Static Behaviour of Laminated Composite Plates using FEM

Chandan Kumar* and P. Pal**
*M. Tech. Scholar, Department of Civil Engineering, MNNIT Allahabad, U.P., India
Chandkumar55@gmail.com
**Assistant Professor, Department of Civil Engineering, MNNIT Allahabad, U.P., India
prpal2k@gmail.com

Abstract: This paper deals with the study of static behavior of laminated composite plates under transverse loading using FEM. The plate has been modelled using eight noded isoparametric elements with six degree of freedom at each node. First-order shear deformation theory (FSDT) is employed in conjunction with FEM approach. The mid plane of the lamina is considered as reference plane. Several numerical experiments are carried out using the ANSYS Workbench 15.0. At first, the convergence study is carried out to validate the present model. Secondly, the parametric studies are carried out for different cases by varying the stacking sequences, fibre orientations, thickness and number of layers in the laminate. The volume of plate is taken as constant throughout the study. Finally, the results obtained from the study are compared to achieve the maximum strength of plate with the best suitable combinations of the stacking sequence of the plate.

Keywords: Isotropic plate, Composite plates, Static behavior, Deflection, FEM, ANSYS 15.0.

Introduction

Laminated composites have high stiffness and strength-to-weight ratio, high durable, high fatigue, light weight and many other superior properties. Owing to these properties these are useful for many applications in the automobile, aerospace, nuclear, marine, biomedical and various civil engineering structures. The use of composite plates in structural application is advantageous by the outstanding strength, light weight, low specific gravity, low maintenance cost, easy to tailor the stiffness and strength in different directions at the initial stage of a structure design. When these materials are used in advanced underwater and space vehicle then the capacity is optimized.

Laminated composite plates are made of one or more material. It may have different fibre unit containing different orientation, mechanical and chemical properties. On the basis of stacking sequence nature, laminates are classified as follows-

(i) Symmetric laminate- A laminate in which material, angle and thickness of the layers are the same above and below the mid plane.

(ii) Anti-symmetric laminate- A laminate in which the material and thickness of the plies are same above and below the mid-plane but the orientation of the plies at same distance above and below the mid plane have opposite sign.

(iii) Cross ply laminate- A laminate in which all the plies used to fabricate the laminate are only 0^0 and 90^0.

(iv) Angle ply laminate- A laminate in which plies of the same thickness and material and are oriented at θ and $-\theta$.

(v) Anti-symmetric laminate- A laminate in which the material and thickness of the plies are same above and below the mid-plane but the orientation of the plies at same distance above and below the mid-plane have opposite sign.

(vi) Balance laminate- A laminate in which pairs of plies with same thickness and material and the angles of plies are $-\theta$ and $+\theta$. However, the balanced laminate can also have layers oriented at 0^o and 90^o.

Reddy & Pandey [1] have developed a finite-element computational procedure for the first-ply failure analysis of laminated composite plates using the first-order shear deformation theory. Pal & Bhar [2] have studied the displacement perspective during ultimate failure of composite laminates. The symmetric and anti-symmetric angle-ply and cross-ply laminated composite plates are studied during its ultimate failure, subjected to transverse load. First order shear deformation theory (FSDT) is used with the finite element approach. Pal & Ray [3], Pal & Bhattacharyya [4] have studied the progressive failure analysis of laminated composite plates under transverse static loading within linear and elastic range by finite element method. Reddy & Reddy [5] have studied three dimensional finite element progressive failure analysis of composite laminates under axial extension. Singh et al. [6] have analysed stiffened plate using FEM. A parametric study is carried out by varying geometry of plate keeping constant volume under different loading conditions. Singh and Pal [7] have studied stiffened isotropic and composite plates using FEM. In this paper deformation is minimized by varying geometry of plates by keeping volume of material constant. Gorai & Pal [8, 9] have analysed the state of impact of cross section of stiffeners in improving the measure of displacement and frequency of stiffened plate using FEM. The deformation is minimized without

increasing the volume of material used. Ahmed et al. [10] have studied static and dynamic analysis of composite laminated plate. The behaviour of laminated composite plates under transverse loading is analysed using FEM. Tu et al. [11] have studied the bending and vibration analysis of laminated and sandwich composite plates based on higher-order theory. Authors used the parabolic distribution of the transverse shear strains through thickness of the plate and rotary inertia effects.
In the present study, the static behavior of laminated composite plate is investigated by applying uniform transverse load by varying the stacking sequences, fibre orientations, thickness and number of layers in the laminate. The main focus of the investigation is to determine the strength characteristics of plate with the best suitable combinations of the stacking sequence of the plate.

Finite Element Modelling

The plate is modelled for different thickness and orientation of ply in the laminate using SHELL 281. This element is suitable for analyzing the thin to moderately-thick shell structures. It is an eight noded element with six degrees of freedom at each node, i.e. translations in the x, y, and z directions, and rotations about the x, y, and z axes. The plate is modelled up to 10 layers in the present investigation.

Results and Discussions

Convergence Study and Validation

At first, the convergence study is carried out to get an appropriate number of nodes required to achieve the minimum error in computation. An isotropic plate of size 1000×1000×10 mm is considered for the study. The plate is modeled with different boundary conditions by applying uniformly distributed load of 1.0 kN/m^2 and a point load of 1 kN at centre. From obtained results as in Fig. 1, it is clearly shown that at mesh size 20×20, the results are converged. Hence, for further study a 20×20 mesh size is used to minimize the error in computation. The material properties of isotropic plate considered are: Modulus of Elasticity, E=2.2× 10^5 MPa, Poisson's Ratio, μ=0.3 and Mass Density, ρ=7850 kg/m^3.

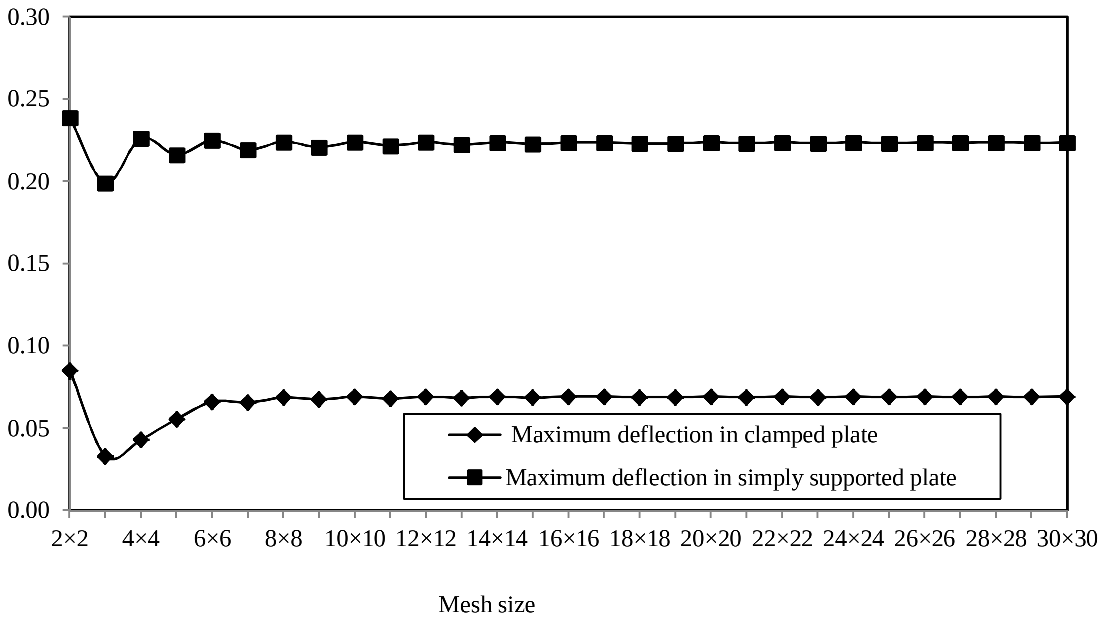

Figure1. Maximum deflection of isotropic plate

An isotropic plate is considered subjected to different loading conditions with different boundary conditions. To validate the efficiency of the present ANSYS model with the published results, the maximum deflection is observed and presented in Table 1. The results are verified with the results published by Timoshenko & Krieger [12]. The same problem was also taken by Singh et al. [6] and Singh & Pal [7] and found in literature. The variation of present results in computation is determined and found to be ok.

Table 1. Comparison of results

S. No.	Case	Maximum Deflection (mm)		Variation (%)
		Present Result	Timoshenko & Krieger [12]	
1	A	0.0692	0.0688	0.5814
2	B	0.3076	0.3058	0.5886
3	C	0.2238	0.2279	1.7990
4	D	0.6386	0.6334	0.8210

A: CCCC with u.d.l (1.0 kN/m^2); C: SSSS with u.d.l (1.0 kN/m^2)
B: CCCC with point load (1.0 kN); D: SSSS with point load (1.0 kN)
Note: (a) CCCC indicates all four edges clamped.
(b) SSSS indicates all four edges simply supported.

Parametric Study

An orthotropic plate subjected to transverse loading with symmetric, anti-symmetric, angle and cross laminated ply with different fibre orientations is studied in the present investigation. The material taken for composite plate is Epoxy_Carbon_UD_230GPa_Prepreg, which is available in ANSYS 15.0 workbench and presented in Table 2. The Geometric properties of plates are presented in Table 3. The thickness of plate is taken as 9.96 mm to maintain the constant volume of the laminate.

Table 2. Material properties of composite plate

Modulus of Elasticity, E_x=1.21×10^5 MPa	Shear Modulus, G_{xy}= Gxz= 4700 MPa
Modulus of Elasticity, E_y=8600 MPa	Shear Modulus, G_{yz}= 3100 MPa
Modulus of Elasticity, E_z=8600 MPa	Tension, X_t= 2231 MPa
Poisson's Ratio, $\mu xy = \mu xz = 0.27$	Tension, $Y_t = Z_t$ =29 MPa
Poisson's Ratio, μyz =0.4	Compression, X_c= 1082 MPa
	Compression, $Y_c = Z_c$ = 100 MPa

Table 3. Geometric properties of composite plate

[1] Dimensions:
Length= 1000mm, Width= $1000mm$, Depth= 9.96mm
[2] Staking sequence:
(i) $(\theta/\theta)_S$; symmetric angle ply
(ii) $(\theta/-\theta)_2$; anti-symmetric angle ply
(iii) $(0^0/90^0)_S$; cross ply
Where, $\theta = 15^0, 30^0, 45^0, 60^0, 75^0, 90^0$.
No. of layers = 2, 4, 6, 8, 10

Example-1*:* In this example, symmetric angle-ply laminated composite plate is considered in which the material properties and geometric properties are same as presented in Table 2 and 3, respectively. The plate is clamped at all edges and is subjected to uniformly distributed load of 1kN/m^2. The number of ply of laminate is varied from 2 to 10 but the volume of plate is taken as constant. The fibre orientation is considered as $(\theta/\theta)_s$, where the value of θ is taken as 15^0, 30^0, 45^0, 60^0 & 90^0. The maximum deflection is obtained and the results are presented in Table 4. The results are plotted in Fig. 2. It is found that as the number of ply laminate increases the deflection of plate decreases. This indicates the increased strength of plate. The minimum of maximum deflection is obtained at 10 ply laminate and for 15^0 or 75^0 fibre orientation and in the case of symmetric ply laminate.

Table 4. Maximum deflection (mm) in symmetric angle ply for different ply orientation and varying layer

Orientation of ply	2-ply	4-ply	6-ply	8-ply	10-ply
$(15^0/15^0)_s$	0.30102	0.29247	0.28607	0.28452	0.28355
$(30^0/30^0)_s$	0.36957	0.33093	0.31010	0.3056	0.30289
$(45^0/45^0)_s$	0.41091	0.34974	0.32132	0.3154	0.31188
$(60^0/60^0)_s$	0.36957	0.33076	0.31011	0.30558	0.30289
$(75^0/75^0)_s$	0.30102	0.29238	0.28607	0.2845	0.28355

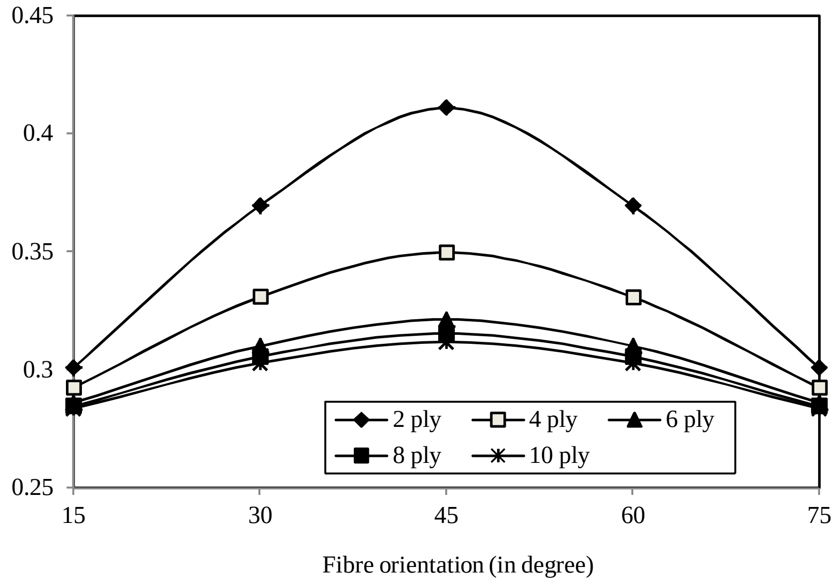

Figure2. Maximum deflection for symmetric angle ply laminate

The following examples are studied for the laminate with same material and geometrical properties as presented in Tables 2 and 3, respectively. The number of ply in the laminate is varied from 2 to 10 with constant volume of the material. The laminate is clamped at all edges and the uniform transverse loading of 1kN/m^2 is applied.

Example-2: In this example, the plate with antisymmetric angle-ply is analysed with fibre orientation of $(\theta/-\theta)_2$. The maximum deflection is computed and the results are presented in Table 5. The results are also shown in Fig. 3. It is observed that as the number of ply laminate increases the deflection decreases and hence, the strength of plate increases. Similarly, the minimum central deflection is obtained for 10 ply laminate with 15^o or 75^0 fibre orientation.

Table 5. Maximum deflection (mm) in antisymmetric angle ply for different ply orientation and varying layer

Orientation of ply	2-ply	4-ply	6-ply	8-ply	10-ply
$(15^0/-15^0)_2$	0.44273	0.30996	0.29381	0.28855	0.28619
$(30^0/-30^0)_2$	0.62238	0.34316	0.31702	0.3088	0.30514
$(45^0/-45^0)_2$	0.67014	0.35465	0.32628	0.31741	0.31346
$(60^0/-60^0)_2$	0.62238	0.34316	0.31702	0.3088	0.30514
$(75^0/-75^0)_2$	0.44273	0.30996	0.29381	0.28855	0.28619

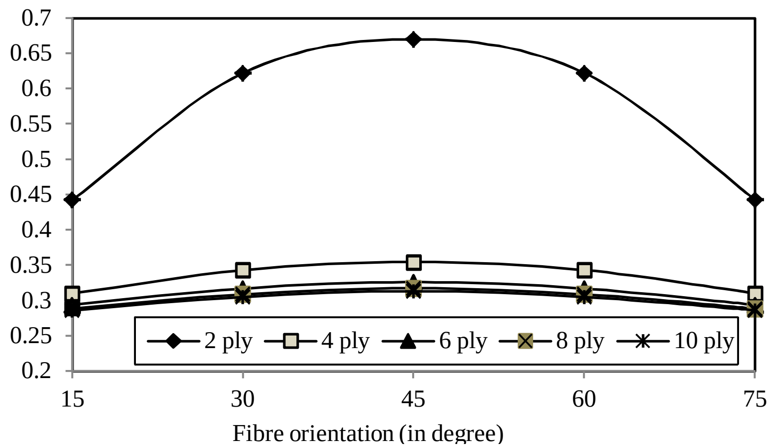

Figure3. Maximum deflection for antisymmetric angle ply laminate

Example-3: The symmetric cross ply laminated plate is analysed in this example. The central deflection is computed and the results are presented in Table 6. The results are shown in Fig. 4. It is observed that the maximum deflection is varied as the number of ply varies. The minimum of maximum deflection is obtained at 4 layers laminate.

Table 6. Maximum deflection of symmetric cross ply laminate

Number of ply	Maximum deflection(mm)
4	0.2891
6	0.29356
8	0.29464
10	0.29502

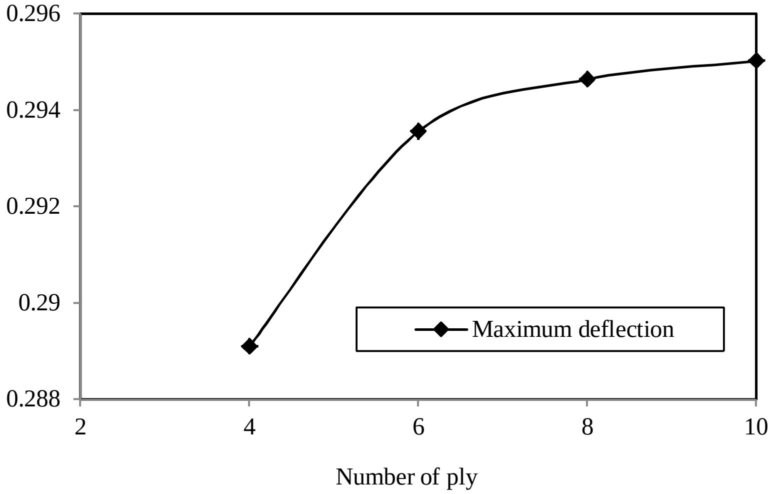

Figure4. Maximum deflection for symmetric cross ply laminate

Example-4: In this example, the antisymmetric cross-ply laminated plate is analysed. The maximum deflection is computed and the results are presented in Table 7. The results are also shown in Fig. 5. It is found that as the number of ply in the laminate increases the maximum deflection decreases and hence, the strength of plate increases.

Table 7. Maximum deflection of antisymmetric cross ply laminate

Number of ply	Maximum deflection(mm)
2	0.63984
4	0.34206
6	0.31471
8	0.30613
10	0.30232

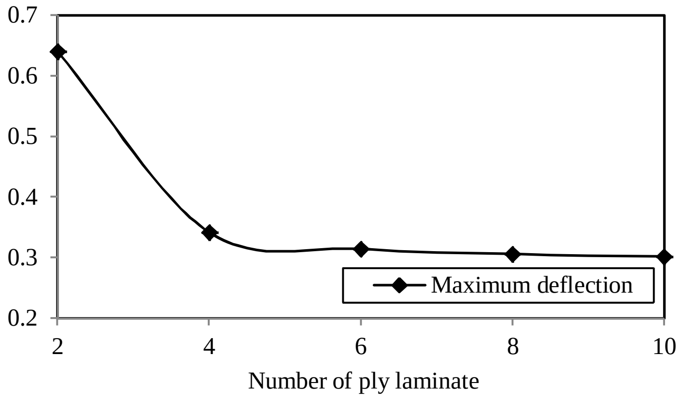

Figure5. Maximum deflection of antisymmetric cross-ply laminate

Example-5: In this example, the plate with symmetric angle ply and symmetric cross ply is studied. The results obtained in Example-1 and Example-3 are considered and presented in Table 8 for comparison. The results are also shown in Fig. 6. It is found that maximum deflection is minimum at 10 ply laminates in symmetric angle-ply.

Table 8. Comparison of results of symmetric angle ply and symmetric cross ply

Number of ply	Deflection in symmetric angle ply (mm)	Deflection in symmetric cross ply (mm)
2	0.30102	-
4	0.29247	0.2891
6	0.28607	0.29356
8	0.28452	0.29464
10	0.28355	0.29502

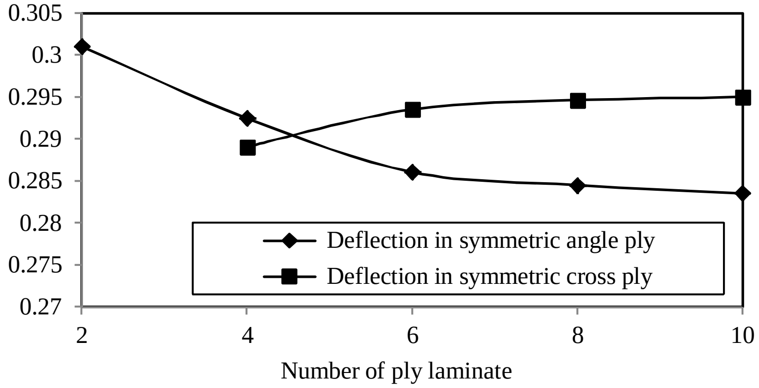

Figure6. Comparison of deflection between symmetric angle ply and symmetric cross ply

Example-6: In this example, the plate with antisymmetric angle ply and antisymmetric cross ply is studied. Similarly, the results obtained in Example-2 and Example-4 are considered and presented in Table 9 for comparison. The results are also shown in Fig. 7. It is found that the minimum of maximum deflection is obtained in antisymmetric angle ply laminate.

Table 9. Comparison of results of antisymmetric angle ply and antisymmetric cross ply

Number of ply	Deflection in antisymmetric angle ply (mm)	Deflection in antisymmetric cross ply (mm)
2	0.44273	0.63984
4	0.30996	0.34206
6	0.29381	0.31471
8	0.28855	0.30613
10	0.28619	0.30232

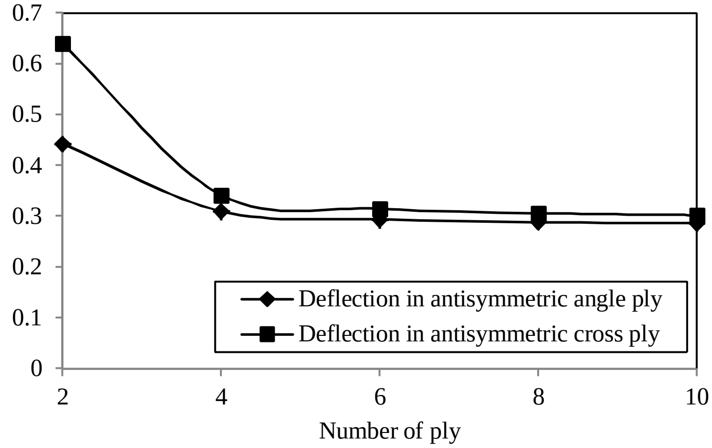

Figure7. Comparison of deflection between antisymmetric angle ply and antisymmetric cross ply

The results obtained in Examples 5 & 6 are represented again and are shown in Fig. 8 to get the minimum deflection of the laminate. It is found that the minimum deflection is obtained in symmetric angle ply laminate with 10 numbers of ply in the laminate.

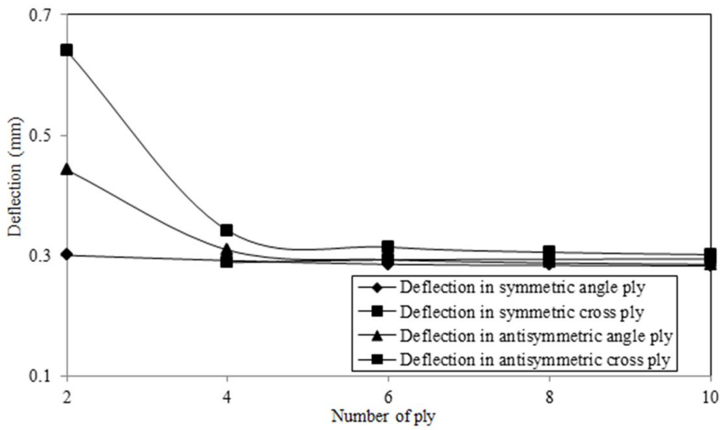

Figure8. Comparison of deflections for different layers and fibre orientations

Conclusions

The aim of present investigation is to find out the maximum strength of laminate with different staking sequence and number of ply. In general, the laminate which gives minimum deflection has more strength. In view of the above, the following conclusions are drawn:

- In case of symmetric angle ply laminated plate, the minimum central deflection is obtained at $(15^0/15^0)_s$ or $(75^0/75^0)_s$ for a laminate consisting of 10 plies. If the number of ply in the laminate increases, the deflection decreases.
- In case antisymmetric angle ply laminated plate, the minimum central deflection is obtained at $(15^0/-15^0)_2$ or $(75^0/-75^0)_2$ for a laminate consisting of 10 plies. If the number of ply in the laminate increases, the deflection decreases.
- In case of symmetric cross ply laminate, the deflection is inceased with the increase in number of layes in that laminate whereas in the case of antisymmetric cross ply the deflection is decreased with the increase in number of layers in tat laminate.
- Antisymmetric angle ply laminated plate gives minimum deflection when compared to antisymmetric cross ply.
- The minimum of maximum deflection is obtained for symmetric angle ply when the laminate is having 10 plies hence, the laminate with more number of plies containing symmetric angle ply has higher strength.

References

[1] J. N. Reddy and A. K. Pandey, "A First Ply Failure Analysis of Composite Laminates", Computers and Structures, 25, 3, 1987, 371-393.

[2] P. Pal and A. Bhar, "The Displacement Perspective during Ultimate Failure of Composite Laminates", An International Journal for the Science and Application of Composite Materials, 20, 2, 2013, 171-183.

[3] P. Pal and C. Ray, "Progressive Failure Analysis of Laminated Composite Plates by Finite Element Method", J. Reinforced Plastics & Composites, 21, 16, 2002, 1505-1513.

[4] P. Pal and S. K. Bhattacharyya, "Progressive Failure Analysis of Cross Ply Laminated Composite Plates by Finite Element Method", J. Reinforced Plastics & Composites, 26, 5, 2007, 465-477.

[5] Y. S. Reddy and J. N. Reddy, "Three-dimensional Finite Element Progressive Failure Analysis of Composite Laminates Under Axial Extension", J. Composite Technology and Research, 15, 2, 1993, 73-87.

[6] Deepak Kumar Singh, S. K. Duggal and P. Pal, "Analysis of Stiffened Plates using FEM- A Parametric Study", International Research Journal of Engineering and Technology, 2, 4, 2015, 1650-1656.

[7] R. R. Singh and P. Pal, "Analysis of Stiffened Isometric and Composite Plate", International Research Journal of Engineering and Technology, 3, 2, 2016, 1-7.

[8] Amit Kumar Gorai and P. Pal, "Effectuality of Stiffeners in Plate using FEM", Journal of Civil & Architectural Engineering, 1, 2, 2016, 1-15.

[9] Amit Kumar Gorai and P. Pal, "Economical Design of Stiffened Plate using FEM", Journal of Structural Engineering and Management, 4, 2, 2017, 50-57.

[10] Junaid Kameran Ahmed, V.C. Agarwal, P. Pal and Vikas Srivastav, "Static and Dynamic Analysis of Composite Laminated Plate", IJITEE, 3, 6, 2013, 56-60.

[11] Tran Minh Tu, Le Ngoc Thach and Tran Huu Quoc., "Finite Element Modeling for Bending and Vibration Analysis of Laminated and Sandwich Composite Plates Based on Higher-Order Theory", 49, 4, 2010, S390-S394.

[12] S. Timoshenko and S. Woinowsky-Krieger, "Theory of Plates and Shells", McGraw–Hill New York, 1959.