Composite Material Testing and Analysis

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Kellogg Honors College Capstone Project

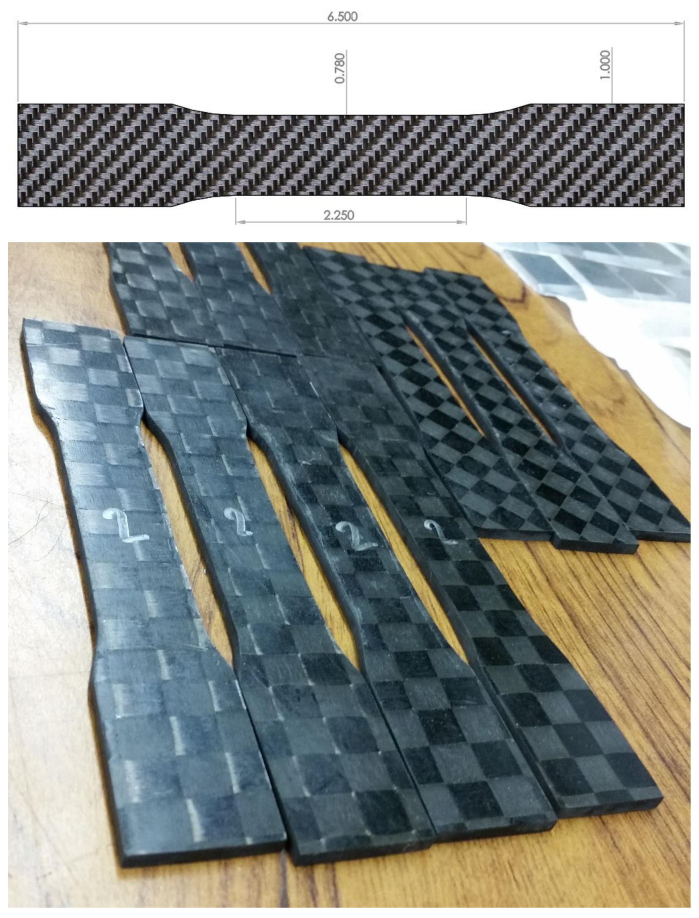


Figure 1. Sample Geometry

Goals:

- Experimentally test a carbon fiber composite material using a 4 point bend test
- Extract material properties from experimental data
- Use classical lamination theory to compare stresses in the sample to theory
- Use the values obtained by experiment and theory to validate the Hyperworks Finite Element Analysis software

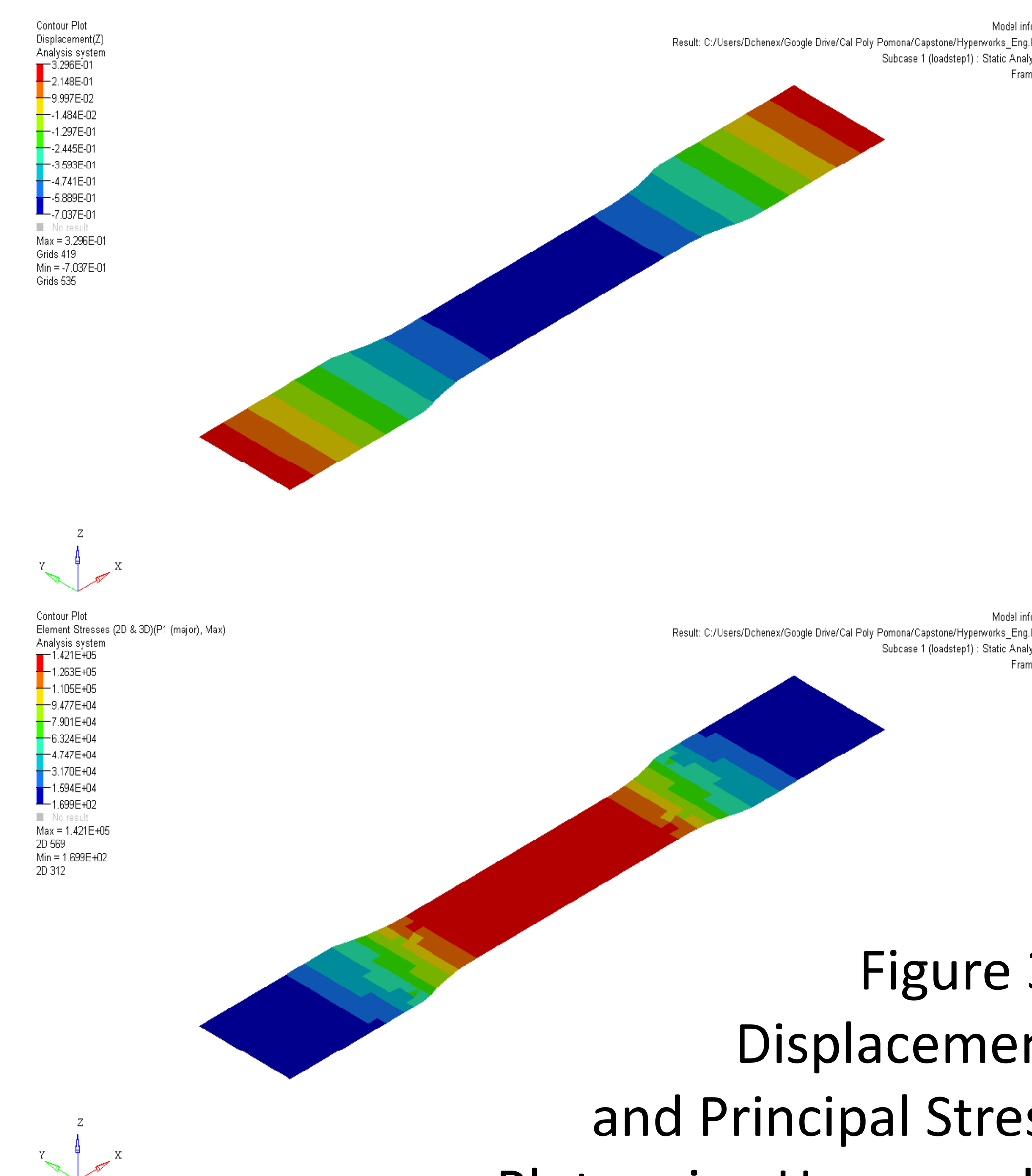


Figure 3. Displacement and Principal Stress Plots using Hyperworks

Four Point Bend Tests:

- Requires test fixture as shown in Figure 2
- Uses a simpler sample geometry
- Used instead of a tension test for testing brittle material where the number of flaws exposed to the testing stress is related to the strength of the material
- A four point bend test provides a uniform load distribution over a section of the sample

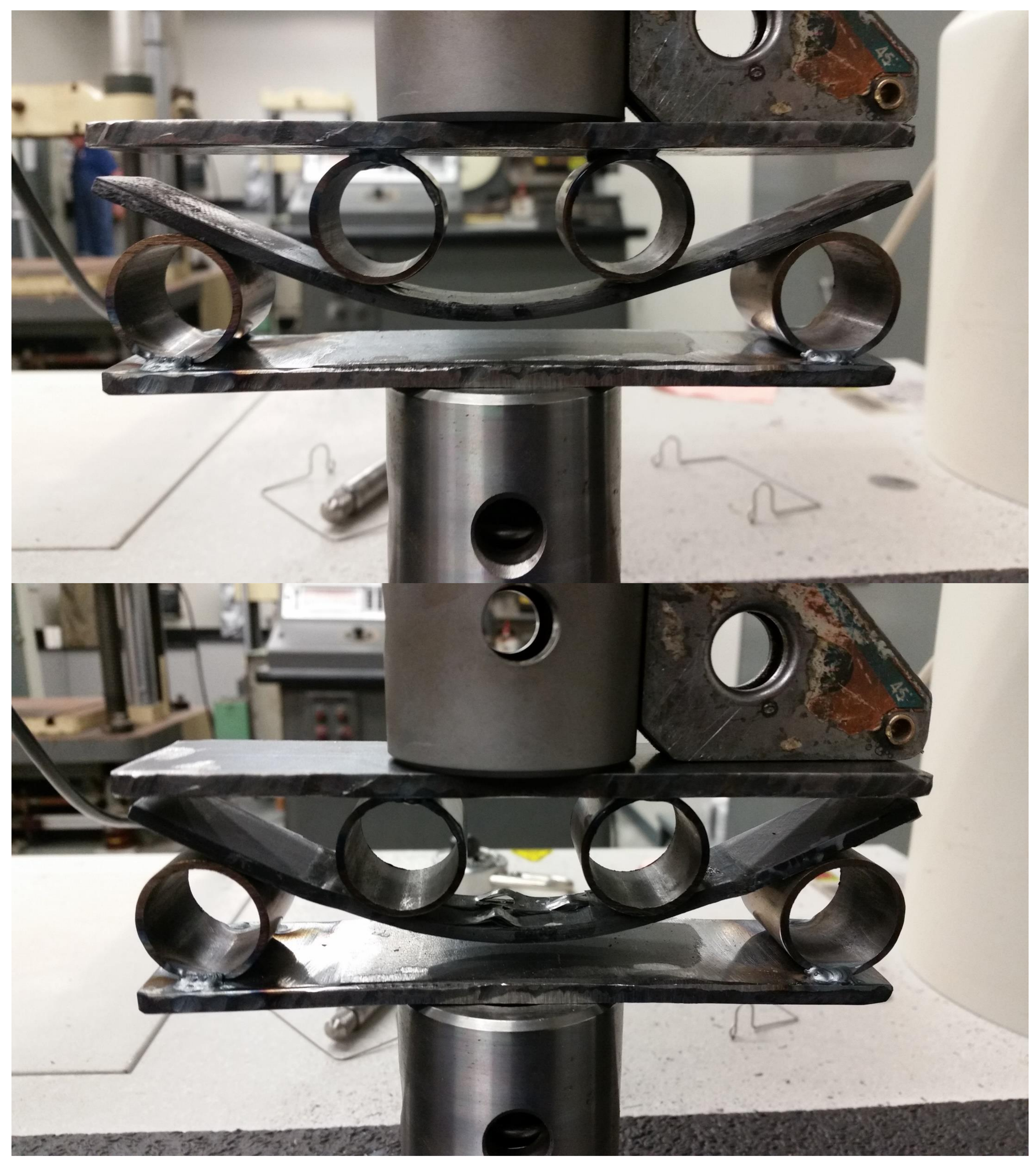


Figure 2. Four Point Bend Test

Hyperworks Finite Element Analysis:

- Hyperworks Suite by Altair:
  - Hypermesh pre processing
  - Optistruct Solver
  - Hyperview post processing
- Created a simulation as representative of the experiment as possible (Figure 3)
- Input material properties found to validate the results of the composite FEA solver

Experiment:

1. Layup large sheet of CFRP prepreg made with 16 layers
2. Cut 6 samples in the dimensions shown in Figure 1, 3 in the 0° direction and 3 in the 90° direction
3. Conduct a four point bend test on the sample using a Bluehill Instron machine and record the data

Classical Lamination Theory (CLT):

- Developed to analyze the stresses in laminates
- Laminates behave dissimilarly to isotropic material because of the anisotropic properties of the lamina and coupling effects due to the stacking sequence of the laminate
- In classical lamination theory, layers are assumed to deform by developing the strains and curvatures in the mid-plane ply
- Using the equations to the right, the stresses in each layer can be found

$$\begin{bmatrix}\mathbf{N}\\ \mathbf{M}\end{bmatrix} = \begin{bmatrix}\mathbf{A} & \mathbf{B}\\ \mathbf{B} & \mathbf{D}\end{bmatrix}\begin{bmatrix}\varepsilon^0\\ \kappa\end{bmatrix}$$

$$\mathbf{A} = \sum_{j=1}^{N} \mathbf{Q}^* \left(z_j - z_{j-1}\right)$$

$$\mathbf{B} = \frac{1}{2}\sum_{j=1}^{N} \mathbf{Q}^* \left(z_j^2 - z_{j-1}^2\right)$$

$$\mathbf{D} = \frac{1}{3}\sum_{j=1}^{N} \mathbf{Q}^* \left(z_j^3 - z_{j-1}^3\right)$$

$$\begin{Bmatrix}N_x\\ N_y\\ N_{xy}\end{Bmatrix} = \int_{-t/2}^{t/2}\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{Bmatrix} dz$$

$$\begin{Bmatrix}M_x\\ M_y\\ M_{xy}\end{Bmatrix} = \int_{-t/2}^{t/2}\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{Bmatrix} z\, dz$$

CLT Equations

Principal Stresses in Individual Layers Using CLT

Layer	σ1 [psi]	σ2 [psi]	τ12 [psi]
1	0	-129090	0
2	0	-111878	0
3	0	-94666	0
4	0	-77454	0
5	0	-60242	0
6	0	-43030	0
7	0	-25818	0
8	0	-8606	0
9	0	8606	0
10	0	25818	0
11	0	43030	0
12	0	60242	0
13	0	77454	0
14	0	94666	0
15	0	111878	0
16	0	129090	0

Data:

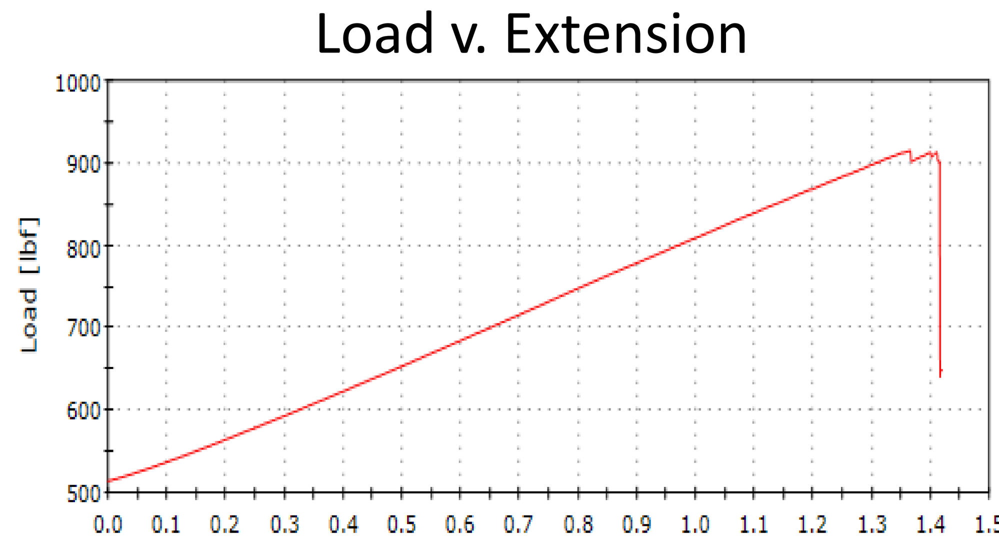
4 Point Bending Test Data Summary

Sample	Thickness [in]	Width [in]	Total Force [lbs]	Total Deflection [in]
1	0.129	0.788	399.50	0.564
2	0.132	0.781	422.08	0.624
3	0.134	0.776	428.96	0.570
4	0.131	0.768	419.10	0.576
5	0.135	0.779	434.58	0.545
6	0.134	0.775	412.31	0.566
Average	0.132	0.776	416.99	0.570

Flexural Strength Experimental Results

Sample	Total Force [lbs]	Flexural Strength [psi]
1	399.50	131645.79
2	422.08	139086.27
3	428.96	141353.12
4	419.10	138105.21
5	434.58	143205.80
6	412.31	135868.98
Avg	416.99	137410.37

Example Graph from Bluehill software: Load v. Extension



Comparison of Flexural Strength:

There is a 6.0% error between CLT and the experimental results and a 3.4% error between FEA and experimental resutls. The Hyperworks FEA is an accurate but conservative estimate of the material's strength.

Comparison of Flexural Strength

SpaceX Reported Strength [ksi]	Average Experimental Strength [ksi]	Classical Lamination Theory Stress [ksi]	Finite Element Analysis Stress [ksi]
111.0	137.4	129.1	142.1