

Saginaw Valley State University
Department of Mechanical Engineering
Principles of Engineering Materials Laboratory (ME250L)

Lab 4: TENSILE TESTING

Educational Goals:

1. In this lab, students are introduced to the operation of a tensile testing machine. Raw data from a tensile test is electronically stored in a data file, and students learn to generate stress-strain curves from these data. In turn, they learn to extract from these curves important mechanical properties including elastic modulus, yield strength, ultimate tensile strength, strain-to-failure, true stress, true strain, engineering stress, and engineering strain. Students also develop an understanding of how significant errors can be produced if machine stiffness is not considered in the analysis.
2. Students also learn how annealing influences the microstructure and mechanical properties of polycrystalline metals. Annealed specimens of aluminum are used to study this behavior.
3. The final goal is to help students practice writing skills that are needed by engineers in industry.

Experimental Goals:

1. Determine yield strength, ultimate tensile strength, and elongation for aluminum samples in two different heat treat conditions.
2. Compare the use of crosshead and extensometer displacement measurements.
3. Examine how cold working increases the strength of an aluminum alloy.

Procedure:

1. *Annealing.* Three identical specimens of 7075 aluminum are provided, each of them cold-worked. Prior to this laboratory, two specimens will be annealed by heating in air to 415 °C for 3 hours in an oven. .
2. *Background Reading.* It is important to read Chapter 7 in your textbook to learn about softening of metals by annealing. In the introduction of your lab report, you should describe the following: (i) the two stages of annealing and their associated changes in microstructure; and (ii) expected changes in tensile strength and ductility as the grain size changes during annealing. In the introduction, you should also discuss the importance of aluminum alloys in engineering applications. Make sure to cite a literature reference.
3. *Preliminary Analysis.* Begin by looking up the tensile strength, yield strength, and ductility of 7075 Aluminum indicated in Appendix B of your textbook. In your lab notebook, use this information to sketch plots of the engineering stress as a function of engineering strain. Visually inspect the two graphs and get a sense of how much stronger the cold-worked specimen is relative to the annealed specimen.
4. *Basic Calculations:* One of the main problems with a tensile test machine is that the load cell (the electronic device which measures tensile load) is prone to catastrophic failure if overloaded. The load cell is also expensive and can cost in excess of \$10,000. To prevent overload, it is important

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to start any tensile test by observing the rated maximum capacity of the load cell (usually printed on a label on the load cell). Divide that number by the cross-sectional area of the gage length of your tensile specimen to calculate the highest tensile strength that particular load cell can tolerate. Compare this number with those you calculate from book values of the tensile strengths you found in step 3 above. Double check your results: from the data generated in step 3, estimate the maximum tensile load that each of your specimens will undergo during a tensile test. Discuss in your lab report how these maximum loads compare with the rated capacity of the load cell.

5. The tensile test machine automatically writes tensile test data to a spreadsheet containing a table with four columns: time (t), load (P), crossarm extension (ΔL), and extensometer displacement (L_2). Build a spreadsheet to convert measured loads to engineering stresses by the following procedure:

$$P = \text{load}$$

$$A_o = \text{initial crosssectional area of the specimen}$$

$$s = \text{engineering stress} = P / A_o$$

6. In the same spreadsheet determine two types of engineering strain: (i) that which is calculated from the crossarm displacement, and (ii) that which is calculated by the extensometer displacement.

$$L_o = \text{gauge length measured on the specimen (4 inches)}$$

$$\Delta L = \text{crossarm extension}$$

$$e_1 = \text{engineering strain measured from the crossarm displacement} = \Delta L / L_o$$

$$L_{20} = \text{extensometer knife edge separation before tensile test (2 inches)}$$

$$L_2 = \text{extensometer knife edge separation at any time during the tensile test}$$

$$e_2 = \text{engineering strain measured from the extensometer} = (L_2 - L_{20}) / L_{20}$$

7. In the same spreadsheet, calculate true stress and true strain using the following formulas:

$$A = \text{instantaneous crosssectional area of the specimen}$$

$$\sigma = \text{true stress} = P/A = s (e_2 + 1)$$

$$\epsilon_1 = \text{true strain measured by crossarm displacement} = \ln [(\Delta L + L_o)/L_o] = \ln (e_1 + 1)$$

$$\epsilon_2 = \text{true strain measured by extensometer} = \ln (L_2/L_{20}) = \ln (e_2 + 1)$$

8. *Effects of Annealing on Tensile Behavior.* It is suggested that you read sections 6.1 through 6.9 in your textbook in order to learn basic aspects of the tensile test. In the lab you will perform four separate tensile tests on 7075 Aluminum. The first test involves loading the cold-worked specimen to failure. Call this sample 1. In the second test, an annealed specimen will be loaded to failure in the tensile testing machine. Call this sample two. On the same graph, plot two curves: σ as a function ϵ_2 for samples 1 and 2 (call this Figure 1). For each specimen, compare the yield strength, ultimate tensile strength and strain-to-failure with literature values. Comment on any differences or similarities.

Saginaw Valley State University
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9. *Effects of Work-Hardening on Tensile Behavior.* In the third test, one of the annealed specimens will be work-hardened by loading the sample above the yield point. Call this sample 3. Immediately thereafter, the load on Sample 3 will be brought to zero. The next step is to load sample 3 to failure. Call this sample 4. In your write-up, plot curves of engineering stress versus engineering strain for samples 2, 3 and 4. Place all plots on the same graph (call this Figure 2) so you can make comparisons between each data set. In your write up, comment on how the yield strength, tensile strength, and strain-to-failure differ among each sample. For example:
- Does the stress-strain curve for sample 3 follow the same curve as in sample 2?
 - Does sample 4 have a different yield strength than sample 3? Why or why not?
 - Does sample 4 have a different strain-to-failure than sample 2? Why or why not?
 - Use what you learned in the textbook and in the classroom about dislocation pile up and strain hardening to explain your reasoning.
10. On a separate graph, plot two curves: σ as a function ϵ_2 for sample one and s as a function e_2 for sample one (call this Figure 3). Does the engineering stress-strain curve overlap the true stress-strain curve near the origin? Why? Compare the ultimate tensile strength and strain-to-failure of sample 1 with literature values. Comment on any differences or similarities.
11. For sample 1, plot two curves on the same graph: s as a function e_1 and s as a function e_2 . Call this Figure 4. Use this graph to determine the Young's Modulus and strain-to-failure of each specimen. Compare the results with literature values. Which plot provides a more accurate measure of the Young's Modulus and the strain-to-failure? Explain why.
12. By now, you've figured out that a serious error results when strain is calculated from the crosshead displacement instead of the extensometer reading. This error stems from the elastic deformation of the tensile machine. Yes, the entire tensile testing machine elastically "flexes" under load (you can't see it with the naked eye). As a result, the strain that you calculate from the crossarm extension will be too large. The severity of this error depends on how much the machine flexes (i.e., the machine stiffness). Use the procedure below to estimate the machine stiffness in the laboratory.

t = time

v = crossarm speed

ΔL = crossarm displacement reading on the tensile testing machine = vt

E = elastic modulus of tensile specimen

D_e = elastic displacement of specimen's gauge length = $s e_1 = s L_0 / E$

K = machine stiffness

D_m = elastic displacement of machine = P / K

Consider the beginning of a tensile test when an aluminum specimen is loaded in with small tensile stresses that are well beneath the yield stress. In this case, there is no dislocation slip, and the strain is purely elastic (reversible). Under these conditions, we can describe the crossarm displacement, ΔL , as the sum of two components: the elastic displacement of the gauge length of the specimen (D_e) plus the elastic displacement of the remainder of the load train (D_m). We shall refer to this load train displacement as the "machine displacement." It's the sum of the

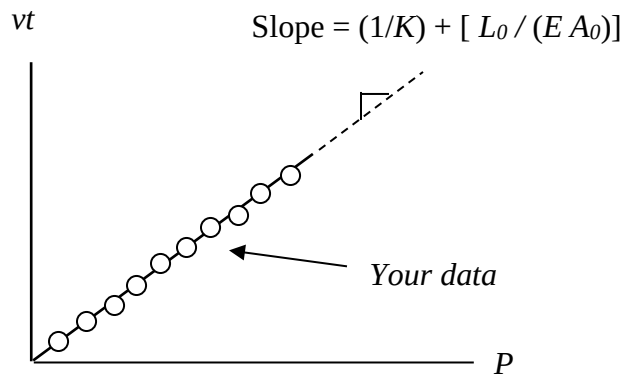
Saginaw Valley State University
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Principles of Engineering Materials Laboratory (ME250L)

deformation of the overall support frame of the testing machine plus the deformation of the crossarm, the deformation of the load cell, the upper grip, the lower grip, and so on. It also contains the elastic deformation of the upper and lower grip sections on an aluminum test specimen. Below, we present an expression for the machine and specimen displacements:

$$\Delta L = D_m + D_e = vt = (P / K) + (s L_0 / E)$$

Substituting $s = P / A_0$ into the above equation and rearranging, we obtain a straight-line relation, which is plotted below:

$$vt = P \{ (1 / K) + [L_0 / (A_0 E)] \}$$



It's possible to determine the machine stiffness, K , by first generating a plot of vt as a function of P . You're asked to do this using your data for sample 1. Call this Figure 5. Keep in mind that this plot should only contain data that are measured during elastic deformation of an aluminum specimen. You'll end up generating a straight-line plot such as shown above. Use your spreadsheet's linear regression utility to fit your data to a straight line. Substitute the resulting slope of the fitted straight line into the equation, $slope = (1/K) + [L_0 / (E A_0)]$, and solve the machine stiffness, K . For this calculation you will need to substitute the right value of Young's Modulus, E . Keep in mind that, earlier, you showed that E can be seriously miscalculated if it is determined on the basis of the crossarm displacement. You are better off using extensometer measurements in Figure 4 to derive a more accurate value of E .