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Effect of Fiber Orientation on Effective Stacking Sequence of Glass/Carbon Hybrid Composite Laminates for Structural Applications

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***Abstract*- Recent times woven fabric Glass/Carbon hybrid composite laminates find extensive applications in automobile, aircraft and machine tool structures. Many researchers have contributed towards achieving the best layering arrangement of the hybrid laminates with improved static and dynamic stability. In the earlier investigation, based on the static and dynamic mechanical test results, the effective layering arrangement for the four layered Glass/Carbon hybrid laminate was established by one of the author. In the present study, the role of fiber orientation over the established effective layering arrangement of epoxy based woven fabric Glass/Carbon hybrid composite laminate was investigated. To study the effect of fiber orientation over the effective layering arrangement, two important fiber orientations such as 45^0 and 90^0 were considered. All the hybrid laminates were fabricated by hand layup method. For understanding and analyzing the effect of fiber orientation, the hybrid composite samples were tested for the mechanical properties such as tensile and flexural strength for more trials and the results were reported and discussed.**

I. INTRODUCTION

Glass and Carbon fiber reinforced polymer composite materials are widely used in structural applications such as aircraft, automobile and marine engineering due to their high strength to weight ratio. Recent times ease of manufacturing the complicated shape and controlling of fiber architecture makes the woven fabrics are more suitable for the above structural applications [1]. In woven fabrics, fibers are interleaved, in two mutual perpendicular directions which improve the dimensional stability of the laminates. Required thickness of the composite structure can be achieved by adding more number of fabric layers in fabrication.

Numerous works have been carried out in the past on the static mechanical properties of composite materials made of Glass and Carbon fibers and these works have mainly focused on unidirectional and angle ply laminate. But the number of studies dealing with mechanical properties of woven fabric hybrid composite laminates is very minimal. Bunsell and Harris studied the tensile behaviour of bonded and unbonded Glass/Carbon hybrid composite laminates [2]. Kretsis reviewed the effect of stacking sequence on tensile, compressive, flexural and shear properties of Glass/Carbon hybrid laminates with unidirectional plies [3]. Saka et al studied the tensile behaviour of epoxy based unidirectional Glass/Carbon hybrid composites [4]. Kedar S Pandya et al studied the hybrid effect on tensile and compressive strength of hybrid composites of 8H satin weave T300 Carbon fabric and plain weave E-glass fabric with epoxy resin [5]. Murugan et al revealed from the earlier study that keeping the high modulus Carbon fiber in outer layer and low modulus Glass fiber as inner layer, improved the dynamic stability of Glass/Carbon hybrid laminates [6]. They established the effective layering arrangement of the epoxy based Glass/Carbon hybrid composite material based on their research. This research is mainly focused on the effect of fiber orientation in the preferred effective layering sequence of Glass/Carbon hybrid composite laminates in terms of mechanical properties like tensile and flexural strengths.

II. FABRICATION OF GLASS/CARBON HYBRID COMPOSITE LAMINATES

Glass and Carbon fabrics of 400 g/m^2 in plain woven fabric form are preferred as reinforcement. Epoxy of grade LY556 with hardener HY951 is used as matrix material. All Glass/Carbon hybrid composite laminates are fabricated by hand layup technique with uniform fiber volume fraction of v_f = 0.5. The effective layering arrangement of four layered Glass/Carbon hybrid laminate, CGGC, is selected from the earlier investigation [6]. In order to study the effect of fiber orientation, two different fiber orientations such as (0^o/90^o) and (45^o/45^o) are considered for the present study.For better understanding, three types of four layered Glass/Carbon hybrid laminates are fabricated. First laminate (H1) is prepared without any change in the fiber orientation in all layers of the laminate. Second laminate (H2) is made by keeping the orientation of the inner Glass fabrics as 45^{o} orientation and without altering the outer Carbon fabric direction. In the third laminate (H3), the fiber orientation of outer Carbon fiber is kept as 45^{o} and the direction inner Glass fabrics layers not altered. Table I shows the layering arrangement, size, and density of the Glass/Carbon hybrid laminates fabricated by hand layup technique. Figure 1 shows the photograph of the three Glass/Carbon hybrid samples made using hand layup technique.

TABLE I
LAYERING ARRANGEMENT, DIMENSIONS AND AVERAGE DENSITY OF THE GLASS\CARBON HYBRID LAMINATES

Specimen	Layering Arrangement	Dimensions (mm)	Density (kg/m^3)
H1	C 0-90 G 0-90 G 0-90 C 0-90	250*250*2.4	1485
H2	C 0-90 G 45-45 G 45-45 C 0-90	250*250*2.4	1468
H3	C 45-45 G 0-90 G 0-90 C 45-45	250*250*2.2	1485

Figure 1. Photograph Showing the Types of Glass\Carbon Hybrid Laminates Fabricated using Hand Layup Technique

III. MECHANICAL TESTING OF GLASS/CARBON HYBRID COMPOSITE LAMINATE

A Tensile Test

ASTM D3039 is the standard test procedure for evaluating the tensile strength of straight-sided rectangular FRP composite coupons [7]. Tensile test specimens were cut from the cured composite laminates according to ASTM D3039 standard. The size of the specimen is 250 mm× 25 mm × t mm. Figure 2 shows the standard size of composite specimen used for tensile test. The tests were conducted on a closed loop servo hydraulic universal testing machine SHIMAD2U-AUTOGRAPH® with the cross head speed of 5 mm/min at room temperature. Figure 3 shows the tensile testing of Glass/Carbon hybrid laminates carried out in AUTOGRAPH® testing equipment. Thin flat strips of composite laminates having a constant rectangular cross section are mounted in the grips of a mechanical testing machine and monotonically loaded in tension and the applied load was recorded. The ultimate strength of the material was determined from the maximum load carried before failure. The stress-strain response of the material was determined by measuring the coupon strain using strain transducers. From the tensile stress–strain graph, the tensile modulus of elasticity was derived.

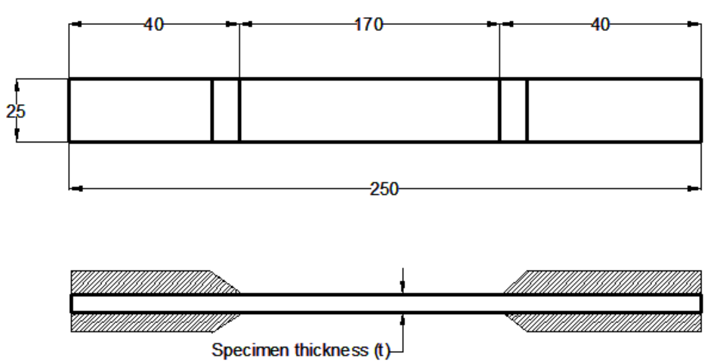

Figure 2. Schematic diagram showing the standard size of tensile test specimen in mm as per ASTM D3039 standard

Figure 3. Image showing the tensile test conducted for Glass/Carbon hybrid composite laminates on SHIMAD2U-AUTOGRAPH® machine

B Flexural Test

Flexural properties of FRP materials were evaluated as per ASTM D790 standard test method [8]. This method includes provisions for measuring maximum flexural strength, and flexural modulus. The test method consists of simply supporting a straight-sided, rectangular cross-section specimen on two supports symmetrically placed about the transverse centerline and loading in flexure with a third point placed on the transverse centerline. The load application and the two supports make up the three point test condition. Flexural strength is often defined as the maximum stress in the outermost fiber. This stress is calculated on the convex side. This test produces tensile stresses on the convex side and compression on the other side. In order to measure the flexural stresses accurately, the shear stress is minimized as much as possible by controlling the ratio of span to depth as 16:1.

The composite specimens are cut to proper dimensions as per the ASTM D790 standard. Then the specimen is placed on two knife edges with over-hanging on both the sides. The load is applied at the midpoint of the specimen. The dimensions of the specimen for flexural test are 126 mm × 12.5 mm × t mm. Figure 4 shows the standard size of composite specimen used for the flexural test. The flexural test was conducted on a standard INSTRON 3382® machine with feed rate of 1.2 mm/min. Figure 5 shows the flexural test conducted on Glass, Carbon and their hybrid laminates in universal testing equipment INSTRON®.

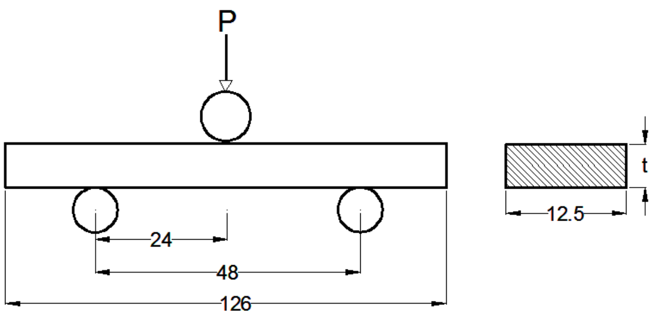

Figure 4. Schematic diagram showing the standard size for flexural test specimen in mm as per ASTM D790 standard

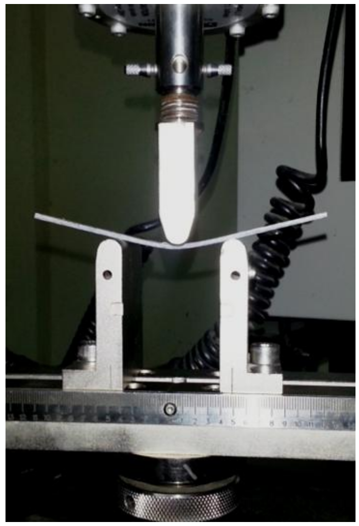

Figure 5. Images showing flexural test conducted for Glass/Carbon hybrid composite specimens on INSTRON® machine

IV. RESULTS AND DISCUSSION

The experimentally evaluated mechanical properties of preferred Glass/Carbon Hybrid laminates are reported in Table II. All the reported values are average of the five trials tested. Figure 6(a) shows the comparison of stress-strain graphs of hybrid composite laminates obtained by tensile test. Table II showed that there is a considerable mechanical strength variation between the hybrid laminates considered due to the change in fiber orientation. During tensile loading, all the four layers of hybrid laminate were equally loaded and corresponding axial strain variation in the layers of Glass and Carbon might caused the marginal difference in tensile strength [5]. From the comparison of stress-strain graphs shown in Figure 6(a), it is revealed that H2 laminate has higher tensile strength, followed by H1 laminate and then H3 laminate with least tensile strength among the three laminates. Also, it is noted that there is high variation in tensile strength between H2 beam and H3 beam where H3 beam has its outer Carbon fabric placed at 45^o and the inner Glass fabric is placed at $0^o/90^o$. From earlier research it is revealed that the fiber glass has more ability to maintain its properties at different flex patterns, i.e. taking more strain though oriented in different patterns, than Carbon fiber [9]. This intrinsic property of Glass fiber is beneficial for H2 hybrid beam, where the inner Glass fabric is placed at the fiber orientation of 45^o, to resist the crack development to minimal during tensile loading condition.

TABLE II
TENSILE AND FLEXURAL PROPERTIES OF GLASS/CARBON HYBRID COMPOSITES LAMINATES CONSIDERED

Specimen	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)
H1	228	7.3	10.5	5.15
H2	244	8.68	15	7.75
H3	216	5.53	9.5	3.23

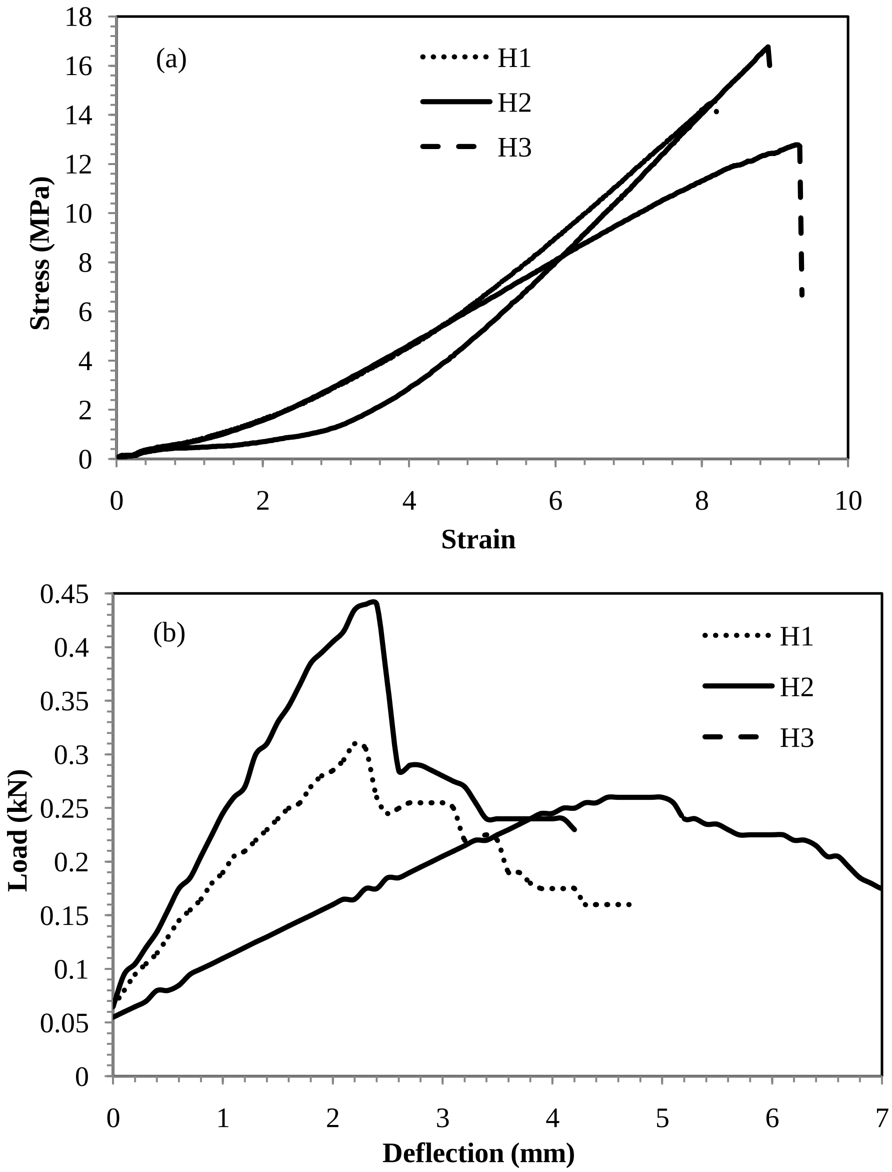

Figure 6. Comparision of (a) Tensile Stress-Strain Graphs (b) Transverse Load-Deflection Graphs of Various Glass \ Carbon Hybrid Laminates Considered

Figure 6(b) shows the load-deflection curves of hybrid composite laminates obtained by flexural test. The initial straight line portion of the load-deflection curve was considered for evaluating the flexural modulus (E_B) as per ASTM D790 standard using the following Equation (4.1).

$$E_B = \frac{m\,L^3}{4\,b\,t^3} \qquad (4.1)$$

where

E_B = flexural modulus (MPa),

L = support span (mm),

b = width of beam tested (mm),

t = thickness of beam tested (mm), and

m = slope of the tangent to the initial straight-line portion of the load- deflection curve (N/mm).

Table 2 shows the experimental results obtained by conducting flexural test on hybrid composite samples made of three different areal densities. There is a considerable flexural strength variation between hybrid laminates H1 and H2 in all three fiber areal densities. H2 layer arrangement has flexural modulus value 46±4% higher than that of H1 arrangement in all three fiber areal densities considered as shown in Table II.

Flexural strength of composite laminate is primarily controlled by the strength of outer layer which is in direct contact with bending load [3]. The variation in the flexural modulus of hybrid laminates confirms that the fiber orientation controls the flexural property of hybrid laminates. Among the three hybrid layering arrangement, the arrangement H2 offered a noticeable increase in flexural modulus as compared to the other arrangements H1 and H2 [10]. When the outer Carbon fabric is placed at 45^0, it makes easier for crack development since the Carbon has least ability to maintain its strength at different flex patterns when compared to standard pattern ($0^0/90^0$). This characteristic behaviour permits high crack propagation in H3 laminate and makes it weaker (59% less in tensile modulus and 140% less flexural modulus of H2) than other two hybrid laminates.

V. CONCLUSION

The influence of fiber orientation on the effective layering arrangement, CGGC, of Glass/Carbon hybrid composite laminates in terms of mechanical properties was experimentally investigated. The mechanical properties of hybrid laminate, H2, controlled with $45^o/45^o$ fiber orientation at the inner Glass fabric layers and $0^o/90^o$ orientation in outer Carbon fabric layers, exhibited increased tensile and flexural modulus than the other hybrid layering arrangements. In hybrid arrangement H2 offered a noticeable increase in flexural modulus of nearly about 51% increase in value, as compared to the other arrangement H1. The intrinsic property of maintaining identical properties at different flex patterns of fiber glass caused this improved mechanical properties of H2 hybrid laminate. The increased tensile and flexural modulus values of H2 laminate, with high modulus Carbon fabric at 0^0-90^0 in the outer layer and Glass fabric with 45^0 orientation as the inner layer, confirmed its improved structural integrity.

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