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Probing the Mechanical And Mode 1 Interlaminar Fracture Toughness of Laminated Composites Using Carbon And Basalt

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Abstract

Recently, there is a spike in the use of natural, eco-friendly fibres as reinforcement in the creation of inexpensive, lightweight polymer composites in the global market. Basalt fibre is one such material of interest that is currently being utilized widely as it is affordable and has appreciable ductility than carbon fibres. High mechanical properties, high thermal resistance, biodegradability, and non-abrasive features are some of the prominent features of Basalt fibres. In this current investigation, we intended to focus on the tensile and Mode-I Interlaminar fracture attributes of the laminated composites reinforced with basalt and carbon fibres exploiting the tensile and Double Cantilever Beam test respectively. Load-displacement curves were exploited to assess the tensile characteristics of the composites. The Mode I interlaminar fracture toughness amiolerates with the enhancement in the content of basalt fibres which may be attributed to efficient fibre bridging and minimal crack propagation owing to the high ductility of the basalt fibres.

Keywords: CFRP; Basalt fibre; Mode-I Interlaminar fracture toughness

1. Introduction

Owing to its exceptional strength to stiffness ratio, low density, and exemplary resistance to fatigue, CFRP is widely deployed in sophisticated structures in the aerospace, wind energy, marine, and transportation industries. However, because of its high cost and intrinsic brittleness, it is rather difficult to employ them in more widespread industrial applications, namely electric cars and mid to low end automobiles [1, 2]. Any material has its own typical properties and intrinsic weaknesses in comparison to materials of other variant [3, 4]. To this end, hybrid composites with multi-fibres as reinforcement in a single matrix is an effective way to reduce the weaknesses of the parent composite, thereby making it more affordable and gaining the capability to deliver improved performance. Additionally, hybridization provide enough flexibility to tailor features like strength, stiffness, and toughness in the composite. Hayashi initially drew attention to this hybrid effect in 1972, when he discovered that around 40% improvement in the failure strain can be procured through embedding unidirectional glass fibres in carbon fibre composites [5]. A lot of research has been done so far to examine the impact of variant fibres to reinforce composites [6, 7]. In light of the above, mixing carbon fibre with other fibre namely glass fibre, has been thoroughly investigated to get around the shortcomings and completely exploit the potential of various fiber types. With regard to its superior qualities, namely good sound insulation, adequate chemical resistance, appreciable heat resistance, and meagre water absorptivity, basalt fibre has gained more and more attention as an effective reinforcement material. In the current study, the reinforcement materials—woven basalt fibre and carbon fibre—were chosen, and epoxy resin served as the matrix for the hybrid composite laminates. Vacuum assisted resin transfer moulding (VARTM) technique was used to create each specimen. The tensile test and DCB test was explored to appraise the effects of carbon to basalt hybrid ratios on the mechanical and fracture characteristics of hybrid CFRP composites respectively.

1. Materials and methods

2.1 Materials

In this experimental investigation, the plain weave fabrics of carbon and basalt were employed as the reinforcements for the composites. The matrix system comprises of Lapox-L12 (epoxy resin) and triethylenetetramine (hardener) with their volume fraction in the ratio of 3:1.

2.2 Fabrication of Laminated composite

VARTM created all of the composite laminates. The following five steps can be used to illustrate the VARTM process. The plain woven textiles were first trimmed to the appropriate size, and then they were put on the plane mould. Secondly, the transport medium for pouring resin swiftly and the release film for removing laminates were inserted in their appropriate locations. Thirdly, turning on the vacuum pump to create a negative pressure. Fourth, until the preform layer was adequately penetrated, the resin was injected under a steady negative pressure of -0.1MPa. Finally, the composite laminates were finally procured after curing for 27 hours at room temperature.

The aforementioned VARTM procedure produced eleven distinct composite sheets. To investigate the effects of different hybrid ratios on the fracture as well as mechanical attributes of carbon/basalt fibre reinforced composites. Eleven different types of composite laminates, including C, CBF1, CBF2, CBF3, CBF4, CBF5, CBF6, CBF7, CBF8, CBF9, and BF were constructed, as discerned in Table 1. Table 1 provides details of the associated codes and C:BF ratio of each type of laminate.

Table 1. Designation and ratio of the laminated composites.

Name	Laminates code	C:BF ratio
C	$[C]_{20}$	1:0
CBF_1	$[C_9B]_S$	9:1
CBF_2	$[C_8B_2]_S$	8:2
CBF_3	$[C_7B_3]_S$	7:3
CBF_4	$[C_6B_4]_S$	6:4
CBF_5	$[C_5B_5]_S$	5:5
CBF_6	$[C_4B_6]_S$	4:6
CBF_7	$[C_3B_7]_S$	3:7
CBF_8	$[C_2B_8]_S$	2:8
CBF_9	$[C_1B_9]_S$	1:9
BF	$[BF]_{20}$	0:1

2.2 Double Cantilever Beam tests

This test method enumerates the assessment of the opening Mode I interlaminar fracture toughness, G_{IC} of the continuous fibre-reinforced composite materials. The beam theory expression for the strain energy release rate of a perfectly built-in (that is, clamped at the delamination front) double cantilever beam is as follows:

$$G_{IC} = \frac{3P\delta}{2ba} \tag{1}$$

where
P = load,
δ = load point displacement,
b = specimen width, and
a = delamination length

Vulnerability to delamination is the prime loophole of laminated composite structures. The information regarding composite material's resistance to interlaminar fracture is useful for design of laminated composites, and its selection for any specific application. Furthermore, the evaluation of the Mode I interlaminar fracture toughness, independent of specimen geometry or method of load introduction is beneficial for establishing the design allowable that is used in damage tolerance analyses of composite structures. In the current research, the DCB specimens for the laminated composites were built in compliance with the ASTM D-5045 standard as revealed in Fig. 1(a).

2.2 Tensile tests

The tensile tests of the laminated composites were carried out in compliance with the ASTM D3039 standard in an INSTRON 5969 universal testing machine (see in Fig. 1(b)). The cross head speed during the tensile tests was set to 1mm/min.

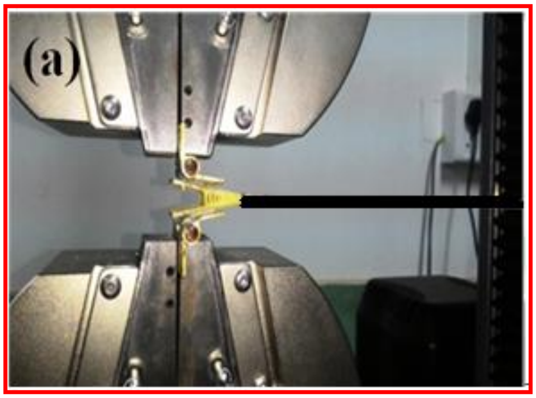

Fig. 1. (a) DCB specimen and test arrangement

Fig. 1. (b) INSTRON universal testing machine

2. Results and discussion

3.1 Tensile behavior

The load-displacement traits of the laminated composites are revealed with the load-displacement plot shown in Fig. 2. It is revealed from the plot that the C composite laminate succumb to catastrophic failure at 40 KN with minimum displacement. This is owing to high amount of carbon fibres which triggers the formation of a single crack through the entire thickness leading to an unanticipated brittle fracture. Whereas the BF curve shows the minimum load bearing capacity i.e., fails around 25 KN because of the lower strength of the fibres than carbon fibres. However, the BF curve reveals better elongation behavior than the C curve due to the better elongation trait of the basalt fibres than carbon fibres. The curve of CBF1 with exorbitant amount of carbon fibres reveals the load failure at 35 KN with improvement in the displacement. This is due to the induced ductility because of the addition of basalt fibres. The curves of CBF2, CBF3, and CBF4 exhibit premature load failure as compared to C and CBF1. However, they reveal significant elongation behavior with CBF4 showing the maximum elongation behavior followed by CBF3, and CBF2. The maximum elongation behavior of CBF4 is attributed to high ratio of basalt to carbon fibres in the inner layers which allows the hybrid composite to reach the ultimate strain of the basalt fibres until failure. It is revealed in the Fig. that the laminates whereby the ratio of basalt to carbon fibres gets higher i.e., in the cases of CBF5, CBF6, CBF7, CBF8, and CBF9, the load bearing capacity of the laminates goes on diminishing since the tensile strength of the basalt fibres are less than the tensile strength of carbon fibres.

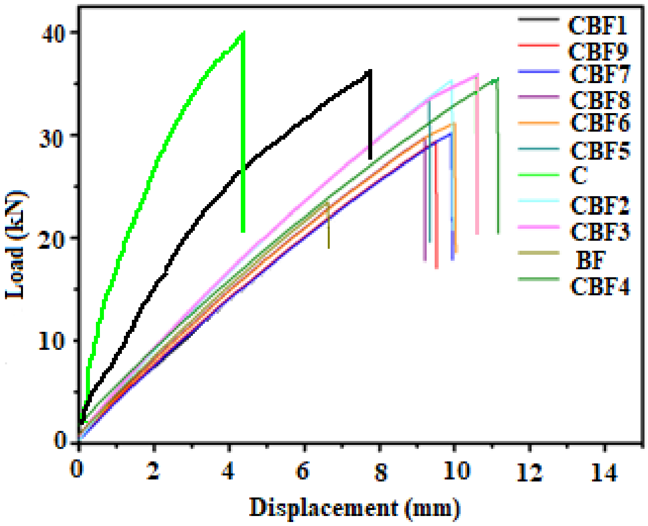

Fig. 2. Load-displacement curves.

3.1 Mode I interlaminar fracture toughness

Double Cantilever Beam (DCB) tests were conducted on the laminated composites using Universal testing machine (Make: Instron, Model: 5969). It is noted that G_{IC} value goes on increasing with the increase in the ratio of basalt to carbon fibres which may be attributed to efficient fibre bridging and minimal crack propagation due to ductility behaviour of the basalt fibres.

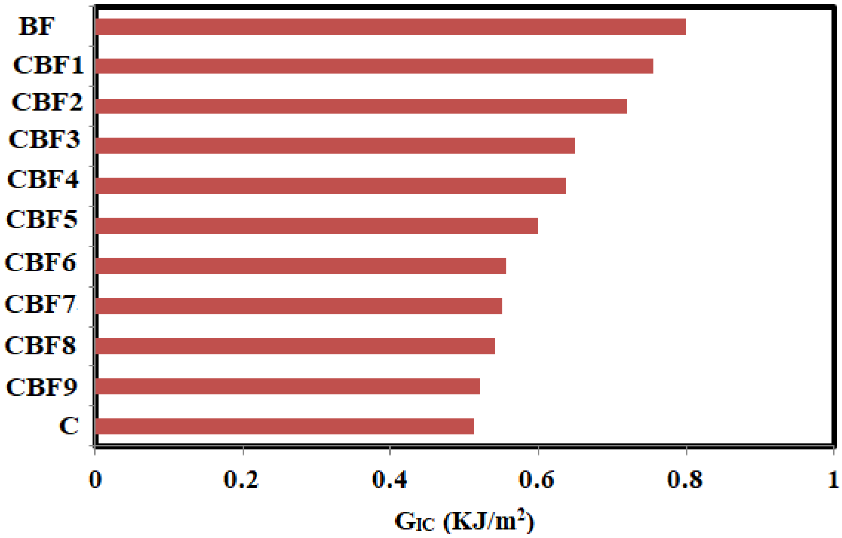

Fig. 3. Bar plot revealing G_{IC}.of laminated composites

3. Conclusion

The novelty of this research is to employ the tensile test and DCB test to examine the effects of carbon to basalt hybrid ratios on the mechanical and fracture characteristics (i.e., Mode I Interlaminar fracture toughness) of carbon/basalt/epoxy composites respectively. When compared to curves C and CBF1; CBF2, CBF3, and CBF4 show signs of premature load failure. Nevertheless, they demonstrate a considerable elongation behavior, with CBF4 exhibiting the greatest elongation behavior, followed by CBF3, and CBF2. The high basalt to carbon fibre content in the inner layers, which enables the hybrid composite to achieve the maximum tensile strain of the basalt fibres before failing, is attributable to the maximum elongation behavior of CBF4. Utilizing a universal testing machine, double cantilever beam (DCB) tests were performed on the laminated composites (Make: Instron, Model: 5969). It has been observed that GIC value increases as the proportion of basalt to carbon fibres increases. This may be explained by effective basalt fibre bridging and low crack propagation caused by basalt fibres' ductility.

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