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Influence of fiber orientation and fiber content on properties of sisal-jute-glass fiber-reinforced polyester composites

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ABSTRACT: The incorporation of natural fibers with polymer matrix composites (PMCs) has increasing applications in many fields of engineering due to the growing concerns regarding the environmental impact and energy crisis. The objective of this work is to examine the effect of fiber orientation and fiber content on properties of sisal-jute-glass fiber-reinforced polyester composites. In this experimental study, sisal-jute-glass fiber-reinforced polyester composites are prepared with fiber orientations of 0° and 90° and fiber volume of sisal-jute-glass fibers are in the ratio of 40:0:60, 0:40:60, and 20:20:60 respectively, and the experiments were conducted. The results indicated that the hybrid composites had shown better performance and the fiber orientation and fiber content play major role in strength and water absorption properties. The morphological properties, internal structure, cracks, and fiber pull out of the fractured specimen during testing are also investigated by using scanning electron microscopy (SEM) analysis. © 2015 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2016**, *133*, 42968.

KEYWORDS: biodegradable; composites; mechanical properties; morphology; polyesters

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INTRODUCTION

Glass fiber-reinforced polymer composites have excellent mechanical properties but the process of disposal and recycling of these composites is very difficult.[1] Nowadays natural fibers composites are replacing the synthetic and conventional fiber composites because of their easy availability, high specific strength, and low cost.[2–4] Natural fibers have comparatively low mechanical strengths, to overcome this issue the natural fibers are hybridized with synthetic fibers.[5,6] According to Silva *et al.*[7] the mechanical properties of sisal fiber-reinforced composites has been considerably improved by adding silica micro-particles. The mechanical properties of pure jute fiber composites are greater than that of the oil palm fruit bunch/jute fiber-reinforced hybrid composites.[8] The dielectric behavior of polypropylene/jute composites has been increased with increase in the fiber content.[9] The mechanical properties of cement mortar-reinforced jute fiber composites has been improved due to jute reinforcement and fiber loading.[10] There is the significant improvement in fracture resistance and fatigue crack growth behavior of slag cement-reinforced composites by adding pulped fibers of sisal, banana, and eucalyptus.[11]

The hybrid composites are eco-friendly and user-friendly materials and contributes significant role in the environmental conditions and variety of applications.[12] The natural fiber has the negative impact on the environment during cultivation stage due to the use of pesticides and on the other side the disposal of these composites had a clear advantage from the environmental point of view.[13] The incorporation of natural fiber with glass fiber improves the tensile, flexural, and impact strength of the materials.[14] The mechanical properties of jute/glass fibers reinforced composites has been investigated and found that there is significant drop in mechanical properties due to moisture absorption.[15] Placing the glass fiber layers at the ends possess very good mechanical strength[16] and using natural fibers as reinforcement can reduce the tool wear while processing and respiratory irritation.[17] Sisal/glass fiber-reinforced hybrid composites take full advantage of the best properties, and these composites are used as the potential alternative structural materials.[18] The effect of jute fiber loading on mechanical properties of the composites were analyzed and found to increase substantially with increasing jute fibers loading.[19] To improve the mechanical properties, banana fiber was hybridized with sisal fiber, results in increasing the mechanical properties and decreasing the moisture absorption property.[20] The mechanical properties of cork powder/sisal fibers reinforced composites has been evaluated and found that, the use of sisal fiber and cork

Table I. Physical Properties of Sisal, Jute, and Glass Fibers[29]

Physical property	Glass fiber	Sisal fiber	Jute fiber
Density (g/cm^3)	2.5–2.7	1.3–1.6	1.3–1.5
Tensile strength (kN/mm^2)	1700–2500	540–720	610–780
Stiffness (kN/mm)	70–75	30–40	15–35
Elongation at break (%)	3–5	2.2–3.3	1.0–1.9
Max. elongation (mm)	20–30	5–10	10–14
Tensile modulus (GPa)	68–75	10–40	12–60
Specific modulus (approx.)	29	18	32
Young's modulus (GPa)	–	13	15–30
Cellulose content (%)	–	65–75	59–70
Hemicellulose content (%)	–	10–15	15–20
Lignin content (%)	–	7–13	11–15
Lumen size (mm)	–	11	13
Fiber length (mm)	–	10–150	120–900
Microfibrillar angle (deg)	–	11–20	8–9
Moisture absorption (%)	–	11	12

powder has improved the tensile and flexural properties of the composites.[21]

The hydrophilicity of natural fibers induces large amounts of water uptake which can be depicted as an aging process.[22–25] The most important key in designing of natural fiber/polymer composite is the interfacial adhesion between the fiber and the matrix.[26] The interfacial adhesion can be controlled by physico-chemical interaction, mechanical interaction, and chemical interaction or bonding.[27] Weak interfacial bonding, however, encourages energy absorption through interfacial cracks, thereby increasing the fracture toughness of the composites.[28] In this present experimental study sisal-jute-glass fiber-reinforced hybrid polyester composites are prepared and the effects of fiber orientation and fiber content on physical and water absorption properties are evaluated. The results indicated that the fiber orientation and fiber content playing significant role on the properties.

MATERIALS AND METHODS

Materials

In this experiment, sisal (Agave sisalana), jute (Corchorus oliotours), and glass fibers are used for the preparation of composite specimen. The sisal and jute fibers were supplied by M/s. Chandra Prakash & Co., Jaipur, Rajasthan, India. The thickness of the sisal and jute fibers are in terms of diameter varying from 160 to 230 µm and length of these fibers are 30 ± 2 mm. The glass fiber, polyester resin, catalyst methyl ethyl ketone peroxide (MEKP) were purchased from M/s. Sakthi fiber glass Ltd., Chennai, India.

The glass fiber used in this investigation is unidirectional mat with 300 gsm. The major chemical constituents of polyester resin are ethylene glycol and phthalic alcohol or maleic acid. Water is given off in what is known as a condensation reaction. The physical properties of fibers used for composite fabrication is presented in Table I and the properties of the polyester resin is presented in Table II.

Hybridization and Composite Preparation

Most natural fibers have low processing temperatures, cannot be processed over 150°C due to its biological nature and fiber preparation below 80°C giving better properties. Hybridization of fibers refers to the combination of conventional fibers with natural fibers by using either synthetic or biopolymer matrix for improving the properties. There are many methods are available for processing polymer matrix composites as well as natural fiber composites. Hand layup technique is one of the simplest and convenient methods for processing of composites; it led to high levels of performance during the tests.[31] Addition of 1% catalyst and 1–1.5% accelerator by weight with polyester resin for quick setting, immediate mixing, and reduce the heat generated due to exothermic reaction. Initially the first layer of the specimen i.e., glass fiber mat is placed over the coated surface after the releasing agent getting dried. Then apply polyester

Table II. Properties of the Polyester Resin[30]

Property	Unit	Range
Density	g/cm^3	1–1.3
Tensile strength	MPa	15–20
Tensile modulus	GPa	0.8–1.2
Compressive strength	MPa	80–220
Flexural strength	MPa	25–32
Flexural modulus	GPa	1.1–1.6
Young's modulus	GPa	4–6
Shear modulus	GPa	1.1–1.6
Poisson's ratio	–	0.45
Specific gravity	–	1–1.5
Shrinkage	%	0.005–0.009

Table III. Thickness, Fiber Orientation, and Fiber Content of Composite Samples

Sample Id	Thickness (mm)	Fiber orientation (Deg.)	Fiber content (Volume %)		
			Sisal fiber	Jute fiber	Glass fiber
H1	4.70±.02	0	40	0	60
H2	4.72±.02	0	0	40	60
H3	4.81±.02	0	20	20	60
H4	4.69±.02	90	40	0	60
H5	4.74±.02	90	0	40	60
H6	4.68±.02	90	20	20	60

resin which is evenly distributed the entire surface by using roller. Allow the resin for 10–20 min getting completely mixed with resin after that, the second layer of the specimen i.e., natural fiber is placed over the glass fiber. The process is repeated for all five layers of the sample as well as for all six samples. Then these samples are taken to the hydraulic press to remove the air gap between layers by applying force about 70 to 100N for 48 h to get perfect samples. Table III shows the thickness, fiber orientation, and fiber content of the composite samples used for the investigation.

Physical Properties

In general, properties of composites were determined by various parameters such as properties of fiber and resin, fiber content, length, orientation of fiber, and interfacial adhesion between the matrix and fiber. From the dimensional analysis, it is suggested that fiber length and aspect ratio did not play a major role on mechanical properties.[32] Therefore, fiber orientation and fiber content have more influence on physical properties and taken as the major factors in this investigation. The testing of the materials has been carried out at the temperature of 35 ± 2°C and an average relative humidity of 65%. All the tests were conducted for five samples in each case and the average values are used for discussion.

Tensile Test. Tensile tests are conducted by using a Universal Testing Machine (UTM) Make FIE (Model: UTN 40, S. No. 11/98-2450). The dimensions, gauge length, and cross-head speeds are chosen according to the ASTM D638 standards. The testing process involves placing the test specimen in the testing machine and applying tension to it until it fractures. The tensile force is recorded as a function of the increase in gauge length. The samples subjected to tensile loading are presented in Figure 1(a).

Flexural Test. The three point static flexure test is the most common flexural test and the tests are carried out by using the same universal testing machine. The test samples are prepared

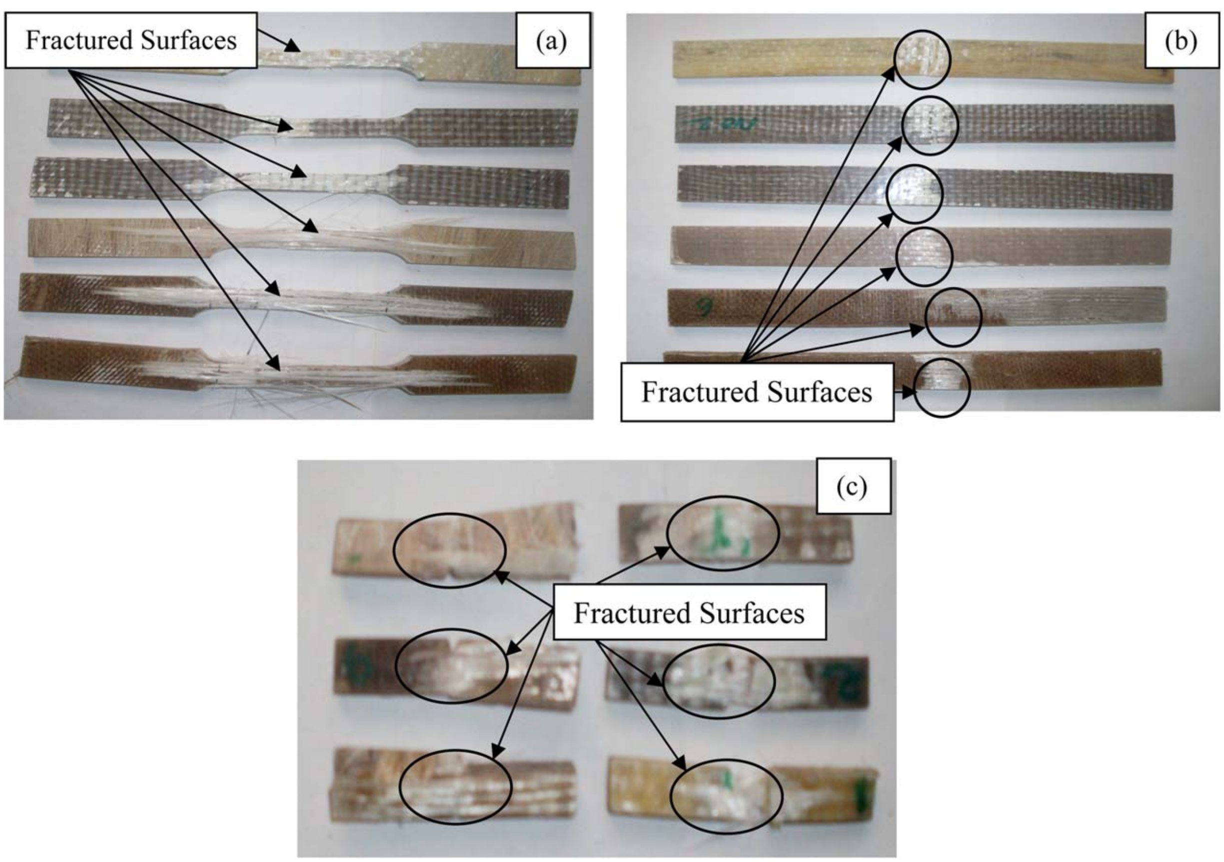

Figure 1. Fractured test specimens due to (a) tensile loading, (b) flexural loading, and (c) impact loading. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table IV. Experimental Results of Different Composite Samples

Sample Id	Fiber orientation (Deg.)	Tensile strength (MPa)	Elongation (%)	Flexural strength (MPa)	Impact strength (Joules)	IFSS (MPa)
H1	0	168.40	10.8	228.74	16	17.2
H2	0	219.34	12.9	242.35	12	13.4
H3	0	232.12	14.4	308.56	18	19.6
H4	90	111.17	10.2	214.06	8	9.8
H5	90	178.32	11.6	256.82	9	10.2
H6	90	184.58	11.8	264.61	10	10.8

as per the ASTM D 790 standard and subjected to flexural loading. Specimen deflection is measured by the crosshead position. The testing process involves placing the test specimen in the universal testing machine and applying force to it until it fractures and breaks. The samples subjected to flexural loading are presented in Figure 1(b).

Impact Test. The Charpy impact test samples are prepared according to ASTM D 6110 standards and the tests were carried out on the notched specimen using a universal impact-testing machine. During the testing process, the specimen must be loaded in the testing machine and allows the pendulum to strike the samples with heavy impact load until it breaks. The energy needed to break the material can be measured easily and can be used to measure the toughness of the material and the yield strength. The specimens subjected for impact loading is presented in Figure 1(c).

Water Absorption. The water absorption experiment has been conducted for the fibers as well as hybrid composite samples. The samples were cut into a size of 100 mm × 20 mm and dried in an oven at 80°C for 24 h. The dried specimens were immersed in distilled water at a temperature of 23 ± 2°C up to 5 h. The samples were taken out in the time interval of 20 min and weighed, after wiping off the water on the surface of the samples with a cloth. The natural fibers are good examples of permeable fibers that are absorb water to a much larger extent than the resin itself, in which they are incorporated.[33,34] The percentage weight gain of the immersed specimen was calculated by using the following eq. (1).

$$\%\ \text{Water absorption} = (W_1 - W_2/W_2) \times 100 \tag{1}$$

where W_1 is the weight of the specimen after immersion and W_2 is the initial weight of the specimen.

The Interfacial Shear Strength (IFSS). The IFSS specimens were cured using the temperature range between 80°C to 120°C for 4 h in an air circulating oven and then cooling slowly at a speed of 1°C/min before testing. A cross-head speed of 5 mm/min was used for the tests. The specimen was fixed in the universal testing machine by using a micrometer. The IFSS was calculated using eq. (2).

$$\text{IFSS} = F/\pi DL \tag{2}$$

where F is the measured force/force required to de-bond, D is the diameter of the fiber and L is the fiber embedded length in the matrix.

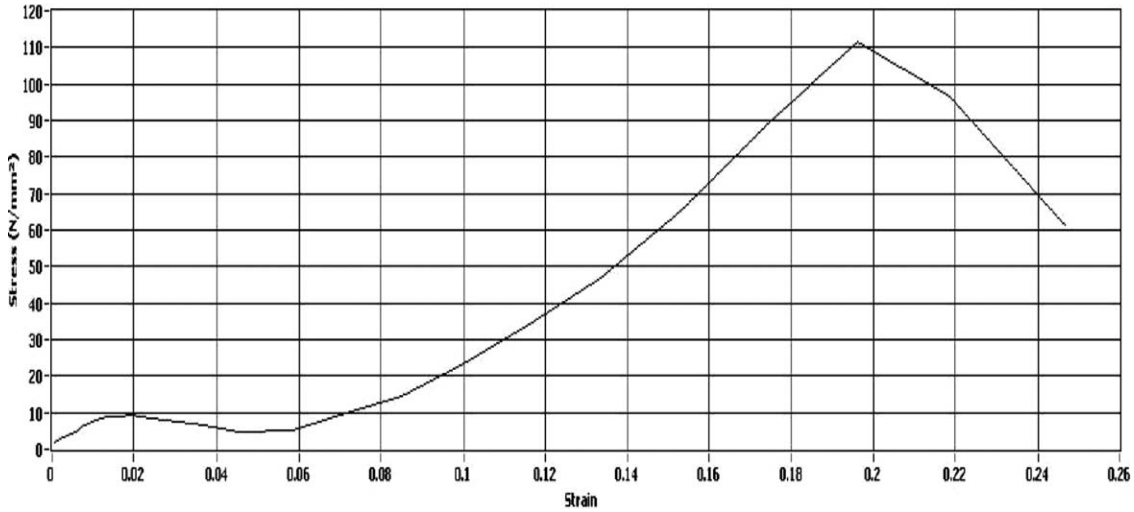

Figure 2. Typical stress vs. strain curve generated directly from the universal testing machine due to tensile loading for 90° fiber orientation and 40% sisal fiber and 60% glass fiber-reinforced composite sample.

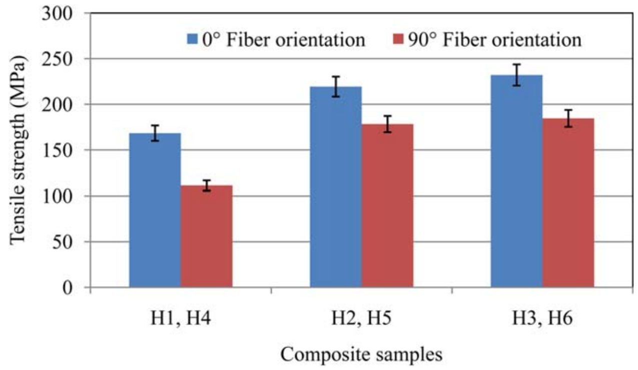

Figure 3. Tensile strength comparison of different composite samples. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

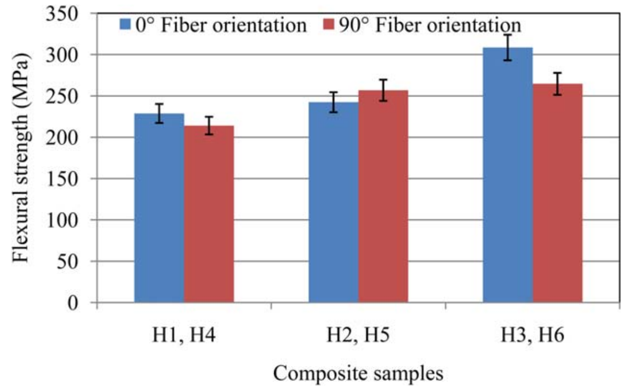

Figure 5. Flexural strength comparison of different composite samples. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

RESULTS AND DISCUSSION

In this present investigation, sisal and jute fibers are reinforced with glass fibers by different fiber orientations, different fiber volume, and their influence on physical and water absorption properties are evaluated. The experiment results are presented in Table IV.

Tensile Properties

The composite specimens are subjected to tensile loading and the results have been analyzed in this study. According to the results, the fiber orientation of 0° composite samples is performing better than the 90° fiber orientation composite samples. As per the fiber content, 20% sisal fiber, 20% jute fiber, and 60% glass fiber-reinforced composite specimen can withstand the tensile strength up to 232.12 MPa followed by 40% sisal fiber and 60% glass fiber-reinforced composite specimen can hold the strength of 219.34 MPa. The typical stress vs. strain curve generated directly from the universal testing machine due to tensile loading is presented in Figure 2. From the graph, the stress is increasing gradually up to 111.17 N/mm^2 for the strain rate up to 0.2 then starts deceasing. This indicates that the stress increases up to the maximum load carrying capacity of the material and start deceasing after the material has been broken. The tensile strength comparison of different composite samples is presented in Figure 3. From the figure, it has been clearly observed that the tensile strength of 0° fiber orientation composite samples is superior to the 90° fiber orientation composite samples and 20% sisal, 20% jute, and 60% glass fiber-reinforced composites are performing better than the other composites are tested.

Flexural Properties

The flexural strength of the composites is also varying in the same manner of the tensile strength. According to the results, the fiber orientation of 0° composite samples and as per the fiber content, 20% sisal fiber, 20% jute fiber, and 60% glass

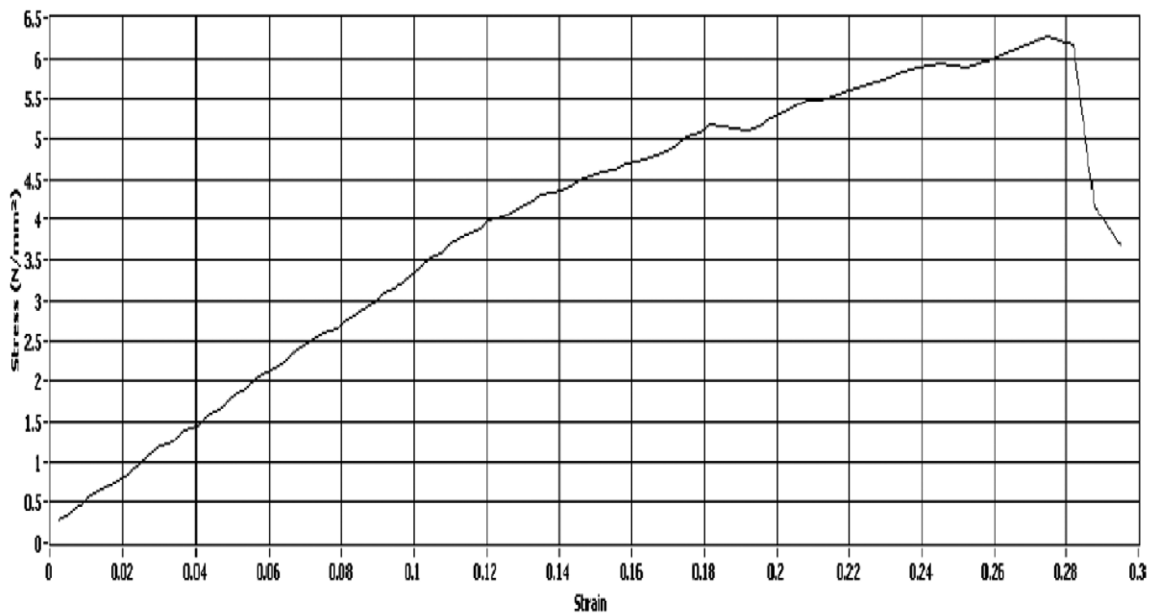

Figure 4. Typical stress vs. strain curve generated from the machine during flexural loading of 0° fiber orientation and 20% sisal fiber, 20% jute fiber, and 60% glass fiber-reinforced composite sample.

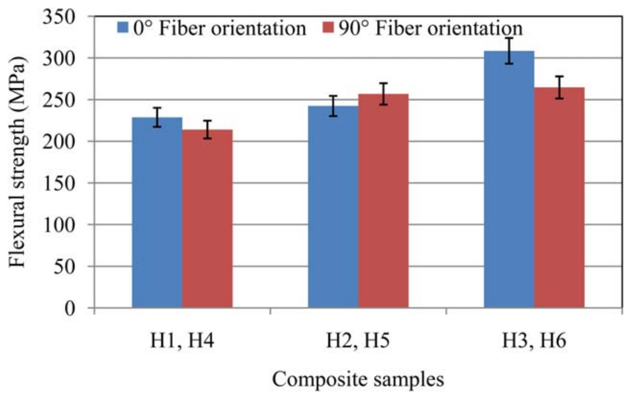

Figure 6. Impact strength comparison of different composite samples. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

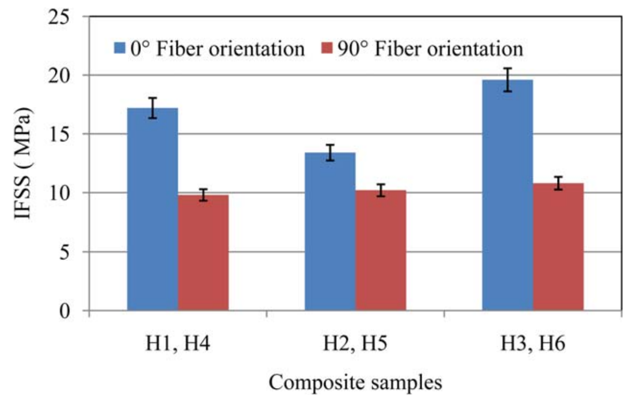

Figure 8. IFSS comparison of different composite samples. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

fiber-reinforced composite specimen can withstand the maximum flexural strength up to 308.56 MPa followed by fiber orientation of 90° and fiber content 20% sisal fiber, 20% jute fiber, and 60% glass fiber-reinforced composite specimen can hold the strength of 264.61 MPa. Figure 4 shows the typical stress vs. strain curve generated from the machine during flexural loading. From the figure, it is observed that the stress increases proportional up to 6.3 N/mm^2 after that it tends to reduce and breaking of the sample occurs. The flexural strength comparison of the two different directional orientations and three different fiber contents are presented in Figure 5. From the figure it is observed that, the sisal, jute, and glass fiber-reinforced hybrid composites are performing better than the single natural fiber reinforcement either sisal or jute and glass fiber.

Impact Properties

The energy loss is found out on the reading obtained from the impact testing machine. It has been reported that the sisal, jute, and glass fiber-reinforced composite sample having the fiber orientation of 0° performing better and holding the maximum impact load of 18 Joules and the other samples are yielding comparatively lower values. The impact strength comparison of the different composite samples based on the directional orientations and fiber content are presented in Figure 6. From the figure it has been clearly observed that the 0° fiber orientation samples are performing better than that of the 90° fiber orientation samples.

Water Absorption Properties

Water absorption curves are presented in Figure 7, where percentage of water absorbed is plotted against the immersion time. It is clear from the figure, that the composites absorb water very rapidly in the initial stage until a saturation level is attained, without further increase in water absorption. The high cellulose content in jute and sisal fibers contribute to more water penetrating into the interface through the micro-cracks induced by swelling of fibers, thus creating swelling stresses leading to composite failure. The figure further revealed that the hybridization of both sisal and jute fibers with glass fiber reducing the water absorption content significantly.

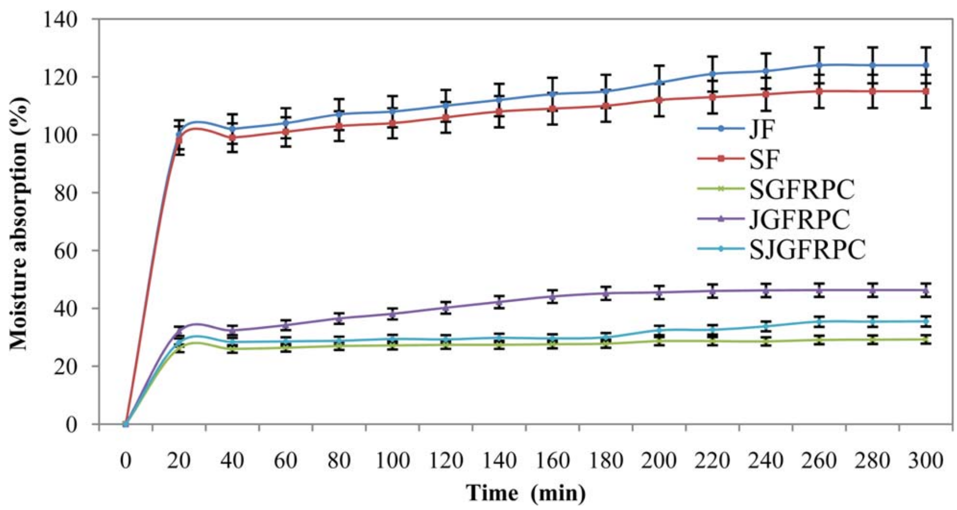

Figure 7. Moisture absorption curves (JF-jute fiber, SF-sisal fiber, SGFRPC-sisal/glass fiber-reinforced polyester composites, JGFRPC-jute/glass fiber-reinforced polyester composites, and SJGFRPC-sisal/jute/glass fiber-reinforced polyester composites). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

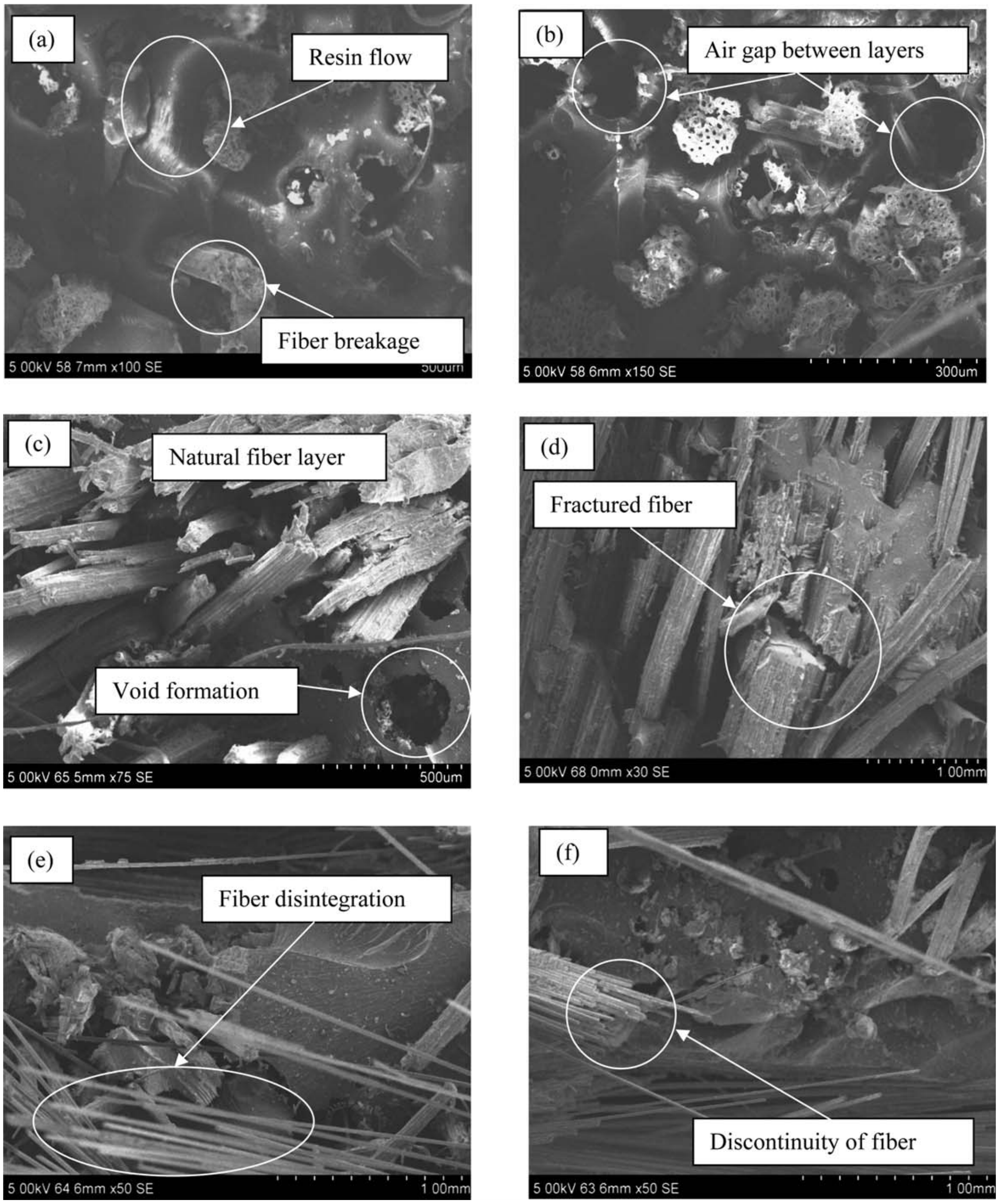

Figure 9. SEM micrographs of the composite samples subjected to (a) and (b) tensile loading, (c) and (d) flexural loading, and (e) and (f) impact loading.

The Interfacial Shear Strength (IFSS) Analysis

Since both sisal and jute fibers have a significant number of polar groups, the IFSS between these fibers and the polyester resin was expected to be strong. The range of IFSS values obtained varies between 9.8 and 19.6 MPa. The comparison of the IFSS vales of the different composite samples is presented in Figure 8. From the figure, it has been observed that the sisal, jute, and glass fiber-reinforced composite sample having the fiber orientation of 0° performing better and holding the maximum IFSS of 19.6 MPa and the other samples are yielding lower values. This is thought to be the result of the effect of the hybridization of both sisal and jute fibers with glass fiber.

Morphological Properties

The surface morphology of the composites is examined through scanning electron microscopy (SEM) analysis. The SEM micrographs show the agglomeration of fiber, interfacial bonding between the fiber and the matrix and dispersion of the fiber into the matrix. The SEM micrographs of the composite samples subjected to the mechanical loading are presented in Figure 9.

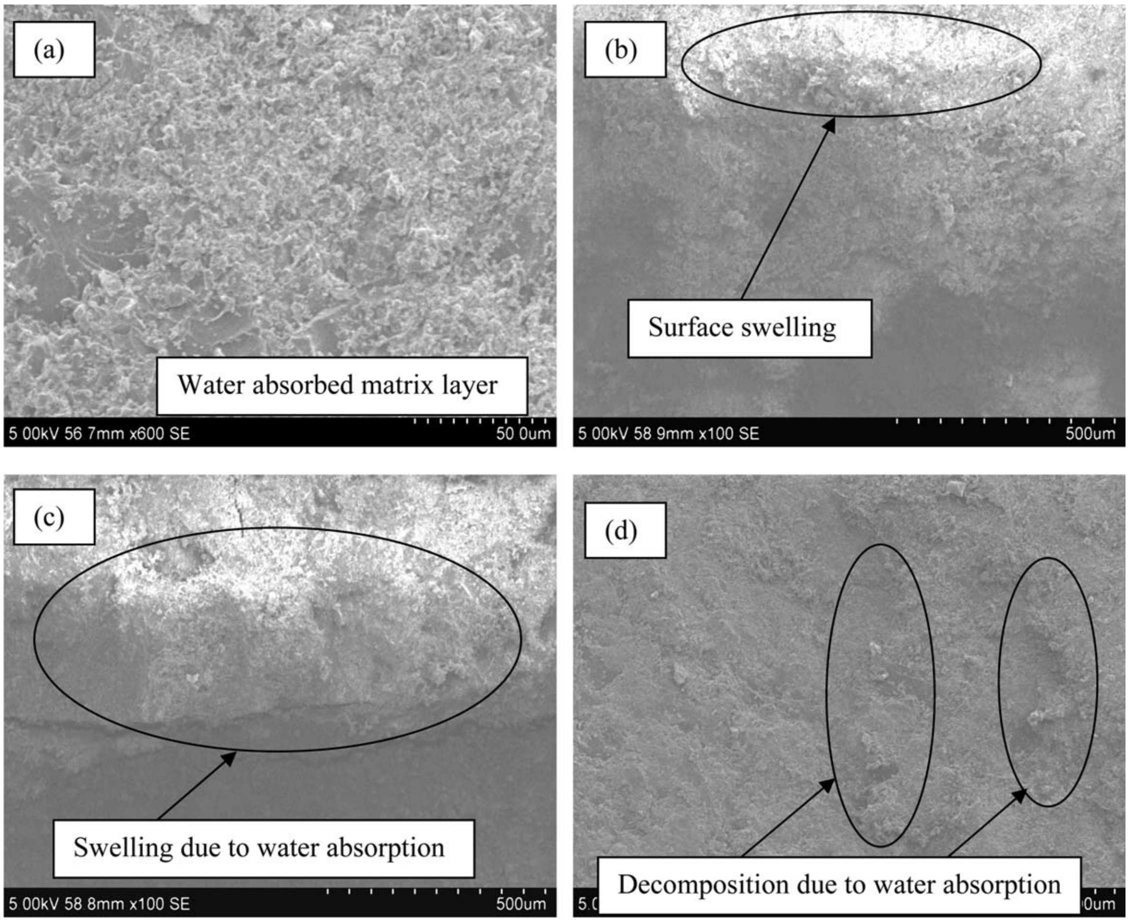

Figure 10. SEM micrographs of the moisture absorbed samples at different time intervals (a) after 120 min, (b) after 180 min, (c) after 240 min, and (d) after 300 min.

From the Figure 9(a,b) the flow of resin, fiber breakage and air gap formed between the fiber and the resin are clearly visible. Figure 9(c,d) refer to the images from the electron microscope for the samples subjected to the flexural loading. From these images, discontinuity of the fiber and incomplete distribution of fiber and resin clearly visible. The micrographs of the samples subjected to the impact loading are given in Figure 9(e,f). The fibers disintegrated during testing are clearly viewable from the figures.

The micrographs of the samples after moisture absorption at different time intervals are presented in Figure 10. The water absorbed matrix layer is clearly visible in Figure 10(a), this is confirmed that the maximum amount of water has been absorbed within first two hours of immersion. The swelled surfaces of the composite specimens are presented in Figure 10(b,c) which shows the water molecules are present inside the specimen. The surface decomposition of the composites takes place when the specimen is immersed in water for a long period of time, which is confirmed from Figure 10(d).

CONCLUSION

The sisal, jute, and glass fiber-reinforced hybrid composite laminates are fabricated with two different fiber orientations of 0° and 90° and three different fiber contents by volume of sisal, jute, and glass fibers are in the ratio of 40:0:60, 0:40:60, and 20:20:60. From the experiment, the following conclusions have been arrived:

- According to the fiber orientation, 0° composite samples are performing better than the 90° composite samples and as per the fiber content sisal, jute, and glass fiber-reinforced samples are yielding better results than the single natural fiber either sisal or jute-reinforced composite samples are tested.
- The maximum strength has been absorbed by the 0° fiber orientation and sisal-jute-glass fibers reinforced sample, can hold the tensile strength of 232.12 MPa, flexural strength of 308.56 MPa, impact strength of 18 Joules, and IFSS of 19.6 MPa.
- The investigation on the IFSS, showed that the interfacial adhesion between the fibers and polyester resin should be strong. The fiber orientation has more influence than fiber content on this property.
- From the water absorption tests, it can be concluded that the incorporation of sisal, jute, and glass fibers into the polyester matrix reducing the water absorption content significantly.
- From the morphology analysis, the fiber fracture, swelling due to water absorption and the internal cracks of the

fractured surfaces are clearly observed. Further it can be asserted that the interfacial bonding between the fiber and matrix is good for the hybrid composite samples and the fibers are well dispersed into the matrix.

- This study provided evidence that durability of natural fiber composites can be tailored by a proper hybridization with synthetic fibers in order to find a suitable cost-performance balance, meanwhile reducing the environmental impact of the material.

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