Effects of Process Parameters on Vibrational Behaviour of *Sansevieria cylindrica* Fiber Reinforced Polyester Composites

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Abstract

The natural fiber composites have attracted much interest among the researchers, due to their low cost, easy availability and enhancement in their properties. Many plants based natural fibers, including banana, sisal, hemp, jute, oil palm, coir and kenaf, among others, have been studied extensively. *Sansevieria cylindrica* fiber (SCF) is one of the plant-based leaf fibers, which has not been explored to a greater extent. The main purpose of this study focused on utilizing SCF as a potential reinforcement to produce polyester matrix composites. Unsaturated polyester resin was used as matrix, because of its low cost and ease of use. In this work, free vibration studies were performed for pure SCF reinforced polyester composites. The SCF composites were fabricated with various fiber percentage weight (wt%) and different curing temperatures. The effects of both fiber wt% and curing temperatures on natural frequency and damping of SCF composites were studied. It was observed that both natural frequency and damping showed significant variations on different process conditions of polymer composites. Based on vibrations studies, the optimum fiber wt% was obtained at 40 and optimum curing temperature was observed as 60 °C. Furthermore, the effects of various chemical treatments on vibration behaviors of SCF composites was also investigated for the optimum fiber loading and curing temperature of 40 wt% and 60 ºC, respectively. $Ca(OH)_2$ treated composite exhibited highest natural frequencies for all the three modes of vibration and silane treated counterpart showed highest damping values for the last two modes of vibration. Therefore, it was evident that chemical treatment significantly influenced the dynamic properties, including natural frequency and damping of SCF reinforced polyester composites. This study can guide the composites/manufacturing companies to design and manufacture composites for engineering system applications, especially where vibration response is inevitable.

Keywords: *Sansevieria cylindrica* fibre, Curing temperature, Vibration, Natural frequency, Damping coefficient.

Introduction

A new type of engineering material, commonly known as composite, emerged in the middle of the 20th century. Composite materials can be defined as a combination of two or more distinct materials, having a recognisable interface between them. Composites consists of a primary phase of a strong load carrying material (reinforcement), which is embedded in a secondary phase of a weaker material (matrix).

Matrix transfers load to fibers and protects the surface of the reinforcement and safeguards against environmental effects, such as mechanical abrasion. Commonly known three major types of matrices are ceramic, metallic and polymeric. The usage of natural fibers has attracted more interest among researchers, due to their easy availability, high strength, low cost and more importantly their eco-friendly nature. Several types of natural fibers, such as sisal, bamboo,okra, pineapple, jute, banana, coconut, palmyra, flax, hemp and ramie, have been used as a reinforcement in polymer matrix composites, as reported by several researchers[1-3] and. Some of them, such as flax and hemp, have found their applications in automotive industries. The strength of all natural fibers and the fiber content depend on cellulose and lignin contents. Two or more different types of fibers combine together in a common matrix is known as hybrid composite. Not only fibers, in some cases, fibers with fillers in a common matrix is also referred to be hybrid composite[4]. Hybridization concept produces different range of properties, as observed extensively by many research works. The material cost is reduced to a great extent and high performance is achieved by the effect of hybridization[5]. Some of the combinations of fibers, such as banana/sisal, glass/banana, glass/sisal, oil palm/sisal, glass/oil palm, pineapple/glass and coir/glass, which produced better performance composites and plenty of research works have been carried out by earlier researchers[6,7]. Natural fibers of various types are reinforced with synthetic fibers for producing a composite with high strength and low cost. Predicated on their higher strength and lightweight capability, the composites have applications in aerospace structures. Composite materials possess technical ability and mechanical properties[8,9]. Structures are usually exposed to mechanical excitement during their performance. The hybridization and surface treatment of fibers help to determine the stiffness of the structures[10-12]. Besides, the fiber reinforced polymer composites technology has rapidly grown, because of tribological[13] applications, among others. This can be attributed to their outstanding structural performance, in addition to their better response over traditional materials in industrial systems, such as claws, chute liners, gears, auto components, to mention but a few.

Due to the porous nature of the fibers, natural fiber composites have extremely high dampings. Idicula et al.[14] carried out static and dynamic mechanical studies of thin, closely mixed banana/sisal hybrid polyester composites. The better fiber/matrix adhesion and stress transfer were obtained by the hybridization. Bamboo fiber reinforced polypropylene composites and effects of chemical modification of them, using silane coupling and filler loading were studied by Sun-Young Lee et al.[15]. It was reported that adhesion improved between the propylene matrix and bamboo fiber by the addition of silane coupling agents. Also, by increasing the bamboo fiber weight percentage, the strength increased. According to Borkar et al.[16] sun hemp fibers with garbage polyethylene bags were piled and composite substances were manufactured, using hot compression molding procedure. Tensile, flexural and impact strengths of sun hemp fiber reinforced with waste polyethylene bags were tested and the results showed that up to a fiber volume fraction of 0.30 V_f, the tensile and the flexural strengths increased and the impact strength increased only up to 0.20 V_f. By using this material, the environmental hazards created by synthetic materials, such as polyethylene bags could be minimized.

Furthermore, natural fiber reinforced thermoset composites showed low strength performance when compared with that of synthetic fiber thermosets. At the same time, addition of small amount of synthetic fiber along with natural fiber increased the strength of composites. Zhaferet al.[17] made reinforced polyester hybrid composite glass fiber/banana fibers and it was observed that with the introduction of a small weight percentage of glass fibers, the tensile and bending strengths improved further. Weibo et al.[18] experimented the vibration, mechanical and lively damping properties of epoxy composites and polyether urethane and reported that polyether urethane damping material loss variable was determined by the connection factor. A complete review study on damping of natural fiber reinforced composite materials was carried out by Chandra et al.[19]

A detailed parametric study was carried out by Patel et al.[20] to study the influences of plate geometry, lay-up, ply-angle and material properties on the free flexural vibration response and frequencies of bimodulus angle-ply composite laminated plates. It was reported that the frequency parameter increased with the number of layers, ply angles and thickness ratio, whereas it decreased with the aspect ratio. Damping and vibration details on polyethylene fiber with varied temperatures were discussed by Raj et al.[21]. Free vibration, effects of sequence on tensile, impact and absorption properties of glass fiber reinforced epoxy composites were analysed by Prabhakaran et al.[22]. Vibration properties and their effects on the woven structures were studied by Xu Lei et al.[23] and reported that the vibration performance of the composite depended mainly on the fiber volume fraction, resin-rich area and the warp architectures of the composites.

Vishwanath et al.[24] reported the analysis of wear on polyester and phenolic composites of reinforced glass fiber. In both composites, the low wear and resin coefficient with percentage weight (wt%) of 30 and higher amount of resin resulted to a high wear rate. Tribological studies on linen and jute fiber reinforced unsaturated polyester resin were carried out by El-Sayed et al.[25], where the fibers were oriented in normal, longitudinal and transverse directions, resulting to an increase in coefficient of friction value and decrease in the wear rate in all cases.

Unal et al.[26] reported a decrease in the freshness coefficient with an increasing load of pure polytetrafluoroethylene (PTFE) and its composites. Erosion behavior studies were conducted by Mahapatra et al.[27]on e-glass fiber-reinforced polyester composites and Taguchi method was used to report the optimal parameter for minimal wear. The abrasive behaviors of untreated sugarcane fiber reinforced unsaturated polyester composites were studied by Mahapatra et al.[28] and it was observed that the fiber length affected the wear effect on the composites. The fiber length of 7-8 mm was identified for minimum wear of the composites.

The novelty of this work was vibration analysis on SCF reinforced polyester composites, as it was first time approach with various process parameters: fiber weight percentages, curing temperatures and chemical treatments. The natural frequency and damping coefficients were measured for various process parametric conditions of the SCF composites.

Materials and Experimental Methodology

Sansevieria cylindrica fiber (SCF) and polyester resin were used to manufacture the composite specimens. Methyl ethyl ketone peroxide (MEKP) and cobalt napthnate were used for curing purpose of the polyester resin. Before fabrication, the curing agent was thoroughly mixed with polyester resin. Initially, the polymer composites were fabricated using SCF length of 40 mm with various weight percentages and different curing temperatures were taken. A compression molding technique was adopted for manufacturing of the SCF polyester composites. After the compression molding, the SCF reinforced polyester composites was ejected from the mold die, then it was cut according to the vibration experimental requirements or dimensions, as shown in Figure 1.

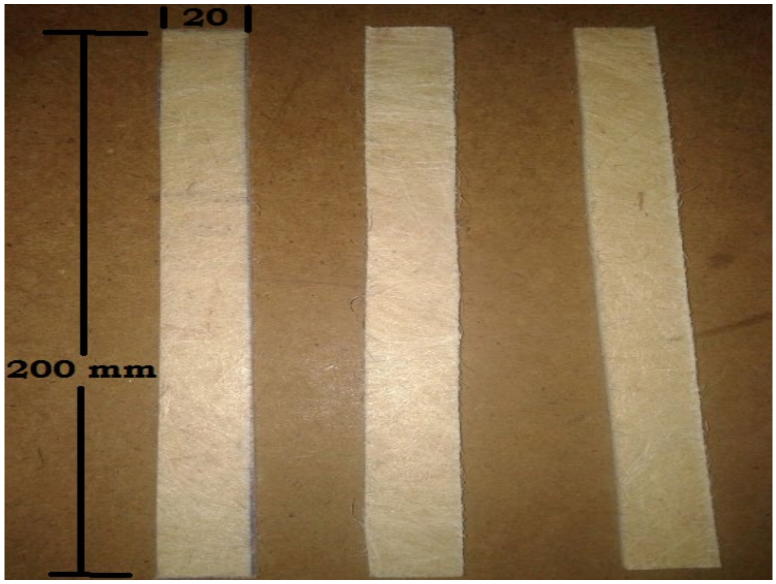

Figure 1. Typical SCF reinforced polyester composite test specimens used for free vibration tests

Vibration studies were carried out, using an impulse hammer technique. Based on vibrations studies, further SCF polymer composites were fabricated for optimum fiber loading at 40 wt% and optimum curing temperature of 60 ºC with various surface modifications of SCF. Both untreated and treated SCFs were used as primary reinforcements. The detailed workflow chart is shown in Figure 2.

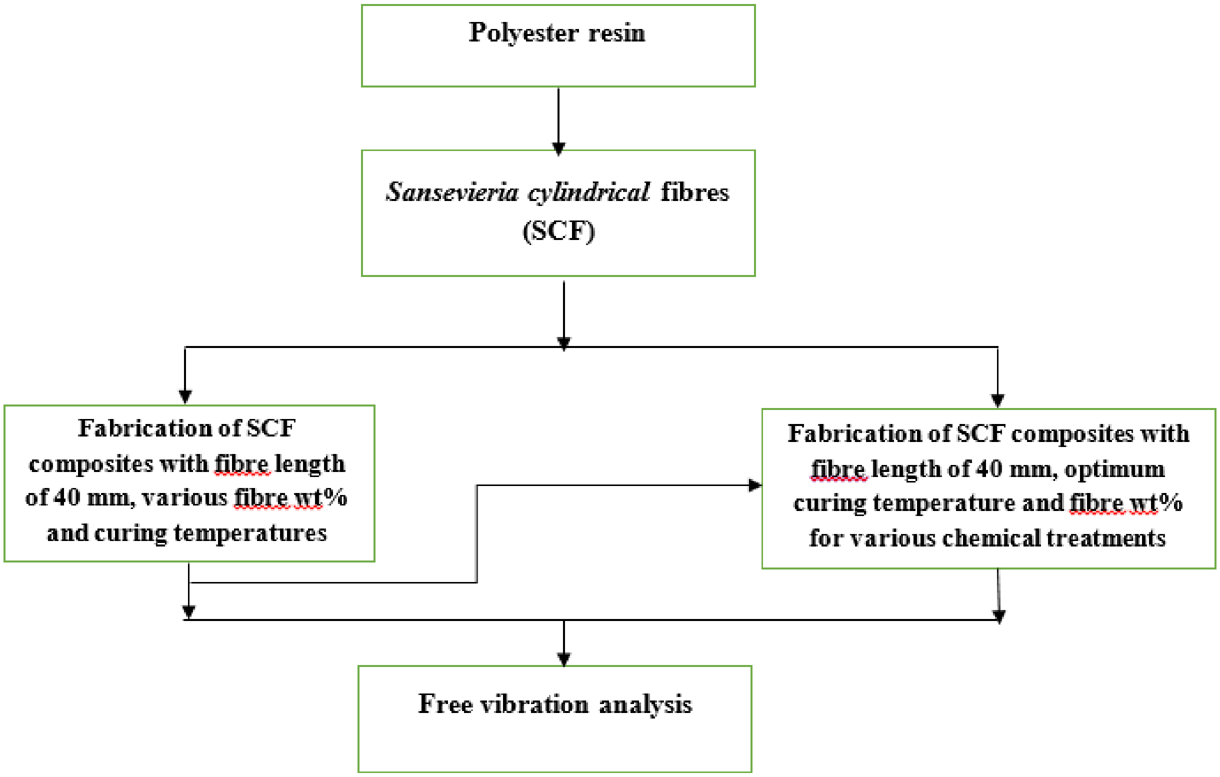

Figure 2. Work flow chart

The experimental analysis was performed on untreated and four various surface treatments on SCF were analyzed. Five different mix plates, including untreated, NaOH, silane, $KMnO_4$ and $Ca(OH)_2$ modified SCF reinforced composites were manufactured with fiber span of 40 mm, fiber loading of 40 wt% and treating temperature of 60 °C. After fabrication of the composites, the specimens were cut into length of 200 mm, width of 20 mm and thickness of 3 mm. The rectangular specimen was clamped up to length of 30 mm. The specimens were tested in evenly spaced location, using a modally tuned impact hammer (Kistler model 9722A500). The measurements were calculated to collect additional measuring data by using the pulsing force from the tip of the beam at six evenly spaced positions. A piezo-electric power transducer connected from the hammer measured the magnitude of the impact hammer response. Frequency response performance of SCF composites were measured from DEW soft for different weight percentages of both untreated and treated SCF composites with the optimum fiber wt%

and curing temperature condition. Damping coefficient factor for the first two modes was calculated by half power method, according to Equation (1).

$$(\xi = \omega 1 - \omega 2 / 2\omega n). \tag{1}$$

Natural Frequency

For dynamic structural applications, the natural frequency of that particular system needs to be studied. Mostly, the failure of the components happens due to the resonant frequency. To prevent the resonance, the situation of coincidence between the natural frequency and excitation frequency should be avoided. Hence, it is mandatory to study the natural frequency of the material with the possible fundamental frequencies. In this work, the first three modes of fundamental frequency were studied under free vibration condition.

Result and Discussion

Effects of Various Fiber Weight Percentages

In general, the strength and stiffness of composites directly affect the dynamic properties of the composites. Furthermore, the interfacial adhesion between the fiber and matrix plays a crucial role to determine the mechanical properties of the composites. There are several parameters which influence the performance of the short fiber reinforced polymer composites. In this work, the influence of fiber length on tensile properties of short randomly oriented SF reinforced polyester composites played a major role to determine the dynamic characteristics of the composites. The reduced tensile strength at higher fiber lengths can be attributed to fiber entanglement. The maximum tensile strength of 63 MPa was obtained for fiber length of 40 mm, which was reported in our previous work[29]. The tensile strength increased with fiber length up to 40 mm then, there was a drop in tensile strength above fiber length of 40 mm. Similarly, an increase in fiber length beyond 40 mm resulted to a drastic decrease in flexural strength. At lower fiber length, more fiber ends were present, which effectively transferred the flexural stress applied over the surface of the composites. Hence, a better strength was achieved. The tensile fractured specimens of short SCF reinforced polyester composites has been also discussed in detail through their micrographic analysis, as reported by Bennet et al.[29]. As the fiber length increased from 30 to 40 mm, number of fiber ends and defects were less in the composites with fiber length of 40 mm and fiber loading of 40 wt%. Therefore, a minimum fiber pull out was observed from the fiber length of 40 mm. When fiber length increased to 50 mm, fiber entanglement and comparatively larger void size were observed, and more fiber pull out occurred, which resultantly reduced the tensile strength. From the mechanical behavior of the composites, the critical fiber length and loading were taken to be 40 mm and 40 wt%, respectively.

Moving forward, the effects of various fiber weight percentages on natural frequency mode 1 of the SCF reinforced polyester composites with fiber length of 40 mm is shown in Figure 3. Among all the fiber weight percentages studied, fiber content of 40 wt% exhibited highest natural frequency at all the curing temperatures. As the fiber weight percentage increased, mass and stiffness of the composite also increased. This can be associated with its highest natural frequency. The composite member was able to withstand highest flexuation before yielding. The effects of various fiber weight percentage on natural frequency mode 2 of SCF reinforced polyester composites with fiber length of 40 mm is shown in Figure 4. Similarly, the same trend was observed with mode 2 vibration. Among all fiber weight percentages, fiber content of 40% showed highest natural frequency. In mode 1 vibration, the highest natural frequency of 29 Hz was obtained for fiber content of 40% cured at 60 ºC. Similarly, for mode 2 vibrations, the highest natural frequency of 195 Hz was exhibited by fiber content of 40% cured at 60 ºC. Generally, the stiffness of the composites directly related to their natural frequencies. Thus, the addition of the SCF and arrangement between fiber and matrix can increased the stiffness of the composites at 40 wt%.

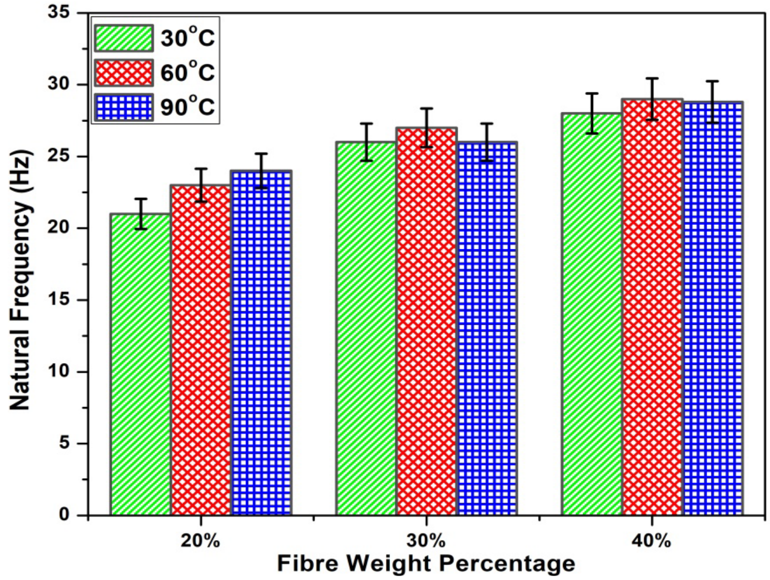

Figure 3. Effects of fiber weight percentages on natural frequencies (mode 1) of SCF composites with fiber length of 40 mm and various curing temperatures

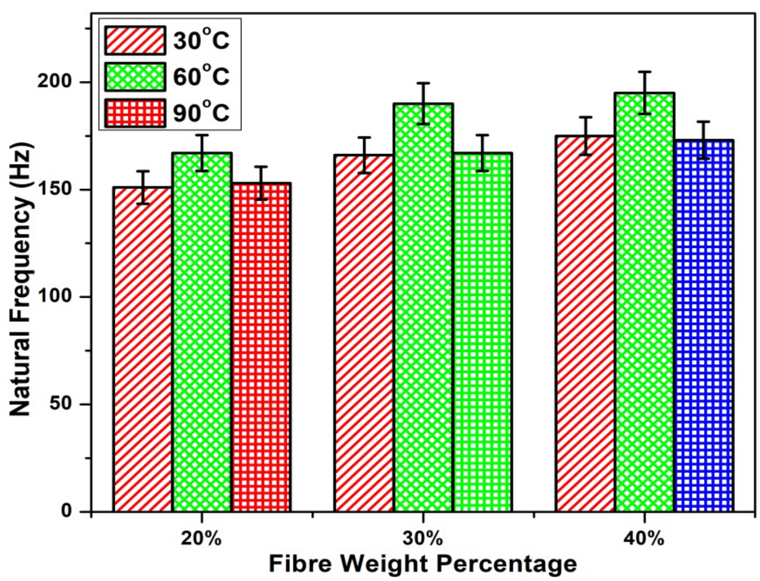

Figure 4. Effects of fiber weight percentages on natural frequencies (mode 2) of SCF composites with fiber length of 40 mm and various curing temperatures

Effects of Various Curing Temperatures

The effects of various curing temperatures on natural frequency modes 1 and 2 of SCF reinforced polyester composites with fiber length of 40 mm is shown in Figures 3 and 4. Among the various curing temperatures, composites fabricated at curing temperature of 60 ^{o}C exhibited highest natural frequency for all fiber weight percentages. The highest value was obtained at 60 ^{o}C and 40%. There was a decrease in viscosity of resin at higher curing temperature, which made it easily occupied the pores of the fiber and produced a stronger specimen. But, when the curing temperature was further increased, there was no substantial variation in natural frequency of the composites. It was difficult to stick within the mould, as the free flow of resin occurred. Similarly, for mode 2 vibration, highest value was obtained from the composites fabricated at a curing temperature of 60 ^{o}C. The composites were able to withstand highest vibrations, when they were tested.

Effects of Chemical Treatment

The effects of the chemical treatments on natural frequency modes 1, 2 and 3 of SCF reinforced polyester composites with optimum fiber length of 40 mm is shown in Figures 5, 6 and 7, respectively. $Ca(OH)_2$ treated composites exhibited a highest natural frequency relative to other composites for both treated and untreated composites. Based on our previous published work[29], the composites also showed highest tensile strength and flexural modulus when compared with other composites. These can be attributed to the highest enhancement in bonding and interlocking between fiber and matrix with less fiber pull out. Silane treated composites showed least natural frequency, among the treated composites across all three modes of vibration. Silane treated composites exhibited least tensile, flexural strengths and tensile modulus, among the treated composites. The composites prone to earlier fracture rather than having longer deformation, when they were subjected to loading.

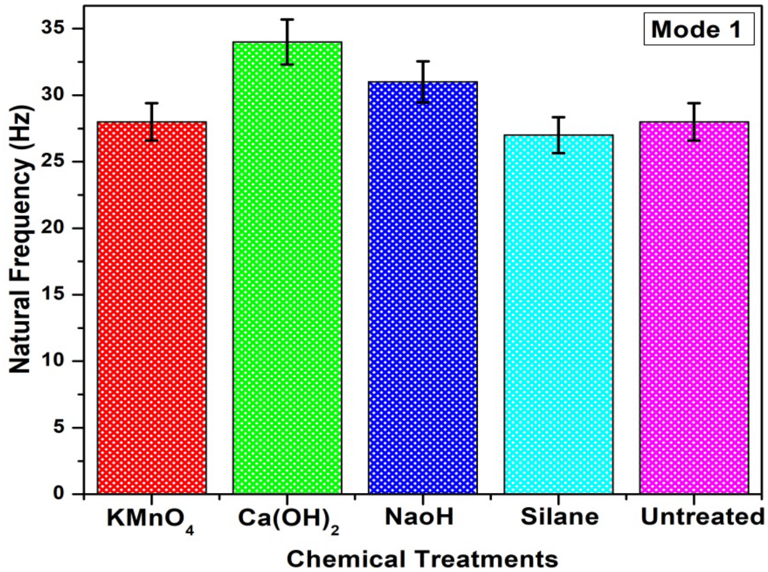

Figure 5. Natural frequencies (mode 1) of SCF composites with fiber length of 40 mm and fiber loading of 40 wt%, curing temperature of 60 ºC and different chemical treatments

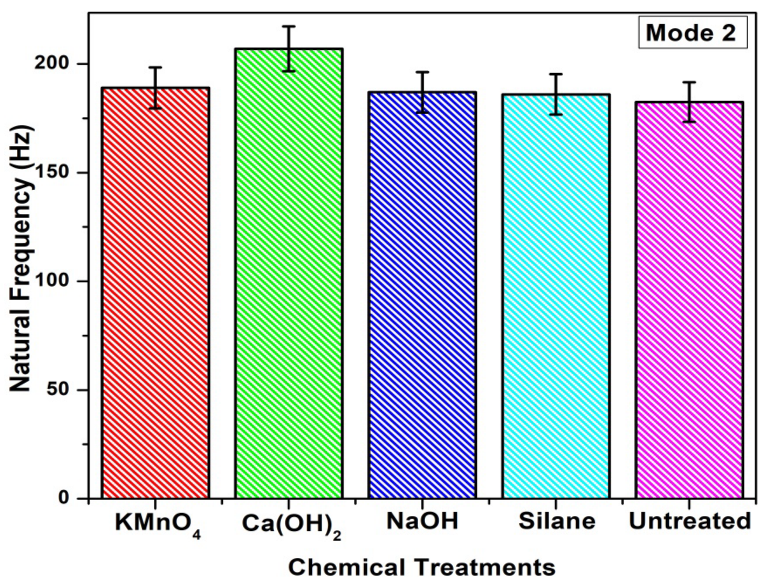

Figure 6. Natural frequencies (mode 2) of SCF composites with fiber length of 40 mm, fiber loading of 40 wt%, curing temperature of 60 ºC and different chemical treatments

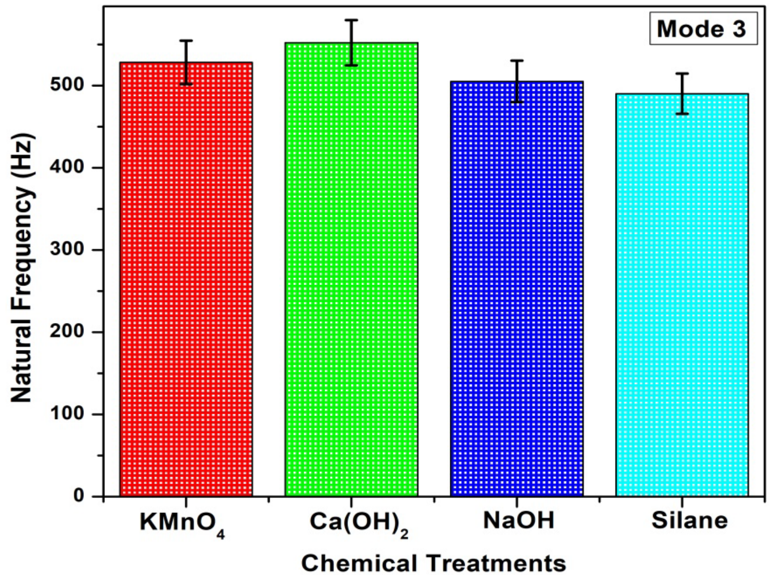

Figure 7. Natural frequencies (mode 3) of SCF composites with fiber length of 40 mm, fiber loading of 40 wt%, curing temperature of 60 °C and different chemical treatments

Besides, the typical FRF curve (Figure 8) depicts the three fundamental resonant frequencies of vibration for $Ca(OH)_2$ treated composites. The deformation patterns occurred when the excitation coincided with one of the natural frequencies of the system. The first bending deformation pattern corresponded to the first natural frequency in the plate was referred to as mode 1. At the second natural frequency, noticed as a first twisting deformation pattern in the plate was referred to as mode 2. In the third natural frequency, the second bending deformation pattern formed mode 3. The fundamental frequency values of 34, 207 and 505 Hz were obtained from the FRF curve, as shown in Figure 8. More also, by considering the selected composites as quasi-isotropy, the natural frequency of the cantilever beams was obtained through theoretical analysis. The equation of motion of the Euler–Bernoulli for the cantilever beam was used to calculate the fundamental modes of frequencies, as reported by Chandradass et al[30]. The experimental (exp.) results were compared with the analytical (theoretical) data obtained, as presented in Table 1 It was observed that the small amount of deviation in the natural frequencies was predicted by the theoretical, this can be associated with the quasi–isotropic assumption.

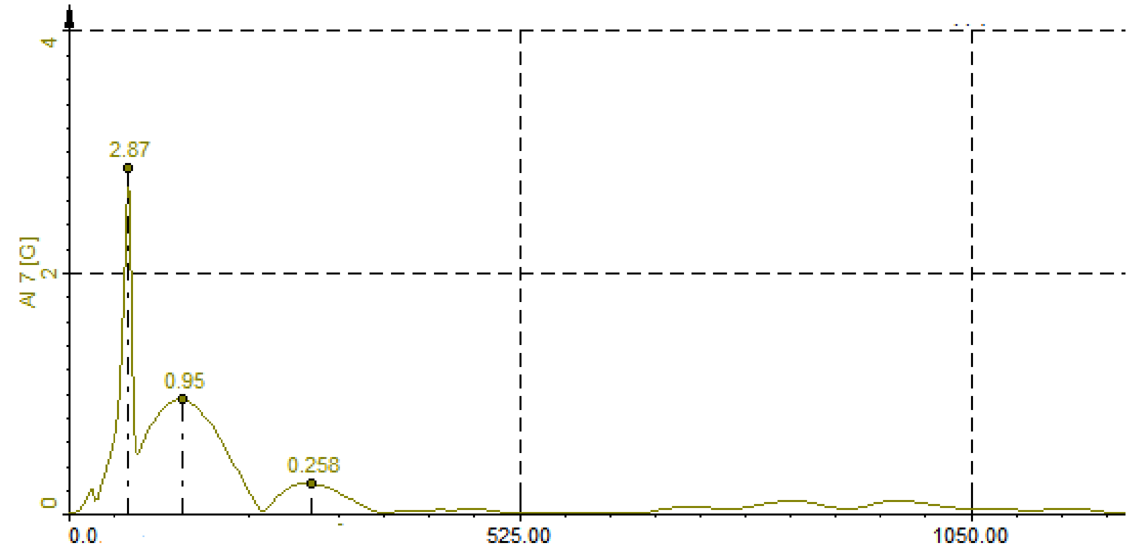

Figure 8. A typical FRF curve for $Ca(OH)_2$ treated composites at optimal condition

Table 1. Comparison on natural frequencies between the experimental and theoretical results for $Ca(OH)_2$ treated SC/polyester composites

Type of composite	Natural frequency (Hz)					
	Mode 1		Mode 2		Mode 3	
	Exp.	Theoretical	Exp.	Theoretical	Exp.	Theoretical
$Ca(OH)_2$ treated SC/Polyester composites	34	37	207	217	505	525

Damping Coefficent

Effects of Various Fiber Weight Percentages

Figure 9 depicts the effects of various fiber weight percentage on damping mode 1 of SCF reinforced polyester composites with fiber length of 40 mm. A highest damping of 0.058 was exhibited by fiber content of 20% cured at a room temperature followed by fiber content of 30% was cured at 60 ^{o}C with a value of 0.055. This response can be attributed to the highest absorption of vibrations and transfer of energy within the composites at a faster pace when compared with other composites. Due to fiber pull out at a lower weight percentage, more area became exposed to absorption of vibrations, hence, more damping was observed from the composites.

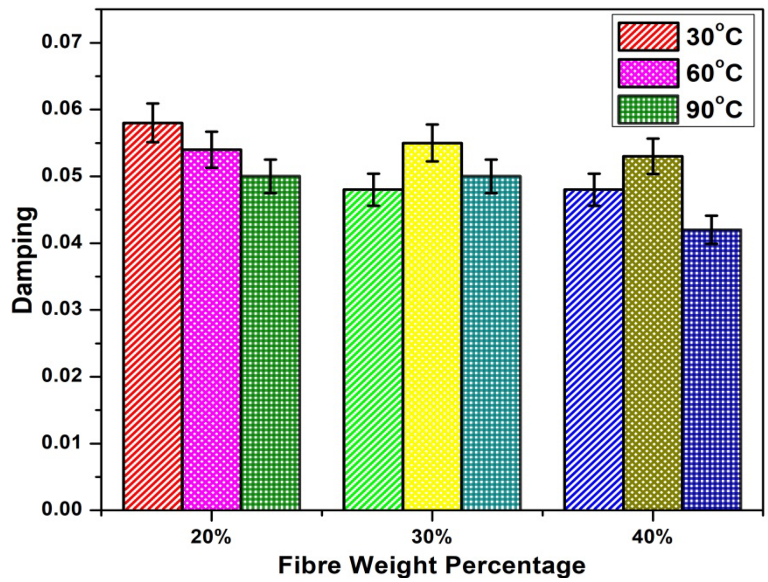

Figure 9. Effects of fiber weight percentages on damping (mode 1) behaviors of SCF composites with fiber length of 40 mm and various curing temperatures

Effects of Various Curing Temperatures

The effects of various curing temperatures on damping mode 1 of SCF reinforced polyester composites with an optimum fiber length of 40 mm is shown in Figure 10. Highest damping was obtained at a room curing temperature and fiber weight of 20%. Composites fabricated with curing temperature of 60 ^{o}C showed a slight increase in damping for fiber weights of 30 and 40% when compared with a room curing temperature. At highest curing temperature of 90 ^{o}C, there was a slight decrease in the damping values across all the fiber weight percentages. At a higher curing temperature of 60 ^{o}C and due to a better bonding and interface between the fiber and matrix, for weight percentages of 30 and 40%, there was an increase in the stiffness and mass of the composite. Furthermore, there was a better absorption of energy and hence, a higher damping was obtained. Due to poor bonding at highest curing temperature of 90 ^{o}C, there was a decrease in damping value with a poor absorption of energy.

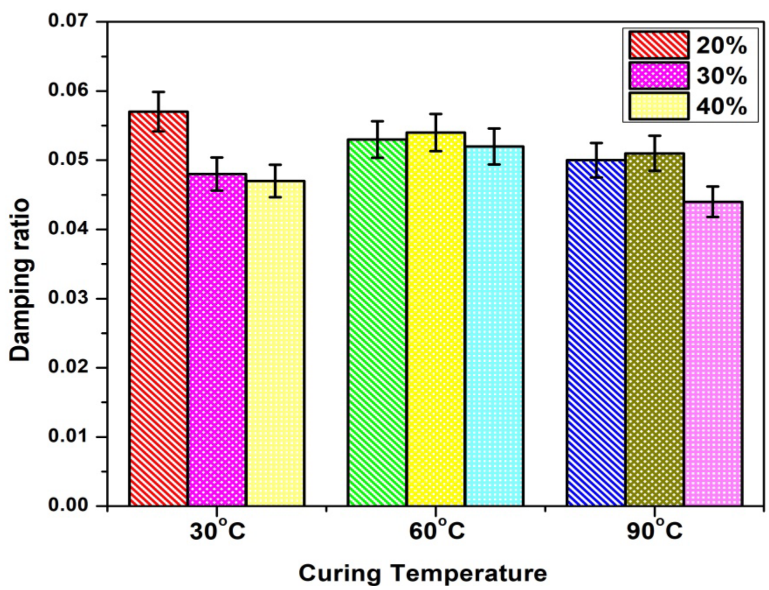

Figure 10. Effects of curing temperatures on damping (mode 1) behaviors of SCF composites with fiber length of 40 mm and various fiber weight percentages

Effects of Chemical Treatments

Figures 11, 12 and 13 show the effects of chemical treatments on damping modes 1, 2 and 3 of the SCF reinforced polyester composites with optimum fiber length of 40 mm, respectively. In mode 1 vibration, NaOH treated composites showed highest damping (Figure 11), among both treated and untreated composites. Silane treated composites exhibited highest damping behavior, while $Ca(OH)_2$ treated composites recorded least damping in mode 2, among treated composites (Figure 12).

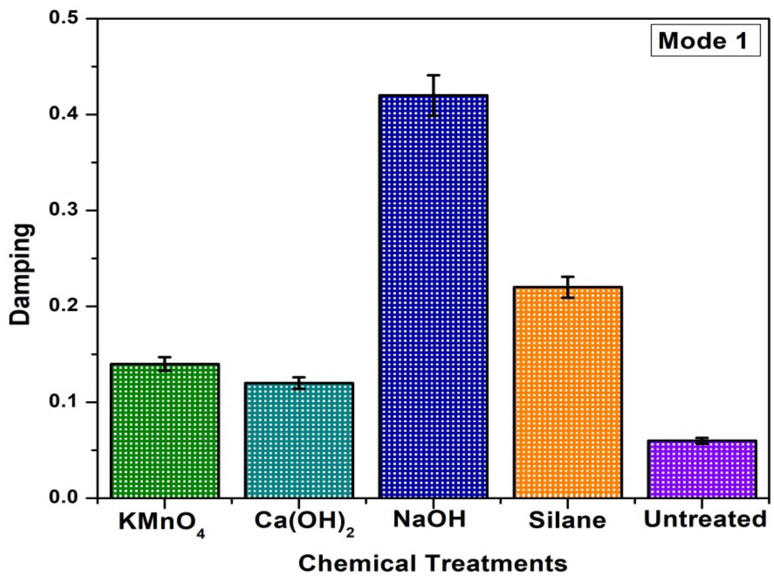

Figure 11. Damping (mode 1) behaviors of SCF composites with fiber length of 40 mm, optimum weight percentage of 40 wt%, curing temperature of 60 °C and different chemical treatments

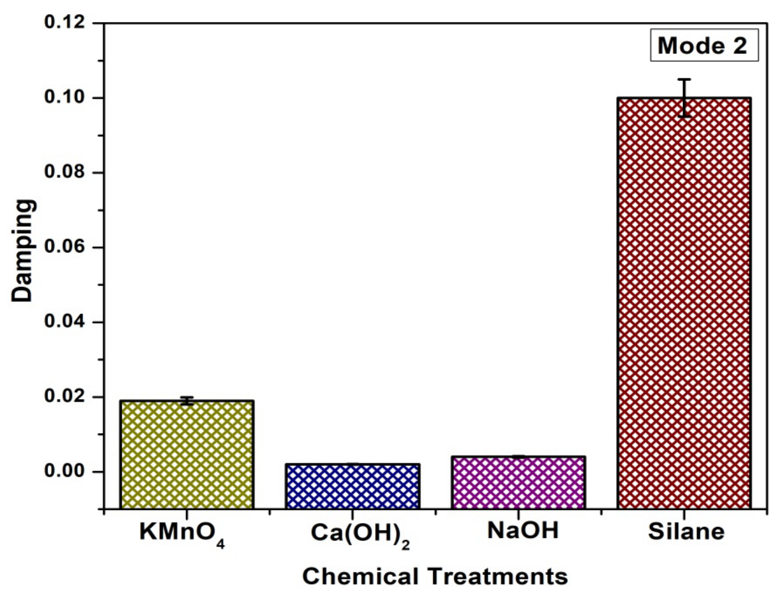

Figure 12. Damping (mode 2) behaviors of SCF composites with fiber length of 40 mm, optimum weight percentage of 40 wt%, curing temperature of 60 °C and different chemical treatments

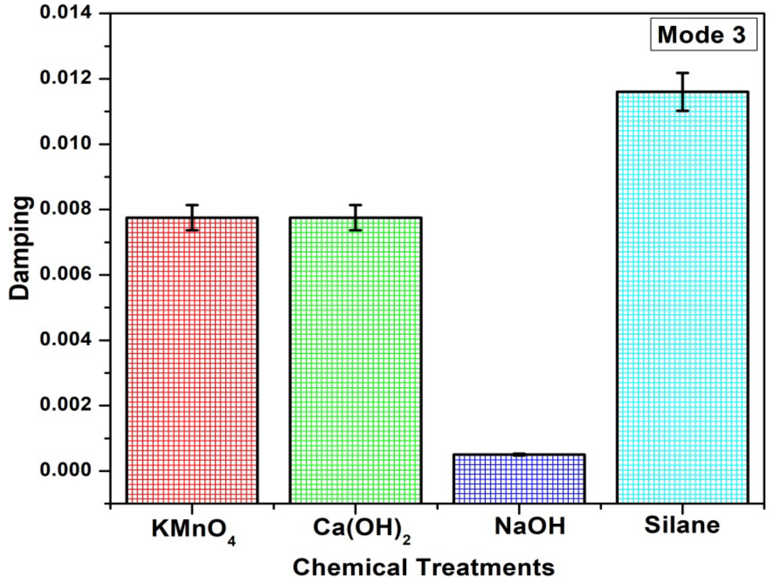

Figure 13. Damping (mode 3) behaviors of SCF composites with fiber length of 40 mm, optimum weight percentage of 40 wt%, curing temperature of 60 ºC and different chemical treatments

Also, NaOH treated composites exhibited least damping response in mode 3 when compared with other treated composites. They were able to absorb less vibrations and showed a relatively higher natural frequency at the corresponding mode of vibration. Significantly, in both modes 2 and 3 vibrations, silane treated composites showed highest damping response when compared with other treated composites.

Conclusions

SCF reinforced polyester composites were fabricated with fiber length of 40 mm, various fiber weight percentages, different curing temperatures and different chemical treatments to investigate into their free vibration characteristics, using compression molding method. Better vibrational properties, such as natural frequency and damping coefficient were observed from fiber loading of 40 wt% under curing temperature of 60 ºC fabrication process for the untreated SCF composites. Higher curing temperature and surface modification of fiber significantly influenced the free vibration characteristics of the composites. The enhanced natural frequency and damping ratio were observed at curing temperature of 60 ºC for both untreated composites and for chemically treated composites when compared with the untreated SCF composites.

Summarily, $Ca(OH)_2$ exhibited highest natural frequencies in all the three modes of vibration and silane treated composites showed highest damping values for vibration modes 2 and 3. Therefore, different applications of the untreated and treated SCF reinforced polyester composites should depend on their various natural frequencies and damping behaviors.

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