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Torsion of Shafts

Mechanics and Dynamics (ACHA 4026)

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December 2025

Word Count: 1383

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1 Introduction

This assignment explores the torsion responses of a Steel, Brass and Aluminium shafts when a weight is added at an angle to one end of the shaft. The results of this will be analysed and used to divert different values such as the modulus of rigidity, polar moment of area, and have said values put into graphs. The practical will show how similar principals can be implemented in motorsport aspects. Conclusions can be made from the graphs about the reliability of the experiment in comparison to official researched results for *Sheer Modulus* and how the experiment may be improved upon if it could be conducted with no resource restrictions.

2 Experimental Procedure

2.1 Components

The provided materials are as follows:

- Work panel, to attach components.
- Three metal shafts, each made of either steel, brass or aluminium.
- Fixed chuck, to keep one side of the shaft gripped and stationary when force is applied.
- Rotating chuck, displays the angle of twist, holds the dynamic end of the shaft and where weight stack is attached.
- Weight stack and weights up to 500 grams.

2.2 Setup

Firstly, the fixed chuck is secured onto the work panel with screws from behind, then the shaft is tightened into the fixed chuck to prevent slippage:



Figure 1: Fixed chuck being attached to the Work panel

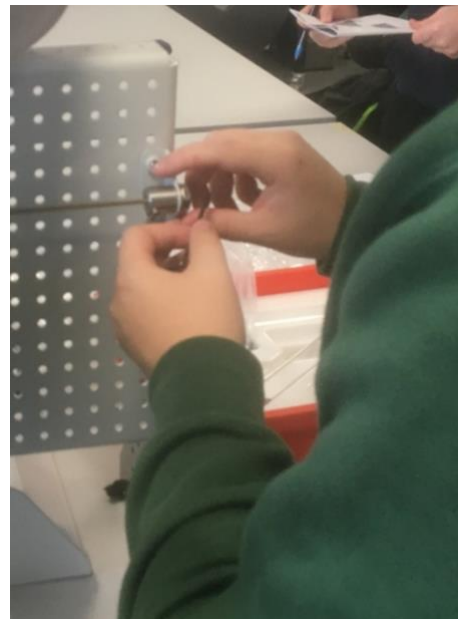


Figure 2: Shaft being attached to the Fixed chuck

Secondly, the rotating chuck is attached to the Work panel, loosely holding the shaft. Before securing the shaft, the rotating chuck's angle measurement is moved to the zero position to get an accurate angle of twist reading:



Figure 4: Setting Rotating chuck angle measurement to zero

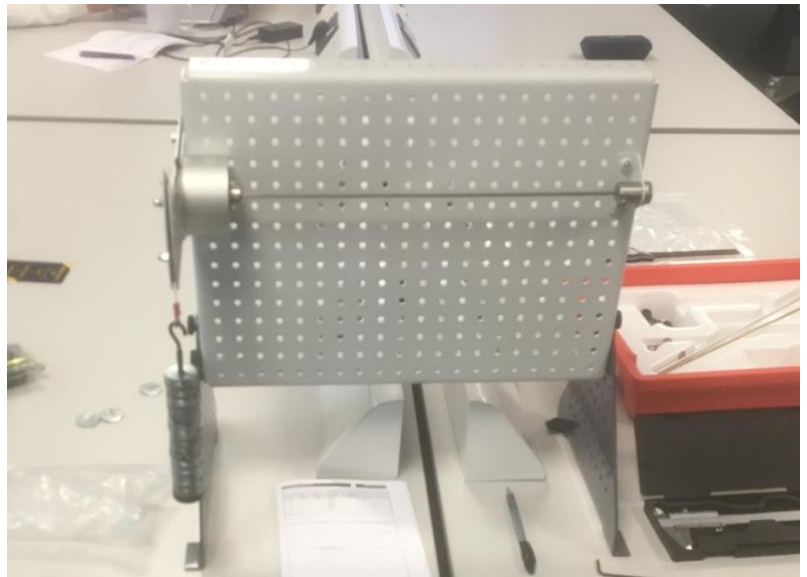


Figure 3: How apparatus should look with weigh stack attached

Finally, the components are now together, and the weights can be added to get an angle of twist reading, the set-up process is the same for each shaft.

2.3 Process

With the components together correctly the practical can begin. The purpose of is to find the angle of twist in degrees, that each bar rotates at, when force is applied. By measuring the diameter of the shaft, we can use the value in the analysis for later calculations.

Now the shaft is in place, 100g of weight should be added to the stack and the twist angle recorded from the rotating chuck. This should be repeated with intervals of 100g until 500g is on the stack, unless using the aluminium shaft which should be recorded until 400g due to the metal being too malleable and at 500g the rotating chuck will read its' maximum angle, over the accurate angle of twist.

The Work panel should be tapped after each addition to reduce friction in the system.

Each shaft's diameter should be measured with a set of callipers clamping down over the widest part of the circumference.

3 Results

Load (Grams)	Twist Angle (Degrees)		
	Steel	Brass	Aluminium
100	3.5	6	8.7
200	6	12.5	16.5
300	8.7	18.5	24
400	11.5	24.5	32
500	14	30.75	
Diameter (mm)	3.1	3.1	3.05

The table above displays the raw data recorded in the practical. It displays that Steel has the most torsional stiffness followed by brass and then aluminium, with the angle of twist increasing with weight at a relatively stable rate.

The aluminium shaft is slightly thinner which decreases the polar moment of area (J) and therefore has a lower Modulus of rigidity (G).

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

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

4 Analysis

4.1 Tables and Data

Below are the raw values after being implemented into excel tables and converted into useful data.

Load (m) (g)	Load (W) (N)	Torque (T) (Nm)	Twist Angle (degrees)	Twist Angle (θ) (radians)	TL	$J\theta$
0	0	0	0	0	0	0
100	0.98	0.098	3.5	0.061086524	0.03332	0.553871511
200	1.96	0.196	6	0.104719755	0.06664	0.94949402
300	2.94	0.294	8.7	0.151843645	0.09996	1.376766329
400	3.92	0.392	11.5	0.200712864	0.13328	1.819863538
500	4.9	0.49	14	0.244346095	0.1666	2.215486046
Material: Steel	L = 0.34 m	D = 3.1 mm	J = 9.067 $\times 10^{-12} m^4$			

Load (m) (g)	Load (W) (N)	Torque (T) (Nm)	Twist Angle (degrees)	Twist Angle (θ) (radians)	TL	$J\theta$
0	0	0	0	0	0	0
100	0.98	0.098	6	0.104719755	0.03332	0.94949402
200	1.96	0.196	12.5	0.218166156	0.06664	1.978112541
300	2.94	0.294	18.5	0.322885912	0.09996	2.927606561
400	3.92	0.392	24.5	0.427605667	0.13328	3.87710058
500	4.9	0.49	30.75	0.536688745	0.1666	4.866156851
Material: Brass	L = 0.34 m	D = 3.1 mm	J = 9.067 $\times 10^{-12} m^4$			

Load (m) (g)	Load (W) (N)	Torque (T) (Nm)	Twist Angle (degrees)	Twist Angle (θ) (radians)	TL	$J\theta$
0	0	0	0	0	0	0
100	0.98	0.098	8.7	0.151843645	0.03332	1.290063607
200	1.96	0.196	16.5	0.287979327	0.06664	2.446672359
300	2.94	0.294	24	0.41887902	0.09996	3.558796158
400	3.92	0.392	32	0.558505361	0.13328	4.745061544
Material: Aluminium	L = 0.34 m	D = 3.05 mm	J = 8.496 $\times 10^{-12} m^4$			

4.2 Graph and analysis

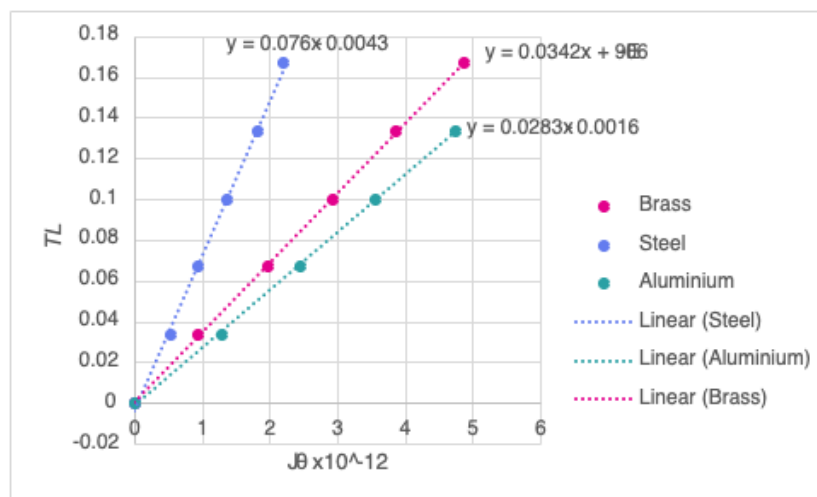
The twist angle is converted into Radians to have it in base units using the equation:

$$\text{Twist angle (Degrees)} \times \frac{2\pi}{360} = \text{Twist angle (Radians)}$$

By using the recorded diameter of each shaft, the Polar Moment of Area (J) can be calculated:

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

When the value of Torque is multiplied by the length of the shaft and the Polar Moment of area is multiplied by the Twist angle (Radians) values can be plotted on a graph, with TL against $J\theta$. The value of G (Modulus of Rigidity) will be the gradient for the line of best fit that the different plots create. Due to the values of J being in $J \times 10^{-12}$ the gradient will need to be converted back to $\times 10^{-9}$ which will present the true GPa value in the conclusion. The graph is displayed below.



The graph shows a linear trend that demonstrates the shafts will stably twist as torque increases (at least till the point of deformation where the shaft loses its elasticity and will not return to its original point). A linear trend implies the practical was carried out appropriately.

Knowledge regarding the torsional stiffness of shafts may be implemented into motorsport to increase performance. Possibly, within drivetrains to maintain a strong component that can handle repeated stress alongside using an alloy that decreases vehicle weight allowing for greater acceleration.

5 Conclusion

Researched Results	
Material	Value GPa GN. m^2
Steel	79.6
Brass	38
Aluminium	25.5

Practical Results	
Material	Value GPa GN. m^2
Steel	76
Brass	34.2
Aluminium	28.3

Comparison:

- Steel's modulus of rigidity was 4.5% less than the Researched results.
- Brass was 10% less than the Researched results.
- Aluminium, surprisingly, had a modulus of rigidity 10.98% higher than the researched results.

For steel and brass the results are expected as if the same shafts have been used repeatedly there would be a decrease in how elastic they behave due to metal fatigue. However, Aluminium having a higher rigidity value is unexpected and suggests an error in the experiment. This error may have come from:

- Miscalculating the weights on the stack.
- Excess friction in the system preventing the rotating chuck from reaching its true value.
- Misreading the twist angle on the rotating chuck.
- Inaccurate shaft diameter reading.

Only one of these issues can be accounted for without repeating the experiment, the diameter reading. If a uniform diameter is assumed between the shafts of 3.1mm then the new value for Modulus of Rigidity becomes 26.54 GPa, though it is still greater than the researched results by 4.1%, this new value is closer to being accurate by 6.9%.

6 Evaluation

6.1 Error Avoidance

Here are procedures taken to reduce errors during the practical:

- Multiple participants checking the angle of twist
- Repeating each weight addition at least twice to get a more accurate average.
- Having an experienced technician watching the process and available for asking pertinent questions.
- Checking the diameter of each rod multiple times and collecting a consensus for accuracy between participants.
- “Tapping work panel to reduce effects of friction”, as referenced in the Engineering Science Worksheet.

6.2 Potential issues

Though the measures will have increased the accuracy of results, they didn't account for potential slipping of the shafts within the chucks, which would make the Modulus of rigidity appear to decrease.

If there were issues with equipment such as the callipers being inaccurate, the shafts being overused, or the rotating chuck being set up incorrectly and slipping, if this was the case the results would be inaccurate however this is unlikely due to the linear trend line shown on the graph.

7 Further Work

Given unlimited resources this experiment could be improved upon greatly with the goal to reduce friction, increase accuracy of readings, reduce slipping of components, take into consideration the continued use of the metal shafts and how metal fatigue may reduce the reliability of results.

If the experiment used low friction bearings or finely machined and well lubricated joints between the rotating components, and was conducted in a clean room, the risk of contaminating moving surfaces would be eliminated. The lack of friction would allow the weight stack to hang at its lowest possible point. If properly cleaned and rebuilt before the next addition in weight, the rotating chuck would read more accurately.

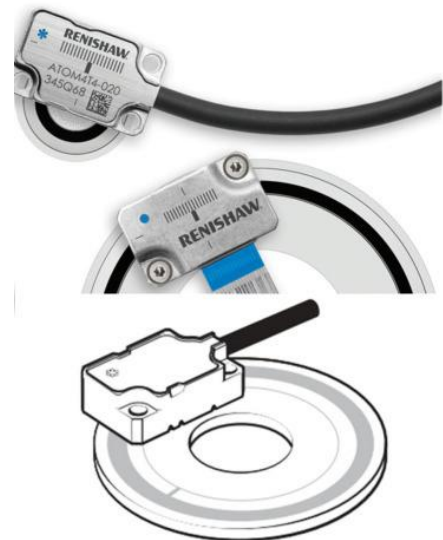
The screws that hold the shaft in place do not apply equal forces by gripping on all sides which causes a slight bowing of the shaft, increasing stress within the system. By implementing a method that clamps down the circumference of the shaft equally this may be avoided.

Angle of twist may be recorded more accurately by multiple avenues and would be necessary for a finer reading as many of the results were between values leading to a guess for the accurate value:

- Larger dial with finer points to read the angle more definitively.
- Electronic angle reader such as the Renishaw ATOM rotary encoder which is accurate to ± 5 micrometres for discs of 100mm, this is ideal for this scenario as the leverage is applied to the shaft at 10cm. [1] However, this may end up requiring a climate-controlled room as past 20 degrees Celsius the accuracy decreases from thermal expansion.

By using a new metal shaft before each experiment, or even by using a new shaft 3 times for each material, it would improve the accuracy of results by reducing the risk of metal fatigue damaging the shaft and decreasing accuracy.

Conducting the experiment within a climate-controlled room would prevent the impact thermal expansion would have on components.



RENISHAW ATOM rotary encoder

8 References

[1] Renishaw plc (2025). *Renishaw: ATOM™ optical incremental encoder series*. [online] Renishaw. Available at: <https://www.renishaw.com/en/atom-optical-incremental-encoder-series--37564>.