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INFLUENCE OF FIBER LENGTH AND MOISTURE CONTENT ON SOUND AND VIBRATION CHARACTERISTICS OF HEMP/EPOXY COMPOSITES

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Bio-composites have become increasingly popular as a substitute for synthetic fibers over the last decade due to their eco-friendly nature. To utilize them effectively in engineering applications, particularly in the automotive industry, a thorough understanding of the material properties is necessary. This experimental investigation focuses on exploring the vibration-damping and acoustic properties of fiber composites made from hemp natural fiber and epoxy resin. The study involved the preparation of composite specimens using both short and long fibers through a hand layup process. The natural frequency and damping ratio of the specimen were computed from time-domain experimental data. The sound absorption coefficient of fiber specimens was determined in the frequency range of 63 Hz to 6300 Hz by using the impedance tube technique. The analysis revealed that the pre-treatment of fiber and the use of long fiber rather than short fiber enhances the damping properties of hemp fiber composites. Immersion of specimens in water resulted in the degradation of damping properties. Acoustic tests clearly showed that the ageing process affected short-treated fiber composites more significantly when compared to long-treated fiber composites.

Keywords: hemp fiber, fiber treatment, damping factor, natural frequency, sound absorption co-efficient

1 INTRODUCTION

In recent years, natural fiber composites are being considered for their significant properties, such as sustainability, environmentally friendly, less weight, cost effectiveness, and a decrease in carbon dioxide emissions into nature. Some of the benefits of natural fibers compared to synthetic fibers are lower density, economical, biodegradability, and recyclability [1]. Nowadays, natural fibers are becoming essential materials in automotive industry. Natural fiber components are used most commonly in interior parts such as dashboards, door trim panels, boot linings, seat cushions, parcel shelves and back door linings due to lightweight. Hemp fiber has replaced glass fiber in automotive components of German automotive industry. Use of composites reduces costs by 20% and the weight of components by 30% [2, 3]. Hemp fiber is made up of six components: cellulose (70–75%), Hemicellulose (18–24%) (which are structural polysaccharides), structural proteins like Lignin (3-6%), Polysaccharides such as pectin (1-2%) (which is homogalacturonan), Moisture content (8-12%) and Waxes (0.5–1.5%). [4,5]. Cellulose, lignin, and hemicelluloses contain hydrophilic hydroxyl (-OH) components in their structures. Atmospheric moisture will interact with groups of hydroxyls, resulting in the formation of new hydrogen bonds of hydrogen in combination with molecules of water. These molecules of water are held by pectin and waxy materials and delay the bonding formation of free hydroxyl components by reacting with the polar matrix. This results in weaker interfacial bonding between fiber and matrix, which can be rectified by pre-treating the hemp fibers with the help of appropriate solutions. This decreases the presence of hydrophilic hydroxyl components on the surfaces of natural fiber [6]. Pre-treatments like alkalization, acetylation, and other treatments will react with the hydrophilic hydroxyl substance of hemp fiber, which advances the hydrophobic properties and creates an atmosphere that enhances the bonding with the matrix [7, 8]. Alkalization treatment decreases the moisture associated hydroxyl groups and results in an improvement in fibers hydrophobic nature. This pre-treatment removes a smaller amount of hemicellulose, pectin, wax, lignin, and oil layers from the surface of cellulose. Potassium permanganate treatment similarly makes a reaction with -OH groups present in lignin and later eliminates them from fiber, which results in the reduction of the hydrophilic properties of fiber. Acetylation treatment offers a rigid and rough surface to fiber and results in good fiber matrix interphase. The dimensional consistency of the composite material will be improved because pre-treatment expands the dispersion of fibers into the matrix [6, 9].

It was proven that the damping properties of natural fiber composite materials are similar to and, in some conditions, better than those of synthetic fiber-reinforced composites. Good vibration and acoustic properties make it a better choice when compared to synthetic fiber-reinforced composites, particularly in the case of automotive component manufacturing [10]. The challenging job for automotive manufacturers is to improve the noise, vibration, and harshness (NVH) level without altering or increasing the weight of the vehicle. Through active and passive methods, it is possible to control automotive noise. When compared to the active method, the passive method is less expensive and less complicated. The passive method uses permeable materials like fibers, foams, glass, wool, and similar materials. But care should be taken not to alter the total weight of the vehicle. In order to control the noise, a suitable composite material must be employed, depending on its acoustic properties and characteristics. Impedance tubes are one of the recommended methods to characterize the transmission loss and absorption coefficient of composite materials.[5,8,11].

Fiber reinforcement in laminates acts as an important factor in terms of the strength of the composites. The functioning and load dispersal of the fiber-reinforced composite depend on the processing of the fiber, shape, length, orientation, composition, and contents of the matrix material [12]. The unvarying load dispersion from matrix to fiber improves the properties of the composites under changing loading conditions. The unidirectional orientation of fiber in the matrix shows higher mechanical properties for the fiber composites than the random fiber composites [13–15]. Short fiber-reinforced composites are better suited for vibration attenuation. If dynamic loading produces vibrations at materials' natural frequencies, then the assemblies will undergo vibrations at extreme levels. The dynamic properties of composites can be studied by free vibration tests in fixed boundary conditions, which is economical as well as effective. This process was used in order to determine the modulus of elasticity under dynamic conditions, and results were obtained for the damping properties of three normal wood-made composite materials, namely high-density fiberboard, plywood, oriented strand board, and others

[16–18].

The present study focused on developing sound-absorbing and vibration-isolating structural materials for automotive applications. The treated Hemp short and long fibers reinforced with epoxy matrix were fabricated using the hand lay-up technique. To understand the effect of moisture intake on sound absorption and vibrational properties, the prepared specimens were subjected to an aging process in distilled water for a duration of 10 weeks. The damping factor, natural frequency, and sound absorption coefficient of pristine and aged specimens were analyzed by conducting a free vibration test and impedance tube.

2 EXPERIMENTAL METHODS

2.1 Materials

The main objective of the present study is to understand the effect of fiber length and aging environment on the vibration and acoustic properties of Hemp fiber-reinforced composites. In this study, Epoxy resin (LY556) and Hardener (HY951) supplied by Herenba Instruments and Engineers, Chennai, India, were used as matrix materials. The long Hemp fibers were procured from Go Green Products, Chennai, India.

2.2 Surface treatments of hemp fibers

Matrix fiber interphase bonding is the key parameter in controlling the structural properties of natural fiber-reinforced composites. To improve the wettability and adhesion of the fiber surface to the matrix, the Hemp fibers were subjected to Alkalization and Permanganate treatment. Initially, hemp fibers were alkalized by using a 6% Sodium Hydroxide (NaOH) solution. Hemp fibers were saturated in a 6% NaOH solution for four hours. This helps in the removal of dust and wax, and it smooths the fiber surface. After alkali treatment, fibers were washed properly in distilled water to eliminate the alkali content existing in those fibers, and then the fibers were again washed and rinsed with fresh water and dried at room temperature for 7 hours.

In permanganate treatment, alkalized Hemp fibers were soaked in a permanganate solution with concentrations of 0.5% in a 2% acetone solution for 3 minutes. The treatment of natural fiber with permanganate solution reduces the hydrophilic tendency of the fibers. As a result, the moisture absorption behavior of the Hemp fiber-reinforced composites can be reduced. The hydrophilic tendency of fiber reduces as the concentration of Potassium permanganate ($KMnO_4$) is increased. However, at higher $KMnO_4$ concentrations of more than 1%, degradation of hemp fiber happens. Later fibers were washed with distilled water and fresh water and dried for 6 to 7 hours.

2.3 Fabrication of composites

The laminates containing treated short fiber (Average length of 5 mm) and long fiber (250 mm in length) were manufactured using hand lay-up techniques and cured in ambient conditions. In both short and long fiber reinforced laminates, the fiber weight fraction was maintained at 60%. The average thickness of the prepared laminate was 3 mm. The specimens for the vibration test and for the acoustic test were prepared from the laminates as per standards by using water jet cutting technology. Figure 1 shows the short Hemp fiber reinforced (SHTF) and long treated Hemp fiber reinforced (LHTF) specimens used for the vibration and acoustic tests.

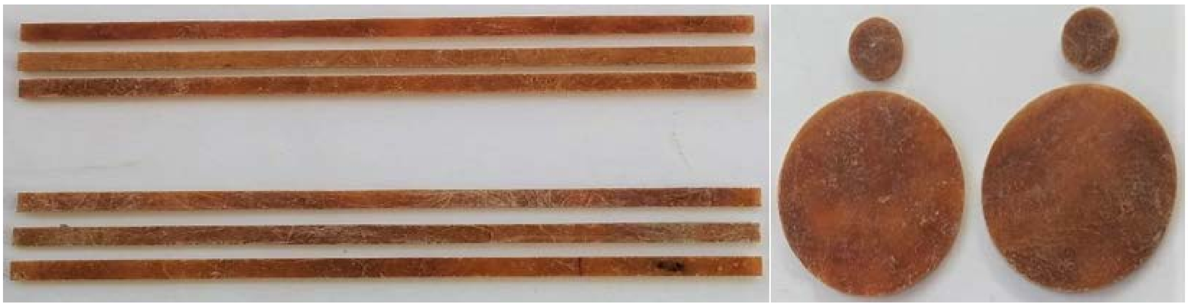

Figure 1: Vibrations and Acoustic test specimens

2.4 Moisture Absorption Test

To understand the effect of moisture intake on the vibration and acoustic characteristics of SHTF and LHTF, the prepared specimens were immersed in distilled water for a duration of 10 weeks in ambient conditions. The moisture gain of the specimens was measured at frequent intervals using digital weighing with an accuracy of 0.001 gram. The percentage of moisture gain at regular intervals was estimated as per the Equation 1[19].

$$M_t(\%) = \left(\frac{M_t - M_o}{M_o}\right) \tag{1}$$

where, M_t is the weight at any given time interval and M_o the initial weight of the dry specimen.

2.5 Natural frequency and Damping Factor Estimation

The natural frequency and damping factor of the pristine and aged specimens were estimated using the free vibration method based on ASTM E 576-05. According to standard dimensions, composite specimens with a size of 250103 mm were prepared as shown in Figure 1. Three specimens from SHTF and LHTF were used for the test, and the average result was used for the analysis. The specimens were fixed in cantilever form, and the vibrations of the specimens were measured by making use of a PCB accelerometer with a sensitivity of 101.9 mV/g. Data acquisition was done using the NI-91234 data card by employing NI-LabVIEW 2016 from National Instruments. The free vibration data was used to calculate the logarithmic decay δ, which in turn was used to compute the damping ratio ζ (Equation 2)[20]

$$\delta = \frac{1}{2\pi_j} \ln\left(\frac{g_i}{g_{(i+1)}}\right) = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}} \tag{2}$$

Where g_i, g_{i+1} are the i^{th} and the $(i+1)^{th}$ peaks obtained from the free vibration test.

2.6 Sound absorption coefficient measurement

In this study, the sound absorption coefficient (*a*) of the specimens was determined using an impedance tube by referring to the transfer function method in accordance with ISO 10534-2. The impedance tube (type SW 477, BSWA Technology Co., Ltd., China) was used in this experimental study. Specimens of 29 and 99 mm in diameter were used for the sound absorption coefficient test. Two 14-inch microphones with sensitivities of 55.6 mV/Pa and 56.2 mV/ Pa were employed, and the absorption coefficient in the frequency range between 63 Hz and 6300 Hz was measured by the transfer function method. Experimental investigation of each pristine and aged specimen is carried out three times in an impedance tube to reduce the probable effects of misalignment and irregularities in the testing specimens. The property of material to absorb unwanted sound is related to sound energy dissipated by passing through the material, and as directed by the fibers, this leads to the conversion of some portion of the energy into heat.

3 EXPERIMENTAL RESULTS

3.1 Moisture Absorption Behaviour

Figure 2 shows the moisture absorption behavior of SHTF and LHTF composites. The moisture absorption curve of both specimens followed Fick's Law of Diffusion, and the obtained curve can be divided into two stages. Moisture gain in the initial period of aging was found to be rapid for both specimens. SHTF composites absorbed more moisture than LHTF composites. The random orientation of fibers in short hemp fiber-reinforced composites increased the void content of the specimens and increased the moisture gain. At the end of the first stage, SHTF and LHTF gained 3.41 and 2.98% of moisture, respectively. In the second stage, the moisture gain increased steadily and showed a linear trend. At the end of the second stage (on completion of 10 weeks of aging), SHTF and LHTF gained 3.74 and 3.24% of moisture, respectively.

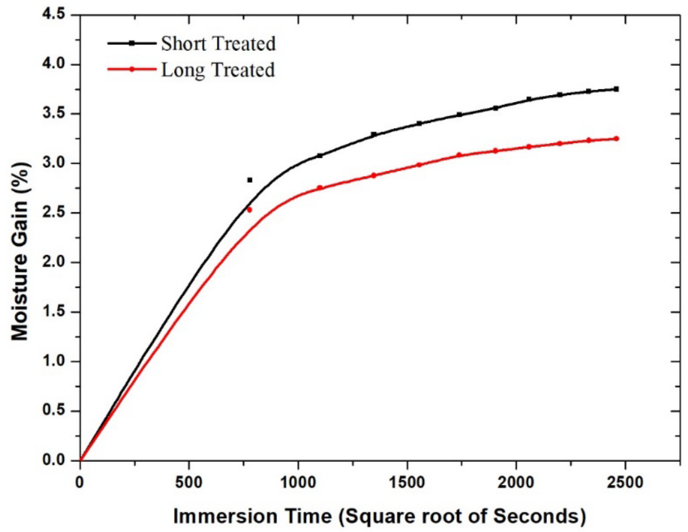

Figure 2: Moisture absorption behaviour of SHTF and LHTF specimens

3.2 Effect of fiber length and ageing process on vibration characteristics

The natural frequency and damping factor of the pristine and aged SHTF and LHTF specimens were obtained by free vibration experiments based on ASTM E-756-05. Figures 3 (a) and (b) show the variation of the natural frequency of pristine and aged SHTF and LHTF specimens. Table 1 shows the comparison of the natural frequency and damping factor of pristine and aged SHTF and LHTF specimens.

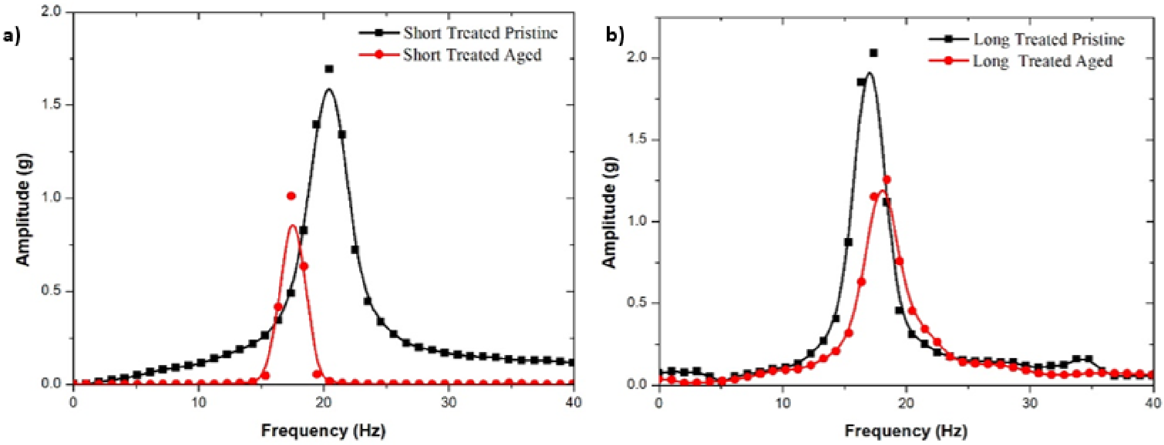

Figure 3: Variation of Natural frequency (a) SHTF, (b) LHTF

Table 1: Comparison of Natural frequency and damping factor of pristine and aged SHTF and LHTF specimens

Specimen	Pristine		Aged	
	Natural Frequency (Hz)	Damping Ratio	Natural Frequency (Hz)	Damping Ratio
SHTF	20.48	0.11	17.41	0.043
LHTF	17.41	0.037	18.43	0.019

The increase in weight in SHTF composites is greater than that in LHTF composites. This resulted in a reduction in stiffness. Due to this, a relatively higher reduction in natural frequency in the SHTF specimen is observed. Whereas in LHTF, even with the increase in weight, the stiffness reduction has a greater influence, which is evident from the slight increase in natural frequency. The relation for the natural frequency of any system is given by the following equation (3)[19].

$$\omega_n = \sqrt{\frac{k}{m}} \tag{3}$$

It can be clearly observed that the reduction in natural frequency is greater in SHTF. For the same volume percentage, short fiber composite absorbs more moisture, and the influence of its weight increase is greater than the decrease in stiffness due to moisture. Since the shirt fibers have more surface area for the same volume concentration, the above phenomenon is observed. Further analysis of the results also reveals that the damping ratio of both types of specimens degrades. The following relationship (Equation 4) can explain this.

$$\zeta = \frac{c}{c_c} = \frac{c}{2\sqrt{km}} \quad (4)$$

where C is the damping coefficient (Ns/m), Cc is the critical damping coefficient (Ns/m), and ζ is the damping ratio. As the specimens absorb moisture, there is a reduction in stiffness, but there is also an increase in mass. Since the effect of mass increases is greater than the decrease in stiffness, the damping ratio is degraded with ageing duration.

3.3 Effect of fiber length and ageing process on sound absorption co-efficient

Sound absorption coefficients of pristine and aged SHTF and LHTF specimens were first analyzed at low (63–1600 Hz) and high (1000–6300 Hz) frequency ranges with a thickness of 5 mm, and testing was done under ambient conditions with reference to ISO 10534-2. Figures 4 (a) and (b) show the sound absorption characteristics of pristine and aged SHTF and LHTF specimens.

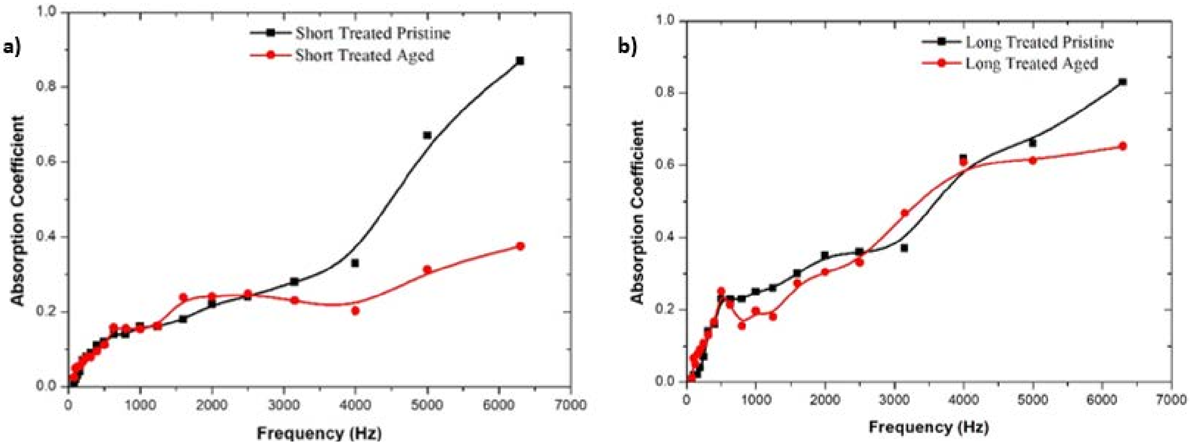

Figure 4: Sound absorption characteristics of pristine and aged (a) SHTF, (b) LHTF

The effect of pre-treatment of fiber, particularly at lower frequencies, plays a significant role in reducing the sound wave's energy. Pre-treatment and acoustic absorption coefficients affect one another; at 2000 Hz, the absorption coefficients of treated long and short fibers are 0.35 and 0.22, respectively. Thus, the acoustic characteristics of sound-absorbing materials at lower frequencies are related to the nature of fiber. The SHTF composites showed relatively better acoustic properties because random fibers result in slightly more porosity than long fibers, resulting in a lower density specimen. The short fiber-reinforced specimen absorbs more moisture, and because of this, the density of the short fiber-treated aged specimen is relatively higher than the long-treated fiber specimen. This is evident from the result, especially in the higher frequency region above 3000 Hz. However, the responses of both specimens at the lower frequency below 3000 Hz are relatively identical. This is a clear indication that ageing affects the short-fiber composite more.

4 CONCLUSION

Two hemp composites with fiber-to-matrix weight fractions ranging from 30% to 35% were prepared using epoxy resin as the matrix. Vibration and acoustic characterization of the pristine specimens were done, and then the specimens were immersed in distilled water for ageing. The specimens exhibited the highest moisture absorption during the first two weeks of aging, with minimal additional gain observed over the following five weeks. SHTF absorbed a greater amount of moisture compared to LHTF. In this, a maximum of 3.7% and 3.2% mass gain were observed in SHTF and LHTF composites, respectively. Specifically, the SHTF composite displayed a maximum mass gain of 3.7%, while the LHTF composite exhibited a gain of 3.2%. Analysis of the natural frequency of the specimens revealed a decrease compared to their pristine values. This decrease indicates a lower damping ratio with higher natural frequencies. The short-treated fiber composite demonstrated a relatively greater increase in natural frequency. Additionally, the LHTF composite exhibited a lower sound absorption coefficient than the SHTF composite at higher frequencies. Acoustic property degradation was observed in both specimens at higher frequencies, but the SHTF composite experienced a significantly higher level of degradation. This disparity can be attributed to the relatively greater increase in density observed in the SHTF composite compared to the LHTF composite.

5 DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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