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Flexural Behaviour of a Fibre-Reinforced Polymer Composite: Experiment and Simulation

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Abstract: This paper involves the investigation of the flexural behaviour of a laminate composite. The three-point bending method is used with reference to ASTM D7264/7264M – 07. The laminate is composed of a single ply with 20 layers of grass fibre as reinforcement. A stacking sequence of $[0_{20}]$ was used. Seven samples cut out from the entire board at 20 x 200 mm were used. The Thickness of the ply was 4.45 mm with a support span of 71mm according to standard. The samples were tested until visible delamination and debonding typified by visible shear and dip in applied compression up to a value of 5.8 mm. The simulation was done using Ansys ACP-Pre (plies) tied with the Mechanical Model (supports) and the Static structural module (unification of both). The results showed good agreement with the experimental result.

Keywords: laminate; bending; compression; simulation; experiment.

1 Introduction

Laminated composites have become a material of choice in modern-day applications of engineering and technology. This is attributed to its high strength-to-weight ratio, low machining cost and possibilities for extended studies in research and development. By studying the mechanical and thermal properties of composites, engineers, technologists and scientists are suitably equipped with the right experimental, numerical and simulation data to predict, with reasonable accuracy, the behaviour of materials in real-life applications. Be it advanced manufacturing techniques, natural-synthetic fibre-reinforced polymer composites, biocomposites, the application and scientific use of composites have grown in leaps and bounds, especially in the use of advanced techniques in investigating failures in composite materials [1, 2]. For years now, applications have forayed into automotive, aerospace, wind energy industries, and new frontiers have unfolded in smart composites and nanocomposites. Although fibre-reinforced composites have their tremendous benefits, they also have their inherent drawbacks and challenges arising from the fibre itself and the finished composite at various stages of their life cycle. Problems can arise in different stages including fabrication, joining, shaping, and disposal. Other concerns arise from functionality and usage, include cost, (arising from the high energy cost of production machining), quality assurance and control, durability, design complications and complexities, moisture conditions, fire resistance, compatibility with other materials, and adherence to applicable international standards for best practices [3, 4, 5]. The use of FE methods has created new ideas in modelling the real-life behaviour and failure modes of composites – be it damage initiation, debonding and delamination of composite materials under bending load [6]. The critical natures of composite materials in use make it of utmost importance that they are prequalified and tested by standards to ensure they are, not only, fit for purpose but also have the highest level of safety and structural integrity. Nowadays there are several high-quality articles that highlights the effect of stacking sequence on the behaviour of composite materials in failure [7]. Improvements in the design of carbon fibre reinforced polymer (CFRP) have led to the suitability of applications at elevated temperatures [8] and also highly dynamic loads in terms of multiaxial and fatigue stresses.

a) Laminate cutting b) Sampling and measurement c) Bending test setup

Fig. 1: Composite laminates cutting, sampling and setting up on the *Tira 2810* test bed.

2 Sample Geometrics and Experimental Setup

The fibres are cut out 250 x 250 mm. The matrix is epoxy resin with hardner mixed at a ratio of 2:1 - exactly 100:50 ml or cm^3. The classic nylon-bleeder-separator- nylon arrangement is used to set up the components before manual roller action. The arrangement is then loaded inside the curing machine for 60 minutes at a compression force and temperature of 20 kN and 75 °C respectively before cooling to ambient temperature inside the chamber. The samples are then cut according to standards as shown in Tab. 1. Seven samples were tested for each composite type.

Tab. 1: Sample Geometrics and ASTM standard specimen.

Sample Type	Fibre Configuration	Laminate Thickness	Thickness-to-Span Ratio	Width	Number of Ply	Support Span
S1	$[0_{20}]$	4.45 mm	16:10	20 mm	20	71.00 mm
S2	$[(0_{2gl}, 0_{ry})_2]s$	3.15 mm	16:10	20 mm	12	71.00 mm
S3	$[0_{16}]$	3.40 mm	16:10	20 mm	16	71.00 mm

The experimental setup is setup according to ASTM D7264/7264M – 07. A trial sample is loaded to the Tira 2810 test bed to decide at what lateral deflection visible damage in the form of surface cracks and debonding. This value is recorded. To ensure uniformity, the machine is then preset to apply this downward bending force as prescribed displacement in all tests. The value in 5.80 mm in the downward y-axis. Data for displacement and force were recorded.

3 Building the Simulation in Ansys ACP-Pre

The process involves creating two parts of the entire structure, then linking the system of ACP-pre (laminate thickness and fibre orientation), mechanical model (modelling the supports and plunger) and static structural (assembly of ACP-pre and support structure) as shown in Fig. 2.

The material data from experiment are used to determine the Young’s modulus and Poisson ratio for the elastic region. The plastic region is fed in as raw data into Ansys as a multilinear kinetic hardening model to deduce the relevant constants.

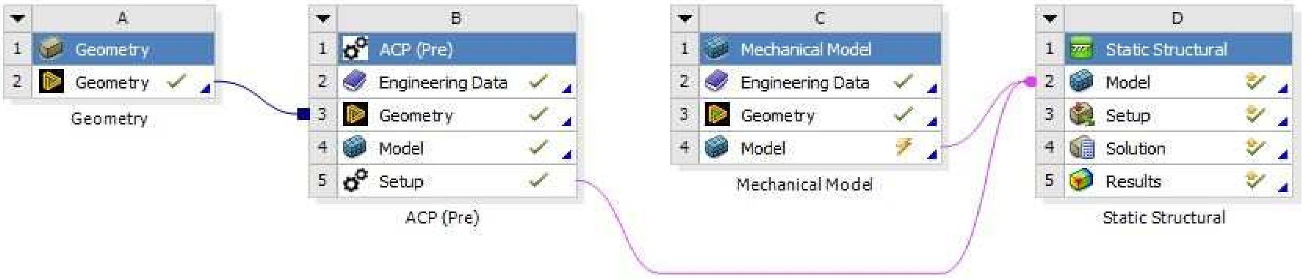


Fig. 2: Simulation layout.

The required boundary conditions and contact behaviour at touching region are created. Contact is set to simple friction with a coefficient of 0.1 between the composite and the indentor whereas it is ideally set to bonded between the supports and the lower part of the composite. The prescribed displacement is set as 5.8 mm in the downward y-direction as in the experiment. Figure 3 shows the basic schematic of the structural layout of the system. The diameter of the hemispherical supports and plunger were measured at 15 mm in the lab and implemented in modelling CAD model of the setup.

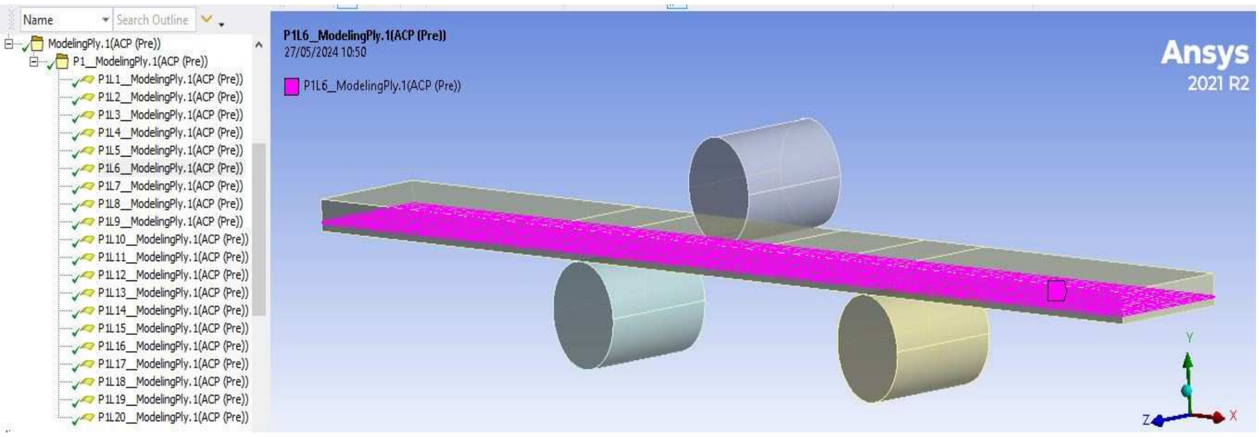


Fig. 3: Schematic of layers in ACP-pre.

4 Results and Discussion

The force-displacement data from each group of S_1, S_2 and S_3 are first averaged according to standard. Both engineering and true stress and strain were deduced for S_1, S_2 and S_3. The Young’s modulus deducted from the computation of experimental data is shown in Tab. 2. The Young’s modulus is calculated from the Eqs. (1) and 2 show the stress and strain respectively of a laminated composite prismatic beam in bending

$$\sigma = \frac{3PL}{2bh^2} \tag{1}$$

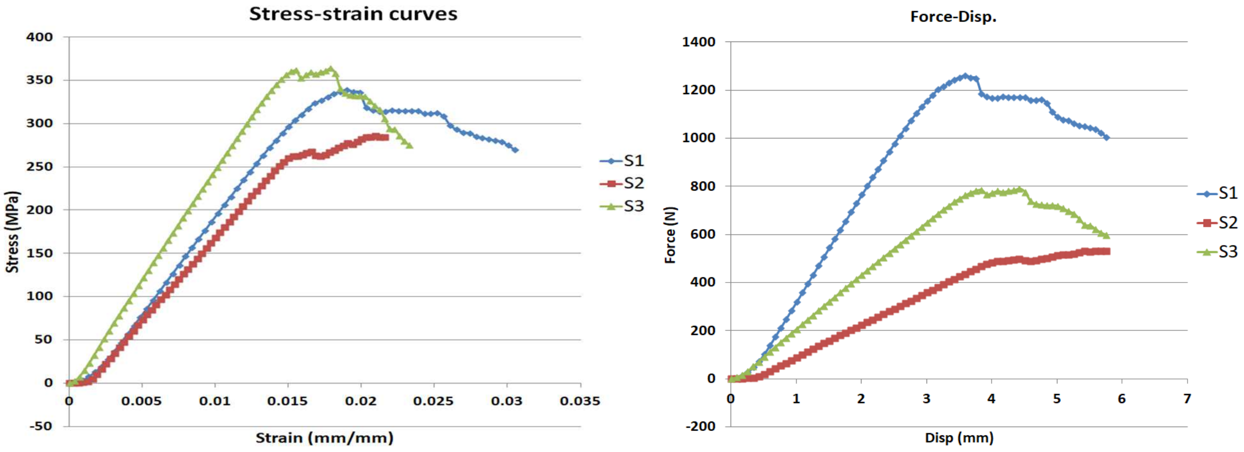
$$\varepsilon = \frac{6\delta h}{L^2} \tag{2}$$

where δ = mid-span deflection (mm), L = support span (mm) (determined by the suing the ASTM 16:1 span:thickness ratio), h = thickness of beam (mm).

Specimen	Young’s modulus (GPa)
S_1	21.195
S_2	18.737

S_3	25.356

Figure 4 shows the plots of stress-strain and force-displacement. The modulus of elasticity is derived from the linear region of the curve. Data from the plastic region is fed into an in-built multilinear kinetic model.



a) Stress-strain plot for the samples

b) Force-displacement

b) Fig. 4: Plots of the result from the flexural tests for all samples.

The test console produces the force, displacement and time data which are used to compute the stress and train after averaging for samples of each group. Figure 5 shows the distribution of Young's modulus for the three samples.

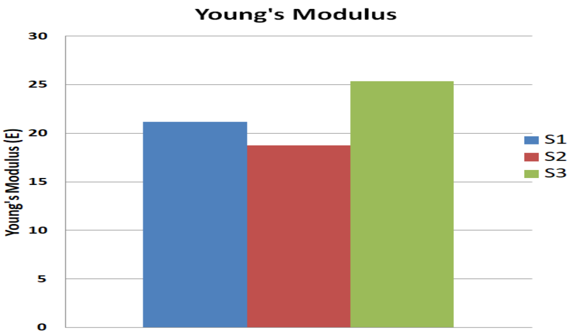


Fig. 5: Plots of Young's modulus (E_1) for the different samples.

A comparison is made of the data collected from Ansys post-processing. The plots are shown in Fig. 6 for the S_1 sample. The differences in the experimental and simulation could be attributed to the difficulty in manufacturing the composites to an ideal physical state. Geometrical nonlinearities are also another factor.

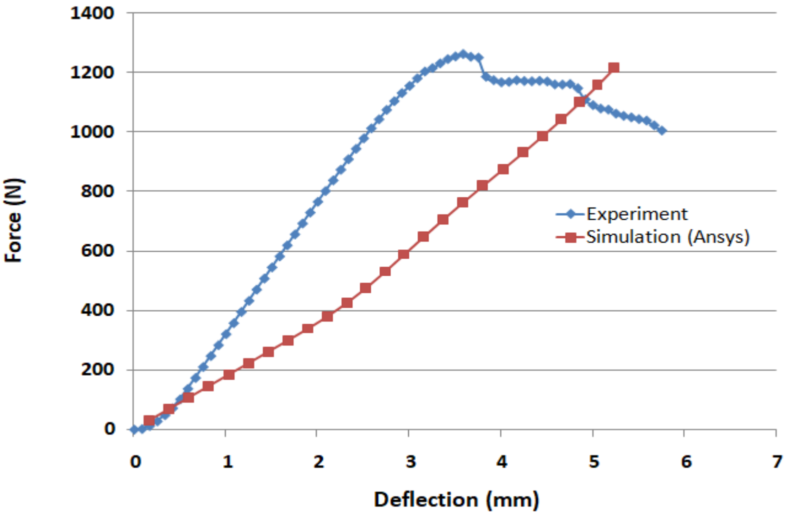


Fig. 6: Force-displacement plot for (S1).

5 Conclusion

The finite element option provides a more convenient, time-saving, yet complex, method of building composite plies Ansys ACP-pre. It also provides a better approach in carrying out both flexural and tensile tests while helping to eliminate such physical ordeals as slippage at the clamps and supports during repeated experimental testing. It also gives the opportunity to appreciate that ply orientation plays a key role in the behaviour of laminated composites. The zero-degree ply has been shown to have the greadest breaking axial force. This is particularly useful when designing components fit-for-purpose. Further work would be in high-speed impact test of the laminated composite with emphasis on the effect of material type (glass fibre, rayon, glass mat).

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