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COMPUTATION OF FAILURE INDEX STRENGTH OF FML AND FRB COMPOSITES

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Abstract –*In this study computation of failure index of fml and frb laminate at different orientations were prepared. To examine the effect of fiber orientations, fml and frb at 0° and± 45° were consider. To study the failure index numerical investigation using ANSYS static and linear analysis reults that FML at 0°possess high strength compared to ±45°, The optimization is done by using ANSYS Composite Prep Post (ACP).The strength behavior of FRP and FML under in-plane load and out of-plane load is compared based on the results. Results show that for in-plane load, due to the substituting of metal alloy sheet for prepared layer, the strength behavior in transverse direction is enhanced and FML has better resistance to biaxial load. For out-of-plane point load, FML offers strength performance superior to that of FRP and is more stable for all the boundary conditions investigated.*

Key Words: **frb, fml, ansys, orientations**

1. INTRODUCTION

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix. Composite materials have successfully substituted the traditional materials in several light weight and high strength applications. The reasons why composites are selected for such applications are mainly their high strength-to-weight ratio, high tensile strength at elevated temperatures, high creep resistance and high toughness. Typically, in a composite, the reinforcing materials are strong with low densities while the matrix is usually a ductile or tough material. The strength of the composites depends primarily on the amount, arrangement and type of fiber and particle reinforcement in the resin.

1.1 FIBER REINFORCED POLYMER

Fiber-reinforced plastic (FRP) (also fiber-reinforced polymer) is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, aramid, or basalt. Rarely, other fibers such as paper or wood or asbestos have been used. The polymer is usually an epoxy, polyester , thermosetting plastic, and phenol formaldehyde resins are still in use.

1.2FIBER METAL LAMINATE

Fiber Metal Laminate (FML) is a new class of composite material for advanced aerospace/aeronautical structural applications arisen in the recent years. It consists of thin aluminum alloy sheets bonded together with fiber-reinforced epoxy prepreg. These laminates demonstrate advantages over conventional monolithic aluminum alloys or fiber reinforced plastic (FRP) composite materials, such as excellent impact properties, fire and corrosion behavior and fatigue properties. In addition, FML retains the conventional workshop practices of metals, namely, easy machining, forming, and mechanical fastening abilities. These advantages facilitate the use of FML for primary structures in aerospace industry.

1.3 SPECIAL CASES OF LAMINATES

Based on angle, material, and thickness of plies, the symmetry or antisymmetry of a laminate may zero out some elements of the three stiffness matrices. These are important to study because they may result in reducing or zeroing out the coupling of forces and bending moments, normal and shear forces, or bending and twisting moments

This not only simplifies the mechanical analysis of composites, but also gives desired mechanical performance.

Symmetric Laminates:

A laminate is called symmetric if the material, angle, and thickness of plies are the same above and below the midplane. If it is subjected only to forces, it will have zero midplane curvatures. Similarly, if it is subjected only to moments, it will have zero midplane strains. It also prevents a laminate from twisting due to thermal loads, such as cooling down from processing temperatures and temperature fluctuations during use such as in a space shuttle, etc.

Cross-Ply Laminates:

A laminate is called a cross-ply laminate if only 0^0 and 90^0 plies were used to make a laminate. In these cases, uncoupling occurs between the normal and shear forces, as well as between the bending and twisting moments.

Angle Ply Laminates:

A laminate is called an angle ply laminate if it has plies of the same material and thickness and only oriented at +θ and –θ directions. These angle ply laminates have higher shear stiffness and shear strength properties than cross-ply laminates.

Antisymmetric Laminates:

A laminate is called antisymmetric if the material and thickness of the plies are the same above and below the midplane, but the ply orientations at the same distance above and below the midplane are negative of each other.

Balanced Laminate :

A laminate is balanced if layers at angles other than 0 and 90°occur only as plus and minus pairs of +θ and –θ. The plus and minus pairs do not need to be adjacent to each other, but the thickness and material of the plus and minus pairs need to be the same.

Quasi-Isotropic Laminates:

A laminate is called quasi-isotropic if its extensional stiffness matrix[A] behaves like that of an isotropic material.

2. METHODLOGY

The aim of the project is to optimize the design of FML based on strength. Here the FML is designed to meet specific requirements by varying the fiber orientation. FML finds its important application in aerospace industry. FML is originally developed for their outstanding fatigue resistance; other characteristics of fiber metal laminates include high specific static properties, ease of manufacture, excellent impact resistance, and good corrosion resistance. In air craft FML finds its application in cargo door and aircraft.

In this praperwork, the optimal strength design of FRP laminates and FML under in-plane load and out-of-plane load is to be conducted.

Step-1: By using Classical Lamination Theory (CLT), the Stresses are predicted in FML Under In-plane Tensile Load.

Step-2: The failure indices are obtained through Tsai-Wu criterion for FRP layers and Von-Mises criterion for metal layers. The maximum and minimum failure index of FRP and FML has to be calculated respectively via altering the fiber orientations of prepreg layers.

Step-3: ANSYS Composite PrepPost (ACP) an analysis optimization tool in ANSYS is to be used for optimization.

Step-4: Based on the results, the strength behavior of FML and FRP is to be discussed and compared and the superiority of FML is to be demonstrated.

3. COMPUTATION OF FAILURE INDEX

This chapter presents the computation of failure index by conventional classical lamination theory.

3.1 GENERALIZED HOOKE'S LAW

Generalized Hooke's law for orthotropic material is given by,

$$\{\sigma\}=[Q]\{\varepsilon\} \qquad (1)$$

Assuming linear and elastic behaviour for a composite is acceptable; however, assuming it to be isotropic is generally unacceptable. Thus, the stress–strain relationships follow Hooke's law, but the constants relating stress and strain are more in number. [Q] is called material stiffness matrix. For plane stress conditions, we can write for each layer:

$$\begin{pmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{23}\\ \sigma_{13}\\ \sigma_{12}\end{pmatrix}=\begin{bmatrix}Q_{11} & Q_{12} & 0 & 0 & 0\\ Q_{12} & Q_{22} & 0 & 0 & 0\\ 0 & 0 & Q_{44} & 0 & 0\\ 0 & 0 & 0 & Q_{55} & 0\\ 0 & 0 & 0 & 0 & Q_{66}\end{bmatrix}\begin{pmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{23}\\ \varepsilon_{13}\\ \varepsilon_{12}\end{pmatrix} \qquad (2)$$

The stiffness coefficients Q_{ij} are related to the engineering constants as the follows.

$$Q_{11}=\frac{E_1}{1-\nu_{12}\nu_{21}} \qquad (3)$$

$$Q_{12}=\frac{E_2\nu_{12}}{1-\nu_{12}\nu_{21}} \qquad (4)$$

$$Q_{22}=\frac{E_2}{1-\nu_{12}\nu_{21}} \qquad (5)$$

$$Q_{44}=G_{23};\ Q_{55}=G_{13};\ Q_{66}=G_{12}$$

Where, E = Young's Modulus, GPa

ν = Poisson's ratio

G = Shear Modulus, GPa

Here, E_1, E_2, G_{12}, G_{23}, G_{13} and ν_{12} are engineering parameters of the nth layer (lamina) in the laminate obtained from rule of mixtures.

With respect to Figure 3.1 the [A], [B] and [D] are given by,

$$[A] = \sum_{k=1}^{n} [Q]_k [h_k - h_{k-1}] \quad (6)$$

$$[B] = \frac{1}{2} \sum_{k=1}^{n} [C]_k [h^2{}_k - h^2{}_{k-1}] \quad (7)$$

$$[D] = \frac{1}{3} \sum_{k=1}^{n} [C]_k [h^3{}_k - h^3{}_{k-1}] \quad (8)$$

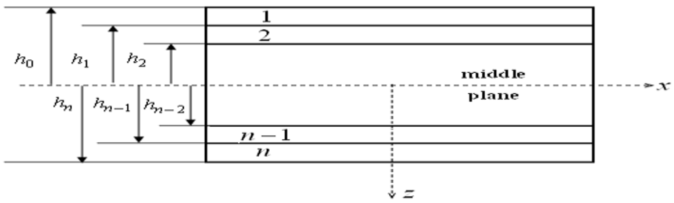

Figure 3.1 Coordinate location of ply in Laminate

3.2 FAILURE STRENGTH PREDICTION

The Tsai-Wu criterion is used to predict the failure of prepreg layer for it can account for interactions between the different stress components, and Von Mises criterion is used for metal layer. The failure criterion of FML can be expressed as follows:

$$\max[f(\theta_f), f(\theta_m)] = 1,$$

where $f(\theta_f)$ denotes the FI of prepreg layer. A small value of FI stands for a safer condition. In a uniaxial loading situation, predicting failure obviously reduces itself to comparing the internal stresses (σ) to the material's strength (S) in the loading direction. In this situation, the failure index (F_I) is defined as:

$$F_I = \frac{\sigma}{S}$$

Due to the extremely $F_I = \frac{\sigma}{S}$

3.2.1 Tsai–Wu Failure Theory

Failure index corresponding to Tsai-Wu criterion in prepreg layer is,

$$F(\theta_f) = F_{11}\sigma_1^2 + F_{22}\sigma_2^2 + F_{33}\sigma_3^2 + 2F_{12}\sigma_1\sigma_2 + 2F_{23}\sigma_2\sigma_3 + 2F_{13}\sigma_1\sigma_3 + F_{44}\tau_{12}{}^2 + F_{55}\tau_{23}{}^2 + F_{66}\tau_{13}{}^2 + F_1\sigma_1 + F_2\sigma_2 + F_3\sigma_3{}^2 \quad (9)$$

$F_{11} = \frac{1}{X_T X_C}$; $F_{22} = \frac{1}{Y_T Y_C}$; $F_{33} = \frac{1}{Z_T Z_C}$

$F_{44} = \frac{1}{R^2}$; $F_{55} = \frac{1}{S^2}$; $F_{66} = \frac{1}{T^2}$

$F_1 = \frac{1}{X_T} - \frac{1}{X_C}$; $F_2 = \frac{1}{Y_T} - \frac{1}{Y_C}$; $F_3 = \frac{1}{Z_T} - \frac{1}{Z_C}$

$F_{12} = -0.5\sqrt{F_{11}F_{22}}$

$F_{23} = -0.5\sqrt{F_{22}F_{33}}$

$F_{13} = -0.5\sqrt{F_{11}F_{33}}$

X_T and X_C - tensile and compressive strengths along the fiber direction,

Y_T and Y_C - tensile and compressive strengths along the transverse direction,

R and T - out-of-plane shear strengths,

S - in-plane shear strength.

3.2.2 Von-Mises Failure criterion

Failure index corresponding to Von-Mises criterion in FML is,

$$F(\theta_m) = \frac{1}{Y}(\sigma_x{}^2 + \sigma_y{}^2 + \sigma_z{}^2 - (\sigma_x\sigma_y + \sigma_x\sigma_z + \sigma_y\sigma_z) + 3(\tau^2_{xy} + \tau^2_{xz} + \tau^2_{zy}))^{\frac{1}{2}} \quad (10)$$

where Y is the yield strength.

3.2.3 Calculation of Stresses in FML

The composite laminate considered for calculation is of stacking sequence [Al/45⁰/-45⁰/Al/Al/45⁰/-45⁰/Al] under uniaxial in-plane load N_x=10 N/mm, where 'Al' indicates aluminium sheet, and 45⁰ 0r -45⁰ represents the angle between the fiber direction and the x-direction. The material of aluminium sheet is 2024-T3, E=76 GPa, ν= 0.34. Each layer is 0.125mm in thickness. The material of FRP layer is GLARE. The material properties for FRP layer [19],

E_1 = 135GPa

E_2, E_3 = 8GPa

G_{12}, G_{13} = 4.5GPa

G_{23} = 3.97GPa

ν_{12}, ν_{23}, ν_{13} = 0.34

X_T, X_C = 1459,1400 (MPa)

Y_T, Y_C = 55,170 (MPa)

R= S= T = 90 (MPa)

Minor Poisson's ratio,

$$\nu_{21} = \frac{E_{22}}{E_{11}}\nu_{12} = 0.02$$

Finding stiffness elements of FRP layer;

$$[Q]=\begin{bmatrix} Q_{11} & Q_{12} & Q_{16} \\ Q_{12} & Q_{22} & Q_{26} \\ Q_{16} & Q_{26} & Q_{66} \end{bmatrix}$$

$$Q_{11}=\frac{E_1}{1-\nu_{12}\nu_{21}} = 135.924\text{GPa}$$

$$Q_{12}=\frac{E_2\nu_{12}}{1-\nu_{12}\nu_{21}} = 2.738\text{GPa}$$

$$Q_{22}=\frac{E_2}{1-\nu_{12}\nu_{21}} = 8.054\text{GPa}$$

$$Q_{66} = G_{12} = 4.5\text{GPa}$$

For FRP the stiffness matrix is,

$$[Q]=\begin{bmatrix} 135.924 & 2.738 & 0 \\ 2.738 & 8.054 & 0 \\ 0 & 0 & 4.5 \end{bmatrix}\text{GPa}$$

The transformed stiffness matrix of FRP is,

$$[Q]_{45}=\begin{bmatrix} 41.8635 & 31.5345 & 31.9675 \\ 31.5345 & 41.8635 & 31.9675 \\ 31.9675 & 31.9675 & 34.6255 \end{bmatrix}\text{GPa}$$

$$[Q]_{-45}=\begin{bmatrix} 41.8635 & 31.5345 & -31.9675 \\ 31.5345 & 41.8635 & -31.9675 \\ -31.9675 & -31.9675 & 34.6255 \end{bmatrix}\text{GPa}$$

The stiffness matrix of FML layer is, $[Q]=$

$$\begin{bmatrix} \frac{E}{1-\nu^2} & \frac{\nu E}{1-\nu^2} & 0 \\ \frac{\nu E}{1-\nu^2} & \frac{E}{1-\nu^2} & Q_{26} \\ 0 & 0 & G \end{bmatrix}$$

$$G=\frac{E}{2(1+\nu)} = 28.3582\text{ GPa}$$

The stiffness matrix of FML is,

$$[Q]=\begin{bmatrix} 85.9339 & 29.2175 & 0 \\ 29.2175 & 85.9339 & 0 \\ 0 & 0 & 28.3582 \end{bmatrix}\text{GPa}$$

Finding [A], [B] and [D] matrices,

$$[A]=\sum_{k=1}^{n}[Q]_k[h_k\text{-}h_{k-1}] \qquad (11)$$

$$[A]=\begin{bmatrix} 63.89 & 30.37 & 0 \\ 30.37 & 63.89 & 0 \\ 0 & 0 & 31.49 \end{bmatrix}\text{X }10^6\text{ Pa-m}$$

$$[B]=\frac{1}{2}\sum_{k=1}^{n}[C]_k[h^2{}_k\text{-}h^2{}_{k-1}] \qquad (12)$$

[B] = 0 (Symmetric laminate)

$$[D]=\frac{1}{3}\sum_{k=1}^{n}[C]_k[h^3{}_k\text{-}h^3{}_{k-1}] \qquad (13)$$

$$[D]=\begin{bmatrix} 5.67 & 2.51 & 0.49 \\ 2.51 & 5.67 & 0.49 \\ 0.49 & 0.49 & 2.57 \end{bmatrix}\text{Pa-m}^3$$

The laminate is subjected to an uniaxial in-plane load, N_x= 10N/mm

$$\begin{bmatrix} N_{xx} \\ N_{yy} \\ N_{xy} \end{bmatrix}=\begin{bmatrix} 10000 \\ 0 \\ 0 \end{bmatrix}\text{N/m}$$

The strain acting in the lamina is

$$\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix}=[A^{-1}]\begin{bmatrix} N_{xx} \\ N_{yy} \\ N_{xy} \end{bmatrix}=\begin{bmatrix} 2.02\,x\,10^{-4} \\ -0.96\,x\,10^{-5} \\ 0 \end{bmatrix}$$

Stresses in the layers of FML,

In 45⁰ Lamina, $\begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix}=[Q]_{45}\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix}$

$$=\begin{bmatrix} 5.429 \\ 2.351 \\ 3.388 \end{bmatrix}\text{x }10^{-3}\text{ GPa}$$

In -45⁰ Lamina, $\begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix}=[Q]_{-45}\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix}$

$$=\begin{bmatrix} 5.429 \\ 2.351 \\ -3.388 \end{bmatrix}\text{x }10^{-3}\text{ GPa}$$

In Al Lamina, $\begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix}=[Q]\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix}$

$$=\begin{bmatrix} 14.553 \\ -2.347 \\ 0 \end{bmatrix}\text{x }10^{-3}\text{ GPa}$$

3.2.4 Calculation of Stresses in FRP:

The composite laminate considered for calculation is of stacking sequence $[0^0/45^0/-45^0/0^0/0^0/45^0/-45^0/0^0]$ under uniaxial in-plane load N_x=10 N/mm, where 45^0 0r -45^0 represents the angle between the fiber direction and the x-direction. Each layer is 0.125mm in thickness.

For FRP the stiffness matrix is,

$$[Q]_0 = \begin{bmatrix} 135.924 & 2.738 & 0 \\ 2.738 & 8.054 & 0 \\ 0 & 0 & 4.5 \end{bmatrix} \text{ GPa}$$

The transformed stiffness matrix of FRP is,

$$[Q]_{45} = \begin{bmatrix} 41.8635 & 31.5345 & 31.9675 \\ 31.5345 & 41.8635 & 31.9675 \\ 31.9675 & 31.9675 & 34.6255 \end{bmatrix} \text{ GPa}$$

$$[Q]_{-45} = \begin{bmatrix} 41.8635 & 31.5345 & -31.9675 \\ 31.5345 & 41.8635 & -31.9675 \\ -31.9675 & -31.9675 & 34.6255 \end{bmatrix} \text{ GPa}$$

The [A], [B] and [D] matrices for the FRP laminate are,

$$[A] = \begin{bmatrix} 88.89 & 17.13 & 0 \\ 17.13 & 24.95 & 0 \\ 0 & 0 & 19.56 \end{bmatrix} \text{X } 10^6 \text{ Pa-m}$$

[B] = 0 (Symmetric laminate)

$$[D] = \begin{bmatrix} 8.118 & 1.202 & 0.49 \\ 1.202 & 1.813 & 0.49 \\ 0.49 & 0.49 & 1.17 \end{bmatrix} \text{ Pa-m}^3$$

The laminate is subjected to an uniaxial in-plane load, N_x= 10N/mm

$$\begin{bmatrix} N_{xx} \\ N_{yy} \\ N_{xy} \end{bmatrix} = \begin{bmatrix} 10000 \\ 0 \\ 0 \end{bmatrix} \text{ N/m}$$

The strain acting in the lamina is,

$$\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix} = [A^{-1}] \begin{bmatrix} N_{xx} \\ N_{yy} \\ N_{xy} \end{bmatrix} = \begin{bmatrix} 129.65x\,10^{-6} \\ -89\,x\,10^{-6} \\ 0 \end{bmatrix}$$

Stresses in the layers of FRP,

In 45^0 Lamina, $$\begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix} = [Q]_{45} \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix}$$

$$= \begin{bmatrix} 2.621 \\ 0.3625 \\ 1.299 \end{bmatrix} \text{x } 10^{-3} \text{ GPa}$$

In -45^0 Lamina, $$\begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix} = [Q]_{-45} \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix}$$

$$= \begin{bmatrix} 2.621 \\ 0.3625 \\ -1.299 \end{bmatrix} \text{x } 10^{-3} \text{ GPa}$$

In 0^0 Lamina, $$\begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix} = [Q] \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix}$$

$$= \begin{bmatrix} 1.737x\,10^{-2} \\ -3.618x\,10^{-4} \\ 0 \end{bmatrix} \text{ GPa}$$

3.2.5 Calculation of failure index in FML layers

Failure index corresponding to Tsai-Wu criterion in prepreg layer is,

$$F(\theta_f) = F_{11}\sigma_1^2 + F_{22}\sigma_2^2 + F_{33}\sigma_3^2 + 2F_{12}\sigma_1\sigma_2 + 2F_{23}\sigma_2\sigma_3 + 2F_{13}\sigma_1\sigma_3 + F_{44}\tau_{12}^2 + F_{55}\tau_{23}^2 + F_{66}\tau_{13}^2 + F_1\sigma_1 + F_2\sigma_2 + F_3\sigma_3^2 \quad (14)$$

$$F_{11} = \frac{1}{X_T X_C} = 4.8957\text{x}10^{-4}$$

$$F_{22} = \frac{1}{Y_T Y_C} = 1.0695\text{x}10^{-4}$$

$$F_{33} = \frac{1}{Z_T Z_C} = 0$$

$$F_{44} = \frac{1}{R^2} = 1.23456\text{X}10^{-4}$$

$$F_{55} = \frac{1}{S^2} = 1.23456\text{X}10^{-4}$$

$$F_{66} = \frac{1}{T^2} = 1.23456\text{X}10^{-4}$$

$$F_1 = \frac{1}{X_T} - \frac{1}{X_C} = -2.888\text{X}10^{-5}$$

$$F_2 = \frac{1}{Y_T} - \frac{1}{Y_C} = -0.0123$$

$F_{12} = -0.5\sqrt{F_{11}F_{22}} = -3.618x\ 10^{-6}$

$F_{23} = F_{13} = F_3 = 0$

Tthe failure index value of prepreg layer in FML is calculated as,

$F(\theta_f) = 0.0307$

Failure index corresponding to Von- Mises criterion in metal layer is,

$$F(\theta_m) = \frac{1}{Y}(\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - (\sigma_x \sigma_y + \sigma_x \sigma_z + \sigma_y \sigma_z) + 3(\tau^2_{xy} + \tau^2_{xz} + \tau^2_{zy}))^{\frac{1}{2}} \quad (15)$$

$\sigma_x = 14.533MPa$

$\sigma_Y = 2.3477MPa$

$\tau_{xy} = 0$

$Y = 381$ MPa

The failure index value of metal layer in FML is calculated as,

$F(\theta_m) = 0.03546$

3.2.6 Calculation of failure index in FRP layers

$$F_{11} = \frac{1}{X_T X_C} = 4.8957x10^{-4}$$

$$F_{22} = \frac{1}{Y_T Y_C} = 1.0695x10^{-4}$$

$$F_{33} = \frac{1}{Z_T Z_C} = 0$$

$$F_{44} = \frac{1}{R^2} = 1.23456X10^{-4}$$

$$F_{55} = \frac{1}{S^2} = 1.23456X10^{-4}$$

$$F_{66} = \frac{1}{T^2} = 1.23456X10^{-4}$$

$$F_1 = \frac{1}{X_T} - \frac{1}{X_C} = -2.888X10^{-5}$$

$$F_2 = \frac{1}{Y_T} - \frac{1}{Y_C} = -0.0123$$

$F_3 = F_{23} = F_{13} = 0$

The theoretically calculated failure index value of prepreg layer corresponding to Tsai-Wu criterion in prepreg layer is as follows.

In 0^0 laminate;

$F(\theta_f) = 0.004744$

In 45^0 laminate;

$F(\theta_f) = 0.0045$

In -45^0 laminate;

$F(\theta_f) = 0.0045$

3.2.7 Theoretical Results

In the laminate, stresses in each layer are predicted theoretically by using Classical Lamination Theory. The failure index values are calculated by using the suitable failure criteria. Tsai-Wu criterion for prepreg layers and Von- Mises criterion for metal layers.

In the FRP with a stacking sequence [$0^0/45^0/-45^0/0^0/0^0/45^0/-45^0/0^0$] and subjected to uniaxial in-plane load N_x=10 N/mm the predicted stress and failure index values are listed in Table 1 Tsai-Wu criterion is used in the calculation of failure index values in all the layers of FRP. In 0^0 prepreg lamina the failure index value for the applied load is -0.0047 and in 45^0 and -45^0 prepreg lamina the failure index value is 0.0045.

Table 1: Theoretically calculated stress and failure index values of FRP

	Theoretically predicted stress values	Theoretically predicted failure index value
0^0 Lamina	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix} = \begin{bmatrix}1.737x\ 10^{-2}\\ -3.618x\ 10^{-4}\\ 0\end{bmatrix}$ GPa	0.004744
45^0 Lamina	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix} = \begin{bmatrix}2.621\\ 0.3625\\ 1.299\end{bmatrix} x\ 10^{-3}$ GPa	0.0045
-45^0 Lamina	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix} = \begin{bmatrix}2.621\\ 0.3625\\ -1.299\end{bmatrix} x\ 10^{-3}$ GPa	0.0045

In the FML with a stacking sequence [Al/45^0/-45^0/ Al / Al /45^0/-45^0/ Al] and subjected to uniaxial in-plane load N_x=10 N/mm the predicted stress and failure index values are listed in Table 2. For calculating failure index value in prepreg layer Tsai-Wu criterion is used and for metal layers Von- Mises criterion is used. In Aluminium lamina the failure index value for the applied load is 0.03546 and in 45^0 and -45^0 prepreg lamina the failure index value is 0.0307.

Table 2: Theoretically calculated stress and failure index values of FML

	Theoretically predicted stress values	Theoretically predicted failure index value
Al Lamina	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}14.553\\ -2.347\\ 0\end{bmatrix}x$ 10^{-3} GPa	0.03546
45^0 Lamina	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}5.429\\ 2.351\\ 3.388\end{bmatrix}x$ 10^{-3} GPa	0.0307
-45^0 Lamina	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}5.429\\ 2.351\\ 3.388\end{bmatrix}$ x 10^{-3} GPa	0.0307

4. RESULT AND DISSCUSSION

The predicted stresses obtained by Classical Lamination Theory of FRP layer and Al layer in FML by ANSYS are listed in Table 3. The predicted stresses obtained theoretically in FRP and by ANSYS are listed in Table 4. Also comparison of failure index values calculated theoretically and by ANSYS listed in Table 3.

For in-plane uniaxial load, the optimum FI of FML and FRP occurs when all the fiber angles are near 0^0 and the worst FI occurs when the fiber angles are near 45^0. The fiber angles are close to 0^0 or 45^0, but not exactly these values. This is due to the characteristic of the evolution nature of the optimization. The optimum FI of FRP is lower than FML, as the longitudinal tensile strength of a lamina is greater than the yielding strength of Al. The worst FI of FRP is greater than FML, as the transverse tensile strength of a lamina is much lower than the yielding strength of Al. It demonstrates that the substituting of aluminium alloy sheet for prepreg layer enhances the strength behaviour of transverse direction. The optimisations results of FML and FRP are listed in Table 5

4.1 Comparison of predicted stress values in FML

For validation, the stress predicted by FEA in FML is compared with theoretically predicted values and stress values referred in the reference is shown in table 3

Table 3 Predicted stresses under uniaxial tensile load in FML

	Theoreticall y predicted stress values (MPa)	FEA predicte d stress values (MPa)	Predicte d stress values in the reference Journal (MPa)	% of deviation	
				In theoretica l results	In FEA results
Al Lamina	σ_x = 14.553 σ_y = -2.347 τ_{xy}= 0	σ_x = 14.6948 σ_y = -2.5661 τ_{xy}= 0	σ_x = 14.695 σ_y = -2.57 τ_{xy}= 0	0.966 8.6 0	0.001 3 0.155 0
45^0 Lamina	σ_x = 5.429 σ_y = 2.351 τ_{xy}= 3.388	σ_x = 5.305 σ_y = 2.566 τ_{xy}= 3.367	σ_x = 5.305 σ_y = 2.56 τ_{xy}= 3.37	-2.33 8.16 -0.29	0 0 -0.089
-45^0 Lamina	σ_x = 5.429 σ_y = 2.351 τ_{xy}= 3.388	σ_x = 5.305 σ_y = 2.566 τ_{xy}= -3.36	σ_x = 5.305 σ_y = 2.56 τ_{xy}= -3.37	-2.33 8.16 -0.29	0 0 -0.089

The results obtained from ANSYS and CLT are compared to Predicted values in the reference Journal for validation. It is found that the results of this approach agree very closely with the reference values and thus validated.

4.2 Comparison of predicted stress values in FRP

For validation, the stress predicted by FEA in FRP is compared with theoretically predicted values as shown in table 4

Table 4 Predicted stresses under uniaxial tensile load in FRP

	Theoretically predicted stress values (GPa)	FEA predicted stress values (GPa)
0^0 Lamina	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}1.737x\,10^{-2}\\ -3.618x\,10^{-4}\\ 0\end{bmatrix}$	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}1.76x\,10^{-2}\\ -3.945x\,10^{-4}\\ 0\end{bmatrix}$
45^0 Lamina	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}2.621\\ 0.3625\\ 1.299\end{bmatrix}$ x 10^{-3}	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}2.42\\ 0.3945\\ 1.2\end{bmatrix}$ x 10^{-3}
-45^0 Lamina	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}2.621\\ 0.3625\\ -1.299\end{bmatrix}$ x 10^{-3}	$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}2.42\\ 0.3945\\ -1.2\end{bmatrix}$ x 10^{-3}

The results obtained from ANSYS and CLT are compared. It is found that the results of this approach agree very closely with each other. The results show that the FE analysis and the CLT modelling can characterize the elastic or elastic plastic properties of FRP at a good level

4.3 Comparison of predicted Failure index values in FML

For validation, the failure index values predicted by FEA in FML are compared with theoretically predicted failure index values as shown in table 5. It is found that the results of this theoretical approach agree very closely with the FEA results and thus validated

Table 5 Predicted FI values under uniaxial tensile load in FML

	Theoretically predicted failure index values	FEA predicted failure index values	Percentage of deviation (%)
Al Lamina	0.03546	0.03857	-8.77
45⁰ Lamina	0.0307	0.0299	2.6
-45⁰ Lamina	0.0307	0.0299	2.6

4.4 Comparison of predicted Failure index values in FRP

For validation, the failure index values predicted by FEA in FRP are compared with theoretically predicted failure index values as shown in table 5

Table 6 Predicted FI values under uniaxial tensile load in FRP

	Theoretically predicted failure index values	FEA predicted failure index values	Percentage of deviation (%)
0⁰ Lamina	0.004744	0.005142	-8.3
45⁰ Lamina	0.0045	0.004495	0.11
-45⁰ Lamina	0.0045	0.004495	0.11

It is found that the results of this theoretical approach agree very closely with the FEA results and thus validated.

5. Conclusion

Using ANSYS, the induced stresses and failure index values of the laminate under uniaxial tensile load were determined. The comparison of results obtained using ANSYS and theoretical results show good agreement. The results are also compared with literature results for validation. Using ANSYS Composite PrepPost (ACP) in the Workbench simulation environment can be, it is believed that this approach will provide designers a feasible and efficient methodology with a great potential in developing the tailoring applications in composite structural design and other complex engineering designs.

Optimisation of composites done in ACP does not require any other software's to be integrated with it. ACP does not require any coding such as used in MATLAB.

Nowadays, besides the existing products of FML, some new types of FML consisting of other constituents are under development. It is expected that the application of FML in aerospace/aeronautical structures will be further enhanced. Optimisation of composites based on minimum number of layers, minimum thickness, volume fraction, material and price rate can also be done.

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