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Torsion of Shafts

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Abbreviations

G- Modulus of Rigidity

L- Length

D- Diameter

J- Polar second Moment of Area

T- Torque

m- Mass

W- Load

θ - Twist Angle

Chapter 1 – Introduction

This paper presents a report of the findings of an experiment carried out for 'Torsion of Circular Sections; Experiment Procedure 2- Shaft Modulus' using the 'Torsion of Circular Shafts' kit in the Engineering Science Lab. The experiment was set out to investigate the effect of differing material specimens on torsion. Following this practical experiment the results were used to calculate the Modulus of Rigidity (G). The materials tested were brass, aluminium and steel, all three were controlled for in terms of consistency across the diameter and length.

Chapter 2 – Experimental Procedure

Fitting the specimen

The dimensions of the first specimen (Brass) were noted, the length (L) measured using a ruler and the diameter (D) of the shaft was measured using Dial Gauge Callipers. The grubscrews on the fixed and rotating chucks were loosened with an Allen Key. The specimen was then inserted fully into the rig, and the fixed chuck was tightened.

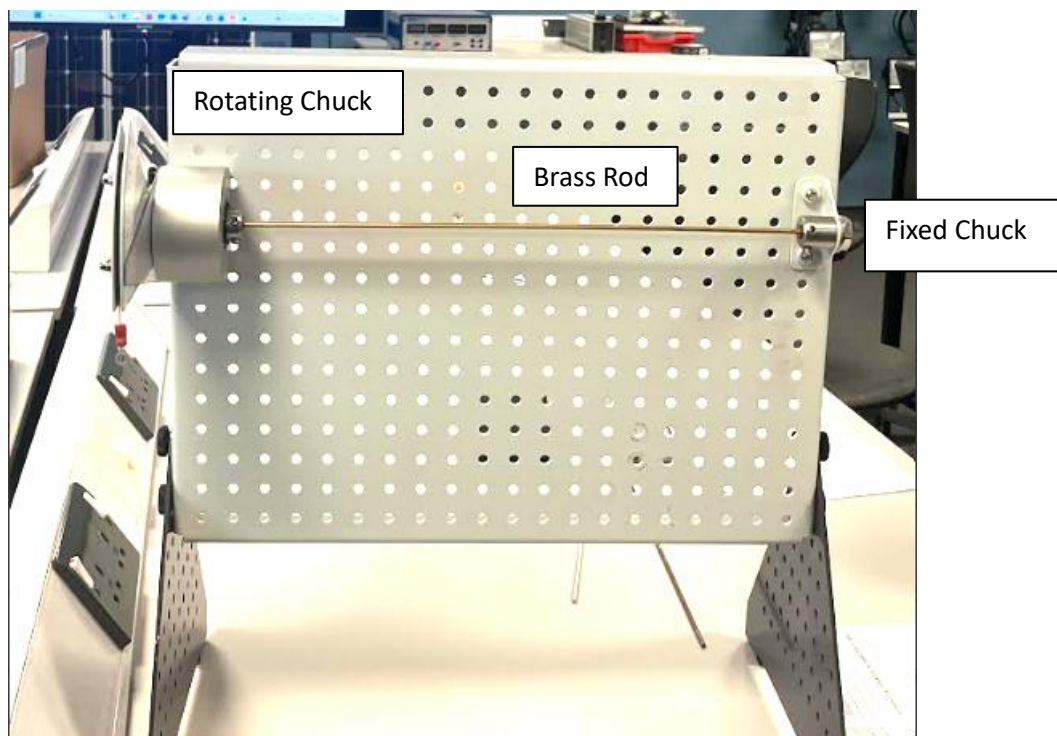


Figure 2.1 - Rod in Chucks

Zeroing the Rotating Chuck

Before the experiment was started the rotating chuck was zeroed. The chuck was zeroed by aligning the 0° mark on the torque arm scale to the indicator, the grub screw was then tightened. It is recognised that the thumbscrews could then have been used to adjust more accurately, on this occasion however adjustment was not required. A slip test of the zeroed value was completed by placing the largest load onto the scale, it was then removed and the scale returned to zero, this showed that it was correctly zeroed and would not slip during the experiment. Were this not the case, the zeroing process would have had to be repeated by tightening grub screws until it was correctly zeroed.

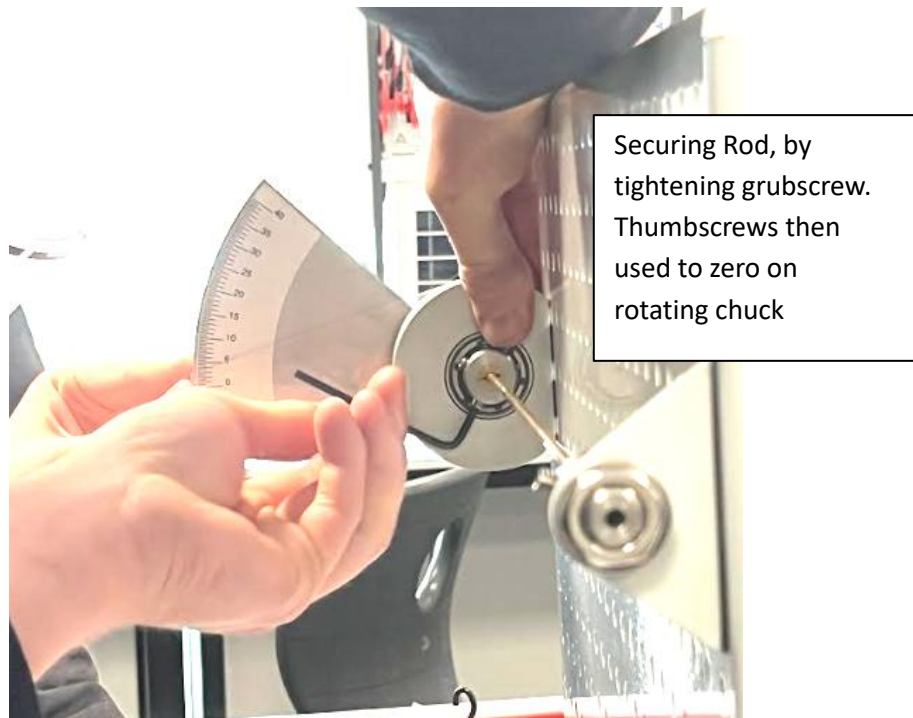


Figure 2.2 - Tightening Grubscrews

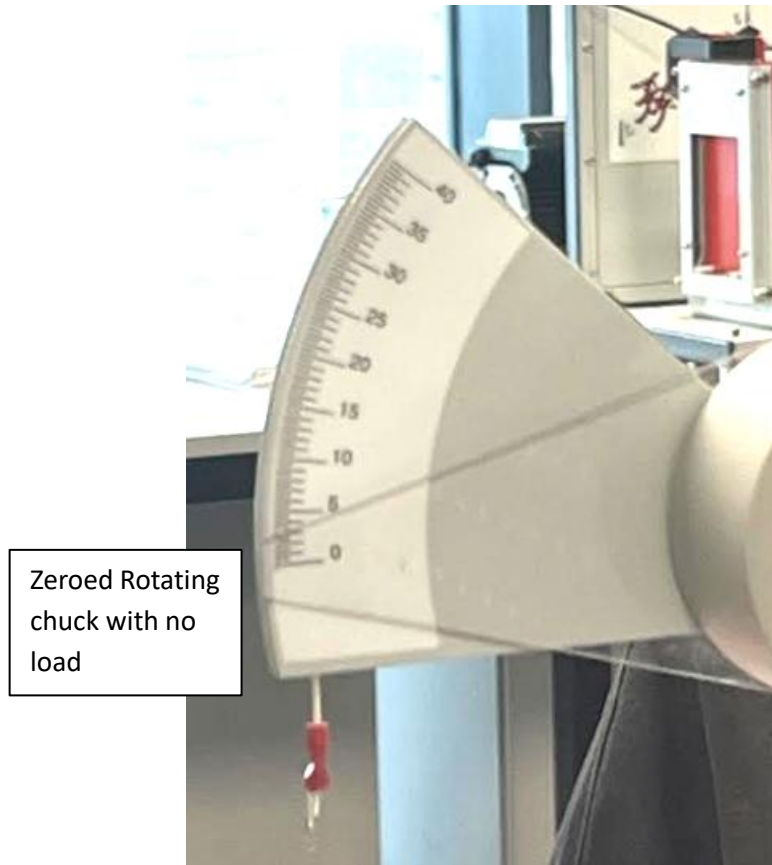


Figure 2.3 - Zeroed Rotating Chuck

Collecting Results

Once the setup for the brass specimen was complete, 100g of mass was added to the rig, at this point the rig was tapped to reduce the effect of friction. The twist angle at the moment arm was then documented on a recording table. This was then repeated up until 500g was achieved, increasing on each occasion by 100g increments. The experiment was then repeated for the steel and aluminium samples with the aluminium shaft stopped at 400g so as to ensure that the rods elastic limit was not exceeded.

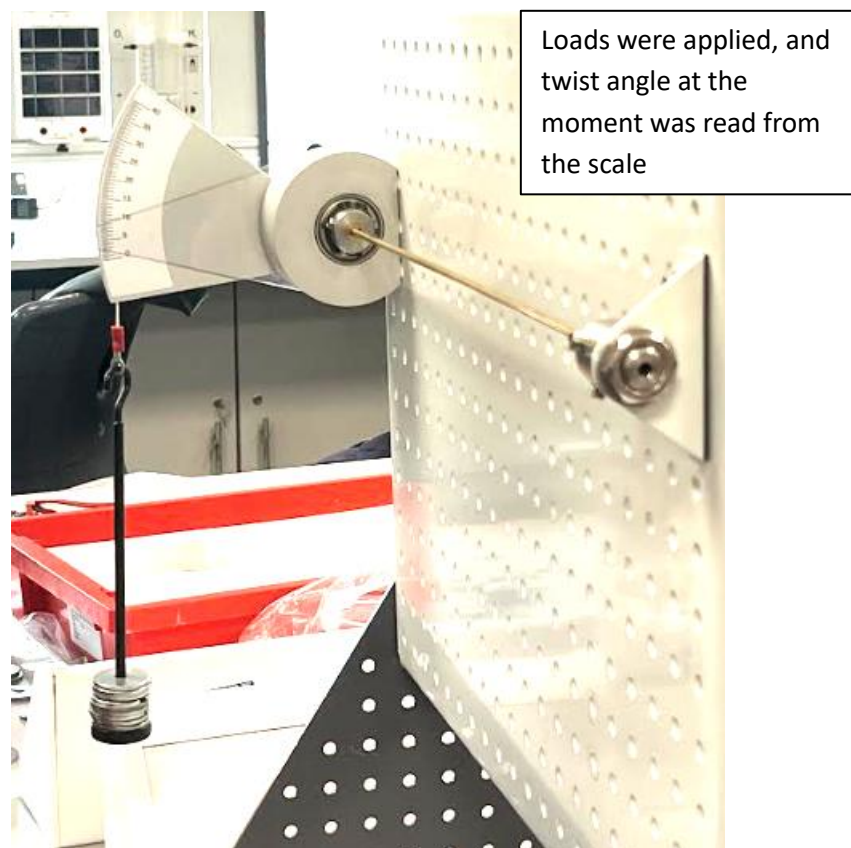


Figure 2.4 - Applied Load



Figure 2.5 - Enlarged Scale Reading

Chapter 3- Results

The collected results were then inputted into an excel file, where further critical values were calculated.

Table 3.1 - Brass Results

Shaft Modulus							
Load (m) (g)	Load (W) (N)	Torque (T) (Nm)	Twist Angle (degrees)	Twist Angle (θ)	TL	J θ	J θ ($\times 10^{-12}$)
100	0.98	0.098	7	0.12	0.03	9.71E-13	1.0
200	1.98	0.198	11.5	0.20	0.07	1.60E-12	1.6
300	2.94	0.294	17.5	0.31	0.10	2.43E-12	2.4
400	3.92	0.392	23.5	0.41	0.13	3.26E-12	3.3
500	4.9	0.49	29.5	0.51	0.17	4.09E-12	4.1
Material: Brass		L= 0.34m	D= 3mm		J= $7.95 \times 10^{-12} \text{ m}^4$		

Table 3.2 - Aluminium Results

Shaft Modulus							
Load (m) (g)	Load (W) (N)	Torque (T) (Nm)	Twist Angle (degrees)	Twist Angle (θ)	TL	J θ	J θ ($\times 10^{-12}$)
100	0.98	0.098	8	0.14	0.03	1.11E-12	1.1
200	1.98	0.198	15.5	0.27	0.07	2.15E-12	2.2
300	2.94	0.294	23.5	0.41	0.10	3.26E-12	3.3
400	3.92	0.392	31.5	0.55	0.13	4.37E-12	4.4
Material: Aluminium		L= 0.34m	D= 3mm		J= $7.95 \times 10^{-12} \text{ m}^4$		

Table 3.3 – Steel Results

Shaft Modulus							
Load (m) (g)	Load (W) (N)	Torque (T) (Nm)	Twist Angle (degrees)	Twist Angle (θ)	TL	J θ	J θ ($\times 10^{-12}$)
100	0.98	0.098	3	0.05	0.03	4.16E-13	0.416
200	1.98	0.198	5.5	0.10	0.07	7.63E-13	0.763
300	2.94	0.294	8	0.14	0.10	1.11E-12	1.11
400	3.92	0.392	10.5	0.18	0.13	1.46E-12	1.46
500	4.9	0.49	13	0.23	0.17	1.80E-12	1.8
Material: Steel		L= 0.34m	D= 3mm		J= $7.95 \times 10^{-12} \text{ m}^4$		

Chapter 4 – Analysis

The data calculated in the above results was then further processed into graphical form. From which the modulus of rigidity could be derived from the calculated gradient.

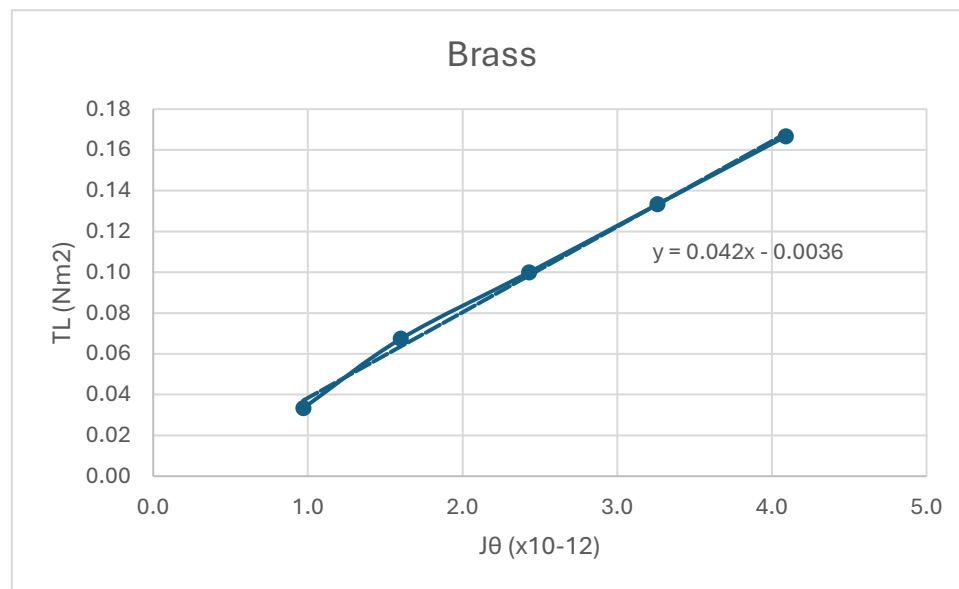


Figure 4.1 – Brass TL vs Jθ

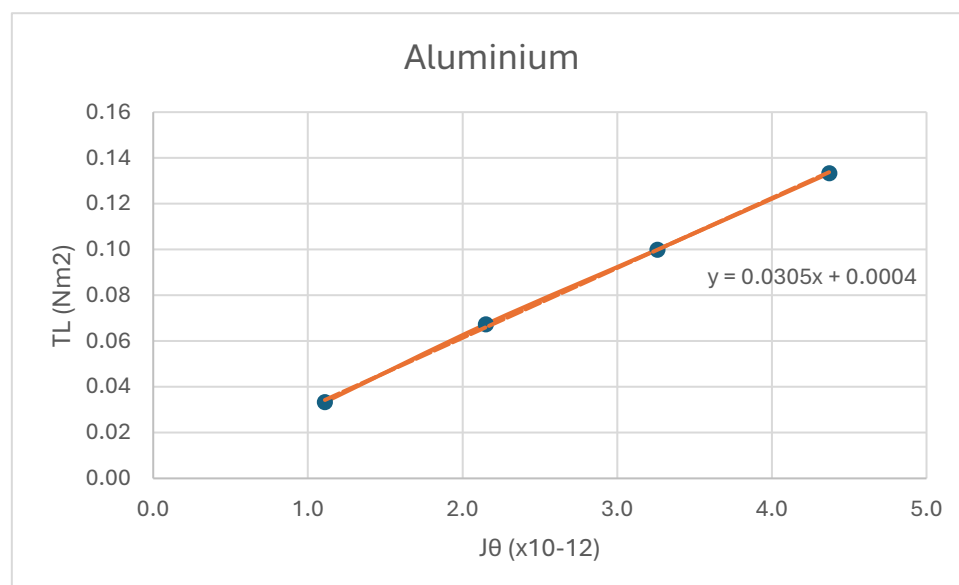


Figure 4.2 – Aluminium TL vs Jθ

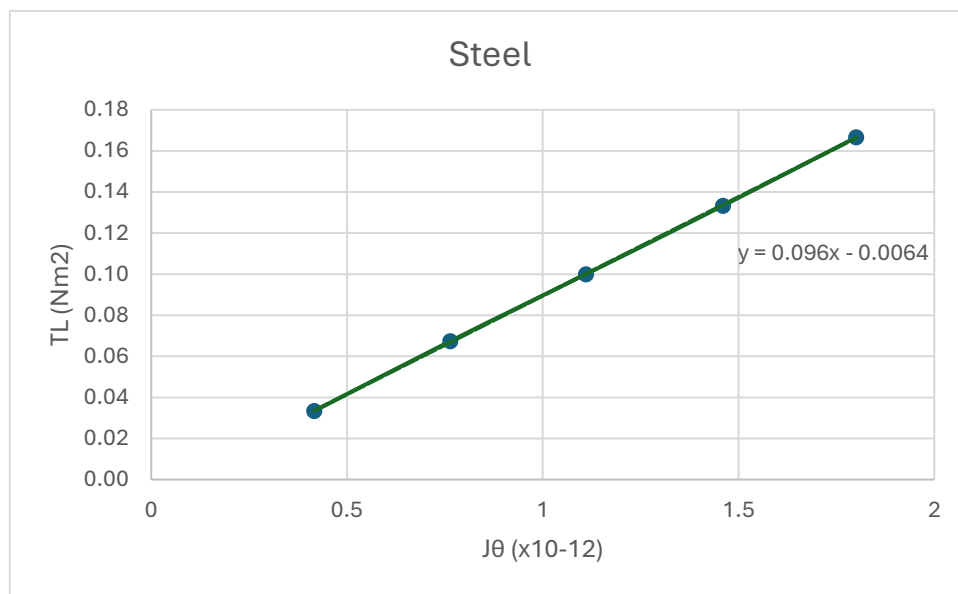


Figure 4.3 – Steel TL vs Jθ

Chapter 6 – Conclusion

$$TL=G(J\theta) \quad (\text{Equation 6.1})$$

Figure 4.1 shows an almost straight line, indicating a strong linear correlation, this is expected from *equation 6.1* and shows that the brass was kept within its elastic region. The gradient of 0.042 can therefore be converted to 42 GPa, which is the calculated value of G . This value of G falls within the expected value of G of around 40 GPa (Engineers Edge, 2025 and The Engineering ToolBox, 2005). The value of the intercept was expected to go through the origin; in this experiment this did not occur. The fact it did not could be attributed to an experimental error such as inaccurate zeroing or minor friction. Awareness of these variables enables some of these to be controlled for, for example by tapping the system to reduce minor friction before applying the load.

Figure 4.2 shows a clear linear relationship, this shows that aluminium obeys Hooke's law within the elastic region. This confirms that stopping at 400g in this case was appropriate to not exceed the elastic limit of the aluminium rod. The line of best fit gives a value for the modulus of Rigidity of 30 GPa. Aluminium normally has a value of G around 27-28 GPa (Kumaar, 2024), showing the experimental value is slightly higher than expected but still within 10% of the range. The non-zero intercept appeared as it had in *Figure 4.1*, however it is marginal and would have little effect to disprove the experimental verification of torsion theory of aluminium.

The steel modulus of rigidity graph also shows a straight line, indicating uniform torsional deformation within the elastic region as TL increases so does $J\theta$. The value of G in this experiment was 96 GPa, this is a high value for steel as it is usual to expect values in the range of 79-82 GPa for steel (AmesWeb, 2016).

Overall, the values of G were consistent with researched results of shear modulus. The steel value of G was slightly higher than the expected values however it was not stated if it was mild steel or if it had been treated which could have an impact on the shear modulus reading. The G value of 96 GPa falls closer to a range of stainless steel or high strength alloys (Ramya, 2024).

Chapter 7 – Evaluation

In experiments small errors are often expected, therefore in this experiment it was important to consider beforehand how best to eliminate experimental errors.

To start with the diameter (D) of the rods were measured in 3 places along the length and averaged. This was an important factor due to the large influence this would exert, and therefore potential for error, when calculating the Polar Second Moment of Area (J) as D is multiplied by the power of 4 (See *Equation 7.1*). The polar second moment of area is the second moment of area of the shaft cross section about the central point rather than an axis and is needed to “relate the stress produced in a beam to the applied bending moment” (Gentle et Al, 2001).

$$J = \frac{\pi \times D^4}{32} \quad (\text{Equation 7.1})$$

Before the experiment was completed the heaviest load was placed onto the zeroed rig and removed to check that the rod would not slip and that the zeroing would remain correct throughout the entire experiment. While the experiment was being completed the reading of the twist angle was read at eye level to the scale to avoid a parallax error (Wallulis, 2018).

In the collected results there was a non-zero intercept, in this experiment it was noted that this was not a consistent value across all of the samples. One reason for this could be due to the rig being incorrectly zeroed. Other factors may also have caused an effect, for example there could have been minor friction in the rig, which would affect all the results. On review of the experiment, it was noted that the process step of tapping the rig to reduce friction was not undertaken and this may have contributed to the results observed.

Chapter 8 – Further Work

To improve this experiment the following could be undertaken:

- More readings could be taken of results, adding 50g or 25g increments instead of the 100g increments which would increase the points to be plotted on the graph allowing for a more accurate line of best fit to derive the modulus value from. This could increase reliability of results and allow for removal of any anomalous results. Given unlimited resources a digital torsion testing rig would provide increased reliability and remove any human errors that may have appeared such as the non-zero intercept seen in the above data.
- It may also be a useful exercise if additional resources were available to test the materials from different sources to try and discern if the manufacturing process or the quality of each material has any impact on the result.
- Had more time been available for the experiment there could have been more checks in respect of the actual processes for the experiment undertaken and omission of the tapping process for friction reduction may have been identified and addressed.
- It would also have been interesting to see where the elastic limit was actually exceeded for each material to build in a margin for a real-world setting. As the shear modulus of a material and temperature are inversely proportional, meaning as shear modulus decreases, temperature increases (Kumar Dey, 2025). Temperature could have had an impact on results compared to expected research values, therefore completing this experiment in a temperature-controlled lab could lead to better consistency in readings.

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