Experiment #2

Torsion Test of

Metallic Materials

MECH-237-007

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Abstract

It is important to understand the mechanical properties of materials for engineers to construct safe projects that will withstand the test of time. So, the main objective of this lab is to determine the shear modulus of rigidity and Poisson's Ratio for hot rolled steel using torsional stress-strain relationships. In order to complete the experiment, an Instron machine, a piece of hot-rolled aluminum steel A36 with a length of 2 inches and a diameter of 0.5 inches, and a computer set-up were used. The Instron machine has a still tighten grip on one side that would hold the piece of steel and a counter-clockwise rotating portion on another side that would allow the piece of hot rolled steel to be under shear stress. After conducting the experiment, 3 graphs are created: Torque vs Rotation, and Shear Stress vs Shear Strain for the entire loading and the elastic region only. In the experiment, it was shown that the shear modulus of rigidity is 80 GPa and Poisson's Ratio is 0.25 for hot rolled steel. The percent error, compared to reference values, were 0.88% and 4%, respectively. This is an allowable margin of error and still give values around the same ballpark, which is why this experiment would be considered a success.

Introduction

The objective of this experiment is to study the linearly elastic behavior of hot rolled steel A36 under torsion. In doing so, the torsional stress-strain relationships will be used to determine the shear modulus of rigidity (*G*) and Poisson's Ratio (*v*). Afterward, the qualitative relationship between the torsional load and angle of twist will be determined for this metallic material under a full range of strain until failure. Finally, this metallic material, hot rolled steel A36, will be assessed to determine whether it fails in tension, compression, or shear when it is subjected to pure shear.

In order to develop safe engineering designs for all different kinds of products, engineers must understand the behavior of mechanical properties for different materials. In order to do this, one of the many important concepts that should be understood is torsion and angle of twist. When metals are ductile, as is hot rolled steel, and they are exposed to torsion, it produces a shear stress-shear strain curve. Torsion (τ) occurs when a metal bar or metal rod undergoes a twisting that is caused by an external force called torque (*T*). The resulting stress is known as shear stress (τ) and can be found using the formula: $\tau = \frac{Tr}{J}$. Here, τ is the torsional shear stress at a point on the surface of a cylinder, *T* is the twisting moment or torque, and *J* is the polar moment of inertia of the cross-section about its center. For the experiment, the rod was a cylinder, so the polar moment of inertia is expressed as $J = \frac{\pi r^2}{2} = \frac{\pi d^4}{32}$where *r* is the radius and *d* is the diameter of the cylinder. The total angle of twist in radians (φ) can be found by dividing the product of the torque acting on the rod (*T*) and the length of the rod (*L*) by the product of the shear modulus of rigidity (*G*) and the polar moment of inertia (*J*): $\varphi = \frac{TL}{JG}$. Since the hot rolled steel is linearly elastic, then according to Hooke's Law, we can say that the shear stress can be represented by $\tau = G\gamma$ where γ is a total shear strain.

Poisson's Ratio (v) is the ratio of the decrease in a material's lateral measurement to its proportional increase in length. It can be determined in a tension test by measuring the lateral contraction, but it would be more practical to calculate it by using the tensile and shearing moduli of elasticity. Poisson's ratio can be used to express the normal strain on a material (ε): $\varepsilon = \frac{\tau}{E}(1 + v)$ where *E* is the modulus of elasticity. Furthermore, if it is assumed that the diagonal shortening and elongation is 45° and 135°, respectively, then we can say that $\gamma = 2\varepsilon$. Finally, it can be concluded that $\varepsilon = \frac{G\gamma}{E}(1 + v)$ and therefore, $G = \frac{E}{2(1+v)}$.

Procedure

Data Acquisition:

1. First measure initial diameter of the hot rolled steel A36.
2. Calibrate the machine. Place the rod into the test apparatus.
3. Tighten the chuck and all corresponding hardware to keep test apparatus in place.
4. Start the Bluehill software to collect the data of the test.
5. Begin the test by initiating the test.
6. Once the rod fails, record the angle of twist and save the data from the test as an excel file.
7. Create 3 graphs of data:
    a. Torque vs Rotation
    b. Stress vs Strain for the entire loading
    c. Stress vs Strain for the elastic region
8. From the Proportional limit graph find:
    a. Modulus of Rigidity

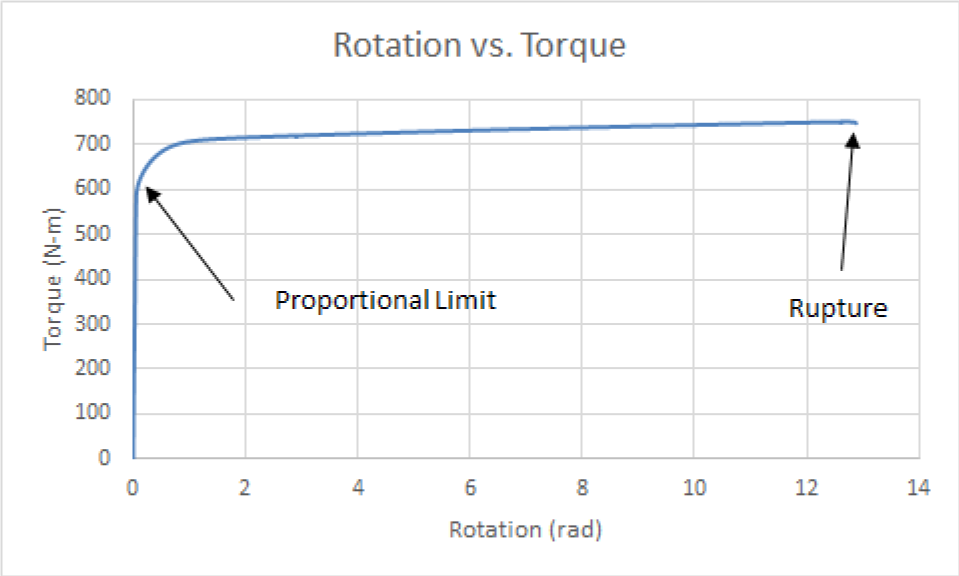
Laboratory Equipment: (See Appendix for visual representation of Equipment)

1. Instron Torsion Testing Machine
2. Hot Rolled Steel A36 Rod

Safety Precautions:

1. Eye Hazard: Safety glasses required since sharp pieces may fly off of the material undergoing fracture
2. Sharp Edges: Handle fractures specimens with caution to avoid any cuts since the specimen may have sharp edges
3. Burn Hazard: Failed specimen may be hot

Data


Rotation vs. Torque
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700
600
500
400
300
200
100
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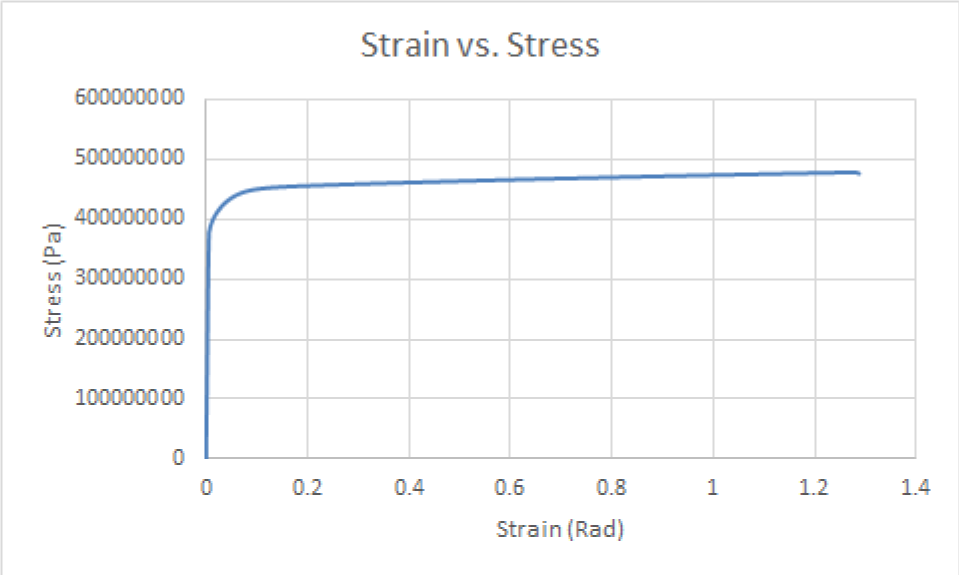
Torque (N-m)
0
2
4
6
8
10
12
14
Rotation (rad)
Proportional Limit
Rupture


Strain vs. Stress
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500000000
400000000
300000000
200000000
100000000
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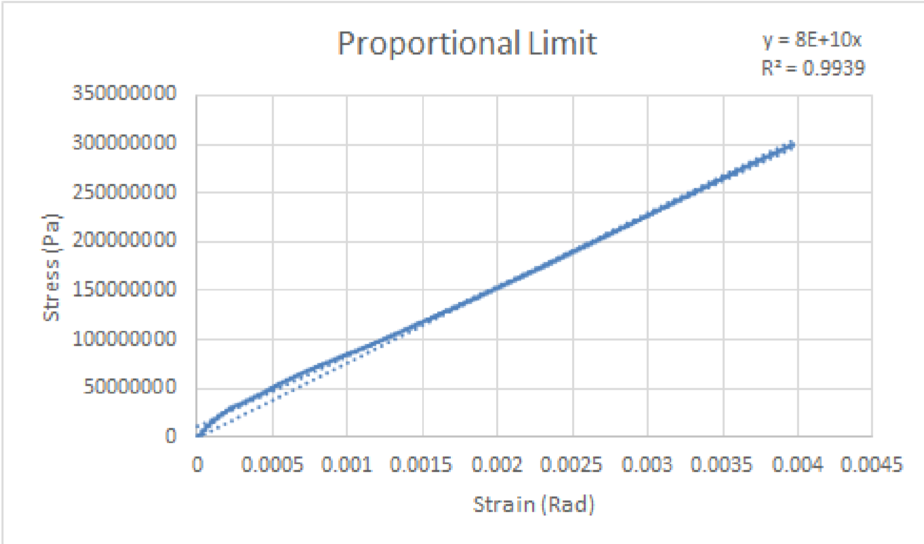
0.2
0.4
0.6
0.8
1
1.2
1.4
Strain (Rad)



	Modulus of Rigidity	Poisson's Ratio	Torque
Experimental	80 GPa	.25	495 N*m
Reference	79.3 GPa	.26	471.2 N*m
Percent Error	.88%	4.0%	5.0%

Analysis

From this lab we learned how to calculate various helpful data from a basic torsional test. The specimen we tested was A36 Hot Rolled Steel. The main objectives of this lab were to familiarize the students with the process of this test, observe the reaction the specimen provides under the torsional stress and lastly to use the information from this lab to validate the modulus of elasticity and Poisson's ratio equations. The main problem which lead to a 4% error in our lab was the inability to exactly pick the point where the graph shift from an elastic region to a plastic region. Which means we had a very close approximation of the strain. This combined with stress in the equation $G = \frac{E}{2(1+v)}$we got a value of 0.25. Comparing our calculated value towards the reference value of .26 we were not far off but only 96% accurate. Now moving to the modulus of rigidity equation we were much closer to the reference value. The calculated value of rigidity was 80 GPa and the reference value was 79.3GPa. Therefore giving us a percent error of 0.88%.

Moving back to the other objectives we can visually see how the specimen reacts when applied a torsional load. To visually aid the demonstration a black line was drawn. Which by the end of the experiment turned into a swirl indicating the amount of turns the specimen had endured. We also saw that the rupture was internal and was not visually observed until the material broke. This shows us how there is no proper way to visualize the rupture of a torsional load because it starts failing on the inside. To avoid this issue we tend to stay in the elastic range of the specimen which went from 0 GPa to just above 40 GPa.

Sample Calculations

Percent Error for Modulus of Rigidity: ((80-79.3)/79.3)*100% = .88%

Poisson's Ratio: 200 GPa - 2(80GPa)/(2*80 GPa) = .25

Percent Error for Poisson’s Ratio: ((.26-.25)/.26)*100% = 4%

Polar Moment of Inertia: Π/32(.02^4) = 1.571*10^-8 m^4

Degree to Radians: 787°*(Π/180°) = 13.7356 rad

Theoretical Torque: (79.3 GPa)*(1.571*10^-8 m^4)*.03974rad/0.1m = 495 N*m

Percent Error for Torque: ((495-471.2)/471.2)*100% = 5.0%

- The experimental value of modulus of rigidity was calculated from the slope of proportional limit graph

Discussion and Conclusion

Discussion:

In Experiment 2, a torsion force was applied to hot rolled steel A36 in order to study the behavior of a metallic material under torsion. To emphasize and visualize the angle of twist on the hot rolled steel, a horizontal line was drawn from end to end on the steel bar. Using the Bluehill software, data of the amount of torque applied and the amount of rotation was recorded until the material failed. The steel bar rotated a total of 12.88 radians, or 737.86 degrees before rupture. From the results, the graphs of torque vs rotation, stress vs strain for the entire duration, and stress vs strain for the elastic region. One of the main objectives of this laboratory experiment was to determine the modulus of rigidity, G. This value was found from the stress vs strain for the elastic region graph labeled "Proportional Limit", and the value determined from the graph is 80 GPa. The proportional limit is the point where plastic deformation occurs and a modulus of rigidity of 80 GPa is very high. When compared to the reference value of 79.3 Gpa, a percent error of 0.88% was found. Overall, this percent error is exceptional and the very little error that exists could be due to machine error.

An additional objective of the laboratory experiment was to determine Poisson's Ratio, given by the formula $G = \frac{E}{2(1+v)}$, where G is the modulus of rigidity, E is the modulus of elasticity and v is poisson's ratio. The calculated value for Poisson's Ratio is 0.25 and the reference value is 0.26. This yields a percent error 4.0% which is not as good as the percent error given by the modulus of rigidity, but it is still acceptable. Similarly, the error obtained for Poisson's ratio could have been due to machine error and possibly the accuracy error in the software. In the end, both the modulus of rigidity and Poisson's ratio has errors that were acceptable.

Conclusion:

The objectives of Experiment 2 were to determine the modulus of rigidity and Poisson's ratio for Hot Rolled Steel A36. From the data received for this experiment, we were able to calculate both the modulus of rigidity and Poisson's ratio. The low percent errors helped confirm the results and meet the objectives of the experiment. The systematic procedure helped make sure that we would not make any mistakes through the experiment and because of the robust procedure, this experiment can be confidently repeated again for this material, most likely yielding similar results. Additionally, this experiment could certainly be used for different materials and would most likely give accurate results when compared to the respective reference values. Overall, the objectives of this laboratory experiment were validated by the accurate results and low percent error.

Bibliography

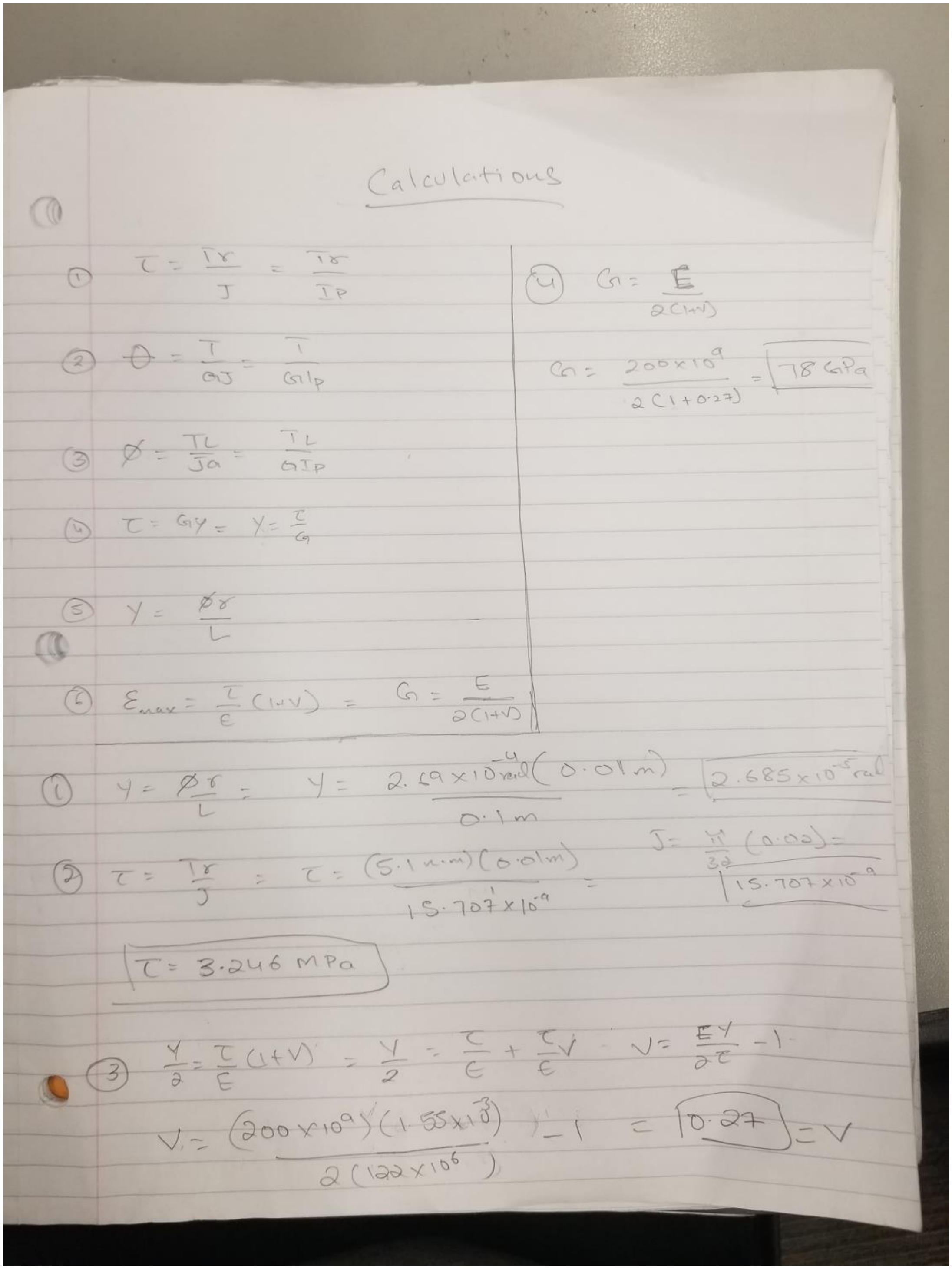
ASTM A36 Steel, bar. (n.d.). Retrieved October 20, 2019, from http://www.matweb.com/search/datasheet_print.aspx?matguid=d1844977c5c8440cb9a3a967f8909c3a.

Beer, F. P., Johnston, E. R., DeWolf, J. T., & Mazurek, D. F. (2020). *Mechanics of materials* (Eighth). New York, NY: McGraw-Hill Education.

Ciesla, M. (2017). *Strength of Materials Laboratory Manual*. (C.-T. Thomas, A. C. Luke, G. Milano, & L. Martin, Eds.) (First). Newark, NJ: NJIT Press.

Appendix

Calculations:



Calculations

① $\tau = \frac{Tr}{J} = \frac{Tr}{I_P}$

② $\theta = \frac{T}{GJ} = \frac{T}{GI_p}$

③ $\phi = \frac{TL}{JG} = \frac{TL}{GI_P}$

④ $\tau = G\gamma = \gamma = \frac{\tau}{G}$

⑤ $\gamma = \frac{\phi r}{L}$

⑥ $\varepsilon_{max} = \frac{\tau}{E}(1+\nu) = G = \frac{E}{2(1+\nu)}$

④ $G = \frac{E}{2(1+\nu)}$

$G = \frac{200\times10^{9}}{2(1+0.27)} = 78\ GPa$

① $\gamma = \frac{\phi r}{L} = \gamma = \frac{2.69\times10^{-4}rad(0.01m)}{0.1m} = 2.685\times10^{-5}rad$

② $\tau = \frac{Tr}{J} = \tau = \frac{(5.1\ N\cdot m)(0.01m)}{15.707\times10^{-9}} =$ $J = \frac{\pi}{32}(0.02) = 15.707\times10^{-9}$

$\tau = 3.246\ MPa$

③ $\frac{\gamma}{2} = \frac{\tau}{E}(1+\nu) = \frac{\gamma}{2} = \frac{\tau}{E} + \frac{\tau}{E}\nu \quad \nu = \frac{E\gamma}{2\tau} - 1$

$\nu = \frac{(200\times10^{9})(1.55\times10^{-3})}{2(122\times10^{6})} - 1 = 0.27 = \nu$

Performing the Experiment:

Machine Used: Instron TorsionTesting Machine

Steel A36 Hot Rolled Fracture: