Static and Dynamic Properties of Sisal Fiber Polyester Composites – Effect of Interlaminar Fiber Orientation

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The effect of fiber orientation was studied relative to the static and dynamic properties of sisal/polyester composites. Different composites were developed using the compression moulding technique with the aid of a specially designed mould. Composite laminates were formulated by stacking a number of fiber lamina with different orientations such as 90º/0º /90º, 0º /90º /0º, 90º /0º /0º /90º, 0º /45º /0º, 0º /90º /45º /45º /90º /0º, and 0º /45º /90º /90º /45º /0º. In general, the performance of static and dynamic characteristics was found to be significantly influenced by the effect of interlaminar fiber orientation. Experimental results exhibited a higher flexural strength of 68 MPa and an impact strength of 320 J/m in the case of 0º /90º /45º /45º /90º /0º oriented composites. Dynamic characteristics such as natural frequency and damping were found to be higher in the case of 0º /45º /0º and 0º /90º /0º, respectively. Morphological analysis was performed for understanding the interlaminar orientation and failure mechanisms between the fiber and the matrix.

Keywords: Fiber orientation;Sisal; Flexural; Impact; Free vibration;Compression moulding technique

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INTRODUCTION

In the current scenerio, the development of biodegradable materials has been attracting many researchers as well as industrialists due to the global requirement of an ecofriendly environment. Accordingly, recent advances in composite technology, have helped bring a steep increase in eco friendly reinforcements such as plant-based fibers in polymer matrix formulations. Natural fibers are cost effective, available in abdundance, and exhibit good compatability with the available various polymer systems. However, the feasibility of implementation of natural fiber composites in real time industrial applications is still a matter of argument.Many of the natural fibers are found to exhibit higher specific strength and modulus compared to man-made fibers such as glass fibers. Such findings have elevated the confidence of materials technologists, in the matter of development of engineering components using these fiber reinforcement. This fact has already been demonstrated from reports in which several natural fibers such as bamboo, jute, banana, sisal, *etc*. are currently used for replacing automobile components, interior parts of aerospace products, electronics, and construction industry components under medium loading conditions (Koronis *et al.* 2013; Pickering *et al*. 2016). The incremental usage of plant fibers in composites has led to the extensive cultivation of these lignocellulosic fibers (Nechwatal *et al.* 2003; Arib *et al.* 2006; Li *et al*. 2006).

Considering the design of structural composites, it is important to take note of the dynamic characteristics such as natural frequency and damping ratio rather than the static mechnical properties. A correlation has been found between the mechanical properties, especially flexural and impact strength with natural frequency. This was confirmed by earlier reports (Kumar *et al*. 2014; Uthayakumar *et al.* 2014). Most of the earlier studies related to natural fiber composites revealed the mechnical performance of the composites with respect to variations in fiber length (Sreenivasan *et al.* 2015), fiber weight percentage (Ahmad *et al*. 2015), different chemical treatments (Kabir *et al*. 2013), and fabrication process (Zakikhani *et al.* 2014). All these studies report the assistance from factors such as optimum conditions of fiber length and wt% of fiber content, type, and percentage of concentration used for chemical treatment in attaining enhanced mechnical performance as well as natural frequency (Rajini *et al.* 2013; Kumar *et al*. 2014). In the aspect of damping, it is well known that the fiber reinforced composites generally possess a higher damping value due to their viscoelastic nature, interface from fiber to matrix, and damping due to damage (Berthelot *et al.* 2006; Jeyaraj *et al*. 2009). One of the earlier works of the authors studied the effects of interlaminar fiber orientation using *Sansevieria cylindrica* fiber as bulk reinforcement with different angles 0º, 30º, 45º, 60º, and 90ºin polyester matrix. Other results revealed maximum mechanical strength in the 0˚ oriented fibre composites compared to the other types of oriented composites. But, this was not found to be superior in the case of dynamic characteristics. Similarly, Kang and Kim (2012) analysed the result of fiber alignment on flexural behaviour. They have also determined the flexural strength of composites using the analytical method, which demonstrated a good agreement with experimetal results.

An extensive literature survey showed that research carried out in the aspect of interlaminar fiber orientation on static mechnical and dynamic characteristics using natural fiber reinforcement has been rather limited. Hence, this research paper examines the static and dynamic characteristics of sisal/polyester composites with respect to interlaminar orientation. A morphological analysis was also performed using scanning electron microscopy (SEM) on the fractured samples to understand the failure mechanism arising from the sudden impact loading.

EXPERIMENTAL

Materials

Sisal fibers were supplied by Shiva Exports, Tirunelveli, Tamilnadu, India. The diameter of sisal fiber was measured with SEM, and the average diameter value was 220 ± 3.5 µm.Unsaturated isophthalic polyester resin, Methyl Ethyl Ketone Peroxide (MEKP) and cobalt naphthenate were procured from Vasivibala Resins (P) Ltd., Chennai, Tamilnadu, India. MEKP (1 mL) and of cobalt naphthenate (1 mL) were used as the catalysts and the accelerator, respectively, in 100 mL of polyester resin at room temperature. The properties of the sisal fiber and polyester resin are shown in Tables 1 and 2, respectively.

Table 1. Mechanical Properties of Sisal Fiber (Idicula *et al.* 2010)

Fiber	Diameter (μm)	Density (Kg/m^3)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at Break (%)	Flexural Modulus (GPa)	Lumen Size (μm)	Microfibrillar Angle (º)
Sisal Fiber	205±4.3	1450	350±7	12.8	6 to 7	12.5 to 17.5	11	20

Table 2. Properties of Polyester Resin

Test	Test method	Specification	Test value	Unit
Appearance	Visual	Pale yellow clear liquid	Pale yellowish clear liquid	Nil
Viscosity at 25 ˚C (Brookfield Viscometer LV DV II+ Pro Spindle 62, rpm 50)	IS 6746 : 1994	500-600	510	cP
Density at 25 ˚C	IS 6746 : 1994	1.100 – 1.110	1.106	gm/cm^3
Volatile content	IS 6746 : 1994	38-42	38.6	%
Acid value	IS 6746 : 1994	13-18	16.28	mg KOH/gm
Gel time at 25 ˚C	IS 6746 : 1994	15-25	16	min

Fabrication of Composites

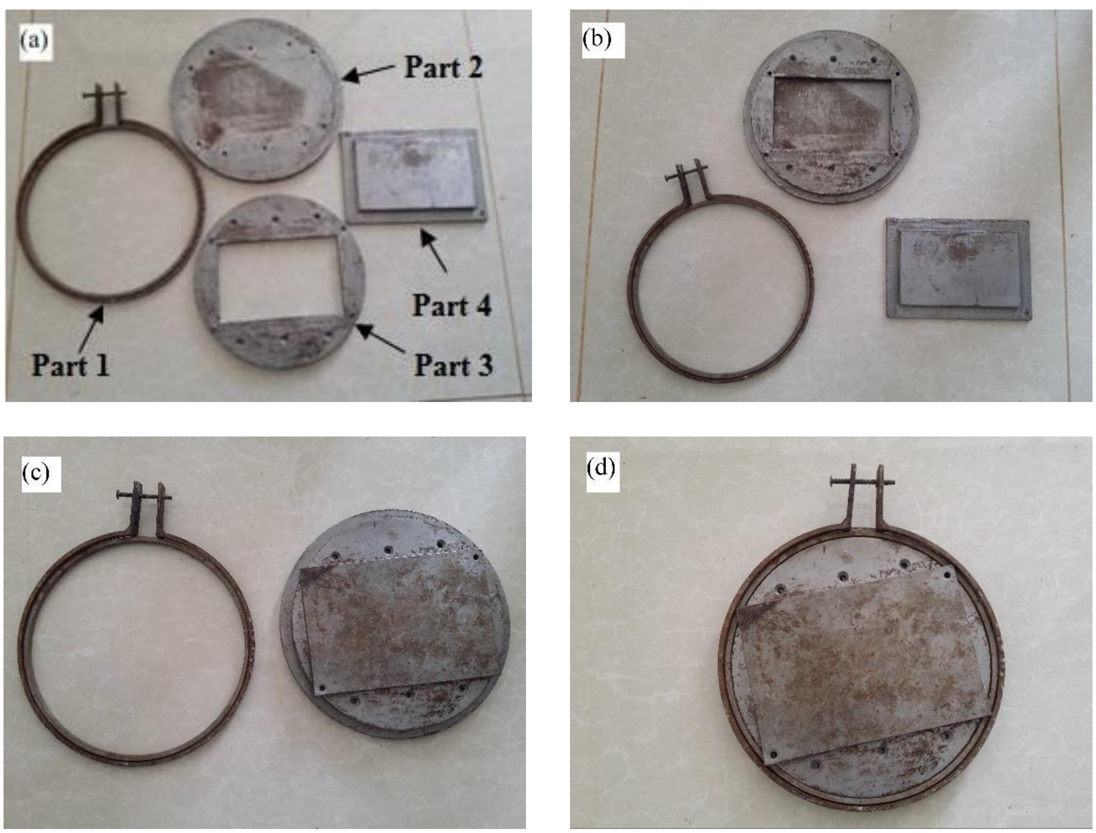

Fig. 1 (a-d). Photographic view of different parts of the mold and its various positions in the fiber oreintation process

The steps involved in the fiber orientation process, as depicted in Fig.1(a-d), are as follows. Figure 1a indicates the different parts of the mold involved in this process. Part (1) in Fig.1a consists of a concentric circular part wherein the inner part is a completely closed solid part and the outer part is surrounded by the inner part with a uniform gap and fastening at the ends. Parts (2) and (3) in Fig.1a indicate the solid circular disc with machined holes and a circular mold with a rectangular cavity of the size of 150 mm X 300 mm. Similarly, part (4) is a male mold with the 3-mm protrusion placed over the rectangular cavity. In the first step, part (3) was placed on part (2) and the fibers were placed along the rectangular cavity mould in the longitudinal direction and spread over the entire surface. Next, the longitudinal direction was marked as a reference line indicating 0° orientation (Fig.1b). In the next step, a circular steel part with fasteners was kept outside the solid circular mould in such a way that would cover all the fibers at the circumference of the solid mould. Then, the fasteners were tightened until a firm grip was provided on the fibers. Next, the circular part was rotated to the required inclination. This was confirmed from the marked protector on the circular part (Fig.1c). At the end, the male mold with the rectangular protrusion was placed over the circular mould with a rectangular cavity and fastened with a hexagonal screw to avoid fiber separation (Fig. 1d). Finally, the concentric circular part was removed without affecting the fiber orientation. Similarly, each lamina was prepared in an identical manner for different required orientations. In continuation of this, the composite laminates were fabricated by stacking the laminae one over another with an overall fiber content of 50±2 wt.%.The resin (with 1.5 wt% of initiator) was poured onto the fibers, and the mold was closed and compressed for 17 MPa, allowing for resin curing for 24 h at room temperature. Table 3 shows various sisal/polyester composite laminates with different interlaminar orientations with their respective notations.

Table 3. Description of Composite Samples with Notations

Notations	Description of composite samples
A	90º/0º /90º
B	0º /90º /0º
C	90º /0º /0º /90º
D	0º /45º /0º
E	0º /90º /45º /45º /90º /0º
F	0º /45º /90º /90º /45º /0º

Methods

Mechanical testing

The flexural strength of the composite specimens was found *via* a three point bending test. An Instron (Series 3382, Instron, Norwood, United States) device was used for determining the flexural strength of the fabricated composites. The cross head speed of the machine was maintained at 5mm/min according to the ASTM D790 (2003) standard. The composite specimen size had dimensions 127 mm× 13 mm× 3 mm. An average of 5 specimens have been reported in this study.

A Charpy impact study was conducted for the fabricated composite specimens. The dimensions of the impact specimen were 65 mm × 13 mm × 3 mm. An unnotched Charpy impact test was conducted in accordance with the ASTM D256 (2004) standard. The specimens were kept in the machine like a beam with a simple support. Once the 'ON' button in the machine (Instron, Norwood, United States) was triggered, the pendulum swung and broke the composite specimen. Impact energy was calculated by the machine. The values were shown in the electronic display. An average of 5 specimens are reported in this study.

Experimental setup for modal analysis

Figure 2 is the schematic diagram of the device used for carrying out the modal analysis of composites using an impact hammer. A sharp hardened impact hammer (Kistler model 9722A500, Kistler Instrument Corporation, New York, USA) and an accelerometer were used in the modal analysis test. The sharp hardened impact hammer was used for exciting the laminate composite [dimensions: 200 mm× 20 mm × 3mm; *Rajini et al.* (2012)], which produced higher frequencies. The accelerometer was attached at the end of the composite by wax. It was used for acquiring displacement signals. A data acquisition system (DAS, DEWE43, Dewetron Corp., 8074 Grambach, Austria) and an integrated circuit piezoelectric (ICP) conditioner (Modular Smart Interface (MSI-BR-ACC) Dewetron Corp., 8074 Grambach, Austria) were used for recording the displacement signals from the accelerometer. Two separate adaptors were used for capturing the output signal.One was attached to the impact hammer, and the other was fixed at the free end of the laminate composite.

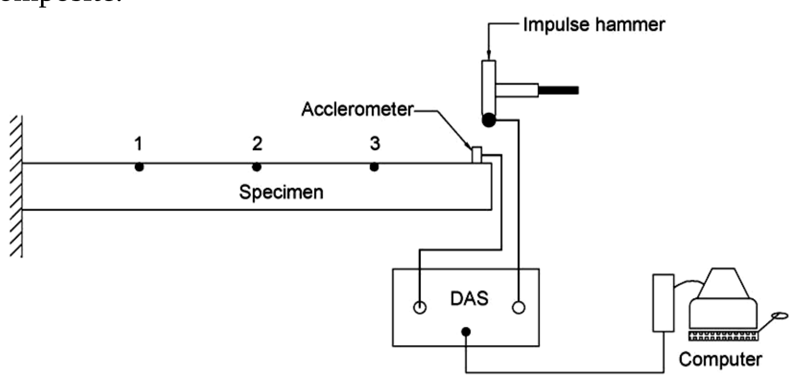

Fig. 2. Schematic diagram of free vibration experimental setup

RESULTS AND DISCUSSION

Interlaminar Orientation by Microscopic Analysis

SEM analysis was performed in the cross section of the sample (Fig. 3) in order to understand the interlaminar orientation. Figure 3 shows the presence of fibers with different angles at each lamina. The number of laminae was varied based upon the type of composites, which was confirmed from the varying morphological views of composites. Interfacial adhesion between the intra layers were altered based on the fiber orientation. Such adhesion decides the load transfer phenomenon during flexural and impact loading.

Generally, combinations of compression and shear mechanism occur during the flexural loading. A larger resistance was expected to occur while the interlamina were oriented at an acute angle. Results of a similar kind were also observed in the flexural loading condition for the composites fabricated with 45° oriented interlaminae at the interface. A significant influence on impact property from different interlaminae oriented composites was also observed.

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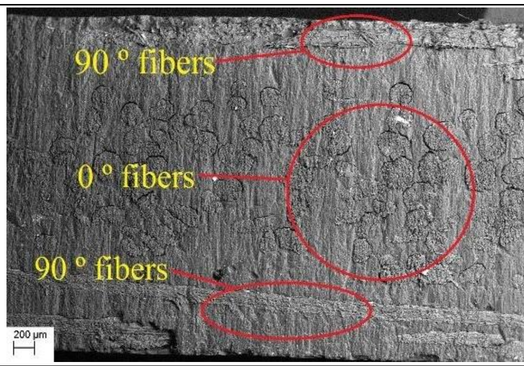
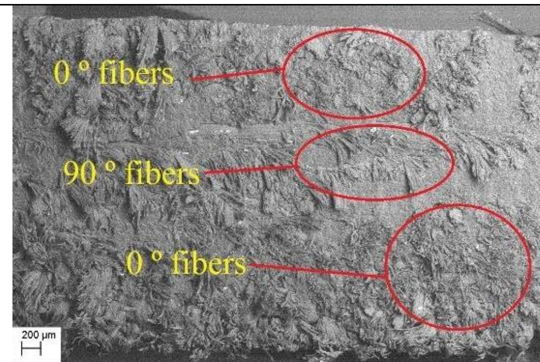
<tr><th>Sample Code</th><th>Fiber orientations of composites</th><th>Sample Code</th><th>Fiber orientations of composites</th></tr>
<tr><td>A</td><td>
</td><td>B</td><td>
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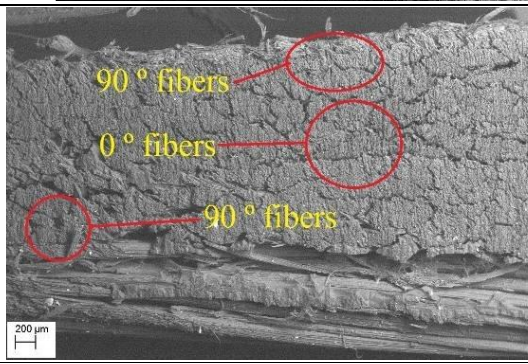
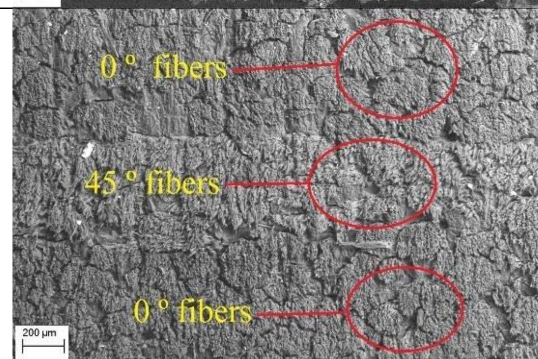
<tr><td>C</td><td>
</td><td>D</td><td>
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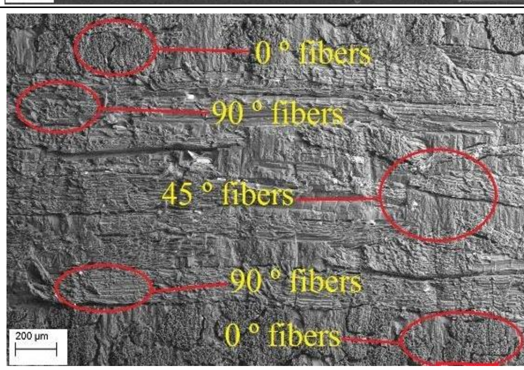
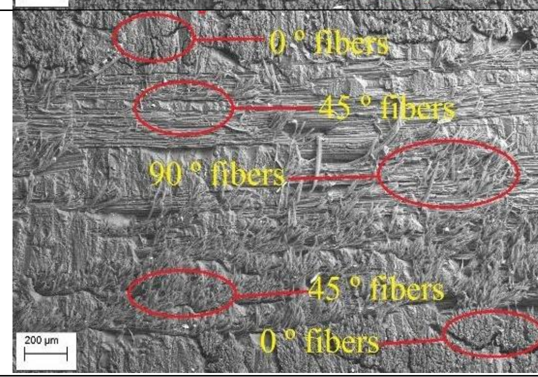
<tr><td>E</td><td>
</td><td>F</td><td>
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Fig. 3. SEM Images of interlaminar fiber orientations

Flexural Strength

Flexural testing is needed for quantifying the performance of composites, mainly in structural components. The effect of variations in the fiber orientation on flexural strength of sisal fiber polyester composites are shown in Fig. 4(a). Examination of the results showed flexural strength of 68.3 MPa for orientation at 0º /90º /45º /45º /90º /0º. Observations of a similar kind were also reported by Yahaya *et al*. (2016), wherein the 0˚/90˚ oriented unidirectional kenaf fiber epoxy composites were found to exhibit better flexural properties than the woven fabric reinforcement. An interesting point to note is that 90º fiber oriented composites at the extreme layer possessed lower flexural strength than seen in the other type of composites. This could be due to the extreme layers of 90º/0º /90º and 90º/0º /0º /90º oriented perpendicular to the load acting on the fiber composites, contributing strongly to the flexural strength of the composites. Increase in the flexural strength of the composites was observed in the other types of flexural composites of 0º /90º /0º, 0º /45º /0º, 0º /90º /45º /45º /90º /0º, and 0º /45º /90º /90º /45º /0º. This could be due to all the fiber composites having 0 º fiber orientations at the extreme layers. Normally, the abrupt failure of the composite can be related to flexural failure, and the gradual decrease in loading indicates with shear failure as the predominant mode. The chances for shearing action are less in the case of interlaminar orientation at 45º, which can provide a larger degree of resistance to the fiber mobility and in turn increase the effective load transfer between the fiber and matrix (Pothan *et al*. 2008). The flexural strength of pure bamboo and hybrid FRP composites has been the subject matter of another study with respect to fibre orientation (0°/90°, ± 45°) on flexural strength. The results of the analysis revealed the presence of a higher flexural strength composites with ±45° orientation at interlamina positions when compared to other orientation (Retnam *et al.* 2014).

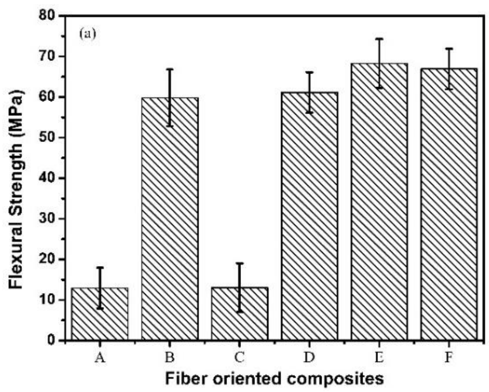

Fig. 4(a). Flexural strength of sisal fiber composites

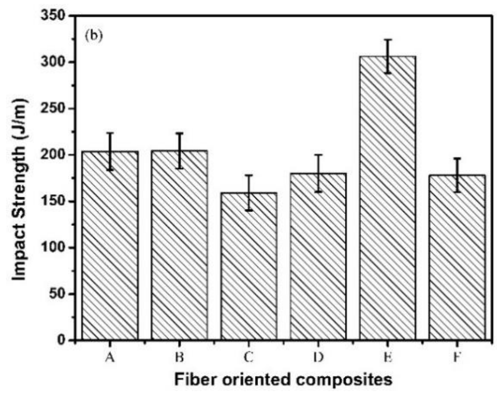

Fig. 4(b). Impact strength of sisal fiber composites

This was arranged along the plane coinciding with the action for the load. The percentage improvements from 90º/0º 90º to 0º /90º /0º, 0º /45º /0º, 0º /90º /45º /45º /90º /0º, and 0º /45º /90º /90º /45º /0º were 78.4%, 78.8%, 81.0%, and 80.7%, respectively. Likewise, the percentage improvements from 90º /0º /0º /90º to 0º /90º /0º, 0º /45º /0º, 0º /90 º /45º /45º /90º /0º, and 0º /45º /90º /90º /45º /0º were 78.2%, 78.7%, 80.9%, and 80.5%, respectively. In this work, 3, 4, and 6 layers were used for fabricating the composites. However, the total fiber wt% maintained in all the composites was seen as 50±2 %, such that the 3 layered composites were 90º/0º/90º, 0º /90º /0º, and 0º /45º /0º. The 4 layered composite was 90º /0º /0º /90º. The 6 layered composites were 0º /90º /45º /45º /90º /0º and 0º /45º /90º /90º /45º /0º. A comparision of the 3, 4, and 6 layered composites with 6 layered composites showed better flexural strength than the other types of composites, leading to the concusion that the flexural strength increases when the number of layers is higher. No other differences were observed between the 0º /90º /45º /45º /90º /0º and 0º /45º /90º /90º /45º /0º composites. Likewise, three-layered composites were 0º /90º /0º and 0º /45º/0º; these did not show any additional differences in the flexural strength of the composites. This argument has been confirmed from the work of earlier researchers in which the fibre orientation were found to influences the properties of the composites (Shibata *et al.* 2005). Vinod and Sudev (2013) studied the effect of fiber orientation on the flexural properties of pineapple leaf fiber reinforcement in bisphenol composite with a view to support the observation. Results reveal substantial influence on the flexural properties of reinforced composites from fibre orientation. They also found the maximum flexural strength in the case of inclined orientated fibers compared to that of uni-directional and bi-directional oriented fibers.

Impact Strength

The impact strength performance of different composites were studied with respect to varying interlaminar fibre orientation. Figure 4(b) shows the influence of variations in fiber orientation on the impact strength of composites. The ‘E’ type of composite exhibited a higher impact strength (306.25 J/m) than the other types of combinations. Even though the ‘E’ and ‘F’ types of composites were created using the same fiber wt.%, the impact strength of the composites was different. Hence, apart from the fiber to matrix interaction, the geometry of the composites and construction (Idicula *et al.* 2010), and the fiber alignment played an important role in influencing the impact strength of the composites. The percentage improvement from ‘F’ to ‘E’ was 41.9 %. In general, the magnitude of impact strength is ascertained from the packing between the fibres and the matrix. Though all the combinations exhibited good impact strength, the composite, ‘E’ showed the highest impact strength. This higher value of impact strength was observed with ±45° orientation placed at the interface (Stanly *et al*. 2014). The composite that was fabricated using the 0º fibers at the extreme layers on both sides of the composites presented a higher impact strength. The lowest impact strength was observed in the ‘C’ type oriented composites (159.0 J/m), while the ‘D’ and ‘F’ types had impact strengths of 180.1 J/m and 177.9 J/m, respectively. No remarkable differences were observed between them. Both ‘D’ and ‘F’ types of composites were fabricated using the 0º /45º oriented fibers at the extreme layers. The ‘A’ and ‘B’ types measured 203.6 J/m and 204.2 J/m, respectively. These two types of composites showedonly slight changes either. Fabrication of these two types of composites at the combination of 90º and 0 º oriented fibers was seen.

A few studies have reported the impact properties of composites with the effect of fiber orientation, which has a significant effect on the nature of the variation in the impact properties. The fracture toughness for 20% unidirectional date plam fiber reinforced composite were reported to have higher value than that of the composite reinforced with 20% woven structure (Wazzan *et al.* 2005). The authors have reported influence on the impact toughness of kenaf/glass hybrid composites from the fiber orientation (Salleh *et al.* 2012). Variation in impact strength by fiber orientation has been reported for glass fiber reinforced polymer matrix composites (Alam *et al*. 2010). The importance of the effect of fiber orientations to the mechanical properties of hybrid composites, as well as for ballistic resistant application (McWilliams *et al.* 2015) was also observed.

SEM Morphological Analysis of Fractured Impact Specimens

Fractured impact tested composites were used for the SEM analysis. This is shown in Fig. 5 (a-b). The ‘C’ and ‘E’ type composites were selected for an identical study of the morphology of the lowest and optimal impact strength. The SEM fractograph of the 90º /0º /0º /90º (Type C) oriented sisal fiber composites after the impact test is shown in Fig. 5 (a). This figure clearly shows the 90º oriented fibers placed at the extreme side and 0º oriented fibers placed next to the 90º fibers. The failure mechanisms for the impact loading were fiber fracture, fiber bending, fiber pull out, and voids (Hariharan and Khalil 2005) and are shown in Fig. 5(a). A poor interfacial bond between the fiber to matrix caused void formation and earlier failure in composites. Moreover, fiber bending could be the failure mechanism arising as a result of the lesser impact strengths of fiber oriented composites.

Details of fracture of the 0º /90º /45º /45º /90º /0º sisal oriented composite are shown in Fig. 5(b). The fiber pull out is shown in Fig. 5(b). This required energy dissipation of a larger magnitude, which was exhibited in the higher impact strength.

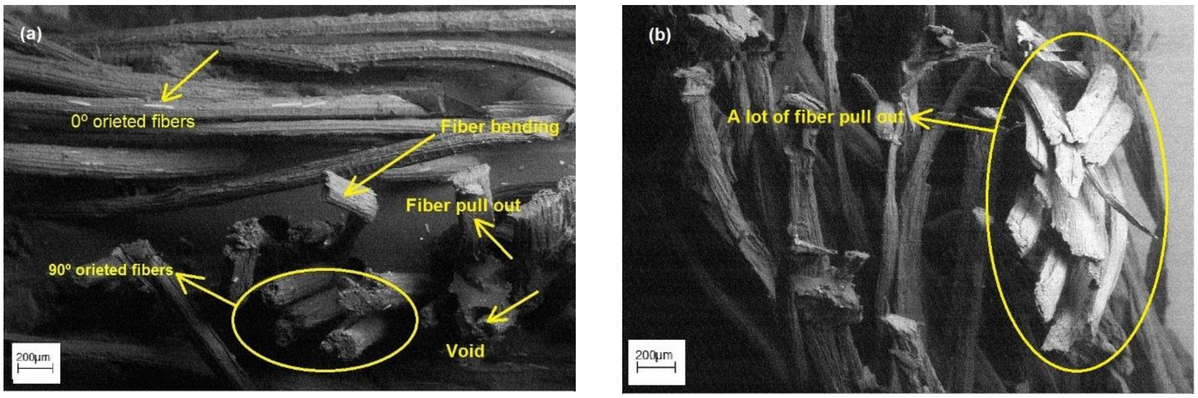

Fig. 5. SEM studies on the effect of 90º /0º /0º /90º (a), and 0º /90º /45º /45º /90º /0º (b) fiber orientation on the impact strength of sisal fiber composites

Natural Frequency and Damping Studies of Fiber Oriented Composites

Modal analysis is a process that describes a structure in terms of the dynamic characteristics, namely natural frequency, damping, and mode shapes. The analysis helps to design all types of structures, including automotives, aircraft, space craft, and computers. Basically, there are characteristics that depend on the weight and stiffness of the structure, which determine the location of these natural frequencies and mode shapes. Rajini *et al.* (2012) studied the effect of free vibration behaviour of chemically modified coconut sheath fiber composites. This process involves the chemical composites under alkali and silane. The silane-treated composites were shown to produce a better natural frequency as a result of the improved stiffness of the composites. The most important parameter that is needed for the experimental modal analysis is the frequency response function (FRF). Stated in simple language, this is the ratio of the output response to the input excitation force. Both the applied force and the response of the structure are due to the simultaneous application of applied force. This measurement is typically acquired, using a dedicated instrument such as an FFT analyzer or a data acquisition system with software that performs the FFT. A typical FRF curve obtained from the impulse hammer test is shown in Fig. 6.

Figure 6 shows the presence of peaks in this FRF, which occur at the resonant frequencies of the system. These peaks occur at the noted frequencies, where the time response was observed to be the maximum corresponding to the rate of oscillation of the input excitation. The overlay of the time trace with the frequency trace led to the observation of the frequency of oscillation at the time at which the time trace reaches its maximum value corresponding to the frequency, where peaks in the frequency response function reach a maximum (Fig. 6). Kumar *et al.* (2016) have studied the effect of layering pattern on vibrational behavior of natural fiber composites. Natural frequency and damping of the composites were found from the FRF curve *i.e.* peaks in the curve. The peak values respond to the stiffness of hybrid composites. In general, the deformation patterns occur when the excitation coincides with one of the natural frequencies of the system.The first bending deformation pattern corresponding to the first natural frequency in the plate is referred to as mode 1. At the second natural frequency, the first twisting deformation pattern noticed in the plate is referred to as mode 2. The second bending deformation pattern forms mode 3 in the third natural frequency.

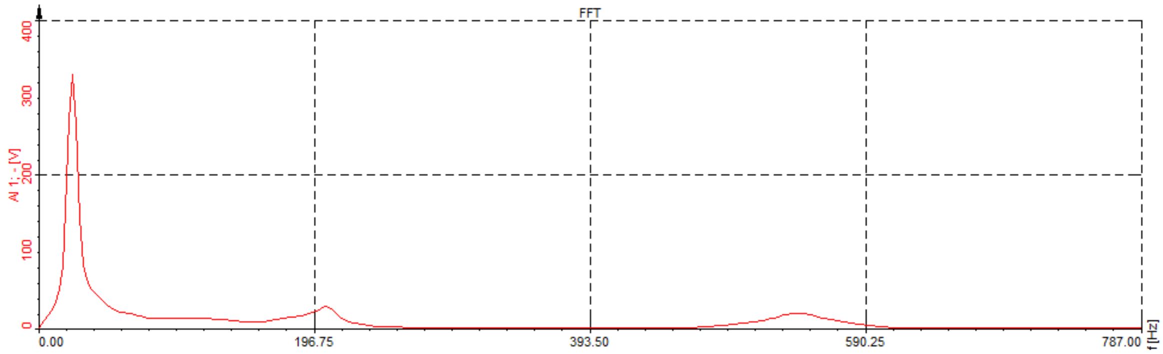

Fig. 6. A typical curve of frequency response function (Kumar *et al.* 2016)

Damping exists in all vibratory systems, whenever there is energy dissipation. For free vibration, the loss of energy from damping in the system results in the decay of the amplitude of motion. The damping factor can be estimated by the half-power method or other related mathematical or graphical methods. In the half-power method, damping is estimated by determining the sharpness of the resonant peak. Figure 7 shows the possibility of relating the damping to the width of the peak between the half-power points.

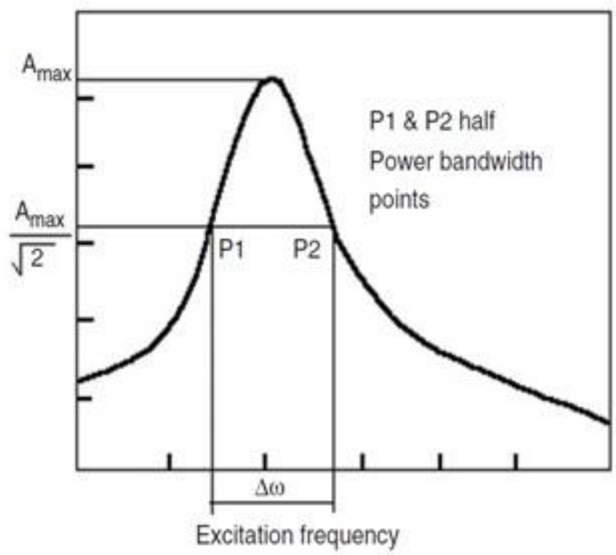

Fig. 7. Half-power band method (Chandradass *et al*. 2008)

The expression for obtaining the damping factor ζ from the half-power band width technique is given by (Chandra *et al.* 1999),

$$Z = \Delta\omega / 2\omega_n \tag{1}$$

where $\Delta\omega$ is the band width at the half-power points of the resonant peak for the n^{th} mode, and ω_n is the resonant frequency. The half-power points below and above the resonant peak indicate the response magnitude, as 0.707 times the resonant magnitude when the linear scale is used. At the same time, it was found as 3dB below the peak value of the FRF for the particular mode when the logarithmic scale is used.

Table 4. Natural Frequency and Damping of Sisal Fiber Polyester Composites- Mode II and Mode III

Type of composites	Natural frequency (Hz)			Damping		
	Mode I	Mode II	Mode III	Mode I	Mode II	Mode III
A	17.09	144.04	341.80	0.09	0.011	0.00466
B	39.06	131.84	285.64	0.76	0.077	0.035
C	18.31	105	251.81	0.477	0.0842	0.0347
D	63.48	129.39	202.64	0.053	0.0260	0.0166
E	29.3	97.67	178.23	0.352	0.1058	0.05798
F	26.88	185.55	261.282	0.481	0.0697	0.04950

Table 4 shows the natural frequency and damping of fiber reinforced composites. The dynamic properties of the first three lowest frequency modes were reported for different fiber oriented composites. The composite specimen size of 200 × 20 × 3 mm^3 was fixed like a cantilever beam (Fig. 2). Generally, the natural frequency of composites is dependent on many factors, namely area moment of inertia, density, Young's modulus, fiber orientation, fiber content, fiber/matrix interface, and chemical treatment, *etc*. So it is a difficult task to find the natural frequency for fiber reinforced composites. Kumar *et al.* (2014) investigated the free vibration and damping behavior of sisal and banana fiber composites. In the study, the authors varied the fiber length and fiber wt%. Variations in fiber length were found to influence the natural frequency and damping properties of composites.

From Table 4, it was clearly noticed that the 'D' type of composites exhibited maximum natural frequency with lower damping value. This is a normally expected result because the high modulus composites can dissipate the energy as quick as possible. Moreover, in this case, the irregular linear trend was observed with respect to fiber orientation,which was found to be dominant than that of the factors like stiffness and weight percent of fiber content. Since the interlaminar oreintation can affect the degree of adhesion, in turn it caninfluence the magnitude of stiffness also. Furthermore, in Mode II, the F type of oriented composites provide the highest natural frequency compared to the other type of composites. The flexural strength is higher for a similar type of composites. Both flexural and natural frequency are measured in the bending condition. So the flexural strength of the 'F' type composite could be the reason for influencing the natural frequency of Mode II values.

Figure 8 shows the time domain of the polyester composite during the testing by impulse hammer method. Table 4 shows the values of natural frequency of Modes II and III.

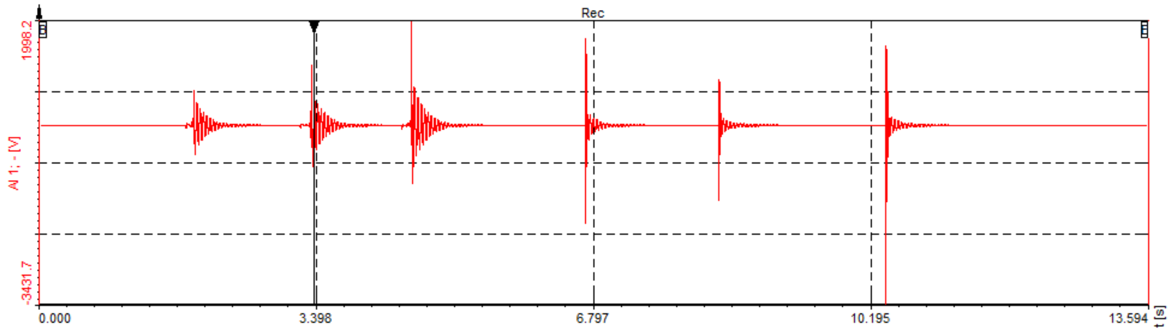

Fig. 8. Vibrational response time domain

The damping factor is attained from the well-known technique referred to as the logarithmic decrement method (Rattan 2014),

$$\frac{Xn}{Xn+1} = e^{\zeta w_n} T_d = \frac{X_0}{X_1} = \frac{X_1}{X_2} = \frac{X_2}{X_3} = \ldots. \quad (2)$$

$$l_n \frac{Xn}{Xn+1} = \zeta w_n T_d \ldots \quad (3)$$

where ζ is the damping co-efficient, $X_n$is the peak acceleration of the nth peak, $X_{n+1}$is the peak acceleration of the n+1th peak, $w_n$is the natural frequency, and $T_d$is the time period.

The damping of fiber-oriented composites are determined on the basis of the above equations 2 and 3. The ‘B’ type of composites showed the highest damping value compared to the other types (Table 4). Natural frequency and damping of A, B, and C types of composites follow a similar type, with a reversal of the remaining types of composites. Furthermore, the ‘D’ type of composites show the lowest value, whereas the same type of composites exhibit the highest value in the natural frequency of fiber composites. The remaining Modes (II and III) are shown in Table 4.

CONCLUSIONS

1. Sisal fiber polyester composites were fabricated using the compression moulding technique. Enhancement in flexural strength, impact strength, and free vibration properties of the sisal fiber composites was found with the effect of fiber orientation.
2. The highest flexural and impact strengthswere presented in 0º /90º /45º/ 45º/ 90º/ 0º (Type E). The lowest flexral strength was presented in 90 º/0 º/90 º. The percentage improvement from lowest to largest was 81.10%.
3. The lowest impact strength was observed in 90º /0º /0º /90º. The percentage improvement from the lowest to largest was observed 48.07%. An impact fracture mechanism was observed in the SEM analysis. A fiber pull mechanism was observed as the main factor of the composite fracture.
4. In the Mode I analysis, the higher natural frequency was observed in the sisal fiber oriented composites in 0º /45º /0º (Type D), likewise the lowest natural frequency

was measured in 90º/0 º /90 º. The percentage improvement from the lowest to the highest was 71.11%.

5. Higher damping values were observed in 0 º /90 º /0 º (Type B) composites. The lowest damping was measured likewise in 90 º/0 º/90 º. The percentage difference from the lowest to highest was 81.3%.

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