Mode II interlaminar fracture toughness of flax-basalt hybrid reinforced Vinyl ester composites

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Keywords: Flax fibres, Interlaminar fracture toughness, Hybrid composites, Mode II.

Abstract

Vinyl ester matrix composites reinforced non-woven flax fibre with basalt hybridized were prepared by a compression moulding process. In order to study the effects of flax fibre reinforcement and basalt fibre hybridization on the Mode II fracture toughness, three-point bend end-notched flexural (3ENF) testing was employed. Both critical energy release rate G_{IIC} and stress intensity factor K_{II} were found to be influenced by the load and deflection levels. From the experimental results, the average value of the fracture toughness G_{IIC} for flax/basalt hybridised vinyl ester composites was larger than flax without basalt with values of 2173 J/m^2 and 1940 J/m^2, respectively. The average value of stress intensity factor K_{II} without hybridization was 134 kPam$^{0.5}$ and with basalt hybrid was increased to 178 kPam$^{0.5}$. It was found that the flax/basalt hybridized composites exhibited an improved fracture toughness behaviour compared to flax/vinyl ester composites without hybridization.

Introduction

A shift in the behaviour and awareness of government and customers of the damage caused by excessive use of synthetic polymers and composites has urged researchers to look for more sustainable and environmentally friendly composites that will be able to reduce the greenhouse effect and CO_2 emissions. Therefore, studies are being carried out to replace synthetics composites by natural fibre composites, which are more environmentally friendly and economically beneficial for industries as they use less energy and cost less to produce than synthetic composites, such as glass and carbon fibres. Other advantages for using natural fibres substitutes include that they are biodegradable and provide a high-strength –to weight ratio [1–3].

Although studies have shown their suitability as a possible replacement for synthetic composites, they are used mainly in the car industry, replacing the interior panels on doors and dashboards. There have been tests and reported work on natural fibre composites related to their mechanical, thermal and environmental behaviours [4–9], but no extensive work and reports exist on the effectiveness in structural components to resist fracture under different conditions, in other words not much has been done to investigate the fracture toughness behaviour of natural fibre composites [10–13].

In order to use natural fibre composites as a replacement in the future, they need to undergo different fracture toughness tests from those that already exist. These experiments are used to measure the interlaminar strain energy release rate of fibre reinforced polymer-matrix (FRP) composite materials and are classified into different Modes. These are:

- Mode I (tensile/opening),
- Mode II (shear),
- Mode III (tearing shear), and
- Mixed Mode I/II [14, 15].

Mode I is the most common and has been intensively studied using the Double Cantilever Beam Test (DCB). It is universally accepted, but for the examples in Mode II, there are fewer experiments that have been done or suggested to validate results obtained.

There are three different tests used in Mode II to measure the strain energy release rate, G_{IIc}, but the most common one is the End Notched Flexure (ENF), which was developed to test the wood fracture characterization. The tests done in Mode II are still awaiting to be fully approved by American Society for Testing and Materials (ASTM), [16, 17].

Composite or hybrid composites are combination of more than one type of fibres in the same matrix. In order to use natural fibres in composites materials, there is an urgent need to look at their mechanical properties when under certain experimental conditions, like temperature and reinforcement of natural fibres in hybrid composites. Despite more and more industries working on replacing synthetic materials by natural ones, there are limited published works on the hybridization of glass, carbon and basalt fibres into natural fibre composites [18–20]. For example, the use of basalt fibres has little impact on the environment or any effect on global warming as these fibres are produced from commonly occurring rock, whereas huge amounts of energy are needed to manufacture glass fibres with similar properties to that of natural fibres.

Most of the studies undertaken in recent years on fracture toughness have been done on composite materials made from glass and carbon fibres, but very few works on the fracture toughness of natural fibre composites, woven and non-woven natural fibre reinforced composites or bio-composites have been carried out.

Although most researchers have studied the fracture toughness of hybrid composites from glass or carbon fibres, the present investigation will be looking at needle punched non-woven flax fibres and basalt fibres used as reinforcements in the Mode II fracture toughness and the use of Scanning Electron Microscopy (SEM) to support the findings on the mechanical behaviour of reinforced natural fibres in hybridized composites. The mechanical properties that include interlaminar fracture toughness and interlaminar shear strength of flax fibre reinforced vinyl ester composites and flax/basalt hybrid composites were investigated.

Experimental

Materials

- Vinyl ester resin and a curing catalyst, methyl ethyl ketone peroxide (MEKP) were used for flax composite laminate fabrication. Supplier GRP Ltd, UK.
- The reinforcement used was needle punched non-woven flax fibres; fabric weight of 330g/m^2 supplied by Ecotecnilin Limited.
- The basalt fibre in the form of woven fabric (BAS 220.1270.P) was obtained from Basaltex-flocart NV (Belgium); areal weight of 220g/m^2.

Composites Fabrication

The making of the laminates was a combination of hand lay-up and compression moulding. For the curing process methyl ethyl ketone peroxide (MEKP) was used. It was mixed with the vinyl ester at a concentration of 1.5wt. % followed by 3 minutes of manually stirring to obtain a uniform mixture. A steel mould of the desired dimensions for the fabrication of the laminates was first coated with mould release agent to remove samples easily from the mould. The flax fibres were placed in layers into the mould and the resin was poured on the fibres. With the help of a small hand roller, the fibres were aligned and this also allowed the fibres to be impregnated and bubbles were removed. The laminates obtained were compressed under a hydraulic pressure of 1MPa and a temperature of 50°C for 90 minutes. The post-curing was done at 85°C for 180 minutes in a fan assisted oven. The fibre volume fraction was approximately 23% and 25% for flax/vinyl ester and basalt/flax/vinyl ester hybrid composites respectively, in a mould plate of 4mm thickness. The void content was approximately 5% and was calculated according to ASTM D2734-94. In order to initiate delamination, a Teflon release film was placed at laminate mid-thickness.

Mode II Interlaminar Fracture Testing Using 3ENF

The dimensions of the samples are given in Fig. 1. The ENF was used to measure Mode II critical strain energy release rate (G_{IIc}). The specimen was placed in a three-point bending fixture and four specimens of each type were tested as a measure of accuracy. In the test, the bending or flexural load was applied at centre of the beam to produce a crack from the insert. The propagation of the crack was initiated as a result of shear forces at the crack tip and observed until failure.

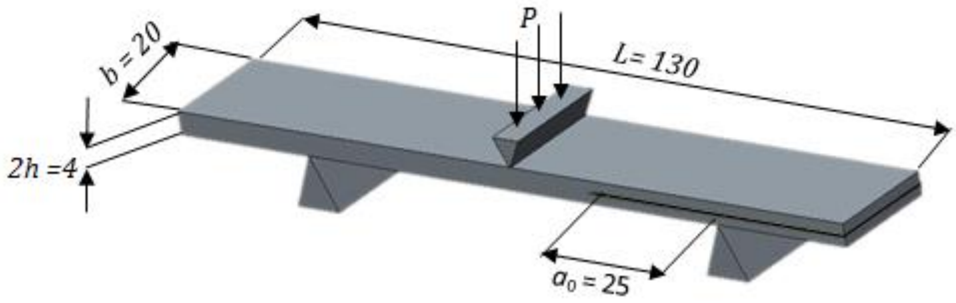

Figure 1. Fracture toughness configuration of Three-Point End-Notched Flexure (3ENF) specimen [21]

The compliance was given by equation (1) and the equation of the critical energy release rate G_{IIc} can be found by applying classical simple beam theory (SBT) [22].

$$C = \frac{\delta}{P} \tag{1}$$

$$C = \frac{2l^3 + 3a^3}{8E_1 bh^3} \tag{2}$$

$$G = \frac{P^2}{2b}\frac{dC}{da} \tag{3}$$

The critical energy release rate for the interlaminar fracture toughness can be obtained from Eq.1 to 4:

$$G_{IIc} = \frac{9P\delta\ \mathrm{a}^2}{2b(3a^3+2L^3)} \tag{4}$$

Where:

- P is maximum load for unstable crack propagation,
- δ is displacement from the central axis of the beam,
- a is crack length measured from the outer pin L is half span of 3-ENF specimen and
- b is beam width.

An indirect approach has been used to calculate the stress intensity factor K_{IC} since it does not depend on whichever Mode is being used:

$$K_{Ic} = \sqrt{G_{Ic}\ \times E} \tag{5}$$

Scanning Electron Microscopy (SEM)

The fractured surfaces of the composite specimens were studied using a SEM JSM 6100 model at normal room temperature. Before using the SEM, a thin layer of gold/palladium was applied to the specimens. The SEM micrographs of the fractured surfaces will provide useful information on the specimens' behaviour under loading and fibre-matrix adhesion, to have a better understanding of failure mechanisms.

Results and Discussion

The experimental results for both specimens are given in Table 1. The results represent the average reading on the four samples used in both studies. Analysis of the numerical values in Table 1 will give a better understanding of whether the presence of basalt layers that hybridised the flax/vinyl ester composition represent a solid response to use natural fibre composites.

Table 1 Interlaminar fracture toughness results for different specimens [21].

Specimens	Displacement, (δ) (mm)	Maximum load,(P) (N)	Fracture toughness, (G_{IIC}) (J/m^2)	Stress intensity factor, (K_{IIc}) (kPam$^{0.5}$)

Flax/VE	6.62 (0.11)	364.10 (41.63)	1940.40 (249.90)	133.74 (16.99)
Basalt/Flax/ VE	6.28 (0.42)	429.89 (39.70)	2172.94 (264.19)	177.84 (15.84)

***Note:** Data in the table are averages with sample size of 4 each specimen type. The numbers in the parentheses are the standard deviation.*

Fig. 2 and 3 give a representation of the energy release rates and the stress intensity factors for both specimens in Mode II. As expected, the numerical values of these characteristics are high in the case of Flax/Basalt/VE. These particular results can only be explained by the presence of basalt fibres in the hybrid composites, since both samples were analysed under the same conditions. Therefore, the hybridized samples provide a better resistance to crack propagation than flax alone when the force is applied on both specimens under the same crosshead displacement at a rate of 2mm/min. Although, theoretically the resistance to crack propagation can be attributed to the presence of basalt layers that were placed at the bottom and top of the flax/VE layers during fabrication, it is to examine how the arrangement of fibres and their structures in the matrix help to give performance if the samples were to be used in structural composites. A better way to look at it is by using Scanning Electronic Microscopy, SEM. With SEM, it will be possible to examine the fractured surfaces and the distribution of fibres and resin inside the matrix of each specimen.

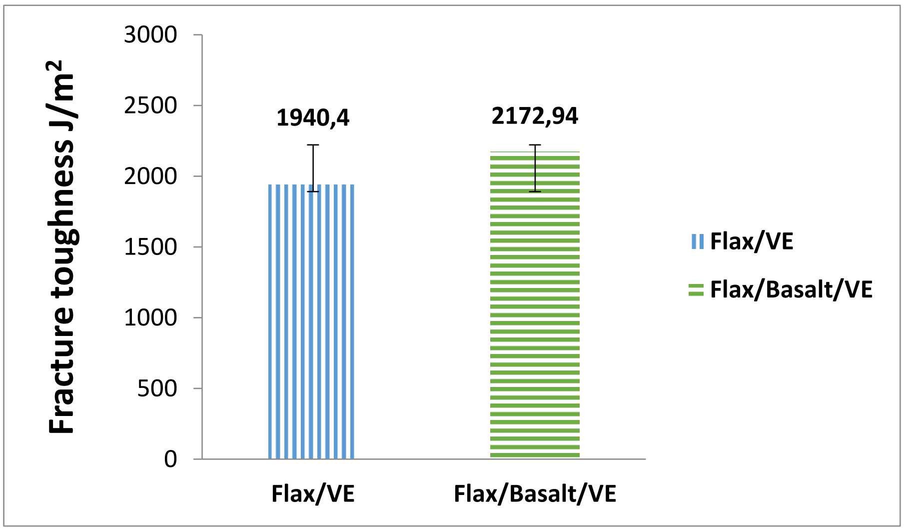

Figure 2. Fracture toughness of flax/VE and flax/basalt/VE [21].

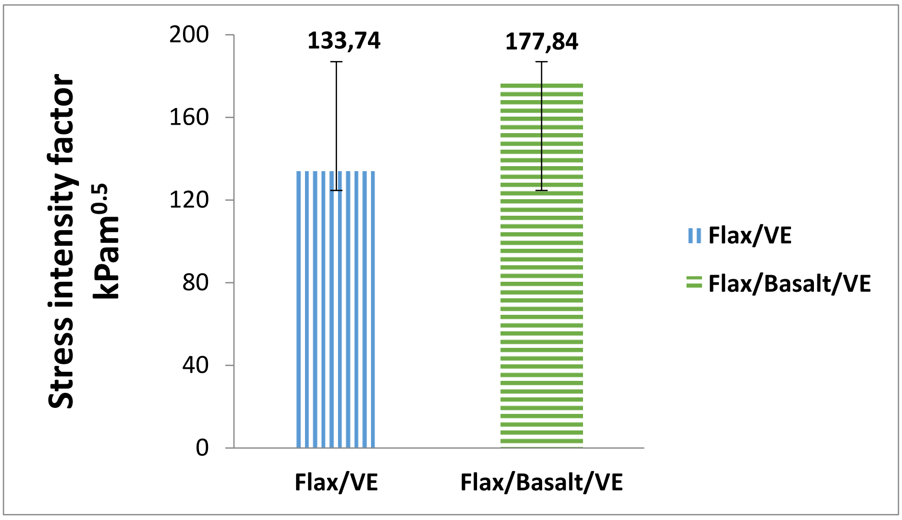

Figure 3. Stress intensity factor for flax/VE and flax/basalt/VE [21].

Failure Mechanism

The analysis results from the SEM pictures after the 3ENF testing for flax/VE showed some distinctive regions within the laminate which were not visible during the test. In Fig. 4 which can be observed that the main failure modes in the specimens are a combination of matrix cracking, fibre pulls-out, fibre breakage and delamination. Some of the fibres have a clear alignment while others are haphazardly distributed within the matrix. There is some debris present with but no accumulation of resin was observed. Fibres also show some characteristic of brittleness that can contribute to the sudden load drop, but the laminates showed ductile behaviour that can explain why the laminates take longer to break after reaching the maximum load. This particular aspect makes natural reinforced fibre composites a much better substitutes for glass or carbon composites, but more investigations need to be carried out to have high performance composites.

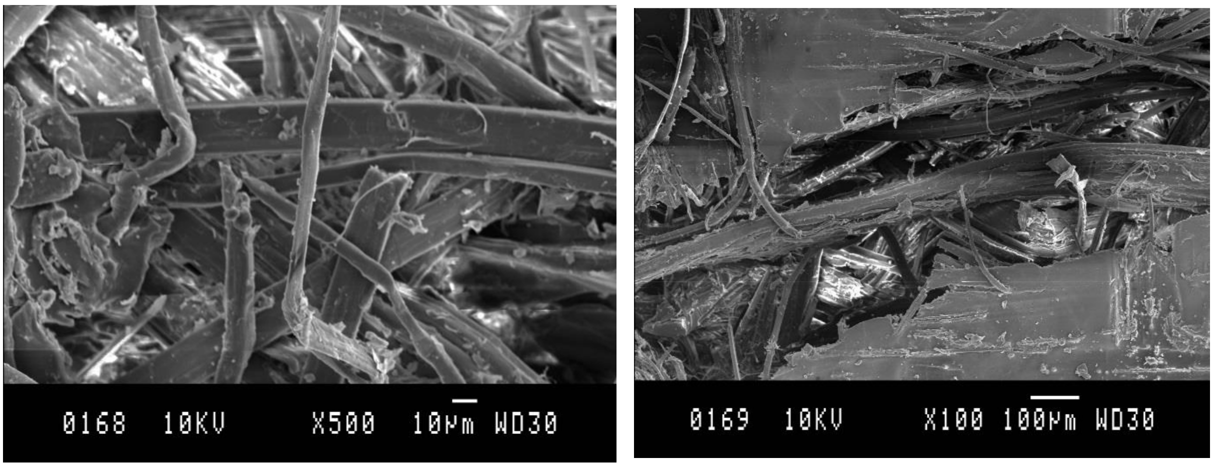

Figure 4. SEM images of fractured surface of flax /VE for mode II.

Conclusions

The experiments undertaken in this study have shown that flax/basalt/VE hybrids are more resistance to crack propagation in comparison to Flax/VE alone. The G_{IIC}, the stress intensity factor for flax/basalt/Vinyl, is much higher in the presence of basalt fibres or when they sandwich flax/vinyl fibres. The physical properties of the hybridized composites were much better than it counterparts (Flax/VE), but more experiments need to be carried out under different atmospheric and physical conditions and compare those results against existing composites. This will be the nature of the next study to improve the Mode II results.

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