Testing Anisotropy Materials in Elastic Region

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Introduction

As anisotropic materials become more prominent in today's material billet, there is an ever growing need to understand how these materials behave, particularly in the elastic region of a stress-strain curve. Our team worked to develop and standardize the testing procedures needed to fully characterize all the elastic constants of general anisotropic materials. This required designing mechanical clamps to work with an Instron testing machine to apply shear and tensile forces in a single plane. Once a force was applied and isolated to a single plane, strain measurements were taken based on the relationships in the general compliance matrix, which allowed us to solve for all necessary constants.

Orientation and Isolated Plane Relationships

Because anisotropic materials typically do not have trivial directionality, it is important to define the orientation of each material for continuity. The stiffest orientation based Standardized Compliance Matrix (STF-OS) [1] gives us a standardized way to orient the materials, so long as these conditions are met.

Condition I The $\hat{x}_1$-axis makes S_{11} reach the global minimum, i.e. the stiffest direction in the whole orientations;

Condition II The $\hat{x}_2$-axis makes S_{22} global minimum within the plane perpendicular to $\hat{x}_1$-axis;

Condition III The $\hat{x}_3$-axis complies with the right-hand coordinate system rule;

Condition IV S_{14} and S_{25} reach their minimum values under above conditions.

In addition, the STF-OS compliance matrix reduces the 21 general compliance matrix constants to 18 constants. Below is the STF-OS compliance matrix and the relationships of stress and strain each constant inherits when a single loading plane (corresponding to the plane of stress) is applied.

$$\hat{\mathbf{S}} = {}^{[1]}\begin{bmatrix} \hat{S}_{11} & \hat{S}_{12} & \hat{S}_{13} & \hat{S}_{14} & 0 & 0 \\ & \hat{S}_{22} & \hat{S}_{23} & 0 & \hat{S}_{25} & \hat{S}_{26} \\ & & \hat{S}_{33} & \hat{S}_{34} & \hat{S}_{35} & \hat{S}_{36} \\ & (sym) & & \hat{S}_{44} & \hat{S}_{45} & \hat{S}_{46} \\ & & & & \hat{S}_{55} & \hat{S}_{56} \\ & & & & & \hat{S}_{66} \end{bmatrix} = \begin{bmatrix} \frac{\varepsilon_{11}}{\sigma_{11}} & \frac{\varepsilon_{11}}{\sigma_{22}} & \frac{\varepsilon_{11}}{\sigma_{33}} & \frac{\varepsilon_{11}}{\sigma_{23}} & 0 & 0 \\ & \frac{\varepsilon_{22}}{\sigma_{22}} & \frac{\varepsilon_{22}}{\sigma_{33}} & 0 & \frac{\varepsilon_{22}}{\sigma_{12}} & \frac{\varepsilon_{22}}{\sigma_{13}} \\ (sym) & & \frac{\varepsilon_{33}}{\sigma_{33}} & \frac{\varepsilon_{33}}{\sigma_{23}} & \frac{\varepsilon_{33}}{\sigma_{13}} & \frac{\varepsilon_{33}}{\sigma_{12}} \\ & & & \frac{\varepsilon_{23}}{\sigma_{23}} & \frac{2\varepsilon_{23}}{\sigma_{13}} & \frac{2\varepsilon_{23}}{\sigma_{12}} \\ & & & & \frac{\varepsilon_{31}}{\sigma_{31}} & \frac{2\varepsilon_{12}}{\sigma_{12}} \\ & & & & & \frac{\varepsilon_{12}}{\sigma_{12}} \end{bmatrix}$$

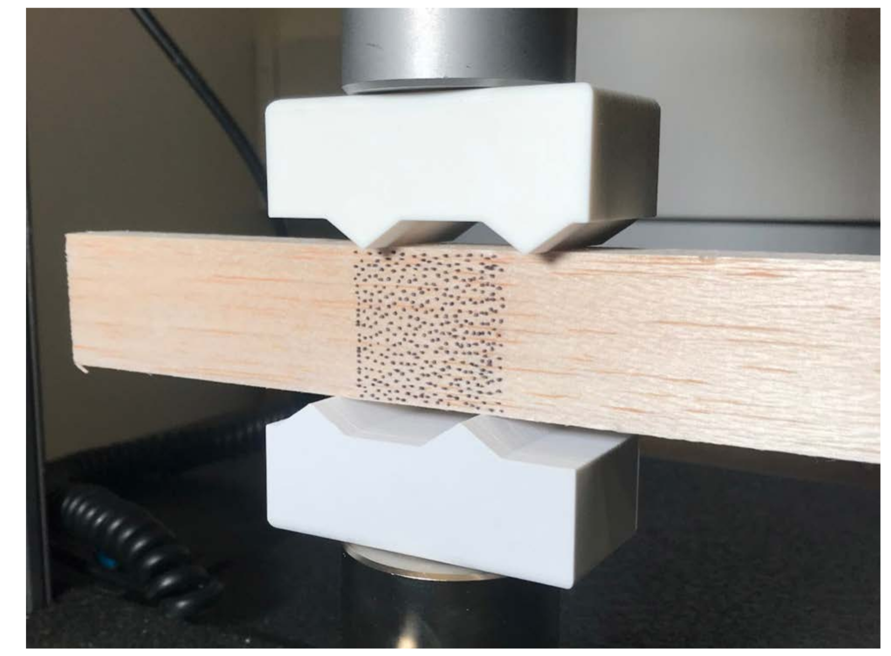
Objectives

- Develop a testing procedure to find all 18 elastic anisotropy constants in the STF-OS matrix.
- Design and manufacture Instron clamps to apply shear and tensile forces in a single loading plane.
- Prove the clamps can isolate a single plane of stress and find results that are within 5% standard error.

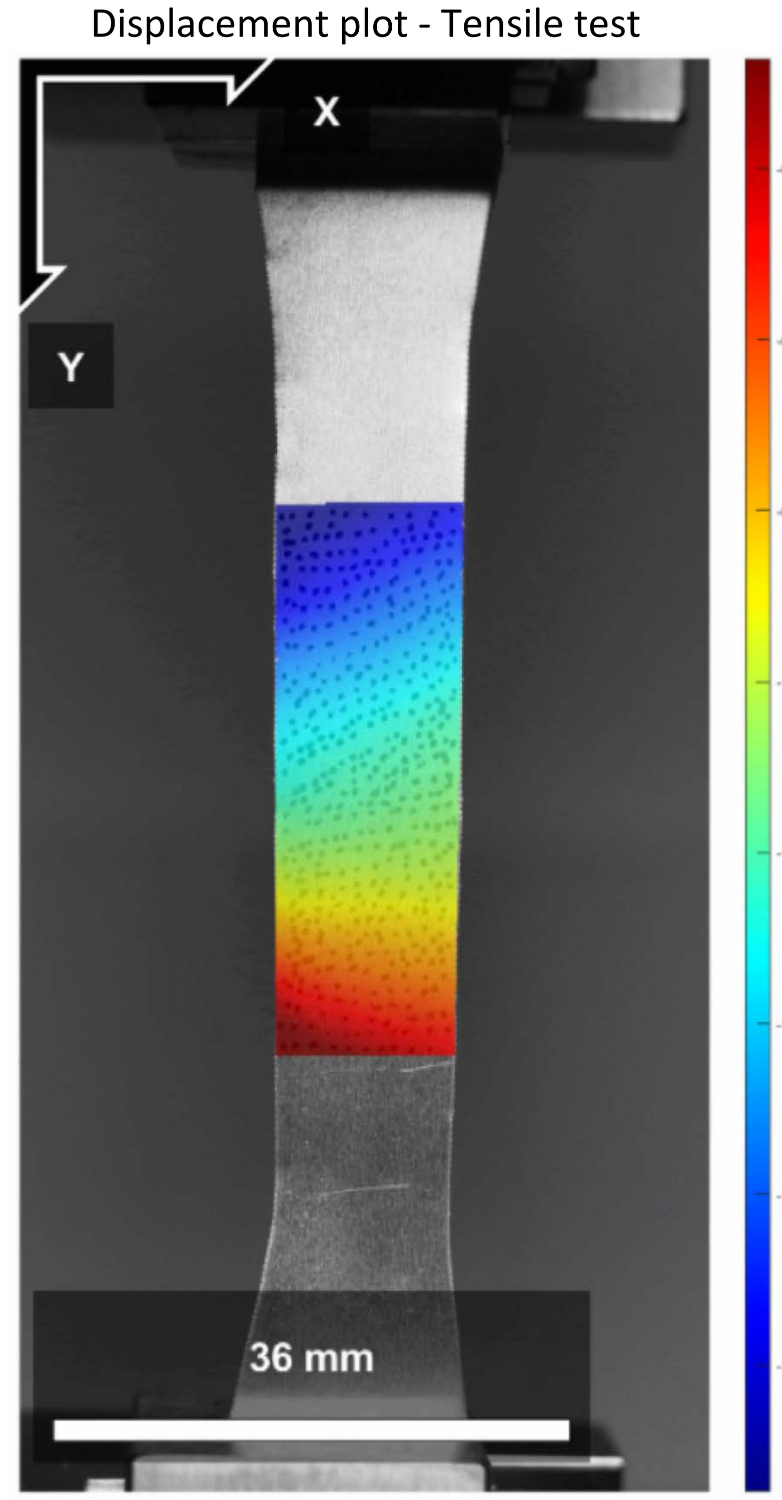
[1] Zhao, Jiamin, Song, Xiaoxiong, Liu, Bin. Standardized compliance matrixes for general anisotropic materials and a simple measure of anisotropy degree based on shear-extension coupling coefficient, AML Department of Engineering Mechanics, Tsinghua University, Beijing 100084, China.

DIC set-up on Instron

Balsa wood sample - Shear test



Displacement plot - Tensile test



User Test Procedures

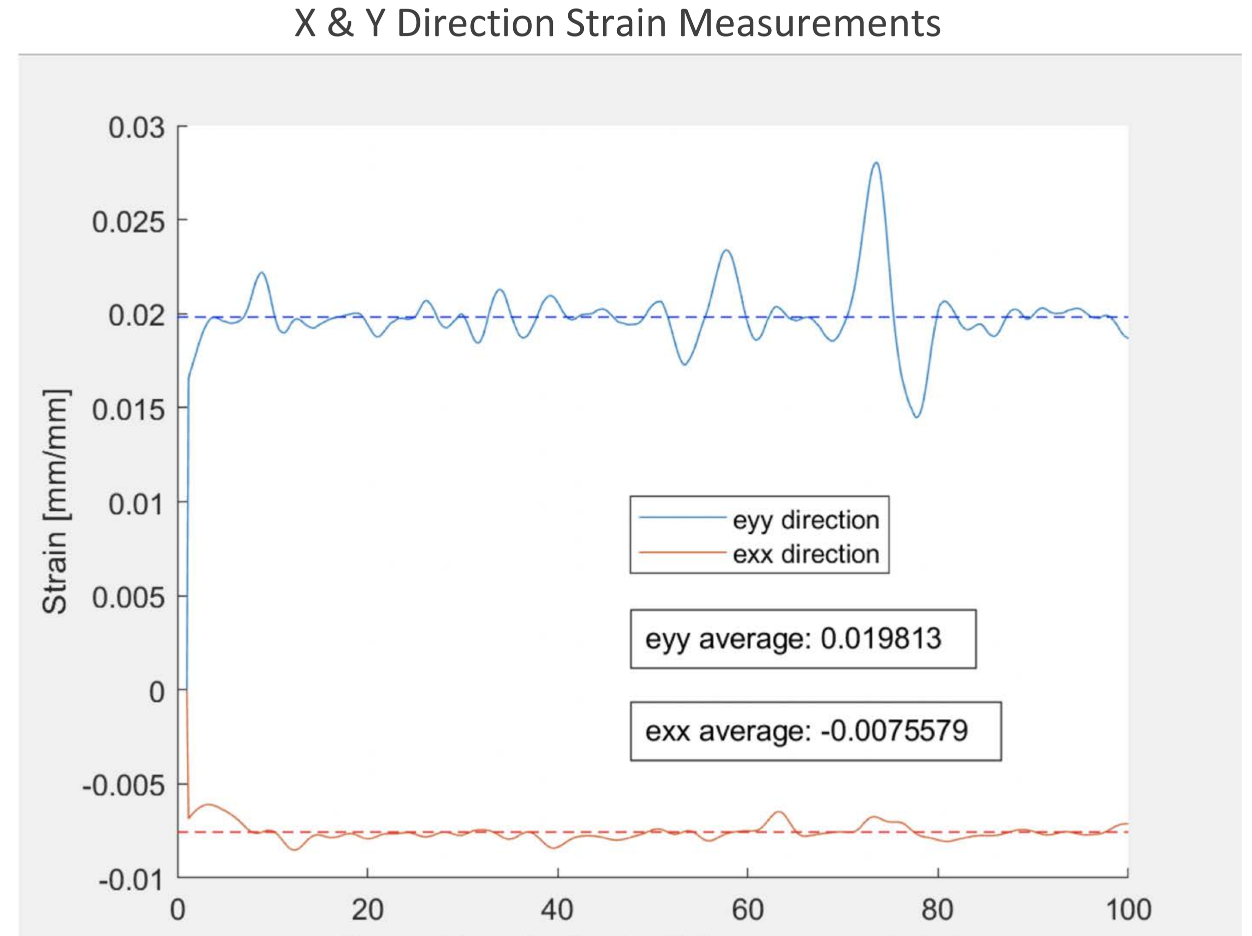
Tensile Tests

- 1 Tensile test in the x_1 direction
  - 1st test measure e_{11} to obtain s_{11}
- 2 Tensile tests in the x_2 direction
  - 1st test will measure e_{22} to obtain s_{22}
  - 2nd test will measure e_{11} to obtain s_{12}
- 3 Tensile tests in x_3 direction
  - 1st test measure e_{33} to obtain s_{33}
  - 2nd test measure e_{11} to obtain s_{13}
  - 3rd test measure e_{22} to obtain e_{23}

Shear Tests

- 3 pure shear tests in x_{23} plane
  - 1st test measure e_{23} to obtain s_{44}
  - 2nd test measure e_{11} to obtain s_{14}
  - 3rd test measure e_{33} to obtainss_{34}
- 4 pure shear tests in x_{13} plane
  - 1st test measure e_{13} to obtain s_{55}
  - 2nd test measure e_{22} to obtain s_{25}
  - 3th test measure e_{33} to obtain s_{35}
  - 4th test measure e_{23} to obtain s_{45}
- 5 pure shear tests in x_{12} plane
  - 1sd test measure e_{22} to obtain s_{26}
  - 2st test measure e_{12} to obtain s_{66}
  - 2nd test measure e_{33} to obtain s_{36}
  - 3rd test measure e_{23} to obtain s_{46}
  - 4th test measure e_{12} to obtain s_{56}
  - 5rd test measure e_{22} to obtain s_{26}

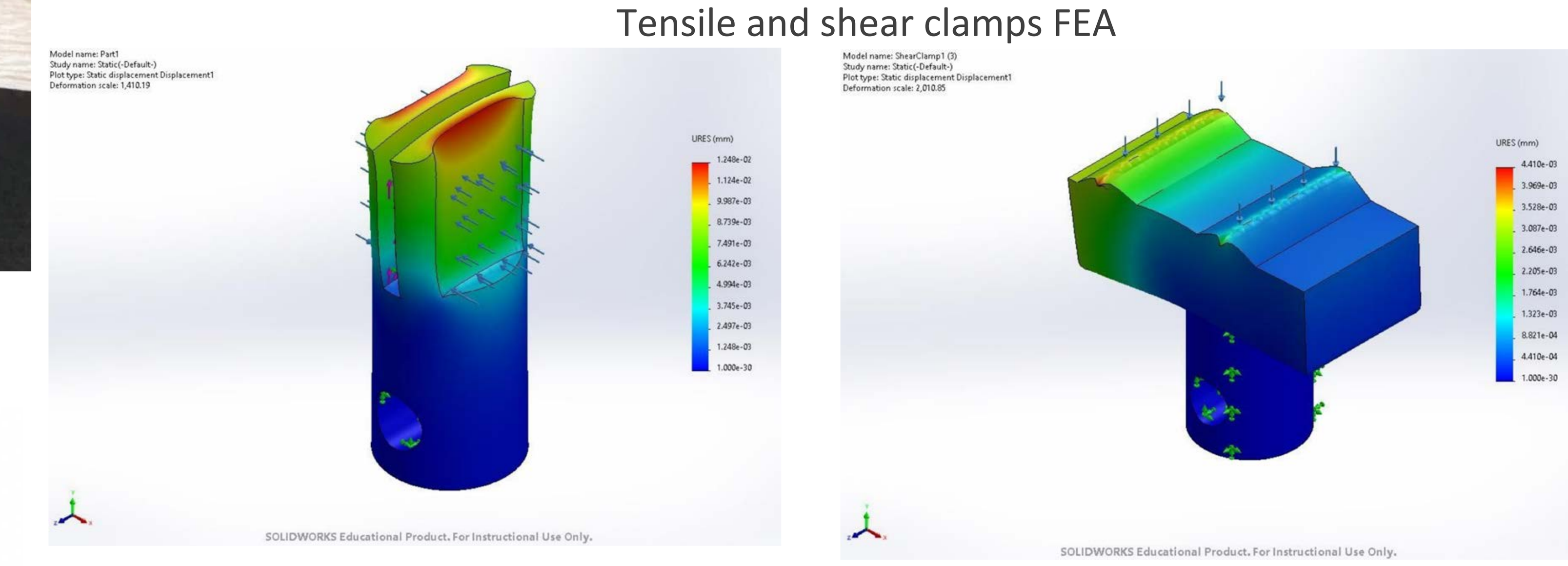
X & Y Direction Strain Measurements



Clamps

The clamps used were 3D printed from PLA material and are designed to apply shear and tensile forces in a single loading plane. To prove the accuracy of the obtained results, our group tested materials with published data and compared that to our actual data. The clamps proved to be reliable because we found a standard error of < 5%. This proves that our clamps can apply force to a single plane without any planes experiencing residual forces.

Tensile and shear clamps FEA



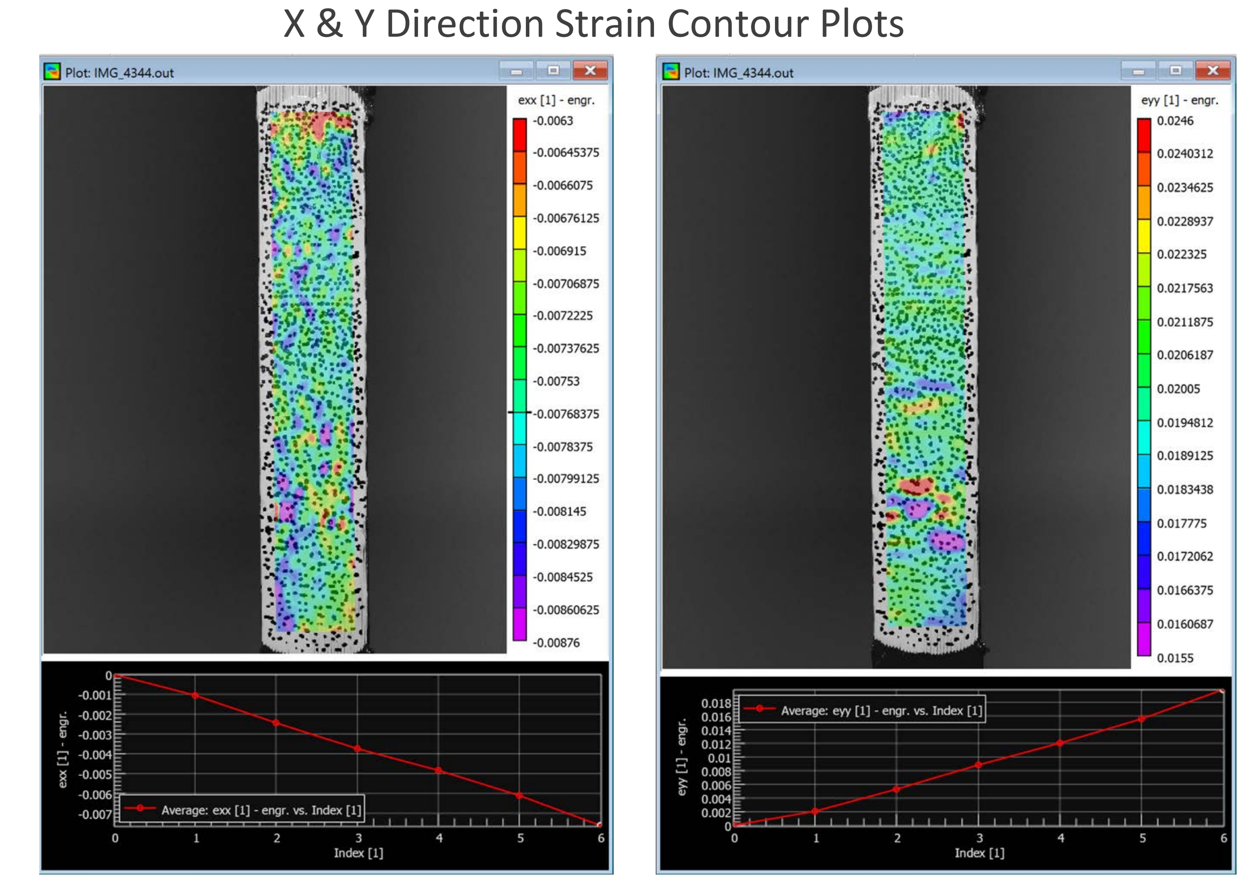
Testing Procedure

We concluded that the easiest way to solve for all STF-OS Compliance Matrix constants is to isolate the force applied to a single stress plane and measure the subsequent strain's associated with the relevant constants. On the left, "User Test Procedures" is a user manual to solve for all constants in the STF-OS Compliance Matrix, assuming a single strain is measured per test.

Digital Image Correlation (DIC)

DIC is a full-field non-contact optical technique that allows us to measure displacement and strain on almost any material. A speckle pattern is created on our sample, and as the sample is being deformed, images are taken at periodic time increments. These images are then processed to get very precise fields of sample displacement and strains. The two DIC softwares that we used are Vic2D and NCorr, along with a combination of MATLAB and image for further calculations and image processing. The use of 2D DIC allowed us to measure strain in multiple directions at once, which reduced the amount of testing needed. Having the strains measured in multiple directions (i.e. x, y, xy, directions) was essential to later calculating the elastic constants.

X & Y Direction Strain Contour Plots



Conclusion

Our idea to find elastic constants of anisotropic materials by defining the stress and strain relationships of each constant under a single loading plane, and creating the subsequent testing procedure, will hopefully further advance the area of anisotropic material testing. This procedure is repeatable and can be applied across all fields of anisotropic material testing. Although our clamps performed adequately for our testing purposes, future work may focus on redesigning our clamps to accommodate stronger and thicker materials.