Lecture 7 - Physical measurements

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schedule

- 8 Feb - Physical measurements
- 10 Feb - Variational Calculus (HW2 Due)
- 15 Feb - Variational Calculus
- 17 Feb - Boundary Conditions (HW3 Due)

outline

- review
- measuring orientation

review

checking transformations

- Follow the procedure here[1]
- This gives a way to systematically check whether your rotations are correct
- You can check any coordinate transformation as long as you know the unit vectors of your primed coordinate system in the global coordinates

$$x = [Q^T]x'$$

[1] https://colab.research.google.com/drive/1NWK3gGaSHLbOgfsK-XZDTvhpALrdCohc?usp=sharing

common homework errors

- Some people had rotations about an axis with zeros along the diagonal
- This is possible with successive rotations, but for a rotation about one of the three axes, you should always have one term along the diagonal equal to 1
- When calculating stiffness in Problem 2, most students had some un-expected behavior
- All four walls had same x_1 component of fibers, you should have gotten C_{11} the same for all 4 walls
- C_{22} or C_{33} should have also been equal to C_{11}, depending on the wall

measuring orientation

measuring orientation

- In micromechanics (and most places where multi-scale modeling would be used), measuring local orientations can be difficult
- For composites, these are some common techniques
  - Microscopy (some ambiguity in orientation tensor)
  - Serial sectioned microscopy (eliminates ambiguity, very expensive)
  - CT-scanning (only gives approximate measure)
  - Micro CT-scanning (only for very small parts)

microscopy

- Cylindrical fiber intersects cutting plane at some angle
- After cutting and polishing, this leaves an ellipse
- By measuring the ellipse, we can calculate the angle between it and the cutting plane
- Microscopy can also be used to measure volume fraction, void content, and fiber spacing

microscopy

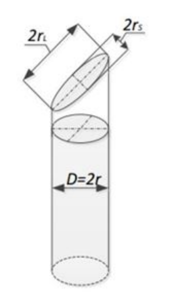

Figure 1: An image showing the ellipse that results from cutting a cylinder at an angle that isn't perpendicular to the axis.

fiber in spherical coordinates

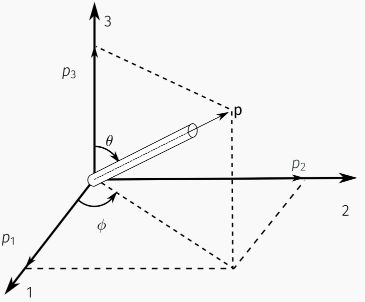

Figure 2: Relating the spherical coordinate system to direction vectors to describe fiber orientation

fiber direction components

Component	Definition
p_1	$\sin\theta\cos\phi$
p_2	$\sin\theta\sin\phi$
p_3	$\cos\theta$

measurements

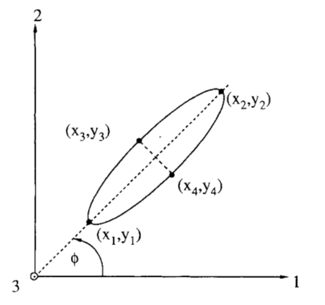

Figure 3: Defining some terms for analyzing the cross-section of an elliptical fiber cut. Phi is the angle between the major axis of the ellipse and the 1 axis, x1, y1 mark the bottom left point of the ellipse, x2, y2 mark the upper right point of the ellipse (the major

calculations

- We find the major (M) and minor (m) axes using

$$
\begin{aligned}
m &= \sqrt{(x_3 - x_4)^2 + (y_3 - y_4)^2} \\
X &= x_1 - x_2 \\
Y &= y_1 - y_2 \\
M &= \sqrt{X^2 - Y^2}
\end{aligned}
$$

orientation tensor

- We can now calculate angles using

$$\sin\phi = \frac{Y}{M}\cos\phi = \frac{X}{M}\cos\theta = \frac{m}{M}\sin\theta = \sqrt{1 - \frac{m^2}{M^2}}$$

microscopy

Figure 4: A microscopic image of a composite laminate, showing plies at different angles

microscopy

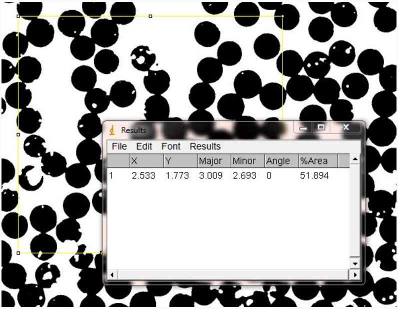

Figure 5: An image from some analysis to find the volume fraction of fibers in an image.

microscopy

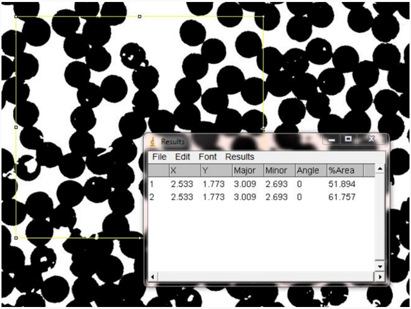

Figure 6: A demonstration that choosing the correct threshold value to convert greyscale images to only black and white is essential to correctly determining the volume fraction.

microscopy

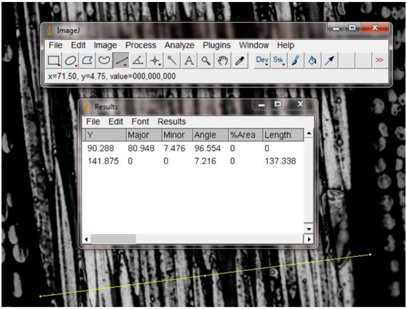

Figure 7: Ply thickness can be measured from a microscopic image

microscopy

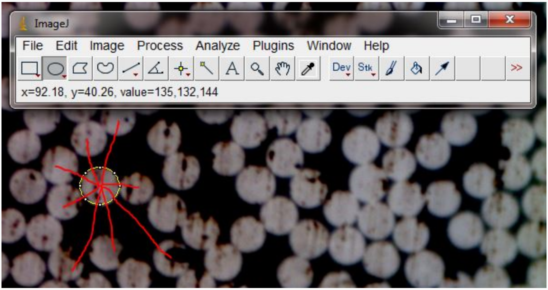

Figure 8: It can also be useful sometimes to measure the distance between a fiber and its nearest neighbors.

software

- If you have to do a lot of microscopy measurements, contact Dr. Sharma, he wrote an automated measurement tool
- Otherwise you can use imageJ[2]

[2] https://imagej.nih.gov/ij/download.html

microscopy

- Need to account for bias in measurement (more likely to see fibers coming out of plane)
- There is some ambiguity in fiber angle
- Fiber at (ϕ, θ) is not distinguishable from $(\phi + \pi, \theta)$
- In the second-order orientation tensor, this affects a_{23} and a_{13}

serial sectioning

- Serial sectioning is a method where you continually polish a specimen after photographing it
- After photograph you grind and polish, then photograph and repeat
- Gives the full 3D state of orientation, but is difficult

CT Scanning

- Even if a CT Scan cannot resolve down to fiber resolution, the gradient information can give an idea of fiber orientation
- This method is not very precise
- But it can view the full-field and detect many forms of damage without destroying a part
- At the micro-scale full orientation can be obtained, but this is not practical for large parts