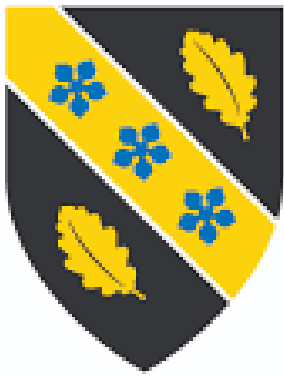


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Torsion of Shafts

Mechanics and Dynamics (ACHA4026)

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Date: 04/01/2026

Word Count: 1495

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1. Introduction

Torsion is a common form of loading in mechanical engineering, where a shaft or rod is subjected to a twisting moment about its longitudinal axis (*Hibbeler, 2021*). Components operating under torsion are widely used in engineering applications such as drive shafts and transmission systems, making it essential to understand how different materials respond to torsional loading (*Beer et al., 2015*).

This assignment investigates the torsional behaviour of circular shafts made from brass, steel, and aluminium using the ES5 Torsion of Circular Shafts kit (*University of Wales Trinity Saint David, 2025*). The primary aim of the experiment is to determine the shear modulus of each material by measuring the relationship between applied torque and the resulting angle of twist. The shear modulus is a key material property that defines resistance to shear deformation and directly influences torsional stiffness (*Gere and Goodno, 2018*).

The relationship between applied torque, shaft geometry, angle of twist, and material properties for a circular shaft in elastic torsion is given by the torsion equation:

$$\frac{T}{J} = \frac{G\theta}{L}$$

where T is the applied torque, J is the polar second moment of area, G is the shear modulus, θ is the angle of twist, and L is the length of the material.

By applying known torques to each material and recording the corresponding angle of twist, experimental values of shear modulus are calculated and compared with published reference values (*Budynas and Nisbett, 2020*). This comparison allows the accuracy of the experimental method to be evaluated and highlights the influence of material properties on torsional performance.

2. Experimental Procedures

As illustrated in Figure 1, the components were mounted onto the work panel, ensuring correct positioning by counting the panel holes as required.

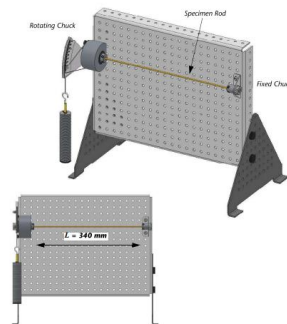


Figure 1: Experimental Setup

1. The supplied Guidance Notes were read before the beginning of the experiment.
2. Three shaft materials of similar dimensions but different materials were provided: aluminium, brass, and steel. The aluminium material had a light grey colour, while the brass material was identifiable by its golden hue.
3. The brass material was securely mounted between the fixed and rotating chucks.
4. The diameter D of the material was measured accurately using the dial calliper gauge supplied, and the polar second moment of area J was calculated.
5. The rotating chuck was set and zeroed in accordance with the procedure outlined in the Guidance Notes.
6. Masses were added incrementally in 100 g steps to the loading cord, up to a maximum of 500 g. After each addition, the work panel was gently tapped to minimise the effects of friction, and the resulting angle of twist was recorded from the moment arm scale.
7. Steps 3 to 6 were then repeated for the aluminium and steel specimens under identical test conditions.

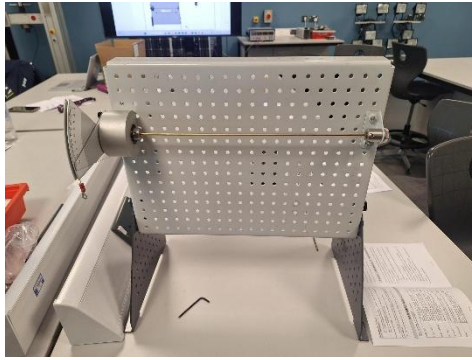


Figure 2: In-person setup of Experiment

3. Results

Load (m) (g)	Load (W) (N)	Torque (T) (Nm)	Twist Angle (°)	Twist Angle θ (rad)	TL	J θ
0	0	0	0	0	0	0
100	0.98	0.098	7	0.122	0.033	9.72E-13
200	1.96	0.196	11.5	0.201	0.067	1.60E-12
300	2.94	0.294	17.5	0.305	0.100	2.43E-12
400	3.92	0.392	23.5	0.410	0.133	3.26E-12
500	4.91	0.491	29.5	0.515	0.167	4.09E-12
Material: Brass		L=0.34m		D= 3	J=	7.95E-12

Table 1: Raw and calculated torsion test data for the Brass rod.

Load (m) (g)	Load (W) (N)	Torque (T) (Nm)	Twist Angle (°)	Twist Angle θ (rad)	TL	J θ
0	0	0	0	0	0	0
100	0.98	0.098	8	0.140	0.033	1.11E-12
200	1.96	0.196	15.5	0.271	0.067	2.15E-12
300	2.94	0.294	23.5	0.410	0.100	3.26E-12
400	3.92	0.392	31.5	0.550	0.133	4.37E-12
Material: Aluminium		L=0.34m		D= 3	J=	7.95E-12

Table 2: Raw and calculated torsion test data for the Aluminium rod.

Load (m) (g)	Load (W) (N)	Torque (T) (Nm)	Twist Angle (°)	Twist Angle θ (rad)	TL	J θ
0	0	0	0	0	0	0
100	0.98	0.098	3	0.052	0.033	4.16E-13
200	1.96	0.196	5.5	0.096	0.067	7.63E-13
300	2.94	0.294	8	0.140	0.100	1.11E-12
400	3.92	0.392	10.5	0.183	0.133	1.46E-12
500	4.91	0.491	13	0.227	0.167	1.80E-12
Material: Steel		L=0.34m		D= 3	J=	7.95E-12

Table 3: Raw and calculated torsion test data for the Steel rod.

4. Analysis

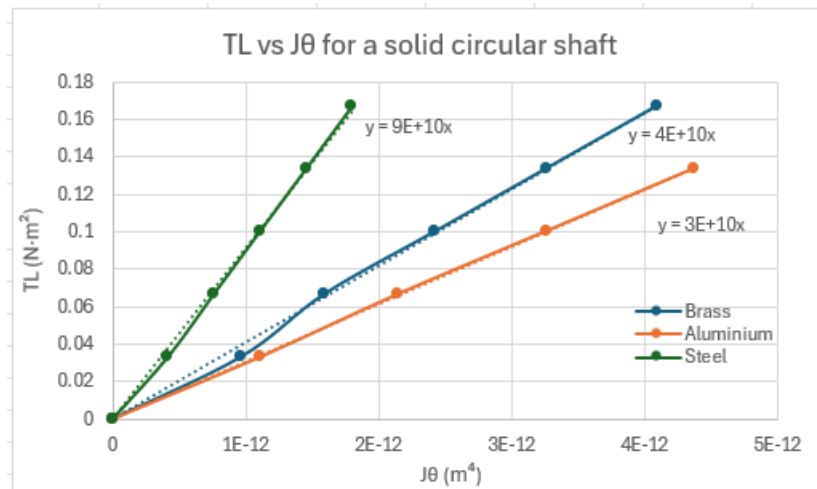


Figure 3: TL versus $J\theta$ for solid circular shaft materials.

4.1. Calculations of Torsion

The applied torque was calculated from the applied load and pulley radius using:

$$T = Wr$$

where T is the applied torque, W is the applied load, and r is the pulley radius.

The polar second moment of area for a solid circular shaft was calculated using:

$$J = \frac{\pi D^4}{32}$$

where D is the material diameter.

The shear modulus was determined by rearranging the torsion equation:

$$G = \frac{TL}{J\theta}$$

From this relationship, a plot of TL against $J\theta$ produces a straight line with a gradient equal to the shear modulus, G .

4.2. Analysis of collected data

Figure 1 shows the relationship between the torque–length product, TL , and the product of the polar second moment of area and angle of twist, $J\theta$, for brass, aluminium, and steel materials (*Beer et al., 2015*). For all three materials, the data produces a straight-line relationship passing close to the origin, indicating proportional behaviour and confirming the validity of the torsion equation within the elastic range of the materials tested (*Hibbeler, 2021*).

The gradient of each line represents the shear modulus, G , of the material (*Gere and Goodno, 2018*). The steel specimen exhibits the steepest gradient, indicating the highest shear modulus, followed by brass, with aluminium displaying the lowest stiffness. This trend is consistent with published material properties, as steel is known to be significantly stiffer in shear than brass and aluminium (*Budynas and Nisbett, 2020*).

Minor deviations from linear behaviour can be attributed to experimental uncertainties such as small errors in measuring the specimen diameter, slight misalignment within the chuck, or inaccuracies when reading the angle of twist. As the polar second moment of area is proportional to the diameter raised to the power of four, even small measurement errors are amplified and have a significant effect on the calculated values of $J\theta$ and the resulting gradient (*Gere and Goodno, 2018*).

Overall, the linear trends observed demonstrate that the specimens behaved elastically under the applied loads and that the experimental method provides a reliable means of determining the shear modulus for solid circular shafts (*Beer et al., 2015*).

4.3. Comparison of Experimental vs Nominal Shear Modulus Values.

The experimental shear modulus values were obtained from the gradients of the linear plots of TL against $J\theta$, in accordance with torsion theory (*Beer et al., 2015*). These values were then compared with published nominal values for each material (*Hibbeler, 2021*).

For brass, the experimental shear modulus was approximately 40 GPa, compared with a nominal value of 38 GPa, representing a small percentage difference of approximately 5% and indicating good agreement between experimental and published data.

For aluminium, the experimental shear modulus was approximately 30 GPa, while the nominal value is 25.5 GPa, corresponding to a percentage difference of approximately 18%. The larger discrepancy may be attributed to measurement errors, particularly in material diameter, which strongly influences the polar second moment of area (*Gere and Goodno, 2018*).

For steel, the experimental shear modulus was approximately 90 GPa, compared with a nominal value of 79.6 GPa, giving a percentage difference of approximately 13%. Although the experimental value is higher than the published value, the correct trend is observed, with steel exhibiting the highest stiffness among the materials tested.

Overall, the experimental results show reasonable agreement with nominal textbook values and correctly reflect the relative stiffness of the materials, with steel being the stiffest, followed by brass and aluminium. The remaining differences can be largely put down to experimental limitations and measurement errors, particularly due to the dependence of the polar second moment of area on the diameter raised to the power of four (*Gere and Goodno, 2018*).

Material	Value (GPa or GN.m ⁻²)
Brass	38
Aluminium	25.5
Steel	79.6

Figure 4: Nominal textbook values of shear modulus for brass, aluminium, and steel.

5. Conclusion

This experiment aimed to determine the shear modulus of brass, aluminium, and steel circular shafts using torsion testing and to compare the experimental results with published values. This was achieved by applying known torques and measuring the resulting angles of twist using the ES5 Torsion of Circular Shafts kit, allowing the torsional response of each material to be investigated under controlled elastic loading conditions.

The experimental shear modulus values showed reasonable agreement with nominal data. Brass produced an experimental value of approximately 40 GPa compared to 38 GPa, aluminium approximately 30 GPa compared to 25.5 GPa, and steel approximately 90 GPa compared to 79.6 GPa. Although discrepancies were observed, the correct trend was demonstrated, with steel exhibiting the highest stiffness, followed by brass and aluminium, which is consistent with established material behaviour.

The linear relationships observed in the TL versus $J\theta$ plots indicate elastic behaviour within the applied load range, confirming the validity of the torsion theory used. The close-to-linear trends passing near the origin suggest that the experimental method was applied correctly and that elastic limits were not exceeded. Overall, the experiment successfully demonstrated the principles of torsion in circular shafts, and the results obtained provide a reliable determination of shear modulus despite unavoidable experimental errors.

6. Evaluation

Several sources of experimental error may have influenced the accuracy of the results. The most significant uncertainty arose from measuring the specimen diameter, as the polar second moment of area depends on the diameter raised to the power of four, meaning small measurement errors were greatly amplified in the shear modulus calculations. Minor misalignment of the specimen in the chuck and reading errors of the angle of twist scale may also have contributed to deviations from ideal linear behaviour.

To minimise these errors, the specimen diameter was measured carefully, the apparatus was re-zeroed before testing, and loads were applied gradually. Readings were taken consistently to reduce parallax error, and multiple data points were recorded to improve reliability.

Overall, although experimental limitations were present, the precautions taken reduced their impact and allowed shear modulus values to be determined with reasonable accuracy.

7. Further Work

Given additional time and resources, the accuracy of the experiment could be improved by using digital angle sensors to measure the angle of twist more precisely and reduce reading errors.

Employing automated data logging would also minimise human error and improve repeatability while enabling continuous data capture during loading (*Gere and Goodno, 2018*). Testing a wider range of materials and specimen diameters would allow further validation of torsion theory and provide a broader comparison of material behaviour under varying geometric conditions.

Repeating the experiment multiple times and applying statistical analysis to the results would improve reliability and allow the effects of experimental uncertainty to be quantified with greater confidence. Additionally, improved alignment fixtures could be used to reduce bending effects and ensure that pure torsional loading is applied throughout testing for more consistent results (*Hibbeler, 2021*).

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