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THE IMPACT OF FIBRE STRENGTH ON THE STRENGTH OF ITS REINFORCED EPOXY POLYMER

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ABSTRACT

Fibre composites are getting more popular as structural materials for their stiffness, strength, and toughness in the direction of fibre longitudinal axis. Three different fibres each of 5.3, 4.6, and 3.4 GP strength were used in this study. They were made in different preforms to make composite materials. The tensile strength values of composites were evaluated on the basis of the fibre tensile strengths and the structure of the preforms used for the production of these composites. Each fibre showed a different mathematical relation with the tensile strength of the corresponding composite material. This gives an indication that the tensile strength of the composite material is affected by that of the fibre in conjunction with the preform structure.

KEYWORDS

Fibres, textile, preforms, composite materials, tensile strength, stress and strain.

1. INTRODUCTION

A large range of materials is included in fibre-reinforced polymers since there are many choices of fibres and polymer resins. Mainly, there are three types of fibres, which are commonly in use; glass, carbon, and aramid fibres. Polymers are also of two main types; thermosetting and thermoplastic polymers and again each of which has sub-divisions. Considering this, a general statement on the effect of fibre strength on the composite strength would be far from existence.

Each fibre/matrix combination, thus, should be studied separately together with the method of production. The fracture of composite materials depends on the tensile strength of the fibres. As the average fibre strength increases, a fibre/matrix interfacial fracture parallel to the loading direction is noticed for smooth edge sample. Yoshiyuki studied the fracture profile of the composite rather than the tensile strength on the basis of the fibre strength when tested axially using smooth edge and notched edge samples (Tomita, Tempaku, 1997).

In uni-axial tension, the pure matrix material has amount of strain to failure, which is higher than that of a composite loaded transversely, and so the matrix effect is much higher in the case of longitudinal tensioning of the composite. The final failure of the polymer matrix composites with continuous fibres usually involves fibres fracture (Asp, Berglund, Gudmundson, 1995). This gives an indication for the importance of fibre strength. The strength of the composites increases, in general, with the increase of fibre orientation factor (Fu, Lauke, 1996).

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Concerning the mechanical properties of composite materials made of fibres; the fibrous filler bears the main load in the composite material so the material strength depends substantially on the arrangement of the fibres i.e. their orientation. Thus, the fibres can be introduced in the form of filaments, tows, tapes, fabrics and multidimensional structures into the matrix.

Carbon fibres are seldom used alone; they are used, however, for reinforcing matrix materials. The carbon fibre composites are expected to bear loads, resist deformation, and give high performance. A better efficiency is attained when carbon fibres are arrayed in more than one direction. Their strength is directly related to the fibre content and direction. The upper-most value is achieved when the fibres are aligned with the direction of applied stress (Etemad et al., 1992). The strength of materials can be defined in different ways; for one layer composite material, for example, the point of the first damage is considered as being its strength. It is necessary to focus on the material's mechanical properties in the through-thickness direction to fully evaluate the mechanical properties of their reinforced polymers (Chen et al. 2012).

Tensile testing requires simple specimens, easy to perform and gives a reliable and accurate measurements (Gommers et al., 1998). Therefore, tensile testing has been performed to the fibres and the composites made from them to determine the effect of the fibre strength and the preform structure on the composite tensile strength. Once either the fibre or the matrix attains its ultimate strength, the corresponding applied overall stress is defined as the ultimate strength of the composite (Huang et al., 1999). The tensile strength, failure strain, tensile stiffness, energy absorption, and resilient energy are all strain rate sensitive (Pibo et al., 2011). There is a close relationship between the mechanical parameters and the rate strain.

In each case, tensile strength tests were performed and stress-strain relations were given. Mathematical relations were given based on the tensile strengths of both fibres and composites. These relations are affected by the preform structure.

2. MATERIALS AND METHODS

Three different carbon fibres were used; they are twos of different linear densities and strengths (each of which contains a large number of fine carbon filaments) made in different structures, each of which was used to reinforce epoxy matrix to make composites.

A mixture of epoxy resin and a hardener (ratio of 4:1) was applied to the preforms to make the composite materials. The specimens were kept in the mould sealed with plastic sheets to prevent moisture evaporation and get rid of air bubbles that may be entrapped in, for 24 hours, under a pressure of 100 Kg/m^2. The samples were then cured at 80°C for 2 hours and post-cured at 120°C for another 2 hours. The twos, the preforms and their composites were then tested for their uni-axial tensile strengths.

Uni-axial tensile testing was performed using the AG 10 Tensile Meter. The load-displacement results were obtained at a strain rate of 2mm/min; a gauge length of 10 cm was used for the twos, and 20 cm gauge length for the preform and the composite materials. To ensure good gripping and to avoid slippage at the tensometer tabs, applying a resin at the tab edges for both the preforms and the composites roughened the edges of the samples, while glue paper wrapped the fibres.
The diameters of the tows were measured under the microscope, and the thickness values of the composites were measured using the thickness meter.

3. RESULTS AND DISCUSSION

3.1 The analysis of the basic data of the materials

The parameters and tensile properties of the materials used in the experiments are shown in Table 1. The tows used to make the unidirectional, the non-woven, and the warp knitted preforms and composites are denoted by UD, NW, and WK respectively.

Table 1: The parameters and tensile properties of the materials

Samples	Twos			Composites		
	UD	NW	WK	UD	NW	WK
Strength (GPa)	5.3	4.6	3.4	1.1	0.8	0.78
Modulus (GPa)	280	152	167	2.73	2.40	0.74
Work of Rupture (Jules)	2608	3754	1975	526	339	441
Specific work (J/Tex, J/gm)	3.18	5.96	8.98	85.01	43.62	40.82

3.2 The impact of fibre strength on the composite strength

The stress-strain data of the three different fibres and their composite materials were plotted in Figure 1. This plot contains the stress-strain values for the fibres and the composites and enables making a quick comparison concerning their tensile properties.

It is clear that the UD tow, being the strongest among the whole group, gave better composite tensile strength. Nevertheless, the other two fibres differ greatly in their stress, but gave composites with almost the same stress values. Since the fabrication process is the same and using the same resin then the fibre strength has the greatest effect on the tensile stress of the composite. Referring to Table 1, the high modulus fibre, the UD fibre too, resulted in the highest modulus of its composite, but the other two fibres resulted in opposite results for their composites. It is worth to announce that the UD fibre has a higher volume fraction compared to the other two fibres.

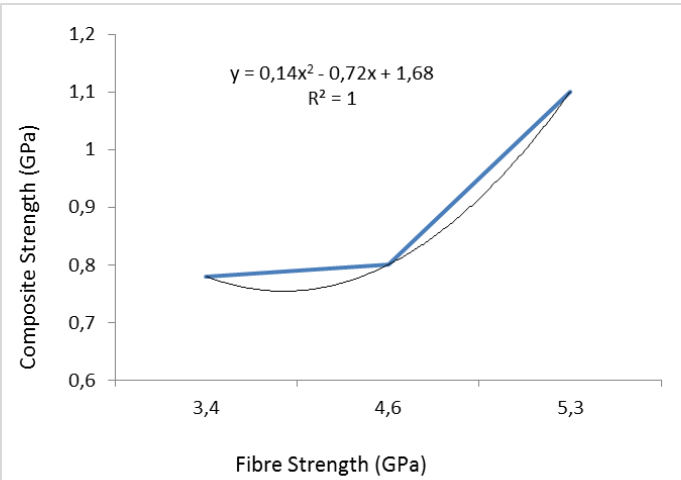

Figure 1: Fibre strength vs. composite strength

3.3 Work of rupture

The values for the work of rupture have different impacts. The highest value for the fibre resulted in the lowest for the composite. This is true regarding to the volume fraction of the fibres. The WK composite showed a better work of rupture, i.e. a higher energy is required to break the material, than that required for the NW composite although the latter has a higher fibre volume fraction.

Table 2 shows the percentages in the tensile properties on the basis of the tensile values of the single tows. These values are calculated by the following formula:

$$\delta_x = \frac{X_f - Xc}{X_f} \text{ x } 100 \qquad (1)$$

Where δ is the loss percentage of each of the tensile properties, *X* represents σ,ε, E, and W respectively, *f* and *c* stand for the fibres and composites.

Table 2: The loss percentages of the tensile properties in composites

Loss in tensile properties	Composites		
	UD	NW	KW
δ_σ	79	83	77
δ_ε	15	56	1.8
δ_E	47	17	53

In this table, the mentioned values indicate the property change percentage from fibre to composite. Low values, thus, arise from the fact that the fibre property has a better impact on the composite property. As the difference between the two relative properties becomes lower, then the fibre property is more dominant.

3.4 Mathematical relations

The following equations relate the fibre strength to the composite strength and show the square regression values attained upon linear relation. They are as follows:

$$\sigma_{Cud} = (\sigma_{Fud} + 107.67)/ 4.6883 \text{ and } R^2 = 0.99035 \qquad (2)$$

$$\sigma_{Cnw} = (\sigma_{Fnw} + 232.04)/5.3962 \text{ and } R^2 = 0.9582 \qquad (3)$$

$$\sigma_{Cwk} = (\sigma_{Fwk} - 36.957)/4.228 \text{ and } R^2 = 0.9934 \qquad (4)$$

Where F and C are fibre and composite respectively, σ for the tensile strength (GPa) and Fud, Fnw, and Fwk stand for the types of preforms used.

From these equations, we can deduce that not only the fibre strength has an effect on the tensile strength of the composites, but also the preform structure. Considering equations 1 and 2, and neglecting the dominator of each equation the composite strength for each preform is increased by a high value added to the strength of the fibre and the regression showed a much closed mathematical relation. However, in the third equation, the composite strength is lower than that of its reinforcing fibre with a very low value and the regression value showed a closer relation compared to the other two.

4. CONCLUSIONS

The tensile fracture stress of the composites is mainly dependent on the tensile strength of the fibres, although the matrix and the fibre volume fraction have their effect on the strength. It is not necessary that stronger fibres lead to stronger composite materials, as in the same way as expected when using different preform structures.

Based on the results attained, we can conclude that the stronger the strand is, the stronger will be the composite as far as unidirectional composites are concerned regarding to volume fractions of the fibres.

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