0.199} * 100$

$= 16.58\%$

Elongation Length

$\%El = \frac{lf-lo}{lo} * 100\%$

$= \frac{2.140-2.000}{2.000} * 100$

$= 7.00\%$

Resilience

Resilience = 3.868 kJ/m^3

As determined using figure 7 by finding the area under the linear section of the graph.

Toughness

$Toughness = 50.45\ kJ/m3$

As determined using figure 6 by finding the area under the entire curve.

Table 2: Comparison of results between steel and aluminium

	Steel	Aluminium
Young's Modulus	18200 MPa	10648.56 MPa
Yield Strength	265 MPa	287 MPa
Ultimate Tensile Strength	429.298 MPa	312.8 MPa
Reduction in Area	67.58%	16.58%
Elongation Length	35.20%	7.00%
Resilience	2.274 kJ/m^3	3.868 kJ/m^3
Toughness	151.8 kJ/m^3	50.45 kJ/m^3

<u>Steel Images</u>

Figure 10: Image of the original steel sample before being placed in the tensile strength machine.

Figure 11: Image of the steel sample after being fractured in the tensile strength machine.

Figure 12: Image showing the steel samples decrease in diameter the closer it gets to the fracture point.

Aluminium Images

Figure 13: Image of the original aluminium sample before being placed in the tensile strength machine.

Figure 14: Image of the aluminium sample after being fractured in the tensile strength machine.

Figure 15: Image showing the aluminium samples decrease in diameter the closer it gets to the fracture point.

Discussion

Steel exhibited a stress - strain relationship which exhibited elastic deformation and plastic deformation. The steel 1018 test piece displayed regions of necking, hardening and yield point phenomenon. Steel 1018 has a low- medium concentration of carbon relative to other carbon steels, at approximately 0.14 - 0.20 %, while also including Manganese (0.6%-0.9%), Sulphur (<=0.04%) and Phosphorous (<=0.05%). The balance of the composition is Iron. Steel is formed through the alloying of iron and carbon. The iron is initially of BBC crystal structure, but when heated to higher temperatures (over 910 degrees Celsius), the crystal structure changes to FCC, allowing for a greater amount of carbon to be mixed, up to the solubility of iron. The mixture is then cooled, a process which forces the carbon atoms into interstitial positions in the crystal structure, deforming the crystal structure of the metal but simultaneously strengthening it. The interstitial carbon atoms interferes with the dislocations of the crystal lattice, resulting in a stronger metal. With the addition of carbon, the steel becomes stronger but less ductile. (Materials: Carbon Steel)

Comparing the results from the lab to an online AISI (American Iron and Steel Institute) table for steel 1018, it was found that only a few results were comparable. Ultimate tensile strength was very accurate, with only 2.43% difference (429.298 MPa to 440 MPa). However, elongation, reduction in area, Young’s modulus and yield strength were significantly different, with percent differences of 57.4, 68.95, -90.9 and -28.4 respectively. No values were to compare with for resilience and toughness. When the initial and final gauge lengths were measured for the steel bar, the values 2 inches and 2.704 inches. Using the equation (Final Length - Initial Length)/Initial Length, we can find the strain at fracture, which is 0.352. However, the final strain in the graphs for steel is 0.435. The variance in strain would affect values which are influenced by strain such as Young’s modulus and yield strength. Using the final strain value of 0.352, the values of the affected properties would be higher, have a smaller percent difference and thus be more accurate. The error in strain values is a significant error for calculations and results. (AISI 1018 Steel, cold drawn)

Aluminium exhibited a stress - strain relationship which exhibited elastic deformation and plastic deformation. The 6061 aluminium test piece displayed regions of necking, and yield point phenomenon. 6061 aluminium is made up of Al (95.8% - 98.6%), Cr (0.04% - 0.35%), Cu (0.15% - 0.4%), Fe (Max 0.7%), Mg (0.8% - 1.2%), Mn (Max 0.15%), Si (0.4% - 0.8%), Ti (Max 0.15%), Zn (Max 0.25%), Other, each (Max 0.05%), Other, total (Max 0.15%) (Aluminum 6061-T6, n.d.).

Aluminium 6061 is heat treated at approximately 533℃ then quenched after a sufficient amount of time. Precipitation hardening can be performed at 160℃ for 18 hours then cooled by air (Aluminium / Aluminum 6061 Alloy (UNS A96061), 2012).

In this experiment Aluminium was to found to have an ultimate tensile strength of 312.8 and a yield strength of 287s this is close to results provided by the Aluminum Association which is 310 MPa and 276 MPa respectively (Aluminum 6061-T6, n.d.).

In comparison to the aluminium sample (Al 6061), steel was stronger, with higher ultimate tensile strength and a larger Young’s modulus. Aluminium has a higher yield strength. Steel is shown to endure more plastic deformation than aluminium as Steel’s fracture point occurs at a higher strain than aluminium’s. Steel is shown to be a stronger and tougher material than aluminum, which makes it a superior metal in many situations. However, a trade-off is that steel is denser and therefore heavier than aluminum for the same volume.

Conclusions and Recommendations

Upon analysis, comparing steel and aluminium mechanical properties of a stress and strain relationship, it was concluded that steel was stronger and able to undergo more stress (having a higher ultimate tensile strength than that of aluminium) and plastic deformation before fracturing. There was margin for error during this experiment including the overall precision of the calliper used for measuring, and the human eye accuracy when reading the changes in lengths. Also, the graphs produced from being linked to the machine have a lag time in order for the machine to get a secure fit on the metal before necking and elastic deformation begin. This could have resulted in unequal fits to each metal and slight variations in results. Overall, the values obtained were reasonable and allowed the respective conclusions to be made.

References

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