Lab Experiment # 3

# Torsion Testing of Metals

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**Objective**

The torsion testing of metal lab looked to see effects of applying torsion loads under different strain rate for both aluminum and steel specimens. Such lab will be conducted by using a torsion testing machine and an engineering stress strain curve will be obtained in order to describe the different mechanical properties of the specimens (shear modulus of elasticity, yield shear strength and ultimate shear strength).

**Equipment**

- 2 Aluminum (Alloy 2024-T351) Specimen
- 2 Steel 1020 (Hot Rolled Steel ASTM-A36) Specimen
- Permanent marker (to mark degree of twist)
- Instron Torsion Testing Machine
- Partner Software
- Caliber (for specimen measurements)
- Hexagonal Socket

**Procedure**

1. Take measurements of the 4 specimen's initial diameters, gage length to be used for calculations in the analysis
2. Draw a straight line across the long edge
3. Place your first specimen into the Torsion machine and tighten each end of the specimen with the hexagonal socket to fix it in place.
4. Input the proper measurement and material into the Partner software and pick an initial strain rate. Each material will go through a strain rate of 288 deg/min and 144 deg/min.
5. Once all the specimen has been tested, a engineering stress strain curve will be plotted from the measured torque at the increasing angle and measurements taken at the beginning of the experiment.

**Results**

The equation used for the calculations are as followed:

$$\tau = \frac{T\,r}{J}$$

Where $\tau$ is the shear stress, r is the initial radius of the specimen and J is the polar moment of inertia (dependent on the cross-sectional area of the specimen). For this lab, the cross section of the specimens used is circular and the J can be found using:

$$J = \frac{\pi r^4}{2}$$

Shear stress can be found using:

$$\gamma = \frac{r\,\theta}{L}$$

Where $\gamma$ is the shear stress, $\theta$ represents the radius and L is the gage length.
The modulus of rigidity (G) is then calculated from the two above mechanical properties using the equation:

$$G = \frac{\tau}{\gamma}$$

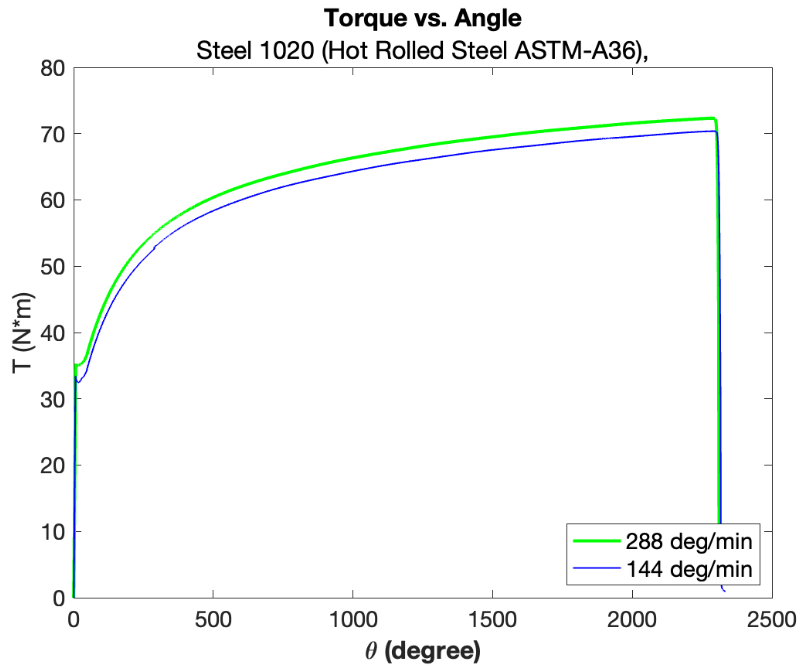


Figure 1: Torque vs Angle of Steel 1020 (Hot Rolled Steel ASTM-A36) at a high strain rate (288 deg/min) and a high strain rate (144 deg/min).

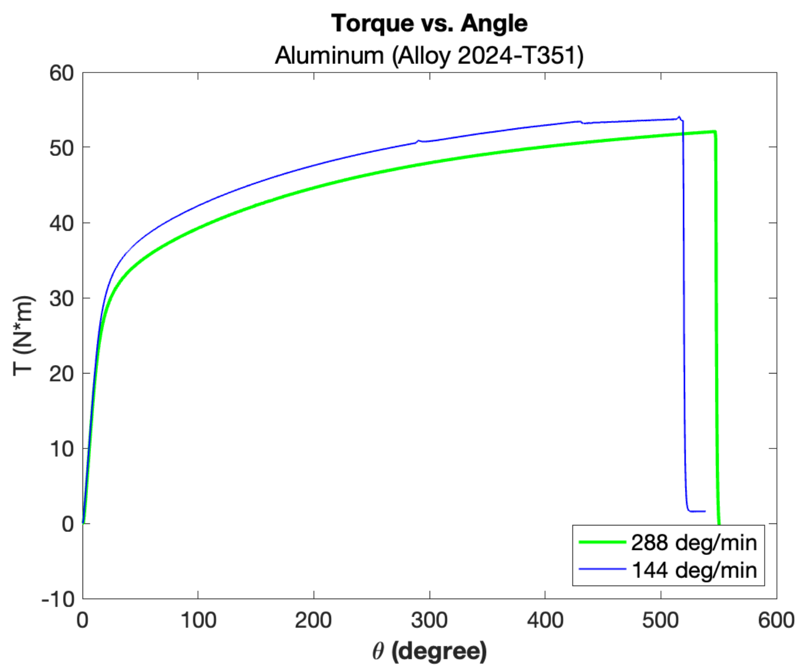


Figure 2: Torque vs Angle of Aluminum (Alloy 2024-T351) at a high strain rate (288 deg/min) and a high strain rate (144 deg/min).

| Specimen | Strain Rate (deg/min) | Energy (Area using trapezoidal rule approximation) (J) | Peak Torque (N*m) |
|---|---|---|---|
| Steel 1020 (Hot Rolled Steel ASTM-A36) | 288 | 2598.08 | 72.30 |
| Steel 1020 (Hot Rolled Steel ASTM-A36) | 144 | 2522.48 | 70.32 |
| Aluminum (Alloy 2024-T351) | 288 | 427.06 | 52.04 |
| Aluminum (Alloy 2024-T351) | 144 | 427.50 | 53.71 |

Table 1: Tabulated results of Aluminum (Alloy 2024-T351) and Steel 1020 (Hot Rolled Steel ASTM-A36 observed from torque vs twist angle graphs in figures 1-2.

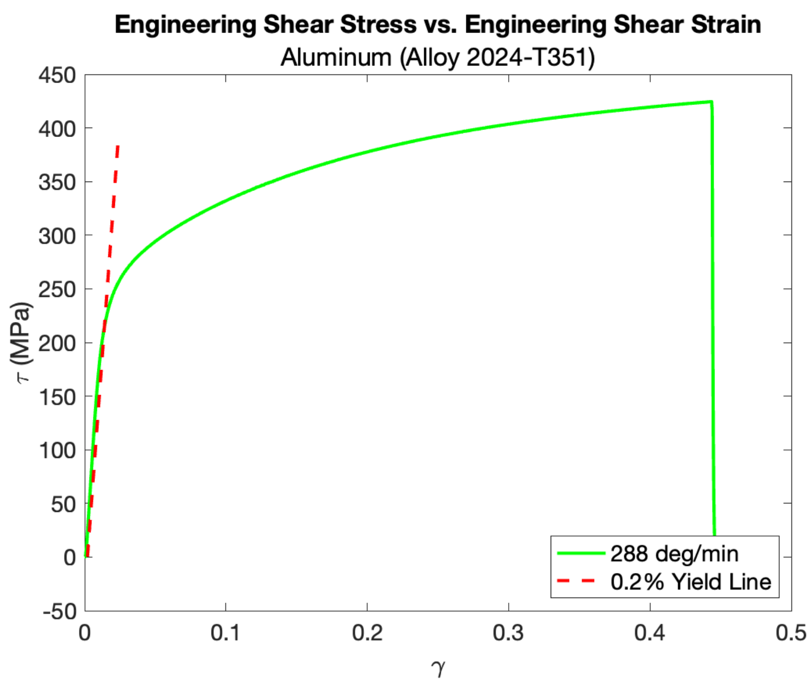


Figure 3: Engineering Shear Stress vs Engineering Shear Strain of Aluminum (Alloy 2024-T351) at strain rate of 288 deg/min

$$\tau_{max} = 423.037 \, MPa$$

$$\tau_y = 212.575 \, MPa$$

$$G = \frac{135.979 \, MPa}{0.00762}$$

$$G = 17.855\ GPa$$

$$G\ \%\ error\ = abs\left(\frac{28 - 17.855}{28}\right) * 100\%\ GPa$$

$$G\ \%\ error\ = 36.23\ \%$$

$$G = 28\ GPa$$

$$\tau_y\ \%\ error\ = abs\left(\frac{283 - 212.575}{283}\right) * 100\%\ MPa$$

$$\tau_y\ \%\ error = 24.89\ \%$$

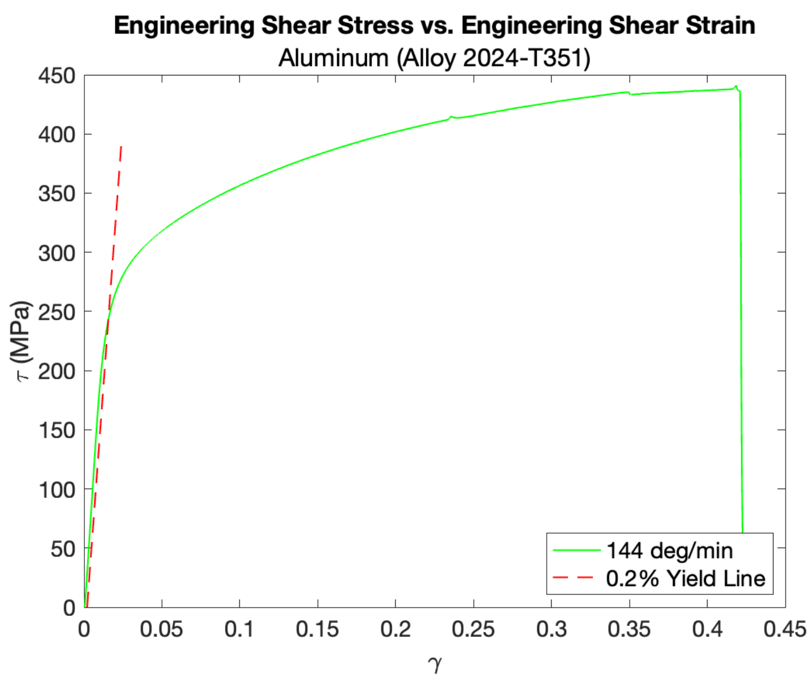


Figure 4: Engineering Shear Stress vs Engineering Shear Strain of Aluminum (Alloy 2024-T351) at strain rate of 144 deg/min

$$\tau_{max} = 438.504\ MPa$$

$$\tau_y = 240.522\ MPa$$

$$G = \frac{180.999\ MPa}{0.0098}$$

$$G = 18.520\ GPa$$

$$G\ \%\ error\ = abs\left(\frac{28 - 18.520}{28}\right) * 100\%\ GPa$$

$$G\ \%\ error\ = 33.857\%$$

$$\tau_y\ \%\ error\ = abs\left(\frac{283 - 240.522}{283}\right) * 100\%\ MPa$$

$$\tau_y \text{ \% } error = 15.01 \text{ \%}$$

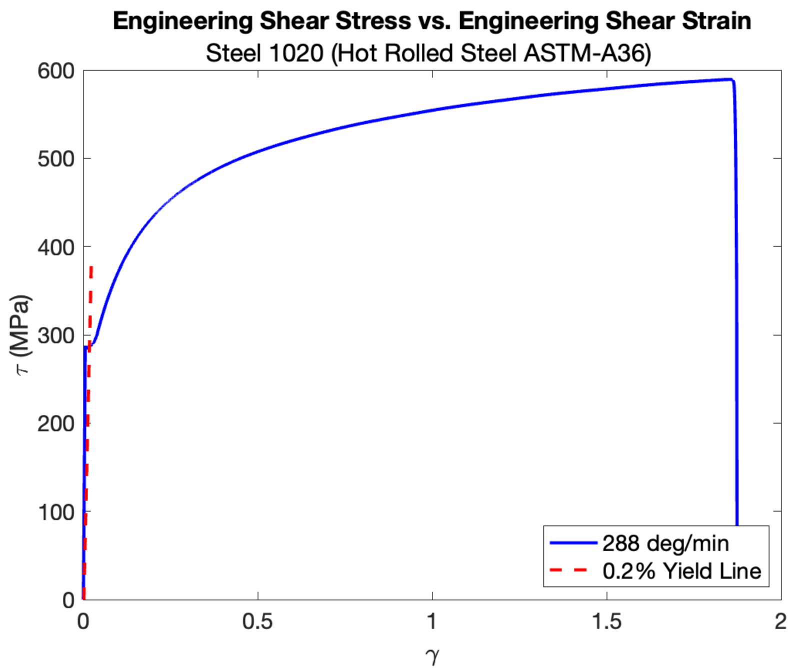


Figure 5: Engineering Shear Stress vs Engineering Shear Strain of Steel 1020 (Hot Rolled Steel ASTM-A36) at strain rate of 288 deg/min

$$\tau_{max} = 588.477\ MPa$$

$$\tau_y = 240.522\ MPa$$

$$G = \frac{191.402\ MPa}{0.004233}$$

$$G = 45.217\ GPa$$

$$G \text{ \% } error = abs\left(\frac{80 - 45.217}{80}\right) * 100\%\ GPa$$

$$G \text{ \% } error = 43.48 \text{ \%}$$

$$\tau_y \text{ \% } error = abs\left(\frac{350 - 240.522}{350}\right) * 100\%\ MPa$$

$$\tau_y \text{ \% } error = 31.28 \text{ \%}$$

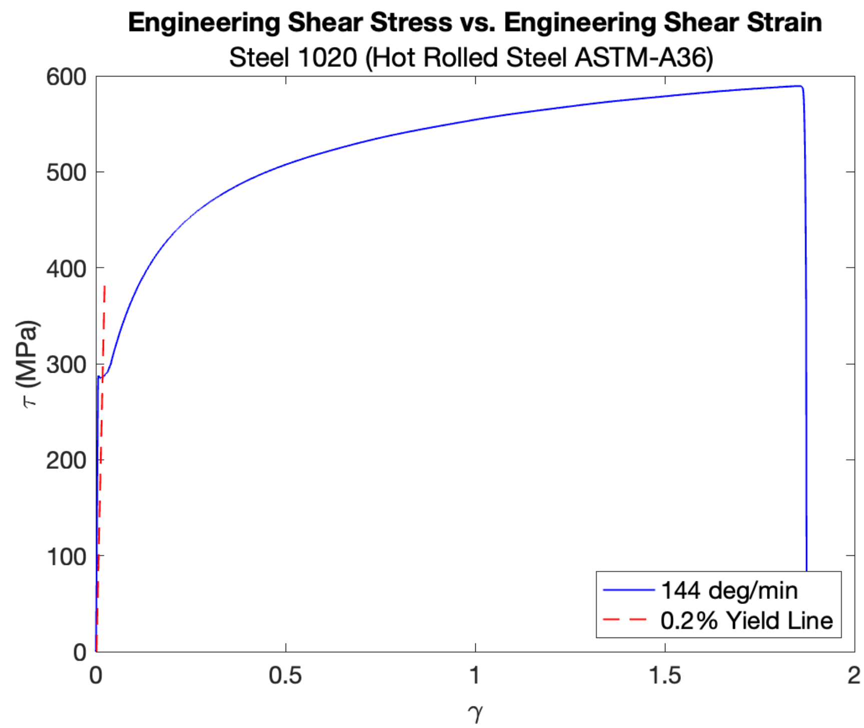


Figure 6: Engineering Shear Stress vs Engineering Shear Strain of Steel 1020 (Hot Rolled Steel ASTM-A36) at strain rate of 144 deg/min

$$\tau_{max} = 572.55\ MPa$$

$$\tau_y = 265.054\ MPa$$

$$G = \frac{161.481\ MPa}{0.03471}$$

$$G = 46.521\ GPa$$

$$\tau_y\ \%\ error\ = abs\left(\frac{350 - 265.054}{350}\right) * 100\%\ MPa$$

$$\tau_y\ \%\ error\ = 24.27\ \%$$

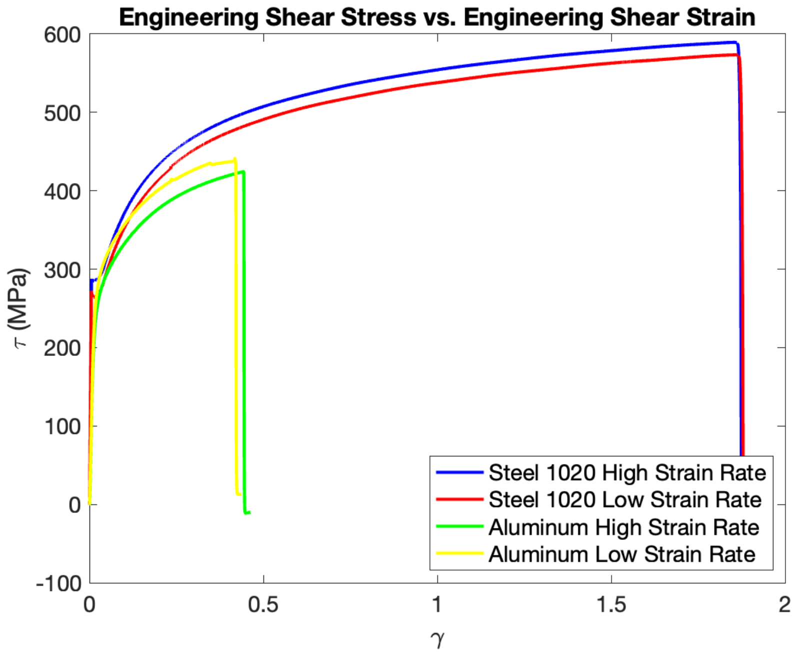


Figure 7: Engineering Shear Stress vs Engineering Shear Strain of Aluminum (Alloy 2024-T351) and Steel 1020 (Hot Rolled Steel ASTM-A36) at a high strain rate (288 deg/min) and low strain rate (144 deg/min).


Figure 8: Steel 1020 (Hot Rolled Steel ASTM-A36) and Aluminum (Alloy 2024-T351) specimen after failure.

## Discussions of Results

The mechanical properties to be determined through the torsion testing of metal includes the ultimate shear stress, yield shear stress and the modulus of rigidity. It can be seen that through the testing of the steel and aluminum specimens that the strain rate does not affect these mechanical properties as no clear pattern between strain rates to any of the mechanical properties. This is expected as mechanical properties should not change much for the same materials, with differences due to error in calculations and material processing.
The maximum shear stress of steel is observed to be 588.477 MPa and at a 288 deg/min strain rate and 572.55 MPa at a strain rate of 144 deg/min. For the aluminum specimen, the values of max shear stress are 438.504 MPa and 423.037 MPa in the same respective order. A lower critical shear stress shows more resistance of the material to torsional load, meaning the steel specimen would be experience less twisting under the same applied load.

The energy found from the torque vs angle of twist curve indicates the amount of load the specimen can handle before breakage. In the comparison of torsional load vs angle, the energy found for steel was 2598.08 J and 2522.48 J and for aluminum it was 427.06 J and 427.50 J, with a much higher energy, steel is more resistant to deformation under the same load. As seen in Figure 8, the line drew prior to adding torsion is seen to be much closer together than that of the aluminum specimen, indicating there was more torsional load prior to the specimens breaking.

**Review Questions**

**1. What are the differences between tensile testing and torsion testing?**

Torsion testing is a way to determine properties such as shear stress, shear strain and the shear modulus. Tensile tests apply a load that is normal to the cross section of your specimen.

**2. Could you observe any similar fracture surfaces as the ones in tensile testing?**

The Aluminum specimen can be seen to have a similar break to that in tensile testing.  Due to its higher ductility, it withstands more plastic deformation before breakage. At the area of breakage, the steel specimen has a more angled cut, consistent of a less ductile material. Similar to its tensile testing the aluminum experiences angled breakage and more necking.

**3. Why are the fracture surfaces in tensile and torsion testing different? Sketch fracture surfaces of failed specimens and described their natures**

The fracture surfaces are different due to the differences of the load effects on the specimen. A applied tensile load introduces necking, a decrease in the cross-sectional area at the sight of failure and a total elongation change. A torsional load will introduce an fracture that angles at a 45 degree for ductile materials.

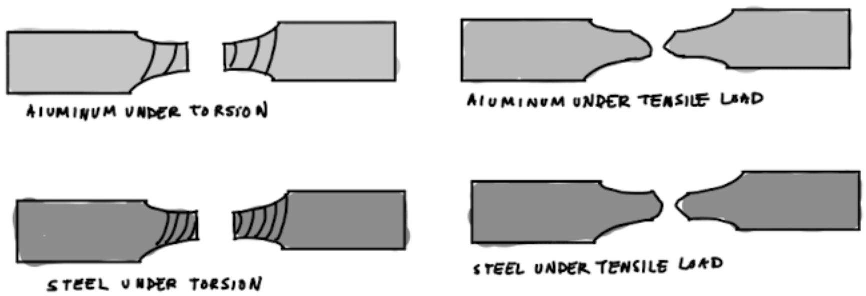


Figure 9: Drawing of Aluminum and Steel specimens under tensile and torsional loadings

As seen in figure 9, steel and aluminum both break in similar manners. However, under torsion, steel would take more twist to break, indicated by the marking in the region of breakage.

**4. What effect does the high strain rate have on the mechanical properties of metals at room temperature? How do you explain the reasons for those effects?**

The testing of the specimen under different strain rate is observed to not have a significant impact/correlation to their mechanical properties. Consistent with its definition, mechanical properties are not influenced by the applied load, including the rate at which it is applied. Mechanical properties are inherent to the material and differ due to imperfections and processing.

**5. Did the higher strain rate influence the mode of failure of any of the specimens? Why?**
The higher strain rate did seem to impact the failure of the steel specimen as the breakage is seen to be angled at a higher strain rate. This may be due to the material experiencing more brittle like behaviors at a higher strain rate. It can be seen in figures 7 that the total area is slightly greater in the higher strain rate, therefore increasing its overall toughness.

**6. Plot shear stress and shear strain relation of all conducted experiments in the same figure. Determine maximum shear stress, shear stress at proportional limit and modulus of rigidity, show your calculations explicitly. Discuss and conclude the obtained experimental results.**

As seen in figures 3-7, the aluminum displays a much smaller toughness, the overall energy that will be experiences by the material before failure. At a higher modulus of rigidity, steel can withstand deformation better than aluminum. With a higher shear stress and shear strain, steel is both stronger and more ductile than aluminum. (Conclusion drawn from the results seen in Discussions of results sections).

**7. In which engineering applications do you think that torsion test is important? Give five examples.**

Torsional testing is important for any application in which a material will be under high shear stress. Such applications include in the use of turbines and generators in which they must be able to withstand a large amount of shear force in its operations. In the field of robotics, torsional testing may be necessary in order to test maximum shear stress loads as the principal driver of robotic movements hinges on rotational movements. In the biomedical field, the need for more flexibility in terms of shear strain give include that of hip implants. In manufacturing, the need to test parts that will be used in high shear stress applications such as producing drill bits and circular saws are important to understand proper material choice and application of the product.

## Conclusion

This lab looked at the effects of different strain rates and material on the mechanical properties of specimens under torsional testing. Engineering Shear Stress and Engineering Shear Strain is plotted to determine maximum yield shear stress and the ultimate shear stress through direct observations of the curve. The value of the modulus of rigidity is determined from the elastic region of this curve. Values calculated within the lab is compared with its tabulated data to measure accuracy of the testing in the lab and the potential changes due to error. Strain rate is determined to have no significant correlations from the two materials used.

## References

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