Torsion Testing

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OBJECTIVE

Perform a torsion (shear) test on a shaft with a circular cross section and measure the shear modulus (G) of a material using two different methods.

INTRODUCTION AND THEORY

TORSION: It is the twisting or wrenching of a body by the exertion of forces tending to turn one end or part about a longitudinal axis while the other is held fast or turned in the opposite direction.
For a body with uniform cross section, following equation holds true:

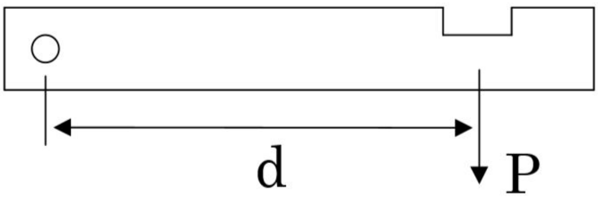
$$\boxed{T / J = \tau / R = G\theta / L}$$

T : External Applied Torque (Nm)
J : Polar Moment of Inertia (m^4)
τ : Maximum Shear Stress (N/m^2)
R : Radius of the Shaft (m)
G : Shear Modulus (N/m^2)
θ : Angle of Twist (radian)
L : Length of the Shaft (m)

TORQUE: Torque is a twisting or turning force that tends to cause rotation around an axis, which might be a center of mass or a fixed point.

$$\boxed{T = Pd}$$

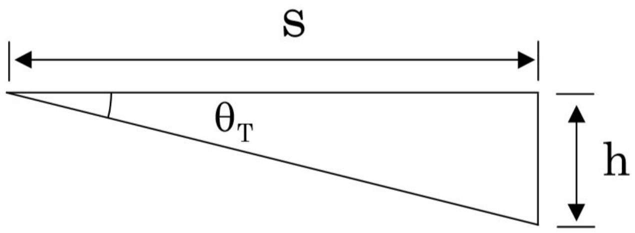
, where **"P"** is external load and **"d"** is the torque arm.



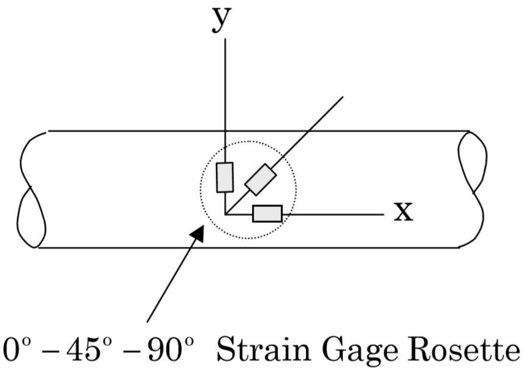
ANGLE OF TWIST: For a shaft under torsional loading, it is the **angle** through which the fixed end of a shaft rotates with respect to the free end.

$$\boxed{\tan\theta_T = \frac{h}{s}}$$

Where **"h"** is the dial gauge reading and **"s"** is the distance between dial gauge and the shaft center.



STRAIN ROSETTE: A strain gauge rosette is a term for an arrangement of two or more strain gauges that are positioned closely to measure strains along different directions of the component under evaluation. Single strain gauges can only measure strain effectively in one direction, so the use of multiple strain gauges enables more measurements to be taken, providing a more precise evaluation of strain on the surface being measured.



$$\boxed{\varepsilon_n(\theta) = \varepsilon_x \cos^2\theta + \varepsilon_y \sin^2\theta + \gamma_{xy} \sin\theta\cos\theta}$$

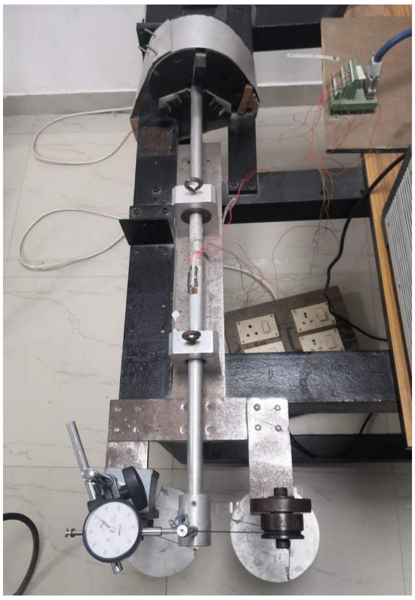
SHEAR STRAIN: It is defined as the length of **deformation** divided by the perpendicular length in the plane of the force applied.
In our experiment, we are calculating shear strain using 'The Strain Rosette" along 0-45-90 degree angles using the below mentioned equations.

$$\varepsilon_0 = \varepsilon_x$$

$$\varepsilon_{45} = \frac{\varepsilon_x + \varepsilon_y + \gamma_{xy}}{2}$$

$$\varepsilon_{90} = \varepsilon_y$$

$$\boxed{\gamma_{xy} = 2\varepsilon_{45} - \varepsilon_0 - \varepsilon_{90}}$$

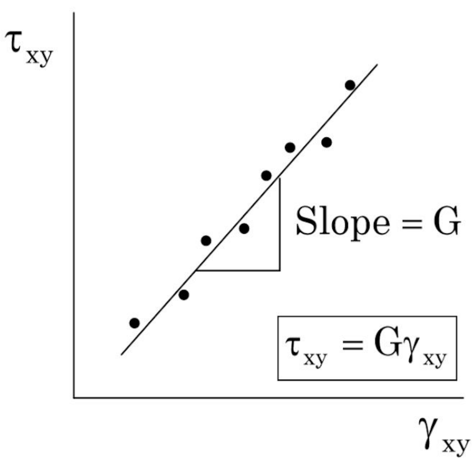


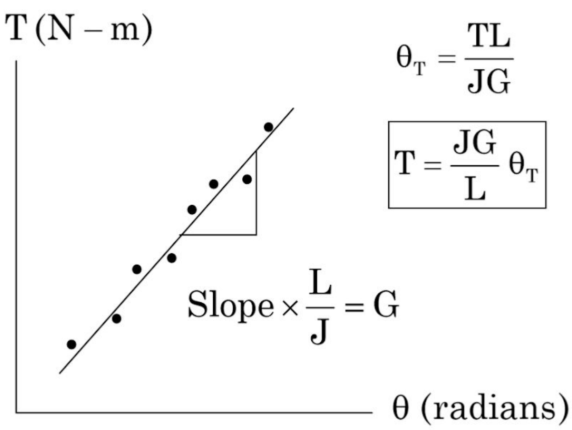
EQUIPEMENTS

- Testing Cylinder (Aluminium Alloy 6063)
- Dial Gauge
- Two Fixtures
- Strain Rosette with Strain Indicator
- Weights (Two 1 Kg and six 0.5 Kg)
- Digital Vernier Caliper
- Weigh Balance System with 2 pans (95 gram each) and 2 pulleys

PROCEDURE

- Apply loads to the torque arm. The load range and the load increment will be given by your lab instructor.
- At each load, record the three strain gage readings, and the vertical deflection of the torque arm.
- Determine the torque, shear strain, and the angle of twist for each applied load. Tabulate all measurements and calculations.
- Use the measured data to generate plots of Shear Stress vs Shear Strain ($\tau_{xy} vs\ \gamma_{xy}$), and Torque vs Angle of Twist (T vs Θ_T).
- Using linear regression fit the data (Draw a best possible straight line fit passing through all the data). Calculate shear modulus using the slope of the straight line fit.
- Compare experimentally measured G to the published value for your specimen material.
- Calculate the percent differences between the measured and published values.
- Identify sources of errors in your measurements.





MEASUREMENTS

INITIAL OBSERVATION

- Length of the shaft (L) = 700 mm
- Distance between shaft center and the dial gauge (s) = 130 mm
- Torque Arm (d) = 344 mm

RADIUS OF THE SHAFT

Three measured values of diameters are:

- 20.06 mm
- 19.98 mm
- 20.12 mm

Average of these values gives the Diameter = 20.053 mm

And the **Radius (R) = 10.03 mm**

Polar Moment of Inertia (J) for circular cross section = $\pi R^4 / 2$

$= 1.5876 \times 10^{-8}\ m^4$

θ Calculation

S No	P = Load (N)	T = P x d (Nm)	h (mm)	Θ = h / s (radians)
1	4.905	0.63765	0.42	3.23×10^{-3}
2	9.810	1.27530	0.84	6.46×10^{-3}
3	14.715	1.91295	1.27	9.77×10^{-3}
4	19.620	2.55060	1.71	13.15×10^{-3}
5	24.525	3.18825	2.15	16.54×10^{-3}

Sample Calculation

At S No 1, P = 4.905 N
Given, s = 130 mm
Torque (T) = P x d = 4.905 x 0.13 = 0.636765 Nm
Dial Gauge Reading (h) = 0.42 mm
$\Theta = h / s = 0.42 / 130 = 3.23 \times 10^{-3}$ radians

Strain Calculation

S No	P = Load (N)	T (Nm)	τ (N/m²)	ε_0	ε_{45}	ε_{90}	γ_{xy}
1	4.905	0.63765	1.06×10^6	0.0	22.5	2.00	43.00
2	9.810	1.27530	2.13×10^6	-1.0	40.5	0.50	81.50
3	14.715	1.91295	3.19×10^6	-1.0	61.0	1.25	121.75
4	19.620	2.55060	4.26×10^6	-1.5	81.4	1.10	163.20
5	24.525	3.18825	5.32×10^6	-2.0	101.5	1.40	203.60

Sample Calculation

At S No 1, P = 4.905 N

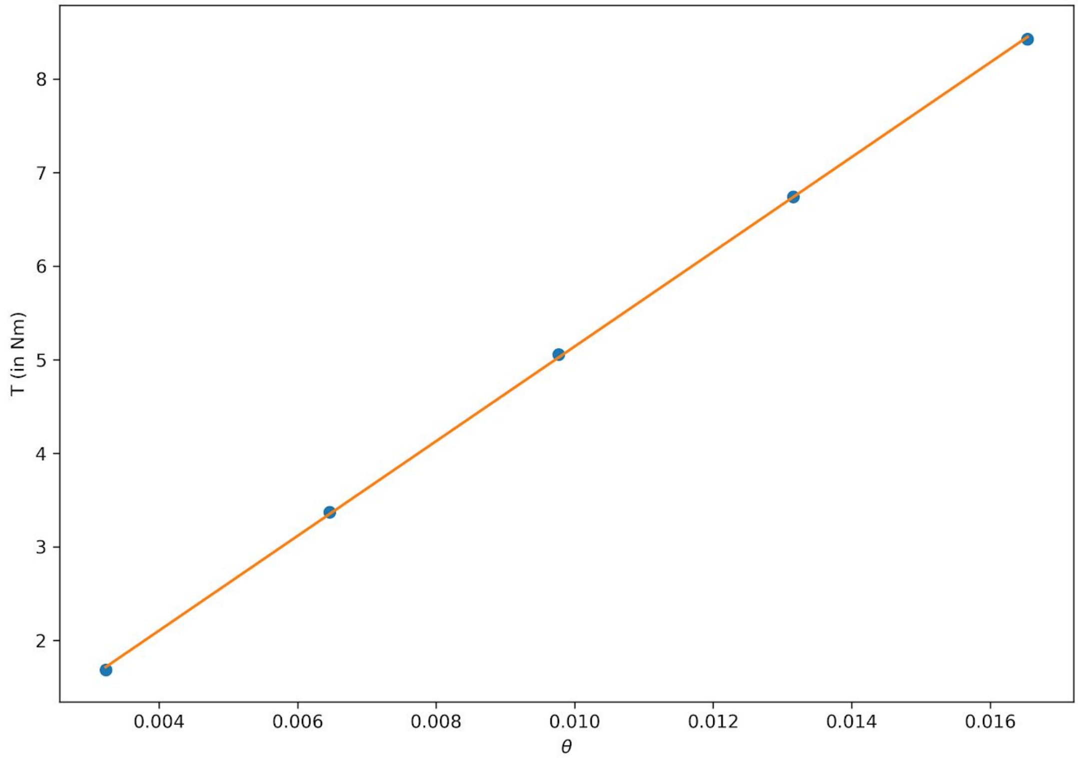
τ = T x R / J = 0.63765 x 0.0103 / (1.5876×10^{-8}) = 1.06×10^6 N/m²

Reading from strain indicator give ε_0 = 0.0, ε_{45} = 40.5 and ε_{90} = 2.00

$\gamma_{xy} = 2\,\varepsilon_{45} - (\varepsilon_0 + \varepsilon_{90})$ = (2 x 22.5) - (0.0 + 2.00) = 43.00

RESULTS

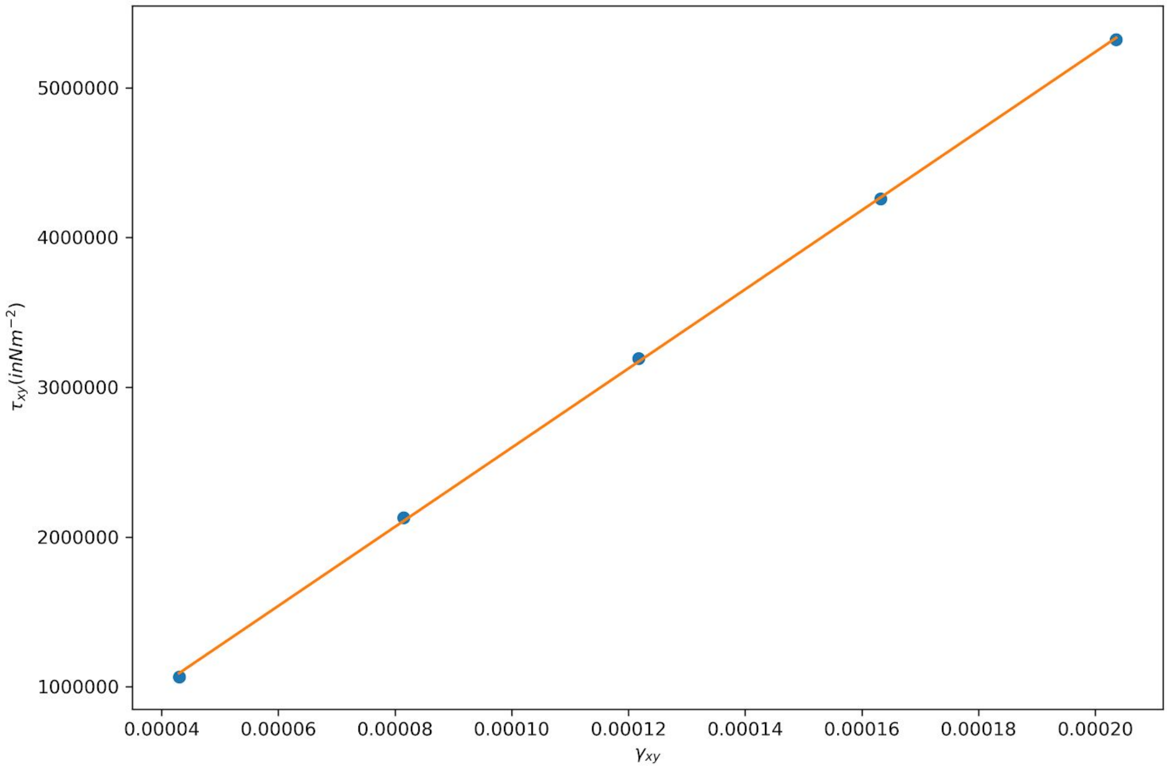
Plot for T vs θ_T



Equation for Best Fit Line: y = 506.02 x + 0.08

G = Slope x L / J = 506.02 x 0.7 / (1.5876 x 10^{-8}) = **22.31 GPa**

Plot for τ_{xy} vs γ_{xy}



Equation for Best Fit Line: y = (26.42 x 10^9) x - 45453.49

G = Slope = **26.42 GPa**

ERROR ANALYSIS

Actual Shear Modulus of Aluminium 6063 = **25.8 GPa**

- Error in Method 1 = (25.8 - 22.31)/25.8 x 100
  = 13.53 %

- Error in Method 2 = (26.42 - 25.8)/25.8 x 100
  = 2.40 %

DISCUSSION

Sources of error:

- Friction in pulleys.
- Elasticity in rope.
- Spaces between fixtures and the aluminum rod.
- Incapability of perfectly fixing the end of rod.
- Unequal weight of pans.

- Inaccurate weight of weights.
- Asynchronous alignment of weights on the pan.
- Environmental factors (temperature, moisture, etc.) changes strain gauge readings.
- Wires may not be properly connected.

CONCLUSION

We successfully calculated the shear strain of Aluminium Alloy 6063 from the two methods and got better results from the second method.

PRECAUTIONS

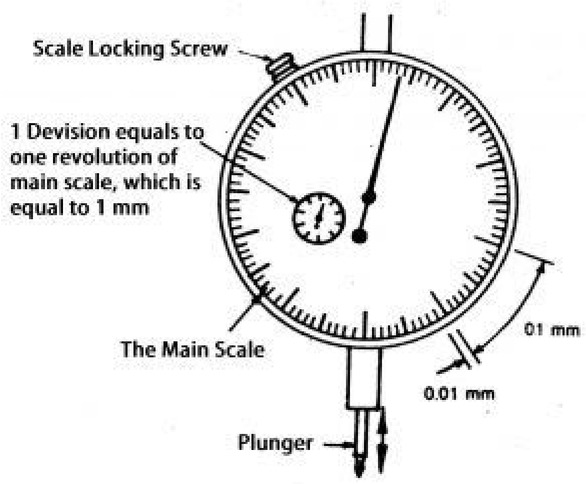
- Ensure that the pulleys are smooth regularly.
- Ensure that the pans are steady while taking readings.
- Ensure that the weights are put on and removed from the pans synchronously.
- Ensure to change the reading of the dial gauge to **zero** after every reading.
- Ensure that all the wires connecting the strain gauge to the indicator properly.
- Ensure strain indicator is changed to **zero** after every reading.
- Wait for a few seconds so that the fluctuations in the reading decreases.

APPENDIX

DIAL GAUGE

Dial gauges are used for checking flatness of surfaces, parallelism of bar and rods, detecting small differences if any in linear measurement of identical objects and for measuring concentricity of round objects.

The clock-like graduated dial of dial gauge carries two pointer arms A1 and A2. The dial is divided into 100 equal divisions where each division represents spindle movement through 0.01 mm. In 1 mm movement of the spindle, the arm A1 makes one complete turn on the dial. The smaller arm A2 registers the number of full turns made by the longer arm A1.



In [4]:

```
import matplotlib.pyplot as plt
import math
import numpy as np
```

In [43]:

```
s = 0.13 # torque arm (in meters)
L = 0.70 # Length of the shaft (in meters)
d = 0.344 # in meters
R = ((20.06 + 19.98 + 20.12)/2)/3 # Average Radius (in mm)
R=R/1000 # in meters
J = math.pi * (R**4) / 2 # Polar Moment of Inertia
P = np.array([0.5, 1, 1.5, 2, 2.5])*9.8 # Load (in N)
T = P*d # Torque (in Nm)
h = np.array([0.42, 0.84, 1.27, 1.71, 2.15])/1000 # in meters
theta = h/s # in radians
t = T*R/J # shear stress in N/(m*m)
e0  = np.array([0, -1, -1, -1.5, -2])/(10**6) # strain at 0 deg
e45 = np.array([22.5, 40.5, 61.0, 81.4, 101.5])/(10**6) # strain at 45 deg
e90 = np.array([2, 0.5, 1.25, 1.1, 1.4])/(10**6) # strain at 90 deg
Yxy = 2*e45 - (e0 + e90) # shear strain

m1,c1=np.polyfit(theta, T, 1)
print('Best fit line equation: y = ',m1,'x +',c1)
fig=plt.figure(figsize=(4,3))
plt.plot(theta, T, 'o')
plt.plot(theta, m1*theta + c1)
plt.xlabel(r'$\theta$')
plt.ylabel('T (in Nm)')
fig.savefig('plot1.png', format='png', dpi=300)

m2,c2=np.polyfit(Yxy, t, 1)
print('Best fit line equation: y = ',m2,'x ',c2)
fig1=plt.figure(figsize=(4,3))
plt.plot(Yxy, t, 'o')
plt.plot(Yxy, m2*Yxy + c2)
plt.xlabel(r'$\gamma_{xy}$')
plt.ylabel(r'$\tau_{xy} (in Nm^{-2})$')
fig1.savefig('plot2.png', format='png', dpi=300)
```

```
Best fit line equation: y =  506.0180045651387 x + 0.08225377050579162
Best fit line equation: y =  26417869915.558365 x  -45453.48934667391
```