Lab 5 – Composite Laminate Design

Section 5, Group 5
Ethan Pickard, Isaac Pollard, Joseph Spewock, Lucas Tavares
10/06/2023

Introduction

Composites are materials formed by merging two or more different materials with different characteristics, developing a new material with properties that are better than those of the original materials for specific applications. They are composed of matrices and fibers. For this lab, we focused on designing and evaluating a fiber-reinforced composite, which is common in the aerospace industry. The fiber-reinforced composite is transversely isotropic and possesses 5 independent constants required to describe its material property.

Classical Laminate Theory (CLT) is a powerful tool for understanding and predicting the mechanical behavior of laminated composite materials. Engineers use CLT to optimize the stacking sequence of laminae to achieve specific mechanical properties, such as stiffness, strength, or weight savings while considering design constraints. Based on the applied loads and material properties, the theory can also be used to predict the failure modes of laminates, such as delamination, fiber breakage, or matrix cracking. It is widely used in aerospace, automotive, and other industries where lightweight and high-strength materials are essential for structural design.

We aim to achieve a maximized twist angle by varying key parameters in the design of fiber-reinforced composite laminates.

Hypothesis

In this lab, we hypothesize that smaller orientation angles in layups resulted in better twist curvature up to a certain point.

Methods and procedure

The first step in our process involved setting up the initial conditions for our given fiber laminate. This material is assigned a given elastic modulus, and modulus of twist E and G of 228 and 120 Gpa respectively. Our plan for discerning an optimal angle for each layer involved beginning at the initial pattern given in the lecture as a control, [-90/-90/-90/-90], and reducing the angle in diminishing sequential steps to reach a maximum. The first jump was 30 degrees, then 15, the angle change through each design would decrease each time as we iteratively converged upon an optimal value.

To avoid reaching unrealistic values for the offset, we also chose from the beginning not enter the region between 10 and 0 degrees, as we felt a laminate design of that type would be too close to having no layer difference at all, which could also cause issues in theoretical estimation.

Our first unique design as with an offset of 60 degrees, which almost certainly would increase K_{xy}. We then jumped down 45 degree offset, assuming this led to an increase we would continue down to 30, etc. until a reduction in K_{xy} was perceived then choose a reduced angle to increase by.

Work Assignments

For the Lab itself we all did this in a group and tested our own ideas and patterns to see what the strongest pattern was and one that made the most sense. Since this was done on our own computers and we did not have any setup this was all that was done as a group for the lab.

The lab report introduction and conclusion section were done by Lucas. The methodology and procedure sections were done by Isaac. The results and analysis were split between Joseph and Ethan, and everyone contributed to the analysis in some way.

Results

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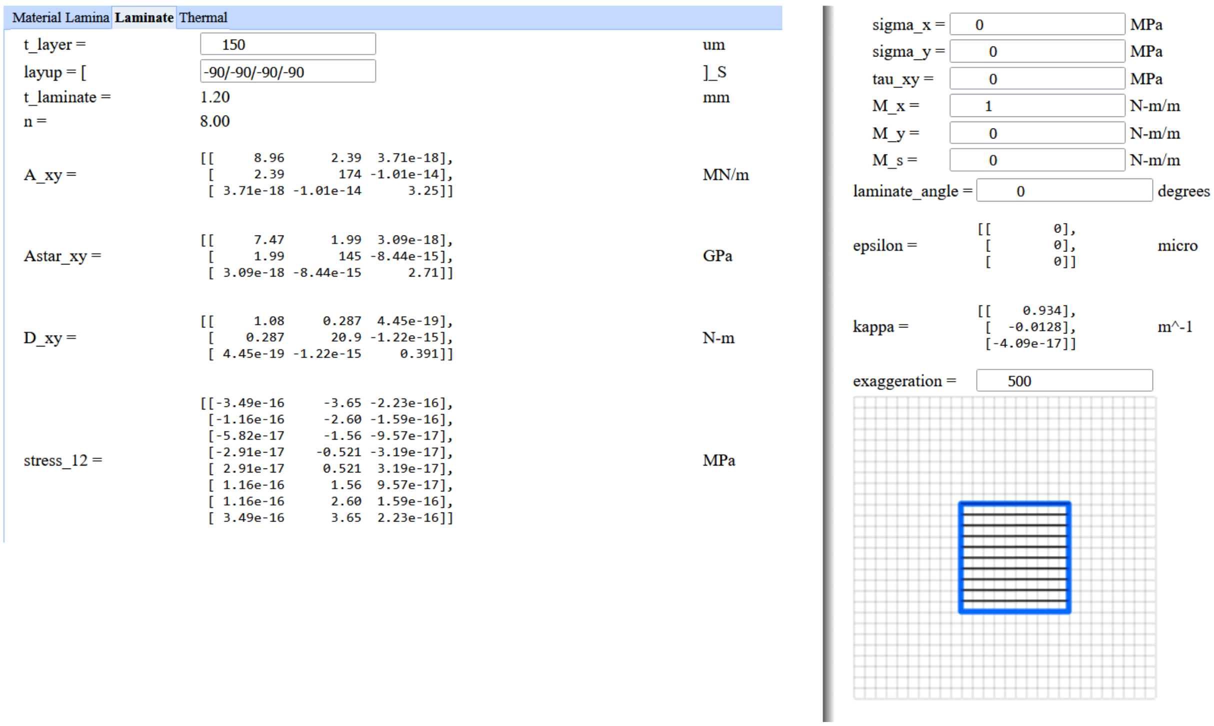

Figure 1. Layup design one

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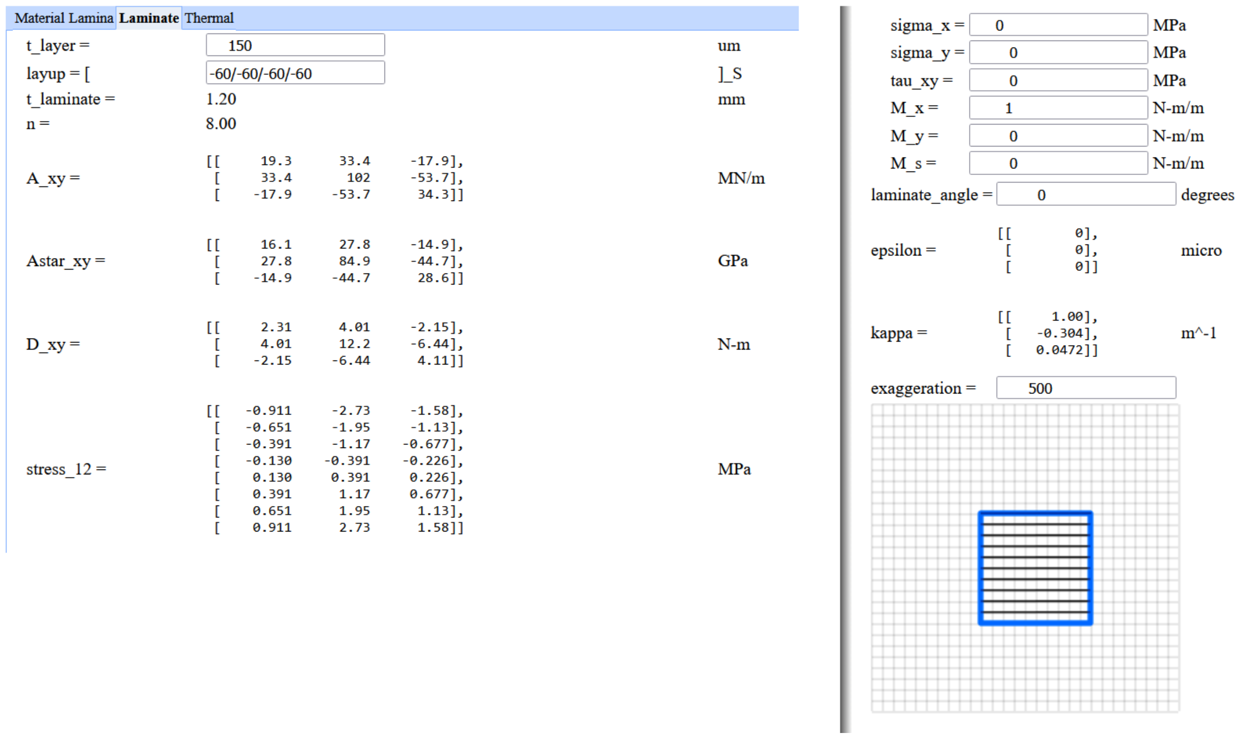

Figure 2. Layup design two

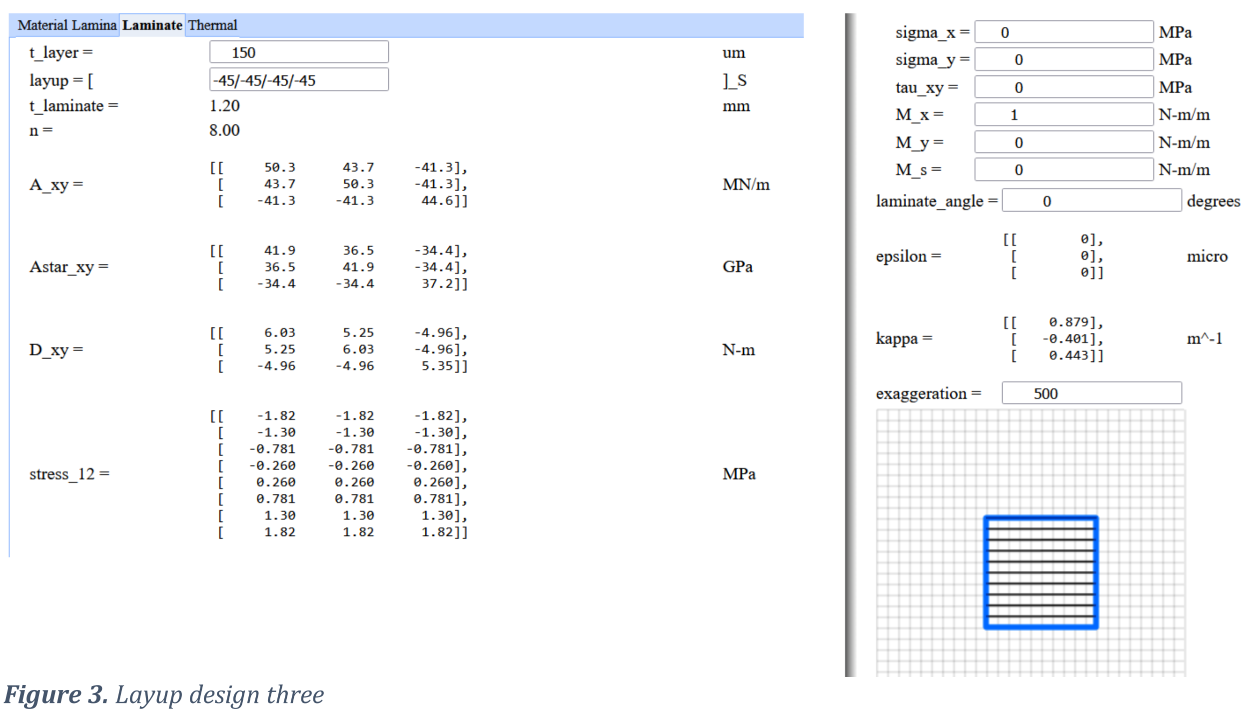

Figure 3. Layup design three

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Material Lamina **Laminate** Thermal

t_layer =	150	um
layup = [	-30/-30/-30/-30	]_S
t_laminate =	1.20	mm
n =	8.00	

```
A_xy =      [[     102      33.4     -53.7],      MN/m
             [    33.4      19.3     -17.9],
             [   -53.7     -17.9      34.3]]

Astar_xy =  [[    84.9      27.8     -44.7],      GPa
             [    27.8      16.1     -14.9],
             [   -44.7     -14.9      28.6]]

D_xy =      [[    12.2      4.01     -6.44],      N-m
             [    4.01      2.31     -2.15],
             [   -6.44     -2.15      4.11]]

stress_12 = [[   -2.73    -0.911     -1.58],      MPa
             [   -1.95    -0.651     -1.13],
             [   -1.17    -0.391    -0.677],
             [  -0.391    -0.130    -0.226],
             [   0.391     0.130     0.226],
             [    1.17     0.391     0.677],
             [    1.95     0.651      1.13],
             [    2.73     0.911      1.58]]
```

sigma_x =	0	MPa
sigma_y =	0	MPa
tau_xy =	0	MPa
M_x =	1	N-m/m
M_y =	0	N-m/m
M_s =	0	N-m/m
laminate_angle =	0	degrees

```
epsilon =   [[        0],      micro
             [        0],
             [        0]]

kappa =     [[    0.561],      m^-1
             [   -0.304],
             [    0.720]]
```

exaggeration = 500

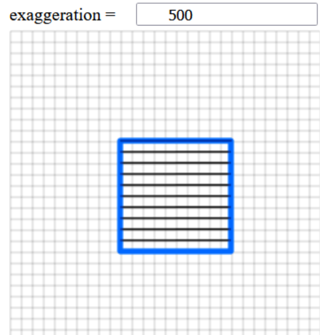

Figure 4. *Layup design four*

Material Lamina **Laminate** Thermal

t_layer =	150	um
layup = [	-15/-15/-15/-15	]_S
t_laminate =	1.20	mm
n =	8.00	

```
A_xy =      [[     153      12.7     -38.6],      MN/m
             [    12.7      9.69     -2.76],
             [   -38.6     -2.76      13.6]]

Astar_xy =  [[     127      10.6     -32.1],      GPa
             [    10.6      8.08     -2.30],
             [   -32.1     -2.30      11.3]]

D_xy =      [[    18.3      1.53     -4.63],      N-m
             [    1.53      1.16    -0.331],
             [   -4.63    -0.331      1.63]]

stress_12 = [[   -3.40    -0.244    -0.911],      MPa
             [   -2.43    -0.174    -0.651],
             [   -1.46    -0.105    -0.391],
             [  -0.486   -0.0349    -0.130],
             [   0.486    0.0349     0.130],
             [    1.46     0.105     0.391],
             [    2.43     0.174     0.651],
             [    3.40     0.244     0.911]]
```

sigma_x =	0	MPa
sigma_y =	0	MPa
tau_xy =	0	MPa
M_x =	1	N-m/m
M_y =	0	N-m/m
M_s =	0	N-m/m
laminate_angle =	0	degrees

```
epsilon =   [[        0],      micro
             [        0],
             [        0]]

kappa =     [[    0.204],      m^-1
             [   -0.110],
             [    0.558]]
```

exaggeration = 500

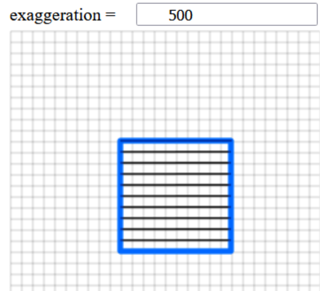

Figure 5. *Layup design five*

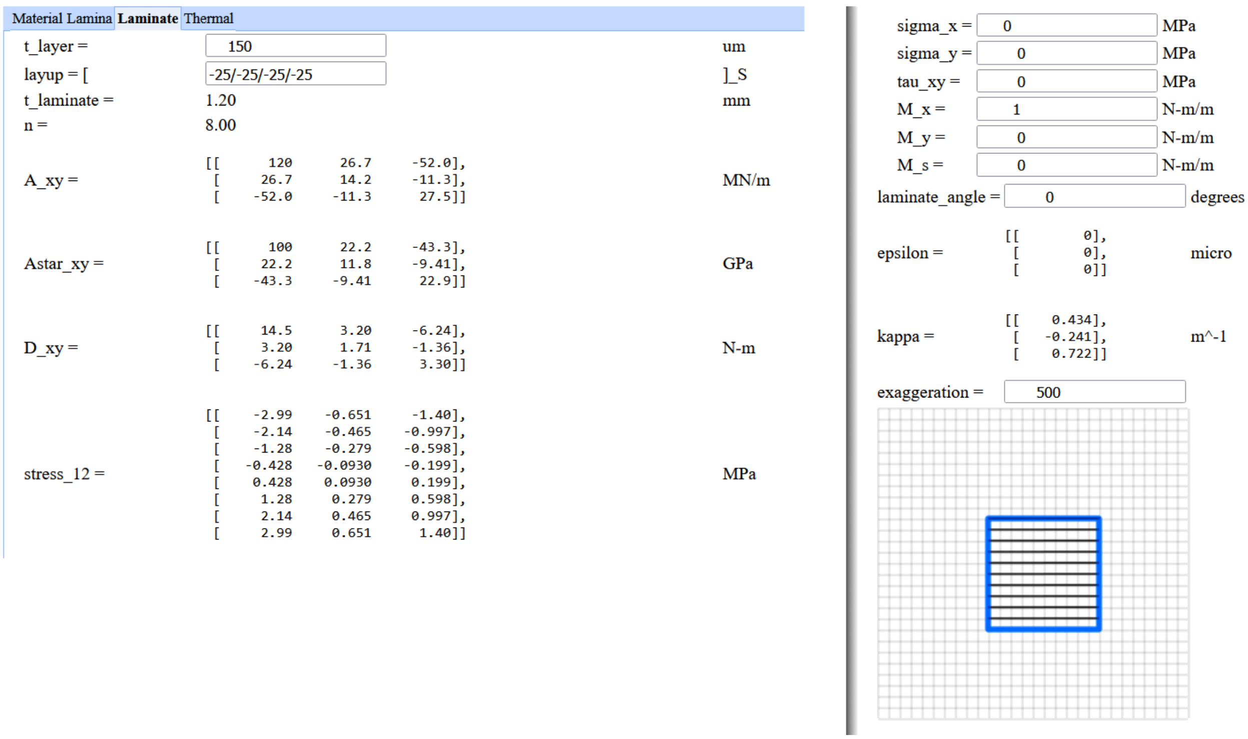

__Figure 6.__ Layup design six

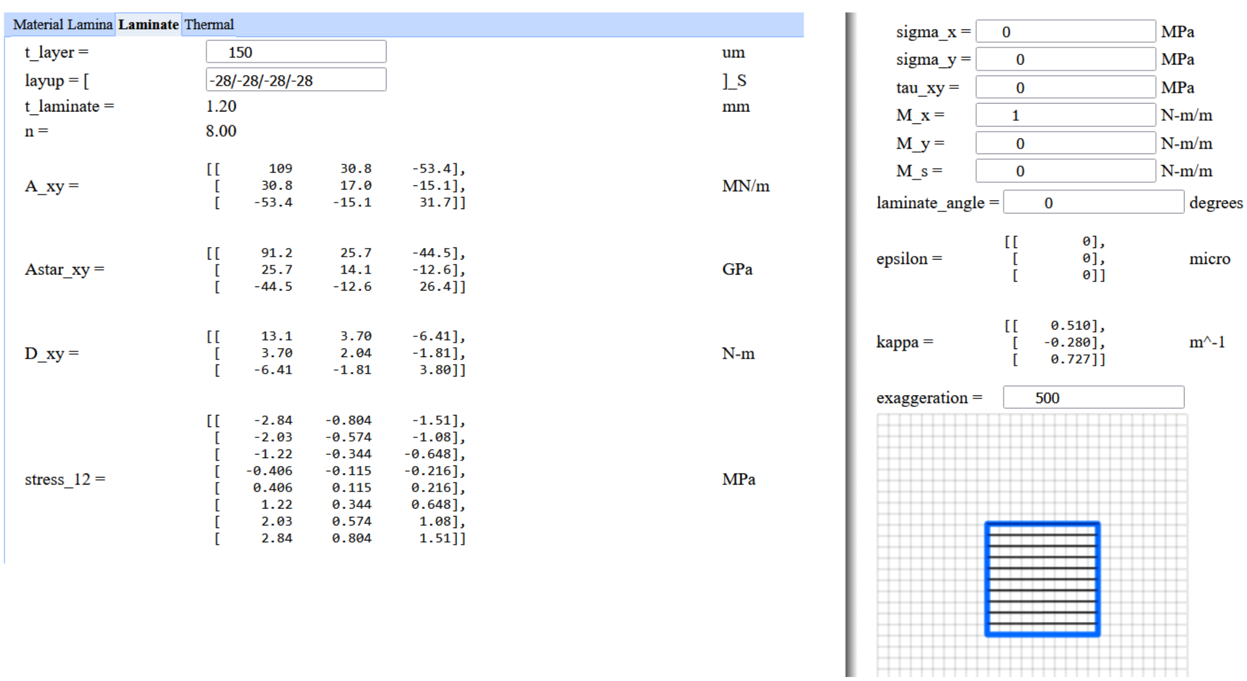

__Figure 7.__ Layup design seven

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Analysis

1)

Stiffness matrix $B = \frac{1}{2}\sum_{i=1}^{k} \bar{Q}_i \left(z_{i+1}^2 - z_i^3\right)$

use matrix components to get to:

$[A^*] = [A]^{-1}$ $[B^*] = -[A]^{-1}[B]$, $[C^*] = [B][A^{-1}]$ $[D^*] = [D] - [B][A]^{-1}[B]$

$D^* = D + [B][B^*]$ $[C^*] = -[B^*]^T$

Since $\{\epsilon^0\} = [A]^{-1}\{N\} - [A]^{-1}[B]\{k\}$

$\{N\} = [A]\{\epsilon^0\} + [B]\{k\}$

$\{M\} = B\{\epsilon^0\} + [D]\{k\}$

We can rewrite to: $\begin{Bmatrix}\epsilon^0\\ M\end{Bmatrix} = \begin{bmatrix}A^* & B^*\\ C^* & D^*\end{bmatrix}\begin{Bmatrix}N\\ k\end{Bmatrix}$

Now $\{k\} = -[D^*]^{-1}[C^*]\{N\} + [D^*]^{-1}\{M\}$

$\Rightarrow \{\epsilon^0\} = \left([A^*] - [B^*][D^*]^{-1}[C^*]\right)\{N\} + [B^*][D^*]^{-1}\{M\}$

By combining equations $\begin{Bmatrix}\epsilon^0\\ k\end{Bmatrix} = \begin{bmatrix}A' & B'\\ B'^T & D'\end{bmatrix}\begin{Bmatrix}N\\ M\end{Bmatrix}$ ← Fully inverted

We can then use to find

$A' = [A]^{-1} + [A]^{-1}[B][D^*]$, $B' = -[A]^{-1}[B][D^*]^{-1}$

$[C'] = -[D^*]^{-1}[B][A]^{-1} = [B']^T$, $[D'] = \left([D] - [B][A]^{-1}[B]\right)^{-1}$

$\begin{bmatrix}A' & B'\\ B'^T & D'\end{bmatrix}$ also $\begin{bmatrix}A & B\\ B & D\end{bmatrix}$ ← Both are symmetric making $[B] = 0$

2) The force component that effects the twist curvature is the moment in the x-direction, as this would create a strain in the xy plane. This is only the case if the composite has symmetry, if it does not then all other forces and moments can have some effect on the twist curvature.
3) In the first design cycle, the layup chosen was [-90/-90/-90/-90]. There wasn't really a specific reason for choosing 90, it was solely selected for a starting point. The normal bending moment was set to 1 N-m/m and stayed that way for all design

cycles. The reason it was set to 1 was because the lab said to set it to a nominal value. This layup design resulted in a twist curvature (K_{xy}) of -4.09e-17.

K_{xy} for design cycle one was very small, so something had to change for design cycle two. The layup chosen was [-60/-60/-60/-60]. This was chosen because in the lecture slides, it was noticed that generally smaller angles resulted in better twist curvature up to certain point. The change of the layup design resulted in a K_{xy} value of 0.0472.

Lowering the angle seemed to be effective in the last cycle, so it was done again for cycle three. The layup design chosen was [-45/-45/-45/-45]. Again, lowering the angle made an increase in the twist curvature. This cycle resulted in a K_{xy} value of 0.443.

Following the same pattern that seemed to be working, a layup design of [-30/-30/-30/-30] was chosen. The laminate orientation was lowered 15 degrees because so far we have noticed that lowering orientation angle has resulted in a greater K_{xy} value. The test was ran and gave a K_{xy} value of 0.720.
Design cycle four had a layup design of [-15/-15/-15/-15]. This was seclected because lowering the angle seemed to be an effective way to produce a greater K_{xy} value. The results from this test gave us a K_{xy} value of 0.558.

In the previous design cycle, it was noticed that lowering the angle by 15 degrees resulted in a decrease in the K_{xy} value. For this cycle, we decided to pick a number between 15 and 30 degrees. The layup design chosen was [-25/-25/-25/-25] and produced a K_{xy} value of 0.722.

The previous cycle resulted in the greatest K_{xy} value yet, so it was decided to raise the orientation angle a little closer to 30 degrees. A layup design of [-28/-28/-28/-28] was chosen and resulted in a K_{xy} value of 0.727.

Overall, after seven design cycles were run, the greatest K_{xy} value produced was 0.727. Raising the normal bending moment would have made this number larger, but the lab instructions said to keep this value nominal.

Conclusions

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The objective was to test how varying key parameters in the design of fiber-reinforced composite laminates could maximize the twist angle. The focus of our designs was to vary the angles of the layups. Repeating design cycles and optimizing them by trial and error, we observed that the maximized K_{xy} would be with an orientation angle in between 25 and 30 degrees. For the designs tested, we could achieve a maximum value of $K_{xy} = 0.727$ for the layup design of [-28/-28/-28/-28].

References

Chiou, Thomas. “Lab 5 composite laminates design (starts Sep 25).pdf” Iowa State University. 2023