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Effect of fibre orientation on mechanical properties of carbon fibre composites

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The research aims to investigate the carbon fibre composite laminate for effect of their layer configuration including their number and relative orientation of fibre angles on their mechanical properties and its consistency with the results obtained from simulated data using finite element analysis (FEA) on mechanical properties. The laminate composite with four types of fiber layer orientations were prepared using total eight layers including unidirectional and cross ply layers with different orientations. The flexural properties of the samples were evaluated. The results of experiments found consistent with the simulated data and it indicates that the fibre orientations and its layer sequence influence the characteristics of laminate composites. The composite with 0° orientated unidirectional fibre layers shows maximum flexural strength. The flexural strain is higher for laminate composite having layers with cross plies (45° fibre orientations). The different position of cross ply in the sequence shows variations in flexural properties because the typical nature of the three point bending flexural test of laminate composite where top side layers are under compression and bottom side layers are under tension.

Keywords: Carbon fibre composite, FEA, Flexural properties, Laminate composites

1 Introduction

A composite laminate is an advanced version of carbon fibre-reinforced polymers (CFRP) consists of multiple layers made up of carbon fibres with same or different orientation[1,2]. The composite laminate based on carbon fibre has variety of structural applications such as automotive, aerospace, and construction industries because of their advanced properties like excellent strength-to-weight and stiffness-to-weight ratios. They have distinct advantages like high strength, high stiffness, long fatigue life, low density, corrosion resistance and wear resistance over the conventional monolithic composites[3,4]. These composites laminate based on carbon fibre are prone to structural damage specific to applied load directions because of their strong anisotropic nature. This anisotropy enhances the mechanical properties in particular direction. The extent that strength, elasticity, and other characteristics are enhanced in a fiber-based composite strongly depends on orientation of the reinforcing fibres. By simulating the composite structure with different fiber orientation, it is possible to predict about the mechanical properties of the composites like flexural strength, modulus, failure mode and other attributes[5]. This kind of simulation on fiber orientation is very much helpful to determine the manufacturing process that offers most consistent and cost-effective ways of fibre placement with specific orientation for the intended application. This enables conveniently to make composite materials based structural components with tailor-made characteristics. For example for a recurve bow limb made up of laminated composites, the tension, stored energy and impact during release primarily depend on its structural design[6]. In light of this in the present investigation finite element analysis (FEA) with ANSYS is performed to understand the effect of fibre orientation on the mechanical properties of the laminate composite and the results are corroborated with the experimental data of mechanical properties of these composite.

2 Experimental

The materials used for preparation of composite samples were a bisphenol-A based epoxy resin Araldite LY 556 and aromatic amine epoxy curing agent AradurHY 5200 (Huntsman Petrochemical Co.) with ratio of 100:25 for epoxy resin to curing agent and all samples were cured at 120 and 160 °C for

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2 and 4 hour srespectively. The samples were prepared by compression moulding method using the desired fabricated SS mould with rectangular cavity of desired dimensions. Prior to compression moulding the prepregs of carbon fibre layer were produced by hand lay-up method using the carbon fibre toe of 3k and splashing epoxy resin mixed with curing agent on each layer. Before lay-up, the moulds were coated with a release agent to ensure that the fibres would not adhere to the mould. The details of the process are as shown in the Fig. 1. The unidirectional carbon fibre T300-3k from Toray, Tokyo, Japan was used. Four types of samples were prepared using eight sequential layers of carbon fibre with different layer orientation *viz* (i) all 8 layers in the sequence with same direction with angle of 0 degree with longitudinal direction, (ii) 8 layers in the sequence of 0,45,0,0,0,0,-45,0 degree angle of layer orientation with longitudinal direction, (iii) 8 layers in the sequence of 0,0,0,45,-45,0,0,0 degree angle of layer orientations with longitudinal direction and (iv) 8 layers in the sequence of 0,45,-45,0,0,45,-45,0 degree angle of layer orientations with longitudinal direction. These samples are nomenclated as LA0, LE45, LC45, and L445 respectively. The samples were evaluated for flexural test by three point bending mode using universal testing machine (make In stron 5967) as per ASTM D638 for flexural strength and modulus. Software based finite element analysis was used to simulate models of 8 layer structure of CFRP laminate for evaluating the flexural properties with different layer configuration.

3 Results and Discussion

The finite element analysis for modelling of the three point bending, flexural properties gives simulated data for maximum load that sample can withstand before failure occurs at various point along the sample. The map of this load at various places on the sample is shown by the left panel and corresponding schematic sequence of layer orientation is shown in right panel of the Fig. 2 respectively for (a and b) LA0, (c and d) LE45, (e and f) LC45, and (g and h) L445. The obtained simulated values of flexural strengths are compared with that of the experimentally observed flexural properties of CFRP laminate composite with different layer sequences are shown in Table 1. The values of the flexural strengths obtained from simulation for different configuration are in well agreement with those obtained from experimental results. Figure 3 shows the representative response of the load taken with flexural strain for different configuration of CFRP laminate composite. The unidirectional (0°) laminates in the LA0 sample

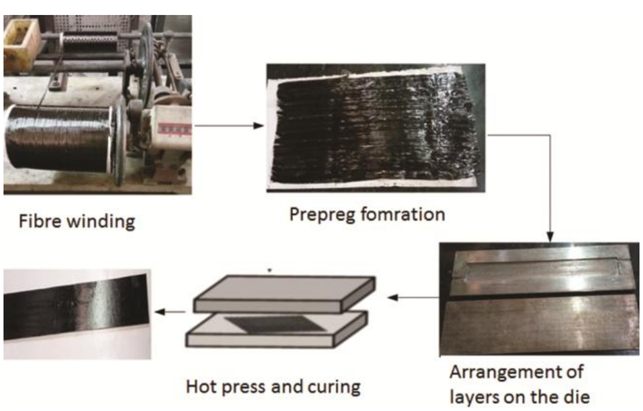

Fig. 1 — Schematic diagram showing the preparation of 8 layer laminate composite.

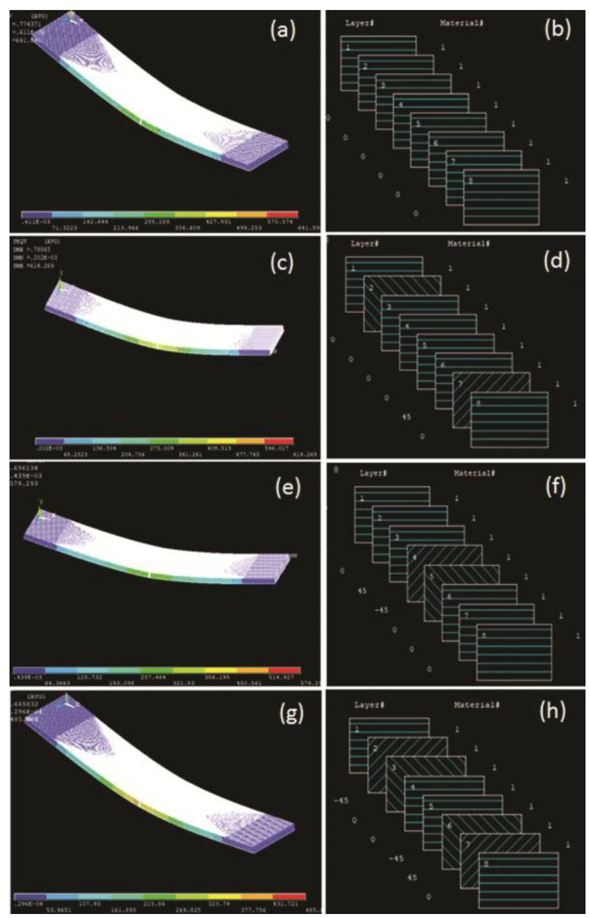

Fig. 2 — The map of the maximum load which sample can withstand at various places on the sample (the left panel images with colour contrast from red to blue for load) and corresponding schematic sequence of layer orientation (the right panel) respectively for (a & b) LA0, (c & d) LE45, (e & f) LC45, and (g & h) L445.

Table 1 — Comparative flexural properties obtained with simulation data using FEA and experimentally measured results for four types of CFRP samples.

Sr. No.	Sample	Strength (MPa) (simulation)	Strength (MPa) (Experimental)	Modulus (MPa) (Experimental)
1	LA0-(all 8 layers in 0deg)	641	621 (±24)	42144
2	LE45-(0,45,0,0,0,0,-45,0)	614	591 (±28)	38040
3	LC45-(0,0,0,45,-45,0,0,0)	579	580 (±42)	41924
4	L445-(0,45,-45,0,0,45,-45,0)	485	447 (±29)	32700

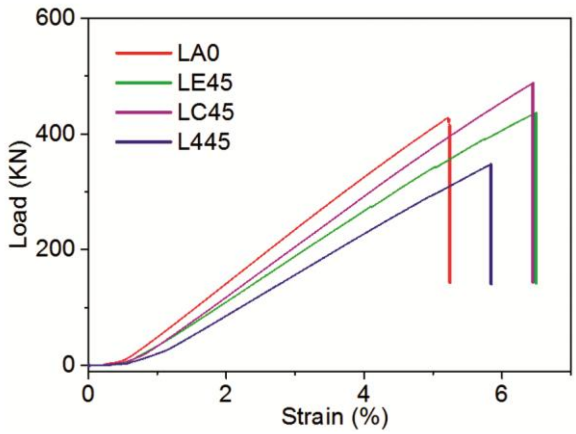

Fig. 3 — Stress-strain curve for LA0-(all 8 layers in 0 degree), LE45-(0,45,0,0,0,0,-45,0), LC45-(0,0,0,45,-45,0,0,0), L445-(0,45,-45,0,0,45,-45,0) samples.

have higher flexural strength and modulus as seen the table 1 which is consistent with earlier studies[7]. It is clearly evident from Fig. 3 that composite laminate with different layer orientation have different slopes revealing variation in strain and stress values. In the flexural mode, the fiber-matrix cracking and delamination easily occurred in the samples with longitudinal (0°) laminates made of identical unidirectional plies due to development of few micro-crakes along fibre matrix interface which resulted in sudden failure with lower strain as compared to other lay-up configuration including the 45 and -45 fibre orientation and these lay-ups sustain the higher deformations and postponed the crack propagation to a later time[8]. Further, for the laminate configuration having 4 layers of cross ply, i.e with fibre orientation 45 and -45° it shows smaller value of flexural strength as compared to configuration having 2 layers of cross ply. This might be because the relatively less amount of fibres oriented in loading direction in these samples. The elastic region of this flexural mode stress strain curves indicates the different slopes for different laminate configuration or orientations owing to different rigidity of the laminate composite[9]. The corresponding slope values are presented in Table 1, the unidirectional laminates (sample LA0) being the most rigid. This can be attributed to a maximum number of fibres located in the loading direction[10]. Therefore, it is noteworthy that the layer orientation has significant effect on stress-strain behavior of composite laminates having different layer orientation.

The failure mode in laminate composite is complex phenomena especially in multiply laminate composite with range of lay-up orientations. By appropriate choice it can be possible to make apparently isotropic laminate composites. This kind of multiply laminate composite in three point bending showed failure modes as a combination of both compressive and tensile mode of failure with top layer under compression and bottom layer under tensile. Hence the sequence of layer orientations is very critical as a particular orientation layer at different position in the sequence gives variation in the flexural properties. This can be seen from different values of flexural strength for sample LE45 and LC45 in which the position of the cross plies (45°) was more towards surface plies and at centre of the sequence in the laminate composite respectively.

4 Conclusions

The flexural properties of four types of samples are investigated using simulation based on Finite element analysis (FEA) for the carbon fibre laminate composite for understanding the effect of their layer configuration including relative orientation of fibre layers and its sequence on their mechanical properties. To check the consistency of the result, four types of samples with same configurations were prepared and tested experimentally for its flexural properties. The simulated data and experimental results are in well agreement. The results indicated that for carbon fibre laminate composite the flexural strength and modulus are higher for 0° layer orientation, whereas flexural strain is higher for other laminate composite having layers with cross plies (45° fibre orientations). This could possibly because of the presence of cross plies in the latter which help for better networking of fibres within the composites and withstand for more deformation and delays composite failure. The samples with two layers of cross ply shows better flexural properties compared to as that of with four layers because of the relative less amount of fibres oriented in loading directions. The stacking sequences of the layers with different orientation influences the flexural properties of the laminate composites. The sample with two centrally located layers of cross ply show better properties as compared sample in which the two cross ply are located near top and bottom surface of the composite. This might be because in the typical flexural test by three points bending the top layer is under compressive load and bottom layers are under tension. The investigation on effect of layer orientation and their sequence on their flexural properties is very much useful for composite making for applications like multi-layer archery recurve bow. The observed agreement of simulated data with experimental results in this study will be very much useful for designing of structural components based on the simulations and plan the experiments to get complex structures with optimal properties.

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