CONCORDIA UNIVERSITY

ENGR 244 – Mechanics of Materials

Experiment 2: Tension Test on Metals

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Objective:
The tension test is a procedure that allows us to determine a material's mechanical properties. The test provides us with information regarding the behaviour of metals particularly under tensile loading. Based on the results of the test we can extract numerous critical values for our design such as the ultimate tensile strength, the reduction in the cross-sectional area, the yield strength, the elastic modulus, and the maximum strain at failure.

Introduction:
In this experiment, the tensile we'll be testing two metal specimens in a tensile testing fixture. The tensile test consists of subjecting a material specimen to controlled tensile loading. Through precise measurement instruments, we can extract the elongation of the specimen at various loading values and use our equations to calculate the parameters that are of interest. Testing metals for tensile strength allow engineers to define their tensile behaviour under a controlled tension load which is a critical part of the design process, since it sets a defined scope of the tensile capacity of the material of interest [1].

To put this experiment in a historical context, signs of rudimentary tensile tests has been observed in the Greek, Egyptian, Roman, and Norman civilizations early on. Although the first recorded tensile strength test has been conducted by French engineer Jean-Victor Poncelet in the 1820s [2].

Choosing a tension test for material can depend on the application of interest, the loading and environmental condition. Different variants of the test are used to test the materials at different temperatures, like the high-temperature tensile test and the cryogenic test. Fatigue and creep testing are tests that based on tensile loading among other loading conditions, to determine the prolonged effect of the load on a material. Dynamic tensile testing is also a similar variant that allows the measurement of dynamic stress-strain response to tensile loading [3].

The test has been chosen for this experiment due to its reliability in providing accurate data about the behaviour of materials under tensile loads.

Prior to the experiment, certain assumptions are to be noted:

- The machine used has been properly calibrated to output the exact loading shown digitally but hasn't been ASTM certified.
- Based on our measurements, the samples have been machined to have a uniform thickness along their gauge length.
- The testing samples are uniformly made of steel for the first, and aluminum for the second.

The tensile test has practical outcomes since it will allow us to define important parameters that'll indicate the capacity of a material to elastically and plastically deform, the different values of stress that set important events in the behaviour of the material in tension such as the yield point, the ultimate strength and the failure point. In a design process, the designer needs the appropriate data to select the best material for the application of interest, tensile tests help inform these decisions, and determine make safe and financially sound decisions. The importance of tensile testing is also noted in the research field has been used to gather the data that are readily available today, but also extensively used in the new composite materials research industry that's significantly expanding.

Procedure:

In this experiment, we used a tension testing fixture locally made to accurately observe the behaviour of two metals specimens, aluminum and steel under tensile loading, see figure 1. The fixture used is comprised of 4 vertically standing rods fixed at the work bench and holds a stationary upper platform that houses an adapter, on the low side of the fixture, an identical adapter is placed axially aligned with the upper adapter, see figure 2. The sample is then set on both its sides into the adapters. Through a hydraulic pump actuated by a simple hand lever, the single axes moving lower platform is pulled vertically downwards, pulling the sample into the indenter, therefore applying a controlled load, see figure 2.

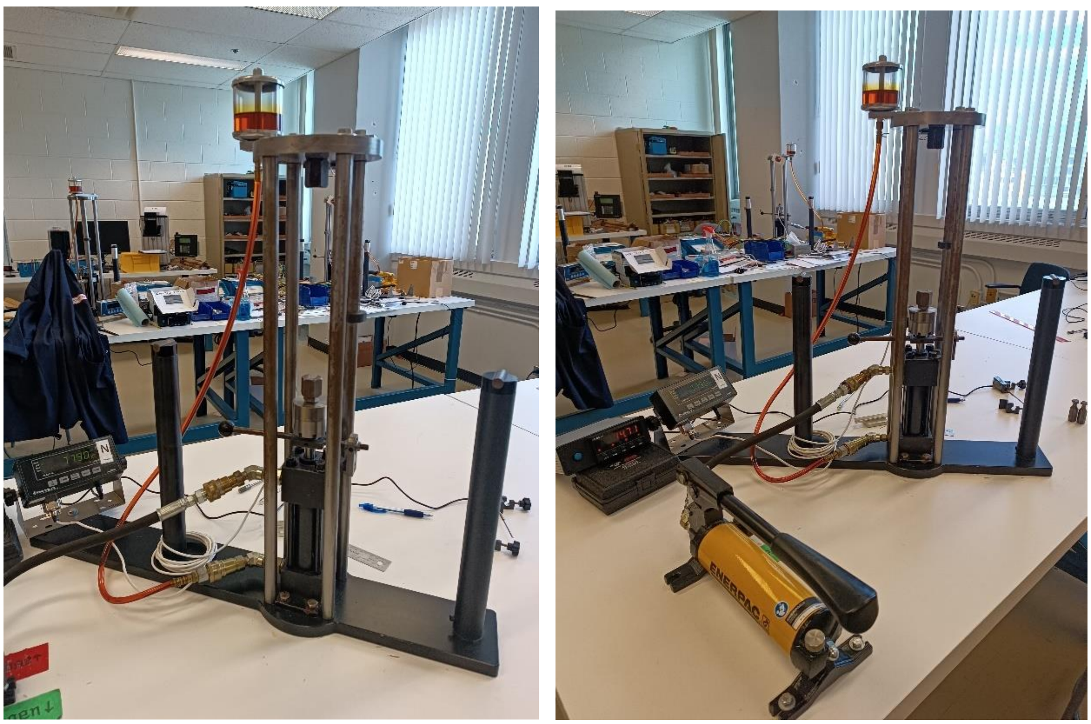

Figure 1: Tension testing fixture.

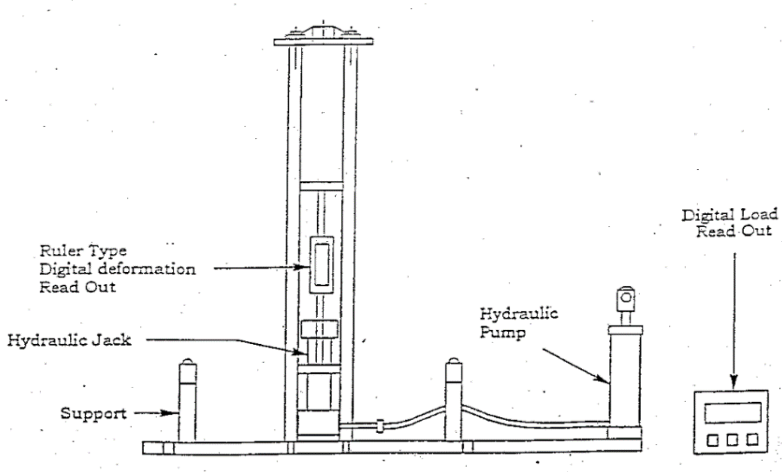

Figure 2: Schematic of the testing machine.

The testing procedure starts by attaching a deformation measuring device to the far ends of the specimen to record the variations in the elongation throughout the test, then threading the end of the sample to a connector compatible with the machine, the metal sample's two ends are then set into the machine adapters. A very small load is applied to the sample (max 10N) to keep the sample aligned with the axis of the elongation. The load applied by the machine and the elongation are simultaneously displayed in live mode, into two digitals screens to observe and record the two values.

We measured the specimen's initial diameter at three different locations along their length, and averaged the values into one as follows:

Diameter of the steel specimen: $d_i = \frac{3.95+3.92+3.96}{3} = 3.94mm$

Diameter of the aluminum specimen: $d_i = \frac{5.00+5.02+5.00}{3} = 5.00mm$

Once the setup is complete, we initiate the test by actuating the pump lever steadily, the pressure on the lever is applied in such a way to increase the load by roughly 100N per second until we get to the desired value. A record of the readings is kept in an interval of 500N until the load reaches 5000N, after this point we decrease the interval to 200N. The interval is then changed again once a stable plateau has been reached, this plateau is noted when the load stops increasing, after this point we recorded the data every 0.25mm of elongation for steel, and every 0.5mm for aluminum until fracture.

Once fracture occurs, we recorded the maximum load applied during the test, the maximum elongation right before fracture, and we measured the diameter of the fracture location as well the final length of the specimen after the fracture.

Results:

The duration of the test has been recoded using a mobile camera to have a precise collection of data, this allowed us to record the elongation at different points of the test under the changing load. After thorough observation based on the recording, we collected the deformation of the specimen at the desired load intervals in table 1 and 2.

ALUMINUM			
Load P(N)	**Deformation δ (mm)**	**Stress σ (MPa)**	**Strain ε**
0	0	0	0
500	0	0	0
1000	0.02	50.94	0.0002
1500	0.05	76.41	0.0005
2000	0.04	101.88	0.0004
2500	0.08	127.36	0.0008
3000	0.13	152.83	0.0013
3500	0.16	178.29	0.0016
4000	0.21	203.77	0.0021
4500	0.25	229.24	0.0025
5015	0.32	255.48	0.0032
5376	1.81	273.87	0.0181

5428	2.31	276.52	0.0231
5484	2.83	279.37	0.0283
5491	3.31	279.72	0.0331
5544	3.81	282.42	0.0381
5616	4.32	286.09	0.0432
5598	4.81	285.18	0.0481
5682	5.30	289.45	0.053
5706	5.80	290.68	0.058
5716	6.30	291.19	0.063
5711	6.81	290.93	0.0681
5714	7.32	291.09	0.0732
5742	7.82	292.51	0.0782
5694	8.31	290.07	0.0831
5743	8.81	292.56	0.0881
5706	9.30	290.68	0.093
5628	9.81	286.70	0.0981
5254	10.31	267.65	0.1031
4716	10.82	240.24	0.1082
4009	11.31	204.23	0.1131
3162	11.57	161.08	0.1157

Table 1: Aluminum specimen data.

STEEL			
Load P(N)	**Deformation δ (mm)**	**Stress σ (MPa)**	**Strain ε**
0	0	0	0
625	0	51.27	0
1000	0	82.03	0
1500	0.01	123.05	0.0001
2000	0.03	164.07	0.0003
2500	0.05	205.09	0.0005
3000	0.06	246.10	0.0006
3500	0.09	287.12	0.0009
4000	0.11	328.14	0.0011
4500	0.13	369.16	0.0013
5000	0.15	410.17	0.0015
5200	0.16	426.58	0.0016
5400	0.17	442.99	0.0017
5600	0.17	459.39	0.0017
5800	0.18	475.80	0.0018
6000	0.20	492.21	0.002
6200	0.21	508.61	0.0021

6400	0.22	525.02	0.0022
6600	0.23	541.43	0.0023
6800	0.24	557.83	0.0024
7000	0.26	574.24	0.0026
7200	0.28	590.65	0.0028
7400	0.34	607.05	0.0034
7617	0.40	624.86	0.004
7747	0.66	635.52	0.0066
7730	0.91	634.13	0.0091
7710	1.16	632.49	0.0116
7695	1.40	631.26	0.014
7452	1.66	611.32	0.0166
7161	1.90	587.45	0.019
6788	2.15	556.85	0.0215
6468	2.40	530.60	0.024
5952	2.65	488.27	0.0265
5963	2.83	489.17	0.0283

Table 2: Steel specimen data.

To calculate the stress and strain, we used the data collected for each loading stage, the equation (1) and (2) used are respectively the following:

$$\boldsymbol{\sigma = \frac{P}{A}}$$

$$\boldsymbol{\varepsilon = \frac{\delta}{L}}$$

σ: tensile stresses on the specimen (MPa).
ε: strain (mm/mm).
P: load applied to the specimen (N).
A: cross sectional area of the specimen (mm^2).
L: gauge length (mm).
δ: elongation (mm).

Here is an example of the calculation we ran to get the stress and strain at load P = 1500N for the aluminum specimen The initial length of the aluminum specimen is L = 100mm, and the cross-sectional area is:

$\mathbf{A = \pi r^2}$
$A = \pi(2.5)^2$
$A = 19.63\text{mm}^2$

We used this area in equation (1) along with the load to determine the stress as follows:

$\boldsymbol{\sigma = \frac{P}{A}}$

$$\sigma = \frac{1500}{19.63}$$

$$\sigma = 76.41 \text{ MPa}$$

Then we used the deformation values in equation (2) to determine strain as follows:

$$\boldsymbol{\varepsilon} = \frac{\boldsymbol{\delta}}{\mathbf{L}}$$

$$\varepsilon = \frac{0.05}{100}$$

$$\varepsilon = 0.0005$$

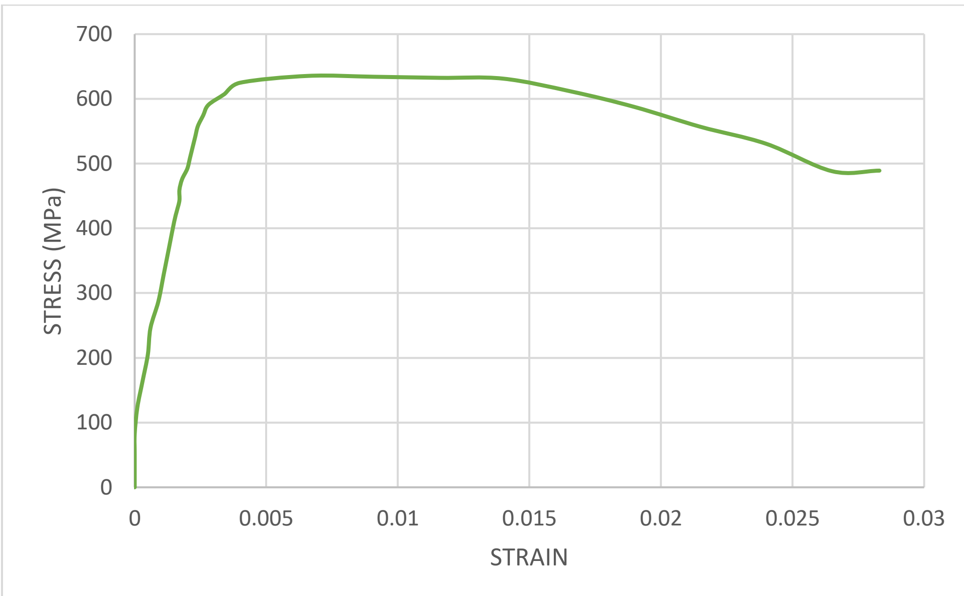

Figure 3: Stress/Strain curve for the steel sample

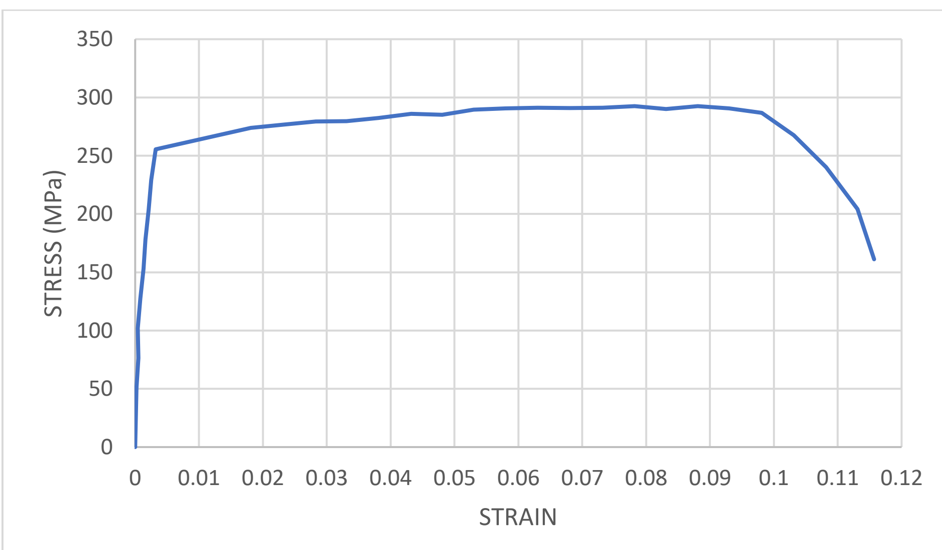

Figure 4: Stress/Strain curve for the aluminum sample

Based on the data computed, we can determine some <u>critical values</u> for the two specimens:

- We can determine the **yield strength** by observing the behaviour of the specimens around the onset of plastic deformation, this point is usually characterized by either a sudden decrease or a static value in stress, accompanied with a steady increase in deformation, it is important to note that an offset value of 0.002 has added to the strain to determine this value. The yield strength for steel is 410MPa, and the yield strength for aluminum is 265MPa.

- The **ultimate strength** can be deduced from the peak load that the material experienced during the experiment, for the steel specimen the ultimate strength is 635MPa, and for the aluminum sample the ultimate strength is 292MPa.

- On order to calculate the **percent elongation** we resort to the following equation:

  $$\%\mathbf{EL} = \frac{\mathbf{L_f - L_i}}{\mathbf{L_i}} \times \mathbf{100}$$

  Let us calculate the percent elongation for the steel sample:

  $$\%\mathbf{EL}_S = \frac{\mathbf{102.52 - 100}}{\mathbf{100}} \times \mathbf{100} = \mathbf{2.52}\%$$

  Let us calculate the percent elongation for the aluminum sample:

  $$\%\mathbf{EL}_A = \frac{\mathbf{111.3 - 100}}{\mathbf{100}} \times \mathbf{100} = \mathbf{11.3}\%$$

- The **elastic modulus** is the slope of the stress strain curve during the linear elastic deformation phase, it can be determined through the following equation:

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

Let us calculate the elastic modulus for the steel sample:

$$\mathbf{E_S} = \frac{(369.16 - 123.05) \times 10^6}{0.0013 - 0.0001} = 205.09GPa$$

Let us calculate the elastic modulus for the aluminum sample:

$$\mathbf{E_A} = \frac{(255.48 - 76.41) \times 10^6}{0.0032 - 0.0005} = 66.32MPa$$

- The **percent reduction in area** can be calculated using the following equation:

$$\%\mathbf{RA} = \frac{\mathbf{A_i - A_f}}{\mathbf{A_i}} \times \mathbf{100}$$

Let us calculate the percent reduction in area for the steel sample:

$$\%\mathbf{RA} = \frac{\boldsymbol{\pi}(\mathbf{1.97^2 - 1.425^2})}{\boldsymbol{\pi} \times \mathbf{1.97}} \times \mathbf{100} = \mathbf{47.68}\%$$

Let us calculate the percent reduction in area for the aluminum sample:

$$\%\mathbf{RA} = \frac{\boldsymbol{\pi}(\mathbf{2.5^2 - 1.385^2})}{\boldsymbol{\pi} \times \mathbf{2.5^2}} \times \mathbf{100} = \mathbf{69.31}\%$$

- The **proportional limit** is the highest point at which the stress-strain relationship is still observed to be linear, this point is slightly bellow the yield strength. The proportional limit for the steel sample is 369MPa, and the proportional limit of the aluminum sample is 255MPa.

- We can compute the **true fracture stress** using the following equation:

$$\boldsymbol{\sigma_{\text{fracture}}} = \frac{\mathbf{P_{fracture}}}{\mathbf{A}}$$

Let us calculate the true fracture stress for the steel sample:

$$\boldsymbol{\sigma_{\text{fracture}}} = \frac{\mathbf{5963}}{\boldsymbol{\pi} \times \mathbf{1.97}} = \mathbf{963.49}\boldsymbol{MPa}$$

Let us calculate the true fracture stress for the steel sample:

$$\boldsymbol{\sigma_{\text{fracture}}} = \frac{\mathbf{3162}}{\boldsymbol{\pi} \times \mathbf{2.5}} = \mathbf{402.59}\boldsymbol{MPa}$$

Observing the fracture site of the samples on figure 5, we note the formation of necking along with elongation and reduction in cross sectional area on both samples, all indicators of ductile fracture.

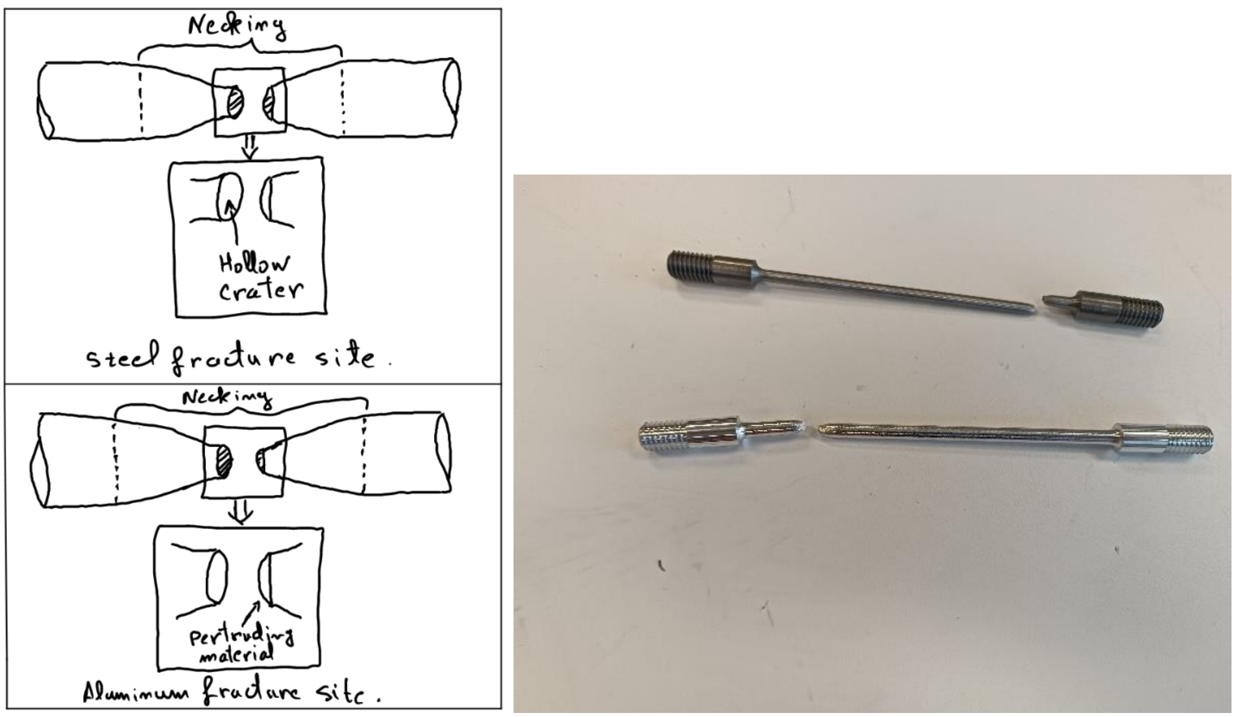

Figure 5: Fracture site of test samples

Discussion:

As we organise our results, we conclude that working with a stress-strain diagram has numerous advantages in facilitating the processing of testing data, as opposed to a load-elongation diagram. The stress-strain diagram is independent of the geometry of the samples, which makes comparability to other materials more feasible, with minimum considerations to the size and shape of the test specimen. As we've noted, the collection of some useful material's properties such as Young's modulus, yield strength, ultimate strength are more readily identifiable through the stress-strain diagram.

The results of the test indicate that the modulus of elasticity is a materials property, the samples that have been tested yielded different values, a higher value of Young's modulus for steel as compared to aluminum. As we observe the diagram, we conclude that the higher the modulus of elasticity the harder it is to deform the material. The steel sample experienced much higher stresses than the aluminum, yet the deformation was greater in the aluminum sample than the steel, while in the elastic range. Our conclusion is that the modulus of elasticity is a quantity that informs the material's resistance to deformation.

Considering that the samples were tested in compression instead of tension, and excluding the possibility of buckling during the tests, we expect to notice some differences in the material's properties due to several factors. The microscopic structure of the material's play and important role in defining its properties, for example the motion of dislocations, the orientation of slip planes and the distribution of phases within the material will influence the material's properties in different testing conditions.

Ductility is an important material's property; it is defined as the ability of a material to undergo plastic deformation before it reaches failure. Highly ductile material absorb energy through large elongation and therefore a large reduction in area. We can quantify the ductility using two main parameters, the elongation which indicates the amount of axial stretching the sample undergoes, and the reduction in area which informs the variation between the initial and final cross sectional are of the sample.

Property	Aluminum (6061-T6)	Steel (C12 L14)
Yield strength (MPa)	375	415
Ultimate strength (MPa)	310	540
% Elongation	12	10
Mod. of elasticity (GPa)	69	200

Table 3: Properties of Aluminum and Steel

Using table 3, we can compare the values that were calculated to the theoretical values presented in the table. We notice that the yield strength for both our samples almost match the values presented. As for the ultimate strength the aluminum sample was slightly lower than the expected value, and the steel sample is almost 100MPa higher than the expected value. The percent elongation for the aluminum sample is slightly lower than the expected value, and the steel sample experienced almost 7.5% less elongation than what is expected. As per the modulus of elasticity, experimental values are very close to the expected values in bot the aluminum and the steel samples. The considerable variations in the results are exclusively present in the steel sample which may be affected by numerous factors. The results indicate a stronger type of steel, with an ultimate strength exceeding the expected value, as well as the % elongation that's considerably lower than the expected value.

Conclusions:

Both materials tested have shown a ductile profile, the formation of necking, along with elongation and reduction in cross sectional area inform a ductile behaviour, more so in the aluminum sample compared to steel. The stress-strain curve formulated based on the test results show an elastic region, and a plastic deformation region. The observed mechanical properties generally match the literature. The testing procedure was followed rigorously in order to minimize the source of error, but the testing setup had its limiting disadvantages.

The tensile test that we performed yielded crucial material properties, these values inform the behaviour of materials under tensile loading, so these results have important practical implications in the engineering process. The designer can rely on this information to make the appropriate decisions regarding the selection of materials based on the desired application. Whether its in structure design, finite analysis, or material's research, these properties inform the designer of the capacity and compatibility of a material within their framework.

Reference:

[1] W. D. Callister 1940- and D. G. Rethwisch, *Materials science and engineering : an introduction*, 10th edition. Hoboken, NJ: Wiley, 2018.

[2] M. S. Loveday, T. Gray, and J. Aegerter, "Tensile testing of metallic materials: A review," *Final Rep. TENSTAND Proj. Work Package*, vol. 1, 2004.

[3] J. R. Davis, *Tensile testing*. ASM international, 2004.