Homogenization of Grewia Optiva Fiber Reinforced Epoxy Composite Using Higher Order Shear Deformation Theory

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Abstract. The present work proposes a computational procedure for evaluating the homogenized property of laminated composite plate. This type of model is beneficial for determining the basic mechanical properties of a laminated composite with significantly lesser computational effort. In this work a formulation is presented which is based on Reddy’s higher-order shear deformation plate theory which takes into account the effect of transverse shear deformation in composite laminates. This method is capable of finding equivalent homogenized properties for the laminated composite having any type of lamination scheme. Further this formulation is used to homogenized property of Grewia optiva fiber reinforced epoxy composite with different volume fraction and lamina scheme are calculated by using the proposed formulation. The accuracy and validity of the present computational algorithm is ensured by comparing the results with the available literature which provides good results.

1. Introduction

As the technology is growing demand for the composite material is growing continuously for the significant applications in the industries. In composite stress and strain varies 3-Dimensionally because of arbitrary orientation of fiber and various other factors, which makes the composite analysis difficult. An equivalent homogeneous model is used to overshoot this problem which can predict the overall behaviour of the laminated composite. This model can predict the equivalent mechanical properties of the composite which can be used further for any analysis. The homogenized model is used by the various researcher, Aref et al. [1] had homogenised (orthotropic Kirchhoff plate) the rib core sandwich panel. Some researchers have used equivalent homogeneous model for the analysis of sandwich panels with truss-core [2], corrugated core [3] and Z-core [4]. Nordstrand et al. have calculated transverse shear stiffness for different core configuration numerically as well as analytically [5]. While McCarthy [6] and Mandal [7] has used equivalent properties for bolt analysis.

A method is presented in this paper where equivalent homogenised properties are calculated by considering 3D elasticity of composite. Reddy’s higher-order shear deformation theory (HSDT) [8] is used to homogenize the arbitrarily oriented lamina (i.e. non-homogenized) of the laminated plate. By using HSDT we have calculated the equivalent stiffness matrix which considers the effect of twisting, bending as well as shear stiffness which other theories exclude. A MATLAB program has been developed for this purpose. This MATLAB program is then used to calculate the Properties of Grewia optiva fiber reinforced epoxy composite with the fiber properties taken from Singha [9].
2. MATHEMATICAL FORMULATION
The Formulation comprises of two stages, in the first stage Micromechanical model is used to calculate the equivalent lamina property of composite by considering fiber and matrix. While in second stage Macromechanical model is used to calculate the equivalent properties of the composite by combining all lamina together with the use of HSDT.

2.1. Micro-mechanical Approach to Calculate Lamina Properties.
In this paper, the nature of fiber is orthotropic or transversely isotropic while the matrix is isotropic in nature. By using these nature of fiber and matrix effective properties are calculated. Volume fraction of fiber and matrix is,

\[ V_f = \frac{\nu_f}{\nu_c} \quad \text{and} \quad V_m = \frac{\nu_m}{\nu_c} \quad (1) \]

where, \( \nu_f, \nu_m \) = Volume of fiber, composite and matrix respectively
\( V_{m,f} \) = Volume fraction of matrix and fiber respectively

2.1.1. Longitudinal Young’s Modulus. Assume composite is stressed in the Longitudinal direction then the total axial force acting on the composite will be the sum of forces acting on fiber and matrix,

\[ F_C = F_F + F_M \quad (2) \]

Now substituting the value of force in terms of axial strain,

\[ E_f A_c = E_f A_f + E_m A_m \quad (3) \]

As strains remain same (\( \varepsilon_c = \varepsilon_f = \varepsilon_m \)) in axial condition, So Eq. (3) becomes,

\[ E_f A_c = E_f A_f + E_m A_m \quad (4) \]

\[ E_f = E_f \frac{A_f}{A_c} + E_m \frac{A_m}{A_c} \quad (5) \]

Eq. (5) by using volume fractions,

\[ E_f = E_f V_f + E_m V_m \quad (6) \]

2.1.2. Transverse Young’s Modulus. Now assume composite is stressed in the transverse direction then stresses remain same for fiber, composite and matrix as,

\[ \sigma_c = \sigma_f = \sigma_m \quad (7) \]

Now, a transverse extension \( \Delta_c \) is,

\[ \Delta_c = \Delta_f + \Delta_m \quad (8) \]

Where,

\[ A_c = h_c \varepsilon_c, A_f = h_f \varepsilon_f, A_m = h_m \varepsilon_m \quad (9) \]

we know,

\[ \varepsilon_c = \frac{\sigma_c}{E_c}, \varepsilon_f = \frac{\sigma_f}{E_f}, \varepsilon_m = \frac{\sigma_m}{E_m} \quad (10) \]
By Eq. (8), (9) & (10)

\[
h_c \frac{\sigma_c}{E_2} = h_f \frac{\sigma_f}{E_f} + h_m \frac{\sigma_m}{E_m}
\]

(11)

Using Eq. (7)

\[
\frac{1}{E_2} = \frac{1}{E_f} \frac{h_f}{h_c} + \frac{1}{E_m} \frac{h_m}{h_c}
\]

(12)

\[
\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m}
\]

(13)

As \(E_2, E_3\) are transverse moduli, \(E_3\) can be found by using Eq. (13) for orthotropic lamina.

2.1.3. Major Poisson’s Ratio. It is the measure of material expansion or reduction in direction perpendicular to the applied load also called Poisson’s effect. Mathematically, it is the negative ratio of the longitudinal strain to the lateral strain, when the normal load is applied in the longitudinal direction. Thus, transverse deformation of the composite is,

\[
\delta_{f,m,c}^T = \text{Transverse deformation in composite, fiber, matrix and composite}
\]

\[
\varepsilon_{f,m,c}^T = \text{Transverse strain in composite, fiber, matrix and composite}
\]

\[
\varepsilon_{f,m,c}^L = \text{Longitudinal strains of fiber, matrix and composite}
\]

\[
\delta_c^T = \delta_f^T + \delta_m^T
\]

(14)

Now use the definition of normal strains are,

\[
\varepsilon_f^T = \frac{\delta_f^T}{h_f}, \varepsilon_m^T = \frac{\delta_m^T}{h_m}, \varepsilon_c^T = \frac{\delta_c^T}{h_c}
\]

(15)

Now putting the above values in Eq. (14) we get,

\[
h_c \varepsilon_c^T = h_f \varepsilon_f^T + h_m \varepsilon_m^T
\]

(16)

Since we know,

\[
\nu_f = -\frac{\varepsilon_f^T}{\varepsilon_f^L}, \nu_m = -\frac{\varepsilon_m^T}{\varepsilon_m^L} \text{ and } \nu_{12} = -\frac{\varepsilon_c^T}{\varepsilon_c^L}
\]

(17)

we get,

\[-h_c \nu_{12} \varepsilon_c^L = -h_f \nu_f \varepsilon_f^L - h_m \nu_m \varepsilon_m^L
\]

(18)

Strains remain same in longitudinal direction \(\left(\varepsilon_c^L = \varepsilon_f^L = \varepsilon_m^L\right)\), thus above Eq. 18 becomes,

\[
h_c \nu_{12} = h_f \nu_f + h_m \nu_m
\]

(19)

\[
\nu_{12} = \nu_f \frac{h_f}{h_c} + \nu_m \frac{h_m}{h_c}
\]

(20)

From Eq. (1) we can write,

\[
\nu_{12} = \nu_f V_f + \nu_m V_m
\]

(21)
Eq. (21) gives us major Poisson’s ratio. For calculating minor Poisson’s ratio

\[
\frac{\nu_{12}}{E_1} = \frac{\nu_{21}}{E_2}
\]  

(22)

2.2. Equivalent Material Properties
In this formulation, the equivalent homogenized properties of the composite are calculated by combining the lamina properties throughout the thickness, by using the HSDT. The reduced stiffness matrix \([Q]\) for each layer of the laminate plate can be calculated by using stress-strain relationship in the laminate. The obtained stiffness matrix describing the elastic behaviour of the ply in-plane loading, thus, Hook’s law for orthotropic material is given as,

\[
\{\sigma\} = \begin{bmatrix}
Q_{11} & Q_{12} & Q_{13} & 0 & 0 & 0 \\
Q_{21} & Q_{22} & Q_{23} & 0 & 0 & 0 \\
Q_{31} & Q_{32} & Q_{33} & 0 & 0 & 0 \\
0 & 0 & 0 & Q_{44} & 0 & 0 \\
0 & 0 & 0 & 0 & Q_{55} & 0 \\
0 & 0 & 0 & 0 & 0 & Q_{66}
\end{bmatrix} \{\epsilon\}
\]  

(23)

Where,
\([Q]\) = Material stiffness matrix,  
\([Q_{11}] = E_1 (1 - \mu_{23} \times \mu_{23}) / \Delta, \quad [Q_{13}] = [Q_{31}] = E_1 (\mu_{13} + \mu_{12} \times \mu_{23}) / \Delta, \quad [Q_{23}] = [Q_{32}] = E_3 (\mu_{23} + \mu_{12} \times \mu_{13}) / \Delta, \quad [Q_{22}] = E_2 (1 - \mu_{31} \times \mu_{13}) / \Delta, \quad [Q_{55}] = G_{13}, \quad [Q_{66}] = G_{12}, \quad [Q_{33}] = E_3 (1 - \mu_{12} \times \mu_{23}) / \Delta, \quad [Q_{44}] = G_{23}, \quad \Delta = 1 - \mu_{12}^2 - \mu_{23}^2 - \mu_{13}^2 - 2 \mu_{13} \mu_{23} \mu_{32}

Now apply the transformation to stiffness matrix \([Q]\). Transformation is needed to apply due to laminate does not consist only unidirectional laminae, Equivalent plate stiffnesses and orthotropic stress-strain relationship for \(k\)th lamina are obtained as,

\[
\{\sigma\} = \begin{bmatrix}
S_{ij} & \sigma_1 \\
S_{ij} & \sigma_2 \\
S_{ij} & \sigma_3 \\
S_{ij} & \sigma_4 \\
S_{ij} & \sigma_5 \\
S_{ij} & \sigma_6
\end{bmatrix} \begin{bmatrix}
\epsilon_1 \\
\epsilon_2 \\
\epsilon_3 \\
\gamma_{12} \\
\gamma_{13} \\
\gamma_{23}
\end{bmatrix}_k = \begin{bmatrix}
S_{ij} & \sigma_1 \\
S_{ij} & \sigma_2 \\
S_{ij} & \sigma_3 \\
S_{ij} & \sigma_4 \\
S_{ij} & \sigma_5 \\
S_{ij} & \sigma_6
\end{bmatrix}^{-1} \begin{bmatrix}
\epsilon_1 \\
\epsilon_2 \\
\epsilon_3 \\
\gamma_{12} \\
\gamma_{13} \\
\gamma_{23}
\end{bmatrix}_k
\]  

(25)

\[
\{\sigma\}_k = \begin{bmatrix}
S_{ij} & \sigma_1 \\
S_{ij} & \sigma_2 \\
S_{ij} & \sigma_3 \\
S_{ij} & \sigma_4 \\
S_{ij} & \sigma_5 \\
S_{ij} & \sigma_6
\end{bmatrix}^{-1} \begin{bmatrix}
\epsilon_1 \\
\epsilon_2 \\
\epsilon_3 \\
\gamma_{12} \\
\gamma_{13} \\
\gamma_{23}
\end{bmatrix}_k
\]  

(26)

\[
[S_{ij}]_k^{-1} = [C_{ij}]_k
\]  

(27)

\[
[S_{ij}]_k^{-1} = [C_{ij}]_k = \begin{bmatrix}
\bar{\sigma} \\
\bar{T}
\end{bmatrix}^{-1} \begin{bmatrix}
[R] \begin{bmatrix}
Q \\
[T] \begin{bmatrix}
Q \\
[T] \begin{bmatrix}
Q \\
[T] \begin{bmatrix}
Q \\
[T] \begin{bmatrix}
Q \\
[T]
\end{bmatrix}^{-1}
\end{bmatrix}^{-1}
\end{bmatrix}^{-1}
\end{bmatrix}^{-1}
\end{bmatrix}^{-1}
\]  

(28)

\[
[C_{ij}]_k = \begin{bmatrix}
\bar{T}
\end{bmatrix}^{-1} \begin{bmatrix}
C_{ij}
\end{bmatrix}_k \begin{bmatrix}
\bar{T}
\end{bmatrix}^{-1}
\]  

(29)
\[
[T] = \begin{bmatrix}
p^2 & q^2 & 0 & 2pq & 0 & 0 \\
q^2 & p^2 & 0 & -2pq & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 \\
-pq & pq & 0 & p^2 - q^2 & 0 & 0 \\
0 & 0 & 0 & 0 & p & q \\
0 & 0 & 0 & 0 & -q & p \\
\end{bmatrix}
\]

(30)

Where, \( p = \cos \theta \) and \( q = \sin \theta \), \( [T]^{-1} \) = Transformation matrix,

Now, for each lamina resultant force and moment are evaluated by integrating each lamina \( k \) along its thickness and summing all resultant forces & moment to get the resultant forces and moment of laminate.

\[
\begin{bmatrix}
N_x \\
N_y \\
N_z \\
N_{xy}
\end{bmatrix} = \begin{bmatrix}
A_{11} & A_{12} & A_{13} & A_{16} \\
A_{21} & A_{22} & A_{23} & A_{26} \\
A_{31} & A_{32} & A_{33} & A_{36} \\
A_{61} & A_{62} & A_{63} & A_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^0 \\
\varepsilon_y^0 \\
\varepsilon_z^0 \\
\varepsilon_{xy}^0
\end{bmatrix} + \begin{bmatrix}
B_{11} & B_{12} & B_{13} & B_{16} \\
B_{21} & B_{22} & B_{23} & B_{26} \\
B_{31} & B_{32} & B_{33} & B_{36} \\
B_{61} & B_{62} & B_{63} & B_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^1 \\
\varepsilon_y^1 \\
\varepsilon_z^1 \\
\varepsilon_{xy}^1
\end{bmatrix} + \begin{bmatrix}
E_{11} & E_{12} & E_{13} & E_{16} \\
E_{21} & E_{22} & E_{23} & E_{26} \\
E_{31} & E_{32} & E_{33} & E_{36} \\
E_{61} & E_{62} & E_{63} & E_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^2 \\
\varepsilon_y^2 \\
\varepsilon_z^2 \\
\varepsilon_{xy}^2
\end{bmatrix} + \begin{bmatrix}
F_{11} & F_{12} & F_{13} & F_{16} \\
F_{21} & F_{22} & F_{23} & F_{26} \\
F_{31} & F_{32} & F_{33} & F_{36} \\
F_{61} & F_{62} & F_{63} & F_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^3 \\
\varepsilon_y^3 \\
\varepsilon_z^3 \\
\varepsilon_{xy}^3
\end{bmatrix}
\]

\[
M_x = \begin{bmatrix}
D_{11} & D_{12} & D_{13} & D_{16} \\
D_{21} & D_{22} & D_{23} & D_{26} \\
D_{31} & D_{32} & D_{33} & D_{36} \\
D_{61} & D_{62} & D_{63} & D_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^1 \\
\varepsilon_y^1 \\
\varepsilon_z^1 \\
\varepsilon_{xy}^1
\end{bmatrix} + \begin{bmatrix}
F_{11} & F_{12} & F_{13} & F_{16} \\
F_{21} & F_{22} & F_{23} & F_{26} \\
F_{31} & F_{32} & F_{33} & F_{36} \\
F_{61} & F_{62} & F_{63} & F_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^2 \\
\varepsilon_y^2 \\
\varepsilon_z^2 \\
\varepsilon_{xy}^2
\end{bmatrix} + \begin{bmatrix}
H_{11} & H_{12} & H_{13} & H_{16} \\
H_{21} & H_{22} & H_{23} & H_{26} \\
H_{31} & H_{32} & H_{33} & H_{36} \\
H_{61} & H_{62} & H_{63} & H_{66}
\end{bmatrix} \begin{bmatrix}
\varepsilon_x^3 \\
\varepsilon_y^3 \\
\varepsilon_z^3 \\
\varepsilon_{xy}^3
\end{bmatrix}
\]

\[
A_{ij} = \sum_{k=1}^{n} [C_{ij}]_k (h_k - h_{k-1}), \quad D_{ij} = \frac{1}{3} \sum_{k=1}^{n} [C_{ij}]_k (h_k^3 - h_{k-1}^3), \quad F_{ij} = \frac{1}{5} \sum_{k=1}^{n} [C_{ij}]_k (h_k^5 - h_{k-1}^5),
\]

\[
B_{ij} = \frac{1}{2} \sum_{k=1}^{n} [C_{ij}]_k (h_k^2 - h_{k-1}^2), \quad E_{ij} = \frac{1}{4} \sum_{k=1}^{n} [C_{ij}]_k (h_k^4 - h_{k-1}^4), \quad H_{ij} = \frac{1}{7} \sum_{k=1}^{n} [C_{ij}]_k (h_k^7 - h_{k-1}^7)
\]

Now we consider resultant shear forces,

\[
\begin{bmatrix}
Q \\
R
\end{bmatrix} = \begin{bmatrix}
A^5 & D^5 & F^5 \\
D^5 & F^5 & \varepsilon_{xy}
\end{bmatrix} \begin{bmatrix}
\varepsilon_{xz} \\
\varepsilon_{yz}
\end{bmatrix}
\]

(31)

\[
\begin{bmatrix}
N \\
M^b \\
M^s \\
Q \\
R
\end{bmatrix} = \begin{bmatrix}
A_1 & B_1 & E_1 \\
B_2 & D_1 & F_1 \\
E_2 & F_1 & H_1 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{bmatrix} \begin{bmatrix}
A_5 \\
D_5 \\
F_5
\end{bmatrix}
\]

(32)
2.2.1. For Symmetric Lamination, the contribution of [A] and [E] is very less compared to [D] matrix while [B] matrix remains zero for symmetric lay-ups. So bending stiffness is considered only as matrix [A], [B] and [E] get neglected.

\[
\begin{bmatrix}
 M_x & M_y & M_z & M_{xy} & M_{xz} & Q_{xz} & Q_{yc} \\
 D_{11} & D_{12} & D_{13} & D_{16} & 0 & 0 & 0 \\
 D_{21} & D_{22} & D_{23} & D_{26} & 0 & 0 & 0 \\
 D_{31} & D_{32} & D_{33} & D_{36} & 0 & 0 & 0 \\
 D_{61} & D_{62} & D_{63} & D_{66} & 0 & 0 & 0 \\
 0 & 0 & 0 & 0 & A_x^z & A_y^z \\
 0 & 0 & 0 & 0 & A_x^z & A_y^z \\
&\end{bmatrix}
\begin{bmatrix}
 \kappa_x \\
 \kappa_y \\
 \kappa_z \\
 \kappa_{xy} \\
 \kappa_{xz} \\
 \epsilon_{xz} \\
 \epsilon_{yz} \\
\end{bmatrix}
\] (33)

By using the above matrix equivalent compliance matrix \([C_{\text{eq}}]\) is calculated as,

\[
[C_{\text{eq}}] = [D]/\varepsilon_3^3 
\] (34)

\[
Z_3 = \frac{1}{3} \left( \frac{h_c}{2} \right)^3 - \left( \frac{h_c}{2} \right) \left( \frac{h_c}{2} \right)^2
\] (35)

i.e.

\[
Z_3 = \frac{h_c^3}{12}
\] (36)

where, \(h_c\) = Total thickness of the laminate plate

\([S_{\text{eq}}]\) = Equivalent elastic compliance matrix

\[
[S_{\text{eq}}] = [C_{\text{eq}}]^{-1} = \begin{bmatrix}
 C_{11} & C_{12} & C_{13} & C_{16} \\
 C_{21} & C_{22} & C_{23} & C_{26} \\
 C_{31} & C_{32} & C_{33} & C_{36} \\
 C_{61} & C_{62} & C_{63} & C_{66} \\
\end{bmatrix}^{-1} = \begin{bmatrix}
 S_{11} & S_{12} & S_{13} & S_{16} \\
 S_{21} & S_{22} & S_{23} & S_{26} \\
 S_{31} & S_{32} & S_{33} & S_{36} \\
 S_{61} & S_{62} & S_{63} & S_{66} \\
\end{bmatrix}
\] (37)

Now, shear stiffness matrix is used to calculate the remaining components of the constitutive matrix as,

\[
[S_{\text{eq}}] = \begin{bmatrix}
 S_{11} & S_{12} & S_{13} & 0 \\
 S_{21} & S_{22} & S_{23} & 0 \\
 S_{31} & S_{32} & S_{33} & 0 \\
 0 & 0 & 0 & S_{66} \\
\end{bmatrix}
\] (38)

\[
[C_{44} \ 0] = \frac{A_x^z}{h_c}
\] (39)

where, \([A^z]\) = Shear stiffness matrix

\[
[C_{44} \ 0]^{-1} = \begin{bmatrix}
 S_{44} & 0 \\
 0 & S_{55} \\
\end{bmatrix}
\] (40)

Now the elastic properties can be obtained using a new compliance matrix as,
\[ E_1 = S_{11}^{-1}, \quad E_2 = S_{22}^{-1}, \quad E_3 = S_{33}^{-1} \]
\[ G_{12} = S_{66}^{-1}, \quad G_{13} = S_{44}^{-1}, \quad G_{23} = S_{55}^{-1} \]
\[ \mu_{12} = -S_{21} \times E_1, \quad \mu_{13} = -S_{31} \times E_1, \quad \mu_{23} = -S_{32} \times E_2 \]

\[ \begin{align*}
\varepsilon_x &= N_x \text{(some matrix)} \\
E_x &= \frac{N_x}{\varepsilon_x} \frac{1}{h} = \text{(some matrix)} \frac{1}{h} 
\end{align*} \]  

Similarly, to calculate \( E_y \) only y-direction load is applied and to calculate \( G_{xy} \) xy-direction load is applied and to calculate the Poisson’s ratio \( \nu_{xy} = \frac{-\varepsilon_y}{\varepsilon_x} \). 

### 3. Results Discussion

#### 3.1. Validation of results

The present method is validated by developing MATLAB code and results are compared with McCarthy [6] and Mandal [7]. Two different lay-ups, quasi-isotropic with stacking sequence [45/0/45/90]_{5s}, and other zero-dominated with stacking sequence [45/0/2/-45/90/45/0/2/-45/0] which is a suitable lay-up for composite aircraft wing skin is used. The model uses ply thickness of 0.13 mm which yields in a nominal thickness of 5.2 mm when cured.

**Table 1:** Comparison of Equivalent Properties* for the quasi-isotropic and zero-dominated lay-ups. 

|                | Quasi-isotropic layup [45/0/45/90]_{5s} | Zero-dominated layup [45/0/2/-45/90/45/0/2/-45/0] |
|----------------|----------------------------------------|---------------------------------------------------|
| Present        | McCarthy et al. [11]                   | Mandal et al. [12]                                |
| Present        | McCarthy et al. [11]                   | Mandal et al. [12]                                |
| \( E_1 \)      | 54.24                                  | 54.25                                             |
|                | 56.18                                  | 56.18                                             |
| \( E_2 \)      | 54.24                                  | 47.89                                             |
|                | 47.89                                  | 47.89                                             |
| \( E_3 \)      | 14.8                                   | 12.59                                             |
|                | 12.57                                  | 12.57                                             |
| \( G_{12} \)   | 20.72                                  | 21.89                                             |
|                | 21.89                                  | 21.89                                             |
| \( G_{13} \)   | 6.47                                   | 4.55                                              |
|                | 4.55                                   | 4.55                                              |
| \( G_{23} \)   | 6.45                                   | 4.55                                              |
|                | 4.55                                   | 4.55                                              |
| \( \nu_{12} \) | 0.31                                   | 0.36                                              |
|                | 0.36                                   | 0.36                                              |
| \( \nu_{13} \) | 0.31                                   | 0.31                                              |
|                | 0.31                                   | 0.31                                              |
| \( \nu_{23} \) | 0.31                                   | 0.34                                              |
|                | 0.34                                   | 0.34                                              |

* Values of \( E_x \) and \( G_{xx} \) are in GPa
3.2. Properties of Grewia Optiva Reinforced Epoxy Composite

Now using the code, equivalent properties of Grewia optiva fibre reinforced composite material is calculated by using the properties of Fibre from Singha [8]. The properties are calculated by taking the fibre volume fraction as 0.4, 0.5 and 0.6. Further two lay-ups are taken Quasi-isotropic layup and Zero-dominated layup.

**Table 2:** Homogenized properties of Grewia optiva reinforced epoxy composite.

|     | Quasi-isotropic layup [45/0/-45/90]_3s | Zero-dominated layup [45/0/-45/90]-45/0/-45/0 |
|-----|--------------------------------------|-----------------------------------------------|
| V_f | 0.4 | 0.5 | 0.6 | 0.4 | 0.5 | 0.6 |
| E_1 | 13.54 | 16.41 | 19.59 | 18.07 | 21.95 | 26.06 |
| E_2 | 13.54 | 16.41 | 19.59 | 10.33 | 12.47 | 14.98 |
| E_3 | 6.91 | 8.13 | 9.88 | 6.95 | 8.18 | 9.96 |
| G_{12} | 5.22 | 6.26 | 7.40 | 5.86 | 5.57 | 6.61 |
| G_{13} | 3.02 | 7.45 | 4.46 | 3.01 | 3.59 | 4.43 |
| G_{23} | 3.04 | 3.61 | 4.46 | 3.13 | 3.73 | 4.60 |
| v_{12} | 0.30 | 0.31 | 0.33 | 0.40 | 0.39 | 0.37 |
| v_{13} | 0.29 | 0.31 | 0.32 | 0.20 | 0.21 | 0.22 |

* Values of $E_x$ and $G_{xx}$ are in GPa

4. Conclusion

- In this paper, a new 3D homogenizations method was proposed to calculate the properties of the laminated composite.
- The approach can find the equivalent properties of any lamination scheme whether symmetric or asymmetric.
- Using this method MATLAB code was developed and used calculated the properties of composite. Further this code is validated through previous literature results which gives a well satisfactory result.
- The present method is compared with the actual 3D layered solid and with the result of Mandal paper by considering different lamination scheme.
- Further properties of Grewia optiva fiber composite is calculated in this work.

References

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