EPJ Web of Conferences **345**, 01014 (2026) https://doi.org/10.1051/epjconf/202634501014
ICE3MT2025

Numerical investigation on the effect of ply symmetry and presence of central hole on tensile performance of polymer matrix composites

Malikarjun Gurav[1*], *Suraj* Rane[1], and *Vikas* Chaudhari[2]

[1]Department of Mechanical Engineering, Goa College of Engineering (Affiliated to Goa University) Farmagudi, Goa 403401, India
[2]Department of Mechanical Engineering, BITS Pilani KK Birla Goa Campus, Zuarinagar, Goa 403726, India

Abstract. This study presents numerical investigation of change in degradation of load carrying capacity in tension due to presence of ply symmetry and a central hole. Four different stacking sequences are used in the study, each having two variations viz. symmetric and non-symmetric. This approach is followed to understand effect of having symmetric layups. Secondly, tensile performance degradation is also estimated for above layups due to a central hole. This approach is used to understand the effect of stacking sequence. Finally, the difference in degradation of load carrying capacity due to symmetry as well as central hole is presented. This approach is followed to understand the effect of layup symmetry and central hole on tensile performance having different stacking sequences. Investigation shows that from the four stacking sequences taken under study, two showed positive effect and one showed negligible effect of symmetry on performance for specimen without and with hole. However. one stacking sequence showed negligible effect for specimen without hole and a negative effect of symmetry for specimen with a hole. Hence, for applications where this stacking sequence is used it is proposed to use non symmetric layups, for better performance in presence of a discontinuity like a hole.

1 Introduction

Polymer Matrix Composites (PMC) have shown promising results in the recent past for various applications including aerospace, defence, domestic as well as industrial scenarios. Due to their inherent superior strength to weight ratio and advancements in technology for developing high performance composites, these are gaining more attention than ever before. Starting from most simple hand layup technique to advanced 3D printing, many fabrication processes are available to obtain required shape and size of components. One key challenge in any of the processes is to obtain precise fibre orientation. Fibre orientations for individual layers, most commonly known as stacking sequence is the pattern in which each layer in a laminate is oriented and stacked with respect to each other. In order to avoid after fabrication

* Corresponding author: malikarjungurav@gmail.com

complications like out of plane warpage and development of residual stresses, symmetric stacking sequences are preferred. However, in recent years researchers have taken interest in exploring the advantages of having residual stresses on various performance related aspects.

2 Research background

Many studies are available in literature where in researches have extensively studied effect central hole along with other design attributes like stacking sequence, on major performance related aspects of PMCs. Most of the literature available is of PMC laminates with symmetric layups.[1–3] . Hashimoto K. et.al. [4]have proposed an asymmetric stacking sequence that can used as a patch to repair composite structures. The stacking sequence of the patch is optimised using genetic algorithm fed with FEM data from tensile tests. Authors reported many optimal stacking sequences all of which are asymmetric. Falkowicz K. et. al. [5] investigated the buckling and post buckling behaviour of asymmetric composite plates with a cutout. Results from the study are compared with experimental findings. A good agreement is reported by the authors. Afsar Hussain et. al. [6] also studied effect of stacking sequence on various mechanical properties on asymmetric CFRP laminates. Authors have developed a model to predict failure modes in asymmetric laminates. Further, assembly of PMC components demands for post fabrication operations like drilling. This causes a lot of changes in overall performance of these components. Decrease in load carrying capacity may be attributed to stress concentration at the hole, reduction in overall resisting area and damage during drilling. Hence it is of great importance to explore the effect of all possible combinations of stacking sequences, both symmetric and unsymmetric when a discontinuity like a hole exists. In this work a novel approach is undertaken in attempt to investigate symmetry and presence of a central hole. Specimens having layers of same fibre orientations but arranged either symmetrically or unsymmetrically along with or without hole, are investigated.

3 Numerical analysis

For numerical analysis, ABAQUS/CAE software is used. ABAQUS/CAE (Complete Abaqus Environment) is widely used for the analysis of composite materials.

3.1 Methodology

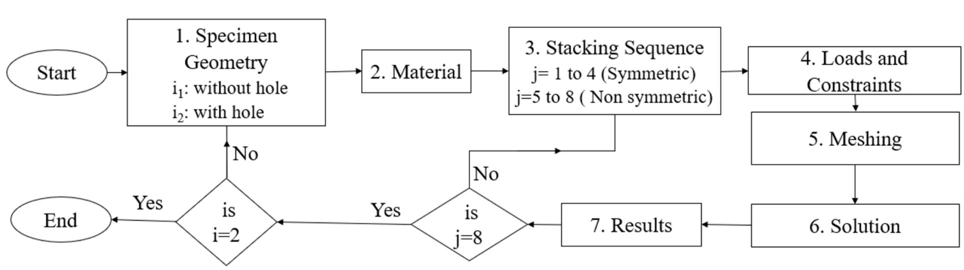

Fig. 1. Methodology flow chart.

A FEM model is created in accordance to ASTM D3039. Figure 1 shows the flow chart. Material properties for glass fibre reinforced plastic are applied. Standard ply angles of 0°,90°, +45° and -45° are used to create four unique stacking sequences. Each having its unsymmetric counterpart. Loads and boundary conditions are applied; solution and results are plotted. Same approach is followed for specimen with hole in accordance to ASTM D5766. In total 16 numerical simulations are performed. Table 1 provides details of layups. Layups B and C are "flipped angle" stacking sequences [8].

Table 1. Symmetric and unsymmetric stacking sequences with codes.

Stacking Sequence Code	Symmetric Layup	Unsymmetric Layup
A	$[0°/90°]_{2s}$	$[0°/90°]_4$
B	$[0°/90°/\pm45°]_s$	$[0°/90°/\pm45°]_2$
C	$[\pm45°/90°/0°]_s$	$[\pm45°/90°/0°]_2$
D	$[\pm45°]_{2s}$	$[\pm45°]_4$

3.2 Stress model

Orthotropic material properties were assigned to each unidirectional composite lamina according to the fibre orientation by using a pre-defined local coordinate system. Linear elastic material behaviour is assumed prior to any damage for each element. Table 2. shows the material properties considered for numerical analysis.

Table 2. Material Properties of PMC Laminate. [7,8]

Young's Modulus (MPa)		Poisson's ratio		Modulus of Rigidity (MPa)	
E_{11}	153000	V_{12}	0.3	G_{12}	6000
E_{22}	10300	V_{13}	0.3	G_{13}	6000
E_{33}	10300	V_{23}	0.4	G_{23}	3700

3.3 Geometry

Two tensile test specimens 250mm X 25 mm with a thickness of 2.5 ±1 mm (in accordance to ASTM D3039 and D5766) are modelled. One specimen with an existing hole of 5 mm. Each specimen is modelled separately with layups discussed in above section.

3.4 Boundary conditions and loading

The tension test specimens are gripped at one end and tensile force is applied at the other end. Figure 2 shows the gripped area and area where load is applied. A displacement of 2 mm is applied at the free end.

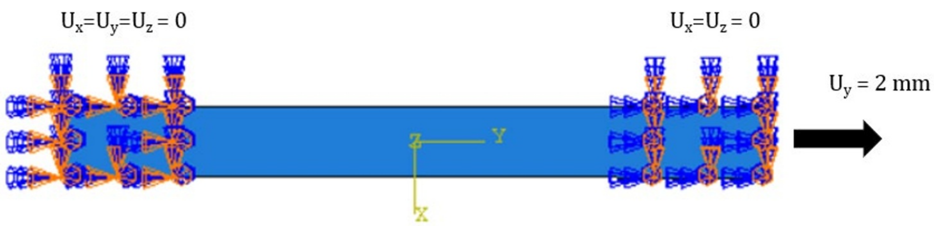

Fig. 2. Boundary conditions and loading for tension test specimen.

4 Results and discussion

As seen in Table 3a, specimen having stacking sequence A and D have negligible effect of symmetry on tensile load carrying capacity. However, B and C show equal positive effect. Table 3b, shows the same data for specimen with hole. Here one can see negligible effect for stacking sequence A. Positive and equal effect on B and C and a negative effect on stacking sequence D.

Table 3a. Effect of symmetry for specimen without hole.

Stacking Sequence	Load for Symmetric (N)	Load for Unsymmetric (N)	% Change
A	5790	5790	0.0050
B	4205	4068	3.2562
C	4205	4068	3.2561
D	1537	1535	0.0930

Table 3b. Effect of symmetry for specimen with hole.

Stacking Sequence	Load for Symmetric (N)	Load for Unsymmetric (N)	% Change
A	5671	5670	0.0139
B	4151	4015	3.2791
C	4151	4015	3.2771
D	1473	1521	-3.2730

Table 4a compares symmetric and Table 4b, compares unsymmetric stacking sequences for tensile load carrying capacity for specimens without and with hole.

Table 4a. Effect of central hole on specimens having symmetric stacking sequence.

Stacking Sequence	No hole (N)	Hole (N)	% Change
A	5790	5671	2.0521
B	4205	4151	1.2638
C	4205	4151	1.2640
D	1537	1473	4.1330

Table 4b. Effect of central hole on specimens having unsymmetric stacking sequence.

Stacking Sequence	No hole (N)	Hole (N)	% Change
A	5790	5670	2.0608
B	4068	4015	1.2871
C	4068	4015	1.2854
D	1535	1521	0.9031

It can be seen from above table that, specimen with stacking sequence D has highest degradation when a central hole exists, for symmetric layup and least degradation for unsymmetric layup. Figure 3. compares the load for layups under study. As we can clearly see for layup D only, there unsymmetric specimen showed better results than symmetric counterpart.

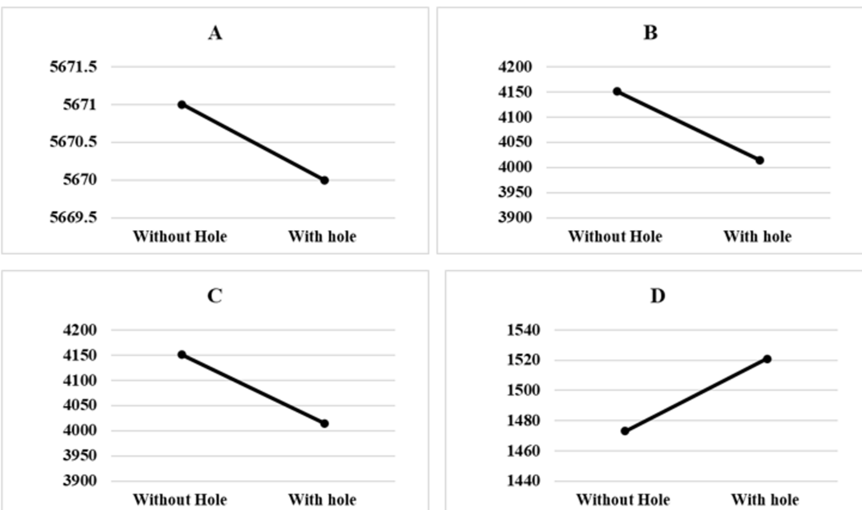

Fig. 3. Effect of symmetry on specimens with hole.

5 Conclusion

For stacking sequence, A, there is negligible effect of symmetry for both with and without hole. B and C stacking sequences showed 3.2 % higher load carrying capacity for both with and without hole due to symmetry. However, for D there is negligible and 3.2 % decrease in the value of load due to presence of symmetry for specimen without and with hole respectively. Hence it is concluded that symmetry for layups having only ±45° fibre orientations have a negative effect on load carrying capacity in tension for specimen with a central hole. For layup B and C, the performance degraded due to unsymmetry. For these layups, interlaminar fibre orientation changes by a magnitude of 45°, unlike 90° for other layups. Due to this, these layups have a different interlaminar stress profile. Further investigation is needed to understand the relation between interlaminar stress and symmetry. In this study, it can be clearly seen that symmetric layups show better performance compared to their unsymmetric counterparts for layups whose interlaminar fibre orientation change is 45°. It can be also seen that B and C perform equally and hence it can be concluded that "flipped angle" stacking sequence has no effect for these two layups.

References

1. S. Lin and A. M. Waas, The effect of stacking sequence on the LVI damage of laminated composites; experiments and analysis, Compos Part A Appl Sci Manuf **145**, 106377 (2021)
2. M. A. Caminero, G. P. Rodríguez, and V. Muñoz, Effect of stacking sequence on Charpy impact and flexural damage behavior of composite laminates, Compos Struct **136**, 345 (2016)
3. Z. Lei, R. Pan, W. Sun, Y. Dong, Y. Wan, and B. Yin, Fatigue damage mechanisms and evolution of residual tensile strength in CFRP Composites: Stacking sequence effect, Compos Struct **330**, 117818 (2024)
4. K. Hashimoto, S. Yashiro, S. Onodera, and K. Ryuzono, Asymmetric stacking patch for debonding suppression in single-sided patch repair of composite structures, Compos Struct **355**, 118843 (2025)
5. K. Falkowicz, P. Wysmulski, and H. Debski, Buckling Analysis of Laminated Plates with Asymmetric Layup by Approximation Method, Materials **16**, (2023)
6. A. Husain, S. H. Khan, and A. H. I. Mourad, Stacking sequence effects on flexural stiffness, failure progression, and energy absorption in asymmetric CFRP laminates, Results in Engineering **27**, 105863 (2025)
7. Y. Shi, T. Swait, and C. Soutis, Modelling damage evolution in composite laminates subjected to low velocity impact, Compos Struct **94**, 2902 (2012)
8. V. Lopresto, A. Astarita, M. Porfiri, and A. Shukla, The International Symposium on Dynamic Response and Failure of Composite Materials, Draf2018, J Mater Eng Perform **28**, (2019)