Failure Test Simulation of Graphite Fiber Reinforced Polymer using Finite Element Analysis

Peeyush Maheshwari[1], Anadi Misra[2]

[1]*Research Scholar*, [2]*Professor*,

Department of Mechanical Engineering, GBPUAT, Pantnagar

Abstract - Present work provides a numerical tool for analyzing first ply-failure test for multidirectional Graphite Fiber Reinforced Polymer plates using finite element simulation in ANSYS. A model has been developed for simulation of the failure test of the laminated composite. Eight plates of Graphite Fiber Reinforced Polymer with various stacking sequences are analyzed for failure load. Failure strength of the composite depends upon the material and orientation of the fiber. In the analysis, it is investigated that Graphite Fiber Reinforced Polymer laminated plate finite element results are very close to experimental results taken from literature. Finite element analysis is preferred over the experimental tests as it is more convenient and economical method of analysis. So this method of simulation is more suitable for future work.

Keywords – First Ply Failure, Laminated Composite, Finite Element Solver.

1. INTRODUCTION

Graphite Fiber Reinforced Polymer plates are extensively used in load carrying structures in engineering and industrial applications. Graphite Fiber Reinforced Polymer consists of graphite and epoxy. Graphite is used as a fiber reinforcement and epoxy as a protection and binding material. Graphite and epoxy phase are not soluble in each other. Graphite Fiber Reinforced Polymer plate has maximum longitudinal failure strength and less transverse failure strength. [8] All the composite plates are considered to have orthotropic behaviour and have nine elastic constants i.e. three young's modulus, three modulus of rigidity and three Poisson's ratio. Orthotropic materials have the maximum and minimum load carrying capacity in the longitudinal and transverse direction respectively.

The computational failure load was obtained by Finite Element Analysis for the specimen that was used in experiment performed by Kam et al. in 1996 and their results are compare. [6] ANSYS, ABAQUS, FORTRAN software are commonly used for carrying simulation. In the present simulation, eight plates of Graphite Fiber Reinforced Polymer with various stacking sequences are analyzed for failure load. The stacking sequence and the loading direction of laminate is shown in fig.1.

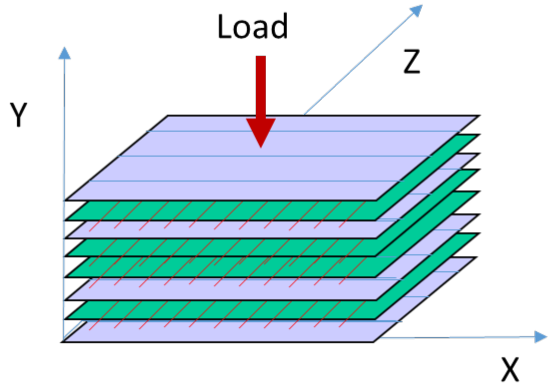

Fig.1 Stacking sequence for (0°/90°/0°/90°)s plates

2. MATERIAL AND MODEL

The elastic and strength properties of Graphite Fiber Reinforced Polymer plate have been taken from Kam et al. as shown in Table-1.

Table-1: Material properties of graphite/epoxy

Sr. No.	Elastic properties	
1	E_1 (GPa)	142.50
2	$E_2 = E_3$ (GPa)	9.79
3	$G_{12} = G_{13}$ (GPa)	4.72
4	G_{23} (GPa)	1.19
5	$\nu_{12} = \nu_{13}$	0.27
6	ν_{23}	0.25
	Strength properties	
1	X_t (MPa)	2193.50
2	X_c (MPa)	2457.00
3	$Y_t = Z_t$ (MPa)	41.30
4	$Y_c = Z_c$ (MPa)	206.80
5	R (MPa)	61.28
6	S = T (MPa)	78.78
7	$X_{\varepsilon t}$ (10^{-3})	15.39
8	$X_{\varepsilon c}$(10^{-3})	17.24

9	$Y_{\varepsilon t} = Z_{\varepsilon t}(10^{-3})$	4.13
10	$Y_{\varepsilon c} = Z_{\varepsilon c}(10^{-3})$	21.12
11	$R_{\varepsilon}(10^{-3})$	51.41
12	$S_{\varepsilon} = T_{\varepsilon}(10^{-3})$	16.69

In the present simulation a model has been developed for the eight Graphite Fiber Reinforced Polymer plates assuming no slipping between the plates. For the analysis of failure load the stacking sequences of ply are taken as $(0^\circ_2/90^\circ_2)$s and $(0^\circ/90/0^\circ/90)$s. All the edges of laminate are fixed in all degrees of freedom. Point load is applied at the centre of the Graphite Fiber Reinforced Polymer laminate. [6]

3. PREVIOUS WORK

Zhang et al. (2009) presented review on the development of finite element procedure for analysis of laminated composites. Study is focused on the development of finite elements methods based on various plate theories for free vibration and dynamics, geometrical nonlinearities and large deformations, buckling and post buckling analysis and failure and damage analysis of laminated composite plates.[12]

Rahimi et al. (2012) calculated first ply failure load and last ply failure load of a laminated composite plate by performing finite element analysis. Commercially available finite element software ANSYS is used to predict failure load. Failure load is determined using Maximum stress and Tsai-Wu failure theories.[9]

Mayank et al. (2014) determined the failure load for laminated composite under tensile loading. In this simulation the analysis of failure stresses of laminated composite has been carried out using ABAQUS. [7]

4. METHODOLOGY

Simulation of Graphite Fiber Reinforced Polymer plates has been done through finite element analysis. [4] There are various finite element software packages available in the market such as ANSYS, ABAQUS, NASTRAN, FORTRAN etc. In the present investigation, ANSYS is used for analysis. [5] Finite element analysis requires three basic steps: pre-processing, processing and post-processing. In pre-processing the elastic properties, strength properties, lamina properties, geometry of lamina, meshing, boundary and loading conditions are defined. In processing step ANSYS analyzes the conditions and solve the problem. In the post-processing step, results are obtained. For the present simulation these results are stress distribution, strain distribution, and failure strength or load. [7]

SHELL281 element is used for analysis in ANSYS. Specification of Element SHELL 281 is 8-node with six degrees of freedom at each node. The element is suitable for analyzing thin to moderately-thick shell structures and is appropriate for linear, large rotation, and large strain nonlinear applications.

The Flow chart for simulation is shown fig.2

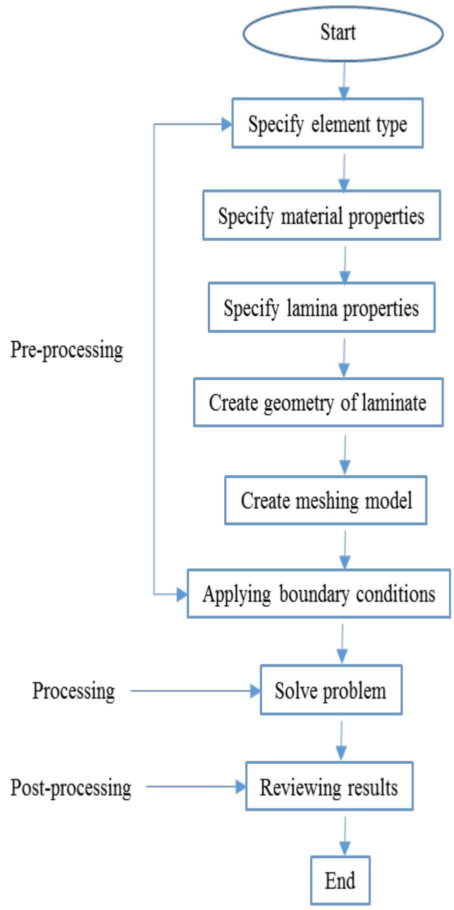

Fig. 2 flow chart fow simulation process

5. SIMULATION RESULTS

Table-2: Ply failure index for $(0^\circ_2/90^\circ_2)_s$ laminate

	Failure Index	
Ply No.	**Max. Stress**	**Tsai-Wu**
1	0.004240	0.004145
2	0.002827	0.002764
3	0.000991	0.000989
4	0.000005	0.000005
5	0.000419	0.000419
6	0.000838	0.000838
7	0.000847	0.000787

8	0.001129	0.001049

In table-2 ply 1 has the maximum failure index hence ply 1 will fail first.

The experimental results have been taken from Kam et al. for sequence $(0^{\circ}_2/90^{\circ}_2)_s$ which are shown in table-3. The first ply failure load has been computed through Maximum Stress, Maximum Strain and Tsai-Wu failure criteria using ANSYS.

Table-3: Comparison of ANSYS results with experimental data for $(0^{\circ}_2/90^{\circ}_2)_s$ laminate

Failure Criteria	First Ply Failure Load (N)		Deviation (%)
	ANSYS	Experimental	
Max. Stress	235.84	253.6	7.00
Max. Strain	265.25	253.6	4.59
Tsai-Wu	241.25	253.6	4.87

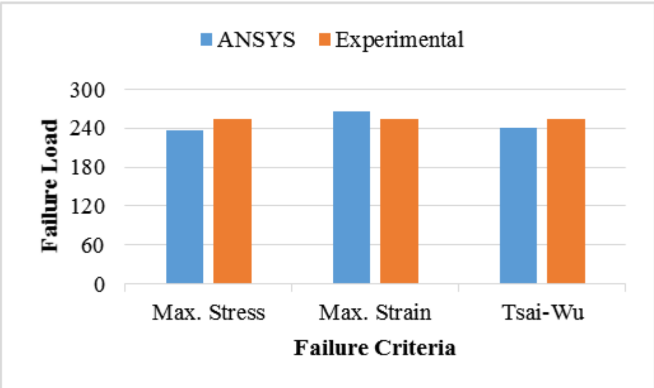

Fig. 2 Comparison of ANSYS and Experimental results for $(0°_2/90°_2)_s$ stacking sequence

The maximum deviation is obtained through Maximum Stress failure criteria and minimum deviation is obtained through Maximum Strain failure criteria. The maximum and minimum deviations from the experimental data are 7.00% and 4.59% respectively.

Fig.3 shows the stress distribution and failure index of laminate for sequence $(0°_2/90°_2)$s. Maximum failure index for Maximum Stress failure criteria is 0.00424.

Fig.4 shows the stress distribution and failure index of laminate for sequence $(0°_2/90°_2)$s. Maximum failure index for Maximum Strain failure criteria is 0.00377.

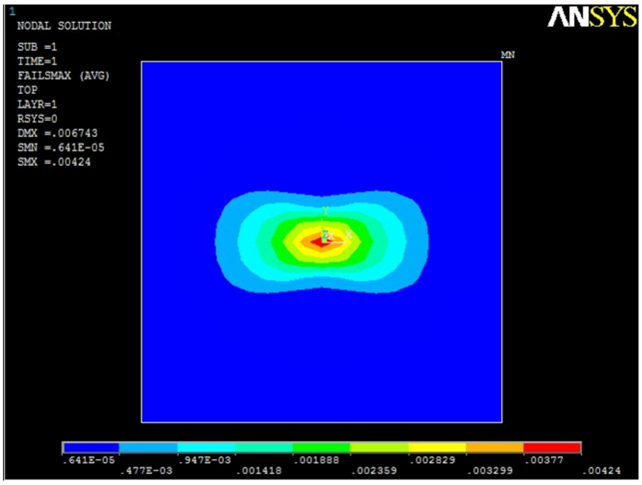

Fig. 3 Maximum Stress failure index for $(0°_2/90°_2)$s laminates

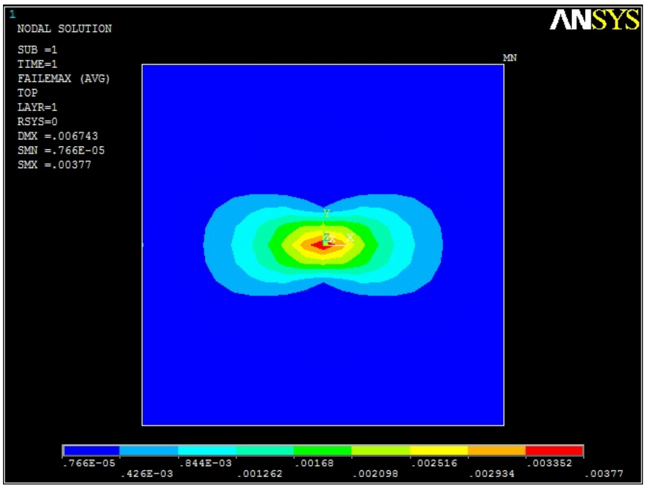

Fig. 4 Maximum Strain failure index for $(0°_2/90°_2)_{slaminates}$

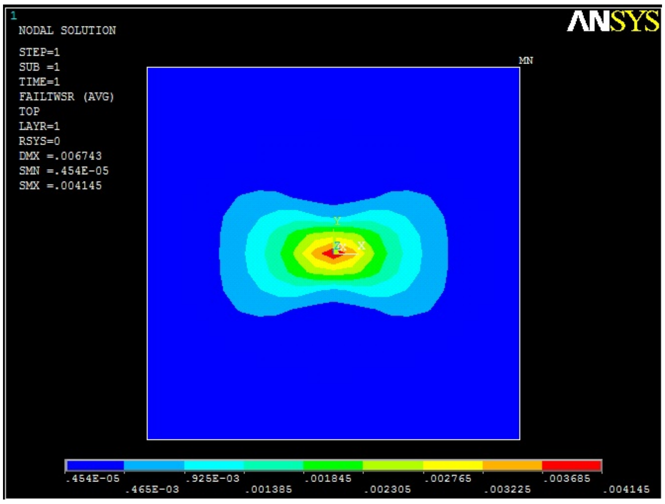

Fig. 5 Tsai-Wu failure index for $(0°_2/90°_2)_s$ laminates

Fig.5 shows the stress distribution and failure index of laminate for sequence $(0°_2/90°_2)s$. Maximum failure index for Tsai-Wu failure criteria is 0.00416.

Table-4: Ply failure index for (0˚/90/0˚/90)s laminate

	Failure Index	
Ply No.	**Max. Stress**	**Tsai-Wu**
1	0.003188	0.003112
2	0.001805	0.001805
3	0.001063	0.001037
4	0.000004	0.000004
5	0.000389	0.000389
6	0.000671	0.000670
7	0.001166	0.001166
8	0.001342	0.001341

In table-5 ply 1 has the maximum failure index hence ply 1 will fail first.

The experimental results have been taken from Kam et al. for sequence (0˚/90/0˚/90)s which are shown in table-3. The first ply failure load has been computed through Maximum Stress, Maximum Strain and Tsai-Wu failure criteria using ANSYS.

Table-5: Comparison of ANSYS results with experimental data for (0˚/90/0˚/90)s laminate

Failure Criteria	First Ply Failure Load (N)		Deviation (%)
	ANSYS	Deviation (%)	
Max. Stress	313.67	317.74	1.28
Max. Strain	335.57	317.74	5.61
Tsai-Wu	321.33	317.74	1.13

The maximum deviation is obtained through Max. Strain failure criteria and minimum deviation obtained through Tsai-Wu failure criteria. The maximum and minimum deviations from the experimental data are 5.61% and 1.13% respectively.

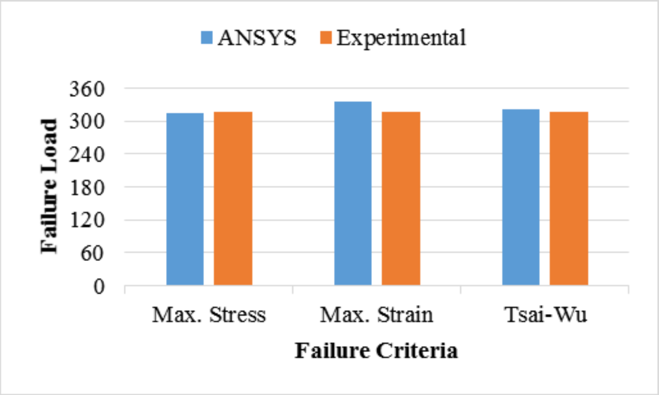

Fig. 6 Comparison of ANSYS and Experimental results for $(0°/90°/0°/90°)_s$ stacking sequence

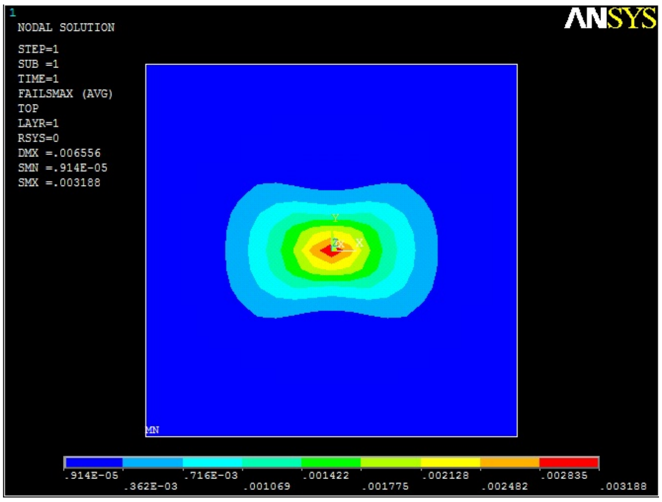

Fig. 7 Maximum Stress failure index for (0˚/90/0˚/90)s laminates

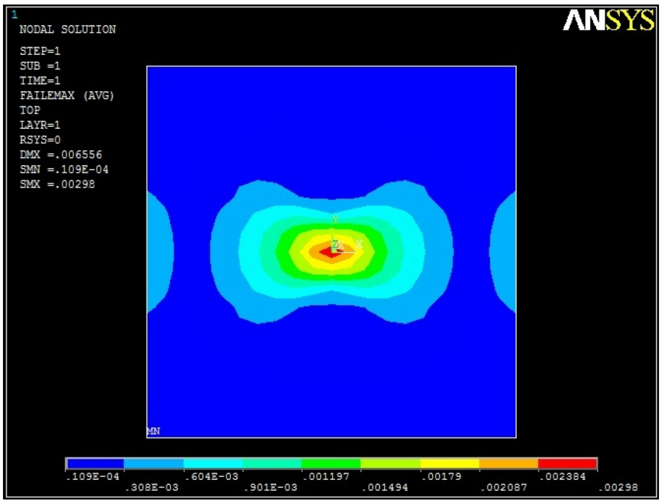

Fig. 8 Maximum Strain failure index for (0˚/90/0˚/90)s laminates

Fig.7 shows the stress distribution and failure index of laminate for sequence (0˚/90̀/0˚/90̀)s. Maximum failure index for Maximum Stress failure criteria is 0.003188.

Fig.8 shows the stress distribution and failure index of laminate for sequence (0˚/90̀/0˚/90̀)s. Maximum failure index for Maximum Strain failure criteria is 0.00298.

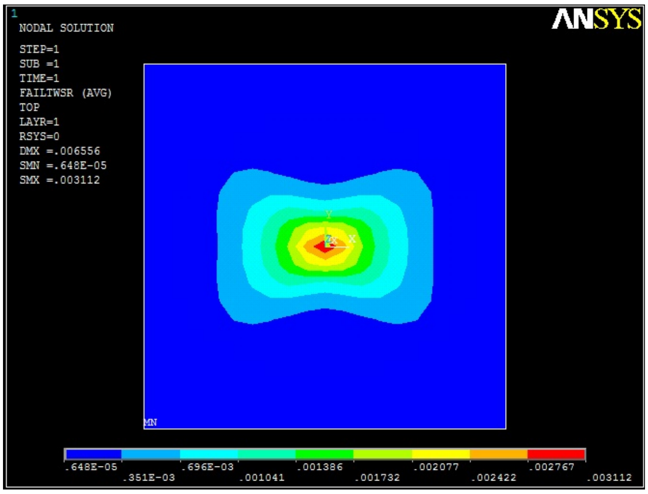

Fig. 9 Tsai-Wu failure index for (0˚/90̀/0˚/90̀)s laminates

Fig.9 shows the stress distribution and failure index of laminate for sequence (0˚/90̀/0˚/90̀)s. Maximum failure index for Tsai-Wu failure criteria is 0.003188.

6. CONCLUSION

In this study, the failure test of Graphite Fiber Reinforced Polymer plates is simulated using finite element analysis software ANSYS. Shell model was developed and analysis of the model was carried out as per given boundary conditions. Shell model was examined and the obtained results were in good agreement with the experimental results. The maximum deviation in the simulated results is 7%. Therefore analysis of the composite structure can be done with Finite Element Analysis.

7. FUTURE SCOPES

In Engineering and structural application, a laminated composite is being used hence it is mandatory to do its failure analysis. Since experimental procedures turn out to be economical and require ample time so we do it by finite element methods.

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AUTHOR'S PROFILE

Peeyush Maheshwari has received his B.Tech degree in Mechanical Engineering from IIMT College of Engineering, Greater Noida, in the year 2013. He joined Rajshree Institute of Management & Technology, Bareilly as an Assistant Professor in Department of Mechanical Engineering in July 2013. Presently, he is pursuing M.Tech. With the specialization of Design and Production Engineering in G. B. P. U. A. T., Pantnagar. His area of interests are Design, Simulation, and Finite Element Analysis etc.

Anadi Misra has received his Ph.D. degree in Mechanical Engineering from GBPUAT, Pantnagar in the year 2000. Presently, he is working as a Professor at G. B. P. U. A. T., Pantnagar. His areas of interests are Dynamics of Machine, Experimental Stress Analysis, Simulation and Finite Element Analysis etc.