Design and analysis of thin walled composite beam

Shiva Sahu and Mukesh kumar singh
School of Engineering & Technology G. G. V. Bilaspur, Chhattisgarh, INDIA
E-mail: mukeshetggv@gmail.com Contact: 8319993842

Abstract. In present research composite beam of Glass/Epoxy has been taken for the analysis of failure bending moment by Finite Element Analysis. The orientation of the plies are oriented as [0°/-45°/45°/90°/90°/45°/-45°/0°] named as S1 are tested and analyzed with the Tsai-Wu failure criteria. It is found that the sample S1 composite having low load carrying capacity and bending moment. Furthermore, another ply are oriented as [0°/90°/0°/90°/90°/0°/90°/0°] named as S4 are tested and analyzed Tsai-Wu failure criteria under same loading condition. It is found that the sample S4 composite having higher load carrying capacity and bending moment. The composite materials such as the Graphite/Epoxy and the Boron/Epoxy have also been considered for the analysis with the same boundary condition as the Glass/Epoxy. Comparative result shows that the Boron/Epoxy having highest load carrying capacity and bending moment as compare to the Graphite/Epoxy and the Glass/Epoxy. The results obtained from the proposed method having good agreement with the results obtained from the previous research.

Keywords: Thin wall composite beam, Failure bending moment, Failure theories, Classical lamination theory.

1. Introduction

The composite material is defined as the combination of two or more materials in a macroscopic scale required to obtain third useful material (having efficient property). The word macroscopic means the component can be identified by the naked eyes. There are different types of material which are microscopically combined and cannot be identified by the naked eyes.

Composite beam is defined as the combination of two different members. Which are joined by shear connector at their contact zone. It is widely used to reproduce the importance of structural elements. Different type of cross section of composite beam used in different applications depending upon their characteristics such as in civil engineering where generally steel-concrete (I and W) cross section of composite beam is used where steel flange is attached to the concrete roof. But now a day’s composite beam is also used in mechanical engineering to make the blades of the wind turbine, part or body of the automobile and in aerospace industry etc. generally graphite-epoxy, boron-epoxy and glass-epoxy composite material is used as a composite material to make composite beam.

2. Literature Review

Adrian Gliszczynski[1] take composite beams of glass fibre reinforced polymer (GFRP) C-shaped thin-walled subjected to pure bending is taken under study for calculating wearing strength. Experimental and numerical analysis were conducted and it concluded following failure criteria- Hoffman failure criteria, Inverse of Tsai-Wu failure criteria and Maximum stress failure criteria reduced to fibre direction. Bending test of Eight layer beam walls with six different staking sequences such as [0/-45/45/90]s, [90/-45/45/0]s, [90/0/90/0]s, [0/90/0/90]s, [45/-45/45/-45]s and [45/-45/90/0]s.

The implementation of failure criteria are found in ranges from 0.5% to 7% for ply systems. In the direction of fibre increasing the compressive strength and tensile strength shows high stiffness degradation and rapid destruction of the structures.
M. Mallouli[2] have taken laminated composite beam of E-glass/epoxy under study of impact damage behavior by using wave finite element (WFE) approach when it is subjected to a transverse low velocity impact. Dynamic analysis is carried out using WFE and damage analysis by failure theories (Tsai-Wu and Hashin’s failure criteria). Calculated failure index was plotted with respect to time and lamina number as shown in figure. In which WFE solution shows more accuracy than the FE model. Tsai-Wu use to calculate impact damage for each or entire ply the Hashin failure criteria used to identify the damage mode (de-lamination, matrix cracks).

Marcela N. kataoka[3] used column connections of composite beam that consist of CFT (Concrete-filled steel tubes), bolts, slabs, endplates and beams. 3D model is prepared on Diana software, this software based on finite element method (FEM). Parametric analysis shows the parameter with greatest influence in the connection which improved the interaction between the slab and beam that means improving the overall connection behavior. In which eight shear connectors contain by model then it enhanced 32% of positive moment and only 1% of negative moment. Other parameter was not affected the performances because of when changing one parameter than other portion become weak area. Bolts can be neglected if diameter of bolt is small but if bolt diameter is large than it also affect the connection failure. The main focus in this study was shear connectors when building is located in seismic region because shear connector provide the connection between slab and beam.

Brendan Kirkland[4] study combined loaded composite beam is analyzed by using finite element method. Flexure, shear and axial load were applied and concentrate on compression and tension load. Moment-shear relation curves for varying values of axial load, span of beam were checking by applying vertical and horizontal load. In first quadrant (i.e. sagging moment and compression) if the shear span is greater than 800 mm than it shows ductile failure with increasing axial compression. Second quadrant (sagging moment and tension) shows if the shear span is 800-2000mm, subjected to low to high level of axial tension than mid span region fail like ductile failure due to concrete crushing. Third quadrant (hogging moment and tension), result shows 800-2000 mm shear span beams assume to very large vertical deflection. Fourth quadrant (hogging moment and compression) shows the most beams were failed due to local buckling.

R.M. Aguiar[5] take laminated composite beam of various cross section were consider for static analysis by different finite element models (FEM). In this study beam is simply supported at the ends and three cross section i.e. rectangular beams, I-beam and clamped box-beam. Loading condition for each beam is uniformly distributed load along the beam length or transverse load. There were some assumptions that were variation in y-direction is neglected, length to width ratio must be large to make curvature negligible. All three cross section are analysed by finite element method and conclude the better result for each cross section. Lamina is fail first so the each lamina is considered for study to find out failure strength and the location of failure point.

Gerand Taig[6] work present the analysis of composite steel-concrete beams using generalised beam theory(GBT). Composite beam is made by reinforced concrete slab and steel beam as shown in figure. In this approach slab and steel plate were considered as thin plates and bending in plane orthogonal with respect to member axis. Assumed that the composite cross section was formed by different materials and all material was assumed as isotropic material and behave like linear elastic fashion. For analysis of principal of virtual work weak formulation was used. The structural behaviour is analysed by finite element method which provide the approximate displacements. There were three types of displacement modes extension, shear and conventional modes. The results of displacement obtained from GBT and ABAQUS were compared. Method used in this study is applicable for open, closed and partial closed composite member.

J. Turmo[7] study partial interaction analysis of composite beam presented. In which modelling of composite beam six types of frame elements were used. Six frame elements of model are follows-first element for concrete slab, second element for steel beam, third element for vertical struts, fourth element for shear connector springs, fifth element shows the distance between the concrete centroid and steel concrete interface of beam and sixth element shows the distance between the concrete centroid and the steel concrete interface. In numerical application two types of beams were analysed first was simply supported composite beam and second were three span continuous composite beams. By using finite element methods reduce the spacing among spring connectors and again produce the analytical
equations results. Behaviour of composite beam is mainly depending on the stiffness of the concrete and steel connection.

3. Theory and Problem Formulation

3.1 Stress and strain relation

3.1.1 One Dimensional Beam

Initially consider a beam of cross section A, subjected to load P then the normal stress is given by Hook’s law at any cross section of beam-

\[ \sigma_x = \frac{P}{A} \]  

And the normal strain is given as

\[ \varepsilon_x = \frac{P}{AE} \]  

Where \( E \) = Young’s modulus of beam

Now consider the beam is subjected to pure bending moment \( M \) and avoid twisting then the assumptions of elementary strength of material are-

- The transverse shear in the beam is neglected
- Cross section of beam retain their initial shape
- The \( yz \)-plane remain unchanged before and after bending and always normal to the \( x \)-axis

At distance \( z \) from centroidal axis strain is given as

\[ \varepsilon_{zz} = \frac{z}{\rho} \]  

Where \( \rho \) = radius of curvature of beam

And stress is given as

\[ \sigma_{zz} = \frac{Ez}{\rho} \]  

3.1.2 Strain and stress in composite laminate

Using reduced stiffness matrix global stress can be calculated at any point along the thickness of laminate as follows-

\[
\begin{bmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{bmatrix} = \begin{bmatrix}
\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{13} \\
\bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\
\bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^0 \\
\varepsilon_y^0 \\
\gamma_{xy}^0
\end{bmatrix}
\]

where \( \bar{Q} \) = reduced transformed stiffness matrix

3.1.3 Force and Moment resultants based on midplane strain and curvatures

Consider \( n \) plies laminate as shown in figure below and the thickness of each ply has \( t_k \), then thickness of the laminate \( h \) is given as

\[ h = \sum_{k=1}^{n} t_k \]  

(3.6)
Then the location of mid plane from the top surface or bottom surface of laminate is h/2. The location of each ply in z-coordinate is given by

Ply 1

\[ h_1 = \frac{h}{2} \text{ (top surface)}, \]  

\[ h_1 = \frac{h}{2} + t_1 \text{ (bottom surface)}. \]  

Ply k (k = 2, 3, ..., n-2, ..., n-1)

\[ h_{k-1} = \frac{h}{2} + \sum_{i=1}^{k-1} t_i \text{ (top surface)} \]  

\[ h_k = \frac{h}{2} + \sum_{i=1}^{k} t_i \text{ (bottom surface)} \]  

Ply n

\[ h_{n-1} = \frac{h}{2} - t_n \text{ (top surface)} \]  

\[ h_n = \frac{h}{2} \text{ (bottom surface)} \]  

Through the laminate thickness integration of the global stresses gives the resultant forces per unit length in each lamina in x-y plane as

\[ N_x = \int_{-\frac{h}{2}}^{\frac{h}{2}} \sigma_x \, dz, \]  

\[ N_y = \int_{-\frac{h}{2}}^{\frac{h}{2}} \sigma_y \, dz, \]  

\[ N_{xy} = \int_{-\frac{h}{2}}^{\frac{h}{2}} \tau_{xy} \, dz, \]  

h/2 = half thickness of the laminate.

Similarly for resultant moments per unit length in x-y plane

\[ M_x = \int_{-\frac{h}{2}}^{\frac{h}{2}} \sigma_x z \, dz, \]
\[
M_y = \int_{-h/2}^{h/2} \sigma_y zdz, \quad (3.14b)
\]
\[
M_{xy} = \int_{-h/2}^{h/2} \tau_{xy} zdz, \quad (3.14c)
\]
From the above equation resulting force and resulting moment in the laminate can be written as in the matrix form as
\[
\begin{align*}
\begin{bmatrix}
N_x \\
N_y \\
N_{xy}
\end{bmatrix}
&= \int_{-h/2}^{h/2} \begin{bmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{bmatrix} dz, \quad (3.15a) \\
\begin{bmatrix}
M_x \\
M_y \\
M_{xy}
\end{bmatrix}
&= \int_{-h/2}^{h/2} \begin{bmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{bmatrix} zdz, \quad (3.15b) \\
\begin{bmatrix}
N_x \\
N_y \\
N_{xy}
\end{bmatrix}
&= \sum_{k=1}^{n} \int_{-h_k/2}^{h_k/2} \begin{bmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{bmatrix} dz, \quad (3.15c) \\
\begin{bmatrix}
M_x \\
M_y \\
M_{xy}
\end{bmatrix}
&= \sum_{k=1}^{n} \int_{-h_k/2}^{h_k/2} \begin{bmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{bmatrix} zdz, \quad (3.15d)
\end{align*}
\]
From Eq. (3.5) substituting the equation (3.15a), (3.15b), (3.15c) and (3.15d) respectively. Then the resultant force and resultant moment in terms of the midplane strain and curvatures can be written as
\[
\begin{align*}
\begin{bmatrix}
N_x \\
N_y \\
N_{xy}
\end{bmatrix}
&= \sum_{k=1}^{n} \int_{-h_k/2}^{h_k/2} \begin{bmatrix}
\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{13} \\
\bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\
\bar{Q}_{13} & \bar{Q}_{26} & \bar{Q}_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^0 \\
\varepsilon_y^0 \\
\gamma_{xy}^0
\end{bmatrix} dz + \sum_{k=1}^{n} \int_{-h_k/2}^{h_k/2} \begin{bmatrix}
\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{13} \\
\bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\
\bar{Q}_{13} & \bar{Q}_{26} & \bar{Q}_{66}
\end{bmatrix} \begin{bmatrix}
\kappa_x \\
\kappa_y \\
\kappa_{xy}
\end{bmatrix} z^2 dz \quad (3.16a) \\
\begin{bmatrix}
M_x \\
M_y \\
M_{xy}
\end{bmatrix}
&= \sum_{k=1}^{n} \int_{-h_k/2}^{h_k/2} \begin{bmatrix}
\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{13} \\
\bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\
\bar{Q}_{13} & \bar{Q}_{26} & \bar{Q}_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^0 \\
\varepsilon_y^0 \\
\gamma_{xy}^0
\end{bmatrix} zdz + \sum_{k=1}^{n} \int_{-h_k/2}^{h_k/2} \begin{bmatrix}
\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{13} \\
\bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\
\bar{Q}_{13} & \bar{Q}_{26} & \bar{Q}_{66}
\end{bmatrix} \begin{bmatrix}
\kappa_x \\
\kappa_y \\
\kappa_{xy}
\end{bmatrix} z^2 dz \quad (3.16b)
\end{align*}
\]
We know that
\[
\int_{-h_k/2}^{h_k/2} dz = (h_k - h_{k-1}),
\]
\[
\int_{-h_k/2}^{h_k/2} zdz = \frac{1}{2} (h_k^2 - h_{k-1}^2), \quad (3.16c)
\]
\[
\int_{-h_k/2}^{h_k/2} z^2dz = \frac{1}{2} (h_k^3 - h_{k-1}^3),
\]
From Eq. (3.16a), (3.16b) and (3.16c) respectively.
\[
\begin{align*}
\begin{bmatrix}
N_x \\
N_y \\
N_{xy}
\end{bmatrix}
&= 
\begin{bmatrix}
A_{11} & A_{12} & A_{13} \\
A_{21} & A_{22} & A_{26} \\
A_{61} & A_{62} & A_{66}
\end{bmatrix}
\begin{bmatrix}
\varepsilon_x^0 \\
\varepsilon_y^0 \\
\gamma_{xy}^0
\end{bmatrix}
+ 
\begin{bmatrix}
B_{11} & B_{12} & B_{13} \\
B_{21} & B_{22} & B_{26} \\
B_{61} & B_{62} & B_{66}
\end{bmatrix}
\begin{bmatrix}
\kappa_x \\
\kappa_y \\
\kappa_{xy}
\end{bmatrix},
\end{align*}
\]

(3.17a)

\[
\begin{align*}
\begin{bmatrix}
M_x \\
M_y \\
M_{xy}
\end{bmatrix}
&= 
\begin{bmatrix}
B_{11} & B_{12} & B_{13} \\
B_{21} & B_{22} & B_{26} \\
B_{61} & B_{62} & B_{66}
\end{bmatrix}
\begin{bmatrix}
\varepsilon_x^0 \\
\varepsilon_y^0 \\
\gamma_{xy}^0
\end{bmatrix}
+ 
\begin{bmatrix}
D_{11} & D_{12} & D_{13} \\
D_{21} & D_{22} & D_{26} \\
D_{61} & D_{62} & D_{66}
\end{bmatrix}
\begin{bmatrix}
\kappa_x \\
\kappa_y \\
\kappa_{xy}
\end{bmatrix},
\end{align*}
\]

(3.17b)

Where,
\[
A_{ij} = \sum_{k=1}^{n} \left[ (\overline{Q}_j) \right]_k (h_k - h_{k-1}), \quad i = 1, 2, 6; \quad j = 1, 2, 6,
\]

(3.18)

\[
B_{ij} = \frac{1}{2} \sum_{k=1}^{n} \left[ (\overline{Q}_j) \right]_k (h_k^2 - h_{k-1}^2), \quad i = 1, 2, 6; \quad j = 1, 2, 6,
\]

(3.19)

The matrix [A] shows relations between the resultant in-plane forces and the in-plane strains. Matrix [D] shows relations between resultant bending moments and the plate curvatures and matrix [B] shows couples the force and moment to mid-plane strains and mid-plane curvatures.

### 3.2 Governing Failure Theories

In present study, the composite laminate is considered with combination of some thin layer of laminas. The material of each lamina consists of continuous and parallel fibres embedded in material of matrix. The most common criterion for analysis of composite materials is the criterion given by Tsai and Tsai and Wu[8]. Once the stress in each lamina is known then failure criterion used to find out the failure load carrying capacity of composite material. There is some failure criterion-

#### 3.2.1 Maximum Stress Failure Criterion

Maximum stress failure theory is an extension of maximum normal stress theory by Rankiene and maximum stress theory by Tresca for isotropic and homogeneous materials. In this failure criterion, each and every one of the stresses in principal material co-ordinates must be less than the respective strength to avoid failure of material.

For tensile stresses,
\[
\sigma_1 \leq X_t, \quad \sigma_2 \leq X_t
\]

(3.20)

For compressive stresses,
\[
\sigma_1 \geq X_c, \quad \sigma_2 \geq Y_c
\]

(3.21)

Also,
\[
\tau_{12} \leq S
\]

(3.22)

where \(\sigma_1, \sigma_2\) and \(\tau_{12}\) are the normal stress and shear component in 1 and 2 direction; \(X_t, Y_t, X_c, Y_c\) and \(S\) are the tensile, compressive and shear strength of the lamina.
3.2.2 Maximum Strain Failure Criterion

Maximum strain failure theory is based on maximum normal strain theory by St. Venant and maximum shear stress theory by Tresca for isotropic materials. This failure criterion is quite similar to the maximum stress failure criterion. In which each and every one of the strain in principal material co-ordinates must be less than the respective strength to avoid failure of material.

\[ e_1 \leq X_{e_1}, \quad e_2 \leq Y_{e_2}, \quad \gamma_{12} \leq S_{e_1}, \quad e_3 \geq X_{e_3}, \quad e_4 \geq Y_{e_4} \]  

(3.23)

where \( e_1, e_2, \gamma_{12} \) are strains in principal material co-ordinates, \( X_{e_1}, Y_{e_1}, X_{e_2}, Y_{e_2} \) are maximum tensile and compressive normal strain in 1 and 2 directions, \( S_{e_1} \) is maximum shear strain in the 1-2 co-ordinates.

3.2.3 Tsai-Hill Failure Criterion

This failure criterion is an extension of distortional energy yield criterion of Von-Mises for isotropic materials to anisotropic materials and unidirectional lamina. According to this failure criterion lamina has failed if

\[
(G + H)\sigma_1^2 + (F + G)\sigma_2^2 + 2H\sigma_1\sigma_2 - 2G\sigma_1\sigma_3 - 2F\sigma_2\sigma_3 + 2L\gamma_{12}^2 + 2M\gamma_{13}^2 + 2N\gamma_{12}^2 \geq 1
\]  

(3.24)

is violated. Hill’s yield stresses \( F, G, H, L, M, \) and \( N \) are the failure strengths of lamina.

3.2.4 Hoffman Failure Criterion

Hoffman extended the Hill’s equation by adding linear terms to account for different strengths in tension and compression. According to this failure criterion lamina has failed if

\[
C_1(\sigma_2 - \sigma_3)^2 + C_2(\sigma_3 - \sigma_1)^2 + C_3(\sigma_1 - \sigma_2)^2 + C_4\sigma_1 + C_5\sigma_2 + C_6\sigma_3 + C_7\gamma_{12}^2 + C_8\gamma_{13}^2 + C_9\gamma_{12}^2 \geq 1
\]  

(3.25)

is violated. Where \( C_i \) are calculated from the strengths of lamina in principal material co-ordinate.

3.2.5 Tsai-Wu Tensor Failure Criterion

This failure theory is based on the total strain energy failure theory. Tsai and Wu derived that a failure surface exist in the form in six dimensional stress space

\[
F_{ij} = F_{ij} \sigma_i \sigma_j \geq 1 \quad i, j = 1, \ldots, 6
\]  

(3.26)

where \( F_{ij} \) and \( F_{ij} \) are strength tensors of the second rank and fourth rank respectively and

\[
F_1 = \frac{1}{X_e} + \frac{1}{Y_e} \quad F_{11} = -\frac{1}{X_e Y_e}
\]  

(3.27)

\[
F_2 = \frac{1}{X_{e_1}} + \frac{1}{Y_{e_1}} \quad F_{22} = -\frac{1}{Y_{e_1} Y_{e_2}}
\]  

(3.28)

\[
F_6 = 0 \quad F_{66} = \frac{1}{S_e^2}
\]  

(3.29)

Tsai-Wu failure criterion is more general character than the Tsai-Hill or Hoffman failure criterion.

4. Results and discussion

In this section, the composite laminate has eight layer of lamina with different ply orientation subjected to pure bending moment taken for the analysis of failure bending moment of the laminate. Once the stress in each lamina is known, failure criteria such as maximum stress failure criteria, maximum strain failure criteria, Hoffman failure criteria, Tsai-Hill failure criteria and Tsai-Wu failure criteria are used to determine the pure bending moment at which any one of the lamina in layup fails. In this work Tsai-Wu failure criteria is used to determine the failure bending moment because it take more parameter and condition for the analysis and gives optimum result. Eight layered Glass/epoxy laminated composite
material is considered for study. The length, width and thickness of composite laminate are 100 mm, 50 mm and 40 mm respectively.

![Geometry and boundary condition of composite beam](image)

### Table 1. Properties of Glass/epoxy

| Properties | Values   |
|------------|----------|
| $v_{12}$   | 0.27     |
| $E_1$      | 38.5 GPa |
| $E_2$      | 8.1  GPa |
| $G_{12}$   | 2.0  GPa |
| $X_t$      | 792 MPa  |
| $X_c$      | 679 MPa  |
| $Y_t$      | 39 MPa   |
| $Y_c$      | 71 MPa   |
| $S$        | 108 MPa  |

### Table 2. Different ply orientation of composite laminate for analysis of failure bending moment

| Given name | Orientation       |
|------------|-------------------|
| S_1        | [0/-45/45/90/90/45/-45/0] |
| S_2        | [90/-45/45/0/0/45/-45/90] |
| S_3        | [90/0/90/0/0/90/0/90]     |
| S_4        | [0/90/0/90/90/0/90]       |
| S_5        | [45/-45/45/-45/-45/45]    |
| S_6        | [45/-45/90/0/0/90/-45/45] |

### Table 3. Validation of result for failure bending moment according to Tsai-Wu failure criteria

| S. No. | Ply Orientation | Failure bending moment (Nm) | Adrian et al. | Present |
|--------|-----------------|----------------------------|----------------|---------|
| S_1    | [0/-45/45/90/90/-45/0] | 3005.6                     | 3159.4         |         |
9

Wherein the result for failure bending moment of eight layered with different ply angle presented and the results are compared with Adrian et al. according to Tsai-Wu failure criteria. The failure bending moment obtained in present study and failure bending moment obtained by Adrian et al. are found to be in good agreement as shown in Table 3. Validation is also presented for failure bending moment obtained in present study verses failure bending moment obtained by Adrian et al.

Two other materials (Graphite/epoxy and Boron/epoxy) are taken for further analysis of failure bending moment. Dimensions, boundary condition and staking sequences of these two materials are same as taken in the Glass/epoxy. Put the material properties of these two materials in MATLAB programme. Then find out the failure bending moment for these two materials. After getting the failure bending moment results compare these three materials for same staking sequences and boundary conditions.

| Properties | Graphite/epoxy | Boron/epoxy |
|------------|---------------|-------------|
| 12\(v_{12}\) | 0.28          | 0.23        |
| 1\(E_1\)  | 181 GPa       | 204 GPa     |
| 2\(E_2\)  | 10.30 GPa     | 18.50 GPa   |
| 12\(G_{12}\) | 7.17 GPa     | 5.59 GPa    |
| 1\(X_1\)  | 1500 MPa      | 1260 MPa    |
| 1\(X_2\)  | 1500 MPa      | 2500 MPa    |
| 1\(Y_1\)  | 40 MPa        | 61 MPa      |
| 1\(Y_2\)  | 246 MPa       | 202 MPa     |
| 1\(S\)    | 68 MPa        | 67 MPa      |

| Table 4. Property of Graphite/epoxy and Boron/epoxy |

| S. No. | Ply Orientation | Failure bending moment (Nm) Graphite/epoxy | Failure bending moment (Nm) Boron/epoxy |
|--------|-----------------|---------------------------------------------|----------------------------------------|
| S_1    | [0/-45/45/90/0/45/-45/0] | 4163.9                                      | 5207.6                                  |
| S_2    | [90/-45/45/0/0/45/-45/90] | 4475.5                                      | 5350.7                                  |
| S_3    | [90/0/90/0/0/90/0/90]    | 5543.6                                      | 6447.4                                  |
| S_4    | [0/90/0/90/0/90/0/90]    | 6327.9                                      | 7309.5                                  |
| S_5    | [45/-45/-45/-45/-45/45]  | 4390.5                                      | 5420.6                                  |
| S_6    | [45/-45/90/0/0/90/45/45] | 4906.7                                      | 5920.4                                  |
5. Conclusion

In present work finite element formulation is done for analysis of cantilever composite beam subjected to pure bending moment. Tsai-Wu failure theory is used to determine the failure bending moment of composite laminate with different ply orientation. Glass/epoxy is taken for the analysis of failure bending moment and which shows very good agreement with the previous paper. Among all ply orientation, [0/90/90/90/0/90/0/90] shows maximum bending moment carrying capacity and [0/-45/45/90/90/45/-45/0] shows lowest bending moment carrying capacity. Composite material such as Graphite/epoxy and Boron/epoxy are also taken for the analysis with same boundary condition as Glass/epoxy. Comparative result shows the Boron/epoxy having highest bending moment carrying capacity as compare to Graphite/epoxy and Glass/epoxy.

6. References

[1] Gliszczynski A and Kubiak T, load carrying capacity of thin walled composite beams subjected to pure bending 2017 vol. 115, no. October 2016, pp. 76–85.
[2] Mallouli M, Ben Souf M A, Bareille O, Ichchou M N, Fakhfakh T, and Haddar M, Damage detection on composite beam under transverse impact using the Wave Finite Element method 2018 Appl. Acoust., no. June 2017, pp. 0–1.
[3] Kataoka M N, Lucia A and El Debs H C, Parametric study of composite beam-column connections using 3D finite element modelling 2014 JCSR, vol. 102, pp. 136–149.
[4] Kirkland B, Kim P, Uy B and Vasdravellis G, Moment-shear-axial force interaction in composite beams 2015 JCSR, vol. 114, pp. 66–76.
[5] Aguiar R M, Moleiro F, and Soares C M M, Assessment of mixed and displacement-based models for static analysis of composite beams of different cross-sections 2012 Compos. Struct., vol. 94, no. 2, pp. 601–616.
[6] Taig G and Ranzi G, Generalised Beam Theory (GBT) for composite beams with partial shear interaction 2015 Eng. Struct., vol. 99, pp. 582–602.
[7] Turmo J, Lozano-galant J A, Mirambell E and Xu D, Modeling composite beams with partial interaction 2015 vol. 114, pp. 380–393.
[8] Karsh P K, Mukhopadhyay, and S Dey S, Spatial vulnerability analysis for the first ply failure strength of composite laminates including effect of delamination 2018 Compos. Struct., vol. 184, no. October 2017, pp. 554–567.
[9] Jones R M, Mechanics of composite material 1999 inc. 325, PA 19106.