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Tensile, Flexural, Impact and Water Absorption Properties of Natural Fibre Reinforced Polyester Hybrid Composites

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Abstract

In this paper, tensile, flexural, impact properties and water absorption tests were carried out using sisal/unsaturated polyester composite material. Initially the optimum fibre length and weight percentage are estimated. To improve the tensile, flexural and impact properties, sisal fibre was hybridised with bamboo fibre. This work shows that the addition of bamboo fibre in sisal/unsaturated polyester composites of up to 50% by weight results in increasing the mechanical properties and decreasing the moisture absorption property. In this research work, the effects of fibre treatment and concentration on the mechanical properties of a short natural fibre reinforced polyester hybrid composite are investigated. The fibres were subjected to 10% sodium hydroxide solution treatment for 24 h. The mechanical properties of composites with treated fibres are compared with untreated fibre composites. The fractured surface of the treated fibre composite specimen was studied using Scanning Electron Microscopy (SEM). The treated hybrid composite was compared with an untreated hybrid composite, with the former showing a 30% increase in tensile strength, 27.4% - in flexural strength, and 36.9% - in impact strength, along with an extreme decrease in moisture absorption behaviour.

Key words: hybrid composites; sisal fibre, bamboo fibre, unsaturated polyester resin, alkali treatment.

Introduction

In recent years, natural fibres have been used as reinforcement fillers for thermosetting and thermoplastic matrices to prepare composites by satisfying both economic and ecological interests. But the presence of moisture and defects in the natural fibres affects the mechanical and physical properties of natural fibre polymer composites. Plant fibres can work effectively through the limited and controlled occurrence of defects, which are irregularly spaced along their length. As a result, the tensile strength of the fibres decreases with their length, and a pronounced strain rate effect can also be observed. This also had an effect on the impact properties of plant fibre composites [1, 2, 25].

Natural Fibre Reinforced Polyester (NFRP) composites are likely to be environmentally superior to glass fibre composites in most cases and natural fibre production has lower environmental impacts compared to glass fibre production [3]. The effect of hybridisation on the tensile properties of sisal and bamboo fibres with epoxy resin were studied by C.Girisha et. al [4]. They observed that the alkali treatment of natural fibres achieved moderate mechanical properties as well as better adhesion between fibres and matrix. Studies were made to improve fibre quality or reduce the effect

of the presence of fibre defects on the final material via improved processing or fibre treatment [5, 6]. The improvements in properties, especially stiffness, can be obtained using chemical treatments of fibres [27]. The strength and modulus of the longitudinal composites in tensile and flexural loading increased with fibre content, as predicted with the rule of mixtures. The mechanical properties of jute fibre unsaturated polyester composites prepared by solution impregnation and hot curing methods were studied [7]. Industrial fibre like glass fibre composites will enable properties such as Good mechanical strength, light weight, being easy to shape, resistance to corrosion and chemical attack, and good surface finish. However, it is environmentally hazardous, and hence for the past few decades researchers have been trying to find a suitable alternative composite made up of natural fibres which can provide comparatively good mechanical strength and, at the same time, is environmentally less hazardous, easy available, recyclable, renewable and of low cost. As mentioned above, the work was actually to prepare and find out the mechanical properties and water absorption behaviour of treated Sisal/ bamboo hybrid NFRP composite.

Various surface treatments like sliver bleaching e.g., with alkali (NaOH) or silane coating were studied to reduce the sensitivity of natural fibre composites

to weathering [8 - 10]. The changes in properties of jute fibres were investigated during surface treatment. Alkali jute fibres treated with NaOH solution of 1% and 8% concentration for 48 h and 2% for 1 h showed improvements in fibre properties by 130% and 13%, respectively [28, 29]. Investigations were carried out on the alkali treatment of isometric jute yarns. An improvement of 120% and 150% in the tensile strength and modulus of jute yarns was achieved with 25% NaOH solution for 20 min and a 60% improvement in jute/epoxy composite properties reinforced with treated yarns. The improvements were attributed to the greater reactivity of the fibres treated with the resin, administering superior bonding [30, 31].

Bamboo and sisal fibres are abundant in India. For the last decade, they have been traditionally used in age-old applications in the form of low weight and high strength ropes to lift heavy-weight objects. Consequently these fibres were used as reinforcement for polyester matrices to prepare hybrid composites. Experiments were conducted on composite specimens varying the length of the fibre, such as 5, 10 and 15 cm as well as the percentages of weight, for instance 10, 15 and 20. Bamboo fibres were added with sisal/unsaturated polyester composites to increase the mechanical characteristics of the materials at different weight ratios, such as as 25%, 50% and 75%. The improvement in mechanical characteristics was achieved by bamboo fibres, leading to hybridisation. The main aim of this research work was to analyse bamboo and sisal fibre in the manufacturing of roof sheets, door panels, dashboards, etc in order to avoid glass fibres due to environmental damage. Furthermore this work was extended to improvements in mechanical properties to reduce the moisture absorption of short bamboo and sisal fibre hybrid polyester composites fabricated using alkali treated bamboo and sisal fibres.

Materials and method

Matrix

The matrix material used was based on commercially available unsaturated polyester resin, supplied by GV Traders, Madurai. The resin had 1258 kg/m³ density, 500 cps viscosity at 25 °C and 35% monomer content. Methyl ethyl ketone peroxide (MEKP) and Cobalt naphthan-

Table 1. Properties of sisal and bamboo fiber [12, 19 - 23].

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

ate were used as accelerator and catalyst, respectively.

Fibre preparation

Sisal fibre was collected from various local sources, whereas bamboo fibre was extracted in a laboratory using the retting and mechanical extraction procedure. The extraction of bamboo fibre was explained in detail in an earlier work [11]. The density and tensile properties of sisal and bamboo fibres are summarised in *Table 1* [12, 19 - 23] for better comparison. The nominal mixture ratio of the Resin/hardener/accelerator is 100:90:1

As regards the characteristics of the fibre [24], the water content is high in the fibre. In order to determine the water content in the fibre, the moisture absorption technique [31] was used in this paper. The estimated water content in the fibre was reduced using the alkali treatment of fibres [30].

Experimental set-up specifications

Alkali treatment of bamboo/sisal fibres

A good wetting of the fibres with the matrix was obtained by interfacial bonding and the formation of a chemical bond between the fibre surface and matrix. By imparting hydrophobicity to the fibres by mechanical, surface and chemical treatments, the mechanical properties and environmental performance of the composites were improved. Mwaikambo LY et al. [14] reported that a change in the surface topography of the fibres and their crystallographic structure was achieved by the alkalisation or acetylation of fibres. Treatment with sodium hydroxide was prior to the washing of fibres. The sodium hydroxide opened up the cellulose structure, allowing the hydroxyl groups to get ready for the reactions. During washing with sodium hydroxide, the wax, cuticle layer and part of the lignin and hemi cellulose were removed. A major reaction took place

between the hydroxyl groups of cellulose and the chemical used for the surface treatment. In this contribution, short bamboo and sisal fibres were soaked in a 10% NaOH solution at room temperature. The fibres were kept immersed in the alkali solution for 24 h. The fibres were then washed with fresh and distilled water to remove any NaOH sticking to the fibre surface and neutralised with diluted acetic acid several times. The short bamboo and sisal fibres were then dried at room temperature for 24 h, followed by oven drying at room temperature for 24 h.

Preparation of mould

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

Preparation of composites

Fibres 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 the composites. The moulds were cleaned and dried before applying unsaturated polyester. The fibres were laid uniformly over the mould before applying any releasing agent. After arranging the fibres uniformly, they were compressed for a few minutes in the mould. Then the compressed form of fibres (sisal, untreated sisal/bamboo and alkali treated sisal/bamboo) was 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 fibre was laid over the coat of unsaturated polyester,

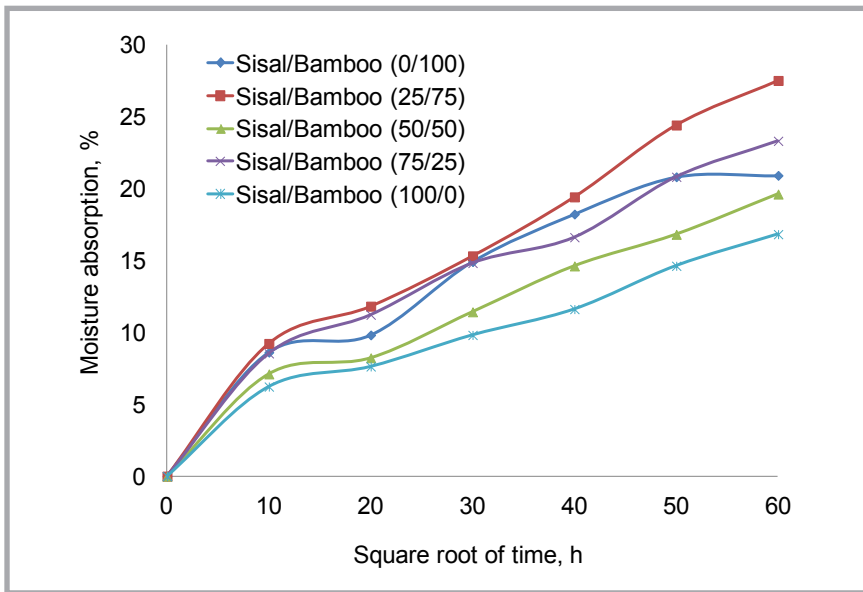


Figure 1. Moisture absorption characteristics of hybrid composites.

Table 2. Effects of fibre length and weight percentage on mechanical properties of sisal/unsaturated polyester.

Fibre length, cm	Fibre weight, %	Tensile strength, MPa	Flexural strength, MPa	Impact strength, KJ/m ²
5	10	12.8	29.4	5.1
	15	17.6	38.1	5.8
	20	15.3	43.2	6.9
10	10	10.5	24.5	8.1
	15	14.8	36.2	11.1
	20	19.8	42.2	10.9
15	10	13.6	28.1	9.5
	15	18.1	38.4	12.1
	20	19.6	54.1	14.8

Table 3. 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	19.6	54.1	14.8	20.9
75/25	21.5	53.1	17.0	27.5
50/50	23.4	56.7	19.1	19.6
25/75	23.5	57.8	19.7	23.3
0/100	23.1	55.4	19.7	16.8

Table 4. Mechanical and moisture absorption properties of treated/untreated hybrid composites.

Fiber content sisal/bamboo (50/50)	Tensile strength, MPa	Flexural strength, MPa	Impact strength, MPa	Water absorption, %
Untreated	23.4	56.7	19.1	19.6
Treated	38.4	78.2	30.3	9.1

ensuring uniform distribution of fibres. At room temperature (31 °C), the curing time of the composite was from 24 to 35 hours [26]. This composite needed 30 hours. The unsaturated polyester mixture was then poured over the fibre 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.

[24], with the surface of the plates nearly smooth.

■ Testing of composites

Tensile, flexural and impact testing

As per ASTM standards, the test specimens underwent a large amount of mechanical tests after the fabrication process was over. ASTM D638-03 [15]

standards were used for the tensile test. The ASTM D790 [16] procedure was used for flexural strength determination. A computerised FIE (FUEL INSTRUMENTS & ENGINEERS PVT. LTD, made by India) universal testing machine was used for computation of the tensile and three-point bending tests. The ASTM D 256 Standard [17] was used for the composite specimen's determination. A Ceast Torino Machine was used in this paper, which was made in Italy. In each case, five specimens were tested to obtain the average value. The cut surface of the composite did not have a completely smooth surface.

Determination of water absorption of composites

Standard ASTM570 [18] was used in this paper to study the water absorption characteristics of untreated and treated sisal/bamboo hybrid fibre reinforced unsaturated polyester composite. Samples are removed at regular intervals and weighed immediately after wiping away water from the surface, and a precise 4-digit balance was used to find out the content of water absorbed. The following Equation 1 is used to determine the water absorption:

$$\text{Moisture absorption} = \frac{W_2 - W_1}{W_1} \times 100 \text{ in \%} \quad (1)$$

with W_1 and W_2 being the weight of the dry and wet samples, the percentage of moisture absorption was plotted against the square root of time (hours) as shown in Figure 1. Figure 1 shows that for all ratios of composites, moisture absorption becomes stable after 55 h. Table 3 shows that the hybrid composite of 50:50 percentage has the lowest water uptake and permeability coefficient.

■ Results and discussion

For untreated materials

When increasing the fibre length and content, the mechanical properties also increases up to a certain limit, which is clearly illustrated in Table 2. The maximum tensile strength is observed from 19.8 MPa, the maximum flexural strength - 54.1 MPa and maximum impact strength - 14.8 kJ/m². These mechanical properties are for a fibre length of 5, 10 and 15 cm, respectively, and a weight percentage of 20 for all cases. On further investigation of Table 2, the maximum tensile properties provided by a 10 cm

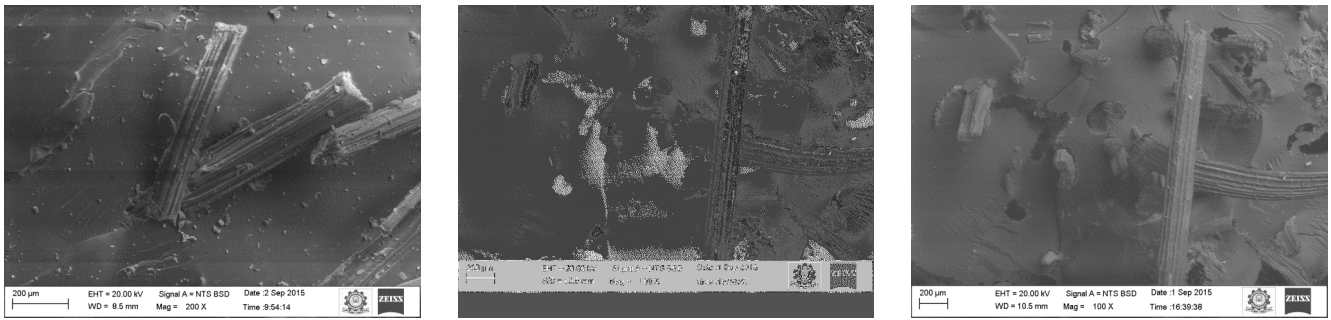


Figure 2. SEM results of fractured surface for 50/50 hybrid untreated composite after (a) tensile test (b) flexural test (c) impact test.

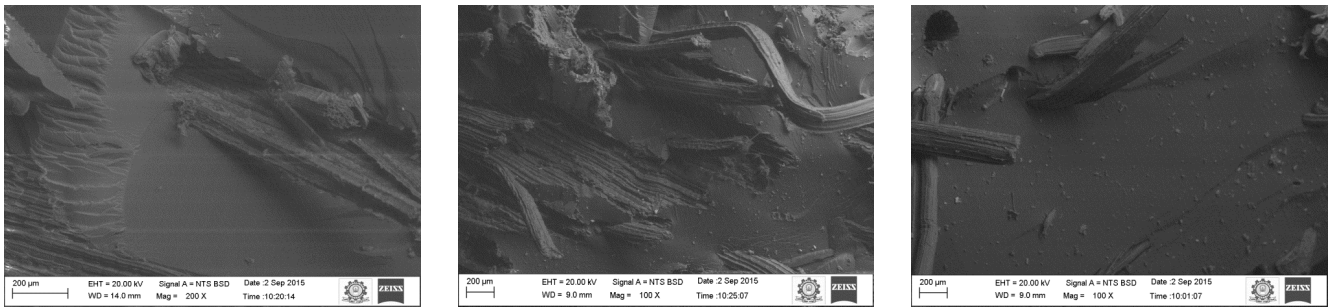


Figure 3. SEM results of fractured surface for 50/50 hybrid treated composite after (a) tensile test (b) flexural test (c) impact test.

fiber length and 20% weight are almost very close to the tensile properties offered by a 15 cm fiber length and 20% weight. Hence the 15 cm fiber length and 20% weight were chosen as the fiber length and weight percentage which provide maximum mechanical properties for the case of the sisal-unsaturated polyester composite. The mechanical properties for this length and weight percentage are 19.6 MPa for the tensile strength, 54.1 MPa for the flexural strength and 14.8 kJ/m² for the impact strength.

In order to improve the mechanical properties of the sisal/unsaturated polyester composite, bamboo fiber was added to bring a hybrid effect. From the results of pure sisal/unsaturated polyester composites, the fiber weight of the composite was fixed at 20% and the fiber length at 15 cm. Within this fiber weight percentage, the bamboo fiber percentage was varied from 0 – 100%. Results of hybridisation are tabulated in **Table 3**. From **Table 3** 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 attained at 50% hybridisation. Considering the water absorption behaviour and mechanical properties as equally important parameters, the optimum condition can be interpreted as 50% bamboo addi-

tion. At this condition, it can be observed that the tensile, flexural and impact strength are increased to around 19%, 5% and 29%, respectively.

Treated materials

The alkali treated bamboo/sisal fibers were used as a reinforcement for polyester based matrices. Alkali treated hybrid composite specimens were prepared by keeping the weight ratio of bamboo and sisal at 50:50. The bamboo and sisal fiber were arranged in a mould of 250 × 250 × 3 mm. The resin was degassed before pouring and air bubbles removed carefully in the roller [26].

The same testing of the composite was used for the treated sisal/bamboo. Bamboo and sisal fiber hybrid polyester composites prepared with treated bamboo, where sisal fibers exhibited a significant increase in all mechanical strength properties. The mechanical properties of the treated hybrid bamboo/sisal polyester composite are 38.4 MPa tensile strength, 78.2 MPa flexural strength and 30.4 kJ/m² impact strength for a 15 mm fiber length and 20% weight ratio, in contrast to 23.4 MPa tensile strength, 56.7 MPa flexural strength and 19.1 kJ/m² impact strength for the composites with untreated fibers.

Scanning electron microscopy analysis

Fractographic studies were carried out on the tensile, flexural and impact fracture

surfaces of short bamboo/sisal polyester hybrid composites using a scanning electron microscope. Interfacial properties, such as fiber–matrix interaction, fracture behaviour and fiber pull-out of samples, were observed after mechanical tests using an Hitachi-S3400N scanning electron microscope (SEM).

An SEM image of the fractured surface of the hybrid composite with treated and untreated fibers from the tensile, flexural and impact tests is shown in **Figures 2** and **3**. From the SEM images, it may be seen that the composite failures during the tensile, flexural and impact tests were due to debonding and the fiber pullout. It was also identified that the brittle fractures of most of the fibers were identified during this study due to the alkali treatment of fibers.

From **Table 4**, the treated hybrid composite as compared with the untreated hybrid composite increased its tensile strength by 30%, its flexural strength by 27.49%, and its impact strength by 36.9%

Conclusion

In this investigation, the effect of the hybridisation of sisal fiber with bamboo bast fiber on the mechanical and water absorption properties was studied. The following conclusions are derived from this study. When increasing the fiber length and fiber content in sisal/un

saturated polyester natural fibre composites, mechanical properties were increased with the fibre content and optimum results of mechanical properties such as tensile strength, flexural strength and impact strength were noticed like 19.62 MPa, 54.12 MPa and 14.82 kJ/m², respectively, at a fibre length of 15 cm and fibre content of 20%. The addition of bamboo fibre in the composite increased the mechanical properties, as opposed to sisal/unsaturated polyester alone. When sisal/bamboo fibre weight percentage was varied from 100/0 to 0/100, 75% bamboo addition leads to increased mechanical properties, whereas low water absorption behaviour is noticed at a 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 hybridisation, and the results at this condition were 23.42 MPa for the tensile strength, 56.71 MPa for the flexural strength, 19.12 kJ/m² for the impact strength and 19.62 % for the moisture uptake. The addition of 50% bamboo fibre in the composite results in a 19% increase in tensile strength, 5% increase in flexural strength and 29% increase in impact strength.

The hybrid polyester composites prepared with treated bamboo and sisal fibres showed a significant increase in all mechanical strength properties, with positive effects being achieved in the tensile, flexural and impact strength. By increasing the treated bamboo fibre concentration in the short bamboo/sisal fibre hybrid polyester composite, the tensile, flexural and Impact strength may be improved. The treated hybrid composite compared with the untreated hybrid composite increased its tensile strength by 30%, its flexural strength by 27.49%, and its impact strength by 36.9%, with its moisture absorption behavior decreasing enormously. Marginal increases in mechanical properties are due to poor interfacial bonding between the matrix and fibre, which is evident from SEM analysis. Interfacial bonding between the fibre and matrix will be improved by chemical treatment with a coupling agent. The treated composite bonds a little better than the untreated hybrid composite.

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