Introduction

This project is an experimental study on plastic deformation in ductile materials. The object is to stimulate interest in engineering undergraduate students the importance of plasticity in structural design and metal forming.

Abstract

Torsion tests were performed on circular cylindrical bars to obtain torque-twist curves which were subsequently converted to torsional shear stress vs torsional shear strain plots. The bars were twisted well into their plastic regions, and as the elastic/plastic torsion continued, the torques seemed to approach their limiting values. Experimental estimates for the limiting torques were in reasonable agreement with the values predicted by Nadai’s Sand Heap Analogy. The specimens were twisted to a predetermined maximum value. The directions of twist were subsequently reversed. After unloading and reloading from the initial loading phase, the materials seemed to yield in the reverse direction with lesser yield strength values demonstrating the Bauschinger Effect in torsion.

Project Overview

- Torque-twist characteristics of the test specimens were obtained for two directions of torqueing.
- Fully plastic torques were extrapolated from the results and compared with the values calculated using Nadai’s Sand Heap Analogy.
- Torque-twist curves were converted to shear stress vs. shear strain curves using elastically calculated shear stress and shear strain from the experimental values of torque and twist.
- Torsional yield strengths were obtained for direct twisting, followed by reverse testing to demonstrate the Bauschinger Effect.

The aluminum and steel specimens were 1 in (25 mm) in diameter with a gauge length of 10 in (250 mm).

Results

![Figure 1: MTS Axial Torsion](image1)

![Figure 2: Torque vs Twist for 6061 Aluminum](image2)

![Figure 3: Torque vs Twist for A-36 Steel](image3)

![Figure 4: τ - γ curve for 6061 Aluminum](image4)

![Figure 5: τ - γ curve for A-36 Steel](image5)

Data and Analysis

Torsional Shear Stress \( \tau = \frac{16T}{\pi d^3} \)
Torsional Shear Strain \( \gamma = \frac{\tau}{G} \)

\( T \) - applied torque, \( \phi \) - twist, \( d \) - specimen diameter (2r), \( L \) - gauge length

Sand Heap Analogy:

Fully Plastic Torque = \( 2G \left( \frac{1}{3} \pi r^2 h \right) \)

\( G \) - shear modulus, \( r \) - radius, \( h \) - height of the cone

Fully Plastic Torque is related to the volume of the cone (created by free falling sand) whose base is the same as the cross-section of the cylindrical rod.

It can be shown that \( h = \frac{k \gamma}{G} \) with \( k = \text{yield strength} \)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Analytical Estimate (lb-in)</th>
<th>Experimental Estimate (lb-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6061 Aluminum</td>
<td>8577</td>
<td>7507</td>
</tr>
<tr>
<td>A-36 Steel</td>
<td>9264</td>
<td>7075</td>
</tr>
</tbody>
</table>

Bauschinger Effect:

Stress distribution from plastic deformation causes stress or strain change in metals that makes characteristics increase/decrease. This property indicates the loss of isotropy that typically occurs in metals.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Direct Yield (MPa)</th>
<th>Reverse Yield (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6061 Aluminum</td>
<td>225.9</td>
<td>155.4</td>
</tr>
<tr>
<td>A-36 Steel</td>
<td>244</td>
<td>181.1</td>
</tr>
</tbody>
</table>

Conclusion

The discrepancy in values in Table 1 is due to the assumption of elastic-fully plastic behavior in torsion. The shear stress vs shear strain curves in Figures 3 and 4 (extracted from experimental torque-twist values) do not represent an elastic-perfectly plastic behavior. The Bauschinger effect reported in Table 2 is based on 0.2% offset yield as shown in Figures 3 and 4.

Acknowledgment

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References