United Arab Emirates university
College of Engineering
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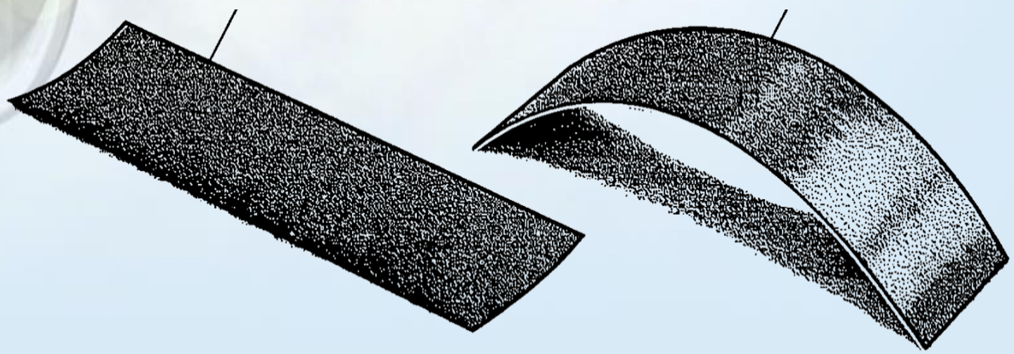

Project title:

Cured Shapes of Unsymmetric Composite Laminates

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Outline

- Scope
- Objectives
- Introduction
- Modeling
- Experimental Procedure
- Results and Discussion

Scope

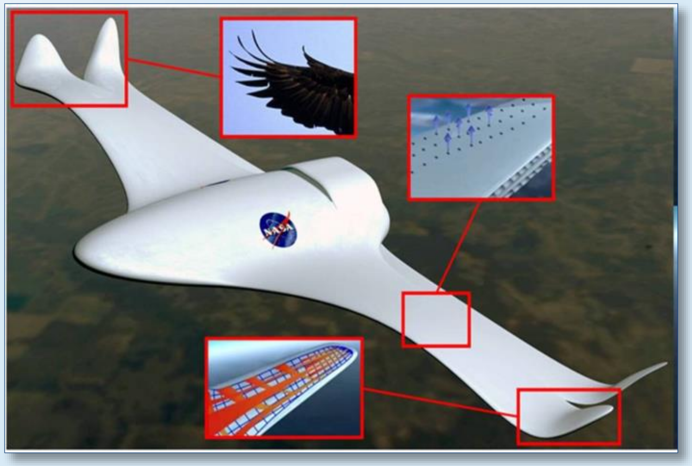
Important topic in Morphing

Motivate us to choose this topic

Scope

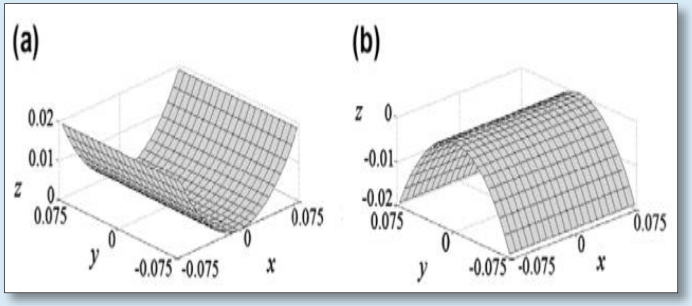
- **What is Morphing?**

✓ Ability to change configuration as per the demand of the operation or the environment.



- **Morphing concepts**

1. Continuously powered actuators to deform structure.
2. Use multi-stable materials; actuators for only changing the shape



Objectives

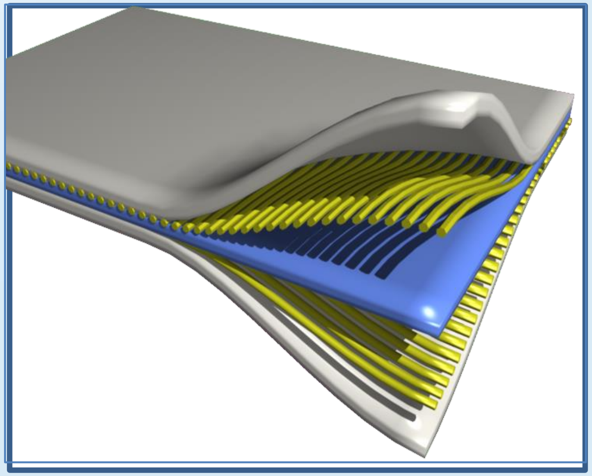
1- Understand the mechanics of un-symmetric laminates.

2- Find un-symmetric laminates’ shapes when they are cooled to room temperature.

Introduction

- **What is a laminated composite material?**

  Matrix of fibers set in a matrix of plastic or epoxy resin oriented in a specific direction stacked in layers.



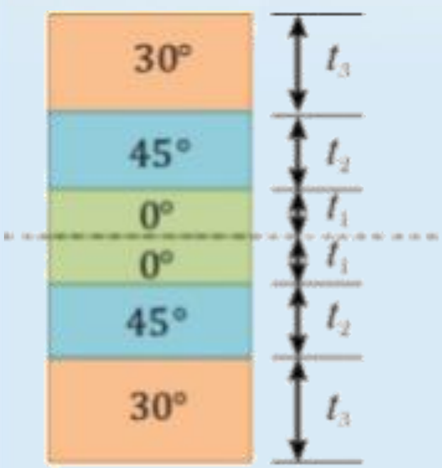
- **Properties of Laminated composites:**

  Depend on layers:

  - Material
  - Number and orientation
  - Dimensions

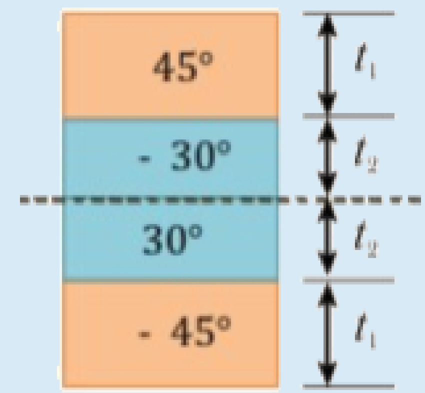
Introduction

- The laminates can be stacked into two manner :



Symmetric

Un- symmetric



Theoretical Model

- Many previous approximation theories have been conducted.

Model Summary:

Stress-strain relations: $$\begin{pmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \tau_{xy}\end{pmatrix} = \begin{pmatrix}Q_{11} & Q_{12} & 0\\ Q_{12} & Q_{22} & 0\\ 0 & 0 & Q_{66}\end{pmatrix} * \begin{pmatrix}\varepsilon_{x}\\ \varepsilon_{y}\\ \varepsilon_{xy}\end{pmatrix}$$

1. Calculate laminate reduced stiffness matrix

$$\boxed{Q_{ij} = \begin{bmatrix}Q_{11} & Q_{12} & 0\\ Q_{12} & Q_{22} & 0\\ 0 & 0 & Q_{66}\end{bmatrix}}$$

$$Q_{11} = \frac{(\mathrm{E}_{11})^2}{\mathrm{E}_{11} - \mathrm{v}_{12} * \mathrm{E}_{22}}$$

$$Q_{12} = \mathrm{v}_{12} * \mathrm{E}_{11} * \frac{\mathrm{E}_{22}}{\mathrm{E}_{11} - (\mathrm{v}_{12})^2 * \mathrm{E}_{22}}$$

$$Q_{22} = \mathrm{E}_{11} * \frac{\mathrm{E}_{22}}{\mathrm{E}_{11} - (\mathrm{v}_{12})^2 * \mathrm{E}_{22}}$$

$$Q_{66} = G_{11}$$

Theoretical Model

2. Calculate the transformed reduced stiffness matrix

$$\overline{Q_{11}} = Q_{11}\,\mathrm{Cos}[\theta]^4 * Q_{11} + 2*(Q_{12} + 2*Q_{66})*\mathrm{Cos}[\theta]^2 * \mathrm{Sin}[\theta]^2 + Q_{22} * \mathrm{Sin}[\theta]^4$$

$$\overline{Q_{12}} = \overline{Q_{21}} = Q_{12}\,(\mathrm{Cos}[\theta]^4 + \mathrm{Sin}[\theta]^4) + (Q_{11} + Q_{22} - 4*Q_{66})*\mathrm{Cos}[\theta]^2 * \mathrm{Sin}[\theta]^2$$

$$\overline{Q_{16}} = \overline{Q_{61}} = (Q_{11} - Q_{12} - 2*Q_{66})*\mathrm{Cos}[\theta]^3 * \mathrm{Sin}[\theta] - (Q_{22} - Q_{12} - 2*Q_{66}) * \mathrm{Cos}[\theta] * \mathrm{Sin}[\theta]^3$$

$$\overline{Q_{22}} = Q_{11} * \mathrm{Sin}[\theta]^4 + 2*(Q_{12} + 2*Q_{66})*\mathrm{Cos}[\theta]^2 * \mathrm{Sin}[\theta]^2 + Q_{22} * \mathrm{Cos}[\theta]^4$$

$$\overline{Q_{26}} = \overline{Q_{62}} = (Q_{11} - Q_{12} - 2*Q_{66})*\mathrm{Cos}[\theta] * \mathrm{Sin}[\theta]^3 - (Q_{22} - Q_{12} - 2*Q_{66}) * \mathrm{Cos}[\theta]^3 * \mathrm{Sin}[\theta]$$

$$\overline{Q_{66}} = (Q_{11} + Q_{22} - 2*Q_{12} - 2*Q_{66})*[\theta]^2 * \mathrm{Sin}[\theta]^2 + Q_{66} * (\mathrm{Cos}[\theta]^4 + \mathrm{Sin}[\theta]^4)$$

$$\overline{Q_{ij}} = \begin{bmatrix} \overline{Q_{11}} & \overline{Q_{12}} & \overline{Q_{16}} \\ \overline{Q_{12}} & \overline{Q_{22}} & \overline{Q_{26}} \\ \overline{Q_{16}} & \overline{Q_{26}} & \overline{Q_{66}} \end{bmatrix}$$

Theoretical Model

3. Calculate the total strains in the x-y coordinate system.

According to Von-Karman Strains

$$\varepsilon_x = \varepsilon_x^o - z\frac{\partial^2 w}{\partial x^2}$$

$$\varepsilon_y = \varepsilon_y^o - z\frac{\partial^2 w}{\partial y^2}$$

$$\varepsilon_{xy} = \varepsilon_{xy}^o - 2z\frac{\partial^2 w}{\partial x\, \partial y}$$

Where

$$\varepsilon_x^o = \frac{\partial u^o}{\partial x} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2$$

$$\varepsilon_y^o = \frac{\partial v^o}{\partial y} + \frac{1}{2}\left(\frac{\partial w}{\partial y}\right)^2$$

$$\varepsilon_{xy}^o = \left\{\frac{\partial u^o}{\partial y} + \frac{\partial v^o}{\partial x} + \frac{\partial w}{\partial x}\cdot\frac{\partial w}{\partial y}\right\}$$

Theoretical Model

4- Calculate ply stresses in the x-y coordinate system.

$$\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \tau_{xy}\end{bmatrix} = \begin{bmatrix}\overline{Q_{11}} & \overline{Q_{12}} & \overline{Q_{16}}\\ \overline{Q_{12}} & \overline{Q_{22}} & \overline{Q_{26}}\\ \overline{Q_{16}} & \overline{Q_{26}} & \overline{Q_{66}}\end{bmatrix} * \begin{Bmatrix}\varepsilon_x - \Delta T \propto_{xx} - \Delta M \beta_{xx}\\ \varepsilon_y - \Delta T \propto_{yy} - \Delta M \beta_{yy}\\ \varepsilon_{xy} - \Delta T \propto_{xy} - \Delta M \beta_{xy}\end{Bmatrix}$$

Where

$$\propto_{xx} = \propto_{11} \cos(\theta)^2 + \propto_{22} \sin(\theta)^2$$

$$\propto_{yy} = \propto_{11} \sin(\theta)^2 + \propto_{22} \cos(\theta)^2$$

$$\propto_{xy} = 2\cos(\theta)\sin(\theta)\,(\propto_{11} - \propto_{22})$$

$$\beta_{xx} = \beta_{11}\cos(\theta)^2 + \beta_{22}\sin(\theta)^2$$

$$\beta_{yy} = \beta_{11}\sin(\theta)^2 + \beta_{22}\cos(\theta)^2$$

$$\beta_{xy} = 2\cos(\theta)\sin(\theta)\,(\beta_{11} - \beta_{22})$$

Theoretical Model

- The mid-plane strain can be expressed as:

$$\varepsilon_x^o = c_{00} + c_{10}x + c_{01}y + c_{20}x^2 + c_{11}xy + c_{02}y^2 + c_{30}x^3 + c_{12}xy^2 + c_{21}x^2y + c_{03}y^3$$

$$\varepsilon_y^o = d_{00} + d_{10}x + d_{01}y + d_{20}x^2 + d_{11}xy + d_{02}y^2 + d_{30}x^3 + d_{12}xy^2 + d_{21}x^2y + d_{03}y^3$$

- The out-of-plane displacement *w* can be assumed as follows:

$$w(x,y) = \frac{1}{2}(ax^2 + by^2 + cxy)$$

- Accordingly, the mid-plane shear strain can be expressed as:

$$\varepsilon_{xy}^o = 2e_1 + (e_2 + c_{01})x + (e_4 + d_{10})y + \left(ab - \frac{c^2}{4} + 2c_{02} + 2d_{20}\right)xy + \left(\frac{1}{2}\left(\frac{ac}{2} + c_{11}\right) + e_3\right)x^2 + \left(\frac{1}{2}\left(\frac{bc}{2} + d_{11}\right) + e_5\right)y^2$$
$$+ (3c_{03} + d_{21})xy^2 + (3d_{30} + c_{12})x^2y + \frac{c_{21}}{3}x^3 + \frac{d_{12}}{3}y^3$$

Theoretical Model

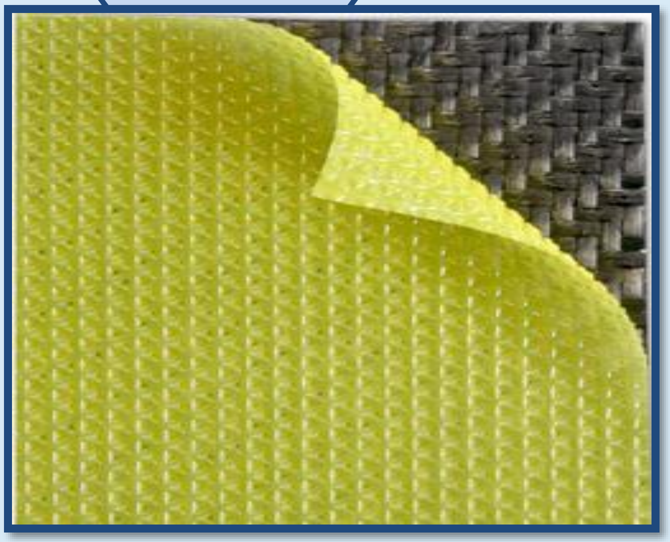
- Therefore, the total potential energy is represented by:

$$
\begin{aligned}
W = \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{-\frac{L_y}{2}}^{\frac{L_y}{2}} \int_{-\frac{L_x}{2}}^{\frac{L_x}{2}} & \frac{1}{2}\overline{Q_{11}}\varepsilon_x^2 + \overline{Q_{12}}\varepsilon_x\varepsilon_y + \overline{Q_{16}}\gamma_{xy}\varepsilon_x + \frac{1}{2}\overline{Q_{22}}\varepsilon_y^2 + \overline{Q_{26}}\gamma_{xy}\varepsilon_y + \frac{1}{2} \\
& \overline{Q_{66}}\gamma_{xy}^2 - \left(\overline{Q_{11}}\alpha_x + \overline{Q_{12}}\alpha_y + \overline{Q_{16}}\alpha_{xy}\right)\varepsilon_x \Delta T - \\
& \left(\overline{Q_{12}}\alpha_x + \overline{Q_{22}}\alpha_y + \overline{Q_{16}}\alpha_{xy}\right)\varepsilon_y \Delta T \\
& -\left(\overline{Q_{16}}\alpha_x + \overline{Q_{26}}\alpha_y + \overline{Q_{66}}\alpha_{xy}\right)\gamma_{xy}\Delta T \, dxdydz
\end{aligned}
$$

- Equating the first variation of the total potential energy to zero and solving the equations results in a, b, c values which determine the shape.

Apparatus

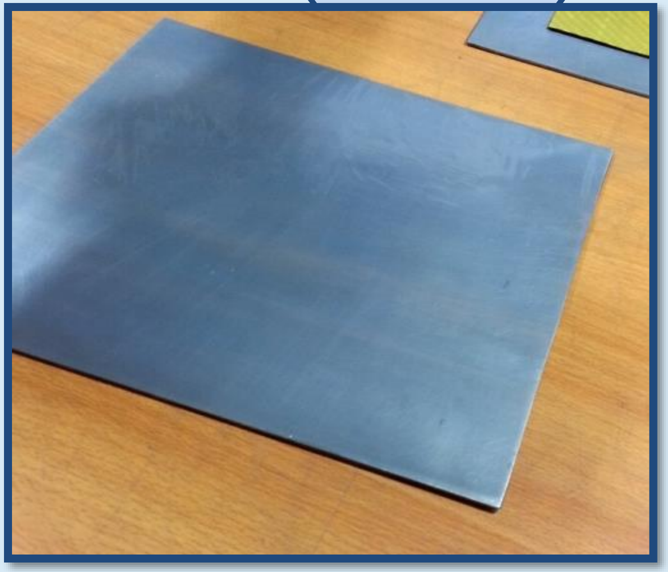
1 Carbon fiber Composite



2 Cleaning Chemical

3 Marker

4 Aluminum mold



Apparatus

5 Release film

6 Sealant tape

7 Peel ply

Apparatus

8 Breather

9 Vacuum bag

10 Pressure Gauge

11 Vacuum valve

Apparatus

12

Tacky tape

13

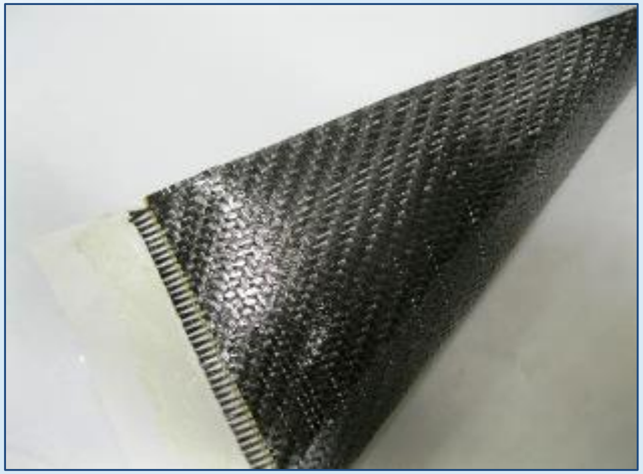
Autoclave

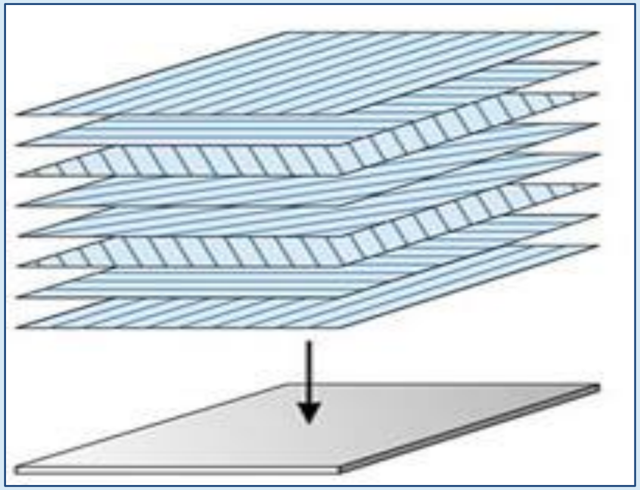
Safety Cautions

1. Wear gloves and safety glasses
2. Wear silicon gloves to avoid direct contact between the skin and the resin.
3. Don't use your tool on top of your work-piece

Experimental Procedure

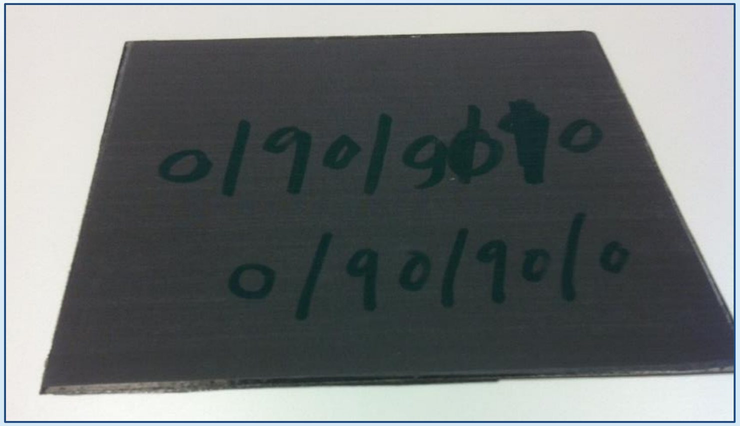
- **Material used**
  - Carbon Fiber Reinforced Plastic
- **Size**
  - 190 x 190 x 0.25 mm
- **Stacking sequences**
  - [0/90/90/0]
  - [0/0/90/90]
- **Manufacturing method**
  - Pre-preg



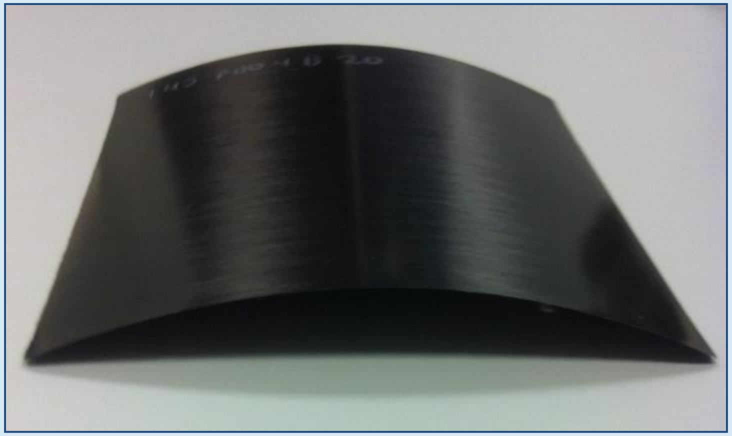


Results and discussion

Symmetry
[0/90/90/0]

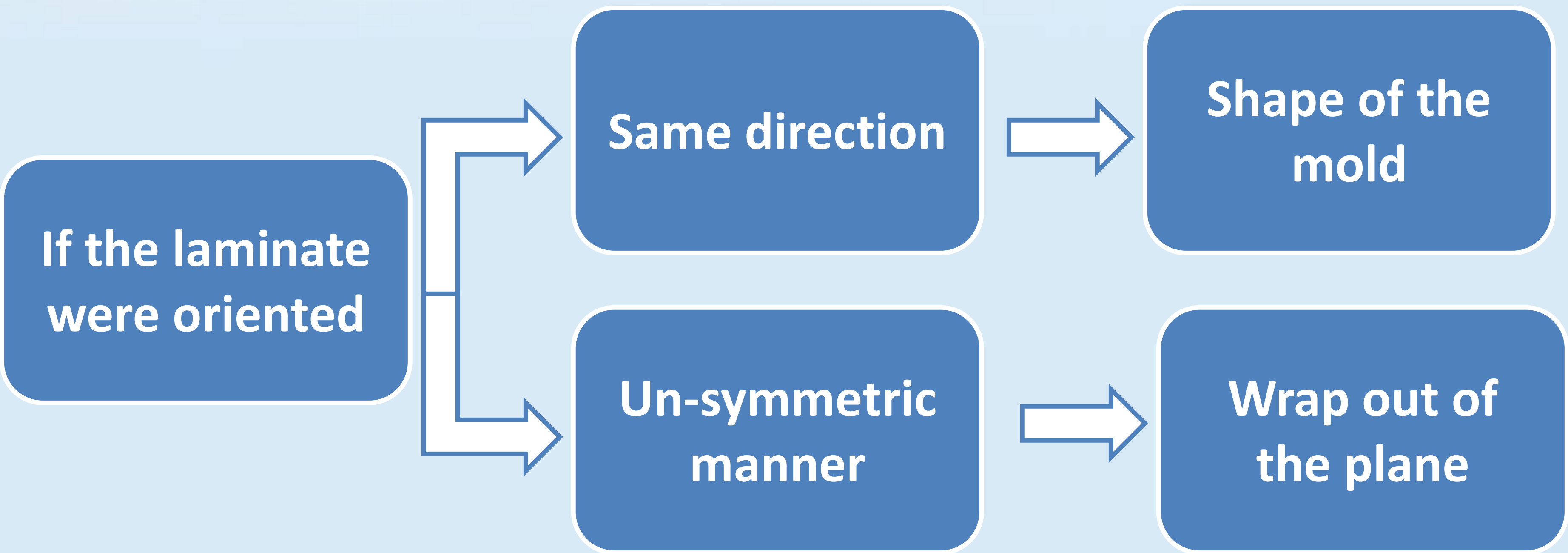


Un-symmetry
[0/0/90/90]



Results and discussion

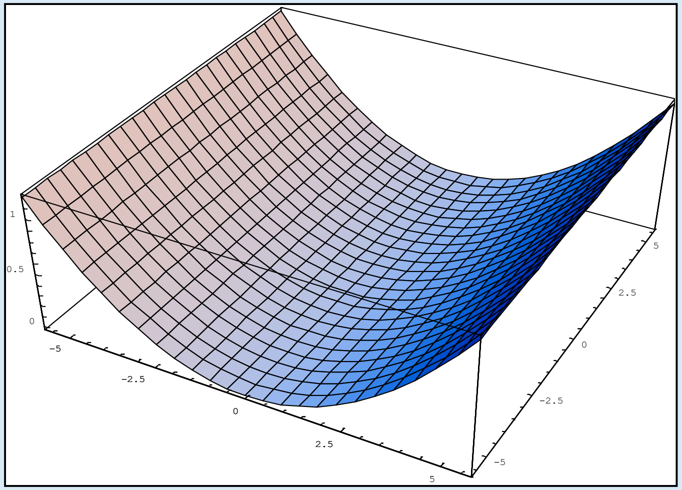
- **Why this phenomena happened?**
  - difference in thermal expansion



Results and discussion

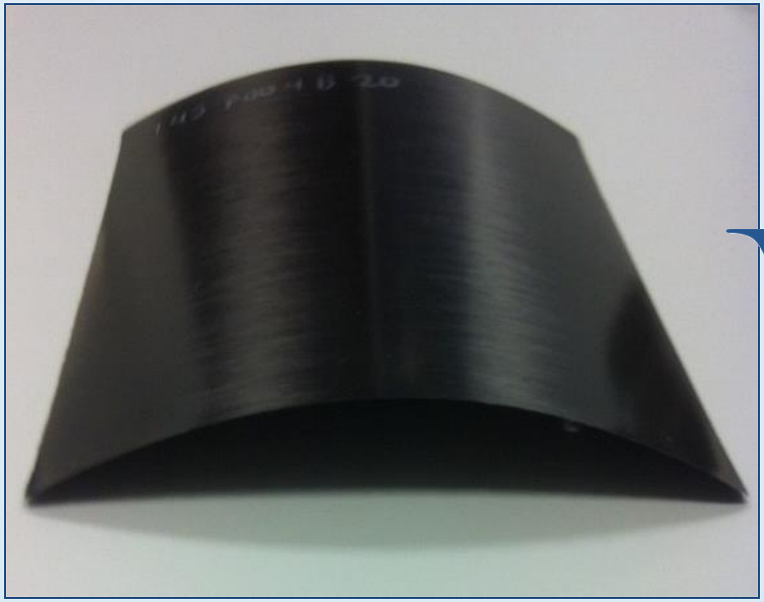
Theoretical Result:

- Data source:
  - Hyer Model
- Software used:
  - Mathematica
- Inputs:
  - Material’s geometry
  - Material’s properties
- Output
  - The expected shape

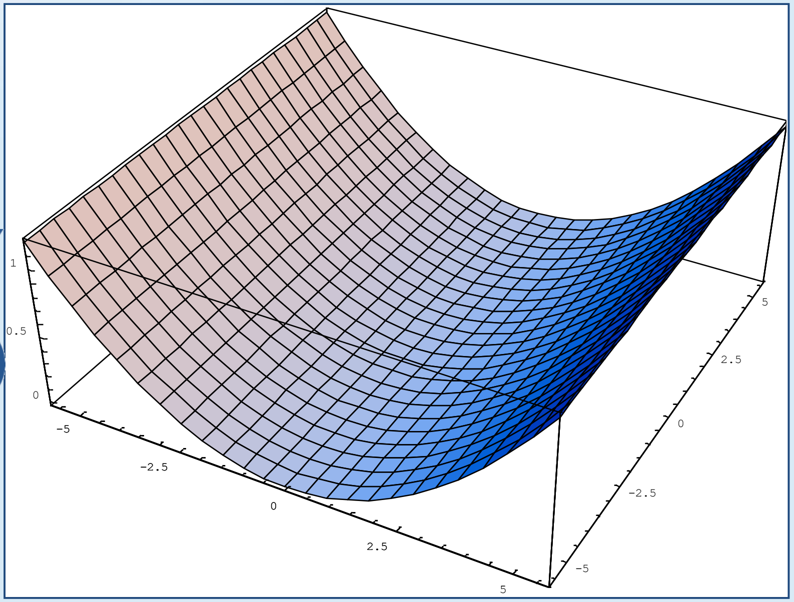


Results and discussion

Experimental Result | **Theoretical Result**



VS



Good agreement

Conclusion

- **Summary**
  - Mechanics of the unsymmetrical laminates were learnt
  - Good agreement between the theoretical and experimental results was obtained
  - Behavior of symmetric vs. unsymmetric laminate was compared

- **Learning experience**
  - Enhanced our research capabilities
  - Helped in discovering new area of interest
  - Good modeling and hands-on skills were gained
  - New software was learnt (Mathematica)

Thank you for listening