Effect of curing temperature and layering pattern on performance studies: a novel hybrid composite

Abstract: The effect of curing temperature and layering pattern on mechanical and free vibrational properties (natural frequency and damping) of Sansevieria cylindrica/coconut sheath fiber reinforced hybrid unsaturated polyester (USP) composites is discussed. The hybrid composites were compression molded using different layering sequences. Curing was carried out at different temperatures (30°C and 60°C). The results show that Sansevieria cylindrica/USP composites are stronger than the coconut sheath/USP composites. At higher curing temperatures, a significant improvement in strength was observed in all composites and layering pattern also played a vital role in enhancing composite strength, with coconut sheath/Sansevieria cylindrica/Sansevieria cylindrica stack yielding a higher strength compared to the other composites. In addition, curing temperature and layering pattern produced a similar effect on the vibrational characteristics of the composites.

Keywords: coconut sheath; curing temperature; hybrid composite; Sansevieria cylindrica; vibrational study.

1 Introduction

Strict environmental regulations have opened new avenues in using natural fibers as an alternative for synthetic fibers as reinforcement in composites. The use of natural fibers has created a lot of interest in the research community because of their low cost, biodegradability, renewability, environmental friendliness, low density and easy availability [1]. Natural fibers have gained worldwide recognition as reinforcement in polymer composites due to their compatibility and comparable mechanical properties. Several natural fiber reinforced composites using sisal, banana, hemp, coir, jute, flax, vakka, and pineapple leaf as renewable resources have shown good mechanical properties with a thermoset matrix, thereby attracting the furniture, food packaging and automobile industries [2]. The replacement of synthetic fibers in the aspect of mechanical strength, using natural fibers, is required at some additional cost and processing time, for the enhanced interfacial bonding with the thermoset matrix. To clarify these aspects, the hybrid composites are formulated with the help of dual fibers, without losing their own identity, to exploit the significance of more than one reinforcement in the polymer matrix [3].

Generally, hybrid composites are reinforced with synthetic and natural fibers to produce novel composites with enhanced mechanical properties. The growing awareness on environment has turned the focus on, hybrid composites which are nowadays prepared by the addition of a natural fiber with another natural fiber. Reddy et al. [4] investigated the performance of impact properties of kapok/glass and kapok/sisal fabrics reinforced polyester hybrid composites and found that the addition of kapok fabric to sisal/polyester composites exhibited great enhancement (34%) on impact strength. The mechanical performance of short randomly oriented banana and sisal hybrid fiber reinforced polyester composites was influenced with the effect of varying volume fraction of fiber content. Authors reported that the tensile, flexural and impact properties increased and better performance was noted at 40% fiber volume fraction [5]. Sreenivasan et al. [6] studied the effects on mechanical properties of randomly oriented short
Sansevieria cylindrica fiber/polyester (SCFP) composites of varying fiber length and fiber content. The analysis of the tensile, flexural and impact properties of short SCFP composites displayed a critical fiber length of 30 mm and an optimum fiber weight percent of 40%.

Winowlin Jappes et al. [1] investigated naturally woven coconut sheath/polyester composites fabricated through compression molding. Results proved the effective utilization of coconut sheath as an alternative reinforcement to glass fiber. Kumar et al. [7] investigated the tensile and flexural properties of composites made by reinforcing Sansevieria cylindrica as a new natural fiber into a rubber-based polyester matrix. The flexural strength of Sansevieria cylindrica fiber composites is more than that of silk fiber reinforced composites and is closer to drumstick fiber composite with respect to the volume fraction of fiber, whereas the flexural modulus is much higher than those of jute, drumstick vegetable fiber composites and also much closer to that of silk fiber composites.

Idicula et al. [8] studied the behavior of randomly oriented short banana and sisal fiber reinforced polyester composites for different layering patterns, by changing the position of banana and sisal fibers; this revealed improved modulus and mechanical strength at different relative wt% values of sisal fiber. The palmyra/glass fiber hybrid composites were fabricated by having palmyra at the core and shell, and it was found that sandwiching palmyra fibers between glass fiber mats exhibited better mechanical properties than intimated types of composites. Further, it was reported that the water uptake characteristics of palmyra fiber reinforced composites decrease with the addition of glass fiber as a hybrid [9].

There are many studies on mechanical properties of natural fiber reinforced hybrid polymer composites fabricated under room curing temperature. Only limited work is available on analyzing the mechanical and vibration properties of natural fiber reinforced hybrid polymer composites under varying curing temperatures. Thus, in this investigation, an effort was made to investigate the effect of curing temperature (30°C and 60°C) on the mechanical (flexural, impact and tensile properties) and vibration properties (natural frequency and damping) of Sansevieria cylindrica/coconut sheath hybrid polyester composites. The hybrid composites were also developed with different layering sequences by keeping the fiber content (50% wt) constant.

## 2 Materials and methods

### 2.1 Materials

The coconut sheath fiber in the form of mat was collected from local resources in and around farms near Theni, Tamil Nadu, India. Sansevieria cylindrica fibers are separated from Sansevieria cylindrica leaves which were collected from farms near Cumbum, Tamil Nadu, India by the retting process. The matrix used was commercially available unsaturated isophthalic polyester resin (VBR4503).
supplied by Vasavibala Resins (P) Ltd., Chennai, India. Methyl ethyl ketone peroxide and cobalt naphthenate were used as the catalyst and accelerator respectively which were procured from same manufacturer. Figure 1A shows the Sansevieria cylindrica plant identified from the Western Ghats, India with extracted loose fibers in the form of roll. Figure 1B shows the coconut tree with a coconut sheath at the outer bask with the extracted coconut sheath fibers in the form of mat.

2.2 Fabrication of hybrid polyester composites

The naturally woven coconut sheath fiber was first cut into rectangular pieces for the required mold size of 300 mm×130 mm. The Sansevieria cylindrica fiber was cut into optimized lengths of 40 mm and allowed to dry in a hot air oven at 100°C in order to remove the moisture content. Finally, the polyester matrix was mixed with the curing agent and spread over the particular fiber mat of interest with a steel brush in each layer, then placed inside the closed mold of size 300 mm×130 mm×3 mm followed by the stacking of other fiber layers. The overall fiber content was kept constant (50% wt). The mold was closed by applying 17 MPa in a press for room temperature curing for another 24 h. Two single-fiber composites were produced, with either coconut sheath (C) or Sansevieria cylindrica (S). Also, four different sequences of layering patterns were fabricated, namely: (CCS), (CSC) (i.e., 33% wt of coconut sheath and 17% wt of Sansevieria cylindrica fiber), (CSS) and (SCS) (i.e., 17% wt of coconut sheath and 33% wt of Sansevieria cylindrica fiber).

2.3 Characterization

The tensile properties of the composites were measured on an Instron Series-3382 universal testing machine according to ASTM D3039. The test was performed with a cross-head speed of 5 mm/min and the gauge length was 100 mm. The samples used for testing were 200 mm×20 mm×3 mm in dimension. The flexure test method measures behavior of materials subjected to simple beam loading. Three-point flexural properties were determined in the same Instron testing machine with 5 kN load-cell, gauge length of 50 mm and cross head speed of 1 mm/ min according to ASTM D790. Impact testing was done as per ASTM D256 (Capacity-25J) using an impact tester. The dimensions of the specimens were 65 mm×13 mm×3 mm.

The fracture of tensile and impact tested specimens were observed using scanning electron microscopy (SEM) for all types of composites using the Hitachi S-3000 model. All specimens were sputtered with a 10-nm-thick layer of gold prior to SEM observation.

The free vibration experimental setup included an accelerometer, piezoelectric impact hammer and computer with the DeweSoft software. The accelerometer (Kistler model 8778A500) was attached to the end of the rectangular composite laminate with wax. The modally tuned impact hammer (Kistler model 9722A500) with a sharp hardened tip was chosen for getting higher frequencies. The displacement signal from the accelerometer was recorded in a personal computer through a data acquisition system (DEWE 43, Dewetron Corp., and Austria) and an ICP conditioner (MSIBRACC). Two separate adopters were used for capturing the output signal, one for receiving the accelerometer signal and the other for measuring the magnitude of the response by the piezo-electric hammer.

3 Results and discussion

3.1 Tensile strength

The results of the tensile strength of Sansevieria cylindrica/coconut sheath reinforced hybrid composites for different layering patterns with two different curing temperatures are shown in Figure 2. At room temperature (30°C) curing, the pristine SSS short fiber reinforced composites showed the highest tensile strength compared to the coconut
sheath fiber mat composites for the same overall fiber content. This significant enhancement in tensile strength of short fiber reinforced composites could be due to the dispersion of randomly oriented short fibers with polyester matrix. This can create a greater number of interfaces in an irregular fashion and thus, compose a more complicated path of crack propagation. Nevertheless, in coconut sheath fiber mat composites the formation of interface acts parallel to the fiber mat both along its axial and normal direction to the fiber surface. This parallel interface can lead to the crack propagation along the lateral direction of fiber surface which can peel off the fiber from the matrix attributed to the debonding between fiber and matrix. The separation of layers due to the debonding between coconut sheath fiber mats and matrix was clearly seen in the tensile fractured specimens shown in Figure 3. However, the irregular fashion of the fractured end was noticed, which could be one of the reasons for getting a higher tensile strength in the case of SSS composites, as seen in Figure 3.

The performance of the composite material depends strongly on the processing characteristics of the matrix. In general, the processing characteristics include the liquid viscosity, the curing temperature and the curing time. Accordingly, in the developed pristine composites, a marginal improvement in tensile strength was observed for both coconut sheath and Sansevieria cylindrica fiber composites at a higher curing temperature (60°C) compared to room temperature (30°C) curing. The percentage of increase in tensile strength appears to be the same for both cases due to the similar nature of interfaces in each composite.

A significant improvement in tensile strength was observed in the case of hybrid composites for different layering sequences. This could be due to the changes in the behavior of molecular interactions in the polyester matrix. Various laminas in a laminate may contain fibers either all in one direction or in different directions. It is also possible to combine different kinds of fibers to form either an interply or an intraply hybrid laminate. An interply hybrid laminate consists of different kinds of fibers in different laminas. The interply type of hybrid composites are developed in this study using two different forms of fibers keeping different layering sequences using polyester matrix.

It was observed that the tensile strength is higher when two layers of coconut sheath fiber reinforced with secondary reinforcing Sansevieria cylindrica fiber are used as core material (CSC). The same tensile strength was noticed for hybrid composites (CSS) having Sansevieria cylindrica fiber as skin material at one end. Conversely, in SCS hybrid composites the tensile strength is lower even though the high strength Sansevieria cylindrica fiber is used as the skin material. Whereas, Idicula et al. [8, 10] reported that sisal/banana/sisal show slightly lower tensile strengths compared to banana/sisal/banana hybrid composites, because high strength banana fiber is used as a skin material. The results obtained from this work reflect a different outlook on the tensile strength of the hybrid composites, that the enhancement is not only because of introducing the high strength material as skin, but is also based on the interfacial bonding between fibers. The interfacial bonding mainly depends on the compatibility nature between the two different kinds of reinforcing elements. The scanning electron micrograph of the tensile fractured specimen of Sansevieria cylindrica fiber and coconut sheath fiber reinforced composites at 60°C are shown in Figure 4.

From Figure 4, the SEM image shows the closely packed and randomly dispersed Sansevieria cylindrica fiber and polyester matrix, resulting in an efficient stress transfer between the matrix and the SSS fibers. Due to this behavior, the Sansevieria cylindrica fiber composites attain a higher load compared to the coconut sheath fiber mat reinforced composites.

3.2 Flexural strength

In fiber reinforced polymer composites, the selection of a matrix has a major influence on the compressive, interlaminar shear, as well as in-plane shear properties of the
composite material. The matrix provides lateral support against the possibility of fiber buckling under compressive loading, thus influencing to a large extent, the compressive strength of the composite material.

The plot shown in Figure 5 depicts that the flexural strength of hybrid composites increases with the rise in temperature, i.e., the composites fabricated at a temperature of 60°C show higher flexural strength.

Generally, the inter-laminar shear strength is an important design consideration for structures under bending loads. SSS composites have maximum flexural strength compared to others, 64.2 MPa, but at curing room temperature, it drops to 35.4 MPa. The increase in inter-laminar shear strength of polyester matrix at high temperature curing could be one of the reasons for getting the better flexural strength in all composites. However, the CCC layer has a very low flexural strength among all other layering patterns, both at higher and lower curing temperatures. Similar to tensile strength, the value of flexural strength also increases with increase in the amount Sansevieria cylindrica fiber reinforcement. In the case of the hybrid composite laminates, the value of flexural strength is higher in CSS (39 MPa), but at normal curing temperature, the flexural strength value is 32 MPa. The composite reinforced with 33% wt of Sansevieria cylindrica fiber has a flexural strength of 39 MPa in the CSS hybrid composite, but it decreases for the same fiber content in a different layering pattern of the SCS laminate, as shown in Figure 5. In SCS, the change in the layering pattern decrease the flexural strength to 30 MPa at 60°C, however, it was higher than at room temperature.

### 3.3 Impact strength

The toughness of the material is one of the key parameters for any newly developed material system when it is subjected to engineering applications. In the layering pattern, the SSS has increased impact strength compared to the others (57.2 J/cm²); at normal room temperature, the value is 41.2 J/cm² (Figure 6). Here also, CCC has a low impact.
strength at both normal room temperature and 60°C; the value is approximately one J/cm².

In the case of the hybrid composite laminates, the value of impact strength is higher in CSS, 34.8 J/cm² at curing temperature, even though changing the layer pattern as SCS and keeping a constant fiber decreases the impact strength value at both curing and normal temperatures to approximately 14.5 J/cm². The value of impact strength also increases with the amount of Sansevieria cylindrica fiber reinforcement. In SCS, the change in the layering pattern caused the drop in impact strength at 60°C.

In the SEM micrographs taken from the fractured impact specimen (Figure 7), it is clearly seen that the SSS pattern has enhanced adhesive bonding of fiber with matrix. However, in the CSC pattern, there is a lack of adhesive bonding of fiber with matrix. Therefore, the impact strength of the SSS layer pattern is higher.

3.4 Natural frequency and damping studies on different layering patterns

The natural frequency and modal loss factor associated with the first three lowest frequency modes have been obtained for different layering patterns. The rectangular specimen of size 200 mm × 20 mm × 3 mm is clamped at a rigid support up to a length of 30 mm. Free vibration is excited on the specimen with the aid of modally tuned impact hammer. The oscillation signal of the laminate is received by an accelerometer through the Dewetron 43 data acquisition system and stored in a personal computer.

From Figure 8, it is clearly seen that the value of composites fabricated at a temperature of 60°C have a higher natural frequency. The trend increases gradually with the increase in temperature. In the layering pattern, the SSS combination shows higher values of natural frequency when compared to others. In the case of hybrid composite laminates, the values of natural frequency are higher in the SCS combination. It is also inferred that the damping properties (Table 1) increase with increased addition of Sansevieria cylindrica fiber. It is clearly seen that the values did not vary uniformly; SSS had the higher damping value (0.9852 Ns/cm²) compared to the other layering patterns. Damping is not uniform while changing the layer pattern and the curing temperature.

Figure 6 Effect of curing temperature on the impact strength of composites.

Figure 7 Fractography of impact damaged composites: (A) SSS; and (B) CSS.
Figure 8 Natural frequency of differently cured pure and hybrid composites: (A) mode-1; (B) mode-2; and (C) mode-3.

4 Conclusions

To conclude, the following observations were made in the investigation of *Sansevieria cylindrica*/coconut sheath fiber reinforced hybrid composites.

1. In general, curing of the composites at 60°C imparts enhanced mechanical properties to the fabricated composites.
2. Compared with the coconut sheath composites, the novel *Sansevieria cylindrica* fiber reinforced composites hold superior mechanical strength.
3. A higher *Sansevieria* content in the hybrid composites imparts greater strength to the composite structure.
4. Among the hybrid composites, the CSS layering pattern preserves the highest flexural strength (cured at 60°C).
5. The vibrational properties of the SCS pattern appear good in natural frequency and damping among the pure and hybrid composites.
6. The overall observation is, inclusion of the *Sansevieria cylindrica* fiber in to the polyester matrix greatly enhances the strength of the polymer composite and significant enhancements in both mechanical and vibrational properties were noted at a higher curing temperature. Between the two different layering patterns of *Sansevieria cylindrica* rich hybrid composites, CSS produced high mechanical strength and SCS developed good vibrational properties.
Acknowledgments: The authors wish to acknowledge the Centre for Composite Materials, Department of Mechanical Engineering, Kalasalingam University for its kind permission to do the experimental part of this work and also wish to thank the Department of Science and Technology (DST), India for funding through FIST Program SR/FST/ETI-275/2010.

References