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Study on physical and mechanical properties of NFRP hybrid composites

R Prasanna Venkatesh[1]*, K Ramanathan[2] & S Rama Krishnan[3]

[1]Anna University, Chennai, Tamilnadu, India

[1,3]Department of Automobile Engineering, SACS MAVMM Engineering College, Madurai 625 301, Tamilnadu, India

[2]Department of Mechanical Engineering, A C College of Engineering and Technology, Karakudi 630 004, Tamilnadu, India

*E-mail: pvprasan@gmailcom, krishrain2@rediffmail.com, ramsananthi@gmailcom

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The tensile, flexural, impact properties and water absorption tests were carried out using sisal/unsaturated polyester composite material. Initially, optimum fiber length and weight percentage were determined. To improve the tensile, flexural, impact properties, sisal fiber was hybridised with bamboo fiber. This work showed that addition of bamboo fiber in sisal/ unsaturated polyester composites of up to 50% by weight results in increasing the mechanical properties and decreasing the moisture absorption property. Morphological analysis was carried out to observe fracture behaviour and fiber pull-out of the samples using scanning electron microscope.

Keywords: Hybrid composites, Sisal fiber, Bamboo fiber, Unsaturated polyester resin

1 Introduction

Natural fiber composites have become a popular new material because of their low raw material cost, easy availability, better strength stiffness, recycle, renewable and environmental friendliness[1-3]. Natural fiber composites are likely to be environmentally superior to glass fiber composites in most cases and natural fiber production has lower environmental impacts as compared to glass fiber production[4]. Hybridization on tensile properties of sisal, bamboo fibers with epoxy resin has been studied by Girisha *et al*[5]. They observed that the alkali treatment of the natural fibers was to get with moderate mechanical properties as well as better adhesion between fibers and matrix Muralimohanrao *et al*[6]. investigated the mechanical properties of vakka, sisal, bamboo and banana fibers with unsaturated polyester resin. In their work, they have concluded that the tensile strength and flexural modulus of the bamboo fiber are better than others.

The strength and modulus of the longitudinal composites in tensile and flexural loading have increased with fiber content as predicted in accordance with the rule of mixtures. The mechanical properties of jute fiber unsaturated polyester composites prepared by solution impreguation and hot curing methods have been studied[7].

The sisal reinforcement can be used as short randomly distributed fibers, long oriented fibers, or as a fiber fabric sisal fibers (Agave sisalana) are extracted from sisal plant leaves. The sisal leaf consists of a sandwich structure composed of approximately 4% fiber, 1% cuticle, 8% dry matter and 87% water[8]. The tensile properties of sisal fiber have been studied by Flavio *et al*[9]. They observed that the failure of sisal fiber in tension is due to pull-out of microfibrills accompanied by tearing of cell wall. The tendency for fiber pull-out decrease with increasing speed of testing Venkateshwaran *et al*[10]. have investigated the mechanical and water absorption properties of banana/sisal hybrid composites with epoxy resin. They observed that the hybridization of banana/sisal composites properties were better than banana/epoxy composites.

Kasama *et al*[20]. investigated the effect of glass fiber hybridisation on properties of sisal-polypropylene composites. Polypropylene grafted with maleic anhydride (PP-g-MA) was used as a compatibilizer to enhance the compatibility between the fibers and polypropylene. Incorporation of glass fiber increases the mechanical, thermal and water resistance properties. Sreekala *et al*[27]. observed the mechanical properties of oil palm fiber with glass fiber and phenol formaldehyde as resin. The investigation revealed that maximum mechanical performance occurs at 40 wt% loading.

The natural fiber composites have been developed from the most widely available sisal fiber and bamboo fibers, which are normally used in yarns, ropes, twins, carpets, mats and handicrafts in the present study. The mechanical and water absorption properties of sisal/bamboo fibers reinforced unsaturated polyester composites and the effect of fiber loading (fiber percentage) have been studied in the present paper.

The experiments were initially conducted for predicting the fiber length and weight percentage which enables maximum mechanical properties in sisal/unsaturated polyester composites. Composite specimens were prepared by varying the fiber length (5, 10 and 15 cm) and weight percentages (10, 15 and 20). Further, to improve the mechanical properties of the sisal/unsaturated polyester composites, bamboo fibers were added at different weight ratio (25, 50 and 75%). Hybridisation by bamboo fibers yields positive improvement in mechanical properties.

2 Experimental Details

The matrix material used was based on commercially available unsaturated polyester resin supplied by GV Traders, Madurai. The resin has 1258 kg/m^3 density, 500 cps viscosity at 25°C and 35% monomer content. Methyl ethyl ketone peroxide (MEKP) and cobalt naphthanate were used as accelerator and catalyst, respectively.

Sisal fiber is collected from various local sources whereas bamboo fiber is extracted in the laboratory using retting and mechanical extraction procedure. The extraction of bamboo fiber was explained in the earlier work[11]. The density and tensile properties of sisal and bamboo fibers[8,15-17,28] have been summarized in Table 1 for better comparison.

Mould used in this work is made of well-seasoned teak wood of dimension 250×250×3 mm with eight beadings. Casting of the composite material was done in this mould by hand lay-up process. The top, bottom surfaces of the mould and the walls are coated with remover and allowed to dry. The functions of top and bottom plates are to cover, compress the fiber after the unsaturated polyester is applied, and also to avoid the debris from entering into the composite parts during the curing time.

Table 1 — Properties of sisal and bamboo fiber

Properties	Sisal fiber	Bamboo fiber
Density (kg/m^3)	1450	910
Tensile strength (MPa)	68	74
Young's modulus (GPa)	9-20	35-46
Elongation at break (%)	3-14	1.4
Diameter (μm)	80-300	88-330
Moisture content (%)	10	11.7
Flexural modulus (GPa)	12.5-17.5	16.2

Fibers of different lengths (5, 10 and 15 cm) and weight percentages (10, 15 and 20) were mixed with unsaturated polyester for the initial preparation of composites. The moulds are cleaned and dried before applying unsaturated polyester. The fibers were laid uniformly over the mould before applying any releasing agent. After arranging the fibers uniformly, they were compressed for a few minutes in the mould. Then the compressed form of fibers (sisal and sisal/bamboo) is removed from the mould. This was followed by applying the releasing agent on the mould, after which a coat of unsaturated polyester was applied. The compressed fiber was laid over the coat of unsaturated polyester, ensuring uniform distribution of fibers. The unsaturated polyester mixture is then poured over the fiber uniformly and compressed for a curing time of 30 h. After the curing process, test samples were cut to the required sizes prescribed in the ASTM standards[10].

3 Testing of Composites

3.1 Tensile, flexural and impact testing

After fabrication, the test specimens were subjected to various mechanical tests as per ASTM standards. The standards followed are ASTM D638–03 for tensile test[12]. The flexural strength[13] was determined as per ASTM D790 procedure. Both tensile and three-point bending test were carried out using computerized FIE universal testing machine. The impact strength of the composite specimens was determined using an Izod impact tester as per ASTM D 256 Standard[14]. Machine used for this purpose is Ceast Torino, Italy. In each case, five specimens were tested to obtain the average value.

3.2 Determination of water absorption of composites

The water absorption characteristics of sisal/bamboo hybrid fiber reinforced unsaturated polyester composite were studied[18] as per ASTM570 by immersion in distilled water at room temperature. The samples were taken out periodically and weighed immediately, after wiping out the water from the surface of the sample and using a precise 4-digit balance to find out the content of water absorbed. Water absorption can be calculated by the following formula:

$$\text{Moisture absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$

where W_1 and W_2 are the weight of the dry and wet samples, the percentage of moisture absorption was

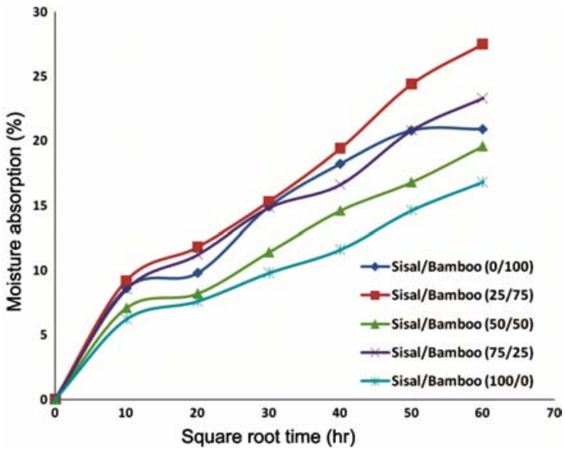

Fig. 1 — Water absorption characteristics of hybrid composites

Table 2 — Tensile, flexural, impact and moisture properties of hybrid composite

Fibre content sisal/bamboo	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (KJ/m^2)	%Water absorption at infinite time
100/0	19.62	54.12	14.82	20.921
75/25	21.54	53.12	17.02	27.523
50/50	23.42	56.71	19.12	19.620
25/75	23.54	57.81	19.71	23.323
0/100	23.11	55.36	19.73	16.832

Table 3 — Effects of fiber length and weight percentage on mechanical properties of sisal/unsaturated polyester composites

Fibre length (cm)	Fibre weight (%)	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (kJ/m^2)
	10	12.81	29.42	5.12
5	15	17.62	38.12	5.82
	20	15.32	43.15	6.92
	10	10.51	24.52	8.12
10	15	14.82	36.21	11.12
	20	19.82	42.15	10.89
	10	13.61	28.12	9.54
15	15	18.12	38.42	12.14
	20	19.62	54.12	14.82

plotted against the square root of time (hours) as shown in Fig. 1. Figure 1 shows that for all ratios of composites: moisture absorption becomes stable after 55 h. Table 2 presents the hybrid composite of 50:50 percentage, has the lowest water uptake and permeability coefficient.

4 Results and Discussion

4.1 Mechanical properties of sisal/unsaturated polyester composite

When increasing the fiber length and fiber content, the mechanical properties also increase up to certain limit which is clearly evident from Table 3. Further, addition of fiber content will be the cause for the poor

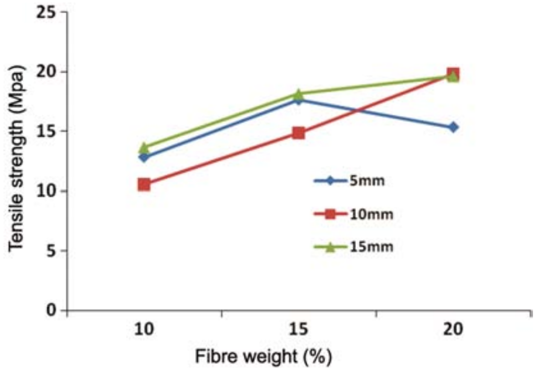

Fig. 2 — Tensile properties of sisal/polyester composites

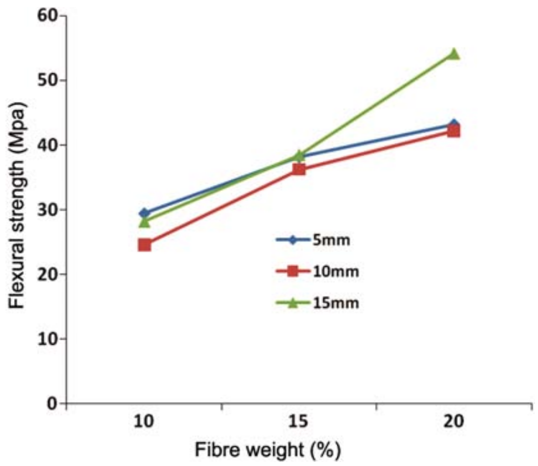

Fig. 3 — Flexural properties of sisal/polyester composites

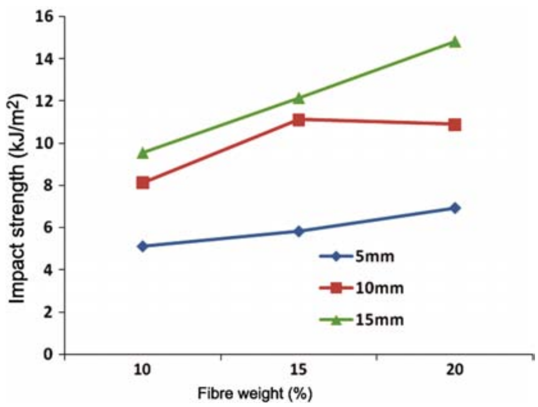

Fig. 4— Impact properties of sisal/polyester composites

interfacial bonding between fiber and matrix and hence mechanical properties will decrease beyond this limit. The effect of fiber length and fiber content on mechanical properties such as tensile strength, flexural strength and impact strength is shown in Figs 2-4. It is evident from the Figs 2-4 and Table 3 that maximum tensile strength is observed as 19.82 MPa, maximum flexural strength as 54.12 MPa and the maximum impact strength as 14.82 kJ/m2. These mechanical properties are for the fiber length of 10, 15 and 15 cm, respectively and the weight percentages of 20 for all cases. Table 3 presents the maximum tensile properties provided by 10 cm fiber length and 20% weight is almost very close to the tensile properties offered by 15 cm fiber length and 20% weight. Hence, 15 cm fiber length and 20% weight are chosen as the fiber length and weight percentage which provide maximum mechanical properties for the case of sisal-unsaturated polyester composite. The mechanical properties for this length and weight percentage are 19.62 MPa for tensile strength, 54.12 MPa for flexural strength and 14.82 kJ/m^2 for impact strength.

4.2 Mechanical properties of sisal/bamboo composites

In order to improve the mechanical properties of the sisal/unsaturated polyester composite, bamboo fiber was added to bring the hybrid effect. From the results of pure sisal/unsaturated polyester composites, the fiber weight of the composite was fixed to 20% and fiber length to 15 cm. Within this fiber weight percentage, the bamboo fiber percentage is varied in the range 0-100%. Results of hybridisation are tabulated in Table 2 and it was shown in Fig. 5 graphically. From Table 2, it can be observed that the addition of bamboo enables increased mechanical properties at 75% of hybridisation whereas water absorption behaviour was low at 50% hybridisation. The enhanced mechanical properties obtained at 75% hybridisation are very close to the results obtained at 50% hybridisation. Considering the water absorption behaviour and mechanical properties as equally important parameters, the optimum condition can be interpreted as 50% bamboo addition. At this condition, it can be observed that the tensile strength, flexural strength and impact strength are increased to around 19%, 5% and 29%, respectively.

4.3 Scanning Electron Microscopy Analysis

Interfacial properties, such as fiber–matrix interaction, fracture behaviour and fiber pull-out of samples after mechanical tests were observed using Hitachi–S3400N scanning electron microscope (SEM).The SEM micrograph of the surfaces was used for direct observation of composite structure and particularly to examine the resin-fiber interface Fig. 6. is the micrographs of fractured specimen of tensile, flexural and impact test. The SEM micrographs indicate the phenomenon of 'pull-out' occurred to a greater extent causing the failure of material. The image analysis also shows the formation of voids due to fiber pull-out. Further, due to absence of fiber-matrix interaction, the fibers tend to agglomerate into

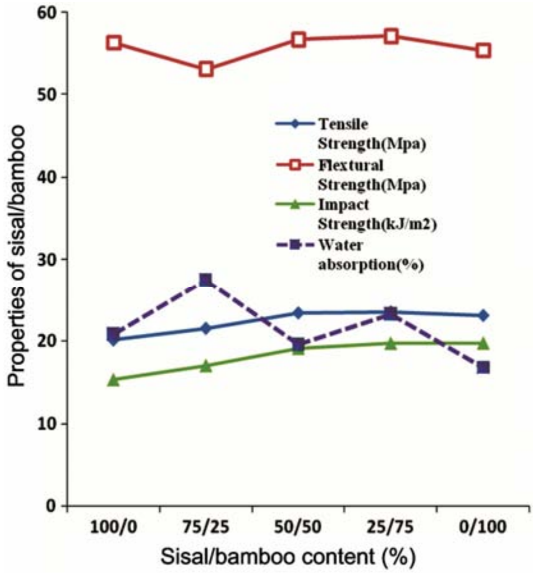

Fig. 5 — Mechanical properties of sisal/Bamboo composites

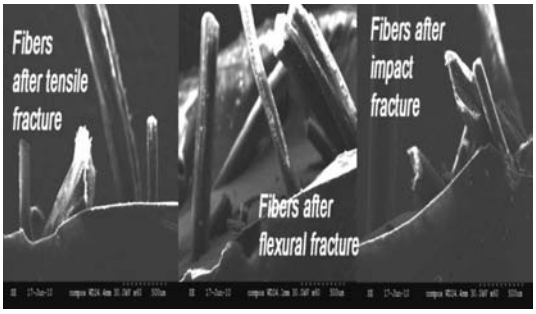

Fig. 6 — SEM micrographs of fractured surface of 50/50 hybrid composite after tensile, flexural, impact test

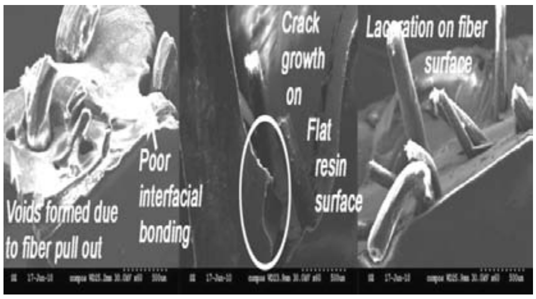

Fig. 7 — SEM micrographs of fractured surface of 50/50 hybrid composite with weak surface

bundles and become unevenly distributed throughout the matrix. Poor interfacial bonding between fiber and matrix is clearly evident from Fig. 7 resulting in low mechanical property when compared with glass fiber composite[27].

5 Conclusions

The effect of hybridisation of sisal fiber on the mechanical properties and water absorption property has been studied. When increasing the fiber length and fiber content to sisal/unsaturated polyester natural fiber composites, mechanical properties were increased with the fiber content and optimum results of mechanical properties such as tensile strength, flextural strength and impact strength have been noticed as 19.62 MPa, 54.12 MPa and 14.82 kJ/m2, respectively at fiber length of 15 cm and fiber content of 20%. Tensile strength of sisal fiber/unsaturated polyester composite is 50.23% more than palmyra/ polyester composite[19], 25% more than the banana/sisal epoxy resin composites[10], 15.3% greater than the woven banana/epoxy composite[3] and 17% more than sisal empty fruit bunch polyester composite[21].

- Flexural strength of sisal fiber/unsaturated polyester composite is 7% higher than banana empty fruit bunch polyester composite[21], around 11% higher than sisal–silk composite[22], 16% more than hemp–polyester composite[23]. Similarly impact strength is 7% greater than banana/sisal epoxy composites[10].
- The addition of bamboo fiber in the composite increased the mechanical properties than sisal/unsaturated polyester alone. When sisal/bamboo fiber weight percentage is varied from 100/0 to 0/100, 75% of bamboo addition enables increased mechanical properties whereas low water absorption behaviour is noticed at 50% bamboo addition.
- Considering mechanical properties and water absorption behaviour as equally important parameters for the composites, the condition which enables maximum mechanical properties and minimum water uptake is concluded as 50/50 sisal/bamboo hybridization and the results at this condition were 23.42 MPa for tensile strength, 56.71 MPa for flexural strength, 19.12 kJ/m2 for impact strength and 19.62 % for moisture uptake.
- The addition of 50% bamboo fiber in the composite results in 19% increase in tensile strength, 5% increase in flexural strength and 29% increase in impact strength.
- Marginal increases in mechanical properties are due to poor interfacial bonding between matrix and the fiber, which is evident from SEM analysis. Interfacial bonding between fiber and matrix can be improved by chemical treatment/treatment with coupling agent[24,25].
- Hybridisation of natural fiber composite by another natural fiber does not yield superior mechanical properties as hybridisation by glass fiber[20,27] and carbon fiber[26] and hence this kind of hybrid composite is suitable for low cost applications.

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