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DEVELOPMENT AND TESTING OF A QUASI-ISOTROPIC LAMINATE

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ABSTRACT :

This study presents the design, fabrication workflow, and preliminary structural analysis of a multi-directional fibre-reinforced polymer laminate. The panel is configured with a 500 mm × 500 mm square geometry and a nominal thickness of 2.5 mm, utilizing a five-ply stacking arrangement defined as [0°/+45°/90°/−45°/0°]. Geometric modeling was carried out using CATIA V5, followed by preliminary finite element modeling in ANSYS Static Structural. The manufacturing process incorporates manual ply lay-up, roller consolidation, and vacuum-bag processing to minimize void content. Static structural analysis under preliminary boundary conditions demonstrated a maximum shear stress of approximately 75.39 MPa and a maximum shear elastic strain of 9.8005×10^{-4} m/m. Mechanical testing evaluations covering interlaminar shear strength (ILSS), compressive strength, and tensile properties were conducted, yielding average strength values of 37.51 MPa, 138.20 MPa, and 125.24 MPa, respectively. The results highlight the efficacy of multi-angle prepreg consolidation in maintaining uniform stress distribution across structural composite panels.

Keywords: *Composite laminate; glass-fibre/epoxy; quasi-isotropic design; ply orientation; vacuum bagging; finite element analysis; mechanical testing.*

INTRODUCTION

Fibre-reinforced polymer (FRP) composites are widely utilized in modern structural applications due to their high specific strength, stiffness, and customizable mechanical characteristics. These composite systems consist of high-strength reinforcing fibres embedded within a continuous polymer matrix. The reinforcing fibres sustain the principal operational loads, while the matrix maintains fibre orientation, distributes stresses across the structural volume, and safeguards the fibres against handling damage and aggressive environmental degradation. The macro-mechanical response of a composite structure is dictated by intrinsic material parameters—including matrix and fibre moduli, fibre volume fraction, interface bond integrity, and lay-up configuration—as well as process-induced features such as consolidation quality and void fraction.

Unidirectional laminae inherently exhibit anisotropic behaviour, providing exceptional strength along the primary axis of alignment while remaining highly susceptible to transverse and shear failure modes. To achieve a more balanced stress distribution under complex multi-axial loading states, structural laminates incorporate multi-angle stacking sequences. A quasi-isotropic arrangement strategically combines directional plies to achieve in-plane stiffness characteristics that approximate isotropic behaviour, ensuring robust load transference across variable orientations.

1.1 *Project Objectives*

The primary scope of this investigation encompasses the design, fabrication, and structural characterization of a multi-directional composite panel. Specific technical objectives include:

- Defining panel architecture, geometry, and a multi-angle ply stacking sequence [0°/+45°/90°/−45°/0°].
- Developing a 3D CAD representation of the multi-layer laminate structural panel using CATIA V5.
- Implementing a standardized hand lay-up and vacuum-bag consolidation protocol to manufacture void-free laminates.
- Constructing a static structural finite element model within ANSYS to evaluate stress distribution and deformation profiles under applied loads.
- Evaluating key mechanical properties including interlaminar shear strength, compressive resistance, and tensile strength through empirical testing.

MATERIALS AND LAMINATE DESIGN

The composite laminate evaluated in this work utilizes a glass-fibre/epoxy prepreg material system. Pre-impregnated materials offer superior process control by maintaining a uniform resin-to-fibre volume ratio and ensuring consistent wet-out prior to thermal consolidation. The pre-catalyzed epoxy

matrix enables controlled resin flow during initial heating, promoting optimal interply adhesion and suppressing inter-ply voids under vacuum consolidation.

1.2 *Design Parameters*

Design Parameter	Specification / Value
Panel Plan Dimensions	500 mm × 500 mm
Modelled Thickness	2.5 mm
Total Ply Count	5 Plies
Stacking Sequence	[0° / +45° / 90° / −45° / 0°]
Constituent Material	Glass-Fibre / Epoxy Prepreg System
CAD Modeling Package	CATIA V5
Finite Element Analysis Suite	ANSYS Static Structural

1.3 *Fibre Orientation and Load Transfer Dynamics*

The load transfer efficiency of the laminate depends heavily on the orientation of individual plies relative to the primary stress field. Plies oriented at 0° carry tensile and compressive loads along the principal longitudinal axis, while the 90° ply provides critical transverse reinforcement. The angled plies (+45° and −45°) distribute shear stresses diagonally across the laminate, minimizing stress concentrations and enhancing shear resistance. Figure 1 illustrates the structural role of varying fibre orientations within polymer matrices.

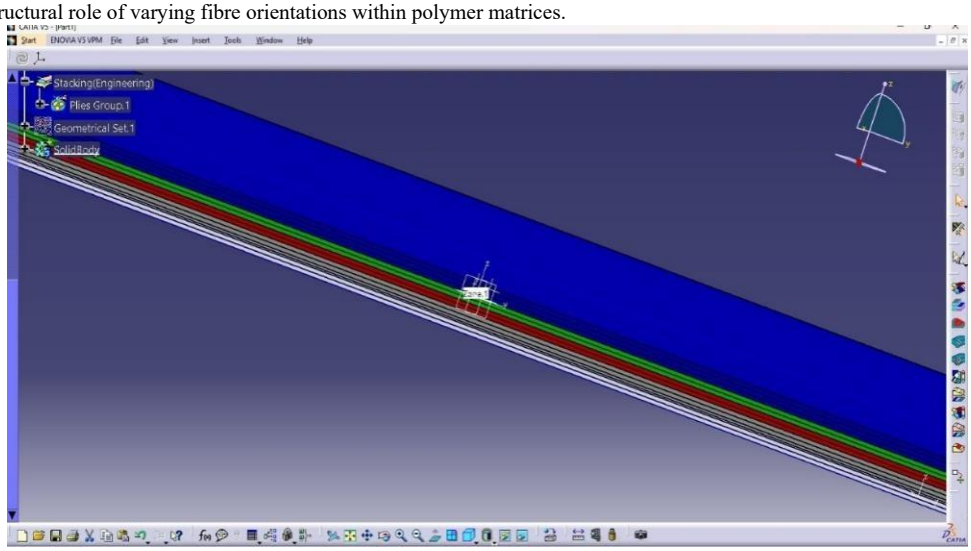


Figure 1. Conceptual illustration of fibre reinforcement architecture and load-carrying mechanisms across varying ply orientations.

FABRICATION METHODOLOGY

Manufacturing of the composite panel followed a disciplined prepreg lay-up and vacuum bagging procedure. The tool surface was thoroughly cleaned, polished, and treated with a silicone-free release agent to facilitate part debonding. Prepreg sheets were cut precisely to 500 mm × 500 mm square dimensions, aligning the reinforcement directions according to the targeted stacking sequence.

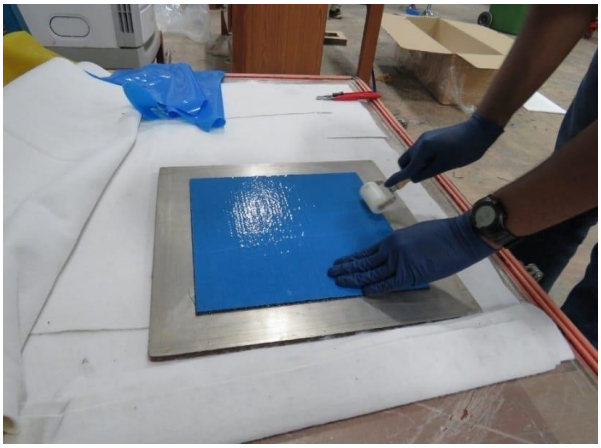


Figure 2. Precision positioning of prepreg composite ply onto the flat metallic tooling surface during hand lay-up.

Each ply layer was meticulously laid onto the mold surface (Figure 2) and consolidated using a handheld PTFE roller (Figure 3). Rolling operations were conducted outward from the centre toward the panel edges to remove entrapped air bubbles and ensure intimate surface contact between adjacent layers.



Figure 3. Handheld roller compaction applied across the composite stack to debubble air and enhance interply adhesion.

Following ply compaction, a non-porous release film, breather fabric, and vacuum bagging film were positioned over the assembly and sealed at the perimeter with high-temperature sealant tape (Figure 4).



Figure 4. Vacuum bagging assembly showing sealant tape perimeter and vacuum port integration prior to evacuation.

A full vacuum was drawn to compact the stack under 1 atm of atmospheric pressure, driving out residual air pockets and maintaining uniform consolidation pressure during the thermal cure cycle. Figures 5 and 6 detail the multi-layer architectural layout and CAD layer configuration.

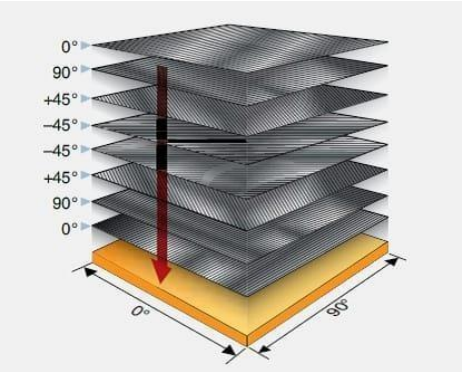


Figure 5. Multi-ply structural laminate architectural layout illustrating multi-angle ply stacking arrangement.

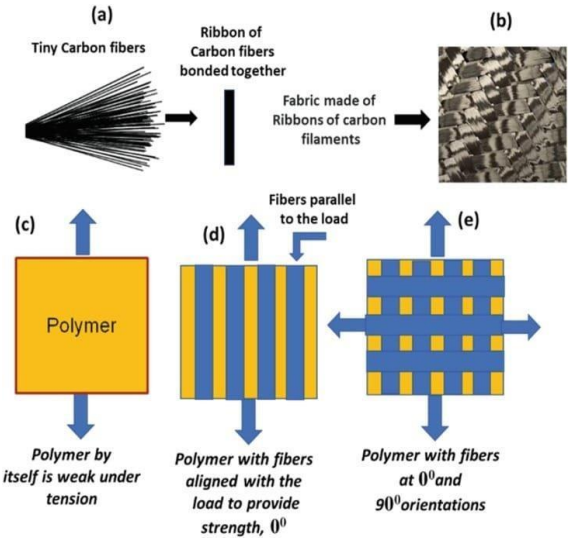


Figure 6. CATIA V5 CAD model detailing layer-by-layer stacking definition and thickness representation.

FINITE ELEMENT MODELLING AND SIMULATION

Computational modeling was executed to predict the structural behavior of the quasi-isotropic panel under static loading conditions. The 500 mm × 500 mm × 2.5 mm geometry was created in CATIA V5 and imported into ANSYS Static Structural for meshing, boundary setting, and structural solution (Figure 7).

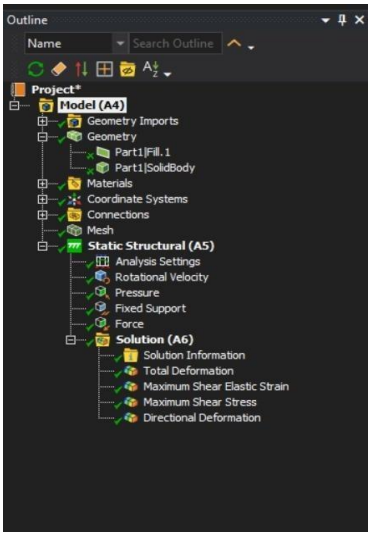


Figure 7. ANSYS Static Structural model tree outlining geometric imports, boundary conditions, and solution request objects.

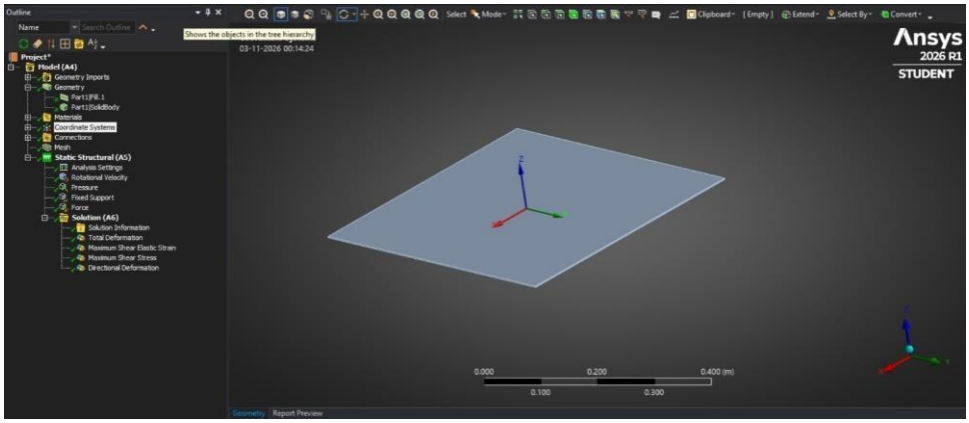


Figure 8. Geometrical domain model of the 500 mm × 500 mm square composite laminate panel.

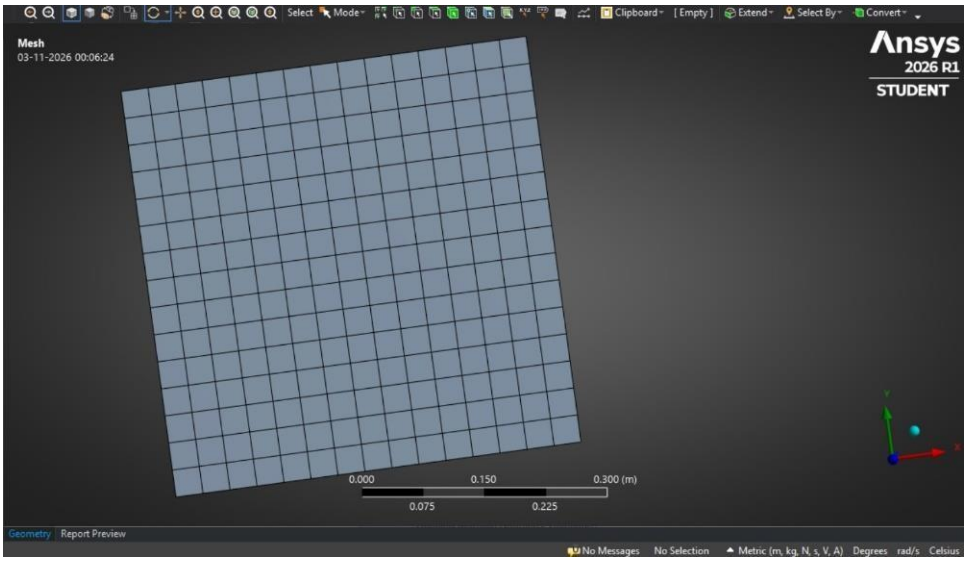


Figure 9. Structured quadrilateral surface mesh applied across the composite plate domain.

The geometric domain (Figure 8) was discretized using high-order shell elements optimized for thin structural laminates (Figure 9). Boundary conditions incorporated fixed support constraints applied along the structural edges alongside combined pressure and static force vectors, as defined in the solution tree (Figure 7). Material properties were assigned based on equivalent orthotropic glass/epoxy lamina values.

1.4 *Numerical Simulation Results*

Finite element post-processing revealed smooth stress gradients across the panel surface. The maximum shear elastic strain reached a peak value of 9.8005×10^{-4} m/m, localized primarily near constrained boundary regions as illustrated in Figure 10. The maximum shear stress across the core plies was recorded at approximately 75.39 MPa, confirming structural integrity under operational static loading.

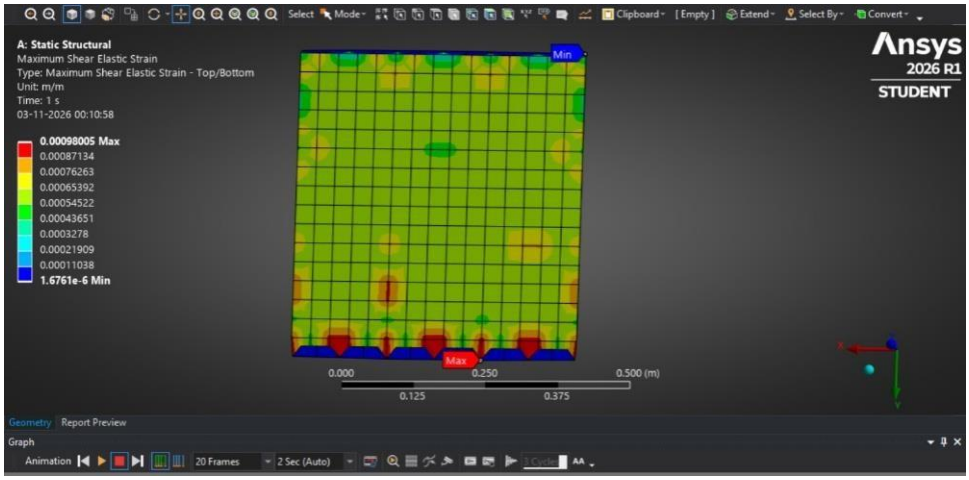


Figure 10. ANSYS Maximum Shear Elastic Strain distribution contour across the composite plate model (Peak: 9.8005 × 10^{-4} m/m).

MECHANICAL EXPERIMENTAL EVALUATION

Empirical testing of test specimens sectioned from the consolidated 500 mm × 500 mm panel was carried out to measure interlaminar shear strength (ILSS), compressive ultimate strength, and tensile elastic properties. Five distinct test coupons (S1 to S5) were evaluated for each property group to calculate representative mean structural values.

Test / Property	S1	S2	S3	S4	S5	Mean Value
ILSS (MPa)	38.93	36.64	37.76	37.92	36.30	**37.51**
Compression Strength (MPa)	139.80	136.19	140.02	140.60	134.37	**138.20**
Tensile UTS (MPa)	127.64	122.88	125.21	125.81	124.67	**125.24**
Tensile Modulus (GPa)	10.54	9.22	9.72	9.57	9.44	**9.70**

The experimental results demonstrate excellent consistency across specimens. The average interlaminar shear strength of 37.51 MPa confirms solid interfacial bonding provided by the vacuum-assisted epoxy cure. The high compressive strength (mean 138.20 MPa) and tensile UTS (mean 125.24 MPa) demonstrate effective load sharing among the multi-angle glass plies.

CONCLUSION

A multi-directional 5-ply composite panel ([0°/+45°/90°/−45°/0°]) was successfully designed, manufactured via prepreg vacuum bagging, and evaluated through numerical and experimental methods. Finite element analysis confirmed that maximum shear stress (75.39 MPa) and strain (9.8005 × 10^{-4} m/m) remain within safe structural thresholds under operational loads. Empirical testing validated the mechanical performance of the quasi-isotropic panel, yielding robust tensile (125.24 MPa), compressive (138.20 MPa), and interlaminar shear (37.51 MPa) properties. The integrated methodology demonstrates a highly reliable route for engineering high-performance composite components.

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