Angle of Twist in Copper Rod

Strength of Materials Lab

ENGR 2145 - Lab 05

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OBJECTIVES

Determine the modulus of rigidity by measuring the angle of twist on a red brass copper rod created with a known applied torque. Compare evaluated modulus of rigidity to reported value.

EQUIPMENT

The following equipment was used to apply torque and collect data in order to calculate the shear modulus of the metal alloy.

- SUU Torsion Testing Apparatus
- Spanner Wrench
- Crescent Wrench
- Copper Rod
- Micrometer
- Ruler
- Weights (4.96 lbs, 7.52 lbs, 10.14 lbs)

The apparatus for this experiment is the SUU Torsion Testing Apparatus. This is shown below in Figure 1 and Figure 2.

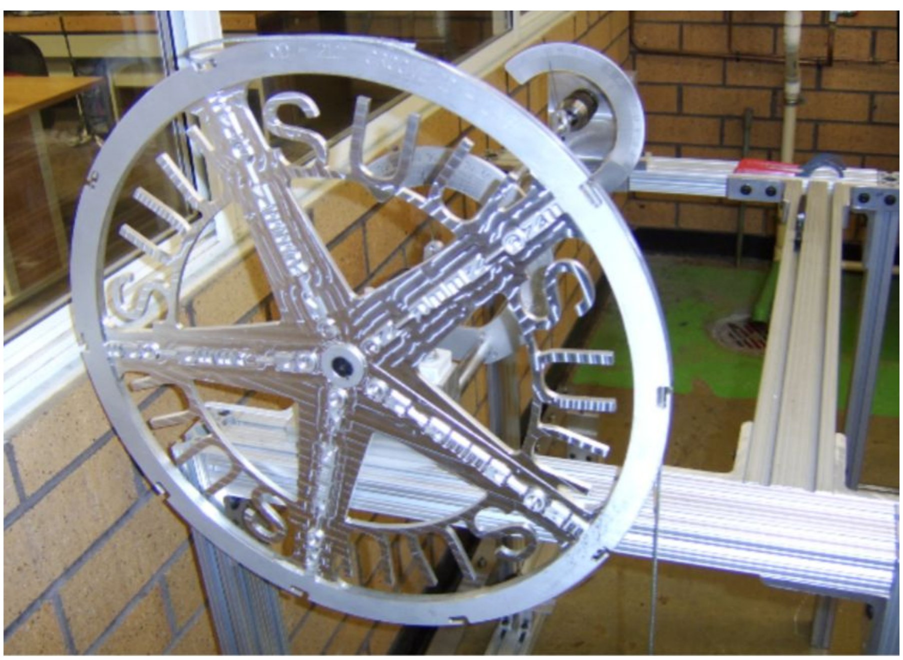

Figure 1. Torsion Testing Apparatus.

Figure 2. Chuck vise, pointer, and protractor scale.

PROCEDURE

The steps below were used to properly set up the apparatus and perform the test in order to collect the necessary data for the calculations.

1. Insert the rod into each chuck vise and tighten using spanner wrench.
2. Use crescent wrench to tighten set screw on fixed vise so jaws fit on the flats of rod.
3. Position each pointer so it is aligned with a reference angle on the protractor scale.
4. Measure the distance between the pointers with the ruler and record as length of rod.
5. Repeat twice and take the average measurement.
6. Measure the diameter of the rod with the micrometer.
7. Repeat twice measuring at different locations and take the average.
8. Measure length of lever arm with the ruler three times and take the average.
9. Apply torque to the rod by suspending weights from the cable attached to the pulley.
10. Load with 4.96 lbs and record the angle of twist at both ends of the rod.
11. Repeat with 7.52 lbs and 10.14 lbs and record angles for both.
12. Enter data collected into a spreadsheet.
13. Estimate maximum torque that can be applied using factor of safety of 1.5.
14. Evaluate maximum weight that can be applied to bar.
15. Calculate modulus of rigidity from measured values.

RESULTS

The key data values found in this experiment through calculation are shown in Table 1. The allowable shear stress was calculated using Eq. (4) and a given safety factor of 1.5. The polar moment of inertia (J) was calculated using Eq. (1) and the measured radius of the rod. The modulus of rigidity (G) was calculated using Eq. (2) as well as previous calculations for each amount of torque applied to the rod. The average of the three values is shown in Table 1. Maximum torque was found using Eq. (3), the allowable shear stress and the given factor of safety. Maximum force was calculated using Eq. (6).

Table 1. Measured Data

Allowable Shear Stress (□) (ksi)	Polar Moment of Inertia (J) (in^4)	Length (in)	Lever Arm (in)	Diameter (in)
7.33	0.00614	19.25	17.83	5.002

Using the measured lever arm length, the applied torque was calculated for each amount of total weight. The angles at each position on the rod for each torque were recorded and their difference is the measured angle of twist at the fixed distance between them. The angles were converted to radians and are shown in Table 2. The values in Table 2 of torque and angle of twist are plotted in Figure 3.

Table 2. Calculated Data

Weight (lb)	Torque (lb*in)	Angle of Twist (degrees)	Angle of Twist (radians)	Modulus of Rigidity (G) (ksi)
4.96	50.11584	1.5	0.02617993878	6,001.6
7.52	75.98208	2.5	0.0436332313	5,459.6
10.14	102.45456	3.5	0.06108652382	5,258.3
Average Modulus of Rigidity 5,569.4 ksi				

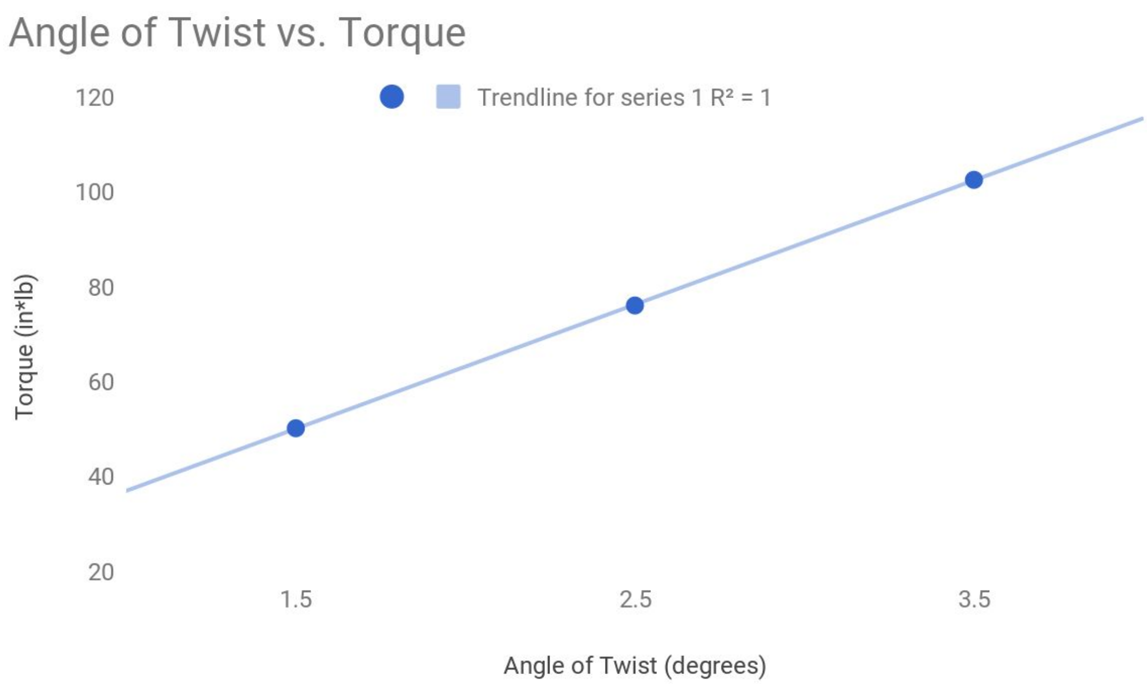

Figure 3. Graph of Angle of Twist and Torque

EQUATIONS

The following equations were used to calculate values pertaining to the experiment. Each equation is found or derived from equations in *Mechanics of Materials* [1].

$$J = \frac{\pi}{2} * c^4 \quad (1)$$

$$G = \frac{TL}{J\theta} \quad (2)$$

$$T(max) = \frac{J * \tau(allow)}{c} \quad (3)$$

$$\tau(allow) = \frac{\tau(yield)}{F.S.} \quad (4)$$

$$Percent\ Error = \frac{Experimental - Reference}{Reference} * 100 \quad (5)$$

$$F(max) = \frac{\tau(max)}{R} \quad (6)$$

DISCUSSION

In order to calculate the modulus of rigidity several values were calculated. Torque was calculated multiplying the applied load and the lever arm. Length of the rod was found by measuring the distance between the pointers. Diameter of the rod was measured with the micrometer. The angle of twist was found by subtracting the angle measured by the first pointer from the angle measured by the second pointer. These values can be applied to Eq. (2) to find the experimental modulus of rigidity. The modulus of rigidity was calculated from each trial and averaged to find the experimental value of 5,569.4 ksi. *Mechanics of Materials* reported modulus of rigidity for red brass copper alloy is 5,400 ksi [1]. The percent error calculated using Eq. (5) is 3.1% difference between the reported and experimental result of 5,569.4 ksi. It is interesting to see how different the modulus of rigidity appears to be in each trial. This error could have been due to several factors that are discussed in the error analysis.

The modulus of rigidity is relatively low compared to other metals such as A992 steel which has a modulus of 11,000 ksi as reported in *Mechanics of Materials* [1]. This means red brass copper is a ductile material compared to other metals. A red brass rod will have a larger angle of twist when compared to an identical steel rod with the same torque applied. Figure 3 shows the linear relationship between the torque on the rod and the angle of twist while the material remains in the elastic region to avoid permanent deformation. The graph has an R^2 value of 1 which means the data perfectly fit the linear trend line fitted to the data. By manipulating Eq. (2) and knowing the length, polar moment of inertia, and modulus of resilience are constants, shows that as the torque increases, the angle of twist will also increase. Using the calculated and measured values, we can estimate the max torque and max weight that can be applied to the rod using Eq. (3) and Eq. (6), respectively. The maximum torque is 180.17 in*lb and the maximum weight is 17.83 lb.

ERROR ANALYSIS

The experiment has many possible sources that caused the 3.1% error between the reported value and the experimental results. The pointer attached on the moveable chuck vise was not long enough to reach the protractor scale. A ruler was placed in alignment with the pointer and used to get the measurement. There was also difficulty in the measurement of the lever arm. This caused variation in the recorded angle of the pointer and the measured radius of the lever arm.

When the weights were removed from the apparatus, the copper rod failed to return to the original position. This could have been caused by permanent deformation of the rod, failure of the apparatus, or improper tightening of the chuck vise. However, since a comparatively small force of ten pounds was used, the rod should have stayed in its elastic region preventing it from going into the plastic yielding region and permanently deforming.

Specimen composition and fabrication could have also affected the data. The copper rod was possibly flawed during manufacturing. Uniform characteristics may not have been present throughout the entire rod. This causes different results each time a trial is performed. There are many possible reasons why the rod may not have been ideal for the experiment that was performed. These include the possibility of being dropped, not being perfectly homogenous, poor treatment in the factory, and non-uniform cross-sectional area.

CONCLUSION

The torsion testing apparatus provided the necessary data to calculate the requested values. The data was used to determine the shear modulus of the copper rod by applying torque and measuring the angle of twist. The maximum torque was estimated using a factor of safety of 1.5. The maximum weight that could be applied to the bar was evaluated and the shear strain angle was calculated from the angle of twist. Comparing the modulus of rigidity to the reported value gives a 3.1% error. This error has multiple sources discussed in the error analysis. In order to minimize this error, it is recommended to have the pointer be long enough to reach the protractor scale to give a more accurate measurement of the angle. Also, to make sure both chuck vises are properly tightened and aligned to avoid the rod not returning to the original position after the load is removed. This would provide more accurate data and may result in a lower percent error. This experiment was successful in applying torque to a copper rod and giving the necessary data to calculate and compare the mechanical properties involving torsion.

REFERENCES

[1] Hibbeler, R. C. (2017) Mechanics of Materials 10th ed. Upper Saddle River, NJ: Pearson Prentice Hall.