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Torsion of Shafts

Mechanics and Dynamics (ACHA4026)

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1. Introduction

This report will cover the experimental procedures of the 'Torsion of Circular sections Kit ES5', a kit designed to show how shafts of different materials are affected by torsion.

This report will also display and analyse the results measured from this experiment using spreadsheets and graphs, as well as aim to validate the data collected for shear modulus and compare the values with other further researched data. Shear modulus is important for engineers to consider in different applications to design a product or structure that can withstand torsional forces without failing. It is defined as a measure of material stiffness, represented as a ratio of shear stress to shear strain when the material is deformed by a force parallel to its surface (Science Direct, 2016).

2. Experimental Procedure

Before the experiment can be conducted, the apparatus must be set up as it is seen in figure 1. The main body of the apparatus, or Work Panel is supported upright by two legs, which the rest of the parts will be mounted to. On the right side of the work panel, there is a fixed chuck, designed to hold the specimen rod of each desired material in place. On the left side, an assembly including a torque arm and a rotating chuck is attached. Both chucks have two grub screws, which should be loosened so that the specimen rod is able to be slid in, and then tightened using an allen key to hold it in place. The fixed chuck should be tightened first, followed by the rotating chuck. It is important that the scale on the torque arm is carefully moved to and held at 0 when the grub screws on the rotating chuck are tightened to get accurate results. There are two thumb screws on the rear of this scale, for any minor adjustments that need to be made to adjust the transparent cursor as close to 0 as possible.



Figure 1 - complete apparatus



Figure 2 - Rotating chuck with torque arm, and cursor

Once this setup is complete, the data can start being recorded. A hanger with weights is added to the cord seen in figure 2, in increments of 100g up to 500g. Each time extra weight is added, the twist angle can be recorded off of the gauge on the torque arm, until 500g is added. The weight is then removed, and the metal shaft is removed and replaced with a different material shaft, repeating the experiment 3 times, for brass, aluminium, and steel.

It is also important to use a calliper to measure the diameter of each metal shaft, in the middle of each shaft for an accurate result. It is also important to note that the aluminium shaft should only be tested up to 400g rather than 500g, as the shaft may snap if it is twisted too far from the extra mass.



Figure 3 - Hanger with 500g of mass

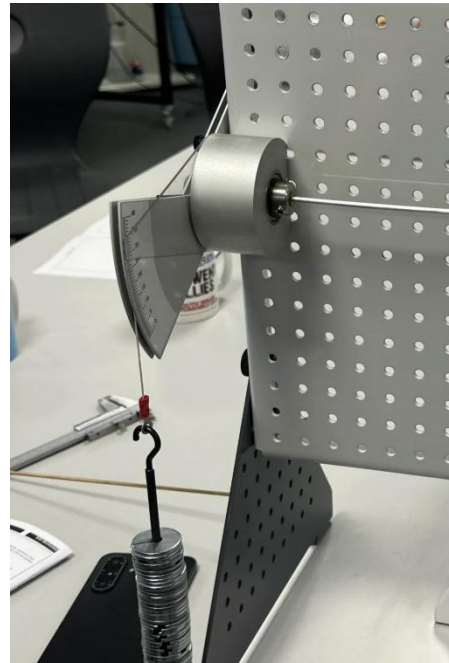


Figure 4 - Hanger attached to Torque arm

3. Results

Below is the data collected from the lab on completion of this experiment, and calculations that can be completed using this data.

Load (g)	Load (N)	Torque (Nm)	Twist Angle (Degrees)	Twist Angle (Radians)	TL	J θ	J θ (x10 ⁻¹²)
100	0.98	0.098	6.25	0.11	0.033	9.89018E-13	0.989
200	1.96	0.196	12.25	0.21	0.067	1.93847E-12	1.938
300	2.94	0.294	18.25	0.32	0.100	2.88793E-12	2.888
400	3.92	0.392	24.5	0.43	0.133	3.87695E-12	3.877
500	4.91	0.491	30	0.52	0.167	4.74728E-12	4.747
D = 0.0031							
L = 0.34							
J = 9.06665E-12							
Material: Brass							

Figure 5 - Brass shaft

Load (g)	Load (N)	Torque (Nm)	Twist Angle (Degrees)	Twist Angle (Radians)	TL	J θ	J θ (x10 ⁻¹²)
100	0.98	0.098	10.5	0.18	0.033	1.66155E-12	1.661
200	1.96	0.196	16	0.28	0.067	2.53189E-12	2.531
300	2.94	0.294	23.5	0.41	0.100	3.71871E-12	3.719
400	3.92	0.392	31.5	0.55	0.133	4.98465E-12	4.985
D = 0.0031							
L = 0.34							
J = 9.07E-12							
Material: Aluminium							

Figure 6 - Aluminium shaft

Load (g)	Load (N)	Torque (Nm)	Twist Angle (Degrees)	Twist Angle (Radians)	TL	J θ	J θ (x10 ⁻¹²)
100	0.98	0.098	2.5	0.04	0.033	3.95607E-13	0.395
200	1.96	0.196	5	0.09	0.067	7.91214E-13	0.791
300	2.94	0.294	7.5	0.13	0.100	1.18682E-12	1.187
400	3.92	0.392	10	0.17	0.133	1.58243E-12	1.582
500	4.91	0.491	12.5	0.22	0.167	1.97804E-12	1.978
D = 0.0031							
L = 0.34							
J = 9.07E-12							
Material: Steel							

Figure 7 - Steel shaft

Key:

Load (g): The load applied the shaft, by putting a mass on the torque arm, as seen in figures 3 and 4 - measured in grams.

Load (N): The load applied to the shaft, measured in newtons. This figure is achieved by multiplying the mass by the figure given to gravity on earth, which is 9.81 (Nasa, 2023)

Torque (Nm): in this case, the torque is measured by multiplying the load (N) by the length of the torque arm in meters (0.1)

Twist Angle (Degrees): This is the figure that you measure by reading off of the torque gauge when mass is applied to the torque arm, it is the amount the shaft has twisted from its starting position.

Twist Angle (Radians): to convert from degrees to radians, you have to multiply the figure by $2\pi / 360$.

Polar Second Moment of Area (J): This is the dimensional property of the shaft, calculated with the equation $J = \frac{\pi D^4}{32}$.

L = length of shaft (m)

D = diameter of shaft (m)

4. Analysis

Using the data collected in the lab, we can create graphs that show us the recorded Shear Modulus of each different material by plotting $J\theta$ on the X axis against TL on the Y axis. [In this instance, $J\theta$ is the value for J multiplied by the twist angle in radians, and TL is the product of Torque and the length of the shaft.] The gradient of the graph should represent the shear modulus for each material respectively.

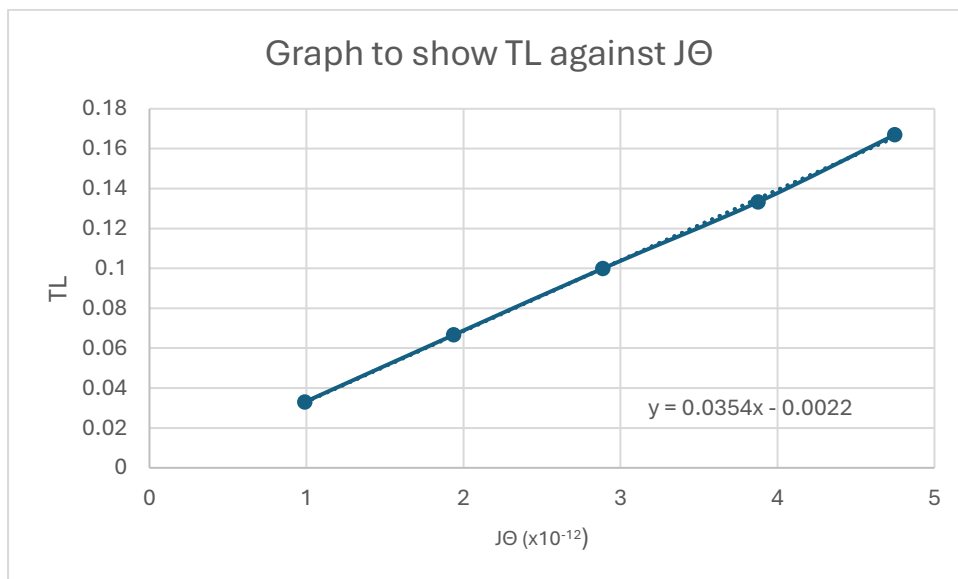


Figure 8 - Graph to show shear modulus of Brass

As seen in figure 8, the value for Sheer modulus or 'G' is 0.0354, or 35.4 GPa (Giga Pascals). The graph follows a linear trendline, indicating a proportional relationship between the Polar Second moment of Area, and TL. This also shows a good level of consistency within the experiment for the Brass shaft.

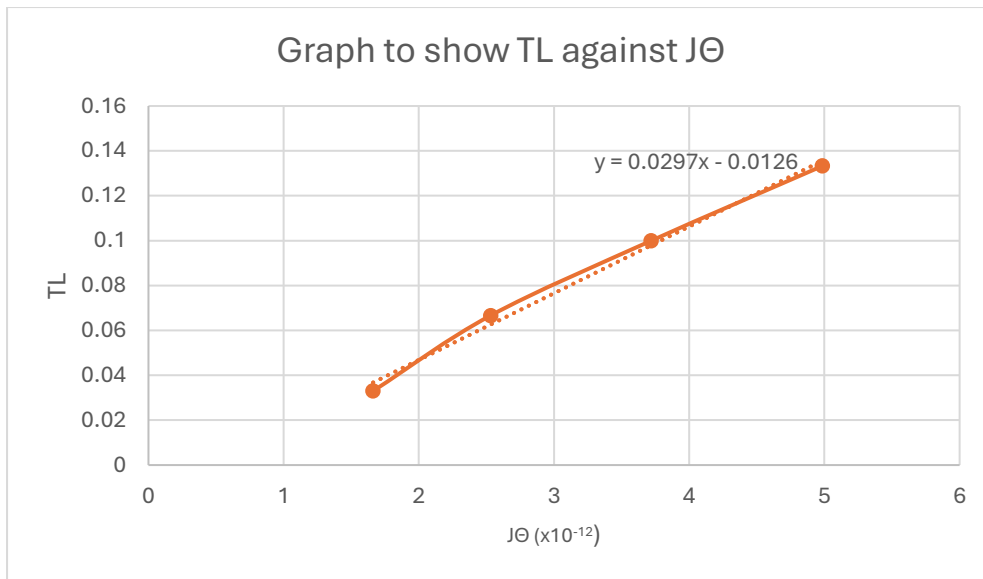


Figure 9 - Graph to show shear modulus of Aluminium

In figure 9, the graph has slightly more varied results than the graph for the brass shaft, with a noticeable curve in the graph. It is also worth noting that since the Aluminium rod should only be measured to 400g of mass instead of 500g, there is one less data point on the graph. Having less points to create a gradient with potentially reduces the accuracy of the gradient. The recorded value for G for Aluminium is 29.7 GPa.

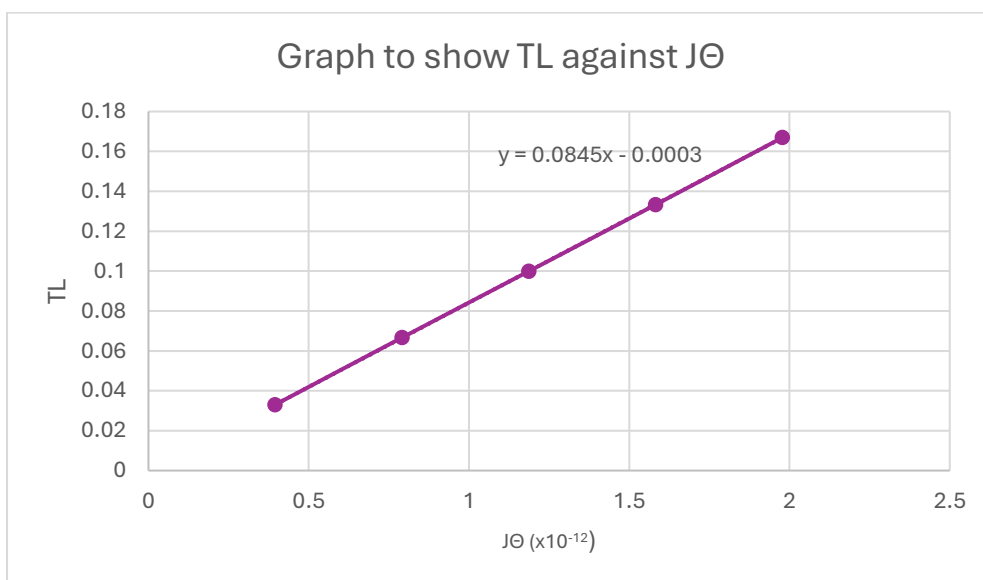


Figure 10 – Graph to show shear modulus of Steel

Figure 10 shows the shear modulus of steel to be 84.5 GPa. The trendline of this graph is significantly more consistent than the results recorded for the Aluminium shaft, indicating that the recorded data was consistent.

5. Conclusion

According to the data recorded, the shear modulus for each shaft is as follows:

Material	Value (GPa)
Brass	35.4
Aluminium	29.7
Steel	84.5

Figure 11 – Table to show recorded values for ‘G’ or Shear modulus

Each material has a tolerance which the shear modulus should fall in, and therefore slight variations may appear when completing this experiment, even if a different rod of the same dimensions and material is being used. This is especially true if the grade of the metal is a different grade or quality.

According to Ezlok (2019) brass has a shear modulus value of 37 GPa. This is a 2.4 GPa difference from the data recorded in the lab. While this is close, 35.4 GPa is potentially on the lower end of what would be expected. Similarly, according to AZO materials (2019) brass should have a shear modulus of between 33 and 46. This aligns with the lab results recorded for shear modulus, but confirms that it is towards the lower end of what is expected from the material.

Aluminium has a shear modulus of 29.7 GPa, according to the data recorded in the laboratory. However, according to MatWeb (n.d.) Aluminium has a shear modulus of 25 GPa. This is a much more significant variation than Brass, especially at a lower value of shear modulus. Looking at the graph in figure 9, one or two of the points deviate from the gradient, indicating that the test conducted on aluminium was less accurate, potentially due to incorrect readings, or a problem with the apparatus.

The steel shaft has the highest shear modulus value, at 84.5 GPa according to the lab data. The research completed by Eurocode Applied (2017) shows the shear modulus of structural steel to be around 81 GPa.

The provided worksheet (TecQuipment, 2012) also presents some expected values for these shafts, as seen below in figure 12. According to the experimental procedure, these figures should fall within 10% of the recorded data in the lab. Brass and steel were well within this threshold, aluminium however was 5.2% over. This builds on the earlier statement that the recordings were likely erroneous, and could benefit from being re-tested.

Material	Value (GPa)	% Difference
Brass	38	7.1
Aluminium	25.5	15.2
Steel	79.6	6

Figure 12 – Table to show expected values for ‘G’ or Shear modulus, and percentage differences from recorded data.

To summarise, this experiment demonstrates a fairly accurate way of measuring the shear modulus of a shaft by recording its twist angle under a load. The recorded data is within a few GPa or GNm^{-2} of the values reported by other companies in the industry, and none of the materials were significantly different to what they were expected to be. That said, relative to the expected values Aluminium did not perform quite as expected, and should be re-tested. It is also important to note that it is not stated in the provided booklet what grade of each metal was provided during the experiment, which could potentially affect the values of each metal for shear modulus.

6. Evaluation

There were many precautions taken to ensure the results of this experiment were as accurate as possible, and to reduce erroneous results. One way this can be achieved is to make sure that the apparatus is zeroed properly after changing the shaft. It is important that it starts on zero for a more accurate reading and data set. It is also important that when the hanger is attached to the apparatus, the beam is secured tightly and does not slip, giving false readings. Furthermore, it is important that the hanger is attached gently. Dropping it onto the hook on the torque arm could cause the shaft to slip.

7. Further work

Given unlimited time and money, there are some significant ways that this experiment could be improved. One of which would be repeat the experiment multiple times, not only as it is, but with different lengths, and thicknesses, to see if the same results are achieved each time. Another way to increase the accuracy would be to use a digital angle gauge instead of an analogue torque gauge as this will give a more accurate result than measuring by eye. It would also be important to complete the experiment in a controlled environment, as different materials, especially metals can be affected by factors such as temperature.

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