Theoretical and Applied Mechanics

Virtual Labs, Real Data

Sample preparation, procedure and data reduction - Engineered materials

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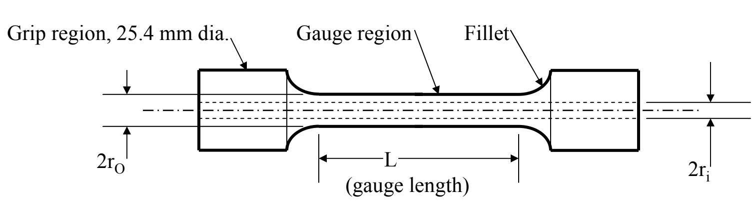
Outline

- **Sample preparation, mounting and measurement**
  - Engineered materials include 2024-T3 aluminum, cast iron, and PMMA
- **Test procedure**
  - Data acquisition
  - Steps in test
- **Data reduction**
  - Torsional stiffness
  - Shear modulus
  - Yield strength of ductile materials
  - Fracture strength of brittle materials

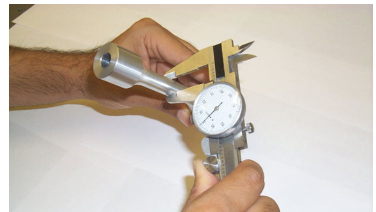
Sample preparation: Engineered materials

- **Aluminum, cast iron and PMMA samples machined on a lathe**
  - Oversize cylinders are first cut to 25.4 mm outer diameter
  - Then center hole is drilled and reamed
  - Then reduced diameter gauge section is cut
- **Tolerance ± 0.025mm (0.001 in.)**



Sample measurement:
Engineered materials

- Measure outer and inner diameter of gauge region
- To determine gauge length, using calipers, locate position where diameter is 4% larger than gauge diameter.
- Mark this location, then measure gauge length



Measuring outer diameter of gauge region

Measuring gauge length

Measuring inner diameter

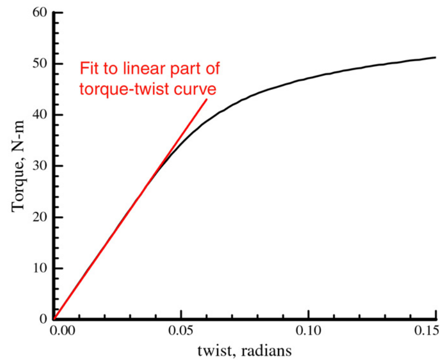
Test procedure and data acquisition

- Samples are measured and marked
- Mount into the test machine grips with axial load set to zero, and twist set to zero
- Samples loaded at a constant rate of twist, from 0.1 to 10 deg./sec.
- Data acquired at 10 data sets/second – (except for PMMA tests where both data acquisition and loading rates vary)
- Data set includes time, axial displacement, twist, axial force, torque

Basic data reduction: Torsional stiffness I

- Sample torque-twist curve for Al. 2024 is shown – remember to convert twist from degrees to radians

  (1 deg=$2\pi/360$ radians)
- Plot over a small twist range
- Fit a straight line to linear portion of curve
- Torsional stiffness, $\boldsymbol{k_{total}}$, is equal to the slope of this line



Data reduction: Torsional stiffness II

- **The test machine is not infinitely stiff**
- **Thus measured twist consists of twist of sample plus twist of test machine**
- **Model machine and sample as springs in series so that**

$$\frac{1}{k_{Total}} = \frac{1}{k_{Sample}} + \frac{1}{k_{Machine}}$$

$$\frac{1}{k_{Sample}} = \frac{1}{k_{Total}} - \frac{1}{k_{Machine}}$$

•Machine stiffness has been measured and is equal to

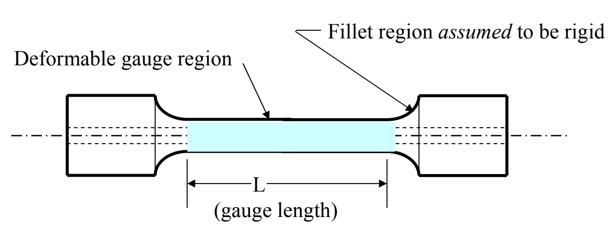
$k_{Machine} = 42800\ N\text{-}m/radian$

Data reduction:
Shear modulus

- Calculate shear modulus from $G=kL/J$ *(see slide 7 of theory talk) where* L is the gauge length, and $k=k_{Sample}$
- Dimensions needed for J, L are given in header of data files.

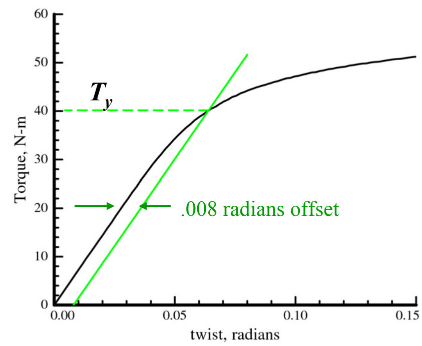
Note on shear modulus determination

- **Equation relating sample stiffness to shear modulus *assumes* that only the gauge section of the sample is deformable and that fillet region is rigid.**



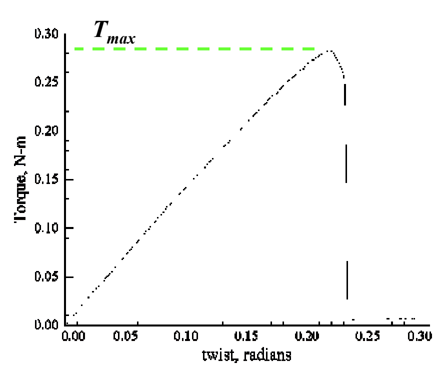
Data reduction: Yield stress of ductile materials

- Determine T_y by offset method.
- Recall that $\gamma = \rho\phi / L$ *(see slide 4 of theory talk).* Calculate twist offset $\phi_{off} = \gamma L / r_O$
- For gauge length of 50mm, outer radius of 6.35 mm, and offset shear strain of .001, ϕ_{off} is .008 radians.
- Draw a line parallel to linear part of curve, but offset by ϕ_{off}. Intersection of this line with torque-twist curve is T_y.
- Calculate yield stress from $\tau_y = T_y\, r_O / J$ *(see slide 12 of theory talk)*



Data reduction: Fracture strength of brittle materials

- Cast iron and other brittle materials have little non-linear deformation before failure.
- Compute ultimate shear strength, τ_u , from $\tau_u = T_{max}\, r_O / J$



Slide 1

In this talk we will review the geometry, preparation and measurement of the circular test samples used for the aluminum, cast iron and PMMA materials. Then we review the steps taken in the test and in data acquisition. In the lab reports section we will ask you to determine shear modulus, and either yield stress in shear (for ductile materials) or fracture stress (for brittle materials). Thus in this talk we also review the data reduction procedures and basic equations. Note that the analyses discussed here apply only to circular cross sections. Data and analysis sheets are provided in the lab manual to help you with your data reduction.

Slide 2

The sample geometry is a circular cylinder with a reduced diameter gauge section as seen at the bottom of this slide. At the ends there is a 25.4mm diameter grip region for holding the samples in our hydraulic collet grips. Some of the samples are hollow cylinders and some are solid. All of the samples start as solid cylinders a few mm larger than the final grip region diameter of 25.4mm. The cylinders are first cut down to 25.4mm (one inch) outer diameter. For the hollow samples, a hole is then drilled. This hole is then reamed to the precise inner diameter. Once the hole is cut, the cylinder is machined to produce the reduced diameter gauge section and fillet.

Slide 3

Before each experiment is run the sample must be measured. Using dial calipers we first measure the gauge section inner and outer diameter. To determine gauge length we first locate the positions at each end of the sample where the diameter is 4% greater than the gauge diameter. These positions are marked and are taken to define the gauge section. Once marked, the distance between the marks is measured to give the gauge length. The choice of fixing the gauge length at a position where the diameter has increased by 4% is somewhat arbitrary – we could have chosen 1% or any other small fraction.

Slide 4

The test procedure and data acquisition are straightforward. Each sample is first marked with a permanent ID number, and then measured. Samples are loaded into the testing machine with the twist set to zero, and with zero axial load. With the axial load control set to zero, the sample is twisted at a constant rate, ranging from 0.1 to 10 degrees per second, depending on the material. During the test, digital data is acquired by the test system computer at a rate of 10 sample sets per second (except for some of the PMMA tests where data were taken at various rates). Each data set includes time, axial displacement, twist, axial force, and torque, all in SI units. The data is in text format and can be downloaded for analysis.

Slide 5

The first data reduction step is to determine the torsional stiffness of the sample. There are a number of approaches to doing this, but what we suggest is to plot the initial part of the torque-twist data, then fit a straight line to the linear part of the curve. Remember to convert your twist from degrees into radians. The slope of this fit gives you the overall stiffness.

Slide 6

Since the test machine is not infinitely stiff, your measured rotation includes the rotation of both the sample and of the test system. To account for this we can model the sample and test system as springs in series, so that the total system stiffness is given by $\frac{1}{k_{Total}} = \frac{1}{k_{Sample}} + \frac{1}{k_{Machine}}$. To determine the stiffness of the test sample re-arrange the equation so that $\frac{1}{k_{Sample}} = \frac{1}{k_{Total}} - \frac{1}{k_{Machine}}$. In a separate experiment we have measured the stiffness of the testing machine to be 42,800 N-m/radian.

Slide 7

Once you have found the total stiffness and then used the previous equations to subtract the test machine compliance and hence to find the test sample stiffness, you can calculate the shear modulus from $G = \frac{kL}{J}$. Note that the information needed to compute J is given in the header of each data file.

Slide 8

You may or may not come up with shear modulus values that agree with the textbook values for the material under consideration. One thing to think about is the assumption implicit in the formula relating shear modulus to sample stiffness. That is, that only the gauge section is deforming. Is this really true? If not, you might want to consider how you could either redesign the experiment to reduce the error due to this assumption, or think of a method to account for deformation in the gauge section.

Slide 9

For the ductile materials we can determine the initial yield stress from the torque-displacement curve. The material yields when it begins to undergo permanent deformation. This permanent deformation is accompanied by nonlinearity of the torque-twist curve. Defining the exact onset of nonlinearity and hence onset of yielding can be difficult. Thus as a practical approach, engineers often use the offset method.

The offset method is usually stated in terms of strain. In this method a line is drawn parallel to the linear part of a stress-strain curve, but displaced to the right by 0.1 to 0.2% strain. The stress where this line intersects the stress-strain curve is then deemed to be the yield stress.

In this lab we do not measure strain directly – we measure twist. To use the offset method, an offset twist must be defined consistent with the offset strain idea. Here we have chosen to reduce the offset to 0.1% shear strain. Using the relation between strain and twist we can calculate an offset twist. For example, for a gauge length of 50mm and outer radius of 6.35mm, the offset twist that is equivalent to 0.1% offset strain is .008 radians. The intersection of the offset line with the torque-twist curve gives the torque at yield, about 40 N-m in the example shown.

Once the yield torque is known, the yield stress can be computed from tau yield equals yield torque times outer radius of gauge section divided by polar moment of inertia, J.

Slide 10

Brittle materials will fracture with little or no yielding. In such materials we cannot talk about yield stress, but instead can discuss the ultimate strength of the material. Plot the torque-twist curve and then determine the torque at which the sample fails. Then the shear strength of the material can be determined from $\tau_u = \frac{T_{\max} r_0}{J}$.