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Analysis of Rectangular Composite Laminated Plates using FEM

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Abstract:

A number of laminated composite plates having angle-ply orientations are analyzed using finite element method. In order to find the effect of ply orientation on the deflections and stresses, four different laminates are chosen and applied to uniformly distributed load as well as sinusoidally varying load on their top surfaces. Simply supported as well as clamped boundary conditions are applied to these laminated plates. It is found that both the boundary condition and the loading type greatly influence the response of the laminated plates, while the responses are seen to change with change in the ply orientation angle.

Keywords: *Composite materials, Laminated plate, Uniform load, Simply supported load, Deflection, Equivalent stress*

I. INTRODUCTION

Composite materials are superior to other conventional materials since they possess many favorable properties such as high specific strength and stiffness. Load bearing structures are desired to have such properties [1]. Since composite materials offer this advantage, they can be used by putting them in different laminate sequences and different materials while making a laminated plate. Designers will have the possibility of exciting new solutions in addressing tough engineering problems. Composite material layers can be combined in a way that best exploits layerwise properties to bring out desired effective properties and minimize response deficiencies. The process of adaption enables designers to skip the obstacles related to the selection and construction of traditional materials. By adopting same principles, designers can use hard and light materials to come out with properties that can be tailored to the design requirements. Fiber reinforced composites are orthotropic composites that possess different properties in different directions. In the past, a number of fiber reinforce composites have been used in different structures and the authors are inspired to take up this analysis in order to strengthen the research carried out in the field of composite structures. For analysis of composite plates, a number of analytical and finite element formulations have been presented by several researchers. A review of these theories is given by Liberescu and Hause [2]. The composite structures can be in the form of laminated composite plates or sandwich plates. Noor and Button [3] have assessed different shear deformation theories for analysis of laminated plates containing a number of composite layers. Analytical theories can be used for simple geometry and boundary conditions and the most accurate analytical solution is the three-dimensional elasticity solution [4]. But when structures involve general support conditions and general loading conditions finite element methods can be used to advantage. Kefal et al. [5] have discussed various finite elements available in the literature for such analyses. From these researches, it is found that finite element method presents an effective way to analysis response of many complex composite structures.

II. Modelling the plate geometry

Consider a laminated plate of orthotropic composite material having dimensions a along x-axis, b along y-axis and h along z-axis. With respect to *xyz* coordinate system and considering *xy* as the bottom plane of the plate, four orthotropic composite layers are placed over each other and perfectly bonded at their interfaces. Such perfect bonding eliminates interlaminar delamination due to relative slip between the layers. It is worthwhile to note here that interlaminar delamination is a primary cause of failure in laminated structures. The dimension of the plate is 50 mm along *x*-axis, 150 mm along *y*-axis. Each of the four layers has thickness 1.25 mm, thus making a total thickness of 5 mm for the laminated plate. The four layers are oriented at different angles with respect to the *x*-axis. Considering layer orientations, three laminated plates are developed. First plate, named plate (a) has $0^0/30^0/90^0/-30^0$ orientations. Second plate, named plate (b) has $0^0/45^0/90^0/-45^0$ orientations and third plate, named plate (c) has $0^0/60^0/90^0/-60^0$ orientations. Each of the laminated plates has been meshed using automatic mesh generation. Graphite epoxy is chosen as the orthotropic material. Its material properties are [4]: E_1 = 172.5 GPa, E_2 = 6.9 GPa, E_3 = 6.9 GPa, G_{12} = 3.45 GPa, G_{13} = 3.45 GPa, G_{23} = 1.38 GPa, $\nu_{12} = \nu_{13} = \nu_{23}$ = 0.25. Let the inplane material axes be inclined at an angle ψ to the global inplane axes *xy* while the transverse directions coincide with each other. Denoting $c = \cos\psi$ and $s = \sin\psi$ and using the transformation matrix T is defined by

$$T = \begin{bmatrix} c^2 & s^2 & 0 & 0 & 0 & 2cs \\ s^2 & c^2 & 0 & 0 & 0 & -2cs \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & c & -s & 0 \\ 0 & 0 & 0 & s & c & 0 \\ -cs & cs & 0 & 0 & 0 & c^2-s^2 \end{bmatrix} \tag{1}$$

The transformed elastic stiffness matrix is obtained as

$$C' = T^{-1}\, C\, (T^{-1})^T \tag{2}$$

where C is the elastic stiffness matrix expressed with respect to the material coordinate axes of the orthotropic composite. Elements of C can be found in Ref. [6]. From the transformed stiffness matrix C, the values obtained for material properties with respect to global coordinate system *xyz* are given in Table 1 for different angle of orientation of the layers.

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Table 1: Material properties at different layer orientations

Angle of orientation (ψ)	E_x (GPa)	E_y (GPa)	E_z (GPa)	G_{yz} (GPa)	G_{xz} (GPa)	G_{xy} (GPa)	ν_{xy}	ν_{xz}	ν_{yz}
30^0	15.123	7.3698	6.900	1.6235	2.5091	5.3282	0.4082	0.1534	0.2029
-30^0	15.123	7.3698	6.900	1.6235	2.5091	5.3282	0.4082	0.1534	0.2029
45^0	9.1391	9.1391	6.900	1.9714	1.9714	6.5094	0.3245	0.1722	0.1722
-45^0	9.1391	9.1391	6.900	1.9714	1.9714	6.5094	0.3245	0.1722	0.1722
60^0	7.3698	1.5123	6.900	2.5091	1.6235	5.3282	0.1989	0.2029	0.1534
-60^0	7.3698	1.5123	6.900	2.5091	1.6235	5.3282	0.1989	0.2029	0.1534
90^0	6.900	172.5	6.900	3.45	1.38	3.45	0.01	0.25	0.25

Finite element analysis is conducted on these plates using ANSYS WORKBENCH 16.1. Each of these plates is subjected to 2 kN perpendicularly applied load on the top surface which is uniformly distributed over the top surface. Two types of boundary conditions are considered, viz, (1) simply supported on all edges and (2) fixed at left edge at x = 0. A typical meshed plate is shown in Fig. 1.

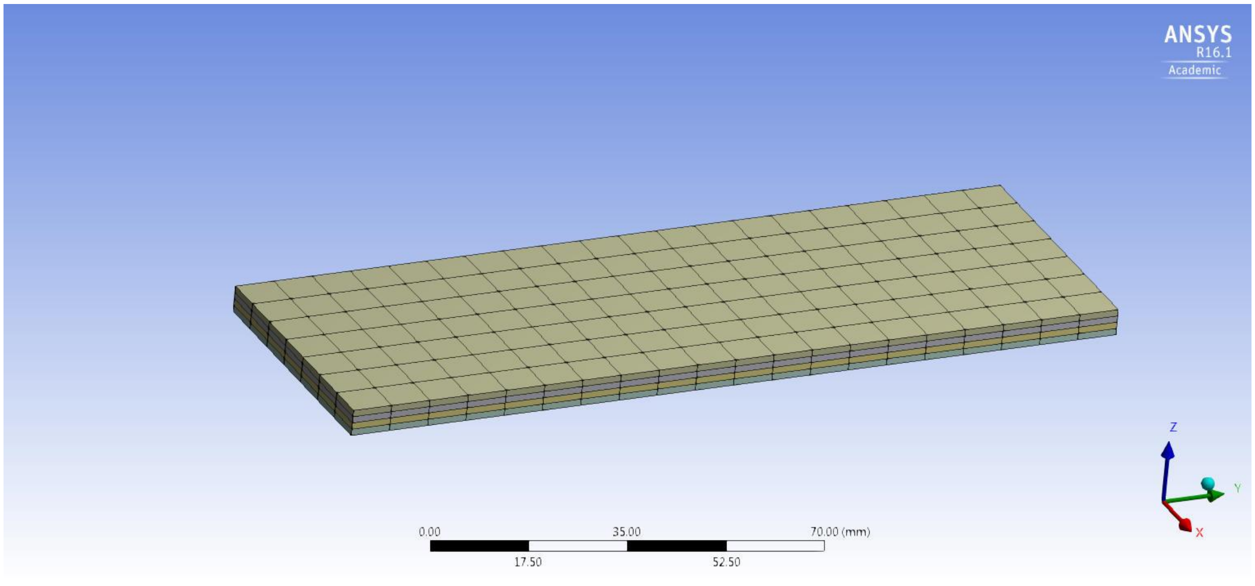

Figure 1.Meshed laminated plate

III. Results and discussion

Responses have been obtained under the two boundary conditions and are discussed below. Figs. 2, 3 and 4 show the total deflection, equivalent stress and equivalent strain respectively in laminated plate (a) under simply supported boundary conditions while the Figs. 5, 6 and 7 show similar responses under uniformly distributed load. Comparison of total deformation between Figs. 2 and 5 reveal that maximum deflection under simply supported condition is 0.074613 mm at the plate centre whereas the maximum deflection under left face clamped condition is 141.1 mm at the right end of the plate. Maximum equivalent stress under simply supported

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condition obtained from Fig 5 is 45.793 MPa at plate center and that under left face clamped condition obtained from Fig 6 is 3245.3 MPa at clamped edge. Maximum elastic strain under simply supported condition obtained from Fig 4 is 0.0034735 at centre of the plate while the same under left face clamped condition obtained from Fig 7 is 0.089728 at clamped face. It turns out that the left face clamped plate yields more deflection, more stress and more strain in contract to the all side simply supported plate.

Similar relative behaviors have been observed for the cases of plates (b) and (c) under these two loading conditions, which are given in Figs. 8, 9 and 10 for plate (b) under simply supported boundary condition, in Figs. 11, 12 and 13 for plate (b) under left face clamped boundary condition. Deformations, stresses and strains for plate (c) are not given for brevity.

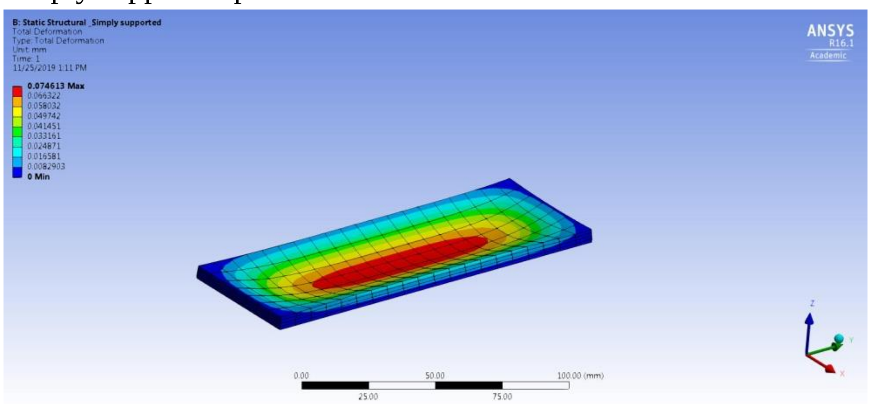

Figure 2. Total deformation in laminated plate (a) under simply supported boundary condition

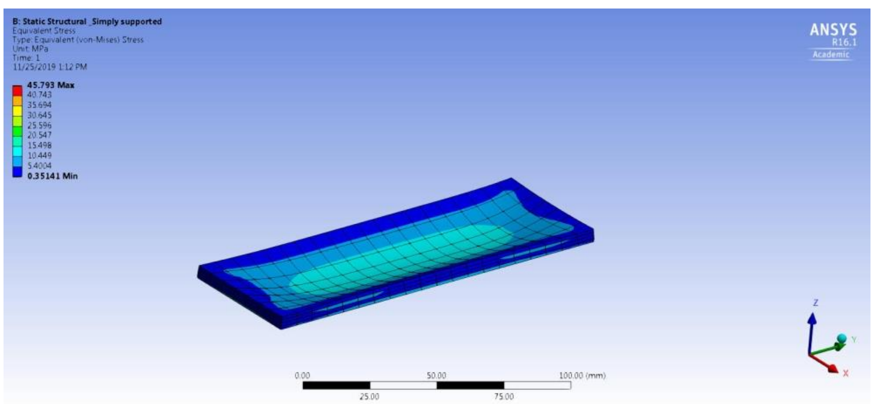

Figure 3. Equivalent stress in laminated plate (a) under simply supported boundary condition

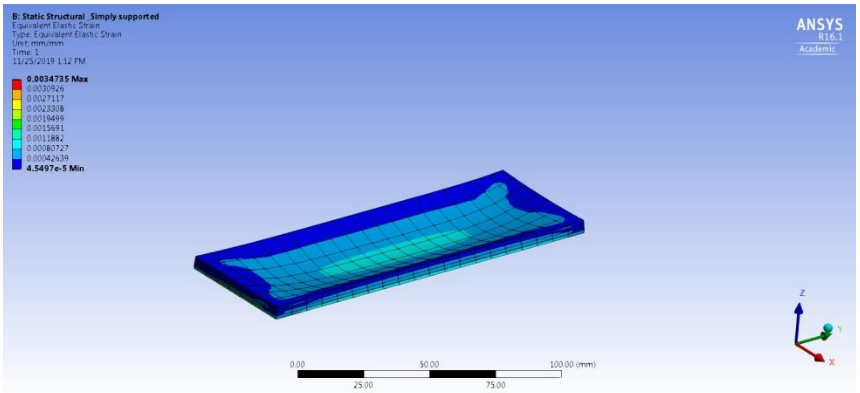

Figure 4. Equivalent strain in laminated plate (a) under simply supported boundary condition

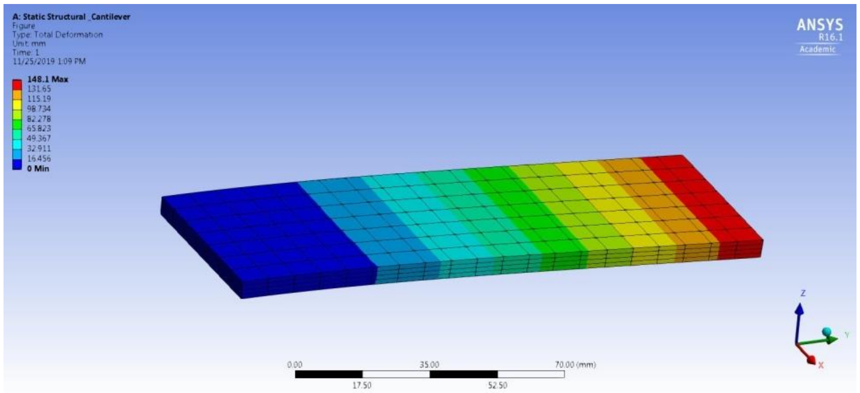

Figure 5. Total deformation in laminated plate (a) under fixed boundary condition on left face

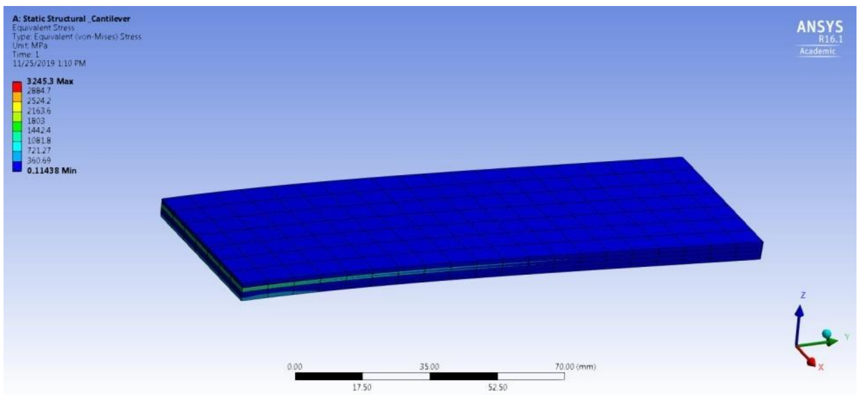

Figure 6. Equivalent stress in laminated plate (a) under fixed boundary condition on left face

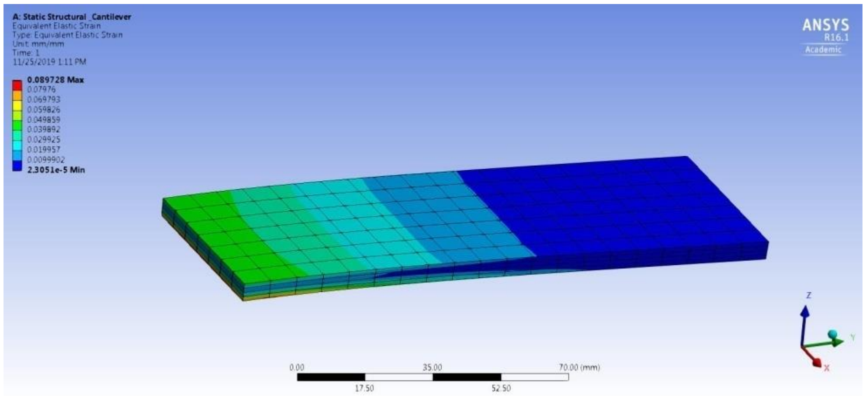

Figure 7. Equivalent strain in laminated plate (a) under fixed boundary condition on left face

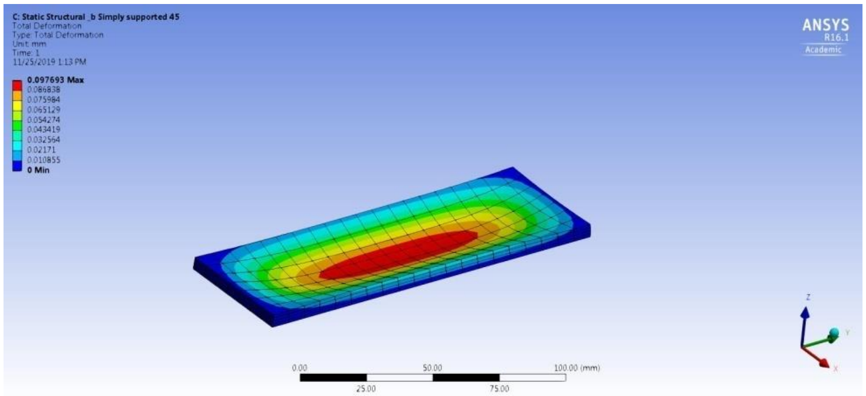

Figure 8. Total deformation in laminated plate (b) under simply supported boundary condition

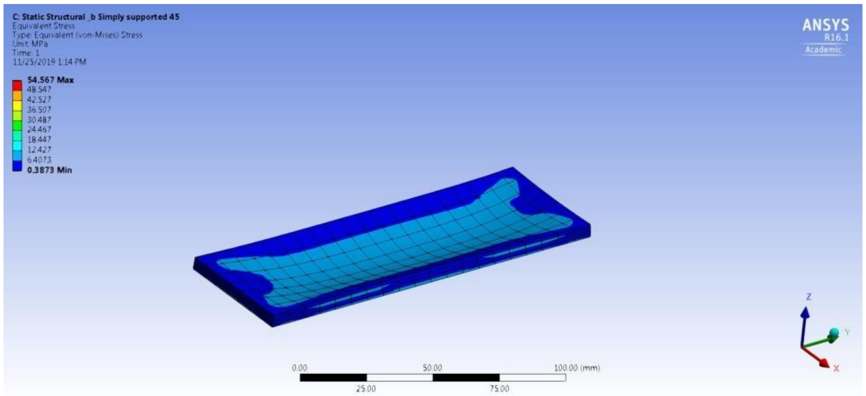

Figure 9. Equivalent stress in laminated plate (b) under simply supported boundary condition

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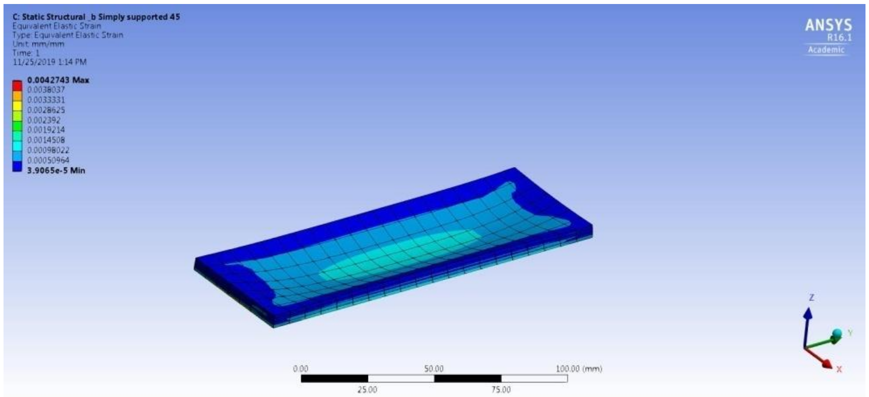

Figure 10. Equivalent strain in laminated plate (b) under simply supported boundary condition

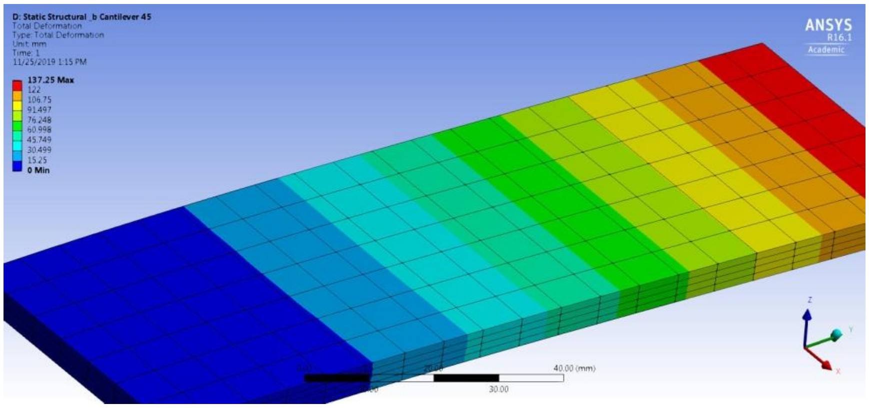

Figure11. Total deformation in laminated plate (b) under fixed boundary condition on left face

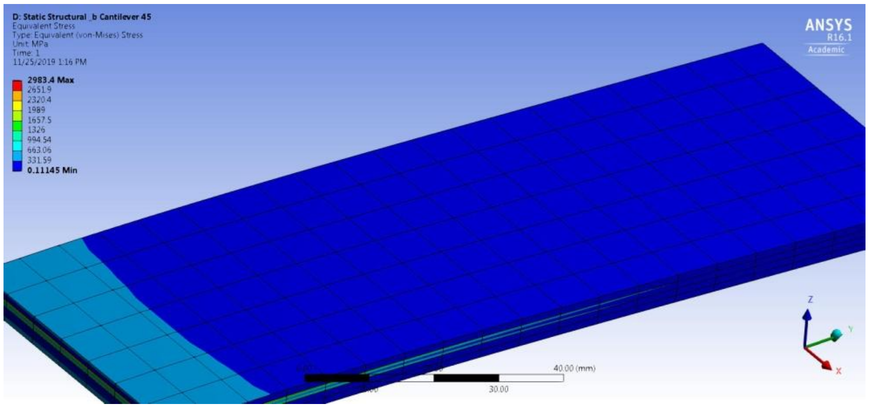

Figure 12. Equivalent stress in laminated plate (b) under fixed boundary condition on left face

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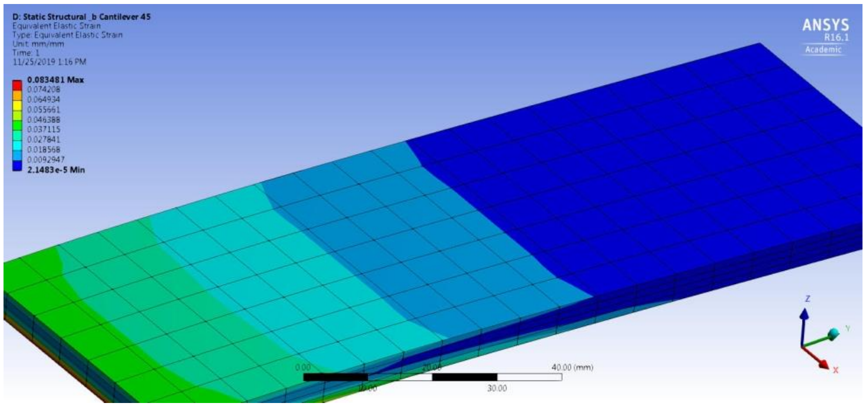

Figure 13. Equivalent strain in laminated plate (b) under fixed boundary condition on left face

Comparison is made between laminated plates (a), (b) and (c) to choose the best configuration under simply supported boundary conditions and that for left face clamped boundary conditions. The comparison are given in Tables 2 and 3. Study of Table 2 reveals that the plate (a) is most stiff and plate (c) is least stiff among these three configurations because of the change in the orientation angle of the angle ply, thereby yielding minimum deflection, minimum stress and minimum strain in plate (a). Under left face clamped condition, plate (a) is also seen to be most stiff yielding least deflection, stress and strain. Thus it is clear that the orientation of the plys plays a vital role in making the laminated plate less stiff or more stiff.

Table 2: Comparison of deflection, stress and strains under simply supported boundary condition

Plate name	Laminate configuration	Maximum deflection (mm)	Maximum equivalent stress (MPa)	Maximum elastic strain
Plate (a)	$0^0/30^0/90^0/-30^0$	0.074613	45.793	0.0034735
Plate (b)	$0^0/45^0/90^0/-45^0$	0.097693	54.567	0.0042743
Plate (c)	$0^0/60^0/90^0/-60^0$	0.11603	61.868	0.0045711

Table 3: Comparison of deflection, stress and strains under left face boundary condition

Plate name	Laminate configuration	Maximum deflection (mm)	Maximum equivalent stress (MPa)	Maximum elastic strain
Plate (a)	$0^0/30^0/90^0/-30^0$	141.1	3245.3	0.089728
Plate (b)	$0^0/45^0/90^0/-45^0$	137.25	2983.4	0.083481
Plate (c)	$0^0/60^0/90^0/-60^0$	193.24	4205.3	0.11391

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IV. Conclusions

Finite element analysis is carried out on a number of laminated plates made of orthotropic composite materials. Static response of the plates have been undertaken under uniformly applied load on their top surfaces for two set of boundary conditions, viz, simply supported boundary condition and left face fixed boundary condition. Effect of change of ply angle on deflection, stress and strain are illustrated. It is found that as the ply angle increases from 0^0 the laminated plate becomes less stiff which gives rise to more deflections and more stresses.

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