University of California Riverside

ME170B Experimental Techniques: Lab 3

Stress Strain Relationships

Group A5

Elijah Perez | Soham Saha | Alex Pham

Fall 2024 - Mon-Wed 8AM Session

December 5, 2024

Abstract

The purpose of this experiment is to determine the stress-strain relationships of four materials (brass, stainless steel, aluminum, and nylon plastic), using standard material samples and the Instron 34TM-50 stress-strain measurement device. It was hypothesized that stainless steel would have the highest yield strength of the four materials, and that nylon plastic would withstand the highest strain before fracture. The experiment was conducted using the Instron 34TM-50 stress-strain measurement device, which measures force and displacement. Placing each sample within the jaws of the device, a preset testing regimen was used to conduct the experiment. It was found that the brass had the highest measured yield strength likely due to experimental errors, while nylon exhibited the greatest strain before failure. Through this experiment, it is concluded that material properties such as ductility, yield strength, and ultimate tensile strength can vary significantly based on composition and structure, emphasizing the importance of stress-strain analysis for material selection in engineering applications.

Introduction

The primary method of developing stress strain relationships is by conducting tensile testing, in which tensile stress is applied to a standard material sample. As the material sample is pulled from both ends, the force applied is measured to calculate the stress on the material. Strain is determined by the distance the material is pulled.

These experiments are crucial for determining the yield strength, modulus of elasticity, and ultimate tensile strength of various materials. The applications of stress strain relationships are endless, and it is typically the job of the mechanical engineer to predict how materials will behave under loading conditions using these relationships. Proper analysis ensures that designed structures will not fail under required loading conditions.

It is hypothesized that for this experiment,stainless steel will demonstrate the highest yield strength of all four materials, meaning that the stainless steel sample will require the highest tension force to yield. It is also hypothesized that that nylon will display the greatest plastic deformation prior to fracturing, but will require the least amount of tension force to yield. This hypothesis is based on general knowledge of the material properties of the four samples.

Theory

Stress-strain relationships describe the deformation of materials under stress. Understanding the stress-strain relationships of various materials allows engineers to make design choices based on a material's strength. Stress-strain relationships are typically plotted on graphs where the x-axis represents strain and the y-axis represents stress. For most metals, the stress-strain relationship begins as a linear elastic relationship described by Hooke's Law. In this region, the stress experienced by the material is linearly proportional to the strain, with the slope being the material's modulus of elasticity, or Young's modulus. Materials that experience elastic strain return to their original form once the stress is removed. However, for most materials, the elastic region is small, and after the stress reaches the yield strength of the material, the deformation becomes plastic and irreversible.

For most engineering applications, reaching yield strength is considered the failure point of the material, deeming the part unsuitable for further use. This is because plastic deformation causes dislocations within the crystal lattice within the material, reducing its ability to maintain its original geometry. Within the plastic region of the stress-strain curve, stress can be applied until the material's ultimate tensile strength, which is the highest stress a material can withstand before it experiences fracture.

Engineering stress is interpreted as a load F evenly distributed over the initial cross-sectional area of a material. For a specimen in uniaxial tension, stress σ is

$$\sigma = \frac{F}{A_o} \tag{1}$$

Engineering strain is the ratio of a specimen's gauge length over its original length. For a specimen in uniaxial tension, strain is given as

$$\epsilon = \frac{\delta L}{L_o} \tag{2}$$

Applying the relationship between stress and strain using Hooke's Law, Equation 1 becomes

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

Hooke's Law states that for small deformations of an object, the displacement caused by the deformation is directly proportional to the applied load. During this process, the deformation is elastic, meaning it is reversible. However, when stresses exceed a material's yield strength, permanent or plastic deformation occurs. The ultimate tensile strength refers to the stress level at which the cross-sectional area of the material begins to decrease. Beyond this point, any additional load will cause the component to fracture.

Yield strength is determined as the point where the slope of the stress-strain curve becomes zero, following the linear elastic region. R.M. Christensen further defines yield strength as the absolute maximum of the second derivative of stress with respect to strain. Ductility measures a material's ability to undergo significant plastic deformation before fracturing. It is often expressed as the percent elongation or percent area reduction obtained from a tensile test. Percent elongation represents the total percentage change in the original length of a specimen at the point of fracture.

$$\%EL = \frac{L_f - L_o}{L_o} \cdot 100 \tag{4}$$

Percent area reduction of the material is the total percent change of the original cross-sectional area at fracture:

$$\%AR = \frac{A_o - A_o}{A_f} \cdot 100 \tag{5}$$

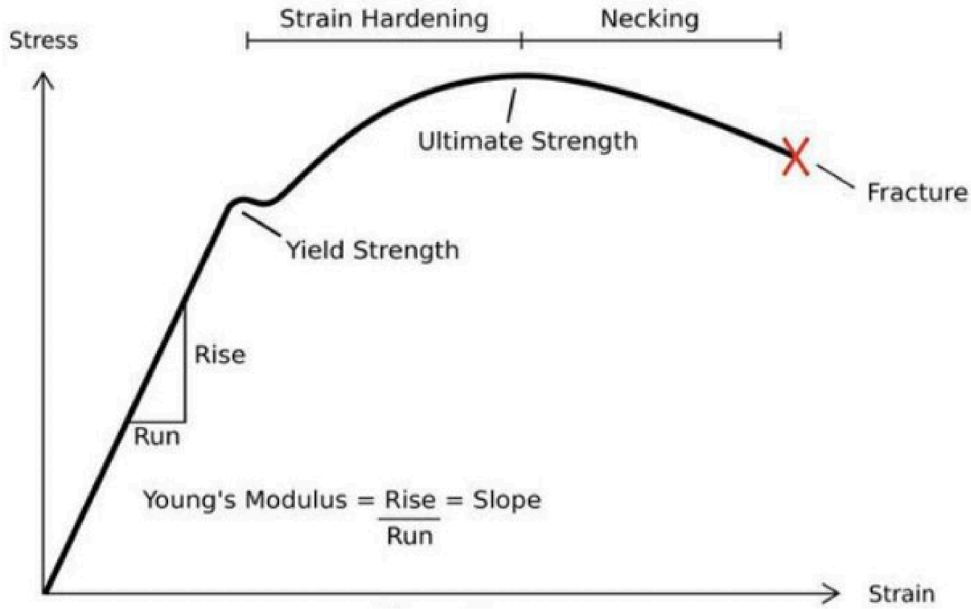

Figure 1: The typical behavior of a material specimen under tensile loading

Experimental Methods

Before performing the stress-strain experiment, it is critical to understand the potential hazards associated with using the Instron Universal Tensile Testing Machine. Always wear eye protection during the procedure, and if the machine emits any loud noises while in operation, immediately press the red emergency stop button to ensure safety. Begin by turning on the Instron machine and the connected computer, then log in using the designated ENGR account. Open the Bluehill software on the desktop and select the appropriate analysis file based on the material being tested(*KC170B.im.tens* for metals or *KX170B nylon.im.tens* for nylon).

Figure 2**:** Instron Machine, used to generate the stress-strain curve of test materials

Place the specimen to be tested between the lower jaws of the machine and tighten. Adjust the height of the jaws and ensure that the sample is clamped down sufficiently by both upper and lower jaws. Zero the force and displacement meters on the software and begin the appropriate test. Stand back and remain cautious as the sample undergoes fracture. Remove the sample and export the data to complete further calculations and analysis.

Results

The stress-strain curve for brass highlights its mechanical performance under stress. The material demonstrates an elastic modulus of 92.5311 kN/mm², indicating stiffness in the elastic region. The yield strength, marking the onset of plastic deformation, is measured at 341 MPa. The tensile strength, representing the maximum stress the material can sustain, is 417.436 MPa, followed by the breaking stress at 299.77 MPa, indicating material failure. The curve also features a wavy pattern during plastic deformation, which could be attributed to dynamic strain aging or dislocation-atom interactions.

The wavy curvature observed in the stress-strain curve during the plastic deformation phase likely results from dynamic strain aging or material instability. This phenomenon, also known as the Portevin-Le Chatelier effect, is common in alloys like brass, where interactions between dislocations and diffusing atoms occur. These interactions create localized bands of plastic deformation, leading to the oscillations observed in the stress-strain response.

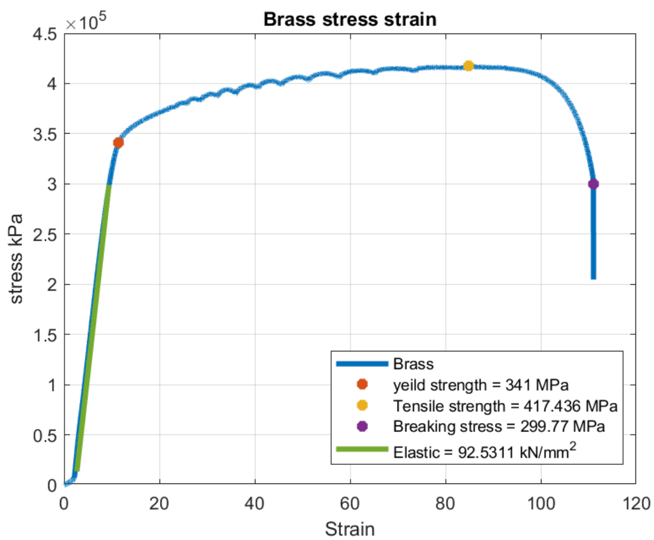

Figure 3: Stress-strain curve of the brass specimen featuring stress oscillations

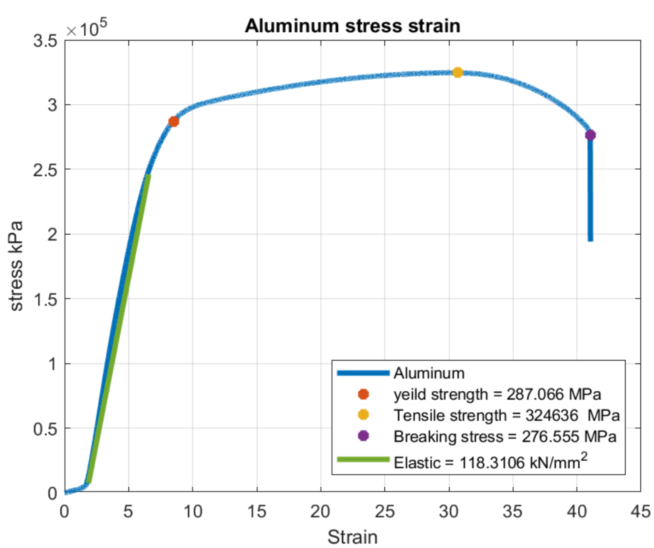

Figure 4: Stress-strain curve of the Aluminum specimen

The stress-strain curve for Aluminum highlights its mechanical performance under stress. The material demonstrates an elastic modulus of 118.3106 kN/mm², with the yield strength measured at 287.066 MPa, marking the onset of plastic deformation. The tensile strength, representing the maximum stress the material can sustain, is 324.636 MPa, followed by the breaking stress at 276.555 MPa, indicating material fracture. The plastic deformation region in this curve is smooth, unlike the brass sample.

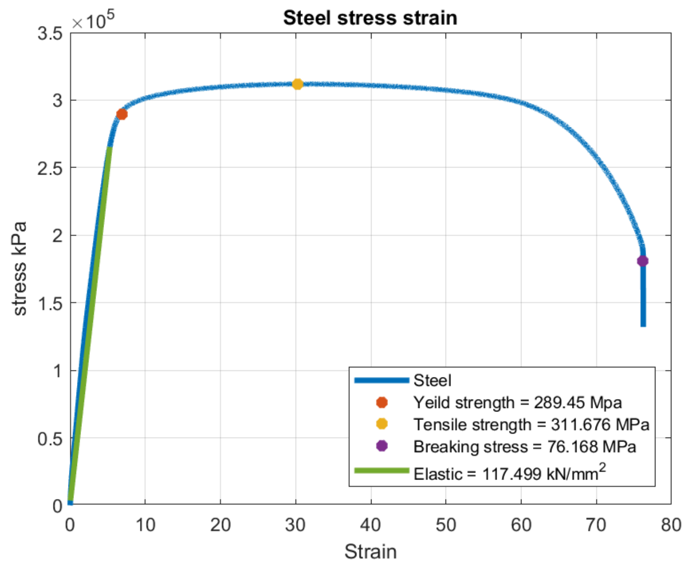

Figure 5: Stress-strain curve of the stainless steel specimen

The elastic modulus is measured at 117.499 kN/mm², indicating stiffness in the elastic region. The yield strength, marking the transition to plastic deformation, is 289.45 MPa. The tensile strength, representing the maximum stress the stainless steel can sustain, is recorded at 311.676 MPa. Finally, the breaking stress is 76.168 MPa, showing a significant drop after the peak stress. These results reflect stainless steel's ductility and strength, although discrepancies may arise from uncertainties such as imprecise cross-sectional area measurements or material heterogeneity.

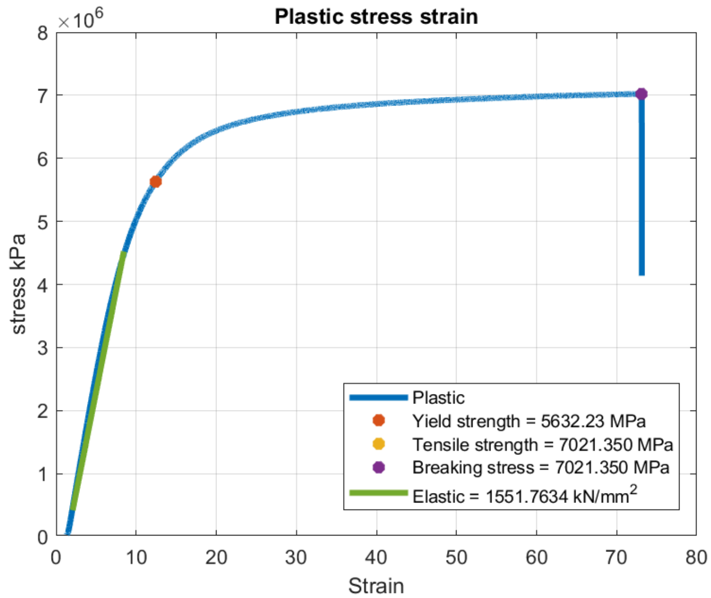

Figure 6: Stress-strain curve of the nylon specimen

The elastic modulus is 1551.7634 kN/mm², reflecting the material's stiffness in the elastic range. The yield strength, marking the onset of plastic deformation, is recorded at 5632.23 MPa. The material reaches its tensile strength at 7021.35 MPa, which also coincides with the breaking stress, indicating a brittle failure mode. These exceptionally high values compared to typical plastics suggest that the specimen may be a high-performance engineering plastic, possibly with experimental uncertainties such as inaccuracies in strain measurement or calibration errors contributing to any discrepancies.

The most prominent source of uncertainty affecting the results was likely the measurement of the cross-sectional area prior to the experiment. Since this cross-sectional area was used to calculate the engineering stress, any error in the initial dimensional measurements will propagate through to all the results. Reporting the area as lower than actual will cause the stress-strain graph to display the stress as higher than it actually is, leading to the observation of higher-than-expected yield strength and ultimate tensile strength.

Discussion

The resulting stress-strain graphs for brass, aluminum 6061-T6, stainless steel, and nylon plastic reveal key mechanical properties, including yield strength, tensile strength, and breaking stress. The measured values were compared to typical values sourced from engineering references to evaluate accuracy. For brass, the yield strength was measured at 341 MPa (typical: 250 MPa), tensile strength at 417.436 MPa (typical: 250 MPa), and breaking stress at 299.77 MPa (typical: 250 MPa), with errors ranging from 19.9% to 66.97%. These deviations may reflect variations in alloy composition or experimental inconsistencies. Aluminum showed measured yield strength of 287.066 MPa (typical: 95 MPa), tensile strength of 324.636 MPa (typical: 110 MPa), and breaking stress of 276.555 MPa (typical: 110 MPa). Errors exceeding 200% suggest possible inaccuracies in specimen cross-sectional area measurements or an unusually high-strength aluminum alloy. For stainless steel, the yield strength measured at 289.45 MPa (typical: 250 MPa), tensile strength at 311.676 MPa (typical: 400 MPa), and breaking stress at 76.168 MPa (typical: 400 MPa), with errors between 22.7% and 80.9%. These results may reflect experimental issues, such as testing misalignments or flaws in the stainless steel specimen. Nylon exhibited extreme discrepancies, with yield strength measured at 5632.23 MPa (typical: 51 MPa), tensile strength and breaking stress both at 7021.35 MPa (typical: 65 MPa), leading to errors over 10,000%. Such deviations likely stem from misclassification of the material or significant experimental inaccuracies.

Given the errors, the initial hypothesis of the experiment is rendered partially invalid as the brass sample had the highest measured yield strength, as opposed to stainless steel. However, it is likely that this unexpected result could stem from experimental errors and uncertainties. Additionally, while the nylon experiment had high errors, it did have the highest strain prior to fracture, rendering the second half of the hypothesis valid.

While this experiment allowed for profound insights into the stress-strain relationships of the four materials, it is crucial to discuss the sources of error, uncertainties and limitations of the experiment. Since the actual experiment was conducted using the Instron 34TM-50 device, it is assumed that the device and associated equipment are calibrated correctly. The force gauges report forces in kN with four decimal places, indicating its measurements are likely within +/-

0.1 N. Similarly, the Instron 34TM-50 device reports displacement in meters with four decimal places, indicating the displacement measurements are likely within +/- 0.0001 meters. One major source of error in this experiment was the initial dimensional measurements of the samples. While this measurement was taken using calipers, it was noticed that the caliper jaws contained scratches that altered measurements by 0.05mm based on which portion of the jaws were used to take the measurement.

Conclusion

In this laboratory, the load each material could sustain until failure was analyzed. Necking occurred as materials were stretched, with the nylon specimen exhibiting the most necking and stretching, whereas stainless steel experienced minimal necking. Based on elongation and area reduction results from the stress-strain experiment, stainless steel proved to be the most ductile material, followed by nylon, brass, and Aluminum 6061-T6. However, stainless steel also showed the highest percent error for yield strength.

Our findings suggest the material used was 2304 stainless steel rather than 18-8 stainless steel, as its material properties aligned more closely with experimental values. Errors arose from factors such as internal lattice structures, imperfections in the milling process, and rods not being fully secured, introducing room for error. These issues, largely beyond our control, could be mitigated with additional resources and advanced technology, explaining the discrepancies between our data and literature values. For future experiments it is recommended to test multiple specimens of each material to account for experimental uncertainties and any imperfections within the material samples. Having multiple samples for each material would also reduce the effect of experimental errors such as improper placement of the samples within the jaws of the device. This would provide more accurate results for the material properties, allowing for a more in depth understanding of the strength of these materials.

References

[1] Flinn, R. A., and Trojan, P. K.,Engineering Materials and their Applications, 4th edition, Houghton Mifflin Company, 1990.

[2] Christensen, R.M., Defining Yield Stress and Failure Stress.

Statement of Contributions

Elijah Perez: Experimental Design, Data analysis, Lab Report

Soham Saha: Experimental Design, Data Collection, Lab Report

Alex Pham: Experimental Design, Data Collection, Measurements

Appendix:

$$
\begin{aligned}
\sigma &= \text{Engineering stress} \\
F &= \text{Force/load applied} \\
A_o &= \text{Initial cross-sectional area} \\
A_f &= \text{Final cross-sectional area} \\
\epsilon &= \text{Engineering strain} \\
\Delta L &= \text{Change in length} \\
L_o &= \text{Initial length} \\
L_f &= \text{Final length} \\
E &= \text{Modulus of elasticity} \\
\%EL &= \text{Elongation percentage} \\
\%AR &= \text{Percent area reduction}
\end{aligned}
$$

	Length (mm)	Width (mm)	Thickness (mm)
Brass	115.07	6	3.14
Steel	115.25	6.06	3.14
Nylon	114.57	5.85	3.27
Aluminum	115.07	5.95	3.07

Table 1: Dimensional measurements of four material samples prior to tensile testing.

	Width 1 (mm)	Thickness 1(mm)	Width 2 (mm)	Thickness 2 (mm)
Brass	5.41	2.88	5.36	2.79
Steel	5.59	2.84	5.62	2.86
Nylon	5.7	3.18	5.67	3.17
Aluminum	5.7	2.88	5.77	2.98

Table 2: Dimensional measurements of each fractured piece of four material samples after tensile testing.

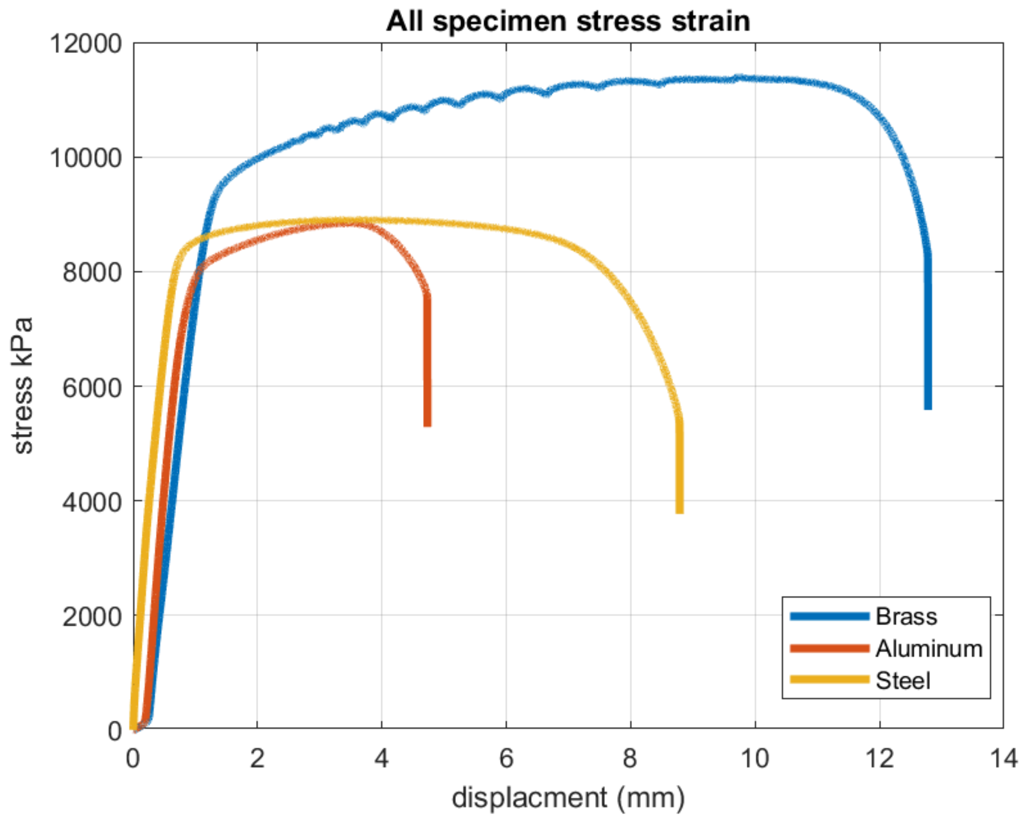

Figure 7: Stress-strain curve comparisons for all elements except nylon.