AEE 325 Lab 01

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I. Abstract

This experiment aimed to characterize the mechanical properties of 1018 carbon steel through a tensile test, following ASTM E8/E8M standards. The test measured critical material properties, including Young's modulus (E), yield strength (S_y), ultimate tensile strength (S_u), fracture strength (S_f), percentage elongation (PE), percentage reduction in area (PA), and power law plasticity coefficients. A standard specimen was loaded axially in an Instron 4411 testing machine until failure. The applied force and elongation were recorded using a load cell and an extensometer. The specimen geometry, including initial diameter and gauge length, was recorded before testing. Engineering and true stress-strain curves were generated from the testing data. Young's modulus E was determined from the slope of the linear region using linear regression. The yield strength was identified using the 0.2% offset method, while S_u and S_f were extracted from the peak stress and fracture stresses. Post-fracture analysis included measuring the neck diameter and final gauge length to calculate percentage elongation and reduction in area as indicators of ductility. Results show that the laboratory procedure was unsuccessful in accurately assessing the mechanical properties of the two samples, yielding larger than acceptable errors across the board compared to established values.

II. Objectives | Procedure

The main objectives of this laboratory procedure are to determine the mechanical properties of the two metals tested through detailed analysis of the stress-strain curves and the quantities that can be extracted from these models. The material behavior can be analyzed, and physical phenomena discussed during lectures, for example, the difference between the elastic and plastic regions, necking, and fracture, can be observed. Finally, the experimental data collected during laboratory testing can be compared to published acceptable values, and any deviations can be analyzed considering proposed experimental uncertainties.

The procedure followed in the laboratory to collect the data began with an analysis of both the 1018 carbon steel and 2024 aluminum specimens. For both samples, measurements were taken of the total length, both threaded lengths, and the diameter using the laboratory calipers. Final measurements were computed as the average of three to four separate measurements. One at a time, each specimen was loaded into the load frame by securing each threaded end and locking the lower head of the load frame. The extensometer was secured to the sample using rubber bands. The test began after the diameter of the sample in question is provided to the data collection software and the 'Start Test' and 'Up' buttons are clicked. The load frame applies an axial tensile force to the sample under a displacement control of one millimeter per minute until the sample fractures, at which point the 'Stop Test' button is clicked to conclude the data collection from the load frame. The final length is measured and recorded as the sum of the length of the two halves, and the final diameter is measured and recorded as the location on the sample where necking has occurred.

The data processing procedure was performed in MATLAB, and the same procedure was applied to the data obtained from both samples. First - the known variables are declared, the required equations are defined symbolically, and inline functions are created to evaluate the symbolic equations for an input vector. The equations are as follows:

$$\sigma_i \approx \mathrm{S_i} = \frac{\mathrm{P_i}}{\mathrm{A_0}} \quad [1]$$

$$\epsilon_i \approx \mathrm{e_i} = \frac{\Delta \mathrm{L_i}}{\mathrm{L_0}} \quad [2]$$

$$A_i = \frac{A_0}{1 + E_i} \quad [3]$$

$$\sigma_i = \frac{P_i}{A_i} \quad [4]$$

$$\epsilon_i = log(1 + e_i) \quad [5]$$

$$PE = \epsilon_i \cdot 100\% \quad [6]$$

$$PAR = \left[\frac{A_0 - A_f}{A_0}\right] \cdot 100\% \quad [7]$$

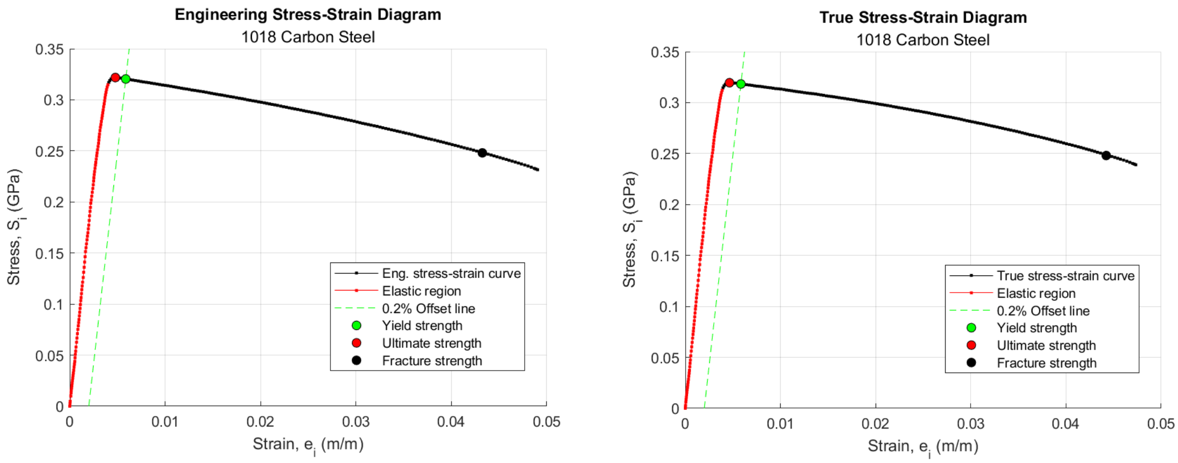
The data from the sample in question is imported and split into metadata & a comma-delimited table, and the MATLAB function ‘unique()’ is used on the data table for pre-processing to remove duplicate values for elongation. Eqs. [1-5] are then used to compute the engineering stress & strain, the instantaneous area, and the true stress and strain. Computed engineering and true data are then run through post-processing, which includes multiple steps. First, noisy stress data is filtered by removing values smaller than $\sim 1\%$ of the maximum stress value. A moving mean filter is applied using the ‘movmean()’ function and a window size of five to smooth the stress and strain vectors and obtain a smoother graph and more accurate elastic slope. Finally, a zero-shift is performed such that the stress-strain curve begins at the origin. To determine the elastic region, the numerical slope differences were computed and analyzed to determine where the slope drops off, and the stress and strain data was truncated at this point. From this region, Young’s modulus E can be estimated by performing a linear regression over this range using ‘polyfit()’ to the first degree. The ultimate strength S_u was found by locating the maximum stress value and the corresponding strain value. The fracture stress S_f was found by extracting the machine computed fracture load from the data file metadata and solving the known equation for S_f:

$$S_f = \frac{P_f}{A0}$$

The 0.2% offset rule is then applied to find the yield strength, S_y, which is defined as the intersection between the engineering stress-strain curve and the 0.2% offset line. This line has a constant slope of the Young’s modulus found prior and an x-intercept of 0.002. The log-log relation of the true stress-strain curve is found for the range between the yield strength and the ultimate strength by isolating this range, applying ‘log()’ in MATLAB, and plotting the results. A first-order regression is applied to determine the approximate slope of this curve. The hardening coefficient is estimated as the slope of the regression, and the stress coefficient is extracted by exponentiating the regression intercept. Finally, the percentage elongation and percentage area reduction are found using Eqs. [6-7], where A_f is the final area.

III. Results | Evaluation | Discussion

The following plots are obtained for the 1018 carbon steel sample:



Figures 1.1 – 1.2: Engineering and true stress-strain curve for the 1018 carbon steel sample.

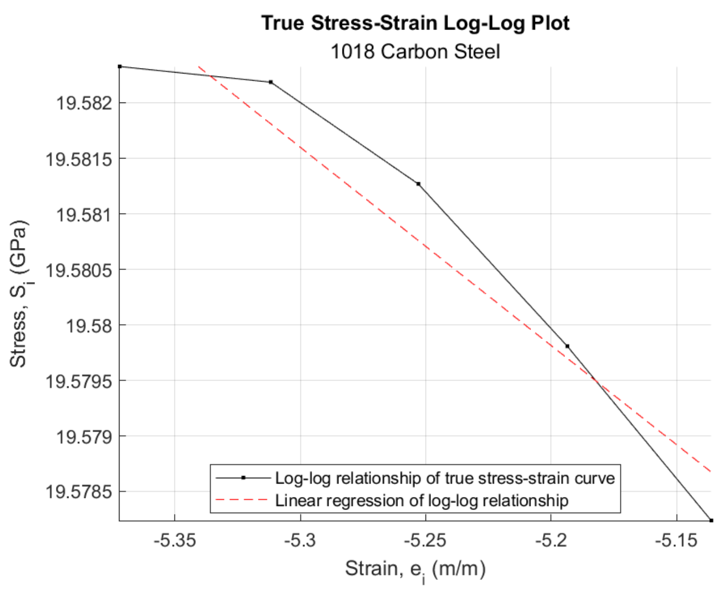
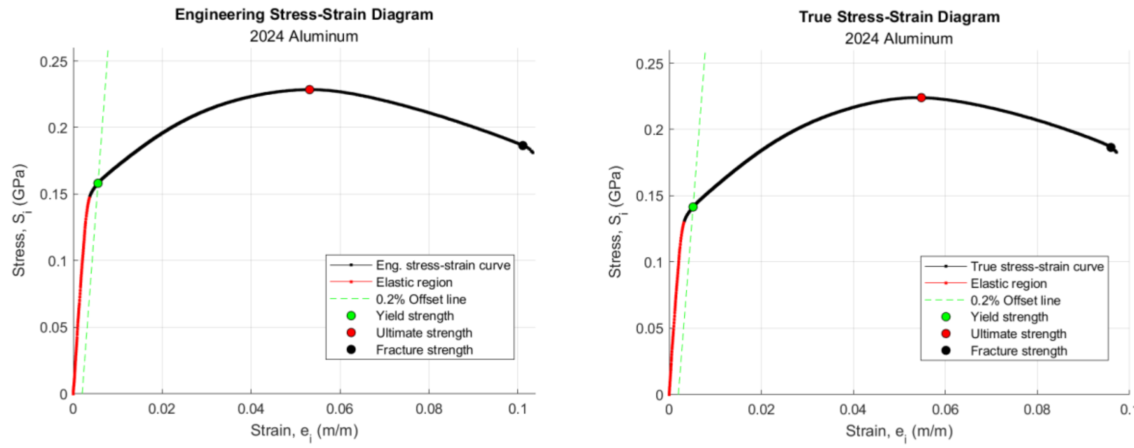


Figure 1.3: The log-log relationship for the 1018 carbon steel sample between the yield and ultimate strengths

From Fig. [1.1], it was determined that the Young's modulus E is $82.74\,GPa$. The yield strength S_y is found to be $320.40\,\mathrm{M}Pa$, the ultimate strength S_u is found to be $321.81\,MPa$, and the fracture strength S_f is found to be $248.06\,MPa$. The percentage elongation and area reduction, PE and PAR, are found to be 4.422% and 7.242%, respectively. From Fig. [1.3] - based on Fig. [1.2] - the power law plasticity coefficients, n and σ_0, are found to be -0.0179 and $290.44\,MPa$, respectivley. These results fall within the expected order of magnitude, as will be discussed later.

The following plots are obtained for the 2024 aluminum sample:



Figures 2.1-2.2: Engineering stress-strain curve for the 2024 aluminum sample.

Figure 2.3: The log-log relationship for the 2024 aluminum sample between the yield and ultimate strengths.

From Fig. [2.1], it was determined that the Young's modulus E is 44.370 GPa. The yield strength S_y is found to be $158.16\,MPa$, the ultimate strength S_u is found to be $228.52\,MPa$, and the fracture strength S_f is found to be $186.48\,MPa$. The percentage elongation and area reduction, PE and PAR, are found to be 9.594% and 81.544%, respectively. From Fig. [2.3] - based on Fig. [2.2] - the power law plasticity coefficients, n and σ_0, are found to be 0.2211 and $438.46\,MPa$, respectivley. These results fall within the expected order of magnitude, as will be discussed later.

To verify the results of this experiment, published data was found for comparison, references to which can be found in the references section below. For 1018 carbon steel, Young's modulus is found to be $200\,GPa$ [1], yield strength is $370\,MPa$ [2], ultimate strength is $440\,MPa$ [2], fracture strength is roughly $300\,MPa$ [1], stress coefficient is $850\,MPa$ [4], and the hardening coefficient is found to be 0.26 [4]. For 2024 aluminum, Young's modulus is found to be $73\,GPa$ [2], yield strength is $345\,MPa$ [3], ultimate strength is $483\,MPa$ [3], fracture strength is roughly $290\,MPa$ [2], stress coefficient is $450\,MPa$ [4], and the hardening coefficient is found to be 0.17 [4]. Reference values

Comparing the laboratory results with the published results, it is seen that there is some deviation across the board, with a few values that are close to accepted values, and some values that are not close at all. For 1018 carbon steel, the Young's modulus varies by 58.63%, the yield strength varies by 13.41%, the ultimate strength varies by 26.86%, and the fracture strength varies by 17.31%. For 2024 aluminum, the Young's modulus varies by 39.22%, the yield strength varies by 54.16%, the ultimate strength varies by 52.69%, and the fracture strength varies by 35.70%. Considering these differences, there is little point in discussing error sources for each quantity independently; a summation of the error in these four values is well over 100% for each material. The steel is 'closer' to acceptable, although the results are still not particularly dependable. It is interesting to note that for the steel, while the Young's modulus varies by almost 60%, the strength values only vary between ten and twenty percent. On the other hand, for the aluminum, the Young's modulus varies by 'only' 40%, but the strength values differ by much more than that. These deviations could result from several different sources, including machine calibration & measurement error, sample measurement errors, material impurities and composition, procedural errors, novice data processing techniques, and environmental factors, among others. Regardless, the data exists as it was measured, and the best effort was made to clean it while preserving trends. Another interesting point is that, for the steel, the hardening coefficient is not only grossly different in magnitude, but also opposite in sign. This could be a result of the 0.2% offset method, which puts the yield strength *after* the ultimate strength. This is a trend not observed for the aluminum sample, which has a much more accurate hardening coefficient relative to published values. The stress coefficient for aluminum is much more accurate as well, while the stress coefficient for steel is grossly incorrect. These trends are also likely due to the yield and ultimate strength curve locations; the aluminum has much more data in the region between these two points, and thus the power law plasticity coefficients are expected to be more accurate. The steel has *very* few data points in this region, and thus the power law plasticity coefficients cannot be honestly evaluated.

IV. Conclusion

While the experiment consistently yielded quantities well outside the acceptable range, the procedure and analysis processes were successful in communicating the theory and ideas intended. Laboratory procedures mirrored those of successful experiments, as well as backing up the concepts learned in lecture with physical applications – helping to de-abstract what we've learned through the lecture slides and mathematical derivations and boosting understanding and intuition. The data analysis procedures reflected those of a more successful experiment as well. While our data was particularly poor, preprocessing and postprocessing will always be a necessary task. The specific techniques used will likely vary – there are undoubtable differences between professional data analysis for professional publications, and this rather novice data processing derived from undergraduate experience and numerous online MATLAB forums. Intermediate calculations based on theory and proper data presentation are also key. These successes taught the differences between the different types of strength denotations, how they're calculated, and what they mean. The difference between engineering and true stress-strain relations is also important to note, and following that, understanding that the parameters and coefficients seen in lecture and typically used without a second thought come from a wide range of sources and methods. Overall, the experimental results were invalid, but the experiment was not a failure.

V. References

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*: Denotes 'main page' sources, from which numerous specific pages were visited.