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COMPRESSIVE BEHAVIOUR OF BASALT FRP AND BASALT-CARBON HYBRID FRP LAMINATES

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ABSTRACT

In this study the compressive strength of new basalt FRP and basalt-carbon hybrid FRP composite laminates were investigated experimentally. The main aim of this paper is to determine the influence of fiber orientation on compressive strength and to estimate the compressive strength of basalt FRP and basalt-carbon hybrid FRP composite laminates. The test specimens with varying orientations were prepared using hand lay-up technique. Compression test was performed according to ASTM test standard D6641 procedure A (untabbed specimens). The different composite laminates included in this study were pure basalt, pure carbon and six hybrid composite laminates. From the experimental analysis the fibre orientation was found to influence the compressive strength of basalt-carbon hybrid composite laminates. All the hybrid composite laminates showed a positive hybridization effect. The basalt–carbon/epoxy hybrid composite C_2 with angle ply layup of $[0_2C/+45B/0B]_S$ was found to be the optimum lay-up with highest compressive strength among all the other laminates.

Keywords: compressive strength, basalt-carbon hybrid FRP, hand lay-up, laminates.

INTRODUCTION

Fibre reinforced polymers offer significant advantages compared to conventional metal materials. Due to their superior mechanical and chemical properties FRP are widely used in various engineering sectors. FRP provide a specific set of strength and performance properties, including high strength, light weight and reduced life cycle costs. Basalt fiber is a relative newcomer to fiber reinforced polymers and structural composites. Basalt is a dark coloured, hard and dense volcanic rock. It is the most abundant rock type in the earth's crust [1]. Although just a few studies are available in the literature, but manufacturers claim basalt fiber as an alternate of glass and carbon fiber because of its extraordinary properties [2]. Wang *et al.* [3] investigated that the interface formed between basalt fiber/epoxy resin was better than glass fiber/epoxy resin. Cziga´ny [4] studied basalt fiber as the reinforcement in concrete matrix and asserted that the cheap basalt fibers can be efficiently applied in hybrid composite systems. Lopresto *et al.* [5] compared the mechanical properties of E-glass and basalt fiber reinforced plastic laminates. The experimental results showed a high performance of basalt fiber in terms of Young's modulus, compressive and bending strength, impact force and energy. Zhang *et al.* [6] investigated the compressive behaviours of 2D plain woven basalt/vinyl ester resin composites along the thickness direction under high strain rates. The authors concluded that the compressive behaviors of plain woven composite could be improved with better design of the woven fabric structures and superior matrix properties. In recent years there has been a great interest in hybrid materials. Hybrid materials are the mixtures of two or more materials created by newly formed chemical bonds. The combination of basalt fiber with carbon fiber is the most recent and advanced area of hybrid technologies [3]. Chikhradze *et al.* [8] proposed the use of hybrid epoxy composites reinforced by carbon, basalt and E-glass fibers for the manufacturing of wind turbines. Basalt-carbon/epoxy hybrid composite with alternate stacking sequence have been developed by Zhang *et al.* [9] to improve the toughness properties of conventional carbon reinforced composites. The experimental results confirmed that hybrid composites containing basalt fibers display 46% higher open hole compressive strength than that of plain carbon fiber composites. There are very limited data available in the literature on mechanical properties of basalt fiber. Surprisingly, no attention has been devoted to the compressive behaviour of basalt fiber and basalt-carbon hybrid composite materials. In particular, the effects of angle ply orientation on the compressive strength of basalt-carbon hybrid composites have not been investigated.

MATERIALS

Basalt fiber (300 g/m^2 unidirectional 0°, 450 g/m^2 woven ±45°) and carbon fiber (300 g/m^2 unidirectional 0°) was supplied by Suretex Composite International China (Figure-1).

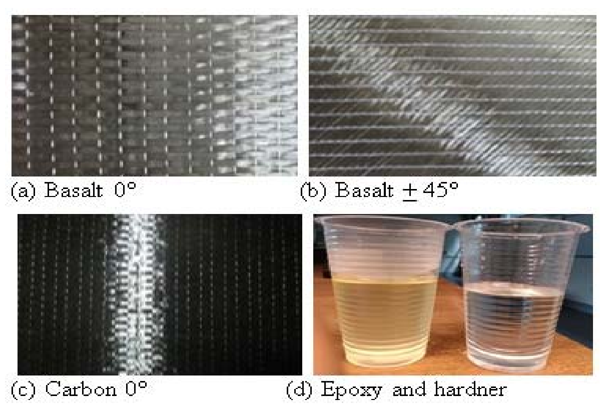

Figure-1. Basalt and carbon fibers.

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The epoxy used in this work was epocast (Bisphenol) and the curing agent was amine based epoharden (cycloaliphatic amine). Both epocast and epoharden was supplied by Portal Trading Malaysia. The resin/hardener mix ratio was 2:1 by weight. Table-1 shows the properties of the present fabrics and resin.

Table-1. Physical and mechanical properties of fibers and matrix.

Properties	Basalt fiber	Carbon fiber	Epoxy
Fabric weight (g/m^2)	300	300	-
Fabric thickness (mm)	0.2 ± 0.02	0.2 ± 0.02	-
Mono filament diameter (µm)	13	7	-
Epocast viscosity (cps, 30°C)	-	-	750 ± 150
Hardener viscosity (cps, 30°C)	-	-	1500 ± 200
Hardness	-	-	Shore D 80 ± 1

FABRICATION OF TEST SPECIMEN

The basalt-carbon hybrid composite laminates were fabricated by the hand lay-up method. The hand lay-up is an open moulding technique suitable for making a wide variety of composites structures. In this study the basalt-carbon hybrid composites were fabricated following the four steps (Figure-2) which include: (i) positioning of the fabric in open mold (ii) resin preparation and pouring into the plies (iii) removal of entrapped air with rollers (iv) curing of fabricated laminates. A total of 40 specimens, 5 of each orientation were cut in accordance with the standard ASTM test standard D6641 as shown in Figure-3. A total of eight plies of basalt and carbon fabric were stacked for each laminate. For all six hybrid composite laminates, the composition of basalt to carbon ratio was maintained at 4:4 with varying stacking sequence. Table-2 lists the stacking sequence arrangement of coupon specimens. The volume fraction of both carbon and basalt was 36-38 % in every laminate of basalt-carbon hybrid composite.

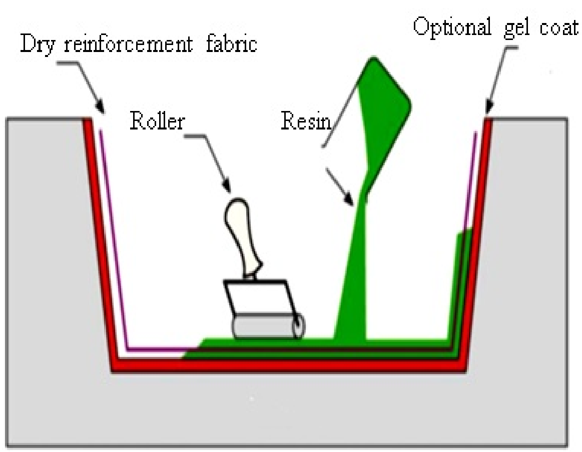

Figure-2. Hand lay-up manufacturing processes for laminate material.

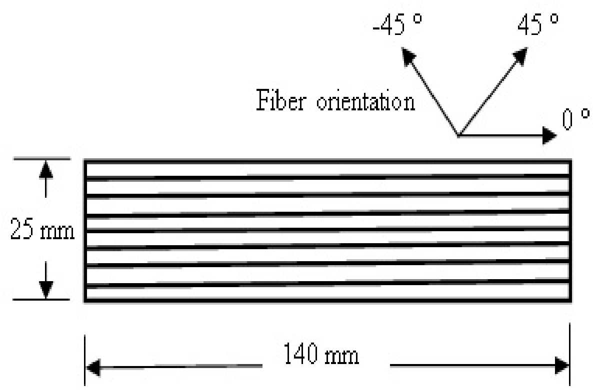

Figure-3. Dimensions of the compression specimen.

Table-2. Stacking sequence arrangement of coupon specimens.

Laminate Code	Stacking Sequence	Fiber Orientation (°)
C1	C_8	$[0_8C]$
B1	B_8	$[0_8B]$
C2	$C_2B_4C_2$	$[0_2C/\underline{+}45B/0B]_S$
C3	$C_2B_4C_2$	$[0_2C/0B/\ \underline{+}45B]_S$
C4	$C_2B_4C_2$	$[0_2C/\underline{+}45_2B]_S$
B2	$B_2C_4B_2$	$[0_B/\underline{+}45B/0_2C]_S$
B3	$B_2C_4B_2$	$[\ \underline{+}45B/0B/0_2C]_S$
B4	$B_2C_4B_2$	$[\ \underline{+}45_2B/0_2C]_S$

TEST SETUP AND PROCEDURE

The uniaxial static compression tests were performed at room temperature under standard laboratory conditions (23±5 °C and 50±10% relative humidity)

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according to ASTM D6641 procedure A (untabbed specimens) as shown in Figure-4. The Zwick Roell 50 kN Universal Testing Machine was used for all the compression tests. The machine was equipped with an extensometer. A crosshead speed of 1 mm/min was utilized for all samples.

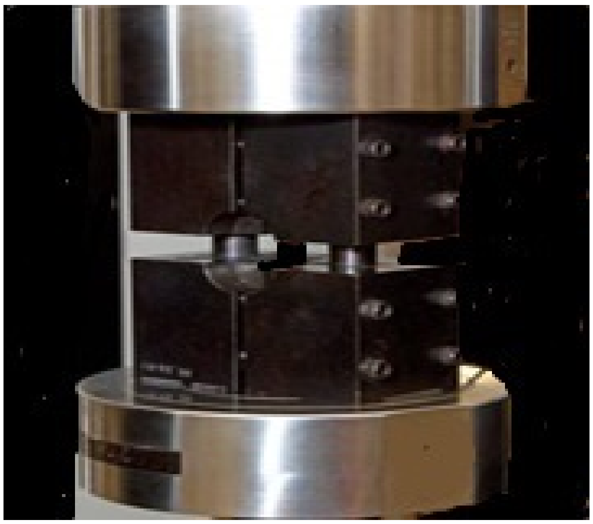

Figure-4. CLC fixture for compression test.

RESULTS AND DISCUSSION

In this study, the ultimate compressive strength, ultimate compressive strain, Young's modulus and stress-strain curve values were measured in longitudinal direction. The reported data in Table-3 consists of the mean values of five tests for each stacking sequence. The derived stress-strain curves are presented in Figure-5. The value of stress was calculated based on the load recorded from the machine and the average cross section of the laminates (average of three measurements).

Table-3. Compressive strength and modulus data summary.

Laminate Code	Compression 0°		
	E_x (GPa)	UCS_x (MPa)	$UC\varepsilon_x$ (με)
C1	28	425	700
B1	19	361	2200
C2	29	485	1600
C3	27	451	1200
C4	27	445	1100
B2	24	473	1800
B3	23	435	1700
B4	23	429	1400

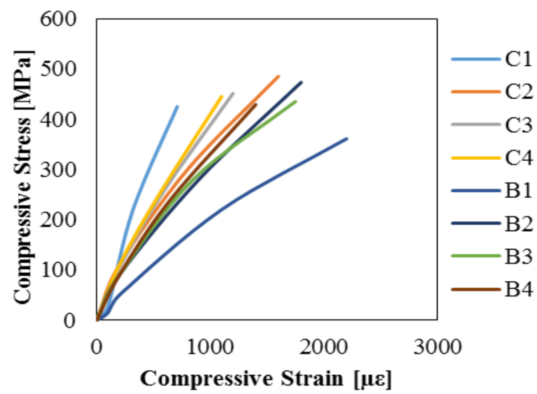

Figure-5. Typical stress-strain diagram curves for compression test.

In the compression test, the compression strength values observed for C1 and B1 are very close to the literature [10, 11]. Meanwhile the hybrid coupons results in the best strength. This can be explained by the fact that hybridization of basalt fiber with carbon fiber has improved the compressive properties. The experimental results indicated that the interaction between the biaxial layers of basalt fiber and unidirectional layers of carbon fiber improved the compressive failure of hybrid specimen, however the failure modes were different between all hybrid composites. From the obtained results, C2 had the highest compressive strength and B1 had the lowest compressive strength with higher rupture strain. The higher compression strength of C2 was due to the effect of biaxial plies of basalt in between the 0° plies, which limit locally the buckling of fiber subjected to compression and highlight the absence of kinking throughout the C2 samples. The compressive strength of C2 was 14.1% higher than C1, and 34.3% higher than B1, while the compressive strength of B2 was 11.2% higher than C1 and 31% higher than B1. The enhanced compressive strength of B2 may be caused by the bridging effect and better fabric dispersion arrangement of 0° carbon fiber layers between the basalt fiber layers. In the case of both unidirectional laminates B1 and C1, kinking was observed in the longitudinal direction [12], while in hybrid composites in plane shear described as a zig-zag shear was seen in the biaxial laminate direction.

FAILURE MODES

The specimen failure was analyzed by using the standard ASTM D6641 failure codes for typical and common modes of failure. During compression test some specimens failed in a manner which were not acceptable according to the standard codes as shown in Figure-6. These specimens were not included in the compression results. In all other specimens the acceptable failure mode and location occurred with reasonable frequency. Figure-7 shows the typical failure of examined specimen after the static compression test.

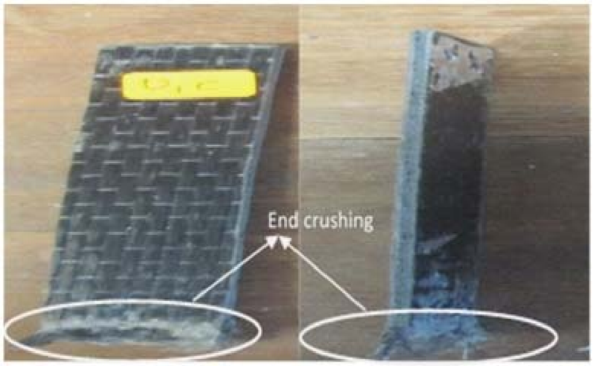

Figure-6. Unaccepted specimens

Figure-7. Typical compressive failure of laminates (a) brooming (b) kinking (c) inplane-shear (d) delamination (e) transverse shear.

The lower compression strength of C1 was due to the local shear instability between the fiber and matrix during the failure, which is in agreement with what was asserted in [13]. Moreover, fiber micro buckling was observed in C1 and B1 as shown in Figure-8 (a) and (b), which may cause premature failure in the specimen. This effect is limited in the case of hybrid composite laminates C2 and B2 due to the presence of biaxial $\pm$ 45^o fiber layers as shown in Figure-8 (c) and (d). In addition, it can be observed that the compressive failure strain of C1 was low. There was crack initiation in C3 and C4 at the carbon fibre layers as shown in Figure-8 (e) and (f), while insufficient bonding was found in B3 and B4 as shown in Figure-8 (g) and (h). Moreover, in B3 and B4, the external biaxial layers were suffering from early failure, which highlights the weakness of B3 and B4, under compressive loads. However, the strength of B3 was better than B4. The reason was because of the higher number of 0° layers in B3 as compared to B4. The same phenomena were observed in C3 and C4.

Figure-8. Compression failure modes of tested specimens.

CONCLUSIONS

The main purpose of this study was to investigate the compressive strength of basalt FRP and new basalt-carbon/epoxy hybrid composite FRP and to determine the effect of angle ply orientation on the compressive strength of basalt-carbon hybrid composite. In this study, we have observed the following.

- The experimental results of this study confirmed the angle ply orientation effect on compressive strength of basalt-carbon hybrid composite.
- Higher compressive strength and modulus were obtained when carbon fiber layers were stacked at the outer side of laminate, with hybrid composite C2 (i.e., $[0_2C/+45B/0B]_S$), showing the best compressive strength and modulus among all the stacking sequence arrangements.

- Lower compressive strength and modulus were observed in pure basalt laminate (i.e., $[0_8B]_S$), among all the stacking sequence arrangements.
- The compressive strength follows the trend: C2 > B2 > C3 > C4> B3> B4> C1> B1. All the stacking sequence showed a positive hybridization effect.

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