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The Role of Stacking order on Interlaminar Shear Strength of Woven Glass/Carbon Fiber Reinforced Epoxy Matrix Hybrid Composite developed by Resin Infusion Technique

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***Abstract*—Fiber reinforced polymer hybrid composites have been widely used in aerospace, automobile, Marine and military applications due to their outstanding mechanical properties such as high specific strength and high stiffness. The study is made to investigate the effect of fiber stacking sequence on the mechanical properties of the hybrid laminates by reinforcing glass and carbon fibers into the epoxy matrix. The hybrid laminates were prepared by the resin infusion technique with a total of 8plies, by varying the position of glass and carbon layers so as to obtain two different stacking sequences by keeping 00/900 orientation throughout the thickness of the laminate. In the present study bi-directional glass (631GSM) and carbon (200GSM) fibers were used to fabricate the laminates. The prepared laminates were cut as per ASTM D2344 to characterize the Interlaminar shear strength (ILSS) at the loading rate of 1mm/min. The test results compared and found the stacking sequence where the carbon fibers at the extreme end show slightly superior to the laminate with glass fiber at the ends.**

I. INTRODUCTION

Hybrid composite materials can be defined as a combination of two or more fiber materials reinforced to a matrix material resulting in synergy effect in their properties than those of individual material alone. The two major constituents of any composite materials are the matrix and reinforcing material [1, 2]. These hybrid materials will have low density, high stiffness, strength, and high strength to weight ratio. These properties are very much essential in the field of aerospace and marine applications. Especially, when these composites are used in the applications where flexural strength is paramount. The hybrid composites made by reinforcing into the epoxy matrix will have excellent flexural strength when compared to that of individual fibers [3-8]. The strength of the hybrid composites comes from the reinforcements. In many cases, the fibers reinforced with the matrix materials are very strong, hard and stiff than the base matrix [9]. Among all the resins come under the class of thermosets, Epoxy resin finds the maximum applications owing to high stiffness and strength, chemical resistance, good dielectric behavior, corrosion resistance, low shrinkage during curing, good mechanical and thermal properties [10]. The mechanical properties of epoxy based carbon/glass hybrid composite basically depend on the orientation and stacking sequence of each ply. It was observed that 00/900 angle orientation of each ply in the hybrid composites yields better tensile strength, tensile modulus and it carries a maximum load [11, 12]. Glass fibers have very less young's modulus, Poisson ratio, and less shear modulus compared to that of carbon fiber which has very good mechanical properties. The combination of both the fibers will give us synergistic effect on the mechanical properties [13]. When the study made to find the flexural and Interlaminar strength among hybrid composites, the composite made of glass/carbon/epoxy has shown very good behavior [14]. There are few typical studies have happened to study the flexural strength and arrives at the conclusion that the flexural strength of the hybrid composite is not only influenced by tensile stress, but also by shear stress. Hence the study of interlaminar shear strength of the interface layers plays an important role [15].

From the literature review, It is found that there are many works found in the mechanical characterization of hybrid composites, not much work happened on the interlaminar shear strength of the hybrid laminates made by reinforcing E-glass and carbon to the epoxy matrix developed by resin infusion technique. Hence, the primary objective of this study is the fabricate the hybrid composites by resin infusion technique and investigate the effect of stacking sequence on the interlaminar shear strength of the interface layers of the laminate.

II. MATERIALS AND EXPERIMENTAL STUDIES

A. Materials Selection

The materials selected to fabricate the hybrid composites were bidirectional glass and carbon fibers as reinforcements.

The epoxy resin and Hardener are mixed in the ratio of 100:38 and used as a matrix. There are 7 layers of fibers used in each laminate. The following are the details of the constituents of hybrid materials.

TABLE I. THE CONSTITUENT MATERIALS OF HYBRID COMPOSITES

Materials	Type	Suppliers
Reinforcement	Bi-directional Glass woven fabric (631 g/m2)	SAERTEX India Private Limited, Pune, India.
	Bi-directional Carbon woven fabric (200 g/m2)	
Matrix	Epoxy resin (Araldite LY 5052-1)	Huntsman Advanced Materials, Americas Inc., Brewster, New York, USA.
	Hardener (Aradur 5052-1)	

B. *Fabrication Method*

Resin infusion technique is the most advanced technique employed to fabricate the composites. Which employs the negative pressure to suck the resin into the prepared vacuum mold cavity. The laminates are fabricated by keeping 4 layers of glass and 3 layers of carbon and varying the stacking sequence of each layer. The thickness of the laminate is 3mm and orientation is maintained as 00/900 angle in both stacking sequences. In all the three laminates, the number of layers of kept constant for the comparison purpose.

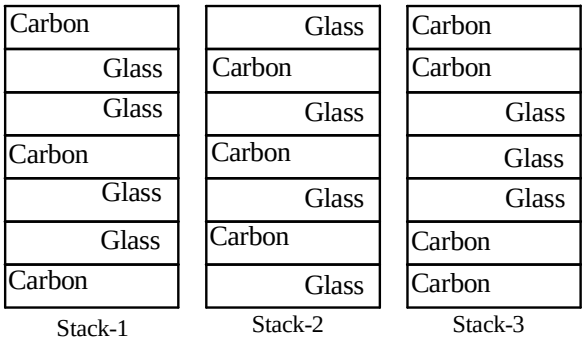

Fig. 1. Stacking sequence in the laminate

C. *Experimental Method*

The specimen for ILSS test is prepared as per ASTM D-2344. The test conducted on Universal Testing Machine 250 kN capacity made by BISS. The test was conducted at room temperature.

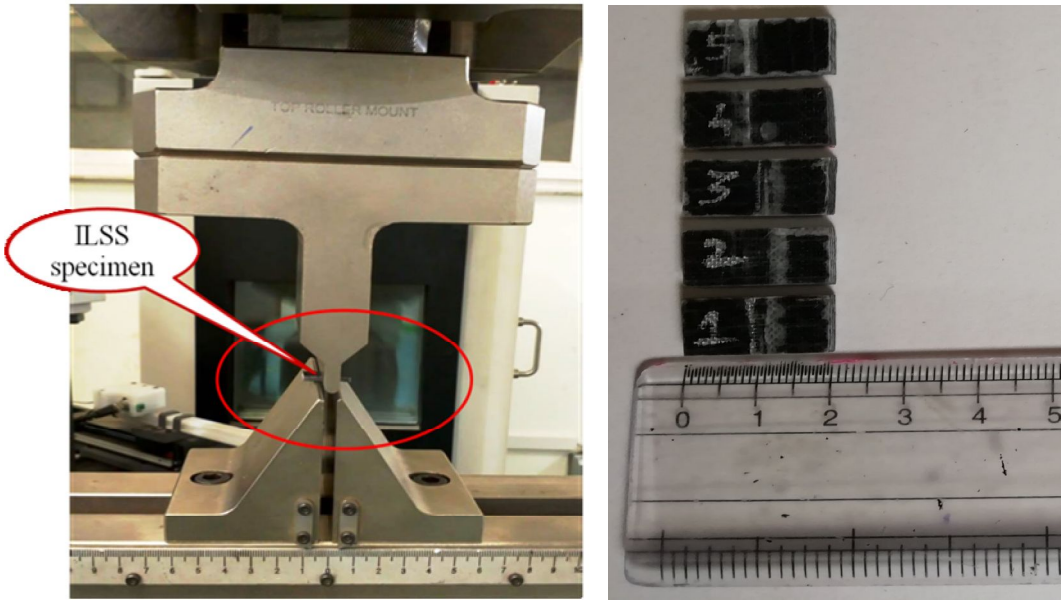

Fig. 2. ILSS specimen loaded on UTM and tested specimens

To find the interlaminar shear strength (ILSS) the short beam shear teat was used. It is very similar to 3-point bending test which is conducted on UTM and most used method to find out interlaminar shear strength in the interface of the layers of fiber reinforced polymer composites. The test was conducted on UTM at the loading rate of 1mm/min. The specimen is placed on the two roller supports at the ends and a cylindrical head is used to apply the load on the specimen at its center and the transverse load is increased until the interlaminar shear fails, by cracking along the longitudinal plane of the specimen between each ply. The measurement of the motion of the cylindrical head is recorded, which is called as deflection. Then, the interlaminar shear strength is found manually by using the formula:

$$ILSS = \frac{0.75P}{bd}$$

Where, P= breaking load, kN

b= width of the specimen, mm

the d= thickness of the specimen, mm

III. RESULTS AND DISCUSSIONS

Inter-laminar shear strength (ILSS) is a very much useful property for composites where the failure of lamina initiate when subjected to shearing stresses. The ILSS through short bear shear for the beam of a rectangular cross section is loaded in 3-point bending, maximum deflection occurs at the mid-thickness of the beam between the center and end

supports. Five specimens are tested from each stacking sequences and found the following results. Typical load-displacement curves are shown to represent the behavior of the material. The response of each specimen from both stacking sequences shows a nearly linear elastic up to peak load and continued inelastic region.

TABLE II. RESULTS OF INTERLAMINAR SHEAR STRENGTH

Scheme	Thickness (mm)	Width (mm)	Maximum Displacement (mm)	Peak Load (kN)	Peak Stress (MPa)
Stack-1	3±0.2	10±0.2	0.4854	1.857	49.490
Stack-2			0.6452	1.786	43.688
Stack-3			0.759	1.278	35.942

The ILSS values are higher in case of glass-carbon reinforced hybrid composites in comparison to that of glass fabric laminate and carbon fabric laminate. Better interfacial bonding is achieved when carbon fabrics are used with glass fabrics. From the results. It is very clear that Interlaminar strength is higher in hybrid stack-1, where the carbon fibers are at the extreme ends.

IV. CONCLUSIONS

The hybrid composites were successfully fabricated using resin infusion technique and its interlaminar shear strength (ILLS) property was studied. The results revealed that the hrbrid composites made by using stack-1 sequence showed higher ILSS when compared to the hybrid composites made by using stack-2 and stack-3 sequences. This shows that the carbon fibers present on the outer layer of the composites withstand higher loads before failure.

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