AE2610, Lab 1

Tensile Testing

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Lab Group A01-Y

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Introduction

This lab explored the stress-strain relationship of ductile metals. Tests like this are crucial to engineering as they allow structures to be designed with the proper properties and strengths. This is especially important in aerospace engineering, as structures must be light and efficient. As such, it is critical that aerospace engineering students learn about and conduct tests to fully understand material properties. During this experiment, two test specimens in an Instron test frame are pulled apart by the machine. These test specimens include billets of aluminum and an unknown metal. Both specimens were thin dog bones, and the experiment occurred at standard ATP conditions in a climate-controlled area. This did not impact the test results. Several data, including the gauge length, initial and posttest dimensions of the billets, and stress-strain data in `.csv` format were collected using the Instron load frame internal sensors, as well as some other tools. These tools included an extensometer, calipers (digital), and a ruler. Billet dimensions are calculated using the average of several students' measurements with the ruler and digital calipers. The Instron load frame is controlled with a Windows computer, operating the Bluehill software. This report will explore the stress-strain relationships for both true and engineering stress of the aluminum sample billet, alongside those same relationships in the mystery billet, and an estimation of the material in the mystery billet.

Data Results

Raw Data

During the monotonic testing process for each specimen, several important metrics were logged by the computer automatically into a `.csv` format. These included tension force, displacement of the machine head, extensometer strain, time, and strain gauge resistance.

Extensometer strain is represented in detail in figures 6-1 and 6-2, utilized heavily in the construction of stress-strain curves. Table I contains the initial dimensions recorded for each specimen at the beginning of the lab. These were taken using calipers and a ruler. The rest of the data underwent reduction before use.

Reduced Data

This reduction was carried out in a Jupyter Notebook (see Appendix B) using an Anaconda environment with Python 3.12, Pandas, NumPy, and MatPlotLib. Figures were then exported for use in this report. The data was primarily reduced using only a few relations. First were the definitions of stress and strain, respectively:

$$\sigma = P/A_0 \tag{1}$$

$$\varepsilon = \delta/L_0 \tag{2}$$

Where sigma is the stress, epsilon is the strain, P is the force collected by the computer, A is cross-sectional area, delta is elongation, and L is the length of the reduced specimen section. These functions were used to generate the plots in figures 1 and 2. Additionally, this information was used in the engineering plots in figures 3 and 4 alongside extensometer data. After this, Hooke's law was used to calculate the Young's Modulus, E, displayed in table II:

$$\varepsilon E = \sigma \tag{3}$$

This relation allowed Young's Modulus to be found for both specimens. The Pandas DataFrame class was then utilized extensively (Appendix B contains a commented export of the Jupyter Notebook for this experiment) to find engineering and true fracture and ultimate stresses and strains using a variety of information from table I. This required relating true quantities to their engineering counterparts, and all the data can be found in tables III and IV:

$$\boldsymbol{\sigma_T = \sigma(1 + \varepsilon)} \quad \textbf{(4)}$$

$$\boldsymbol{\varepsilon_T = ln(1 + \varepsilon)} \quad (5)$$

These true values were also used in figures 3 and 4. A few points were selected to find true values at such as the ultimate and fracture stress points, and a plot was created of the true stress-strain curve for each metal. Once this data was reduced, the strain hardening coefficient n and strength coefficient K were found. When true stress and strain are plotted against each other on a log-log scale, the following linear equation emerges, which was solved to populate table V:

$$\ln(\sigma_T) = \ln(K) + \mathrm{n}\ln(\varepsilon_T) \quad (6)$$

The slope n was calculated using 2 arbitrarily selected data points along each line. Then, the slope was calculated using the two points for each metal, and the intercept of the line was found.

Which material was the mystery material?

As is visible in table VI, only the Young's Modulus of available materials was used. This is because this was enough to decide on the material, as there was only one remotely reasonable material. The only material with a similarly low Young's Modulus to the mystery metal was 510 Bronze. Note that all gray and silver metals were excluded from this table, as the specimen was very clearly yellow in color.

Discussion

As is especially visible in tables II and V, the data collected in this lab was of highly suspect quality, even though most of the system was automated. There are a few clear sources of potential error. The most important is the calculation of the engineering strain from equation 2. This quantity is dependent upon the initial length. This is of major consequence, as this was by far the hardest data point to collect in the entire lab. Using calipers to measure the reduced section of the specimen has inherent error, as it is very difficult to tell as a human where the curvature begins. In the future, it would be far better to utilize the CAD file needed to machine the specimen for dimensions or engineer a specimen with slanted sides to improve visibility.

This lab demonstrated real-world applicable engineering principles. Potentially, the biggest lesson was in structural design. Learning about the two main regions of deformation teaches that a structure should never be built to ultimate tensile stress, as this will cause permanent plastic deformation. While some displacement is fine (else the stress-strain curve in the elastic region would be vertical), the proportional stress limit should not be crossed. This property of ductile materials can be observed in all figures. While this does require structures to use more weight and material, it is ultimately far safer and can prevent structural failure.

Tables and Figures

Table I. Specimen Dimensions

	Aluminum Specimen (m)	Mystery Specimen (m)
Reduced Section Length	0.06716	0.06494
Reduced Section Width	0.01268	0.01281
Reduced Section Thickness	0.00207	0.00203
Fractured Section Width	0.01176	0.00918
Fractured Section Thickness	0.0018	0.00152
Uniform Section Width	0.01202	0.0109
Uniform Section Thickness	0.00191	0.00181
Final Reduced Length	0.07494	0.07637
Extensometer Gauge Length	0.00508	0.00508

Table II. Young's Modulus of Specimens

	MPa	ksi
Young's Modulus, Aluminum	57770.2194	8378.861928
Young's Modulus, Mystery	69364.16202	10060.42114
YM, Published Aluminum	73100	10602.25863

Table III. Aluminum Tensile Test Data

	Aluminum
Engineering ultimate tensile stress, MPa	465.9435529
True ultimate tensile stress, MPa	649.7472321
Engineering fracture stress, MPa	275.4804249
True fracture stress, MPa	418.010455
Engineering ultimate tensile stress, ksi	67.57939881
True ultimate tensile stress, ksi	94.23786862
Engineering fracture stress, ksi	39.9550576
True fracture stress, ksi	60.62729073
True ultimate tensile strain from extensometer, m/m	0.157620653
True fracture strain from extensometer, m/m	0.165339847
True fracture strain from initial dimensions, m/m	0.201905922
True fracture strain from fracture dimensions, m/m	0.180944779
Engineering fracture strain from initial dimensions, m/m	0.223732877
Engineering fracture strain from fracture dimensions, m/m	0.200505738

Table IV. Mystery Metal Tensile Test Data

	Mystery
Engineering ultimate tensile stress, MPa	380.0794484
True ultimate tensile stress, MPa	722.5237625
Engineering fracture stress, MPa	187.1882727
True fracture stress, MPa	522.2120829
Engineering ultimate tensile stress, ksi	55.12586334
True ultimate tensile stress, ksi	104.7932119
Engineering fracture stress, ksi	27.1493636
True fracture stress, ksi	75.7404591
True ultimate tensile strain from extensometer, m/m	0.340554607
True fracture strain from extensometer, m/m	0.368898629
True fracture strain from initial dimensions, m/m	0.403434509
True fracture strain from fracture dimensions, m/m	0.343054039
Engineering fracture strain from initial dimensions, m/m	0.496957191
Engineering fracture strain from fracture dimensions, m/m	0.422579547

Table V. Log-Log Relation Coefficients for True Stress-Strain Data

	Aluminum	Mystery
K, Pa (Strength coefficient)	962332728.5	613653858.7
n (Strain hardening index)	0.313178984	0.216960259

Table VI. Young's Moduli of Suspect Mystery Metals

	Young's Modulus
Mystery Metal	69.4 GPa
145 Copper	120.7 GPa
110 Copper	110 GPa
510 Bronze	41.4 GPa
260 Brass	110 GPa
353 Brass	104.8 GPa

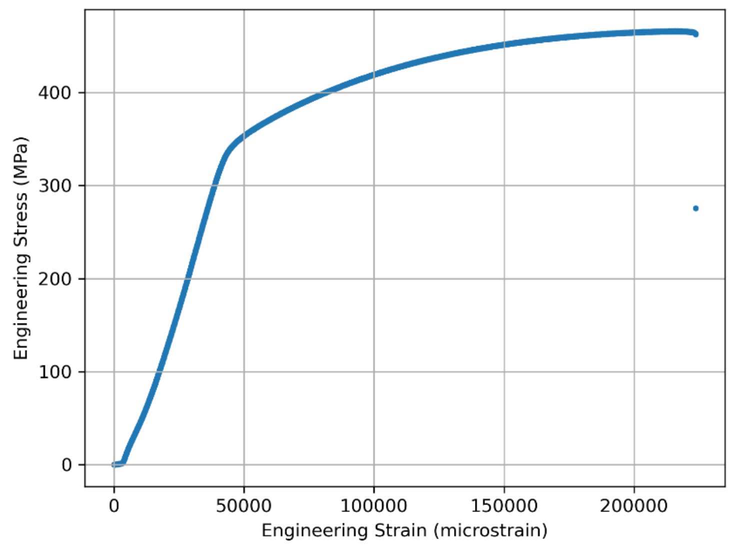

Figure 1. Aluminum Engineering Stress-Strain Curve

Caption: Engineering stress-strain curve for 2024-T3 aluminum alloy calculated from machine head displacement over time. Note the lack of a defined necking region, emphasizing sudden structural failure.

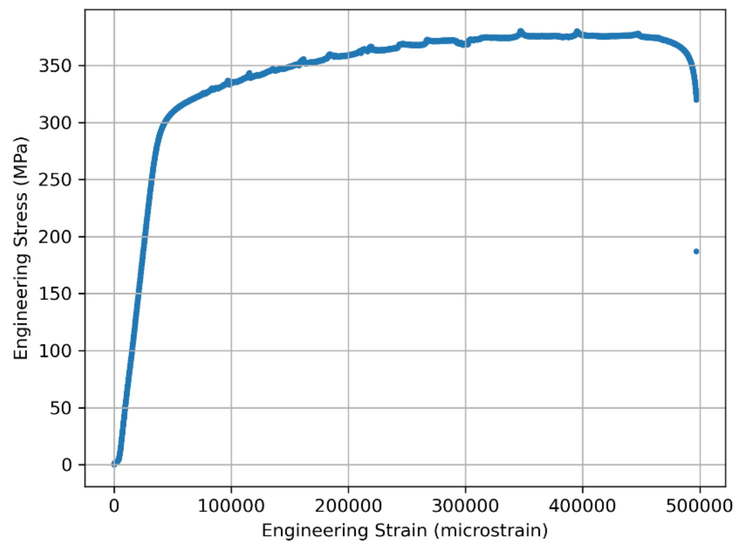

Figure 2. Mystery Metal Engineering Stress-Strain Curve

Caption: Engineering stress-strain curve for the mystery metal calculated from machine head displacement over time. Note the perturbations in the curve, caused by an unknown artifact. One suspect is machine head slippage.

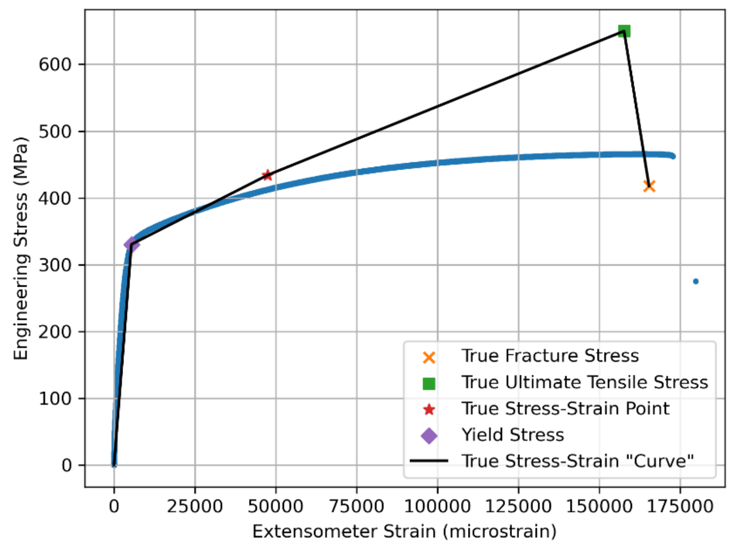

Figure 3. Aluminum Extensometer Stress-Strain Curve

Caption: Stress-strain curve for 2024-T3 aluminum alloy calculated from extensometer data. This curve is much better defined with cleaner data and a more ductile curve. The true stress-strain curve fits as expected.

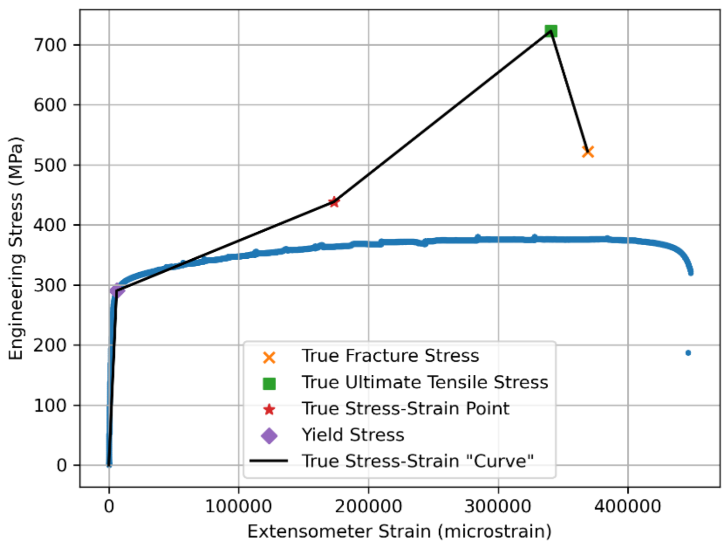

Figure 4. Mystery Metal Extensometer Stress-Strain Curve

Caption: Stress-strain curve for the mystery alloy calculated from extensometer data. This curve is much better defined with cleaner data as well. The true stress-strain curve does not fit as expected. This may be caused by the same artifact that was causing the perturbations in the plastic deformation region.

Appendix A: Laboratory Notebook Copy

Please proceed to the next page.

Appendix B: Jupyter Notebook Copy

Please proceed to the next page.