Chapter 5

Hybrid Fibre Reinforcement with Banana and Glass Fibres

Abstract
In this study, the merits of combining high modulus glass fibers and banana fibres in phenol formaldehyde resin to develop high performance, cost effective, lightweight hybrid composites were discussed. Banana glass hybrid composites were prepared with special reference to the effect of glass fibre content and banana glass layering patterns. It was observed that mechanical properties were dependent on layering pattern. The highest tensile strength value was obtained for intimate mixture of both the fibers and maximum flexural and impact strength was obtained for composite samples prepared of interleaving layers of banana fibre and glass fibre. Tensile, flexural and impact properties of the composites increased with increasing volume fraction of glass fibre. Scanning electron micrographs showed the fracture mechanism and fibre/matrix adhesion in these composites.

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Hybrid composites are materials made by combining two or more different types of fibres in a common matrix. They offer a range of properties that cannot be obtained with a single kind of reinforcement. By careful selection of reinforcing fibres, the material cost can be substantially reduced. Glass fibres impart excellent performance when used as reinforcement in polymeric matrices. High strength, light weight, dimensional stability, resistance to corrosion and electricity are the major advantages of glass fibre reinforced composites. Addition of glass fibre in banana fibre reinforced PF composite will lead to improved performance of the composite. The hybridization with glass fibre will improve the thermal stability and resistance to moisture and water absorption.

Investigations on lignocellulosic fibres have shown that the properties of fibre can be better utilized in hybrid composites (1-5). Clark and Ansell (2) reported the improvement of various jute/glass hybrid laminates with different arrangement of jute and glass in the laminate. Studies on sisal/glass in polyester have showed a linear increase in the work of fracture by varying the volume fraction of glass at the core (3). Hybridization using glass fibre is found to be an effective method to improve the mechanical properties of oil palm fibre reinforced phenolics [4] and banana fibre reinforced polyester [5]. The degree of mechanical reinforcement that could be obtained by the introduction of glass fibres in biofibre (pineapple leaf fibre/sisal fibre) reinforced polyester composites was assessed by Mishra et al. [6]. Addition of relatively small amount of glass fibre to the pineapple leaf fibre and sisal fibre-reinforced polyester matrix enhanced the mechanical properties of the resulting hybrid composites.

Plain woven hybrid ramie—cotton fabrics were used as reinforcement in polyester matrix composites by Junior et al. [7]. The tensile strength of the
composites was shown to follow a common rule of mixtures law, disregarding the contribution of the cotton fibres. Imielinska and Guillaumat [8] subjected two different woven glass/aramid fibre/epoxy laminates to water immersion ageing followed by instrumented low velocity impact testing. No important effect was found in the case of aramid/glass-fibre configuration (woven hybrid fabric of glass and aramid fibres or aramid fibre fabric interlaminated with layers of glass fibre fabric) on moisture absorption and impact tests characteristics. Recently properties of sisal/oil palm hybrid fibre reinforced natural rubber and sisal/banana hybrid fibre reinforced polyester composites were analyzed in our laboratory [9,10,11]. Composites can be used for structural applications by enhancing their performance through hybridization [12,13].

In this chapter a detailed investigation on the effect of layering pattern and glass fibre volume fraction on the mechanical properties of banana/glass/PF composites has been carried out. The objective of the present work is to produce specialty composite materials using banana fibre by incorporating glass fibre in small amounts (up to a volume fraction of 0.35 %), maintaining the cost effectiveness and improving the moisture resistance and mechanical properties of the banana fibre composites.

5.1 Effect of hybridization on mechanical properties

5.1.1 Tensile properties

Figure 5.1 represents the tensile stress-strain behavior banana /PF composite (with a volume fraction of 0.3) and banana glass hybrid composites (keeping the total fibre volume fraction constant (0.3) and varying glass volume fractions).

The general nature of stress-strain curve gets altered by an increase in glass volume fraction. The stress-strain curves of hybrid composites with different glass volume fractions show an inflection point as observed by
Short and Summerscales [14]. The stress-strain curve becomes more brittle as the content of glass fibre increases. As the content of the low modulus fibre in the composite is greater than the critical content, an inflection occurs in the stress-strain curve, corresponding to the high modulus glass fibre.

![Tensile stress-strain behaviour of intimately mixed banana/glass hybrid composites (30%) with the addition of different percentages of glass fibres](image)

*Figure 5.1. Tensile stress-strain behaviour of intimately mixed banana/glass hybrid composites (30%) with the addition of different percentages of glass fibres*

The variation of tensile modulus and tensile strength of banana/PF composites with varying glass volume fraction when total volume fraction of two fibres is kept constant are shown in Figure 5.2.
Figure 5.2. Variation of tensile properties of banana /PF composites (30%) with the addition of glass fibre

The modulus values are found to increase with increase in glass fibre volume fraction. Glass fibre has a greater tensile modulus than banana fibre and incorporation of high modulus glass fibre increases the tensile modulus of the composite. Incorporation of even 0.09% of glass fibre was found to have more than 100% increase in the tensile modulus compared to banana/PF composite of same volume fraction.

Tensile strength of the samples increased linearly with the increase in glass volume fraction. Occurrence of a hybrid effect negative or positive will depend on the relative volume fraction of two fibres [15]. Analysis of fracture surface of samples subjected to tension revealed that the fracture of sample was proceeded by the failure of glass fibre, the low elongation component in the hybrid. As a result, the tensile strength of the hybrid composite uniformly increases with glass fibre content. However, at relatively higher glass content failure by delamination occurs and tensile strength value showed a slight decrease. When the volume fraction of glass fibre was changed from 0.26 to 0.35, the tensile strength value
showed a slight decrease. This is because at higher volume fraction of glass fracture occurs in the composite mainly by interlayer delamination.

Scanning electron micrographs of the tensile fracture surfaces of banana fibre reinforced phenol formaldehyde composites and glass fibre reinforced composites are shown in Figure 5.3. From the figure it is clear that there is very good adhesion in banana/PF system while the interaction between the glass fibre and PF resin is very poor. So the more prominent fracture mechanism in banana/PF composites was fibre fracture while in glass fibre system, the fibre was pulled out of the matrix easily.

![Figure 5.3 Scanning electron micrographs of tensile fracture surfaces of (a) glass/PF and (b) banana/PF composites showing a strong interface in banana/PF system](image)

Figures 5.4a, 5.4b and 5.4c show the fracture surface of hybrid composites having 9%, 12% and 35% of glass fibre. In Figure 5.4a, there is only a little amount of glass fibre and the system seems to be like one having single type of fibre. Similar is the case with Figure 5.4b also, which contain 12% glass fibres. But as the glass fibre content increases the chance of delamination also increases. In Figure 5.4c, where the glass fibre content is raised to 35%, layering out of the composite occurs and the composite failure is mainly by interlayer delamination.
Figure 5. 4 Scanning electron micrographs of tensile fracture surfaces of banana/ PF composites (30%) with the addition of glass fibres (a) 9%, (b) 12%, and (c) 35% glass fibre

5.1.2 Flexural properties

Flexural strength is a combination of tensile and compressive strengths, which directly vary with interlaminar shear strength. Just like tensile
properties, the flexural strength and modulus values of banana/PF composites with increasing glass fibre concentration are shown in Figure 5.5.

![Graph showing flexural strength and modulus vs. volume fraction of glass fibre](image)

**Figure 5.5. Influence of glass fibre volume fraction on flexural properties of banana/PF composites (30%)**

The flexural strength values are found to increase with increase in amount of glass fibre. Maximum value of flexural strength and modulus is obtained at 26% of glass. Further increase of glass fibre addition decreased the flexural properties of the composites.

### 5.1.3 Impact properties

The impact strength of fibre-reinforced composite depends on many factors like nature of constituents, fibre/matrix adhesion, the construction and geometry of the composite and test conditions. The energy dissipation mechanism in fibre-reinforced composites is believed to be fibre pull out [16]. The applied load transferred by shear to the fibers, may exceed the fibre/matrix interfacial bond and debonding may occur. The frictional force along the interface may transfer the stress to the debonded fibre. If the fibre stress level exceeds the fibre strength, fibers may fracture. The fractured fibers may be
pulled out of matrix, which involves energy dissipation [17]. Variation of impact strength of the banana fibre composites with increasing glass volume fraction is shown in Figure 5.6. The impact strength of banana/glass/hybrid composite was found to increase with increasing volume fraction of glass fiber. Misra et al. [18] observed 34% increase in impact strength by the addition of 8.5% glass fibres in sisal fibre reinforced polyester composites. Due to the surface smoothness and regular cross section of glass fibres they can be easily pulled out of the matrix while in banana fibre such a mechanism is not favored due to the mechanical interlocking between fibres and matrix. It was observed that the energy dissipated by fibre fracture was small in hybrid composites of banana fibre and glass fibre.

Figure 5.6. Variation of impact strength with glass fibre loading in banana fibre/PF composites (30%)

5.2. Effect of banana glass layering

5.2.1. Tensile properties

Hybrid composites of various layering patterns were prepared by keeping total volume fraction of fibres in the composite as 0.3 and banana fibre and glass fibre in the ratio 78:24. Figure 5.7 shows the tensile strength values of the different layering patterns. Among these layering patterns the highest
tensile strength is found in the intimate mixture of the two fibres. When banana fibre and glass fibre are intimately mixed, failure by delamination will be more difficult to occur because of greater energy involved in creating large amount of a new surfaces in an intimate mix than that is required to cause delamination in a layered hybrid. The tensile strength value was found to be 63% higher in intimately mixed composite than that of a bilayer composite of both the fibers. Comparing the tensile strength of various layered hybrids it was found that the higher the number of layers present, the higher is the tensile strength. The tensile modulus was found to be the maximum for the one having higher number of layers present and minimum for BGB arrangement. This is based on the chances of delamination in hybrid composites.

![Figure 5.7. Tensile properties of banana/glass hybrid composites (30%) having various layering patterns](image)

The scanning electron micrographs of the tensile fracture surfaces of the hybrid composites with different layering patterns are shown in Figure 5.8.
Hybrid fibre...

Figure 5.8. Scanning electron micrographs of tensile fracture surfaces of banana/glass hybrid PF composites (containing 26% glass fibre) with different layering patterns (a) GB, (b) BGB and (c) intimate mixture of B&G
In GB and BGB arrangement there was interlayer delamination as is evident from Figures 5.8a and 5.8b. The chance for interlayer delamination decreases as the number of layers increases. But the fracture mechanism in intimately mixed composite was different. There is no chance for interlayer delamination here. In the Figure 5.8c, a crack initiates in the interface and propagates through the matrix to the fibres. Due to this stress concentration in the fibre/matrix interface, some of the fibres are pulled out of the matrix and some others undergo fracture. These fractured fibres can also carry some load before the ultimate failure of the composite. So the intimately mixed fibres can withstand stress to greater extent than the layered composites.

### 5.2.2 Flexural Properties

The flexural strength and modulus of composites with banana fibre and glass fibre in the ratio 74:26 are given in Figure 5.9. The flexural strength was found to be the maximum in the composites in which glass and banana fibres were arranged as interleaving layers (GBGBG arrangement). This is due to small core thickness of each layers, which reduces the crack propagation. As the number of layers in composites decreased the flexural modulus value is was found to have a different trend. The modulus was maximum in composites with glass fibre at core and banana fibre at periphery and minimum value was obtained in the one having only two layers.
5.2.3 Impact properties

Figure 5.10 shows that the layering pattern is having considerable dependence on the impact strength of the fibers. The highest impact strength was obtained when banana fibre and glass fibre were kept as interleaving layers due to the small core thickness. When a crack tip approaches a fibre, the crack crosses the fibers and cuts them as well as the matrix. Then the crack changes its direction and moves through the matrix parallel to the fibers. The impact strength showed a decrease with decreasing number of layers. Intimately mixed composites are found to have lowest impact strength. Harris and Bunsell [15] have also reported the inferior impact properties of intimately mixed hybrid composites due to finer state of subdivisions.
5.10. Influence of glass fibre layering on impact strength of the banana/glass hybrid PF composites (30%) with different layering patterns

5.3 Theoretical Modeling

Several theories have been proposed to model the tensile properties of composite material in terms of different parameters. For determining the properties of randomly oriented fibres in a rigid matrix, series and Hirsch's model are useful [Chapter 3].

Hybrid reinforcing effect of the two fibres has been theoretically calculated. The law of additive rule of mixtures was used to calculate the hybrid effect. The rule is given by

\[ X_H = X_1 V_1 + X_2 V_2 \]  \hspace{1cm} (5.1)

where \( X_H \) a characteristic property of hybrid, \( X_1 \) and \( X_2 \) characteristic properties of individual composites, \( V_1 \) and \( V_2 \) volume fractions of each reinforcement in the composite. Figure 5.11 shows the experimental and theoretical tensile strength values of the hybrid composites. The values obtained from series model were found to be lower than that of the
Experimental values. The experimentally obtained tensile strength values were found to fit with Hirsh's model. A positive hybrid effect was observed in the hybrid composites.

![Diagram](image)

**Figure 5.11.** Experimental and theoretical tensile strength values of banana/glass hybrid fibre reinforced phenolic composites (30%)

**References**


15. B Harris, AR Bunsell. Composites, 6 (1975) 197

