Study on Mechanical Properties of Uni-Directional Carbon Fibre Reinforced Polymer Composite Fabricated with Different Fibre Orientations

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Abstract—**Composites are replacing metal parts in the present manufacturing sector. The demand for higher strength and low weight components is required in almost all aspects of the production to improve the efficiency of automobile and aerospace vehicles. Carbon fibre reinforced polymer composite has been gaining importance due to its unique mechanical properties and high resistance to corrosion and environmental conditions. The property of carbon fibre reinforced polymer depends on various factors, including the orientation layers of fabric stacked to form a laminate. In this work, different orientations of 0/90° and 0/+45/-45/90° quasi-isotropic symmetric orientation was followed for fabricating uni-directional carbon fibre reinforced polymer composite by using 16 layers of carbon fabric. The mechanical properties such as flexural, interlaminar shear strength, impact, and hardness of composites were determined. Composite fabricated with quasi-isotropic symmetric orientation showed maximum improvement in mechanical properties with 2.83% and 1.52% increase in flexural strength and modulus, 1.38% for interlaminar shear stress, 1.13% for impact, and 1.58% improvement in hardness.**

Keywords—Carbon fibre reinforced polymer, orientation, mechanical property

I. INTRODUCTION

The word composite became familiar in the 1960s as the demand grew for high strength with lightweight materials [1]. Various types of composites are heavily used in different types of industries such as aerospace, marine, automobile, and satellite applications [2–4]. The commonly used composites include glass fibre reinforced polymer (GFRP), carbon fibre reinforced polymer (CFRP), aramid fibre, and Kevlar fibre used in bulletproof jackets [5,6]. Among the various composites, carbon fibre has been the most efficient and highly application-oriented composite material as they have high strength-to-weight properties. They are used maximum in the aerospace industry and satellite applications. An aircraft structure is built using composite material, as shown in Fig. 1.

Boeing and airbus have shifted from metals to composite materials to reduce their aircraft weight and improve fuel efficiency. Boeing 767 consists of 30% of its external surface composed of composites. Boeing uses CFRP for the construction of fuselage [7].

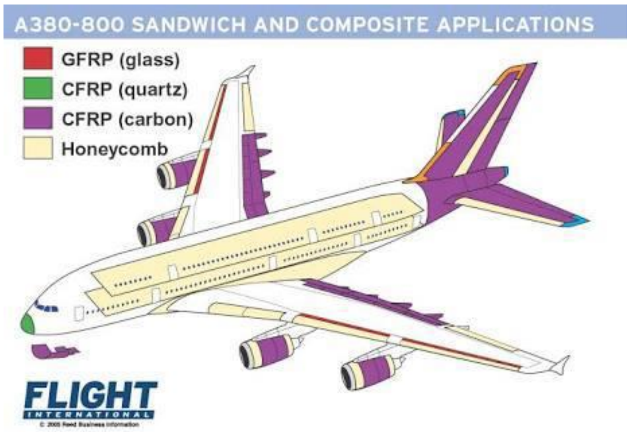

Fig. 1. Application of various composites in the construction of airbus [1]

Carbon fibre reinforced polymer is a combination of carbon fibre and a thermoset matrix. Carbon fibre acts as a reinforcement, whereas the thermoset matrix act as a load distribution component. Uni-directional (UD) carbon fibre is used highly instead of bidirectional (BD) in the construction of an aerospace structure as the mechanical properties obtained are higher in the case of uni-directional carbon fibre reinforced polymer composites[8]. In addition to enhancing the mechanical properties, the orientation of placing the uni-directional carbon fibre play an essential role in obtaining the maximum mechanical properties.

In this research work, mechanical properties such as flexural, interlaminar shear stress, hardness, and fracture toughness has been studied for UD-CFRP composites with two different orientations. UD-CFRP composite was prepared by using carbon fibre as reinforcement and epoxy resin as a polymer matrix. Two different orientations (0/90°) and (0/+45/-45/90°) are followed to determine the enhancement of various mechanical properties.

II. EXPERIMENTAL WORK

A. Fabrication of composites

Uni-directional carbon fibre with 200 GSM, type 3K and Bisphenol-A resin with amine-based hardener were procured from Bhor Chemical and Plastics Pvt. Limited. The resin to hardener ratio as supplied by the manufacturer was 100:30.

Uni-directional carbon material was cut into the orientation of 0°, 90°, 45° and -45°, as shown in Fig. 2. The quasi-isotropic symmetric orientation was followed for fabricating the composites.

Fig. 2. Cutting of carbon fibre fabric into 45° orientation

Composites were prepared using the mild steel mould of 250 mm × 250 mm × 6 mm (i.e., length, width and height). Two CFRP composites were prepared using the hand lay-up method with 16 layers having a (0/90°) fibre orientation and (0°/+45°/-45°/90°) quasi-isotropic symmetric orientation. The thickness of the composite obtained was 3 mm. The hand lay-up method is represented in Fig. 3. After the hand lay-up operation, the stacked fibers were compressed using compression molding, and the room temperature curing was followed for 24 h.

Fig. 3. Hand lay-up method

III. MECHANICAL PROPERTIES

Mechanical properties such as flexural strength, interlaminar shear strength (ILSS), impact test, and hardness for CFRP 3 mm and 6 mm thickness composite are determined based on ASTM standards. The fabricated composites were cut using CNC abrasive water jet cutting. All the tests were performed at room temperature 25 ℃ at an average relative humidity of 30%. Table 1. represents different ASTM standards followed.

Table 1. Different tests performed based on ASTM standards

Test	ASTM Standards
Flexural test	ASTM D7264 [9]
ILSS test	ASTM D2344 [10]
Impact test	ISO 179 [11]
Hardness	ASTM D2583 [12]

A. *Flexural test*

A flexural test was done to quantify the flexural strength and modulus of the CFRP composite. Flexural samples were cut according to ASTM D7264 with a span to thickness ratio of 32:1. The flexural test was determined using the universal testing machine (UTM), as shown in Fig. 4. Based on ASTM standards, the flexural strength and flexural modulus were calculated. A total of five samples were tested as per ASTM standards, and the average load value was considered for calculating flexural strength.

Fig. 4. Flexural test performed on UTM

B. *Interlaminar shear strength test*

The samples were cut using abrasive water jet cutting based on ASTM D2344 standards to perform the interlaminar shear test. Fig. 5. represents the UTM used for determining ILSS. ILSS is the most important parameter associated with delamination damage mode. Stresses developed between the interface of two adjacent layers are termed inter-laminar shear stress. As the stress intensity increases, the failure between laminar takes place.

Fig. 5. ILSS testing using UTM

C. *Impact test*

A Charpy impact test was performed. Specimen dimensions were cut according to ISO-179. Charpy test was performed using impact tester as shown in Fig. 6.

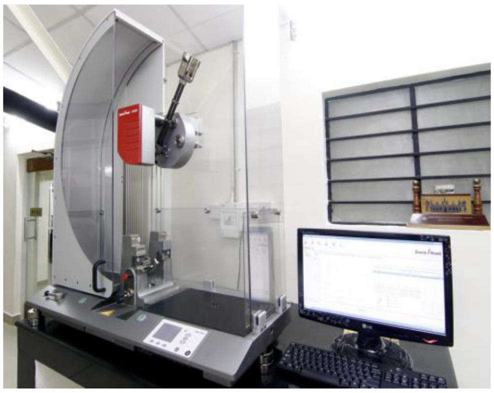
Fig. 6. Impact tester

D. *Hardness test*

The barcol hardness test was performed per ASTM standards D2583 to determine the barcol hardness number. The barcol hardness test was performed using the barcol indenter, as shown in Fig. 7. The specimen were cut into dimensions of 30×30 mm^2.

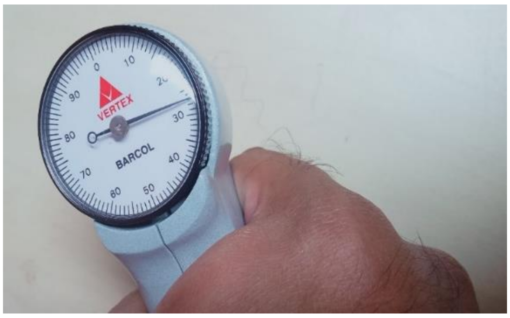

Fig. 7. Barcol hardness tester

IV. RESULTS AND DISCUSSIONS

Mechanical properties were determined as per the ASTM standards, and the standard testing types of equipment were used for experimenting, as mentioned in the above section. In this section, the different results obtained are discussed and reported.

A. *Flexural behavior of composites*

Flexural property determines the flexibility of a material under different load conditions. Flexural strength determines the materials having brittle properties and high hardness. Similarly, flexural modulus indicates the stiffness of the composite materials. Three-point bending test was performed using UTM, and the flexural strength and flexural modulus were calculated using Eqn. 1 and 2.

$$\text{Flexural strength, } \sigma_F = \frac{3P_{max}\ L}{2bh^2} \text{ (MPa)} \qquad 1$$

$$\text{Flexural modulus, } E_F = \frac{mL^3}{4bh^2} \text{ (GPa)} \qquad 2$$

Fig. 8. represents the bar graph of flexural strength for different orientations, whereas Fig. 9. represents the flexural modulus of the composites. The maximum flexural strength and modulus were noted for composite fabricated with quasi-isotropic symmetric orientation. 2.83% and 1.52% improvement was noted in flexural properties for quasi-isotropic symmetric orientation.

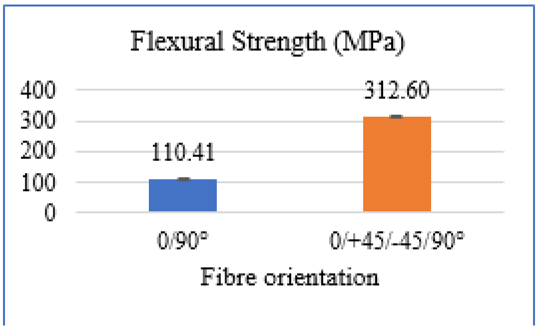

Fig. 8. Flexural strength of composite

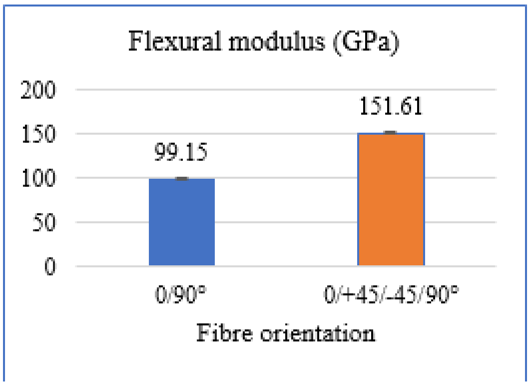

Fig. 9. Flexural modulus of the composite

B. *Interlaminar shear strength property*

Interlaminar shear stress is defined as the stress between two adjacent laminas. It represents the measure of composite resistance to delamination under shear forces parallel to the layers. Due to the stresses developed, relative deformation occurs; with the increase in deformation, the failure occurs between the laminated layers, causing the failure of the composite.

Specimen length = Thickness×6 3

Specimen width = Thickness×2 4

Interlaminar shear strength was calculated from Eqn. 5.

$$\text{ILSS } \sigma_{sbs} = 0.75 \times \frac{P_m}{b \times h} \text{ (MPa)} \qquad 5$$

where P_m – maximum load at the failure (N)

b- measured specimen width (mm)

h- the measured thickness (mm)

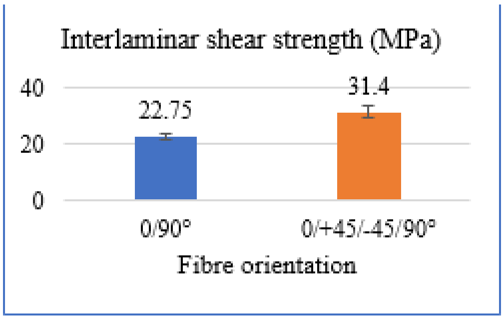

Fig. 10. Interlaminar shear strength of composite

The interaction of individual intra-laminar failure modes, particularly fibre fracture, depends heavily on loading direction concerning fibre orientation. The quasi-isotropic orientation composite showed a maximum improvement of 1.38% in inter laminar shear strength, as shown in Fig. 10.

C. *Fracture toughness of composites*

Impact strength of the composites were calculated by the eqn. 6. Charpy test was performed using an impact tester.

Impact strength = absorbed energy/ cross-sectional area (kJ/m^2) 6

In a laminate, the impact damage mechanism is a complicated process. It is caused by matrix cracking, surface buckling, delamination, fibre shear-out, fibre fracture, and several other factors. 1.13% improvement in fracture toughness for quasi-isotropic symmetric orientation, as shown in Fig. 11.

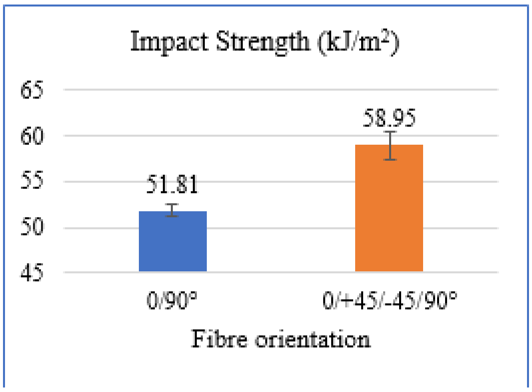

Fig. 11. Impact strength of composite

D. *Hardness of composites*

Hardness measures the plastic deformation that a material experiences when subjected to external stresses. As a result of the increased resistance to plastic deformation, fibre reinforcement increases the material's hardness. According to the findings of this study, the hardness values reached their maximum for the quasi-isotropic symmetric orientation. The 1.58% enhancement in hardness was observed, as represented in Fig. 12.

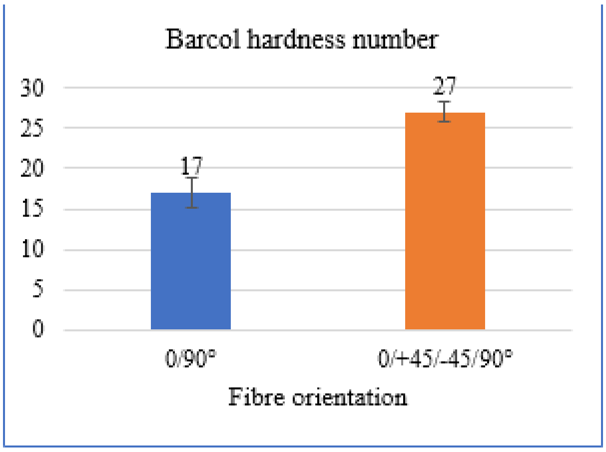

Fig. 12. Hardness number of composite

V. CONCLUSIONS

This study aimed to examine the flexural, interlaminar shear strength, impact behavior, and hardness of uni-directional CFRP composites at 0/90° and 0/45/-45/90° orientations. Based on the experiment results, the following conclusions are drawn:

1. Fibre orientation has a significant impact on the mechanical properties of CFRP composites.
2. 0/45/-45/90° orientation gave maximum results in enhancing the mechanical properties compared to 0/90° fibre orientation.
3. The improvement in flexural strength and modulus are 2.83% and 1.52%.
4. A maximum of 1.38% enhancement for interlaminar shear stress was obtained.
5. An enhancement of 1.13% for impact strength and 1.58% improvement in hardness is obtained for the quasi-isotropic symmetric orientation.

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