Subjecting Copper Wires to Tensile Testing

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***Abstract*—This lab aims to calculate and observe the qualities and characteristics of copper wire under increasing tensile force. The values that will be measured explicitly will be the copper's modulus of elasticity, yield point, ultimate strength, and its elastic limit. To determine these quantities copper wire was subjected to forces that increased over time. The stress was measured by dividing the current load by the copper wires initial cross-sectional area. The strain was determined by measuring the change in voltage, and then multiplying that by the calibration constant divided by the original length of the copper wire. The resulting modulus of elasticity was 3.589 GPA which indicates that copper is extremely ductile. The yield point and ultimate strength were 36.80 MPa and 258.7 MPa respectively while illustrates that copper undergoes substantial plastic deformation before it fractures.**

***Index Terms*—Load-Based, Modulus of Elasticity, Strain, Stress**

I. Introduction

This lab observes how different materials deform and behave when subjected to varying amounts of force. The lab aims to measure stress and strain of the material via Load-Based Stress. The lab aims to determine these values and find the uncertainty of these calculations and what these findings mean and what one can infer from them.

This lab is putting materials under stress to cause elastic and plastic deformation. This deformation can be determined by plotting the stress vs strain on a graph and determining the yield stress. If the elastic region is profound, then one can determine that it is a ductile material and one can determine the Young's Modulus by taking the derivative of this elastic region. By finding all of these properties it will determine the fracture point and determine a material if it is unknown.

This lab in particular is studying a copper wire specimen under uniaxial tension with incrementally increasing force. It will determine the stress-strain curve of the copper wire to calculate the values of its modulus of elasticity, ultimate strength, elastic limit, and its yield point. The procedure uses varying lengths of copper wire to gain a better understanding of the material's linear elastic region (longer copper wires) and how the failure and ultimate tensile strength are related. Then develop uncertainties for each of these values to understand the significance of the measurements. After all of these measurements are taken, this lab aims to compare its results with industry standards, see how this test could be improved, what information this tells us about copper, and how this experiment opens up new avenues and questions in studying Load-Based Tensile Testing. The stress can be calculated by determining the cross-sectional area and then dividing the measured load by that value. The strain can be estimated by measuring the initial length of the coper wire from peg to peg, taring the voltage from the LVDT and the DAQ, calculating the change in length from the change in voltage, and then dividing the change in length by the initial length [2, pp.92].

II. Procedure

Experiment Procedure

The first step that was completed was to have an updated LabVIEW VI that functioned with the DAQ. After that was updated, the LVDT was powered on and connected to the DAQ (channel 0). Then the calibration constant was determined to be 2.0619 mm/V since it was multiplied by voltage [3]. Then the voltage had to be tared to set a baseline to measure a change in voltage from the LVDT. After these steps were completed, a variety of copper wires were cut that varied in length ranging from 40mm to 60mm. The wires were then attached to the hanger by securing it behind a thumb screw and wrapped around the peg to ensure it was in the vertical direction. After that it was secured to the hanging device via looping it around the peg 360° and fastening it between the washers and the aluminum plate. Once the copper wire was secure in the hanger, the LVDT device had to be loosened to allow the hanger to be inserted into it. The hanger was about 1 inch from the top of the LVDT since there were some dead spots in the LVDT where it wouldn't record the voltage change and to reduce the chance of saturation from the LVDT. Then secure the LVDT device using an allen wrench.

After the device was set up completely it was time to measure the forces of the weights that the copper wire would be subjected to. First the weight of the hanger was measured to determine the initial elongation done by the system. The forces of the weights were calculated using a scale (N) and the weights would be measured with increasing weight on the scale, not individually, to reduce the propagation of uncertainty in these measurements. After the forces of the weights were recorded, they were loaded on incrementally from the smallest load to the largest load. As the copper was subjected to the load the force was inputted into the LabVIEW VI to get an accurate and up to date value of stress. This process was repeated until failure occurred in the copper wire. After failure occurred, the LabVIEW VI was stopped, and the data was saved. If the results weren't sufficient or correct the whole procedure would be repeated from the beginning to the end.

Materials

The materials that were needed to complete this lab are as follows: laptop with an updated LabVIEW VI that functions with a DAQ, LVDT, copper wire, scale to measure force, weights, ruler, allen wrench, and the tensile loading mechanism [2, pp.101-102].

III. Results

As the copper was subjected to increasing load it deformed elastically until its yield point, where it had permanent elongation. The change in voltage the copper wire underwent was 0.753V, the change in length was 1.55441 mm and it experienced a maximum force of 8.123 N. The strain value at the point of fracture can then be determined to be 0.0444.

The copper wire's change in voltage, change in length, and maximum force at the yield point are 0.000325V, 0.00067mm, and 1.1788N respectively (Fig. 1).

The change in voltage, change in length, and the maximum force of the copper wire at its ultimate strength was 0.753V, 1.55441, and 8.123N

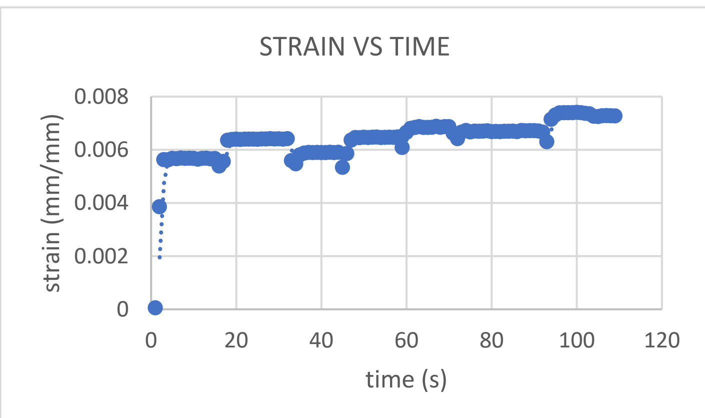

Fig. 1 Strain vs Time of the copper wire which tracks the elastic and plastic deformation at varying loads.

The change in strain from unloading the force which caused the copper to yield was 0.000104. This is considerable enough change to determine this force as its yield point (Fig. 1)

IV. Discussion

This lab aims to examine the properties of a copper wire subjected to varying loads. The specific values to be determined are as follows: modulus of elasticity, yield point, ultimate strength, and elastic limit. These values will then be compared to industry standards to ensure they are correct and how the test can be improved. These will be determined by having the copper wire in tension while measuring a change in voltage and the current force to accurately plot a stress vs strain diagram. The key results found is that the copper wire elongated by 1.5541 mm at its fracture point and withstood a maximum force of 8.123N before failing.

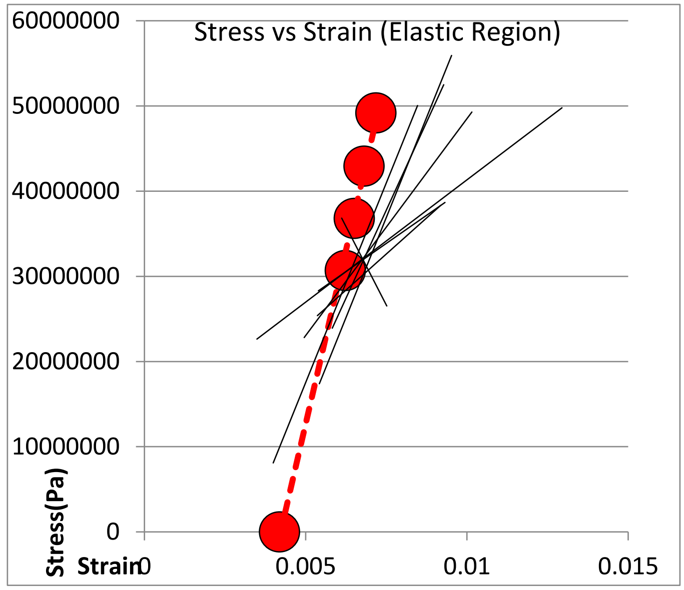

Fig. 2. Stress vs Strain of the copper wire to determine the Youngs Modulus (slope of trendline).

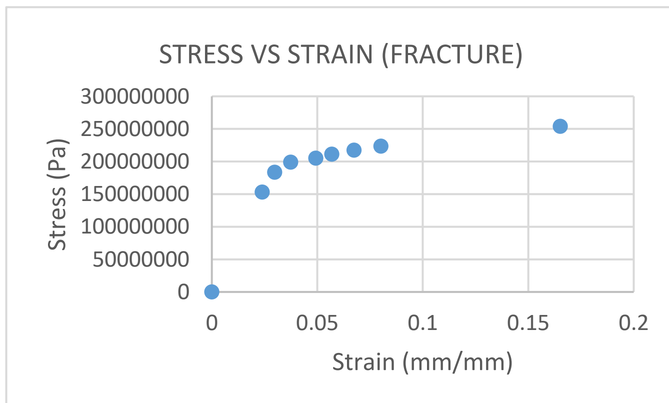

Fig. 3. Stress vs Strain of the copper wire in which it was subjected to increasing weight to induce fracture.

The Modulus of Elasticity was determined in two different ways. One way was by plotting stress vs strain and then finding the slope of the trendline of the points and accounting for the uncertainty by using a Monte Carlo Simulation program. This method yielded the result of 16.3 GPa. The alternate method is to use the following equation:

$$E = \frac{\sigma}{\varepsilon} = 3.58E9 \qquad (1)$$

This equation yielded a result of 3.58GPa. Loading the weights with a small load initially and then increasing the load by small increments produces a relatively linear trend that illustrates how strain increases as the copper is subjected to greater loads (Fig. 2). The fracture of the specimen was found by inducing the copper wire to significant loads until it broke. The largest stress value the copper wire withstood was 258.7 MPa (Fig. 3).As the copper wire was subjected to increasing loads, it plastically deformed for a substantial length before it finally broke. After its yield point, its stress increased by a factor of 6 (Fig. 3). The elastic limit was observed to be approximately

30.68 MPa. This was determined by loading and unloading the weights on the copper and seeing if the wire elastically deformed back to the original strain or not by plotting strain vs time (Fig. 1). The ultimate strength is assumed to be the same value as the fracture point (258.66 MPa). The modulus of elasticity and the yield point of the copper wire suggest that it is extremely ductile and malleable making it useful for electric wires, jewelry, and for some musical instruments [1]. The yield strength and ultimate strength are relatively close to the industry standards. They differ by 11% and 23% respectively indicating that this lab produced precise and accurate results despite some limitations [1]. The stress vs strain graphs produced were consistent with previous studies done on copper wires in which they illustrate how copper is able to plastically deform significantly until its fracture point. Future studies should be done to identify and calculate the molecular integrity of the copper wire without load when it was plastically deformed at different severities.

There were a variety of limitations that cause the results to not be generalizable. One of the significant limitations is that the force wasn't applied to the copper wire continuously and the current cross-sectional area wasn't taken into account when calculating the current stress. Another limitation is that this lab only studied forces in the vertical direction where in real life tension will occur in 3D space making the results of the lab only applicable to single dimensional systems. Another experimental limitation was the use of a LVDT and the tare value. This tare value would not be equal to the resting voltage of the LVDT which would cause a shift in the initial strain value and might have skewed some initial results. The final limitation that occurred was the possibility of creep being in the system. If creep caused the copper wire to permanently deform it could alter the results and give incorrect values for the modulus of elasticity and the yield point. This would make the results not comparable to standard copper stress vs strain curves and its respective values.

V. Conclusion

A. *Summation of Copper Wire in Tension*

This lab determined the modulus of elasticity, yield point, and ultimate strength to be 3.580 GPA, 36.80 MPA, and 258.7 MPa respectively. These results are critically important because they are able to determine how to safely utilize copper as a crafting material. These results can help determine the yield point and ultimate strength of varying copper materials of different shapes and cross-sectional areas since it has been relatively accurate compared to industry standards. Steps to improve the accuracy and precision of the results would be to subject the copper wire to continuous load and have the computer auto calculate the load, and to calculate the current cross-sectional area to get an accurate stress value. The next steps are to test copper wires in compression and test its heat and electrical conductivity. These tests and their subsequent results will help scientists utilize copper to its fullest potential.

Appendix

Measurement	Value	Uncertainty
Force (N)-F	1.574	± 0.00098
Li (mm)	35.00	± 0.5
V_{tare}(V)	4.4439	± 0.0172
ΔV(V)	0.2380	±0.00172
Area (mm^2)-A	0.0314	± 1.27E-5
Diameter (mm)-D	0.200	± 0.00025
ΔL(mm)	0.4910	±0.0103
Calibration Constant (mm/V)-C	2.062	± 0.00067
Strain-ϵ	0.014	± 3.56E-3
Stress (MPa)-σ	50.12	± 0.5689
Elastic Modulus (GPa)-E	16.3	± 0.285
Yield Point (MPa)	36.80	± 0.5689
UltimateStrength (MPa)	258.7	± 0.1092
Elastic Limit (MPa)	30.68	± 0.0336
Hanger (N)	0.2403	± 0.00098

The uncertainty in the force of the weights calculated was given by the scale manufacturer [4]. The uncertainty of Li was determined by the ruler being able to measure by the millimeter [4]. The uncertainty in ΔV was determined by the uncertainty of the DAQ. The uncertainty of the V_{tare} is the standard deviation between the LVDT voltage and the tare value multiplied by 2 [2]. The uncertainty of the area was found using the following equation [4]:

$$U_A = \sqrt{\left(\frac{\partial A}{\partial D}\right)^2 (U_D)^2 + \left(\frac{\partial A}{\partial \pi}\right)^2 (U_\pi)^2} = 1.27E-5 \tag{2}$$

The uncertainty of ΔL was found by following the propagation of uncertainty of multiplying the calibration constant (which was given) and the ΔV [2],[4]. The uncertainty of the strain was found by using the following equation [4]:

$$U_\varepsilon = \sqrt{\left(\frac{\partial \varepsilon}{\partial \Delta L}\right)^2 (U_{\Delta L})^2 + \left(\frac{\partial \varepsilon}{\partial L_i}\right)^2 (U_{L_i})^2} \tag{3}$$

The uncertainty of stress was found by using the following equation [4]:

$$U_\sigma = \sqrt{\left(\frac{\partial \sigma}{\partial F}\right)^2 (U_F)^2 + \left(\frac{\partial \sigma}{\partial A}\right)^2 (U_A)^2} \tag{4}$$

The uncertainty of the yield point was found by using the stress uncertainty equation but using the yield point value of stress:

$$U_{\sigma_y} = \sqrt{\left(\frac{1}{0.0314}\right)^2 (0.00098)^2 + \left(\frac{1.574}{0.0314^2}\right)^2 (1.27 \cdot 10^{-5})^2} 0.5689 \tag{5}$$

The uncertainty of the ultimate strength was found by using the stress uncertainty equation but inputting the ultimate strength for the stress value:

$$U_{\sigma} = \sqrt{\left(\frac{1}{0.0314}\right)^2 (0.00098)^2 + \left(\frac{8.123}{0.0314^2}\right)^2 \left(1.27 \cdot 10^{-5}\right)^2} = 0.1092 \quad (6)$$

The uncertainty of the elastic limit was found by using the stress uncertainty equation but inputting the elastic strength for the stress value:

$$U_{\sigma} = \sqrt{\left(\frac{1}{0.0314}\right)^2 (0.00098)^2 + \left(\frac{0.9633}{0.0314^2}\right)^2 \left(1.27 \cdot 10^{-5}\right)^2} = 0.0336 \quad (7)$$

The elastic modulus's uncertainty was found by calculating the standard deviation of the uncertainties of stress and strain. This value was determined to be 0.285 GPa and was determined by imputing points into a Monte Carlo Simulation.

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