Stress Analysis of Glass/Epoxy Symmetric and Asymmetric Composite Laminated Plate by using Finite Element Method in MATLAB

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Abstract— The objective of current study is to understand the behaviour of glass/epoxy composite plate under same loading condition by using finite element analysis in MATLAB. For the purpose of finite element analysis eight-nodded isoperimetric element is considered. At each node five degrees of freedom considered that are three displacements and two rotations. The result shows the stresses of glass/epoxy plate under pressure with fiber oriented in hexagonal array. Glass/epoxy composite lamina of different orientation angles like 00, 450, 900 is used for analysis purpose and stress values of all models found under uniform distributed transverse load.

Key words: Glass/Epox, Finite Element, MATLAB

I. INTRODUCTION

Composite laminates have been used increasingly in different areas like aviation, aerospace and automotive industry. This is due to high stiffness and strength-to-weight ratios, long fatigue life, resistance to electrochemical corrosion, and other superior material properties of composites. Finite element method is used to solve many engineering problems. So it is an efficient method for the analysis of composite laminates. The study of the fiber orientation, the length to thickness ratio, the aspect ratio on the buckling load of glass/epoxy laminated composite plate was done. As there is increase in length-to-thickness ratio and fiber angle, buckling load decreased (1). Different theories were used for Finite element analysis of laminated composite plate. Higher order shear deformation theory with assumed strains was used for the finite element analysis of plate. A four node element with seven degrees of freedom per node is developed for stress analysis (2) .Optimum design of fiber orientation in composite laminate plates for out-plane stresses was done in 2012. The effects of transverse shear forces are considered. In this paper out plane stresses optimization along with in plane stresses were done (3). Study on hybrid composite joint using finite element method in ANSYS was done to find Von mises stress, shear stress and normal stress. 3D model created in PRO-E and analysis was carried out in ANSYS workbench. In this study analysis of Symmetric and Asymmetric Glass/Epoxy laminate carried out. Following asymmetric plates analyzed that are [0|90|0|90], [0|45|0|45] and [-45|45|-45|45]. Also symmetric plates analyzed for comparison are [0|90]s, [0|45]s and [-45|45]s.

II. FINITE ELEMENT MODELLING

A. Problem Statement

Purpose of this study is to find out the bending stresses in glass/epoxy composite laminated plate which is under uniform distributed transverse load of 100 MPa. To study structural components under bending loads plate models are used. In finite element modelling an eight-node isoparametric element is considered for stress analysis of laminated plate.

B. Constitutive Relations

The displacement field of a laminated plate with respect to the x, y, z coordinate axis system in the following form

$$\begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = \begin{Bmatrix} u_0 \\ v_0 \\ w \end{Bmatrix} - z \begin{Bmatrix} \theta_x \\ \theta_y \\ 0 \end{Bmatrix} \quad (1)$$

Where u, v, w are the displacements in the x, y and z-directions at any point and u0, v0 and w are those at middle plane of the plate. θ_xAnd θ_y are the rotations of the normal to the undeformed mid-plane.

The middle plane of the plate is considered as the reference plane of the plate.

The strain components according to the strain-displacement relationship of linear elasticity are

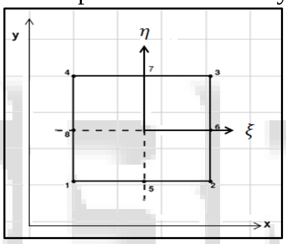

Fig. 1: The configuration of eight-nodded finite element [11]

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_s \\ \varepsilon_{xz} \\ \varepsilon_{yz} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \varepsilon_s^0 \\ \varepsilon_{xz}^0 \\ \varepsilon_{yz}^0 \end{Bmatrix} + z \begin{Bmatrix} k_x \\ k_y \\ k_s \\ 0 \\ 0 \end{Bmatrix} \quad (2)$$

Where ε_x^0 , ε_y^0 and ε_s^0 are the midplane strains and k_x , $k_y$and k_s are the curvatures of the laminated plate.

C. Formulation of Plate Element

The displacement components of node r of the eight-nodded isoperimetric element are

$$\{\delta_r\} = \begin{Bmatrix} u_0 \\ v_0 \\ w_0 \\ \theta_x \\ \theta_y \end{Bmatrix} = \sum_{r=1}^{8} N_r \, [I_5] \begin{Bmatrix} u_{0r} \\ v_{0r} \\ w_{0r} \\ \theta_{xr} \\ \theta_{yr} \end{Bmatrix} = [N]\{\delta\}e \quad (3)$$

The element stiffness matrix is derived using the principle of minimum potential energy. The potential energy of the plate element is given by

$$\Phi = \frac{1}{2}\iint \{\varepsilon\}T \, \{F\} dx\, dy - \iint \{f\} \, Tq \, dx\, dy \quad (4)$$

Where

$$\{F\} = [D][B]\{\delta\}e, \quad (5)$$

q Is any discrete loading inside the element

$$[B] = \sum_{r=1}^{8} \begin{bmatrix} \frac{\partial N_r}{\partial x} & 0 & 0 & 0 & 0 \\ 0 & \frac{\partial N_r}{\partial y} & 0 & 0 & 0 \\ \frac{\partial N_r}{\partial y} & \frac{\partial N_r}{\partial x} & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{\partial N_r}{\partial x} & 0 \\ 0 & 0 & 0 & 0 & -\frac{\partial N_r}{\partial y} \\ 0 & 0 & 0 & -\frac{\partial N_r}{\partial y} & -\frac{\partial N_r}{\partial x} \\ 0 & 0 & \frac{\partial N_r}{\partial x} & -N_r & 0 \\ 0 & 0 & \frac{\partial N_r}{\partial y} & 0 & -N_r \end{bmatrix}, \quad (6)$$

$$[D] = \begin{bmatrix} A_{xx} & A_{xy} & A_{xs} & B_{xx} & B_{xy} & B_{xs} & 0 & 0 \\ A_{yx} & A_{yy} & A_{ys} & B_{xy} & B_{yy} & B_{ys} & 0 & 0 \\ A_{xs} & A_{ys} & A_{ss} & B_{xs} & B_{ys} & B_{ss} & 0 & 0 \\ B_{xx} & B_{xy} & B_{xs} & D_{xx} & D_{xy} & D_{xs} & 0 & 0 \\ B_{yx} & B_{yy} & B_{ys} & D_{ys} & D_{yy} & D_{ys} & 0 & 0 \\ B_{sx} & B_{sy} & B_{ss} & D_{ss} & D_{sy} & D_{ss} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & A^z_{xx} & A^z_{xy} \\ 0 & 0 & 0 & 0 & 0 & 0 & A^z_{yx} & A^z_{yy} \end{bmatrix}. \quad (7)$$

Combining equations

$$\Phi = \frac{1}{2}\iint \{\delta\}_e^T [B]^T\ [D][B]\{\delta\}_e\, dxdy - \iint \{\delta\}_e^T\, [N]^T\, q\, dxdy \quad (8)$$

The principle of minimum potential energy requires

$$\left\{\frac{\partial \Phi}{\partial \{\delta\}_e}\right\} = \{0\} \quad (9)$$

Therefore, performing partial differentiation

$$\left\{\frac{\partial \Phi}{\partial \{\delta\}_e}\right\} = \iint [B]^T\,[D]\,[B]dxdy\{\delta\}_e - \iint [N]^T\ q\ dxdy = \{0\} \quad (10)$$

Or,

$$[K]_e\,\{\delta\}_e = \{P\}_e \quad (11)$$

Where

$$[K]_e = \iint [B]^T [D]\,[B]dxdy \quad (12)$$

$$\{P\}_e = \iint N^T\, q\, dxdy \quad (13)$$

Where $dxdy = |J| d\xi\, d\eta$

Where $|J|$ is the determinant of the Jacobian matrix[J]. Therefore, the element stiffness matrix is rewritten as

$$[K]_e = \iint [B]^T\,[D][B]|J|\ d\xi\, d\eta \quad (14)$$

An explicit evaluation of $[K]_e$ is indeed tedious. The integration is carried out by employing the Gaussian quadrature rule

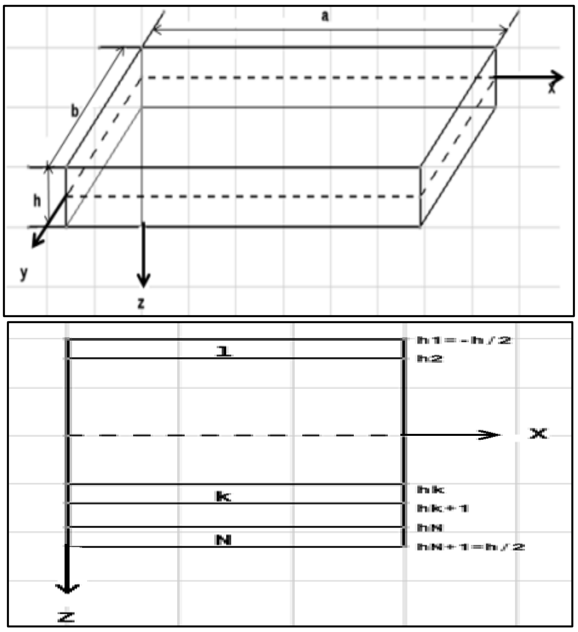

Fig. 2: Composite Plate Showing Individual Lamina

D. Material and Plate Details

An orthotropic composite plate fixed at all edges under transverse loading condition is considered for present study. Plate is having length 0.5 m, width 0.5 m and thickness is 0.01m for each layer. A four layer rectangular plate with all edges fixed under uniform distributed transverse load 100 MPa is taken for the investigation and stresses on plate is obtained. Two 8-nodded isoperimetric elements are considered for stress analysis. Volume fraction of glass fibers are considered 0.6 and matrix means epoxy volume fraction as 0.4.

III. Results and Discussion

Results are plotted for different models of composite plate. Glass/epoxy composite is considered in that again symmetric and asymmetric composite laminate was considered for analysis.

A. For Glass/Epoxy Asymmetric Composite Laminate Plate

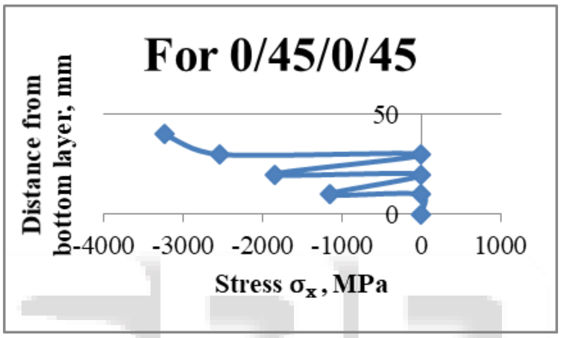

Fig. 3: Variation of Normal Stress Σxin the Laminate from Bottom Layer to Top Layer

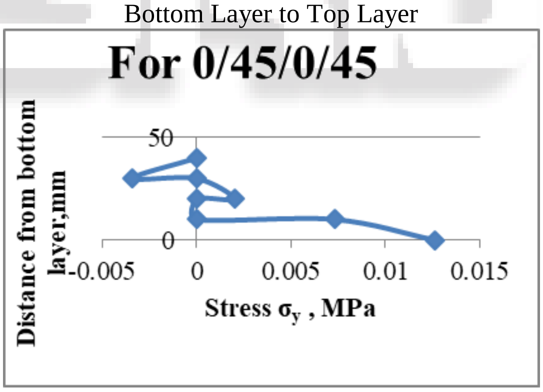

Fig. 4: Variation of Normal Stress Σyin the Laminate from Bottom Layer to Top Layer

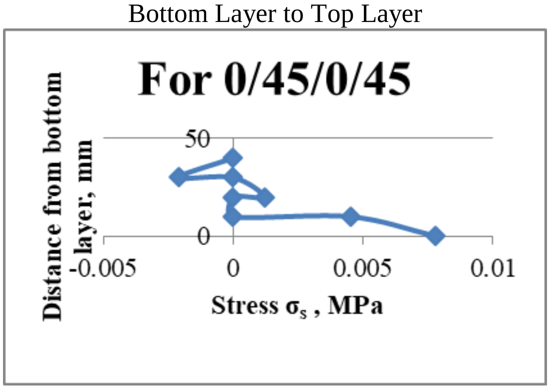

Fig. 5: Variation of Normal Stress Σs in the Laminate from Bottom Layer to Top Layer

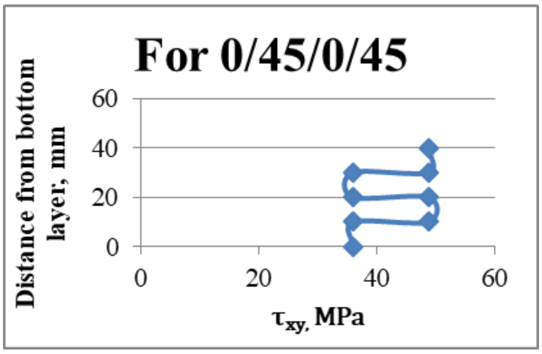

Fig. 6: Variation of Shear Stress Txyin the Laminate from Bottom Layer to Top Laye

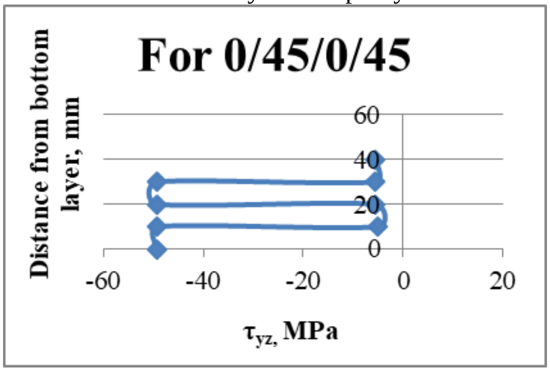

Fig. 7: Variation of Shear Stress Tyzin the Laminate from Bottom Layer to Top Layer

B. *For Glass/Epoxy Symmetric Composite Laminate Plate*

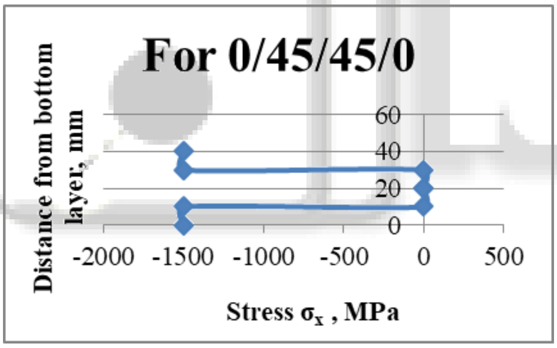

Fig. 8: Variation of Normal Stress Σx in the Laminate from Bottom Layer to Top Layer

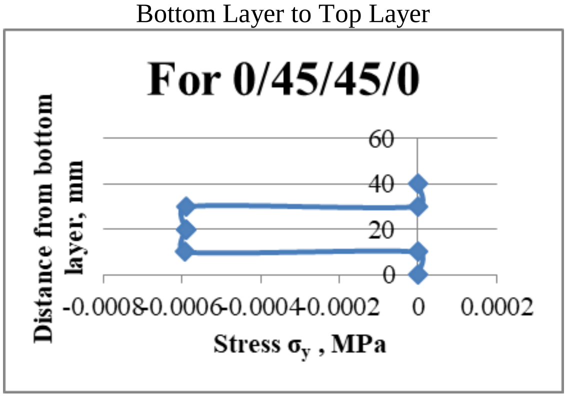

Fig. 9: Variation of Normal Stress Σyin the Laminate from Bottom Layer to Top Layer

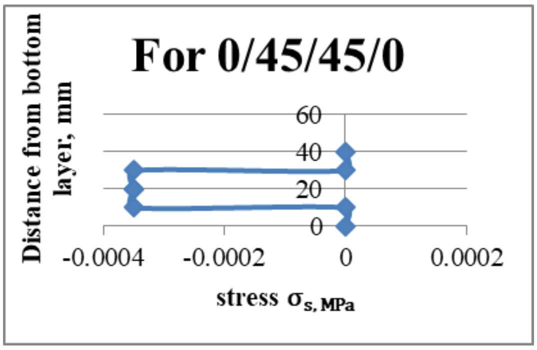

Fig. 10: Variation of Normal Stress Σs in the Laminate from Bottom Layer to Top Layer

Here for comparison purpose [0/45] symmetric and asymmetric laminates are considered. From graph it is clear that for given loading condition symmetric laminate is better than asymmetric laminate because in symmetric composite laminate plate shear stress is not induced. Also nature of stresses present in the symmetric laminate is smooth and magnitude was also less in all examples. Same type of conclusion will get from [0/90] and [-45/45] laminate.

IV. CONCLUSION

Stress analysis of glass/epoxy composite laminated is presented in this study. The symmetric laminate plate is showing better performance under uniform distribute load than asymmetric laminated plate. So Strength of symmetric laminated composite plate is more than asymmetric laminated composite plate under transverse loading. Thermal stresses are not considered in this study.

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