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Torsion of Shafts

Mechanics and Dynamics (ACHA4026)

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1.Introduction

Drive shafts, axles and torsion bars are all subject to torsional loading where a twisting moment is applied along the axis of a member. When a shaft is subject to torque, shear stresses are induced along the cross section which then results in angular deformation known as angular twist (*Holmes, 2019*). Understanding this is essential in mechanical and automotive engineering to ensure components operate to a safe degree within their elastic limits and do not experience permanent deformation or failure.

The resistance to a material deforming is characterized by its shear modulus, which can be also referred to as the modulus of rigidity. It relates the applied torque to the resulting angle of twist and depends on both material properties and their geometric characteristics, which include its length and moment of area. In particular, circular shafts, the relationship can be expressed by the torsion equation which means the shear modulus can be determined experimentally.

The aim of this experiment is to determine the shear modulus of three different material types, aluminium, brass and steel. By using a torsion shaft test rig, loads were added to each material and therefore the resulting angle was measured. Experimental values of the shear modulus were then calculated.

2.Experimental Procedure

The experiment was conducted using a torsion shaft test rig to determine the shear modulus of the circular shafts made from brass, steel and aluminium. Before testing each shaft was measured in length using a steel rule, and the diameter was measured as well using a vernier calliper.

Each material was mounted between the fixed and rotating chucks of the torsion apparatus, ensuring the alignment was correct to minimize the bending effects. The rotating chuck attached to it has an angular scale which was set to zero before any sort of load was applied. An overview of the experimental setup is shown in figure 1.

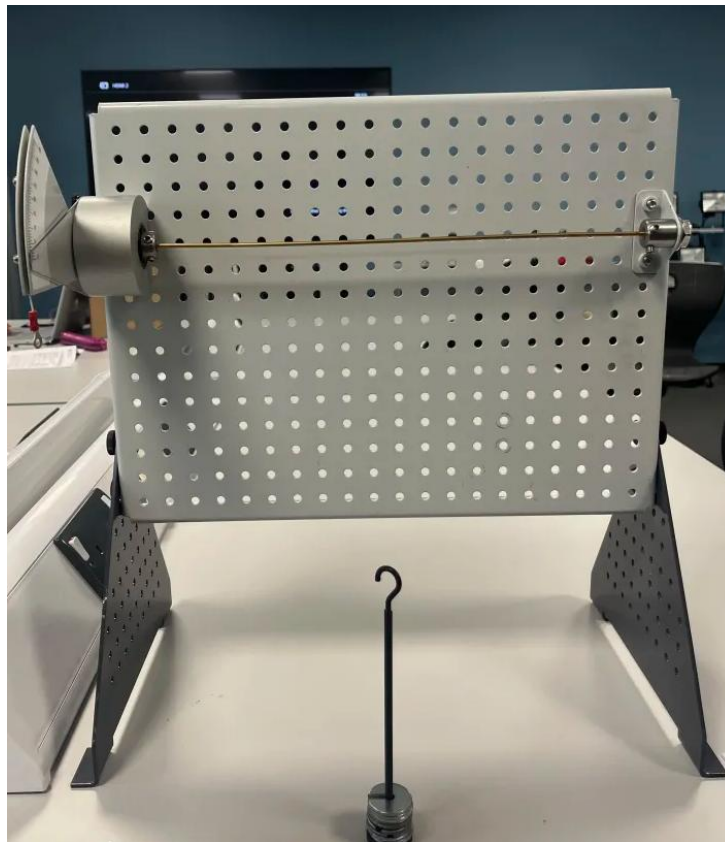


Figure 1 Torsion of Circular Shaft Test Rig setup

Torsion loading was applied by using known masses from a moment arm which was attached to the rotating end of the rig as shown in figure 2 below. The applied force was calculated from the suspended mass and gravitational acceleration. The torque was determined using the moment arm radius, loads were applied incrementally. After each load increase the angle of twist was recorded once the system had stabilised.

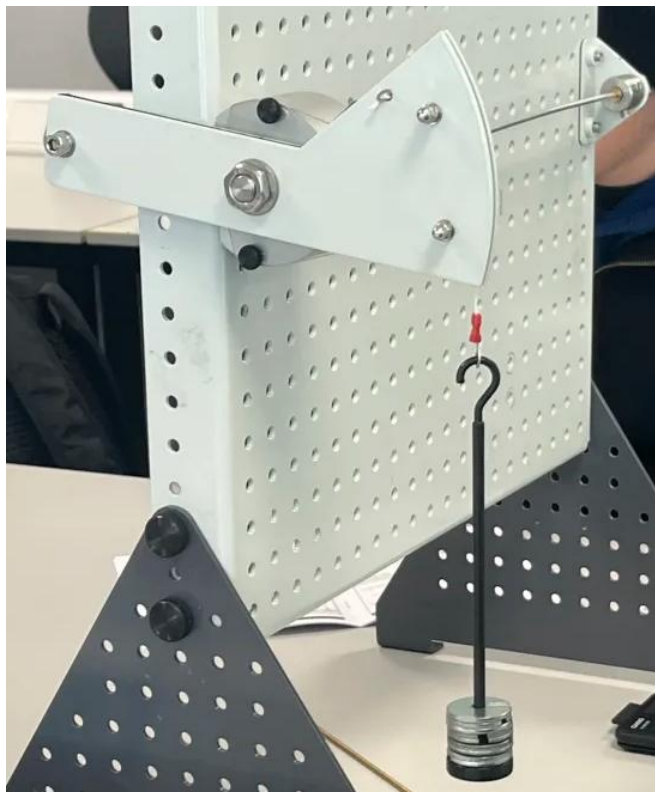


Figure 2 Application of Torsional load using hanging masses

The load was increased gradually so the elastic limit would not be exceeded. The aluminium was set to a lower maximum load compared to brass and steel specimens to reduce the likelihood of permanent deformation. All values were recorded down onto a book for later analysis.

3. Raw Results

All measured and calculated results obtained from the torsion tests carried out on the materials, brass, aluminium and steel shafts are presented here. Raw measurements of applied load and angle of twist were recorded.

Tables 1 – 3 show results from each material including calculated torque values, angular displacement in radians, and the derived quantities TL and J θ .

Brass						
Load(m) g	Load(w) g	Torque (T) Nm	Twist Angle (deg)	Twist Angle (rad)	TL	J θ
100	0.98	0.098	6	0.105	0.033	9.52E-13
200	1.96	0.196	11.6	0.202	0.067	1.83E-12
300	2.94	0.294	17.9	0.312	0.1	2.82E-12
400	3.92	0.392	23.5	0.41	0.133	3.72E-12
500	4.91	0.491	30	0.524	0.167	4.75E-12
L=0.34m	D= 3.1mm				J=9.07 x 10 ⁻¹² m ⁴	

Table 2 Raw and Processed results for Brass

Steel						
Load(m) g	Load(w) g	Torque (T) Nm	Twist Angle (deg)	Twist Angle (rad)	TL	J θ
100	0.98	0.098	2	0.035	0.033	3.17E-13
200	1.96	0.196	4.5	0.079	0.067	7.16E-13
300	2.94	0.294	7	0.122	0.1	1.11E-12
400	3.92	0.392	9.7	0.169	0.133	1.53E-12
500	4.91	0.491	12.5	0.218	0.167	1.98E-12
L=0.34m	D=3.1mm				J=9.07 x 10 ⁻¹² m ⁴	

Table 3 Raw and Processed results for Steel

Aluminium						
Load(m) g	Load(w) g	Torque (T) Nm	Twist Angle (deg)	Twist Angle (rad)	TL	J θ
100	0.98	0.098	7	0.122	0.033	1.43E-12
200	1.96	0.196	14.5	0.253	0.067	2.96E-12
300	2.94	0.294	22.3	0.389	0.1	4.55E-12
400	3.92	0.392	30	0.524	0.133	6.13E-12
L=0.34m	D=3.3mm				J=1.17 x 10 ⁻¹² m ⁴	

Table 1 Raw and Processed results for Aluminium

4. Analysis

This experiment is based on the torsional relationship for a circular shaft, where the angle of twist is related to the applied torque and the shaft stiffness:

$$\theta = TL/JG$$

Rearranging gives us:

$$TL = G(J\theta)$$

$y = mx + c$ is in the linear form, where $y = TL$, $x = J\theta$, and the gradient m is equal to shear modulus G . So, plotting TL against $J\theta$ should therefore produce a straight line relation for the materials, provided they all stay within their elastic region.

4.1 Data processing

For each load added, the applied load was converted from mass to force using $W=mg$ (with $g = 9.81 \text{ m s}^{-2}$). Applied torque was calculated using $T = Wr$ where r is the moment arm of the rig. The twist angle readings were taken in degrees later converted to radians.

The second moment of area J for each material was calculated from the measured diameter using:

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

This can explain why small measurement errors in diameter can significantly affect results, as the diameter is to the fourth power. Using the calculated J value and the measured twist angle (in radians), $J\theta$ was found for each load added. Furthermore, the torque length term TL was calculated using the specified length from assignment workbook of $L = 0.34\text{m}$. These values were processed in excel to create graphs of TL against $J\theta$ for all three materials, linear trendlines were added.

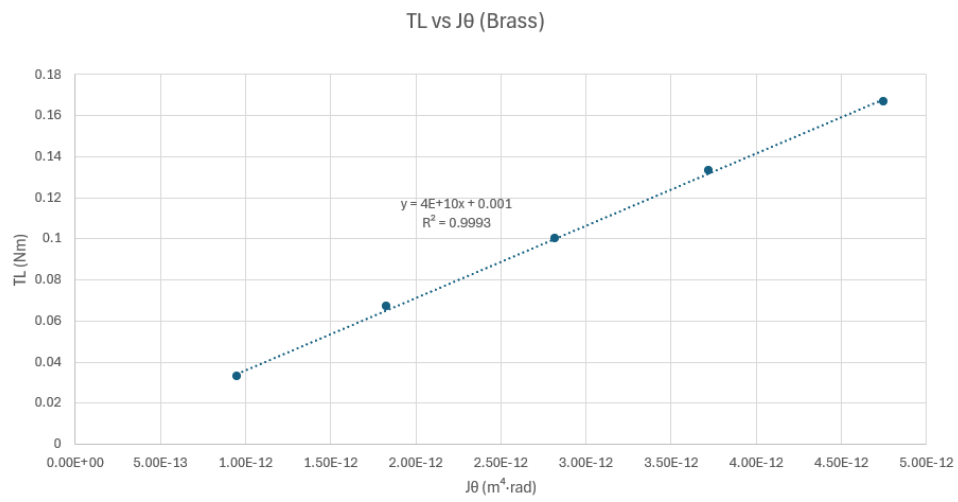


Figure 3 TL vs $J\theta$ for brass showing linear trendline and R^2

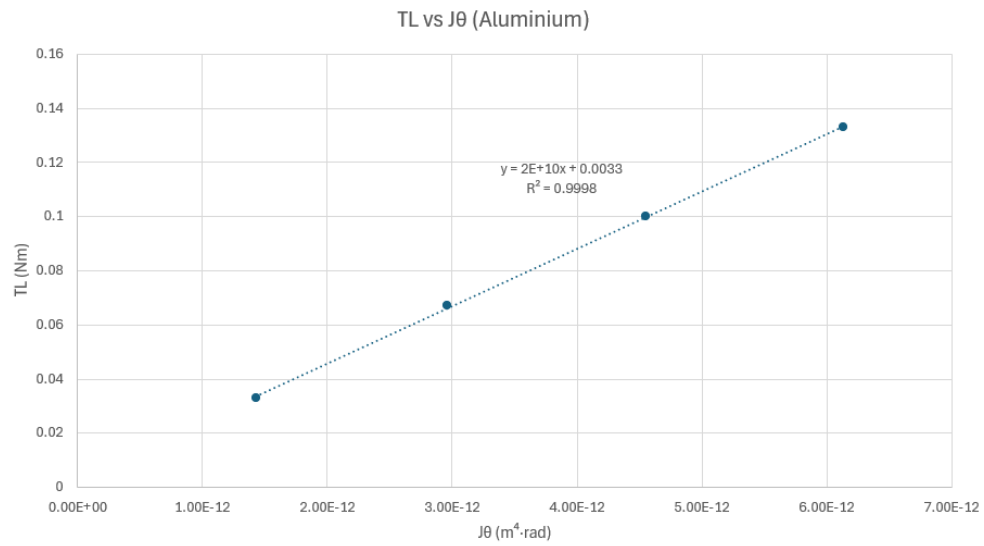


Figure 4 TL vs $J\theta$ for aluminium showing linear trendline and R^2

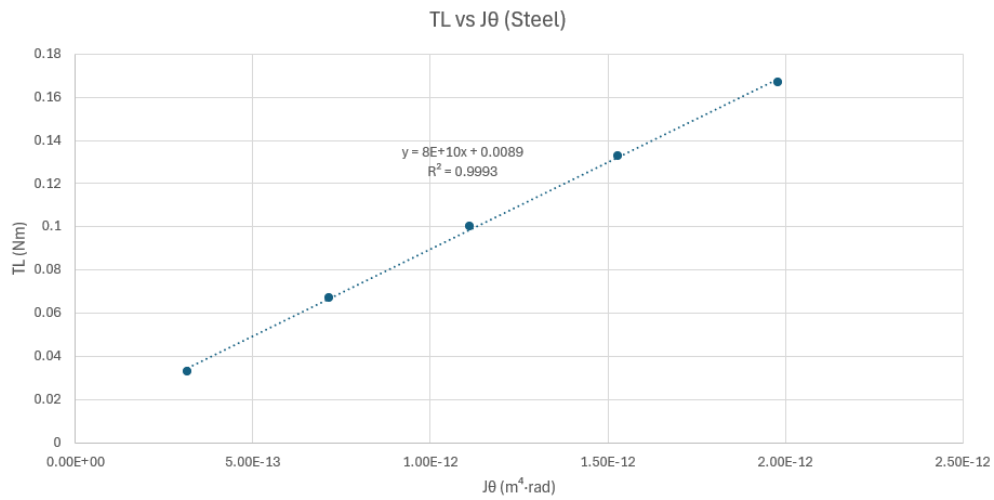


Figure 5 TL vs $J\theta$ for steel showing linear trendline and R^2

4.2 Graphical method and shear modulus results

Figures 3 to 5 show TL vs $J\theta$ plots for each material, brass, aluminium and steel, since the relationship has been rearranged to $TL = G(J\theta)$, the gradient of the trendlines gives us the experimental shear modulus G , while the coefficient of determination R^2 shows how closely the data follows a linear elastic relationship.

Brass (figure 3) $y = 4 \times 10^{10}x + 0.001$, $R^2 = 0.9993$ $G = 4.0 \times 10^{10} \text{ Pa} = 40 \text{ GPa}$

Aluminium (figure 4) $y = 2 \times 10^{10}x + 0.0033$, $R^2 = 0.9998$ $G = 2.0 \times 10^{10} \text{ Pa} = 20 \text{ GPa}$

Steel (figure 5) $y = 8 \times 10^{10}x + 0.0089$, $R^2 = 0.9993$ $G = 8.0 \times 10^{10} \text{ Pa} = 80 \text{ GPa}$

All graphs produce a very high R^2 value close to 1, which means strong linearity and suggesting that the materials remained within their elastic region. The small positive intercepts on each trendline indicate small systematic effects such as friction in the rig, zeroing error on the angle, or slack in the cord before full load was applied.

4.3 Comparison with nominal values

The values calculated were compared to what was given in the assignment textbook, shear modulus values: (brass 38.0 GPa, aluminium 25.5 GPa, mild steel 79.7 GPa). The percentage difference was calculated, Brass = 5.26%, Aluminium = 21.57%, Steel = 0.50%.

Steel produced the closest agreement with the nominal value, meanwhile aluminium showed the largest deviation, this could be due to aluminium being more sensitive to measurement uncertainty and experimental error. Small inaccuracies in reading the twist angle at higher masses may also affect results more significantly due to its lower stiffness and therefore larger displacement per load.

5. Conclusion & Evaluation

Overall, this experiment was used to determine the shear modulus of brass, aluminium and steel by adding incremental torques using mass and measuring the resulting angle of twist. Using the relationship $TL = G(J\theta)$, the shear modulus was obtained from the gradient of the TL vs $J\theta$ plots. The values obtained from the experiment were 40GPa for brass, 20GPa for aluminium, and 80 GPa for steel. Steel showed the closest match to the value given in the assignment brief (0.50% difference) from 80GPa, while brass was also quite similar at 5.26% different from the nominal value of 38.0GPa. Aluminium however showed the furthest deviation from the nominal value given 25.5GPa (21.57% difference). Very high R^2 values indicate strong linear behaviour and suggest all materials stayed within their elastic range, supporting the validity of the graphical method.

However, several factors likely contributed to the remaining differences. The angle of the twist was read from an analogue scale, which could imply human error in readings, not zeroing the rig properly either, which is consistent with the small non zero intercepts seen on the trendlines. Friction within the rotating mechanism may also oppose initial motion, particularly at low torques, and any slight slip at the chucks or variation in the arm would reduce the true torque to the material. In addition, diameter measurement uncertainty is significant, small errors in diameter produce larger changes in calculated $J\theta$ and therefore G . To reduce these effects, the chuck was zeroed before loading, loads were all applied in consistent increments, readings were taken once the system was stationary finally the aluminium was limited to a lower load to reduce the risk of plastic deformation

6.Further Work

To improve accuracy, the angle of twist should have been measured with a digital rotary encoder rather than an analogue scale to remove the human error and increase accuracy therefore readings would be more reliable (Holman, 2012). Each load level should also be repeated several times and the mean and uncertainty reported (John Robert Taylor, 1997). In addition, using a direct torque measurement method for example a torque sensor instead of solely relying on hanging masses, would reduce error from friction and small changes in the arm (Holman, 2012). Finally testing a wide range of other materials, with different diameters and lengths would strengthen the validation of torsion theory and highlight sensitivity to geometry (Goodno and Gere, 2018).

7.References

Goodno, B.J. and Gere, J.M. (2018). Mechanics of Materials. 9th ed. Boston, MA: Cengage Learning.

Holman, J.P. (2012). Experimental Methods for Engineers. 8th ed. New York: Mcgraw-Hill.

Holmes, D. (2019). Mechanics of Materials: Torsion» Mechanics of Slender Structures | Boston University. [online] Bu.edu. Available at: <https://www.bu.edu/moss/mechanics-of-materials-torsion/>.

John Robert Taylor (1997). An introduction to error analysis : the study of uncertainties in physical measurements. 2nd ed. Sausalito, Calif.: University Science Books.