LAB 1

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ABSTRACT

Multiple specimens were placed under axial tension in the materials testing system so that their mechanical behavior and tesnisily could be analyzed. Said specimens were aluminum 6061-T651, water quenched steel 1018, and annealed steel 1018. The data produced was used to calculate various values for the samples that describe their material properties and how they react when placed under tension.

INTRODUCTION AND OBJECTIVES

In this experiment, the objective is to determine various values that represent the material properties of the given samples. The purpose is to gain a better understanding of the different materials and how they react to increasing tensile forces.

PROCEDURE

We begin with three samples of differing mechanical behavior: aluminum 6061-T651, water quenched Steel 1018, and annealed steel 1018. Each of the two steel samples were heated in a furnace. The water quenched specimen was then taken out of the furnace and placed in cold water to cool quickly, while the annealed steel sample was placed in a room temperature environment and allowed to cool naturally at a slower rate. The aluminum specimen was unaltered.

The equipment used during the experiment is the MTS Alliance RT/50 and extensometer built by MTS Landmark. The MTS machine is used to test the tensility for each specimen. This machine consists of the fixed beam at the bottom, a moving beam at the top known as the crosshead, and a large motor at its base. The extensometer is placed on the specimen, which is used to accurately measure the elastic strain so Young's modulus can be determined. After the specimens reach their points of fracture, the two steel samples are photographed using the Keyence Digital Microscope VHS 900F. This device can take images at different Z heights and splice them together, returning a focused image despite the rough fracture sites of the materials.

The thickness, width, and length of each specimen was recorded using a digital caliper. All three samples have a thickness of 0.125 inches, width of 0.375 inches, and gage length of 2.00 inches. Each material it is mounted between the two grips on the MTS machine, attached to the bottom fixed beam and the top moving crosshead. The load cell and extensometer must be calibrated before the test begins. The crosshead is adjusted so there is a 1-lbf load on the load cell before the test begins, and the load cell is zeroed. Once the tensile test begins, the strain within the specimen is subsequently generated by the movement of the crosshead relative to the fixed beam. To measure the applied force on the tensile specimen, the crosshead beam is fit with a 2-inch load cell, and the values are gathered using a program called "Test works". During the first portion of the test, we have an extensometer connected to the specimen which eliminates error in the elastic strain measurement, focusing only on the macroscopic rate of elongation of the sample in this period. While the extensometer records specimen elongation, the load is measured with a load cell in series with the sample. This creates a plot for the load and specimen elongation as a function of time, which is converted into a stress strain curve that is necessary for analysis.

The extensometer is removed before fracture to prevent any damage to the device. Once the extensometer is removed, the elongation of the specimen is estimated by Test Works, considering the displacement of the crosshead, force, and machine stiffness. This process is repeated for all three sample materials, and the final cross-sectional area is measured both at the neck and away from the neck, along with the final total length. Fracture surface images are taken of both the steel samples at 50x and 200x magnification.

RESULTS

Figure 1 displays the raw data gathered for each sample during the experiment. The recorded elements include the initial gauge length, thickness, width, and cross-sectional area, the final gauge length, the final thickness, width, and cross-sectional area in the necked region, and the final thickness, width, and cross-sectional area away from the necked region. All samples followed the standard for initial conditions. Initial gauge length (GL_i) is 2 inches, initial thickness (t_i) is 0.125 inches, initial width (w_i) is 0.375 inches, and initial cross-sectional area (A_i) is 0.0469 inches^2.

Away from the necked region of the Aluminum 6061-T651 sample, the final thickness (t_f) is 0.215 inches, final width (w_f) is 0.364 inches, and final cross-sectional area (A_f) is 0.0455 inches^2. In the necked region of the Aluminum 6061-T651 sample, the final thickness (t_{fn}) is .0960 inches, final width (w_{fn}) is 0.303

inches, and final cross-sectional area (A_{fn}) is 0.0291 inches^2. The final gauge length (GL_f) of the Aluminum 6061-T651 is 2.29 inches.

Away from the necked region of the Water Quenched Steel 1018 sample, the final thickness (t_f) is 0.122 inches, final width (w_f) is 0.370 inches, and final cross-sectional area (A_f) is 0.0451 inches^2. In the necked region of the Water Quenched Steel 1018 sample, the final thickness (t_{fn}) is 0.0490 inches, final width (w_{fn}) is 0.320 inches, and final cross-sectional area (A_{fn}) is 0.0157 inches^2. The final gauge length (GL_f) of the Water Quenched Steel 1018 is 2.15 inches.

Away from the necked region of the Annealed Steel 1018 sample, the final thickness (t_f) is 0.115 inches, final width (w_f) is 0.348 inches, and final cross-sectional area (A_f) is 0.0400 inches^2. In the necked region of the Annealed Steel 1018 sample, the final thickness (t_{fn}) is 0.0810 inches, final width (w_{fn}) is 0.268 inches, and final cross-sectional area (A_{fn}) is 0.0217 inches^2. The final gauge length (GL_f) of the Annealed Steel 1018 is 2.72 inches.

Young's Modulus (E) of each sample was determined by measuring the slope of the linear region of the corresponding stress-strain curve. Since this region was not exactly a straight line on the graphs produced from the data, lines of best fit and their slopes were used. The Aluminum 6061-T651 sample has a Young's Modulus of 7.43×10^6 pounds per square inch. The Water Quenched Steel 1018 sample has a Young's Modulus of 3.01×10^7 pounds per square inch. The Annealed Steel 1018 has a Young's Modulus of 1.80×10^7 pounds per square inch.

The value of yield stress (σ_Y) was calculated using the 0.2% offset method: drawing a line parallel to the elastic region of the graph, intersecting 0.2% to the right of the top of the linear region. This produced yield stresses for Aluminum 6061-T651, Steel Water Quenched 1018, and Steel Annealed 1018 of 4.29×10^4 psi, 1.43×10^5 psi, and 5.19×10^4 psi, respectively. A similar method is used to find the ultimate stress (σ_U), producing values of 4.69×10^4 psi, 1.81×10^5 psi, and 6.35×10^4 psi, once again respectively.

Percent area reduction in the necked region (%RAN) was calculated using Eqn. (6). For each sample, the initial cross-sectional area (A_i) of the sample was substituted for the variable A, and the final cross sectional-area in the necked region (A_{fn}) was substituted for the variable A_o. For the Aluminum 6061-T651 sample, the percent area reduction of the necked region is 37.9%. For the Water Quenched Steel 1018 sample, the percent area reduction of the necked region is 66.5%. For the Annealed Steel 1018 sample, the percent area reduction of the necked region is 53.7%.

$$\%\, Area\ Reduction = \frac{A - A_o}{A} * (100) \tag{6}$$

Percent area reduction away from the necked region (%RAUN) was calculated using Eqn. (6). For each sample, the initial cross-sectional area (A_i) of the sample was substituted for the variable A, and the final cross sectional-area away from the necked region (A_n) was substituted for the variable A_o. For the Aluminum 6061-T651 sample, the percent area reduction away from the necked region is 2.99%. For the Water Quenched Steel 1018 sample, the percent area reduction away from the necked region is 3.84%. For the Annealed Steel 1018 sample, the percent area reduction away from the necked region is 14.7%.

Percent elongation at failure (%EAF) was calculated using Eqn. (5). For each sample, the initial gauge length (GL_i) of the sample was substituted for the variable L, and the final gauge length (GL_f) of the sample was substituted for the variable L_o. For the Aluminum 6061-T651 sample, the percent elongation at failure is 14.5%. For the Water Quenched Steel 1018 sample, the percent elongation at failure is 7.50%. For the Annealed Steel 1018 sample, the percent elongation at failure is 36.0%.

$$\%\, Elongation = \frac{L - L_o}{L} * (100) \tag{5}$$

The value of strain at failure (ε_F) was calculated using Eqn. (3). The initial gauge length (GL_i) was measured for each sample at the beginning of the experiment, and the value of displacement (δ) was calculated using the final gauge length (GL_f) for each sample after the test was completed. This calculation used Eqn. (2) where GL_f was substituted for L, and GL_i was substituted for L_o. Both gauge length measurements were taken using a caliper. The value of strain at failure for the Aluminum 6061-T651 was 0.145, and the final values for the Steel Water Quenched 1018, and Steel Annealed 1018 are 0.0750 and 0.360 respectively.

$$\delta = L - L_o \tag{2}$$

$$\epsilon = \frac{\delta}{L_o} \tag{3}$$

As stated above, the value of initial length (GL_i) was measured at the beginning of the experiment. Similarly, the length (GL_f) was found at the end of the experiment, using the caliper to measure the final length of each specimen post-testing. These numbers were plugged into Eqn. (7) to produce values for Aluminum 6061-T651, Steel Water Quenched 1018, and Steel Annealed 1018 of 0.135, 0.0723, and 0.307, respectively.

$$\epsilon_{True} = \ln\left(\frac{L}{L_o}\right) \tag{7}$$

The value of the volume change at yield (ΔV_Y) was calculated using Eqn. (8). With respect to each material, the change in length ($GL_i - GL_f$) was substituted in for the variable ΔL and the original gauge length (GL_i) was substituted in for L. In addition, Poisson's ratio (v) was substituted with the values (0.27 for steel and 0.33 for aluminum) provided in the lab manual. With these substitutions, the volume change at yield for the aluminum, annealed steel and water quenched steel were 4.62×10^{-3} in^3, 5.13×10^{-3} in^3, and 2.46×10^{-2} in^3 respectively.

$$\Delta V_Y = V * (1 - 2v) * \frac{\Delta L}{L} \quad (8)$$

Discussion Questions:

a. Young's modulus will stay the same because the unloading curve which is parallel to the linear region. yield stress increases because the loading curve intersects with the stress strain curve at a greater stress value. Ultimate stress will not change because this point is after the intersection of the unloading curve with the stress strain curve.

b. For both the annealed steel and water quenched steel, Young's modulus stays the same. The effect of the heat treatment does not change for the proportional limit. Yield stress will decrease for both steels, but the water quenched will have a larger decrease than the annealed steel because the water quenches steel is more brittle due to the different cooling technique.

c. According to table H-1, the mass density of aluminum alloys ranges from 5.2 to 5.4 slugs/ft^3 and the mass density of steel is 15.2 slugs/ft^3. The weight density of aluminum alloys ranges from 160-180 lb/ft^3 and the weight density of steel is 490 lb/ft^3. The density of steel is ~3x greater than the density of aluminum, therefore any steel sample will have higher strength than any aluminum sample.

d. The modulus of toughness for aluminum 6061-T651,a annealed steel 1018, and water quenched steel 1018 is 6.81×10^3 psi, 2.26×10^4 psi, and 1.37×10^4 psi respectfully. In applications such as a shear pin, the structural element needs to absorb as little energy as possible before it fails. This is the sacrificial element protecting the rest of the system from damage. The best material which absorbs the least energy possible is the aluminum 6061-T651. To determine the area under the curves, the trapezoidal numerical integration function (trapz) on MATLAB was used. This method calculates the area beneath the stress versus strain curve through trapezoidal numerical integration. The resulting area is equal to the modulus of toughness of each material tested.

e. The reported results for Young's modulus are not consistent with the known behavior of materials. From table H-2 of Gere and Goodno, the value of the modulus of elasticity for an aluminum alloy should fall between 1.0×10^7 and 1.14×10^7 Psi. The value of 7.43×10^6 psi given in lab is not within the parameters given by the table in the book.

The value of true stress (σ_{True}) was calculated using Eqn. (1). This produced true stresses for Aluminum 6061-T651, Steel Water Quenched 1018, and Steel Annealed 1018 of 1.00×10^6 psi, 2.18×10^6 psi, and 5.34×10^6 psi, respectively.

$$\sigma_{True} = E\epsilon \quad (1)$$

For both steel samples, an expected value from the table H-2 ranges from 2.8×10^7 – 3.0×10^7 psi, which is very close to the measured value for the water quenched steel sample, 3.1×10^7 psi. However, the annealed steel value of 3.8×10^7 psi is not within the given range. Additionally, the values of modulus of elasticity of water quenched and annealed steal should be the same but are off by a factor of two. Reasons for these inconsistencies are likely due to human and machine error that are caused by direct experimentation. These may include slight issues with measuring the initial dimensions of the specimens or come from factors with the tensile testing machine such as an inaccurate load cell capacity or axial misalignment.

f. A more productive procedure that could add to the experiment to deeper understand the tensile testing is repeating the experiment over a longer period. For example, applying the same load over a 24-hour period rather than a few minutes could be more beneficial. This would more closely follow the principles of static testing, whereas executing the experiment quickly is dynamic. Static testing provides more accurate results, so it is preferred over dynamic testing when possible.

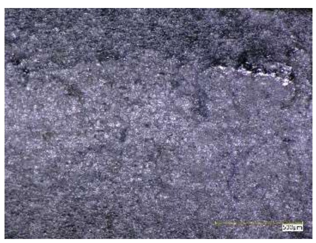
g. Engineering fracture stress is equal to the applied load divided by the original cross-sectional area. True fracture stress is equal to the applied load divided by the instantaneous cross-sectional area. For ductile materials, there is a significant difference between the engineering fracture stress and true fracture stress. Ductile materials experience a lot of deformation prior to fracture, and therefore the instantaneous cross-sectional area is significantly less than the original cross-sectional area and engineering fracture stress will be less than true fracture stress. For brittle materials, there is no significant difference between engineering fracture stress and true fracture stress. Brittle materials do not experience much deformation before fracture; therefore, the original cross-sectional area is extremely close to the instantaneous cross-sectional area and engineering fracture will be approximately equal.

h. The initial cross-sectional area of both samples is 0.0469 in^2. The final cross-sectional area of the annealed steel is 0.0400 in^2, and the final cross-sectional area of the water quenched steel is 0.00451 in^2. The final area for the water quenched steel is relatively close to the initial area, whereas the final area for the annealed steel is significantly less. Therefore, the annealed steel is the ductile sample and the water quenched steel is the brittle sample.

i. When metals experience ductile fractures, this means that they undergo large plastic deformation before the fracture point. This occurs in the form of necking and absorbs a significant amount of energy.

j. For the ductile sample of the annealed steel, the image shows the greater deformation caused by the force because there is a smaller surface area at the fracture point. Also, the annealed steel has a rougher surface, which indicates a longer period of deformation. Both observations indicate a necking period and therefore indicate ductility. For the brittle water quenched steel, the image shows a cross-sectional area that is almost the same size at the original cross-sectional area. Also, the water quenched steel has a smoother surface at the point of fracture. Both observations indicate that there was not a necking period and therefore indicate brittleness.

Annealed Steel 50x



Annealed Steel 200x

Water Quenched Steel 50x

Water Quenched Steel 200x

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REFERENCES

Goodno, Barry J., and James M. Gere. *Mechanics of Materials*. Cengage Learning, 2009.

ANNEX A

FIGURE 1
RAW DATA

	Aluminum 6061-T651	Steel Water Quenched 1018	Steel Annealed 1018
w_i	0.375 in	0.375 in	0.375 in
t_i	0.125 in	0.125 in	0.125 in
A_i	0.0469 in^2	0.0469 in^2	0.0469 in^2
GL_i	2.00 in	2.00 in	2.00 in
w_f	0.364 in	0.370 in	0.348 in
t_f	0.125 in	0.122 in	0.115 in
A_f	0.0455 in^2	0.0451 in^2	0.0400 in^2
w_{fn}	0.303 in	0.320 in	0.268 in
t_{fn}	0.0960 in	0.0490 in	0.0810 in
A_{fn}	0.0291 in^2	0.0157 in^2	0.0217 in^2
GL_f	2.29 in	2.15 in	2.72 in

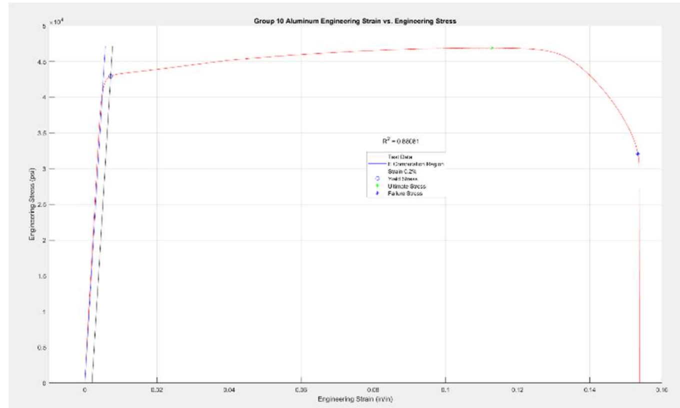
Raw data gathered during the experiment.

FIGURE 2
EVALUATED QUANTITIES

	Aluminum 6061-T651	Steel Water Quenched 1018	Steel Annealed 1018
E	7.43 x 10^6 psi	3.01 x 10^7 psi	1.80 x 10^7 psi
σ_Y	4.29 x 10^4 psi	1.43 x 10^5 psi	5.19 x 10^4 psi
Method	.2% offset	.2% offset	.2% offset
σ_U	4.69 x 10^4 psi	1.81 x 10^5 psi	6.35 x 10^4 psi
%RAN	37.9 %	66.5 %	53.7 %
%RAUN	2.99 %	3.84 %	14.7 %
%EAF	14.5 %	7.50 %	36.0 %
ε_F	0.145	0.0750	0.360
$\varepsilon_{True,\,F}$	0.135	0.0723	0.307
ΔV_Y	4.62 x 10^{-3} in^3	5.13 x 10^{-3} in^3	2.46 x 10^{-2} in^3
$\sigma_{True Y}$	1.00 x 10^6 psi	2.18 x 10^6 psi	5.34 x 10^6 psi

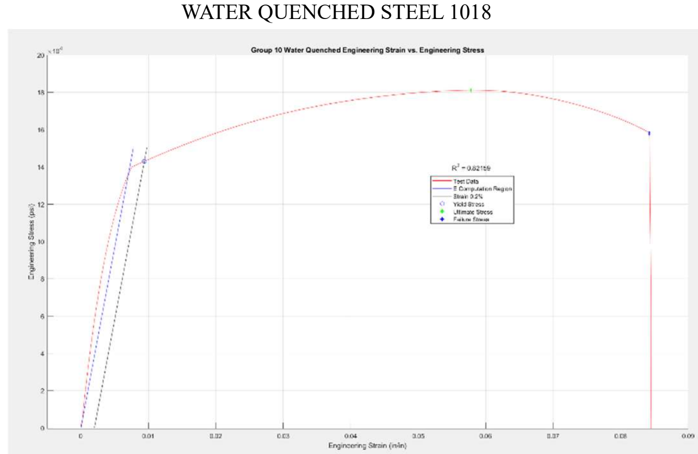
Calculated results based on raw data.

FIGURE 3
ALUMINUM 6061-T651



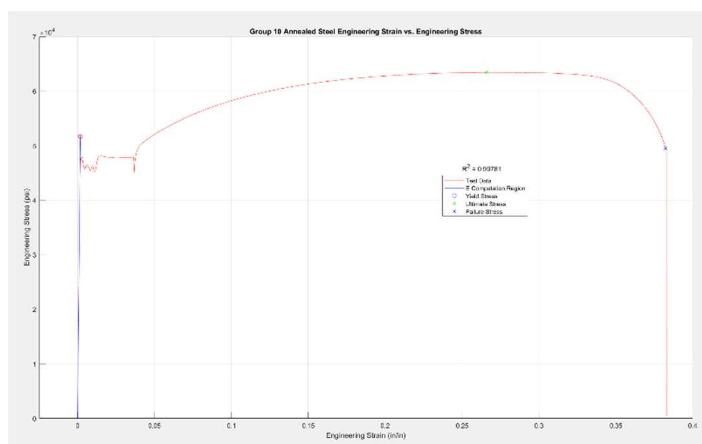
Stress strain curve produced when aluminum 6061-T651 sample was placed under tensile test.

FIGURE 4
WATER QUENCHED STEEL 1018



Stress strain curve produced when water quenched steel 1018 sample was placed under tensile test.

FIGURE 5
ANNEALED STEEL 1018



Stress strain curve produced when annealed steel 1018 sample was placed under tensile test.