SUSTAINABLE MATERIALS FOR HIGH PERFORMANCE COMPOSITES

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Abstract: As industry attempts to lessen the dependence on petroleum based fuels and products there is an increasing need to investigate more environmentally friendly, sustainable materials to replace existing synthetic materials. This paper describes the salient features of sustainable composite materials. Hence performance of popular natural fibre reinforced composites is reviewed. Furthermore the results of an investigation into the mechanical properties of a novel natural fibre composite material are presented. In this way it is possible to develop new high performance materials that would potentially compete with short fibre glass reinforced polymer composites.

1. Introduction:

During the past decade, increasing environmental awareness, new global agreements, and international governmental policy and regulations have been the driving force behind renewed interest in natural fibre reinforced thermoplastics. The attractiveness of a plant-based fibre as an alternative reinforcement material comes from its high specific strength and stiffness, natural availability, and environmental 'friendliness'

The UK Government published Securing the Future: Delivering UK Sustainable Development Strategy (2005). This has lead to increasing emphasis on sustainability in both industry (Sustainable Development, 2008) and in agriculture (A strategy, 2008) with a revival of interest in materials from sustainable sources.

In the past few decades, research and engineering interest has been shifting from monolithic materials to fibre-reinforced polymeric materials. These composite materials (notably aramid, carbon and glass fibre reinforced plastics) now dominate the aerospace, leisure, automotive, construction and sporting industries. Glass fibres are the most widely used to reinforce plastics due to their low cost (compared to aramid and carbon) and fairly good mechanical properties. However, these fibres have serious drawbacks as indicated in Table 1. The shortcomings have been highly exploited by proponents of natural fibre composites. Table 1 compares natural and glass fibres and clearly shows areas the former have distinct advantages over the latter. Carbon dioxide neutrality of natural fibres is particularly attractive. Burning of substances derived from fossil products (e.g. petroleum) releases enormous amounts of carbon dioxide into the atmosphere. This phenomenon is believed to be the root cause of the greenhouse effect and by extension the world's climatic changes (Larbig et al, 1998). Attempts have been made to use natural fibre composites in place of glass mostly in non-structural applications. So far a good number of automotive components previously made with glass fibre composites are now being manufactured using environmentally friendly composites (Larbig et al, 1998), (Leao et al. 1997).

	Natural Fibres	Glass fibres
Density	Low	Twice that of natural fibres
Cost	Low	Low , but higher than NF
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	high
Distribution	Wide	Wide
CO2 neutral	Yes	No
Abrasion to machines	No	yes
Health risk when inhaled	No	Yes
Disposal	biodegradable	Not biodegradable

Table 1. Comparison between natural and glass fibres

Currently, plenty of research material is being generated on the potential of cellulose based fibres as reinforcement for plastics. All researchers who have worked in the area of natural fibres and their composites are agreed that these renewable (unlike traditional sources of energy, i.e., coal, oil and gas that are limited (Larbig et al, 1998), abundantly available materials have several bottlenecks: poor wettability, incompatibility with some polymeric matrices and high moisture absorption by the fibres (Vazguez et al.1999).

The first and the most important problem is the fibre–matrix adhesion. The role of the matrix in a fibre reinforced composite is to transfer the load to the stiff fibres through shear stresses at the interface. This process requires a good bond between the polymeric matrix and the fibres. Poor adhesion at the interface means that the full capabilities of the composite cannot be exploited and leaves it vulnerable to environmental attacks that may weaken it, thus reducing its life span. Insufficient adhesion between hydrophobic polymers and hydrophilic fibres result in poor mechanical properties of the natural fibre reinforced polymer composites. These properties may be improved by physical treatments (cold plasma treatment, corona treatment) and chemical treatment (maleic anhydride, organosilanes, isocyanates, sodium hydroxide, permanganate and peroxide) (Luo and Netravali 1999),(Ràcz and Hargitai, 2000).Gassan et al. (1999) improved the tensile, flexural strength and stiffness of Jute-Epoxy composites by treating the fibres with silane. Tripathy et al. (1999) found that delignification by bleaching produces better interfacial bond between jute fibre and polyester matrix and hence better mechanical properties of the composites.

The absorption of steam by sisal, hemp and banana fibre /novolac resin composites was found to reduce after esterification of the –OH groups with maleic anhydride (Mishra et al. 2000). The tensile strength of the maleic anhydride treated fibre composites was found to be higher than that of untreated fibre composites.

Table 2. Properties of natural fibres in relation to those of E-glass [14]

	Fibres						
Properties	E-Glass	Hemp	Jute	Ramie	Coir	Sisal	Flax
Density g/cm3	2.55	1.48	1.46	1.5	1.25	1.33	1.51
Tensile strength (MPa)	2400	550-900	400-800	500	220	600-700	400
E-Modulus (GPa)	73	70	10-30	44	6	38	12
Specific (E/d)	29	47	7-21	29	5	29	8
Elongation at failure(%)	3	1.6	1.8	2	15-25	2-3	3.10
Moisture absorption (%)	-	8	12	12-17	10	11	8-25

Luo and Netravali (1999) found an increase in the mechanical properties of "green" composites prepared from pineapple leaf fibres and poly(hydroxybutyrate-co-valerate) resin (a biodegradable polymer with the fibres in the longitudinal direction. However, the researchers report a negative effect of the fibres on the properties in the transverse direction (Netravali and Luo 1999). Gauthier et al. (1998) report that adhesion may be improved by using coupling agents like maleic anhydride to incorporate hydroxyl groups on the matrix through hydrophilization and consequently enhancing the wetting effect of the resin on the fibres. The hydroxyl groups then interact with –OH molecules on the lignocellulosic fibres via hydrogen bonding thus producing a stronger bond (Gauthier et al. 1998), (Gauthier et al. 1998). Second, the composite properties are influenced by the fibre properties. Natural fibre properties are highly variable and depends on conditions of growth. It is therefore very difficult to get the same mechanical properties after repeat testing. The fibre properties, such as dimensional instability, have been found to improve after treatment with chemicals such as maleic anhydride, acetic anhydride and silanes. Although the mechanical properties of natural fibres are much lower than those of glass fibres (Table 2 (Beukers and Van Hinte 1999)), their specific properties, especially stiffness, are comparable to the stated values of glass fibres. Moreover, natural fibres are about 50% lighter than glass, and in general cheaper. Table 3 gives a list of some of the main work on natural fibre composites that have been reported in the literature.

2. Experimental details:

In this study a novel type of short natural fibres has been used to reinforce epoxy (HY750) polymer. For commercial reasons it is not possible to reveal the nature of the natural fibres used. The catalyst used to cure the resin was Aradur HY1300GB with a catalyst/ resin ratio of 30/70 w/w.

The tensile strength of the composites was determined using a Hounsfield testing machine (model H20K-W). Tests were carried out according to British standards (BS EN 2747:1998), with 10 mm/ min crosshead speed. Tensile strength values are average results of five tested specimens.

Specimens submitted to tensile tests were cut and the composite intact fracture surface was analysed using JEOL JSM5310 scanning electron microscopy with tungsten filament operating at 20 kV, employing low vacuum technique and secondary electron detector.

3. Results and discussion:

Comparison between the averaged tensile strength of different natural fibre composites and short glass fibre reinforced polymer (GRP) is informative (Figure 1). It can be seen that although GRP possesses a relatively high strength but the specific strength is comparable with some natural fibre composites including ramie and sisal composites. Although the specific strength of the new novel natural fibre is 17% lower than GRP, ramie and sisal but with a fraction of the cost.

Comparison of the stress–strain curves of the family of the novel fibre composite (Figure 2) indicates that as the fibre content increases so does strain to failure and tensile strength, the latter by as much as 75%. However the increase in fibre content does not seem to affect the tensile modulus or ductility of the composites. It can also be observed that the increase in strength an failure strain follows a direct linear relationship with fibre content.

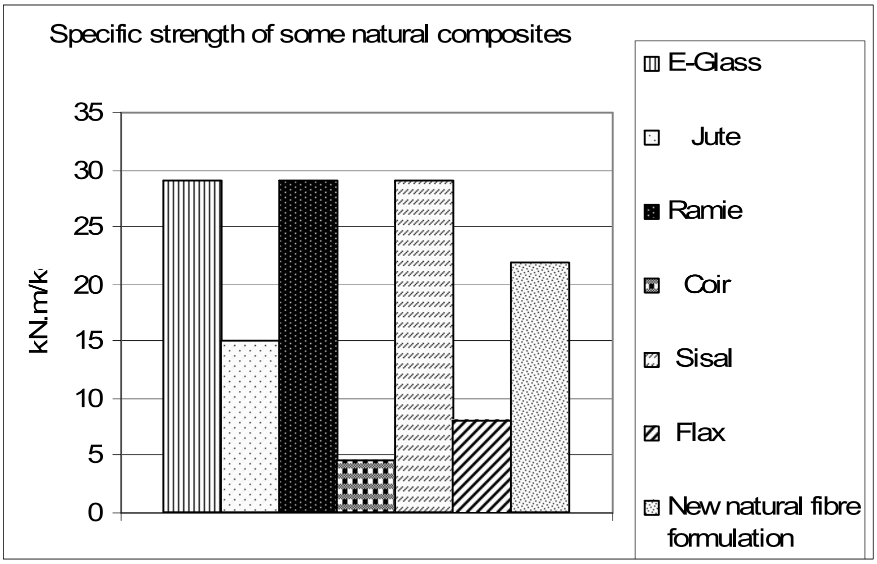

Figure 1Comparison of specific strength of natural fibres in relation to that of E-glass

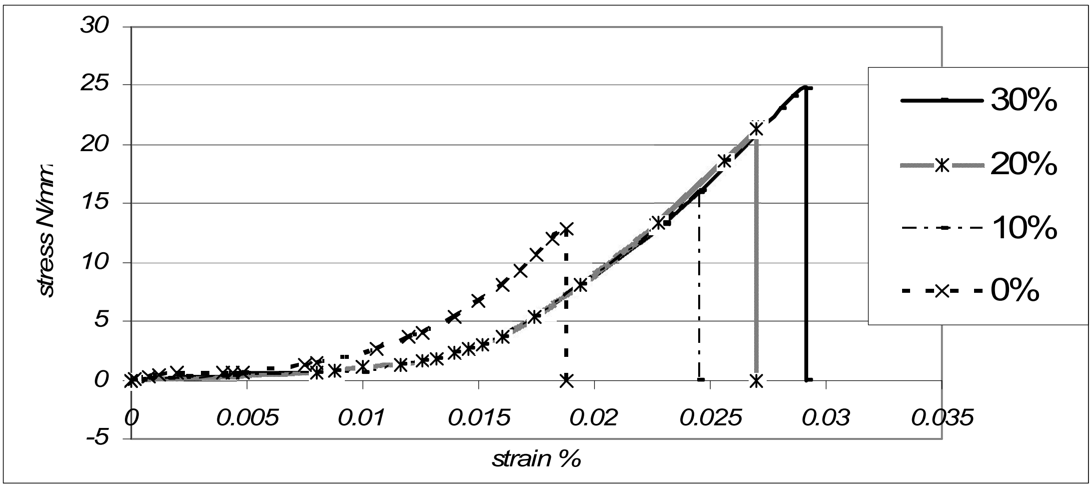

Figure 2 Tensile stress- strain curves for the novel natural fibre composite with different fibre weight fractions

The greater variability of measurement of composite strength comes with increasing fibre weight fraction. This is particularly noticeable at values of 20% and above. We believe this effect is related to the clumping of the fibres and inadequate impregnation of the fibre particles by the polymer during the moulding process. The fracture surface appearance of a failed specimen supports this suggestion (Figure 3). Impregnation of the short fibre particles by the polymer appears to be satisfactory up to a fibre content of about 20%. It can also be observed from Figure 3 that the composite does not possess a strong fibre-matrix bond which has resulted in particles pulling out of the matrix resin. To resolve this problem, it is suggested to treat the reinforcement with a compatible coupling agent which can also improve the wettability and fibre- resin adhesion.

Finally, these experimental results agree well with theoretical predictions based on a simple rule-of-mixture and a 3/8 fibre orientation correction factor for in-plane random fibre orientations. Using a fibre modulus of 40 GPa and a matrix modulus of 1.2 GPa we can predict the composite stiffness for random short fibre composites with different fibre volume fractions. Theoretical values predicted using such a first approximation are 1.2, 1.5 and 1.9 GPa for fibre volume fractions of 10, 20 and 30%, respectively. Clearly this data is in reasonable agreement with the experimental data shown in Figure 2, indicating that these materials follow the rule-of-mixture behaviour.

4. Conclusion:

In comparison to short glass fibre reinforced polymer composite, the novel natural fibre composite is attaining similar mechanical properties and reaching useful values. Future research direction should concentrate on treatment of the fibres with suitable coupling agents.

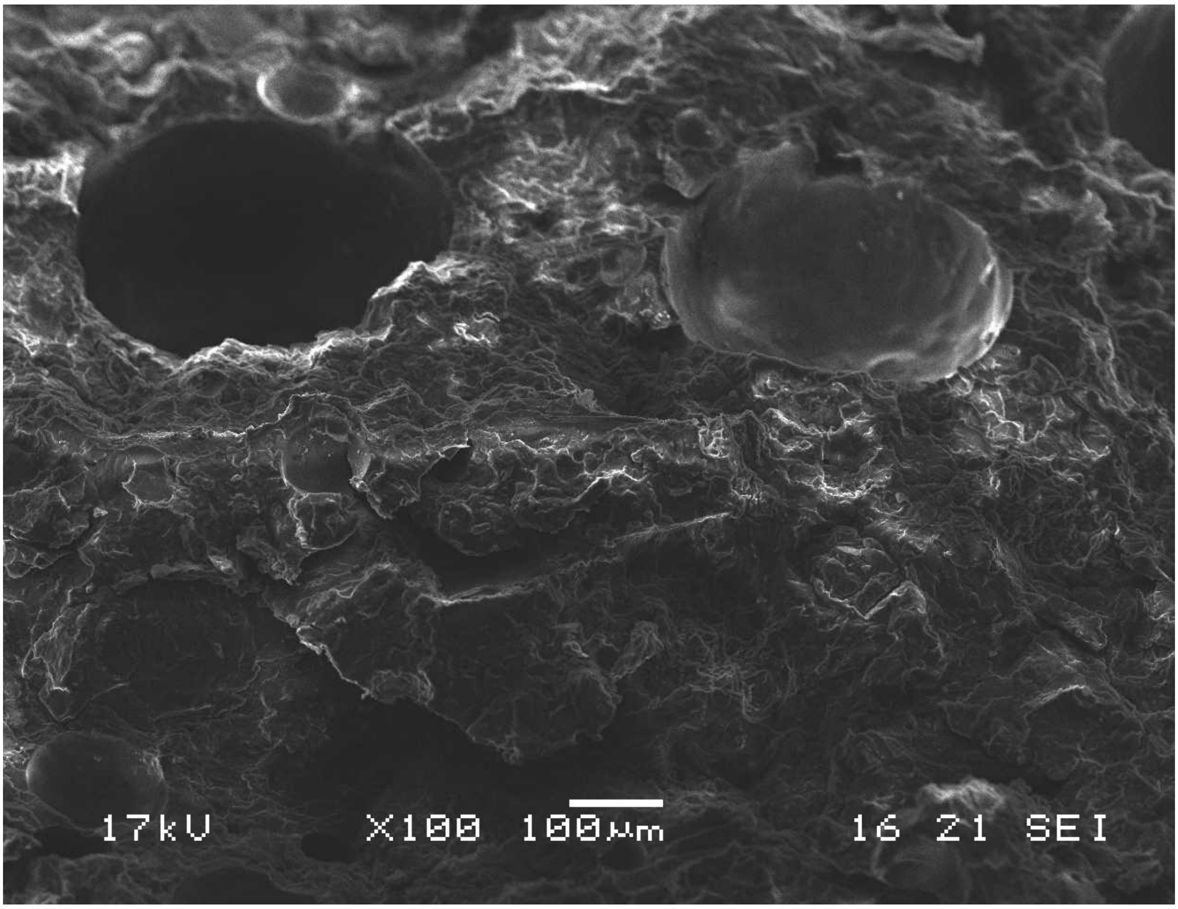

Figure 3 SEM micrograph of the novel composite formulation with 30% fibre content, showing the fracture surface after tensile testing

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