INVESTIGATION OF THE VIBRO-ACOUSTIC BEHAVIORS OF LUFFA BIO COMPOSITES AND ASSESSMENT OF THEIR USE FOR PRACTICAL APPLICATIONS

Garip Genc

Marmara University, Vocational School of Technical Sciences, Mechanical Department, 34722 Istanbul, Turkey
email: ggenc@marmara.edu.tr

Hasan Koruk

MEF University, Mechanical Engineering Department, 34396 Istanbul, Turkey

New materials as alternatives to petroleum-based composite materials are needed due to adverse effects of chemical materials on nature. On the other hand, there is a need to characterize and evaluate new alternative materials to be effectively used in practical applications. The vibro-acoustic behaviors including damping and elastic properties, sound absorption and transmission loss levels of luffa bio-composites are investigated and their use for practical applications is evaluated in this study. First, the procedure for manufacturing luffa composites is summarized and materials and methods are presented. After that, the acoustic absorption and transmission loss levels of sample luffa composites are explored by using the impedance tube method. The damping and elastic properties of sample luffa composites are determined by using experimental and theoretical modal data. Furthermore, the interface properties of the luffa fibers and matrix are examined by using Scanning Electron Microscope. All the results are evaluated and the potential of the use of luffa composites in practical applications is assessed.

1. Introduction

Natural fibers are environmentally friendly materials and offer some advantages over synthetic fibers such as glass, carbon and aramid fibers [1-3]; hence, natural fibers are proposed as alternative materials to synthetic fiber reinforcements. Some of the unique properties of natural fibers include low density, easy processing, non-toxicity, recyclability, resistance to corrosion and low cost [1]. The growing importance of these new biodegradable materials is evident from the increasing number of studies during the last decade [2-9]. The major bio-fibers including flax, jute hemp, kenaf and sisal were investigated in many studies [3-9] though there are some challenges such as cultivation and continuity for these plant materials. In the recent years, luffa plant has been recognized as a new potential natural fiber [3, 10-25] though there is a need for more research on the composites of luffa fibers to evaluate and use them for practical applications.

It was found that luffa fibers consist predominantly from holocellulose (%82,4 [10]), lignin (%1.6-11.2 [10, 11]), extractives (%3.2 [10]) and ashes (%0.4-0.9 [10, 11]), where the ratios depend on the growth region, cultivation and climate conditions. Boynard and D'Almeida [12] used the sponge gourd (luffa cylindrica) as reinforcement in resin matrix composite materials and investigated the morphology of the fibrous vascular system of luffa fruit and mechanical properties such as tensile strength. Shen et al. [15] presented a series of compressive tests to examine the stiffness, strength and energy absorption characteristics of the luffa sponge material under quasi-static compressive load. The elastic moduli of luffa composites depending on the matrix used (polyester or epoxy resin) were reported to be between 1-12 GPa for luffa-polyester composites [11-15]. Recently, it was shown that the acoustic absorption coefficient of luffa fiber with a 1 cm thickness can be as high as 0.7 especially at high frequencies [5]. The results showed that the transmission loss level of a luffa composite with a 1 cm thickness and the epoxy/luffa volume fraction values of 0.4/0.6 was quite high being 20-30 dB for 1-6 kHz [5].

In this paper, the vibro-acoustic behaviors including damping and elastic properties, sound absorption and transmission loss levels of luffa bio-composites are investigated and their use for practical applications is evaluated. The method for manufacturing luffa composites is outlined and materials and methods of the study are presented. The acoustic absorption and transmission loss levels of sample luffa composites are determined by using the impedance tube method. The damping and elastic properties of some sample luffa composites are identified by using experimental and theoretical modal data. The interface properties of the luffa fibers and matrix are examined using by Scanning Electron Microscope (SEM). All the results are evaluated and the potential of the use of luffa composites in practical applications is discussed.

2. Materials and methods

The luffa cylindrica fibres of the Mediterranean region of Turkey were used to prepare composite samples as shown in Fig. 1a. Epoxy resin was used as matrix to manufacture luffa composite samples. Luffa fibers were prepared without any surface treatment as described the hybrid composite in the literature [3, 12]. The manufacturing process is as the following. The mould was cleaned with acetone solution to remove any residues (agent, dust, etc.) and dried thoroughly and then mould release wax was applied with a circular motion using a brush. The epoxy resin (Duratek 1200) was catalyzed and a coating of epoxy resin was applied to the mould surface. Luffa fibers were placed in the mould and the previously applied epoxy resin passed through it. Additionally, resin was applied to the other surface of the dry fiber and all fibers were rolled until thoroughly wetted out with epoxy resin. The samples were pressed using a hydraulic press machine which have heated plates for curing the epoxy resin. The lower plate is fixed to the machine frame while the upper plate is controlled by a PLC (Programmable Logic Controller) system of 5 bars pressure to compress the stacked laminates. And the temperature was adjusted to 80 °C during the curing process for 300 minutes. The luffa/epoxy volume fraction of composites is 0.5±0.1 in this study. A sample of luffa composite plate is shown in Fig. 1b.

a) b)

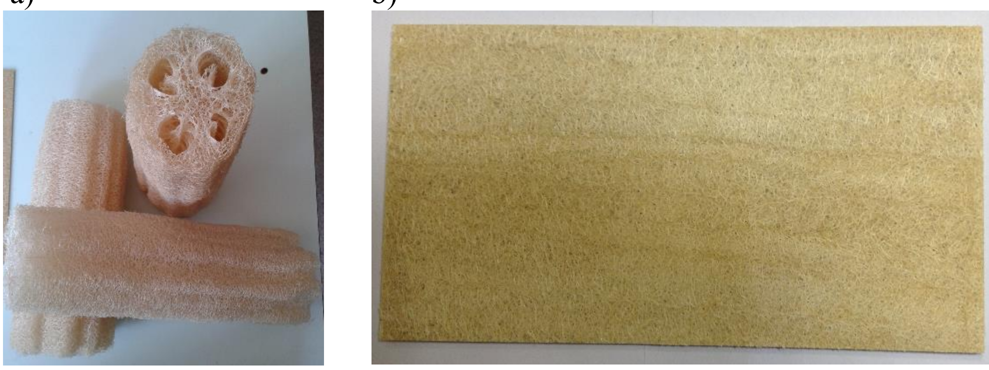

Figure 1: Dry luffa fibers (a) and reinforced luffa composite plate (b).

A circular luffa composite sample (plate) with thickness of 9±0.5 mm and diameter 29 mm was prepared to identify sound absorption and isolation properties of luffa composites. Sound absorption coefficient of sample luffa composite at normal incidence as a function of frequency was determined by:

$$\alpha(f) = 1 - \left|\tilde{R}(f)\right|^2 \tag{1}$$

where $\tilde{R}(f)$ is complex valued reflection coefficient measured using the impedance tube method based on two microphones with diameter with d = 29 mm [26]. Measurements were performed using a standard empedance tube (B&K 4206), two microphones (B&K 4187), an analyser (B&K 3560C) and a power amplifier (B&K 276 C). The ambient temperature, atmospheric pressure and relative humidity were T = 20 ^{0}C, p_a = 101 kPa and ϕ = 80%, respectively during the measurements. The transmission loss levels of the test samples were determined using the empedance tube (B&K 4206T) based on four microphones [27].

A luffa composite sample with dimensions 4 mm x 15 mm x 210 mm was prepared for identification of damping and elastic properties of luffa composites. The density of the luffa composite was 1100 kg/m^3. Acoustic frequency response functions without any mass loading adverse effects [28] were measured using the composite test sample. The structure was excited by a modal hammer (Endevco 2302-10), the response to the excitation was measured by a microphone (B&K 4189) and the data acquisition and signal processing was conducted by the same analyser for acoustic tests mentioned above. The elastic properties of luffa composite structure were determined using free vibration frequencies of a beam [29] given as:

$$f_1 = 1.028 \frac{h}{L^2} \sqrt{\frac{E}{\rho}} \tag{2}$$

$$f_n = 0.441(n + 0.5)^2 f_1 \tag{3}$$

where n is the number of elastic modes of the free-free beam, h is thickness and L is the length of the beam. Modal parameters of the beam-like luffa composite structure were extracted using the measured frequency response functions [30, 31].

The interface properties of the luffa fibers and matrix were examined using SEM microscopy (JSM-5910LV model). SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. Data is collected over a selected area of the surface of the sample and a two-dimensional image is generated displaying spatial variations in properties and orientation of materials.

3. Results and discussion

Sound absorption coefficient of the luffa composite sample measured as a function of frequency using the two-microphone impedance tube is shown in Fig. 2. It is seen that the sound absorption coefficient of the luffa composite in general increases as frequency increases. The average absorption coefficient is about 0.1 for 0.8-4 kHz even for this thin luffa composite sample (thickens: 9±0.5 mm). It should be noted that a single luffa plant was used for manufacturing each luffa composite plate in this study. Therefore, the thickness of the luffa composite samples is limited by the structure and dimensions of the luffa plant. However, thicker luffa composite samples can be manufactured by using more than one luffa sample along the thickness. The material thickness has a great impact on the sound absorption performance of a material [32]. It is clear that high sound absorption coefficient will be obtained when the thickness of luffa composite is increased.

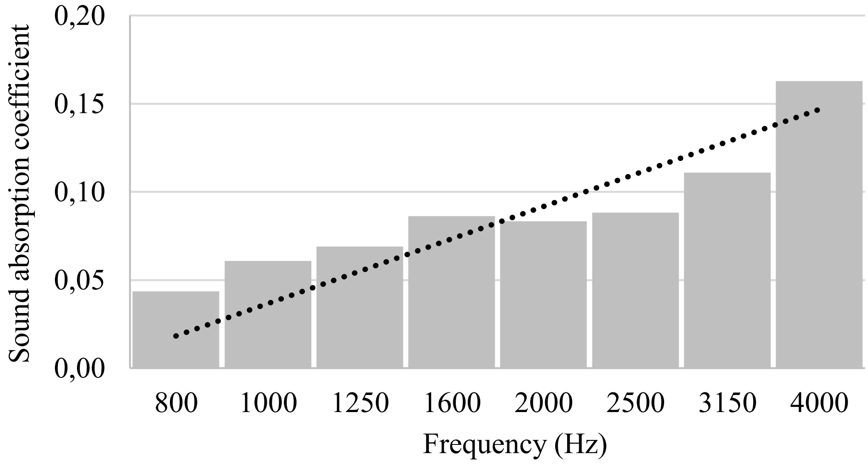

Figure 2: Sound absorption coefficient of the luffa composite sample.

Sound transmission loss levels of the luffa composite sample (thickness: 9±0.5 mm) with respect to frequency measured using the four-microphone impedance tube are shown in Fig. 3. It is seen that sound transmission loss levels in general increases as frequency increases. The average transmission loss level is 25 dB for f=1-5 kHz. The results show that the transmission loss values of luffa composite are quite promising; being more than 20 dB even for a thin sample.

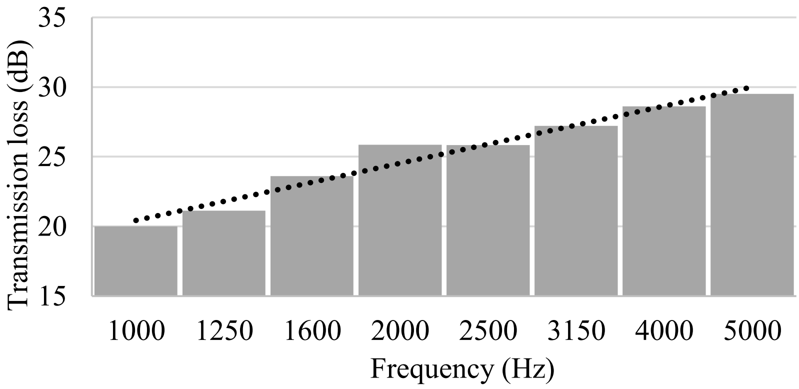

Figure 3: Sound transmission loss levels of the luffa composite sample.

Experimental natural frequencies of the luffa sample identified using the measured acoustic transfer functions are 161.0, 444.5, 870.7, 1440.9, 2128 and 2968.5 Hz for the first six elastic modes. The loss factor of the luffa composite structure is identified to be 0.01 for the given modes. It is noted that damping is a dominating factor of the vibro-acoustic behaviors of structures. The identified loss factor value for the luffa composite samples (i.e., 0.01 or 1%) is greater than the damping level of many materials for the given frequency range [28, 31] though a higher loss factor can be obtained for luffa composite structures by optimizing the luffa/epoxy ratio and compression ratio. Elastic moduli of luffa composite identified using the experimental natural frequencies of the luffa beam-like sample and Eqs. (2-3) are presented in Fig. 4. Results show that dynamic elasticity modulus of the luffa composite sample is quite high; the average elasticity modulus is 3.53 GPa for the given modes.

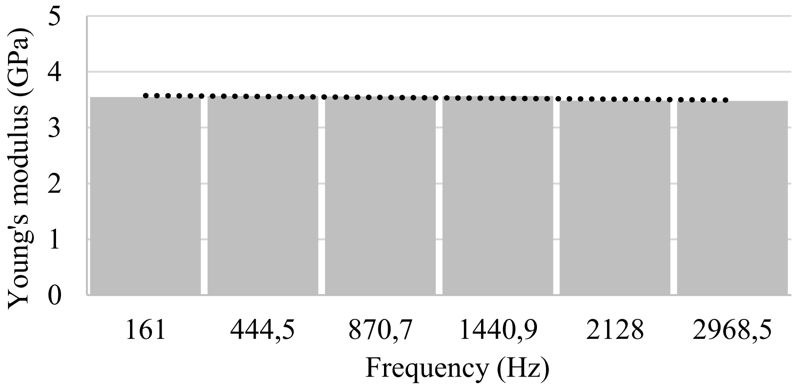

Figure 4: Elastic moduli of luffa composite sample.

SEM photomicrograph for test samples of the luffa composite sample are shown in Fig. 5. It can be seen clearly that on the fractured surface the interfacial acceptable compatibility between the luffa fiber and epoxy matrix even if without surface treatment of luffa fiber (hybrid composites). The image shows the random distribution of fibers in the matrix. Enough adhesion between luffa fiber and epoxy is obtained even though some defect depend on fiber structure.

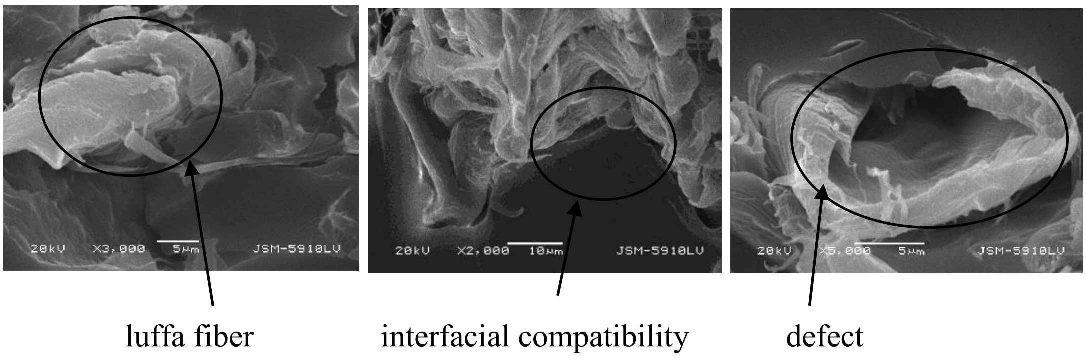

Figure 5: SEM photomicrograph for test samples of luffa inert epoxy matrix.

It is known that the fire resistance of natural fibers alone is low [33]. However, they can be quite resistive to fire and durable if an appropriate resin is used [34]. The durability and fire resistance of luffa fibers and their composites which are outside the scope of this paper may be the subject of a future study.

4. Conclusion

The vibro-acoustic behaviors of luffa composites were investigated in this paper. Sound absorption, transmission loss and damping and elastic properties of luffa composites were determined and discussed. It is seen that the vibro-acoustic properties of luffa composites are quite promising to be used in practical applications. Potential products to be made from luffa composites are disposable dishes such as cups and plates and furniture such as chairs and tables as they have considerably high elastic modulus. The high damping and elastic properties of luffa composites may allow them to be used in many sound and vibration isolation applications including aero-plane, automotive and yacht to enhance the environmental friendly materials. It should be noted that the luffa composites used in this study can not be considered fully environmental friendly because of the presence of epoxy matrix. However, the use of natural resins may be possible to manufacture fully environmental friendly in future. The luffa composites have potential to be used in architectural applications such as concert saloons to absorb reverberant noise and provide sound transmission as their sound absorption and isolation capabilities better than many plant materials. They seem to be suitable for decoration purposes.

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