A REVIEW OF BANANA PSEUDO-STEM FIBRE REINFORCED COMPOSITES

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ABSTRACT

The use of banana pseudo-stem fibre as reinforcing agent in polymer based composites is reviewed from viewpoints of status and future expectations of natural fibres in general, composition and physical properties of banana pseudo-stem fibre, fibre surface modifications, and mechanical properties of banana pseudo-stem fibre based polymer composites. The use of banana pseudo-stem fibres as a source of raw material in plastic industry not only provides a renewable resource, but could also generate a non-food source of economic development for farming and rural areas.

Keywords: *Banana pseudo-stem fibres, fibre-matrix interaction, mechanical properties*

INTRODUCTION

Economic and other related factors in many developing countries where natural fibres are abundant demand that scientists and engineers apply appropriate technology to utilize these natural fibres as effectively and economically as possible to produce good quality fibre reinforced polymer composites for housing and other needs. Among the various natural fibres, banana *Musa sapientum* (L) pseudo-stem is of particular interest; in that its composites have high impact strength besides having moderate tensile and flexural properties compared to other lignocellulosic fibres. The present paper surveys the research work published in the field of banana pseudo-stem fibre reinforced polymer composites with special reference to the structure and properties of banana pseudo-stem fibre, processing techniques, and the physical and mechanical properties of the composites.

Cellulosic fibres like banana pseudo-stem, sisal, palms, bamboo, wood in their natural condition, as well as several waste cellulosic products such as shell flour, wood flour and pulp have been used as reinforcement agents of different thermosetting and thermoplastic resins (George *et al.* 2001, Pothan *et al.* 2003, Varghese *et al.* 1994, Mi *et al.* 1997). During the transformation of the raw fibres into cordage, approximately 10% of waste fibres are produced. These waste fibres can be profitably used in the manufacture of fibre polymer reinforced composites because they posses attractive physical and mechanical properties (Coutinho *et al.* 1997). They impart the composite high specific stiffness and strength, a desirable fibre aspect ratio; they are biodegradable and are readily available from natural sources and, more importantly, they have a low cost per unit volume.

Unlike the traditional engineering fibres, e.g. glass and carbon fibres, along with mineral fillers, these lignocellulosic fibres are able to impart to the composite certain benefits such as: low density; less machine wear than that produced by mineral reinforcements; minimal health hazards; easily biodegradable and a high degree of flexibility. The latter is especially true because these fibres, unlike glass fibres will bend rather than fracture during processing. Whole natural fibres undergo some breakage while being intensively mixed with the polymeric matrix, but this is not as notorious as with brittle or mineral fibres (Wambua *et al.* 2003).

The present work in the field of banana pseudo-stem fibre reinforced composites with special reference to the composition and physical properties of banana pseudo-stem fibre, fibre surface modifications, and mechanical properties of banana pseudo-stem fibre polymer composites would be initiated.

Research background

Natural fibres like sisal, jute, coir, oil palm fibre have all been proved to be good reinforcement in thermoset and thermoplastic matrices (Joseph *et al.* 1996, Nishinoa *et al.* 2003, Geethamma et al. 1998). The idea of using natural fibres as reinforcement in composite materials is not a new or recent one. Man has used this idea, since the beginning of our civilization when grass and straw were used to strengthen mud bricks. During the seventies and eighties, these cellulose fibres were gradually substituted by newly developed synthetic fibres

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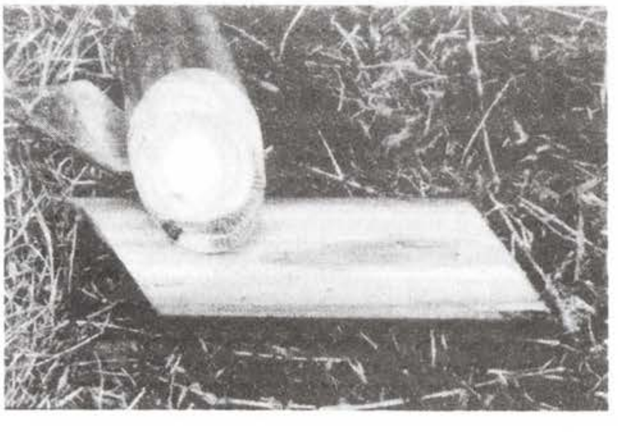
because of their better performance (Bledzki and Gassan 1999). Then, the use of cellulose fibres has been limited to the production of rope, string, clothing, carpets and other decorative products (Joseph *et al.* 1999). However, over the past few years, there has been a renewed interest in using these fibres as reinforcement materials to some extent in the plastics industry. This resurgence of interest is due to the increasing cost of plastics, and also because of environmental concerns for using renewable and biodegradable materials (Sapuan *et al.* 2001, Muhammad 2004).

Among the various natural fibres, banana pseudo-stem is of particular interest in that its composites have high impact strength besides having moderate tensile and flexural properties compared to other lignocelluloses fibres (Pothan *et al.* 2003). This agricultural activity generates a large amount of residues, because each plant produces only one bunch of banana, after its harvesting the bare pseudo-stems are cut and usually left to decompose. Thus, it could be estimated that few tons per hectare are produced annually (Sinha 1982). These crops could be utilized as a source of cellulosic fibres in papermaking and as reinforcing fibres in composite materials.

Structure and properties of banana pseudo-stem fibre

The cellulosic fibres obtained from the pseudo-stem (Figure 1) of banana plant is a bast fibre with relatively good mechanical properties. Banana contains fibres in the pseudo stem which may be extracted by scraping with a blunt knife or by using an extractor machine. The fiber is coarser than jute, has a non-mesh structure and long filaments with good strength and greater extension than those of jute (Paul 1980). Drying of fibres before processing is an important factor, because water on the fibre surface acts likes a separating agent in the fibre–matrix interface. This phenomena lead to a decrease of mechanical properties of natural fibre reinforced composites if it is not properly controlled. Therefore, fibre drying can be done in a vacuum stove at different temperatures. This results in different degrees of loss of humidity (Bledzki and Gassan 1999).

Figure 1. **Banana pseudo-stem (*Musa sepientum*[L])**



The properties and performance of a given agro-based fiber depends on chemical composition and the physical properties (Table 1 and 2). What part of the plant the fiber came from, the age of the plant, and how the fiber was isolated, are some of the factors which affect the performance of those fibres in a composite. Even with the data available, it has been collected under different laboratory conditions and, therefore, it is impossible to compare one set of data with another set. This information is critical before agro-based fibres will reach their highest potential (Joseph *et al.* 1999)

The importance of research

Sapuan *et al.* (2001) observed that plant based fibre reinforced composites to be potentially good alternative to conventional fibre reinforced composites. The fibre which serves as a reinforcement in reinforced plastics may be synthetic or natural. Although glass and other synthetic fibre-reinforced plastics possess high specific strength, their fields of application are very limited because of their inherent higher cost of

Table 1. **Details of composition analysis of banana pseudo-stem fibres (Sinha 1982)**

Composition	Banana-fibre
Major constituents (% of dry fibre)	
Holocelulose	88.7
α-cellulose	61.5
Lignin	9.7
Pentosan	14.9
Uronic anhydride	5.3
Pectin	1.6
Acetyl content	2.8
Minor constituents (% dry fibre)	
Fat and wax	1.3
Nitrogen matter	1.6
Ash	4.7
Other parameters	
Loss on water boiling	2.5
Loss on 1% alkali boiling	28.6
DP of α-cellulose	1300
Ultimate all length (mm)	0.9-4.0
Ultimate all diameter 10^{-4} cm	12-33
L/B ratio	100

Table 2. **Physical properties of banana pseudo-stem fibres (Sinha 1982)**

Physical characteristics	Banana fibre
Single fibre tenacity (gf per tex)	50 (17.0-78.8)
Single fibre extension at Break (%)	2.5 (1.5-3.4)
Fibre bundle tenacity (gf per tex)	28.4 (22.0-33.4)
True density (g cm^{-3}	1.31
Apparent density (g cm^{-3}	0.62
Fibre porosity (%)	53
Uncombed linear density (tex) of 2 mm cut length	10.5 (30-12.0)
Flexural rigidity (dyn cm-2)	33 (20-50)
Moisture regain at 65% Relative humidity (%)	15-2
Length of raw fibre (cm)	85 (45-100)

production. Some of these natural fibres are not only strong and lightweight but also relatively cheap (Paramastvam and Kalam 1974).

These fibres, which are available in bulk due to the increasing cultivation of banana needs immediate attention for their exploitation. Investigations on banana pseudo-stem fibre clearly indicate that these agro wastes can be suitably processed into useful products. Banana pseudo-stem fibre can also be used, as is evident from its chemical nature, as a cellulosic raw material for paper, board, cellulose derivatives, etc.

Their proper use will improve the economy of cultivation of the fruits and benefit farmers. They will also satisfy the need of plastic product based industries for raw materials or supplement the growing demand for industrial fibres and do away with the necessity of bringing in additional land for their production. The prerequisites for channelling the fibres to industry are: (i) the optimisation of the properties of the fibre, as well as its yield, by following improved techniques of fibre extraction; (ii) a steady bulk supply; (iii) development of a processing technology for the fibres; (iv) and development of a market for the products (Sinha 1982).

Research on banana pseudo-stem fibres composites

The mechanical properties of the natural fibre composites tested were found to compare favourably with the corresponding properties of glass fiber polypropylene composites. The specific properties of the natural fibre composites were in some cases better than those of glass (Table 3). This suggests that natural fibre composites have a potential to replace glass in many applications that do not require very high load bearing capabilities.

Banana pseudo-stem fibre is comparable to fibres of other agricultural crops, such as sisa and pineapple

Table 3. **Comparison between natural and glass fibres (Wambua *et al.* 2003)**

Properties	Natural fibres	Glass fibres
Density	Low	Twice that of natural fibres
Cost	Low	Low, but higher than NF
Renew-ability	Yes	No
Recycle-ability	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 4). The influence of fibre content and fibre length from banana pseudo-stem fibres epoxy composites were examined by Bledzki and Gassan (1999) and it was found that in glass-fibre-reinforced polypropylene, the impact strength increases with increasing fibre length.

Fibre-matrix interaction

Franco and Gonzalez (2004) studied the mechanical behavior of continuous natural fiber reinforced composite and found that the fiber-matrix interaction were changed by modifying the surface properties of the fiber. Firstly, the area of contact was increased, then the cellulose microfibrils were exposed to improve fibre wetting and impregnation. To improve the adhesion between the cellulosic fibres and the polymer, different authors have suggested various chemical modifications (Botaro and Gandini 1998).

However, plant based fibre reinforced composites require surface treatment (fibre surface treatment by bonding/coupling agent) for better performance, especially fibre resin interfacial bonding. Pothan and Thomas (2003) concluded that composites with better modulus and low damping ideal for use as a substitute

Table 4. **Mechanical properties of natural fibres and work of fracture of their composites Joseph *et al.* 1999).**

Fibre Properties				Composite Properties	
Fibre Type	Tensile Strength	Elongation (%)	Toughness (MM m^{-2})	Fibre Pull-out Layer (mm)	Work of (KJ m^{-2})
Sisal	580	4-3	1250	3.5	98.7
Pineapple	640	2.4	970	2.2	79.5
Banana	540	3.0	816	1.9	51.6

for building material can be developed from banana pseudo-stem fibre and polyester resins by the judicious control of the interphase chemistry. Silane A174 was found to be an ideal coupling agent for improving fibre-matrix adhesion in banana-polyester system. Joseph *et al.* also (2002) found that interfacial shear strength values obtained from single fibre pull out test reveal that the interlocking between banana pseudo-stem fibre and phenol formaldehyde resin is much higher than that between glass and phenol formaldehyde resin.

Mechanical properties

Pothan *et al.* (2003) found that the dynamic mechanical properties of short banana pseudo-stem fibre reinforced composites are greatly dependent on the volume fraction of the fibre. The maximum improvement in properties is observed for composites with 40% fibre loading, which is chosen as the critical fibre loading. Another study leaded by O'Donnell *et al.* (2004) found that natural composites were found to have mechanical strength suitable for applications such as housing and automotive. It is also suggested that this composites study still need further investigation in order to monitor the post-curing behaviour and degradation over a long period of time (aging).

The stress relaxation behaviours of banana pseudo-stem fibre-reinforced polyester composites have been found to be dependent on the amount of banana pseudo-stem fibre. The rate of stress relaxation was found to be at a maximum during the initial stages. Incorporation of fibre reduced the rate of stress relaxation and the highest reduction was observed in the case of composites with the highest fibre loading (Pothan *et al.* 2004).

Zhu and Tobias (1994) found that a pulped banana fibre is a satisfactory fibre for incorporation into a cement matrix suitable for use as building material. In term of design, Sapuan and Maleque (2005) employed a systematic approach of total design process in the fabrication of natural woven fabric reinforced epoxy composite for household telephone stand.

Mechanical analysis of short randomly oriented intimately mixed banana/sisal hybrid fibre reinforced polyester composites was investigated by Idicula *et al.* (2005) with special reference to the total volume fraction of the fibre and varying the relative volume fraction of the two fibres. The tensile strength, tensile modulus, flexural, strength, flexural modulus and impact strength of the composites at different volume fraction of fibres are outlined in Table 5. All this behaviour shows that effective stress-transfer and fibre/

Table 5. **Mechanical properties of banana/sisal hybrid composites having different volume fraction of the fibres (Idicula *et al.* 2005).**

Volume fraction of The fibre (banana + sisal).	Tensile strength (MPa)	Tensile Modules (MPa)	Flexural Strength (MPa)	Flexural Modules (MPa)	Impact Strength (MPa)
0.19	39	1347	48	2247	16
0.32	51	1443	53	2376	32
0.40	57	1601	62	2842	36
0.48	58	1597	56	2950	38

matrix interaction takes place at a fibre loading of 0.40 volume fraction.

CONCLUSION

Mechanical properties of short banana pseudo-stem fibre reinforced composites are greatly dependent on the volume fraction of the fibre. The optimum improvement in properties is observed for composites with 40% fibre loading, which is chosen as the critical fibre loading. The mechanical properties of composites are influenced mainly by the adhesion between matrix and fibres. As in the case of glass-fibres, the adhesion properties can be changed by pretreating the fibres. So, special processings, such as chemical and physical modification methods should be developed. Banana Pseudo-stem Fibre Polymer Composites With And Without Hybridization Should Be Developed And Characterized So As To Arrive At A Series Of Composites Which May Find Use In Several Areas Such as Structural, Consumer Articles and Industrials Applications.

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