Material Science – ENGG*2120: Fall 2017
LAB SUBMISSION COVER SHEET
(Must be included for all group submissions)

Lab Performed: Tensile Properties of Materials

Date Performed: Friday, October 20th, 2017

Date Submitted: Friday, November 3rd, 2017

Group Number: K1

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GROUP PARTICIPATION EVALUATION FORM

ALL GROUP MEMBERS MUST SIGN TO RECEIVE THEIR MARKS

By signing the cover sheet each member is stating that they made a significant contribution to the writing of this lab report and that the distribution of sections completed is accurate.

One form is required for each group report submitted. One report is to be submitted **per group.**

All submissions to be submitted electronically to the dropbox in Courselink by **NO LATER THAN** 4:00 p.m., two (2) weeks after the assigned experiment is performed (unless otherwise indicated in the course outline).

Group Members		Sections Completed
Name (Printed)	Signature	
Noah Montag	[illegible]	Introduction, Conclusion, Experimental Apparatus and Procedures
Melissa Hardy	MHardy	Discussion Questions 2-4,8, References, Proofread Summary/Introduction/Conclusion
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TENSILE PROPERTIES OF MATERIALS

November 3rd, 2017

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SUMMARY

The purpose of this experiment is to examine how tensile strength varies in different materials. Through this lab, the tensile strength values of a hot rolled AISI-1020 steel, cold rolled AISI-1020 steel, AISI-1095 steel, 6061-T6 aluminum alloy, and thermoplastic polymers were examined using the tensile test, which was conducted by applying a unidirectional force onto the material. Using the tensile test, a stress-strain curve was plotted which portrayed useful properties such as the yield strength, ultimate tensile strength, modulus of elasticity, and the breaking strength which aided in the understanding of the different material properties of each sample. The hot rolled steel obtained the highest Young's modulus with a calculated value of 25499 MPa, demonstrating that it is stiffer than the other tested materials and possesses the strongest of the interatomic binding energies and the lowest ductility (inferred by the high Young's modulus). The higher the Young's moduli, the steeper the slope of a stress versus strain curve line, indicating decreased ductility.

By analyzing the graphs and data collection tables, one can deduce that the AISI-1095 Steel acquired the highest ultimate tensile strength with a value of 681.60 MPa, demonstrating that it can withhold the most stress at highest applied force (or maximum stress on the engineering stress-strain curve) compared to the other materials tested and thus has the highest strength. Since strength and ductility are inversely proportional, this explains why the 1095 Steel resulted with a low percent elongation of 13.4%. Conversely, the most ductile material was the HDPE that was pulled at 20mm/min, with an ultimate tensile strength of 27.4 MPa and a percent elongation of 94.25%. Additionally, it is evident in the graphs that the AISI-1095 acquires the highest breaking stress with a value of 571 MPa and the highest yield stress with a value of 652

MPa, indicating that it can withstand the more stress than the other tested materials before transitioning from elastic to plastic deformation and reaching the moment of complete failure.

Overall, the conclusion of this experiment portrays that metals are generally stronger than polymers as a result of the difference in bonding patterns; metals are bonded by metallic bonds while polymers are bonded by covalent bonds and Van der Waals forces. The type of atomic bonding that is present in a material determines the respective characteristics of that material, including the strength and ductility. Ionic bonds are the strongest of all bonding types, and causing a material would to be both strong and brittle, as demonstrated in the experiment by the metal samples. Van der Waals forces and covalent bonds, however, are the much weaker, and cause a material to be weaker but more ductile, as demonstrated by the HDPE samples.

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INTRODUCTION

This experiment measured the tensile strength of several different materials through a tensile test. A piece of a known material with measured dimensions was put inside of a Instron testing machine and slowly pulled until it broke apart. The load required to achieve failure is measured by the machine and then the new dimensions of the material are taken. A stress-strain curve can then be calculated. Some materials had an extensometer clipped onto them to more accurately measure the change in length up until the point that plastic deformation begins when it was removed to avoid damage because of the material failing.

The materials that had their tensile strength tested were; hot rolled AISI-1020 steel, AISI-1095 steel, 6061-T6 aluminum alloy, 2 cold rolled AISI-1020 steel, HDPE (20mm/min), and HPDE (50mm/min). The purpose of a tensile test is to determine the tensile strength of a material or discover properties for a material from a stress-strain curve created from the data (Young's modulus, yield stress, ductility, ultimate tensile strength, etc.).

The purpose of this experiment is to see how different materials behave when introduced to tension and how their tensile strengths, stress-strain curves, and final shapes differ. Knowing these things is very important when it comes to choosing a material to use in any form of engineering. If a part only needs to withstand a certain amount of stress then a less expensive and lighter plastic can be used as opposed to a heavy and expensive metal.

Hot rolled steel is used in a lot of structural situations where the precise shapes aren't required where as cold rolled steel is used when tolerances, surface condition, concentricity, and straightness are important. Aluminum is used commonly in things that require something strong, lightweight, malleable, conductive, and corrosion resistant. Plastic polymers are most commonly used in things that don't need to be as strong as a metal since they are cheaper. The use of different materials is usually determined based on the strength required as the main factor, since if it cannot withstand a certain amount of stress it will fail.

Experimental Apparatus & Procedures

Equipment

- Instron testing machine with a 50 kN load cell
- Extensometer
- Micrometer and Vernier calipers

Samples

- 1 hot rolled AISI-1020 steel
- 2 cold rolled AISI-1020 steel
- 1 AISI-1095 steel
- 1 6061-T6 aluminum alloy
- 2 HDPE samples

Experiment Procedures

1. The width, thickness, and gauge length of all tensile specimens were measured and recorded in data sheets.
2. A material was put in the Instron testing machine and the machine was set to the correct test conditions. If a material needed the extensometer on it then it was put on.
3. The test begins and the machine slowly pulls the material apart.
4. If the material has the extensometer on it then it gets removed prior to plastic deformation occurring. The test continues after it is removed.
5. Once the material fails, it is removed from the Instron testing machine and its dimensions are measured and recorded in data sheets.
6. Repeat steps 2-5 using each material until all have been tested.

Note: Lab manual instructions and all safety precautions were strictly followed and no additional changes were made to either.

RESULTS

Table 1: Calculated Properties of Each Material

	Hot Rolled Steel Without Extensometer	1095 Steel With Extensometer	Aluminum 6061 With Extensometer	Cold Rolled Steel With Extensometer	Cold Rolled Steel Without Extensometer	HDPE (20mm/min)	HDPE (50mm/min)
Young's Modulus (MPa)	25499	20611	17012	18799	19212	952.03	378.41
UTS (MPa)	454.6980751	681.6036023	381.8097421	413.3795	455.498	27.46947	28.77166
Breaking Stress (MPa)	333	571	287	371	347.5	2.15	1.64
Yield Stress (MPa)	73	652	329.2	321	429	10.3	26.76
% Elongation (%)	30.24683925	13.3756543	21.54595253	22.36329	14.99053	94.25044	43.57437

Table 2: Theoretical Properties of Each Material

	Hot Rolled Steel Without Extensometer	1095 Steel With Extensometer	Aluminum 6061 With Extensometer	Cold Rolled Steel With Extensometer	Cold Rolled Steel Without Extensometer	HDPE (20mm/min)	HDPE (50mm/min)
Young's Modulus (GPa)	205	205	68.9	205	205	1.241	1.241
UTS (MPa)	825	825	310	680	825	38	38
Yield Stress (MPa)	455	455	276	525	455	13	13
% Elongation (%)	10	10	15	10	10	130	130

Table 3: Percent Differences of Calculated and Theoretical Properties of Each Material

	Hot Rolled Steel With Extensometer	1095 Steel With Extensometer	Aluminum 6061 With Extensometer	Cold Rolled Steel With Extensometer	Cold Rolled Steel Without Extensometer	HDPE (20mm/min)	HDPE (50mm/min)
Young's Modulus (MPa)	87.56146341	89.94585366	75.30914369	90.8297561	90.62829268	23.28525383	69.50765512
UTS (MPa)	99.94488508	99.91738138	99.87683557	99.9392089	99.94478812	99.92771192	99.92428511
Breaking Stress (MPa)	99.92681319	99.87450549	99.89601449	99.92933333	99.92362637	99.98346154	99.98738462
Yield Stress (MPa)	99.27	93.48	97.80533333	96.79	95.71	99.99207692	99.97941538
% Elongation (%)	202.4683925	33.75654304	43.63968351	123.6329	49.9053	27.49966154	66.48125385

Table 4: Descending Ranking of Each Material

-	Highest	2nd Highest	3rd Highest	4th Highest	5th Highest	6th Highest	7th Highest
Young's Modulus	Hot Rolled Steel With Extensometer	1095 Steel With Extensometer	Cold Rolled Steel Without Extensometer	Cold Rolled Steel With Extensometer	Aluminum 6061 With Extensometer	HDPE (20mm/min)	HDPE (50mm/min)
UTS	1095 Steel With Extensometer	Cold Rolled Steel Without Extensometer	Hot Rolled Steel Without Extensometer	Cold Rolled Steel With Extensometer	Aluminum 6061 With Extensometer	HDPE (50mm/min)	HDPE (20mm/min)
Breaking Stress	1095 Steel With Extensometer	Cold Rolled Steel With Extensometer	Hot Rolled Steel Without Extensometer	Cold Rolled Steel Without Extensometer	Aluminum 6061 With Extensometer	HDPE (20mm/min)	HDPE (50mm/min)
Yield Stress	1095 Steel With Extensometer	Cold Rolled Steel Without Extensometer	Aluminum 6061 With Extensometer	Cold Rolled Steel With Extensometer	Hot Rolled Steel Without Extensometer	HDPE (50mm/min)	HDPE (20mm/min)
% Elongation	HDPE (20mm/min)	HDPE (50mm/min)	Hot Rolled Steel Without Extensometer	Cold Rolled Steel With Extensometer	Aluminum 6061 With Extensometer	Cold Rolled Steel Without Extensometer	1095 Steel With Extensometer

Figure 1: Stress/Strain Curve for Hot Rolled Steel WITH Extensometer

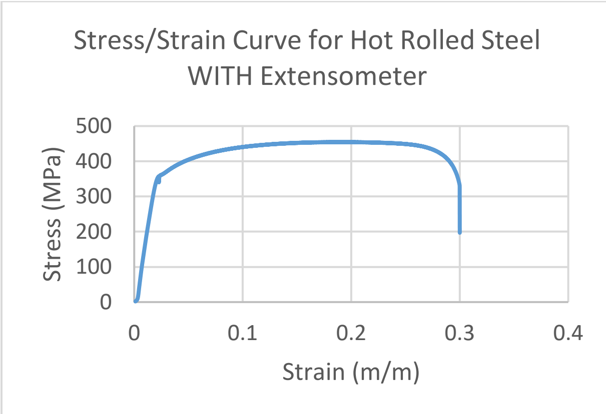


Figure 2: Stress/Strain Curve for 1095 Steel WITH Extensometer

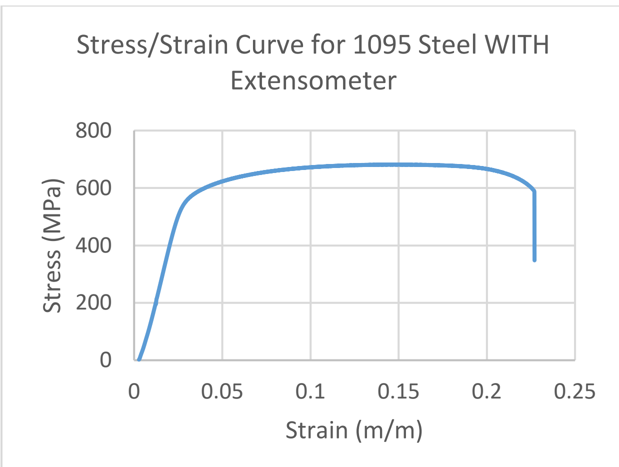


Figure 3: Stress/Strain Curve for Aluminum 6061 WITH Extensometer

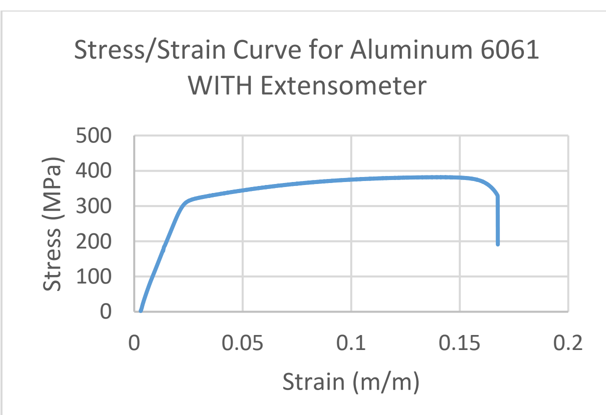


Figure 4: Stress/Strain Curve for Cold Rolled Steel WITH Extensometer

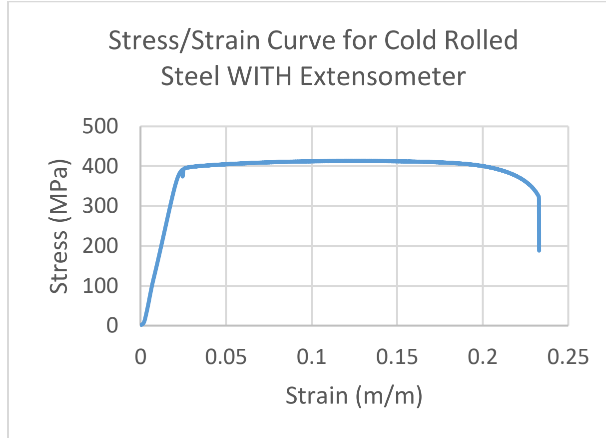


Figure 5: Stress/Strain Curve for Cold Rolled Steel WITHOUT Extensometer

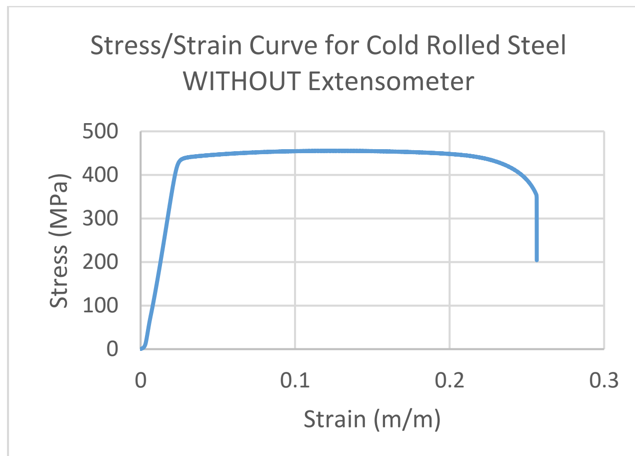


Figure 6: Stress/Strain Curve for HDPE (20mm/min)

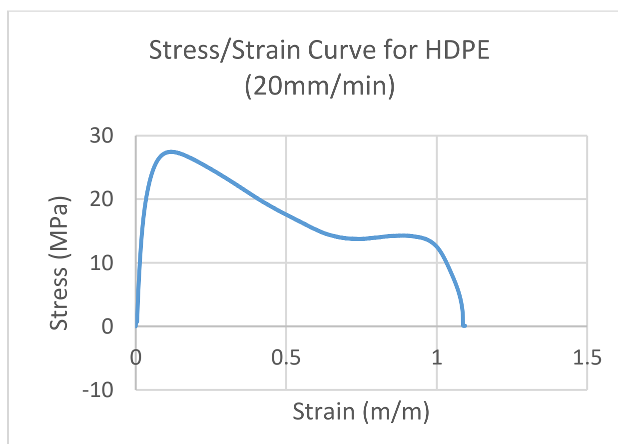
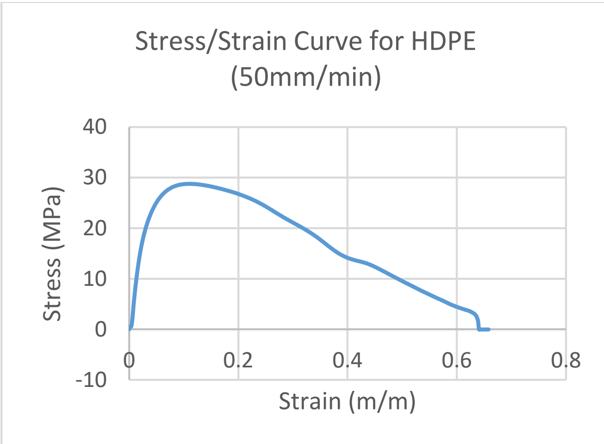


Figure 7: Stress/Strain Curve for HDPE (50mm/min)



Discussion

Of all the materials tested, the strongest material was the 1090 Steel. It had the highest Ultimate Tensile strength, with that being 681 MPa. Conversely, the weakest material had the lowest Ultimate Tensile Strength. This material was the HDPE that was pulled at 20mm/min with an ultimate tensile strength of 27.4 MPa. The most ductile material was also the HDPE that was pulled at 20mm/min and it had a percent Elongation of 94.25%, and the least ductile material was the 1095 Steel with a percent Elongation of 13.4%. A designer would want to use a strong material when the material would be subject to very large forces. One such scenario would be construction applications. All the materials used in construction need to support their own weight, and the weight of the structure as well. Due to the scale of construction projects, the weights of buildings can be very great, and as such, the materials used in buildings need to be very strong to not break from loading. A ductile material would be desired for applications where a designer would need a material to not break due to plastic deformation. This is important for considering safety of designs. Ductile materials absorb energy, to a certain extent, when being plastically deformed, meaning they are less likely to break than brittle materials when being plastically deformed. Similar to ductile materials, tough materials absorb energy when impacted. A designer would want to use a tough material when anticipating lots of impacts in a design. For example, hockey equipment needs to be made from tough materials, as players need to absorb the impact from pucks (when shot) and impacts from other players.

The way in which the bonds between the atoms that compose a material are formed play a quintessential role in the properties of that material. Primary bonds, which include metallic, covalent, and ionic bonds are much stronger than secondary forces, which involve exclusively Van der Waal forces. The strength of the atomic bonds within a material proportionally affects the respective strength of the material, whilst affecting the ductility of said material in an inversely-proportional manner. In metallic bonding, valence electrons are shared between multiple nuclei simultaneously. This large positive charge to small negative charge ratio creates a strong bond between atoms, however this bond strength is still relatively low in comparison to that of covalent and ionic bonds due to the multiple distributed charges, opposed to a shared bond between one positive nuclei core and one negative electron. Covalent bonds are formed between two atoms that share an electron(s) to satisfy the eight-electron rule within their valence shells. Since this electron(s) is so crucial to each of the atoms' stability, the bond between them is very strong. Nonetheless, the binding energy of ionic bonds is the highest of the primary bonding types, as the two atoms essentially "trade" electrons, allowing one of them to gain a negative charge and the other to become positively charged; this difference in electronegativity between atoms causes a strong attraction of much greater intensity than that of covalent, metallic, or Van der Waals. Since the steels and aluminum materials within this experiment are bonded by metallic bonds, they have a higher binding energy and thus higher strength that that of the HDPE (which is bonded covalently), but also consequently have lower ductility, as illustrated in the "UTS" and "% Elongation" in *Table 1*. In polymers specifically, which are covalently bonded, strand length and shape also play a role in the binding strength of the material; the longer the chain the greater the Van der Waals and consequently the stronger the material and the greater the amount of side groups on a chain, the less ductile the material due to decreased ability for polymer chains to “glide” past one another during tensile testing.

At the microstructural level, metals and thermoplastic polymers react very differently to applied loads due to their contrasting atomic structures and binding patterns. In thermoplastics, the elastic region of deformation is significantly smaller than that of metals as seen in *Figures 1-7* and *Table 1*, since elasticity is defined as the ratio of stress (force applied per unit area) and strain (deformation due to stress) and thus the greater the Young’s modulus of a material, the more elastic deformation it can withstand before permanent deformation begins. As the material begins to “neck”, the area decreases, thus force required to continue plastic deformation is also decreased, leading to failure. In thermoplastics specifically, the amount of necking that occurs is dependent on both temperature and strain rate; the higher the temperature and/or slower the strain rate, the more plastic deformation the material can undergo before reaching its breaking strength. This is unique to thermoplastics due to their viscoelastic nature, which is demonstrated by the slow strain rate of the Instron, allowing the polymer chains to “flow” past one another smoothly and thus allowing large amounts of plastic deformation (the temperature aspect does not apply to this experiment since it was conducted at room temperature) (Clemmer 2017). Metals do not exhibit the same “viscoelastic” properties as thermoplastics and thus can undergo smaller amounts of plastic deformation before reaching their respective breaking strengths.

Strength of steel increases proportionally to the carbon content of the sample, while the formability decreases proportionally (Clemmer 2017). Furthermore, hot-rolled steel is much more malleable than cold-rolled steel, which is stronger and more resilient (Dilthey 2017). These characteristics are illustrated in *Table 4*, with the exception of Hot Rolled Steel Without Extensometer, which has high potential to be inaccurate due to the lack of use of the extensometer (which produces more accurate readings). The 1095 steel has the highest carbon content of all three steels, thus it will possess the highest strength; the 1020 cold-rolled steel will have a higher strength than the 1020 hot-rolled steel. In applications that require a flexible but relatively strong material, such as sheet metal and railway tracks, hot-rolled steel would be the material of preference in comparison to cold-rolled or high-carbon steels. The latter would be more applicable in designs such as car bodies, since the higher strength would be able to withstand higher impacts and thus keep the passengers of the vehicle safer than if the structure was composed of hot-rolled or low-carbon steel.

An extensometer is used to measure tiny changes in deformation when performing a tensile test. It is used as a more accurate gauge than the machine conducting the tensile test because the actual machine applying the tensile force is subject to reaction forces from the sample, and as a result, the data is skewed. This device is often used in tensile tests because it can measure small deformations in the sample without being subject to any forces from the testing apparatus. As stated above, the built-in extension gauge in the Instron test machine is subject to reaction forces, skewing the results for the extension values. The extensometer precisely and accurately measures deformation reaction force free. As a result, calculating values such as Young's Modulus, the 0.2% Offset Yield Stress and the percent Elongation becomes more accurate.

The Cold Rolled 1020 Steel was measured twice, once with the Extensometer and once without. Taking a quick glance at the data, one might assume not much changed, Young's Modulus was a little smaller than without the Extensometer, the Ultimate Tensile Strength was a bit smaller with the Extensometer, the Breaking Stress was a little larger with the Extensometer, the Yield Stress was smaller, and the percent Elongation was a little bigger with the Extensometer. Looking at this data, one might assume there is not much different but giving a closer look to the Stress/Strain curves, there are some notable differences. For the curve with the Extensometer, a drop off can be seen around the 0.2% Offset Yield. This is the Upper and Lower Yield values, which are not to be seen in the curve where the Extensometer was not used. The design of the Tensile test affected the results due to the accuracy of the tools used. A Contact Extensometer was used, which is fairly accurate to a degree, but due to being a mass that is in contact with the test subject, affected the results of the test, even if it was by a very insignificant margin. A laser or video Extensometer would have been more accurate as it would not have been intrusive to the Tensile testing machine during the test.

Hot Rolled 1020 Steel has good strength, ductility, and fracture resistance. It is very inexpensive and is machined and welded easily. Due to this, it can be used for many applications and is very common. As the cooling process warps the size of the piece of metal, Hot Rolled Steel can be used when inaccurate dimensions are acceptable. It is mainly used for I beams in construction and for railroad tracks in transportation. Cold Rolled 1020 Steel has very similar properties to Hot Rolled Steel, aside for one main difference, it does not deform during cooling. As a result, Cold Rolled Steel can be used for applications when dimensioning is very important, such as screws, bolts, washers, gears, and casings for machines. The 1095 Steel is strong, brittle and hard. It is easily formed and can be easily welded. Because of its hardness, it can be used for cutting tools and springs. The Aluminum 6061 alloy has a relatively low cost, low density, good thermal and electrical conductivities, and is resistant to oxidation and corrosion. Because of these properties, Aluminum 6061 can be used for Aircraft bodies, beverage cans, and certain automotive parts. High-Density Polyethylene (HDPE) is chemically resistant, rigid, and a good insulator. It can be used for a wide range of applications such as water bottles, construction hats, drinking straws, and types of plastic ropes.

Based on the values calculated and recorded in *Table 4*, it is evident there were large sources of error throughout the experiment, one of the most prominent being the incalibration/lack-of-use of the extensometer in the portions of the experiment in which it's use was designated. This is evident due to the overt similarities in the percent differences between the theoretical and calculated values of the cold-rolled steel with and without the extensometer. For this reason, the assumption was made that the extensometer was either broken or not calibrated properly, since percent differences should have decreased substantially when the extensometer was used. Additionally, potential sources of error include incalibration of the Instron machine and the calipers, as well as flaws within the sample materials.

CONCLUSION

The strongest material out of all the tested materials was 1095 Steel. It had a much greater ultimate tensile strength than that of the HDPE polymer which was identified as the weakest material. However, the HPDE polymer was the most ductile of the tested materials, having an ultimate tensile strength of 27.4 MPa and a percent elongation of 94.25%, whereas the 1095 Steel values of 682 MPa and 13.4%, respectively. This makes sense based on general knowledge about how polymers restructure themselves to allow for more plastic deformation and how metals tend to be more brittle but stronger. Stronger and more brittle materials would be used in applications needed to support a lot of weight or withstand a lot of force. A ductile material would be used in applications where energy needs to be absorbed and material failure needs to be completely avoided. The chemical composition of the materials is what determines their ability to either absorb energy and plastically deform or to withstand high amounts of applied force. The strength of the atomic bonds within the material consequently determines the strength of the material. The reason the polymer was able to plastically deform in the manner demonstrated within the experiment was because it has secondary bonding forces acting within the atomic structure of the material, allowing it to continue to have some binding energy even when its primary bonds are broken, allowing the chains to slide apart. Stronger but brittle materials don't possess any secondary bonding forces, so although the bonds have higher strength and can withstand larger amounts of applied force, once they break there is no longer any binding energy holding the material together, causing complete failure to occur.

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APPENDIX

Tensile Lab Sample Calculation: Aluminum 6061

Cross Sectional Area

$$A = (width)(thickness)$$

$$A = (18.3 \times 10^{-3}\ m)(2.79 \times 10^{-3}\ m)$$

$$A = 51.1 \times 10^{-6}\ m^2$$

Stress

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

$$\sigma = \frac{104.7\ N}{51.1 \times 10^{-6}\ m^2}$$

$$\sigma = 2.051\ MPa$$

Strain

$$\varepsilon = \frac{(Extension)}{(length)}$$

$$\varepsilon = \frac{0.24375 \times 10^{-3}\ m}{0.08215\ \ m}$$

$$\varepsilon = 2.9671 \times 10^{-3}\ m/m$$

Ultimate Tensile Strength

$$\sigma_{UTS} = MAX\{\sigma_1, \sigma_2, \cdots \sigma_n\}$$

$$\sigma_{UTS} = 381.81\ MPa$$

Where *n* is the number of data points for a given sample, and σ_1 through σ_n are stress values

Young's Modulus

Young's Modulus is the slope of the elastic region. To find the elastic region, the domain where the rate of change was constant needed to be found. To do this the approximate derivative was taken using the formula:

$$\frac{d\sigma}{d\varepsilon} \sim \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}$$

$$\frac{d\sigma}{d\varepsilon} \sim \frac{4.508686\ MPa - 2.020649\ MPa}{0.003104 \frac{m}{m} - 0.002967 \frac{m}{m}}$$

$$\frac{d\sigma}{d\varepsilon} \sim 18013\ MPa$$

The region where this value was approximately the same as the adjacent values was deemed to be the Elastic region. As it was not ideal to "eyeball" approximately 3000 data points for 7 graphs, another method needed to be used to find where the elastic region was. The Percent differences were found between the derivatives using the formula:

$$\%Diff_{bewteen\ points} = \frac{(\frac{d\sigma}{d\varepsilon})_1 - (\frac{d\sigma}{d\varepsilon})_2}{0.5((\frac{d\sigma}{d\varepsilon})_1 + (\frac{d\sigma}{d\varepsilon})_2)} \times 100$$

$$\%Diff_{bewteen\ points} = \frac{14840\ MPa - 18013\ MPa}{0.5(14840\ MPa + 18013\ MPa)} \times 100$$

$$\%Diff_{bewteen\ points} = 19.3\%$$

Where $\frac{d\sigma}{d\varepsilon}_1$ is the first value of the derivative and $\frac{d\sigma}{d\varepsilon}_2$ is the next value of the derivative. Approximating the "actual" point to be the midpoint between the two data point is ok as an approximate percent difference to be used to find the approximate elastic region. Theoretically, if the elastic region was a perfect line, every percent difference in the elastic region would be 0%. In the real world, this is not the case. To be determined as a possible region of the elastic region, a logical operator was used. The logic is as follows:

$$0 < \%Diff_{bewteen\ points}\ AND\ \%Diff_{bewteen\ points} < 15$$

If both operators are true, Excel would flag that row as a potential data point in the elastic region. 15% difference was an arbitrarily "small" upper bound to be in the elastic region. After that, with the visual help of the original Stress/Strain graph and what Excel flagged, the elastic region could be plotted. Then, the Elastic region was plotted to its own graph and a linear trend line was found. The slope of the trend line was Young's Modulus.

<u>0.2% Offset Yield</u>

To find the 0.2% Offset Yield Strength, a line of the same slope of Young's Modulus needed to be shifted over by 0.2% of each corresponding Strain value. To do this, each Strain value in the Elastic region was multiplied by 0.002 and added to the original value, to shift it over by 0.2%. The formula used was as follows:

$$\varepsilon_{shifted} = \varepsilon_O + 0.002(\varepsilon_O)$$

$$\varepsilon_{shifted} = 0.002967\frac{m}{m} + 0.002\left(0.002967\frac{m}{m}\right)$$

$$\varepsilon_{shifted} = 0.002973068\frac{m}{m}$$

Where $\varepsilon_{shifted}$ is the strain value of the 0.2% shift line and ε_O is the original strain value. Each of its Stress values remained untouched. Taking any of the points, a slope (Young's Modulus), and a point were given. Hinging the equation of a line, $\sigma_{ELastic} = E\varepsilon + b$, where b is the stress-intercept, the equation of a line was found and plotted on the Stress/Strain curve. Finally, the point of intersection between the line and the curve was looked at, and recorded as the 0.2% Offset Yield Stress.

<u>% Elongation</u>

$$\%Elongation = (\frac{(Final\ Length) - (Original\ Length)}{(Original\ Length)}) \times 100$$

$$\%Elongation = (\frac{0.09985\ m - 0.08215\ m}{0.08215\ m}) \times 100$$

$$\%Elongation = 21.54\%$$

<u>% Difference (Using Young's Modulus for Example)</u>

$$\%Diff = \left|\frac{E_{literature} - E_{measured}}{E_{literature}}\right| \times 100$$

$$\%Diff = \left|\frac{205\ GPa - 25.4\ GPa}{205\ GPa}\right| \times 100$$

$$\%Diff = 87.5\%$$