Tensile Test Analysis

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Abstract: This experiment had annealed and non-heat treated samples of aluminum, copper and brass that underwent a tensile test in order to examine the effect on their mechanical properties. The specific properties that are reviewed are the effect of alloying, cold working and reducing grain size. All samples of each material were tested individually and then compared based on what property was to be examined. From each test, the annealed sample for all materials experienced a longer plastic deformation region and lower ultimate tensile strengths when compared to their untreated sample.

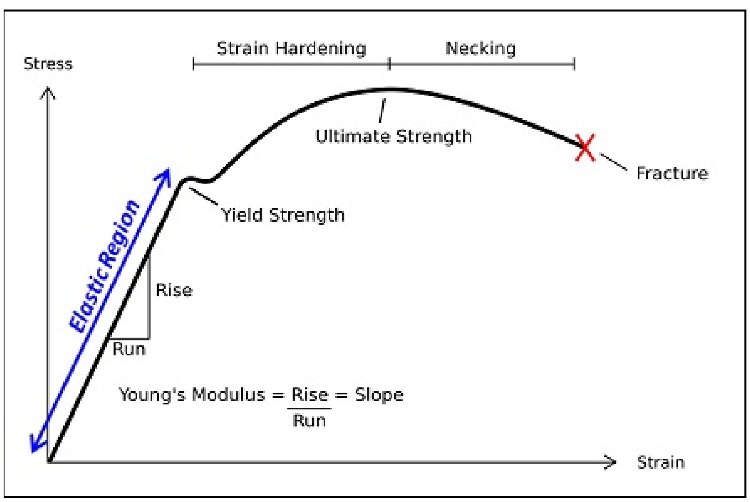
INTRODUCTION

For this experiment, as received and annealed aluminum, copper and brass samples were put under a tensile test. From the tensile test, a stress-strain curve was constructed from the data observed and determined what properties the material has. The properties found are as follows, yield strength, tensile strength, elastic modulus, percent-elongation, toughness, and resilience. Also from each sample's defined curve, the work hardening coefficient, n was calculated and the type of necking condition that occured was indicated. Further, the effect of grain size, cold working, and composition on mechanical properties were also observed at room temperature.

Before being put under tensile load, the samples for each material were categorized in three areas: no heat treatment, annealed for 10 minutes and then annealed for 3 hours. By comparing the untreated samples with the 10 minute annealed samples the effect of cold working is revealed where the 3 hour annealed samples shows the effect of grain growth. Similarly, comparing the copper to brass samples allowed for observations regarding effects on alloying. From reviewing the data presented in the stress-strain curves, annealed samples of aluminum, copper and brass presented more ductility than their untreated sample by having longer plastic deformation regions. Furthermore, brass had higher yield stresses for both untreated and annealed samples when compared to copper.

BACKGROUND THEORY

- **Stress-strain curve**



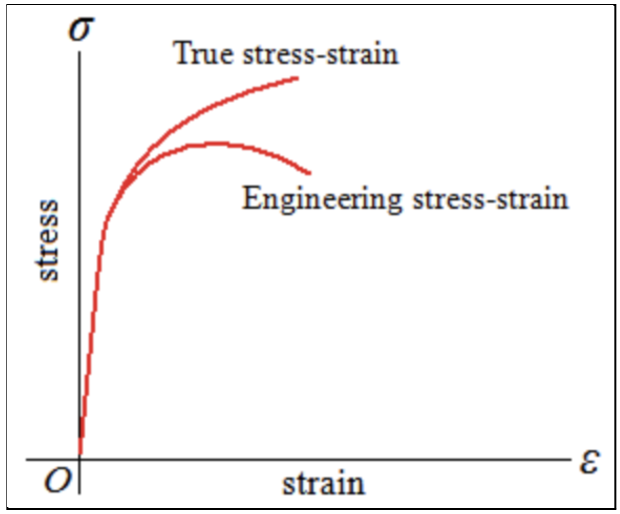
[2]

Yield strength: before reaching yield strength, materials will deform elastically.
Ultimate tensile strength: it is the max stress that can be applied on the material before fracture. Necking will happen after reaching the ultimate strength.
Toughness: it is the area under the stress-strain curve. The more area underneath, the tougher the material will be.

Resilience: it is the area under the elastic deformation region of the stress-strain curve. It represents the ability to absorb energy without plastic deformation.
Ductility: the distance from the beginning to the strain corresponding to ultimate stress represents the ductility of the material. Usually, tougher material is more ductile.
Necking: it is localized deformation happening after reaching ultimate stress where the plastic deformation is no longer uniform.

- ❖ **True and Engineering stress and strain**

(Eq1) $\sigma = \frac{P}{A_0}$	engineering stress
(Eq2) $\sigma_t = \frac{P}{A}$	true stress
(Eq3) $\varepsilon = \frac{\delta}{L_0}$	engineering strain
(Eq4) $\varepsilon_t = \ln \frac{L}{L_0}$	true strain



[3]

P: load
Ao: initial cross-sectional area of specimen
A: cross-sectional area at certainly applied force (instant area)
δ: how much it elongated
Lo: the original value of the gage length
L: instant length

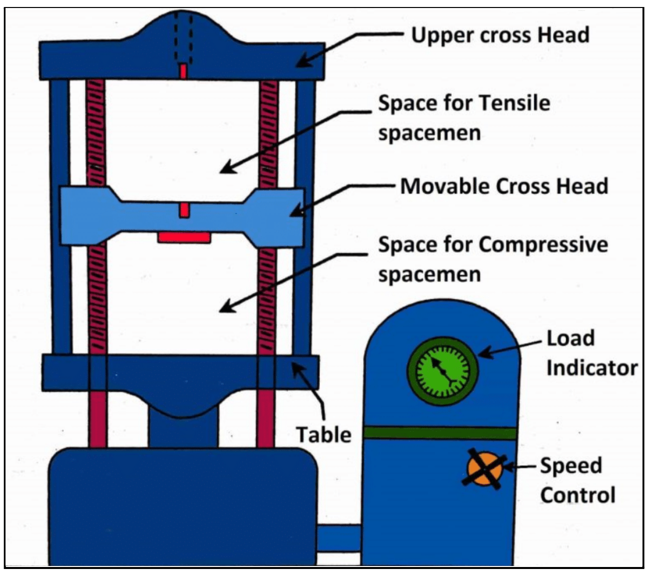
True stress-strain curves always have a positive slope whereas engineering stress-strain curves always have a positive value and then negative value after reaching ultimate stress. This is because true stress is counted by instant area at a given force. When necking occurs, the area will decrease making the material tougher and able to stand higher forces.

- ❖ **Material**

Brass: it is a zinc-copper alloy. If the zinc content of the brass ranges from 32% to 39%, it will have increased hot-working abilities but the cold-working will be limited. If the brass contains over 39% zinc, it will have a higher strength and lower ductility (at room temperature).[4]

THEORETICAL ANALYSIS

Tensile strength testing machine, also known as universal testing machine (UTM) or Instron, is used to test the compressive and tensile strengths of materials. UTM is composed of 2 main parts: load unit and control unit. The load unit is composed of load frame, upper crosshead and lower crosshead, and elongation scale. The control unit is composed of hydraulic power unit, load measuring unit and control devices. The hydraulic power unit contains an oil pump helping non-pulsating oil flow into the main cylinder of the load unit. Load measuring unit displays the load on the dial. The control devices can either be electric or hydraulic. Electric control devices will have multiple switches on them and the switches control the crosshead and turn on the unit. Hydraulic control devices usually contain 2 valves. Valves are able to apply load and release load on the specimen. [1]

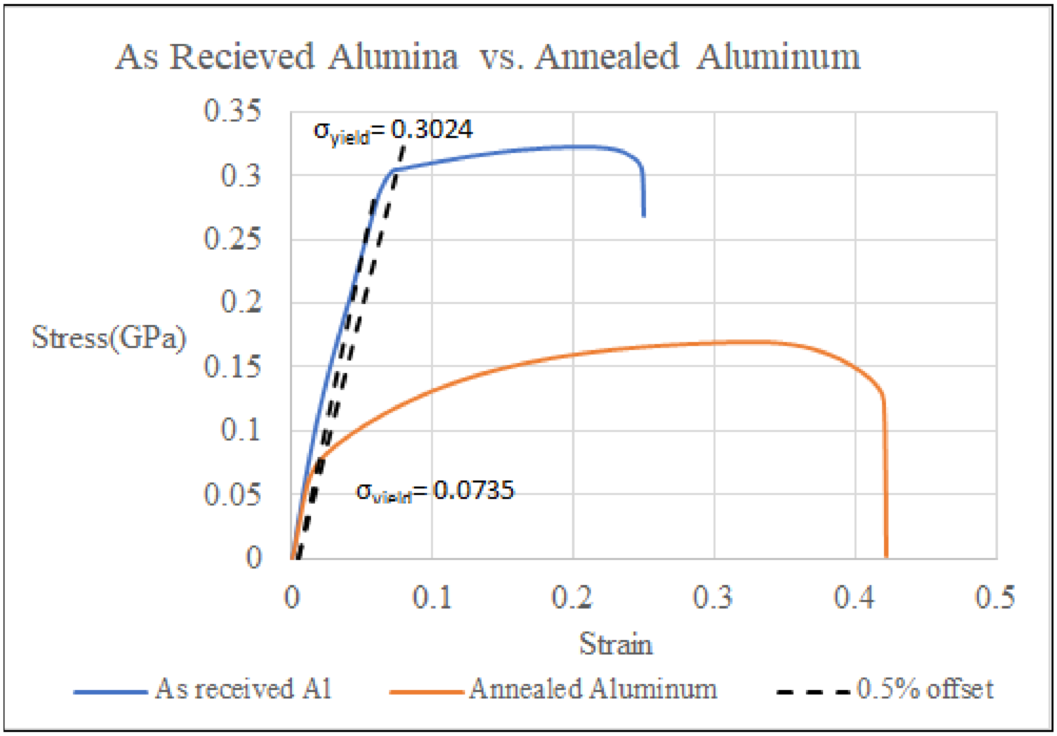


[1]

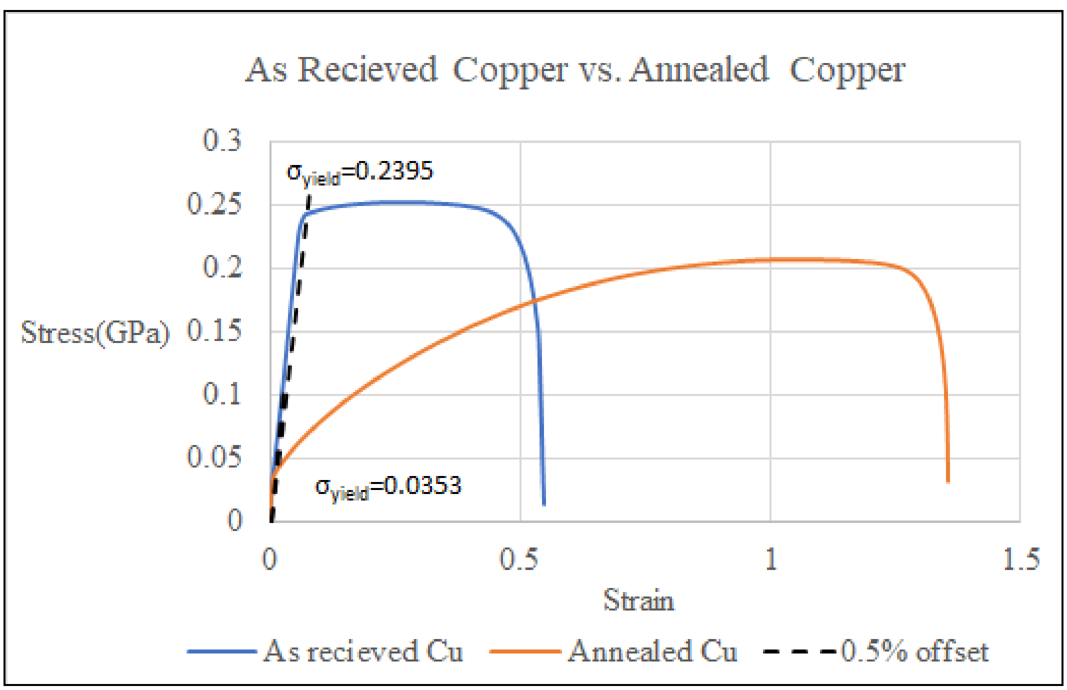
PROCEDURE

The tensile test was done to investigate the effect of grain size, cold work, and composition on materials' property. In this experiment, as received aluminum, annealed aluminum, as received copper, annealed copper, as received brass and annealed brass were prepared. Annealed samples were prepared by heating them up to 550°C for 10 minutes and 3 hours and cooling them down to room temperature. After polishing them with 220~320 grit sandpaper and recording the initial cross-sectional areas, samples were then tested on Instron by inerting forces on each side and gradually pulling them apart until fracture. The force and elongation of specimens were also able to be recorded during the process. At the end, after fracture, the cross-sectional area and final elongation were measured again.

RESULTS



<u>Figure 1:</u> Stress- Strain curve for Alumina Samples



<u>Figure 2:</u> Stress- Strain curve for Copper Samples

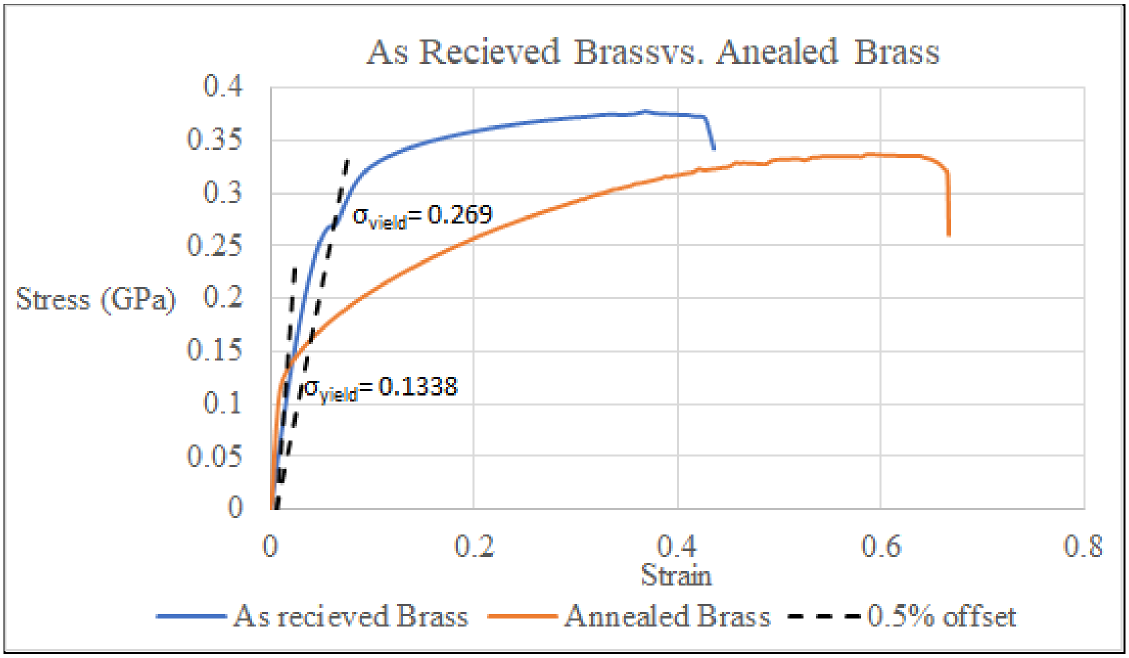


Figure 3: *Stress- Strain curve for Brass Samples*

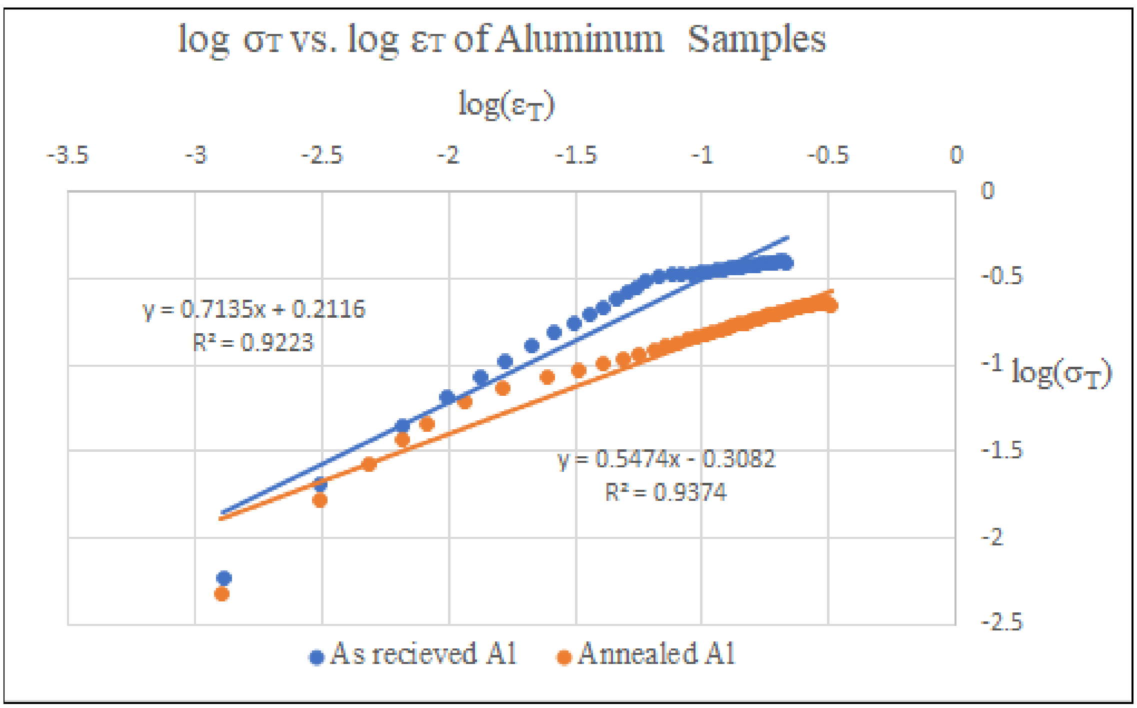


Figure 4: *log(σ_T) vs. log(ε_T) for Alumina Samples*

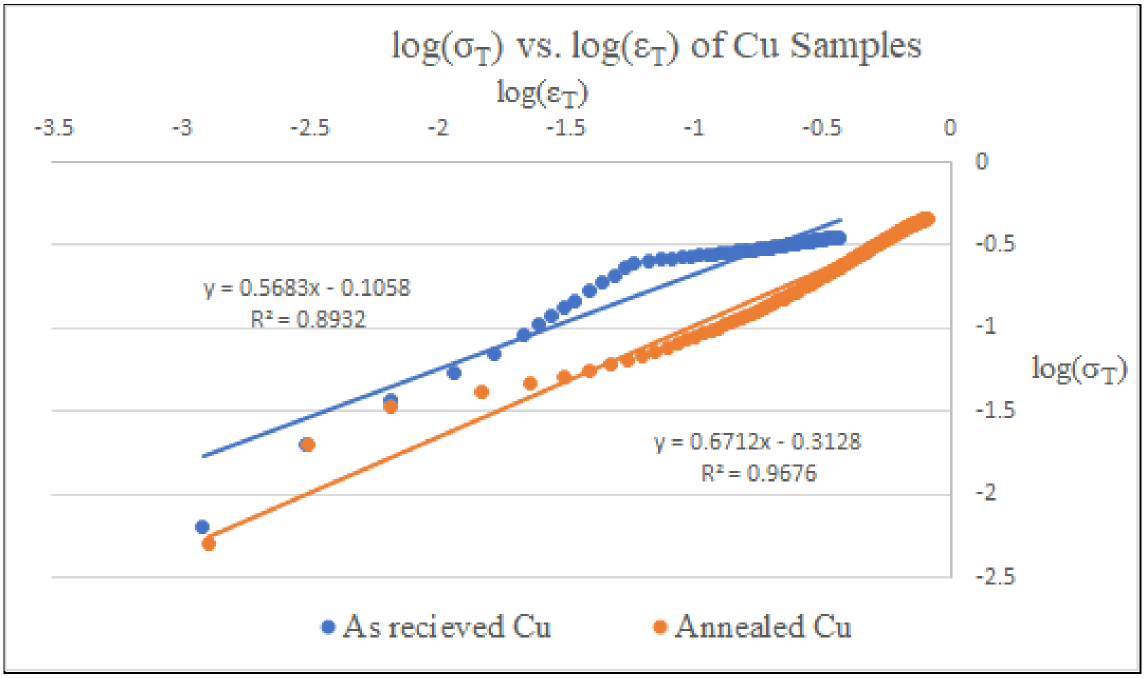


Figure 5: *log(σ_T) vs. log(ε_T) for Copper Samples*

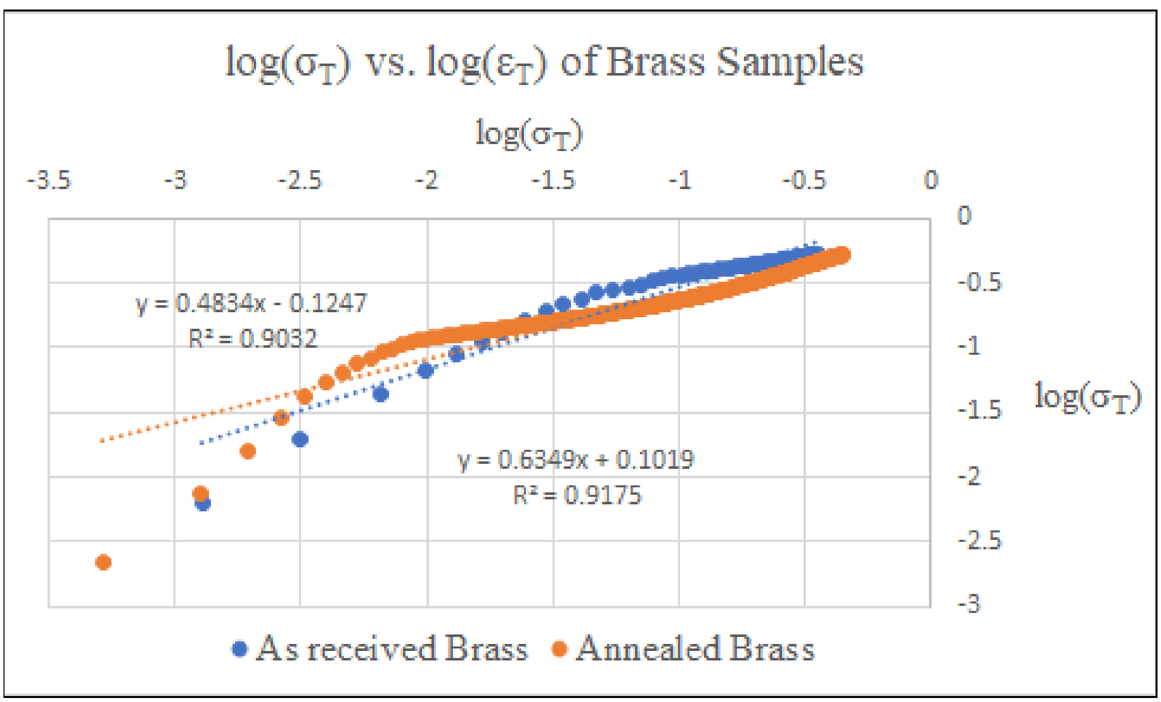


Figure 6: *log(σ_T) vs. log(ε_T) for Brass Samples*

	σ_{Yield} (GPa)	σ_{UTS} (GPa)	$\varepsilon_{Necking}$	Ductility	Young's Modulus (N/m^2)	K	n	% of elongation
As Received Al	0.03024	0.3223	0.2066	0.2158	4.3214	0.216	0.7135	5.26%
Annealed Al	0.0735	0.1701	0.33	0.3364	5.2521	-0.308	0.5474	17.71%
As Received Cu	0.2395	0.2517	0.2616	0.3543	3.5226	-0.106	0.5683	41.66%
Annealed Cu	0.0353	0.2072	1.065	1.1555	5.0516	-0.313	0.6712	66.23%
As Received Brass	0.269	0.376	0.3683	0.3705	4.7185	0.1019	0.6349	20.6%
Annealed Brass	0.1338	0.3356	0.588	0.586	12.162	-0.125	0.4834	52.22%

All calculated results shown above.

Equations got involved:

As the data is given with the displacement and the load. Also the dimension of the sample is given, therefore, using the equation (1) and (2), the stress-strain curve can be determined.

$$\sigma = \frac{F}{A_0}$$ ....(1)

$$\varepsilon = \frac{l - l_0}{l_0} = \frac{\Delta l}{l_0}$$ ....(2)

$$\varepsilon_T = ln(\varepsilon + 1)$$
$$\sigma_T = \sigma(1 + \varepsilon)$$ ....(3)&(4)

$$\sigma_T = K\varepsilon_T^n$$ ....(5)

[$L_{(final)}$-$L_{(Initial)}$]/$L_{(Initial)}$=% Elongation………………......(6)

Then the equation (3),(4)&(5) are used to plot the log(σ_T) vs. log(ε_T) curve and calculate the strength coefficient and strain hardening exponent.

% Elongation is calculated through equation (6), where all required data is given on the data sheet.

DISCUSSION

In all of the materials tested, the samples that were annealed experienced a lower yield stress and were capable of more plastic deformation before rupture, this shows that ductility increased. Annealing the samples also decreased the ultimate tensile strength. The annealing process includes raising the material to a high temperature to cause the growth of grains and relaxation of internal stresses in the material. This change in the microstructure altered the material's properties.

After these values were gathered, they can be used for all of the values listed in the tables below. A major source of error in this experiment is due to the variance in microstructure of the samples. Even if they all underwent the same processes, two samples are never exactly the same. Small variances in grain size or pre-existing small cracks can lead to error in the data gathered and the values calculated.

In **figure 1**, **Figure 2** and **figure 3**, the linear parts shows elastic behavior of material which can be defined by Hooke's law $\sigma = E \ \varepsilon$. The slope of the graph shows the value of E which is elastic modulus of the sample. By comparing the E value, the stiffness of the material can also be determined. For aluminum samples, the slope of two lines is almost overlapping. Thus, the heat treatment did not have a large effect on Al. In **figure 2**, the slope is even more overlapping than **figure 1**. In **figure 3**, it shows a similar trend as **figure 1** that the difference in slope is still very tiny. Thus, it can be concluded that annealing only has a tiny effect on materials' elastic modulus.

In **figure 4**, **figure 5** and **figure 6**, best fitting lines are formed by thousands of dots. The slope of the regression line represents the K value and the interaction of the Y axis represents the n value. According to the table, as-received Al has the highest n and K value among others. Thus, it can be concluded that as-received Al is the hardest because larger n represents harder material.

As the strain hardening coefficient and strength coefficient of each sample are collected in the table in the results section. It can be seen that in all samples, the received sample is larger than its corresponding annealed sample. The larger n, the harder the material. Therefore, in terms of hardness, the cold-worked samples are harder than the annealed samples.

DISCUSSION QUESTIONS

1) Plot the engineering stress-strain curve for each brass specimen tested (one curve at each aging condition). (See results section)

2) What is the yield strength, tensile strength, elastic modulus, and percent-elongation for each sample tested?

Sample	*Yield Strength (MPa)*	*Tensile Strength (MPa)*	*Elastic Modulus (GPa)*	*Percent Elongation*
As Received Aluminum	302	322	60.5	5.26%
Annealed Aluminum	73.5	170	14.7	17.71%
As Received Copper	240	262	47.9	41.66%
Annealed Copper	35.3	207	7.1	66.23%
As Received Brass	269	376	53.8	20.6%
Annealed Brass	134	336	26.8	52.22%

3) What is σ_0 and k in the H-P equation for the samples we used in this lab?

Sample	σ_0 *(MPa)*	*k*
As Received Aluminum	229	0.216
Annealed Aluminum	58	-0.308
As Received Copper	182	-0.106
Annealed Copper	27	-0.313
As Received Brass	204	0.102
Annealed Brass	102	-0.125

4) What is the etchant used for copper and its alloys? (Find it in the appropriate ASTM manuals.)

The etchant used for copper and its alloys is Ferric chloride.

5) What are the strength coefficient, K, and strain hardening exponent, n, for brass? Is it consistent with the different grain sizes? How do they compare with published values for brass?

Before annealing, brass was found to have a strength coefficient of 0.102 and a strain hardening exponent of 0.6349. After annealing caused the grains to increase in size, a strength coefficient of -0.125 and a strain hardening exponent of 0.4834 were found. Published values for strength coefficients are 0.58 and 0.9 and strain hardening exponents are 0.34 and 0.49 for cold-rolled and annealed brass respectively.

6) What is the ratio of yield strength to density for copper, brass, and aluminum? How does that affect your decision in choosing the right materials for a specific application?

Copper: *26.8*
Brass: *30.8*
Aluminum: *111.9*

In many applications, such as parts for airplanes, an ideal material must be both strong and light. A part made out of copper or brass would have to be many times heavier than an aluminum part to have the same structural integrity.

CONCLUSION

The tensile test is an incredibly useful test to determine the material's physical properties. Data from this test can be used to calculate material important constants. Annealing a metal relaxes internal stresses in the material and increases the grain sizes. The primary results of this process is the increase in ductility of the material, and a lowering of the yield stress. Tests like this one allow engineers to determine when a substance will fall; this information is vital to ensure products perform as required.

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