Processing and Characterization of Epoxy/Luffa Composites: Investigation on Chemical Treatment of Fibers on Mechanical and Acoustical Properties

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This study focuses on the development of epoxy/luffa composites and the investigation of their mechanical and acoustical properties. The fibers underwent an alkalization treatment, and its effects on the mechanical and sound absorption properties of the composites were measured utilizing a universal testing machine and two-microphone transfer function impedance tube methods. The effects of chemical modifications on the fibers were studied using a scanning electron microscope (SEM). The thermal analyses of composites were conducted using thermo-gravimetric analysis (TGA). The composite's functional group was identified and evaluated using Fourier transform infrared spectroscopy (FTIR). The sound absorption coefficient of untreated and treated composites across a range of frequencies was very similar. Untreated composites appeared to perform better than those that were treated. Compared with untreated fiber composites, there was an improvement in the tensile strength of the treated fiber composites. The SEM characterization showed that the alkaline treatment changed the morphology of the fibers, resulting in a decrease in the sound absorption coefficients of the composites. The thermal characterization of composites showed that dehydration and degradation of lignin occurred in a temperature range of 40 to 260 °C, and the maximum percentage of cellulose was found to decompose at 380 °C.

Keywords: Composites; Natural fibers; Acoustic absorption; Mechanical Properties; Characterisation

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INTRODUCTION

Asbestos was one of the first materials used in many industrial applications. According to the 12th Report on Carcinogens (NTP 2011), there are six common types of naturally occurring mineral fibers inside asbestos that have been commercially exploited, namely crocidolite, anthophyllite, chrysotile, amosite, tremolite, and actinolite. Thermal, electrical, and sound insulation made from asbestos materials is widely used in industrial applications. This application has been exploited by increasing the absorption capacity, wear durability, and frictional properties. These indirectly enable the fabrication of paper and felt-type asbestos materials for flooring and roofing product for sound insulation (NTP 2011). However, the use of asbestos material poses a threat to human health and the environment. Because of the health hazard posed by asbestos, the use of asbestos in most applications has been banned in most countries in the world. For example, the members of the European Union voted to ban asbestos use by late 2005 (Kogel *et al.* 2006). Because

of these tight restrictions, many industries have stopped using asbestos materials and pursued alternative materials, such as synthetic fibers.

Synthetic fibers are also called man-made fibers and can be created industrially. There are several hundred types of synthetic fiber in the world. Synthetic fibers are often manufactured with cellulose as the starting material (Rouette 2001). Although the manufacturing of synthetic fibers was meant to replace the wide usage of asbestos material in various industries, the results of studies that have been conducted in the laboratory indicate that synthetic fibres can possess the same human health hazard as asbestos material (Su and Cheng 2009). Because of this health risk, other alternatives have been investigated, such as the use of natural renewable fibres rather than synthetic fibres. With the recent increasing attention towards sustainability and environmental awareness, there is a large need to find clean, green, and sustainable materials that can be used as replacements; this is where natural biomass-derived fibres play a vital role. According to Manthey *et al*. (2010), such natural fibres are inexpensive, easy to process, renewable and they are recyclable. Luffa fiber is a light-weight natural material that has the prospective to be used as an alternative sustainable material for various engineering applications such as acoustic and vibration isolation, impact energy absorption, and packaging (Shen *et al*. 2013). Cellular materials with hierarchical microstructures have attracted much attention due to their excellent mechanical performance and the potential to achieve multi-functions such as vibration and shock isolation, thermal insulation, catalyst support, and acoustic absorption (Shen *et al*. 2014). Alkaline treatment, also known as alkaline mercerization, is the most commonly used chemical treatment of natural fiber composites in the preparation of thermoset and thermoplastic reinforced natural fiber composite material. In the alkaline treatment process, the network structure of the hydrogen bonding is altered due to reaction of sodium hydroxide (NaOH). This process is important for increasing the surface roughness of the natural fibres. According to Demir *et al.* (2006), the alkalization treatment of natural fiber improves adhesion and creates better mechanical properties of reinforced natural composite materials. Moreover, the alkaline treatment process can remove the wax, oils, and lignin at the cell wall surface of the natural fibers. However, there is limited research on the effect of the sound absorption coefficient due to the chemical treatment. Thus, more research on composite materials and natural fibres needs to be performed to better understand the effect of chemical treatment on the sound absorption coefficients.

According to Koizumi *et al.* (2002), bamboo fiber samples reveal similar sound absorption properties of glass wool fibres. The enclosing surface of bamboo fireboard materials yields high sound absorption properties compared to plywood materials, which have similar densities. The same result can also be seen in composite boards of randomly cut rice straws and wood particles (Mehta and Parsania 2006). It tends to exhibit higher sound absorption properties compared to particleboard, fireboard, and plywood in the frequency range of 500 to 8000 Hz. The use of composite materials made from plant fibres is currently receiving great attention. This is because reinforced natural fiber composites can be superior to reinforce synthetic fiber composites in certain properties, such as being lightweight, biodegradable, combustible, and recyclable. The good physical properties of natural fiber composites have ranked them among high-performance composites, which have environmental and economic advantages (Avella *et al.* 2000). Sound absorbing materials are chosen in terms of material types and dimensions and also based on the frequency of sound to be controlled (Simon and Pfretzschner 2004). Poly (l-Lactic acid) reinforced ramie fiber shows the sound absorption coefficients of 0.089 to 0.353 in the

frequency range of 250 to 1600 Hz (Chen *et al*. 2010). Polypropylene reinforced with wheat straw had higher sound absorption coefficients (0.03 to 0.2) within the range of 0.3 to 1.8 kHz than that of composites reinforced with jute fiber reinforced polypropylene composites (Zou *et al*. 2010). Sound absorption coefficients of zein-jute composites showed higher sound absorption (0.06 to 0.8) compared with polypropylene-jute composites between frequency ranges of 1 and 5 kHz (Reddy and Yang 2011). Composite boards made of rice straw; wood particle reinforced commercial urea formaldehyde showed higher sound absorption coefficients than particleboard, fibreboard, and plywood in the frequency range of 500 to 8000 Hz (Yang *et al*. 2003). Commercial polyurethane reinforced rice straw and waste tire particle composites were found to have higher sound absorption coefficients at frequencies within the range of 2000 to 8000 Hz than particleboard, fibreboard, and rice straw-wood particle composite board (Yang *et al*. 2004).

The following lines explain the factors affecting sound absorption coefficients of materials. According to Koizumi *et al*. (2002), as sound absorption coefficient of composites increased, the fiber diameter decreased. This is because thin fibers can move more easily than thick fibers in response to sound waves. One of the most significant characters that determine the sound absorbing features of a fibrous material is the specific flow resistance per unit thickness of the material. A study by Ibrahim and Melik (1978) showed the increase of sound absorption only at low frequencies, as the material gets thicker. A study conducted by Koizumi *et al*. (2002) showed the increase of sound absorption coefficients in the middle and higher frequency as the density of the sample increased. Castagnede *et al.* (2000) demonstrated that compression of fibrous mats decreases the sound absorption properties. Tortuosity is a measure of the elongation of the passageway through the pores, compared to the thickness of the specimen. According to Knapen *et al.* (2003), tortuosity explains the influence of the inner construction of a material on its acoustical properties. The number, size, and type of pores are the important factors that one should consider while studying sound absorption mechanism in porous materials. This study focused on the evaluation of reinforced untreated and treated Luffa fiber epoxy composites, which includes the sound absorption coefficients and mechanical properties. The features of the composite were evaluated using scanning electron microscopy (SEM) to look into the morphology, thermo-gravimetric analysis (TGA) to examine the thermal stability, Fourier transform infrared (FTIR) to see the functional groups involved, and tensile strength testing to ascertain the mechanical properties.

EXPERIMENTAL

Materials

Premixed epoxy resin BBT-7892, which is the product of Bisphenol-A and epichlorohydrin, was supplied by Borneo Indah (Malaysia) Sdn. Bhd. This type of epoxy resin has a low reactivity, yellowish color, and slow curing.

The luffa fibres were obtained from local sources in Kuching, Sarawak, Malaysia. For chemical treatment of fibres, pellets of sodium hydroxide (NaOH) were used, which have a low reactivity and are soluble in distilled water.

Methods

Fiber preparation

The luffa fiber can be extracted from the *Luffa cylindrica* plant in two ways, by either naturally drying on the plant itself or by cutting it when it has matured and drying under the sun. When luffa is dried, the hard top part of the luffa needs to be cut off to remove the seed inside the luffa pod. Striking the luffa pod against a hard wall will remove the skin and the seed. Later, the luffa is sprayed or soaked with water to remove the sap color. Because the luffa fiber is in the form of a sponged pod, it was dried before being chopped into smaller sizes (1 mm to 10 mm) for use in specimen preparation. The good specific energy absorption of luffa sponge is attributed partially to its light base material as well as a higher densification strain. Due to the high strength-to-weight ratio of cellular materials, luffa sponge can be used as a good packaging material and an excellent energy dissipation material (Shen *et al*. 2012).

Fig. 1. Example of (a) luffa sponge and (b) chopped luffa fiber

Specimen preparation

There were a total of 40 specimens prepared for the sound absorption test and 32 specimens prepared for the tensile test. Both sets of specimens were divided into two classes, untreated and treated. For untreated specimens, the luffa fiber was rinsed with distilled water and dried in an oven at 60 °C for 48 h. For treated specimens, the luffa fiber was immersed in a 5 % NaOH solution at 25ºC for 48 h. The purpose of immersing the luffa fiber inside the alkaline solution was to remove impurities and to increase the surface roughness of the fiber. The surfaces of an untreated fiber are covered with a layer of substances, which may include pectin, lignin, and other impurities. After sodium hydroxide treatment most of the lignin and pectin had been removed, resulting in a rough surface with some fibrils (Sgriccia *et al*. 2008). The immersed luffa fiber was cleaned with distilled water and dried in an oven at 60 °C for 48 h. Specimens for the sound absorption test were prepared by the following hardener to epoxy ratios 1:2, 1:4, 1:6, 1:8, and 1:10 to test the influence of binder on sound absorption. In this research a hardener to epoxy ratio of 1:4 was used as the control specimen for the tensile test. A circular mould with a diameter of 25 mm and thickness of 4.5 mm was used to fabricate the sound absorption specimens. For curing purposes, the mould was cold pressed under a pressure of 7 MPa using a hydraulic

press for 24 h. For the tensile test, a mould with a thickness of 5 mm and cross-sectional area of 72.5 mm^2 was used. The compositions for both tensile and sound absorption specimens were set at 5/95, 10/90, 15/85, and 20/80 wt. % of luffa/epoxy.

Composite testing

The sound absorption properties of the composites were assessed using a locally fabricated and calibrated two-microphone transfer-function method according to ASTM E1050-10 (2012), as shown in Fig. 2. This setup was employed to measure different acoustical parameters in the range of 500 to 6000 Hz. A loudspeaker was placed as a sound source at one end of the tube, and the test material was placed at the opposite end to measure the sound absorption properties. An impedance tube is a rigid, straight and smooth cylindrical pipe composed of two sections or tubes, a transmitting, and a receiving tube to test a material's acoustic absorption coefficient (α) by producing a sound wave incident on the material being tested; the difference between the incident and reflected wave is then measured. Based on Muehleisen (2005), the two-microphone method measures the magnitude and phase difference of the pressure reflection coefficients that are used to measure the sound absorption coefficients of composites.

The TGA was performed on a TA-60WS workstation analyser (Shimadzu Corp.; Kyoto, Japan) at a heating rate of 10 °C/min. Specimens were examined under flowing nitrogen (80 mL/min) over a temperature range of 30 to 900 °C. According to Monteiro *et al.* (2012), thermal analysis studies of composites are important to understand the relationships between the structural properties and the production of composite materials, especially in the wide field of applications based on reinforced fibre composites. The morphological studies of the chemically treated luffa fibres were observed using a JEOL JSM-6390LA SEM (Tokyo Japan) with a field emission gun and an accelerating voltage of 5 kV to collect images of the surface of composites. The test specimens were sliced and mounted on aluminum stubs with double sided adhesive tape and sputter coated with gold for 5 min to a thickness of approximately 10 nm under 0.1 torr and 18 mA to make the sample conductive. Micrographs were recorded at different magnifications to ensure clear images. The FTIR spectroscopy was performed on a Shimadzu FTIR-8101 spectrometer in the range from 4000 cm^{-1} to 400 cm^{-1}. The FTIR was used to collect and understand the functional groups of the composite materials. Tensile testing was performed with a LS-28011-50 Universal Testing Machine (T-machine Technology Co., LTD, Taiwan) using ASTM D638 - 10 (2012) as the control specimen.

Fabrication of two-microphone impedance tube

To fabricate the two-microphone transfer function impedance tube, all of the criteria mentioned in ASTM E1050-10 (2012) were used as a standard reference. Calculations were performed to ensure the equipment had a working frequency from 500 to 6000 Hz. According to ASTM E1050-10 (2012), to maintain the plane wave propagation, the frequency upper limit is defined in Eq. 1,

$$d < \frac{Kc}{f_u} \quad (1)$$

where f_u is the upper frequency limit (Hz), c is the speed of sound in the tube (m/s), d is the diameter of the tube (m), and K is a constant with a value of 0.586. The spacing between the two microphones can be improved by creating a large gap; however, the microphone

spacing must be smaller than the shortest half-wavelength needed. This can be determined with Eq. 2,

$$s \ll \frac{c}{2f_u} \quad (2)$$

where s is the microphone spacing (m), c is the speed of sound (m/s), and f_u is the upper frequency limit (Hz).

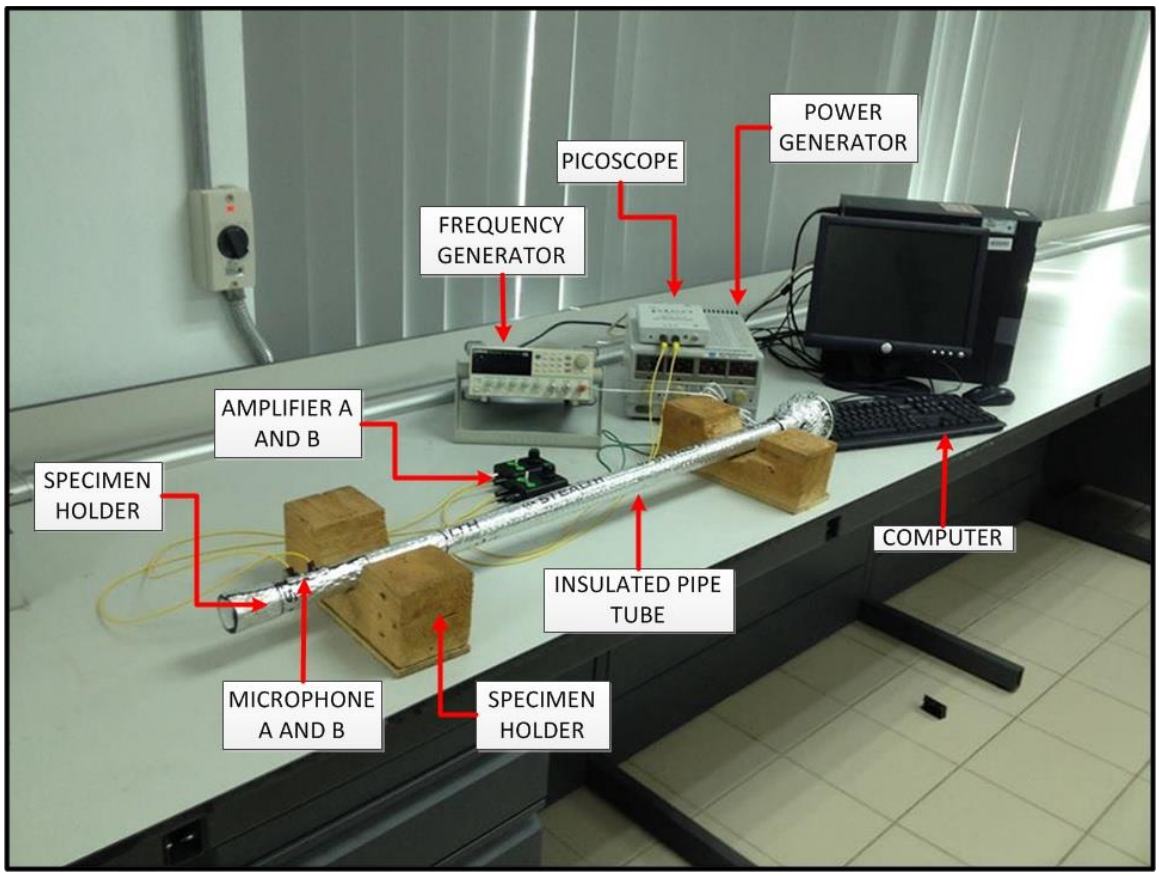


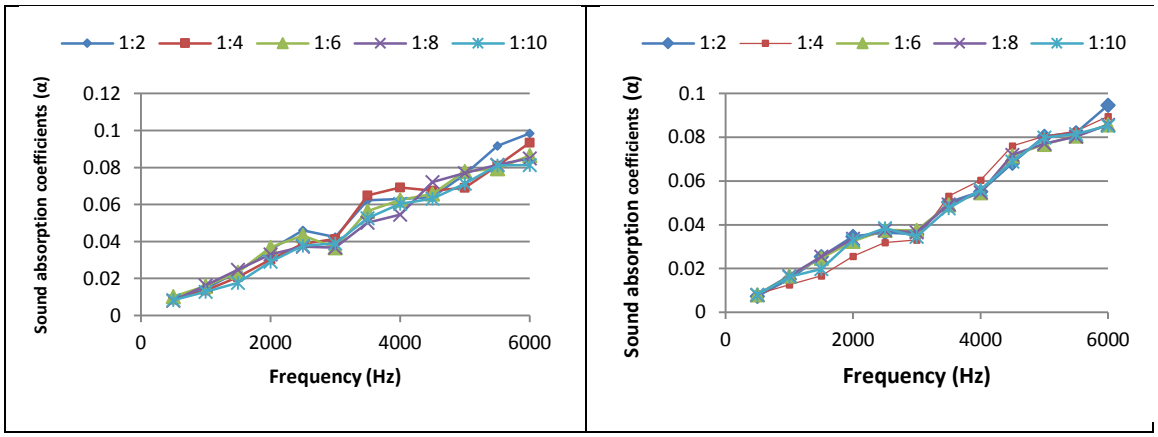
Fig. 2. The two-microphone transfer function Impedance tube Equipment set up

RESULTS AND DISCUSSION

Effect of Binder Concentration on Sound Absorption

The sound absorption coefficient of untreated and treated 10 wt. % fiber reinforced epoxy composites with different binder ratios across a range of frequencies can be observed in Fig. 3a and 3b. Generally, specimens with a lower binder concentration of 1:2 exhibited a higher sound absorption coefficient at all frequencies. According to Shoshani and Yakubov (2001), a nonwoven web to have a high sound absorption values, porosity should increase along the propagation of the sound wave. The increase in porosity inside the composites causes more friction, especially on the surface, which causes the sound to disappear or become dissipated. Fouladi *et al.* (2011) claimed that the mix between the fiber and binder during fabrication causes the fiber and binder to become part of the material itself. The binder will cover up the fiber by filling up the empty voids within the

fiber, which causes a decrease in porosity. According to Gle *et al*. (2011), as the binder concentration increases, the reduction in the porosity of the composites will minimize the sound absorption coefficient of composites.



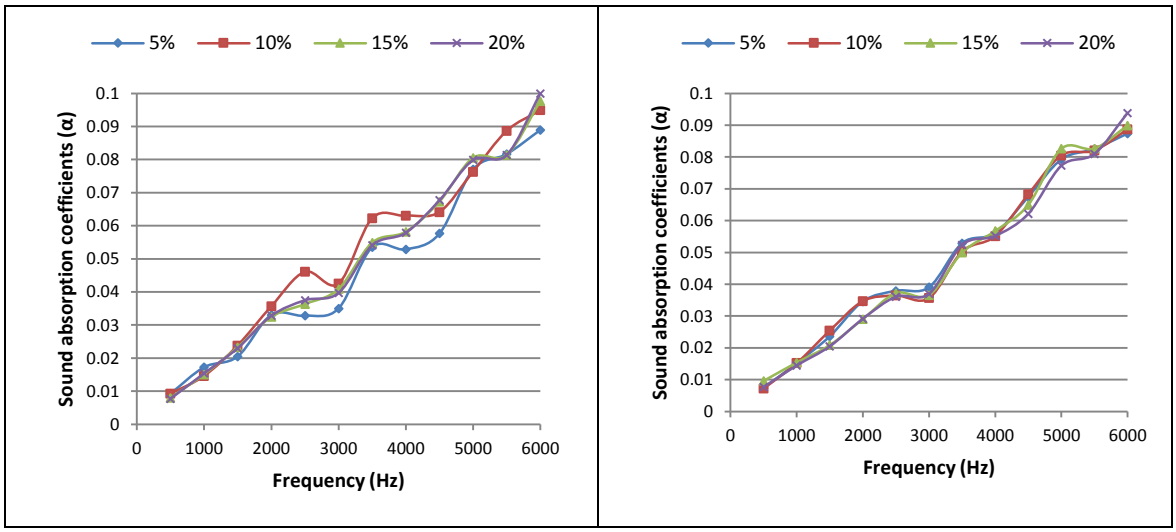
a **b**

Fig. 3. Sound absorption coefficients for specimens with various binder ratios for 10 wt.% fiber; (a) untreated reinforced luffa fibre epoxy composites and (b) treated reinforced luffa fiber epoxy composites

When a porous material is exposed to incident sound waves, the air molecules at the surface of the material and within the pores of the material are forced to vibrate and, in doing so, they lose some of their original energy. This is because part of the energy of the air molecules is converted into heat due to thermal and viscous losses at the walls of the interior pores and tunnels within the material (Crocker and Arenas 2007). However, the sound absorption decreased at the frequency of 3100 Hz and increased again. This kind of decrease and increase was due to the specific characteristics of natural fibers reflecting sound at 3100 Hz, but absorbing sound in the middle and high frequency ranges (Yang *et al.* 2003).

Effect of Fiber Content on Sound Absorption

Based on Fig. 4a and 4b, it can be observed that high fiber content exhibits a high sound absorption coefficient as the frequency is increased. From Fig. 4a and 4b, the sound absorption of 20 wt.% untreated and treated fiber had a higher sound absorption coefficient compared to other fiber contents. With increasing luffa fiber content in the composite, a higher sound absorption coefficient can be found. When the amount of fiber in the composite increases, the structure becomes more and more compact. The compact structure reduces the size and volume fraction of air voids and makes the air passages much narrower and more tortuous. Therefore, in the compact structure the sound wave travels a longer distance. Consequently, there can be more reduction of sound energy (Huang *et al*. 2013). This was supported by the research of Jiang *et al.* (2012) using seven-hole polyester fibre (SHPF) composites, which showed an increase in the sound absorption coefficient as the SPHF content increased.

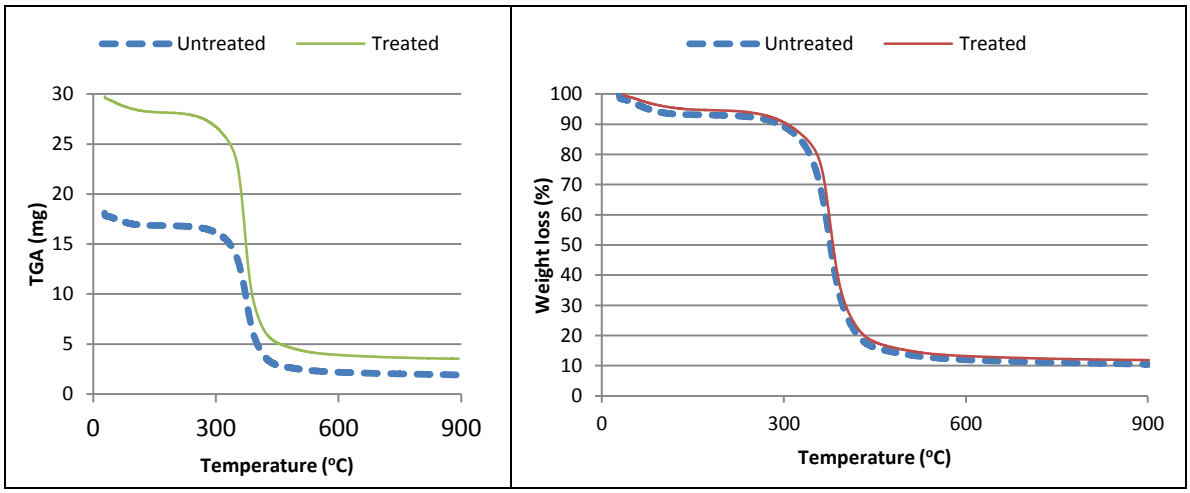


a **b**

Fig. 4. Sound absorption coefficients for specimens with various fiber contents; (a) untreated reinforced luffa fiber epoxy composites at a 1:10 binder ratio and (b) treated reinforced luffa fiber epoxy composites at a 1:10 binder ratio

Thermal Stability Analysis

Figures 5a and 5b show the TGA curves of reinforced luffa fiber epoxy composites. The thermal decomposition of the specimen of 20 wt.% fiber with a 1:4 binder concentration ratio took place from 30 to 900 °C. The major degradation began at 280 °C and was fully completed at 430 °C. Treated reinforced luffa fiber epoxy composites have a higher thermal stability than untreated luffa fiber epoxy composites.



a **b**

Fig. 5. (a) The TGA (mg) *versus* temperature (°C) and (b) weight loss (%) *versus* temperature (°C) of untreated and treated 20 wt% fiber reinforced luffa fiber epoxy composites

The weight loss of these composites is clearly shown at different temperatures in Fig. 5b. The high thermal stability of treated fibres is due to the improved interaction between the binder and the fiber, which produces additional intermolecular bonding between the matrix and fiber.

According to Nguyen *et al.* (1981), the thermal decomposition of cellulose begins at temperatures in the range of 210 to 260 °C by dehydration and is followed by a major endothermic reaction due to its decomposition. It is known that hemicellulose decomposes at a maximum temperature of 290 °C, and lignin thermally decomposes from 280 to 520 °C. Saheb and Jog (1999) stated that cellulose, hemicellulose, and lignin degradation are a crucial aspect of the thermal stability of reinforced natural fiber composites. The thermal changes indirectly affected the sound absorption properties of the natural composites due to the expansion of airflow size and porosity inside the natural composites, as the change in frequency created a different pressure friction on the surface of the material, which caused dispersion of energy as heat.

Morphological Analysis

Figures 6a, 6b, and 6c show the micrographs of reinforced luffa fiber epoxy composites. By observing the microstructures of a natural fiber cross section from Fig. 6c, it can be realized that natural fiber possesses a multi-scale structure. A single luffa fiber is made up of a bundle of hollow subfibers. The cell wall of a subfiber is made up of millions of nano-fibrils Yang *et al.* (2012). The nano-sized fibrils would also lead to the extra vibration, which caused more sound energy dissipation. The distributed fibres in the composites create a porous structure that helps to support sound absorption.

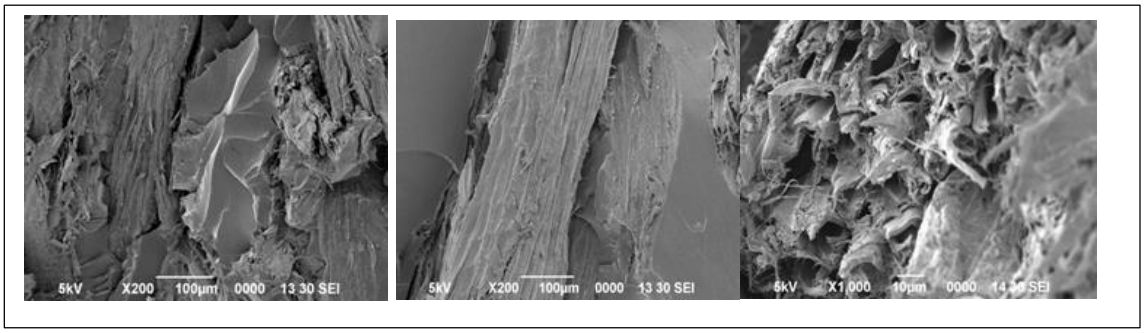


Fig. 6. The SEM images of the surface of reinforced luffa fiber epoxy composites; (a) treated, (b) untreated, and (c) cellwall of luffa fibers

As the sound wave is incident on the surface of the porous reinforced luffa epoxy composite structure, the air compression and motion tend to cause vibration and friction between the microspore walls and restrict the movement of the air. Because of the friction and viscous forces, some parts of the sound energy are converted to heat energy, which causes sound energy attenuation. Likewise, the heat loss caused by the heat exchange between the air, microspores, and microspore wall will also cause sound energy attenuation.

Based on Fig. 6a, the treated reinforced luffa fiber epoxy composites tended to reflect the sound wave when it hit the composite wall because of its heavy bonding and tightly arranged structure. The higher reflection and lower sound absorption is due to the dense layer created by the pectin, lignin, hemicellulose, and other lower-molecular weight

materials on the surface of the composites. According to Yilmaz *et al*. (2012), the treatment caused the fiber flow resistivity to be reduced, which makes it one of the primary factors influencing reducing the sound absorption coefficients of composites. Figure 6b shows that the surface of untreated luffa fiber composites exhibited unsticking, which is an indication of poor adhesion between luffa fibers and epoxy.

Spectral Analysis

The infrared spectra of both the untreated and treated luffa fiber were characterized by FTIR spectroscopy to confirm the effects of chemical reactions on the lignocellulosic constituents (cellulose, hemicellulose, lignin, and pectin) of natural fibres. The important modification done by alkaline treatment is the disruption of hydrogen bonding in the network structure, thereby increasing surface roughness. FTIR spectra of untreated and treated luffa fiber are presented in the region 4000 to 700 cm^{-1} in Fig. 7a and 7b.

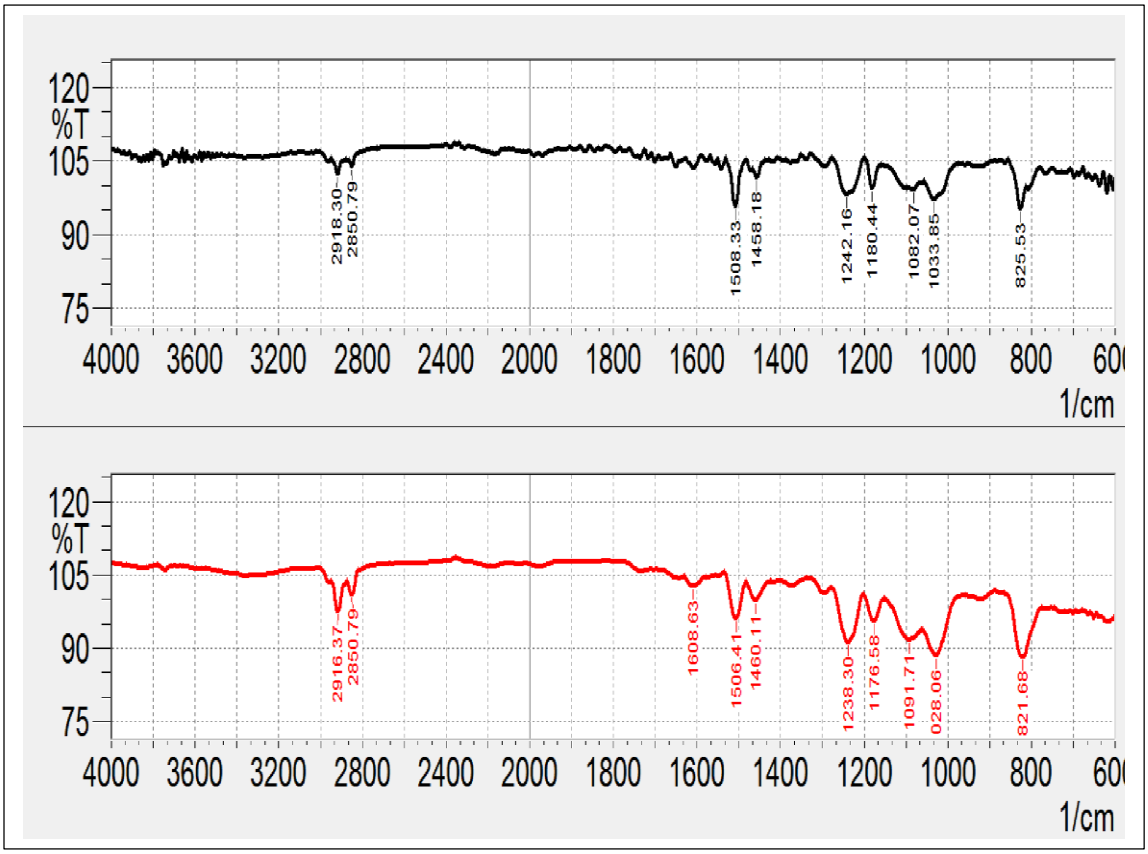


Fig. 7. The FTIR results for reinforced luffa fiber epoxy composites; (upper) untreated and (lower) treated

According to Khan *et al.* (2005), the characteristics of the spectrum for the luffa fibres are due to its constituents. Based on Fig. 7a and 7b, a strong and broad absorption band in the region 3200 cm^{-1} to 3500 cm^{-1} can be characterized as due to alcohols and phenols. In this region, the composite will undergo O-H stretching and H-bonding (Ganan *et al.* 2008). Based on Saw *et al.* (2013), and Ramadevi *et al.* (2012), the O-H stretching and H-bonding were due to the presence of carbohydrates (hemicellulose and cellulose).

Analysing Fig. 7a, it is clear that the untreated composites tended to exhibit more absorbance than the treated composites. This demonstrates that the luffa fiber and epoxy both contributed to the characteristics of the composites. This indirectly shows that the sound absorption can be affected by both luffa fibres and epoxy.

Furthermore, Figs. 7a and 7b show that the peak at 1608.63 cm^{-1} in untreated reinforced luffa fiber epoxy composites was completely reduced after treatment. This is due to the alkalinisation treatment, which causes the removal of hemicellulose. According to Han and Jung (2008), the decreased intensity of the band at 1608.63 cm^{-1} is due to the removal of O-H bending because that tends to absorb water molecules throughout the alkalization treatment. A similar peak can be observed in the spectra between the untreated and treated reinforced luffa fiber epoxy composites that contribute to the C-H stretching at the peak of 2850.79 cm^{-1}. The peak at 1242 cm^{-1} C-O stretching of acetyl group of lignin was reduced due to chemical treatment.

Mechanical Properties

From Fig. 8, it is clear that there was an increase in the average tensile and yield strength for both untreated and treated reinforced luffa fiber epoxy composites, based on the average of four samples for each fiber contents. The maximum tensile and yield strength was achieved at the optimum fiber contents of 15 wt.% of untreated luffa fiber epoxy composites. For treated reinforced luffa fiber epoxy composites, the optimum fiber content occurred at 10 wt.% fiber. The increase in average tensile and yield strength of untreated luffa fiber was due to the increase in the fiber content in the composites. The increase in the fiber content caused the distribution of load on the fiber to be more uniform.

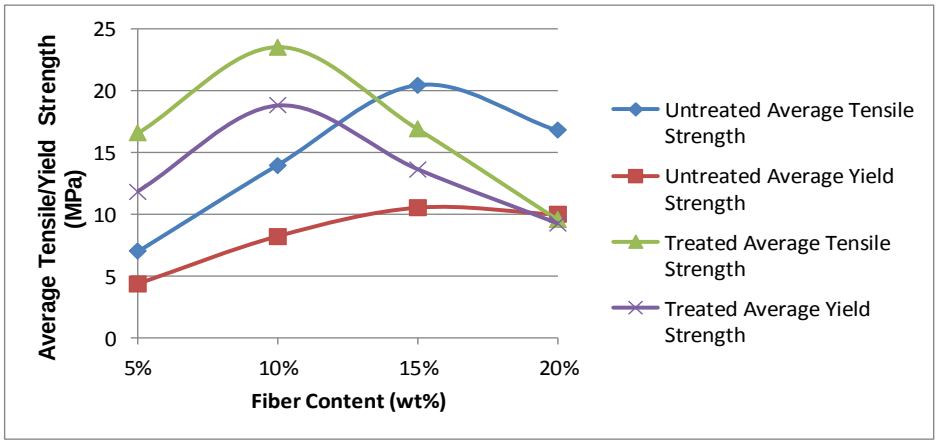


Fig. 8. Average tensile and yield strength for untreated and treated reinforced luffa fiber epoxy composites

After a peak point, Fig. 8 shows a decrease in the average tensile and yield strength, due to the decrease in the epoxy binder content in the composites. The decrease in the epoxy binder content was caused by the increase in the presence of the untreated luffa fiber content in the material. According to Liu *et al.* (2009), the increase in the tensile strength is due to the presence of fibres, which creates a dispersed matrix that allows a uniform distribution of stress on the material. Also, a decrease in the tensile strength after the optimum level was due to the high amount of fiber in the material, which contributes to the initiation of cracks. Cracks have been reported to cause non-uniform stress transfer due to

fiber agglomeration within a jute matrix (Liu *et al.* 2009). On the other hand, the highest result at 10 wt% of content is due to changes in the lignocellulosic characteristic (cellulose, hemicellulose, and lignin) in the fiber which happens because of the chemical treatment. According to Balakrishna *et al.* (2013), the chemical treatment removes the moisture and impurity of the fiber, which increases strength. Apart from that, the decrease in average tensile strength and average yield strength is very drastic for the treated luffa fiber. As the chemical treatment changes the properties of the luffa fiber, it indirectly manipulates the absorption characteristics of the luffa fiber, which has high water absorption. (this relates to epoxy because it is in the liquid state before hardening).

Another reason for the decrease in the average tensile and yield strength is the incomplete failure of composites. During such incomplete failure the binder starts to break before the fiber, as can be seen in Fig. 9. According to Boynard and D'Almeida (2000), this type of incomplete failure or fracture is known as controlled fracture in which it is not only distinct from normal failure, but also safer than the normal failure which could occur suddenly.

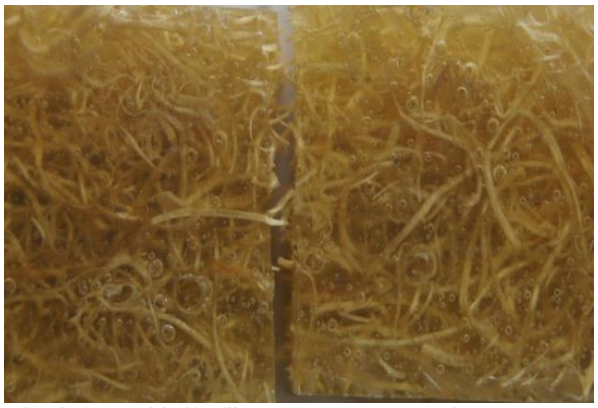


Fig. 9. Control fracture of reinforced luffa fiber epoxy composites

CONCLUSIONS

1. Mechanical test results clearly showed that sodium hydroxide treatment of luffa fibres in the composites increased the tensile and yield strength. Sodium hydroxide treatment caused changes in lignocellulosic characteristics of the fiber, which caused a lower sound absorption coefficient of composites.
2. The increase in the fiber content and changes in binder concentration can cause changes in sound absorption coefficients of composites, whereas the higher fibre contents and lower binder concentrations produce higher sound absorption coefficients.
3. The thermal stability of treated fiber composites were found to be higher than that of untreated fiber composites and can be explained based on the better thermal stability of treated fibres and improved fiber-matrix interactions in treated fiber composites.
4. Morphological studies by SEM reveal the hollow lumen structures of natural fiber and the distribution of luffa fiber in the epoxy composites. These special structures and the distribution are the main reason for better sound absorption.
5. The FTIR analysis provided information on the changes in the functional groups due to chemical treatment in a composite material.

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REFERENCES CITED

ASTM D638-10. (2012). "Standard test method for tensile properties of plastics," *ASTM International*, West Conshohocken, PA.

ASTM E1050-10. (2012). "Standard test method for impedance and absorption of acoustical materials using a tube, two microphones and a digital frequency analysis system," *ASTM International*, West Conshohocken, PA.

Avella, M., La Rota, G., Martuscelli, E., Raimo, M., and Sadocco, P. (2000). "Poly (3-hydroxybutyrate-co-3-hydroxyvalerate) and wheat straw fiber composites: Thermal, mechanical properties and biodegradation behaviour," *J. Mater*. 35(4), 829-836.

Balakrishna, A., Rao, D. N., and Rakesh, A. S. (2013). "Characterization and modelling of process parameters on tensile strength of short and randomly oriented *Borassus flabellifer* (Asian Palmyra) fibre reinforced composite," *Compos. Part B: Engineering* 55, 479-485.

Boynard, C. A., and D'Almeida, J. R. M. (2000). "Morphological characterization and mechanical behaviour of sponge gourd (*Luffa cylindrica*)-polyester composite materials," *Polym.-Plast. Technol.* 39(2), 489-499.

Castagnede, B., Aknine, A., Brouard, B., and Tarnow, V. (2000). "Effects of compression on the sound absorption of fibrous materials," *Applied Acoustics* 61, 173-182.

Chen, D., Li, J., and Ren, J. (2010). "Study on sound absorption property of ramie fiber reinforced poly(l-lactic acid) composites: Morphology and properties," *Composites: Part A* 41, 1012-1018.

Crocker, M. J., and Arenas, J. P. (2007). "Use of sound-absorbing materials," in: *Handbook of Noise and Vibration Control*, Crocker, M. J. (ed.), John Wiley and sons, New York, Chapter 57.

Demir, H., Atikler, U., Balkose, D., and Tihminlioglu, F. (2006). "The effect of fibre surface treatments on the tensile and water absorption properties of polypropylene-luffa fibre composites," *Compos. Part A: Applied Science and Manufacturing* 37(3), 447-456.

Fouladi, M. H., Ayub, M., and Nor, M. J. M. (2011). "Analysis of coir fibre acoustical characteristics," *Appl. Acoust.* 72(1), 35-42.

Ganan, P., Zulunga, R., Restrepo, A., Labidi, J., and Mondragon, I. (2008). "Plantain fiber bundles isolated from Colombian agro-industrial restudies," *Bioresource Technology* 99, 486-491.

Gle, P., Gourdon, E., and Arnaud, L. (2011). "Acoustical properties of materials made of vegetable particles with several scales of porosity," *Appl. Acoust.* 72(5), 249-259.

Han, S. O., and Jung, Y. M. (2008). "Characterization of henequen natural fiber by using two dimensional correlation spectroscopy," *J. Mol. Struc*. 883-884, 142-148.

Huang, C.-H., Lin, J.-H., Lou, C.-H., and Tsai, Y.-T. (2013). "The efficacy of coconut fibers on the sound-absorbing and thermal-insulating nonwoven composite board," *Fibers and Polymers* 14(8), 1378-1385.

Ibrahim, M. A., and Melik, R. W. (1978). " Physical parameters affecting acoustic absorption characteristics of fibrous materials," *Proceedings of the Mathematical and Physical Society of Egypt*, 46.

Jiang, S., Xu, Y., Zhang, H., White, C.B. and Yan, X. (2012), "*Seven-hole hollow polyester fibres as reinforcement in sound absorption chlorinated polyethylene composites*", Applied Acoustics, vol. 73, no. 3, pp. 243-247.

Knapen, E., Lanoye, R., Vermeir, G., and Van Gemert, G. (2003). "Sound absorption by Polymer-modified porous cement mortars," 6th International conference on Materials science and restoration, MSR-VI Aedificatio Publishers, pp. 347-358.

Khan, M. A., Hassan, M. M., and Drzal, L. T. (2005). "Effect of 2-hydroxy ethyl methacrylate (HEMA) on the mechanical and thermal properties of jute-polycarbonate composites," *Compos. Part A: Applied Science and Manufacturing* 36(1), 71-81.

Kogel, J. E., Tridevi, N. C., Barker, J. M., and Krukowski, S. T. (2006). *Industrial minerals and Rocks*, Society of Mining, Metallurgy, and Exploration, 7th Edition, Littleton, Colorado.

Koizumi, T., Tsujiuchi, N., and Adachi, A. (2002). "The development of sound absorbing materials using natural bamboo fibers," *Hi. Per. Struct. Mat.* 4, 157-166.

Liu, L., Yu, J., Cheng, L., and Qu, W. (2009). "Mechanical properties of poly(butylene succinate) (PBS) biocomposites reinforced with surface modified jute fibre," *Compos. Part A: Applied Science and Manufacturing* 40(5), 669-674.

Manthey, N., Cardona, F., Aravinthan, T., Wang, H., and Cooney, T. (2010). *Incorporating Sustainable Practice in Mechanics and Structures of Materials*, Sam Fragomeni, S. and Venkatesan, S. (eds.), CRC Press, Boca Raton, FL, pp 956.

Mehta, N. M., and Parsania, P. H. (2006). "Fabrication and evaluation of some mechanical and electrical properties of jute-biomass based hybrid composites," *J. Applied Polymer Sci.* 100(3), 1754-1758.

Monteiro, S. N., Calado, V., Rodriguez, R. J. S., and Margem, F. M. (2012). "Thermogravimetric behaviour of natural fibers reinforced polymer composites," *Mat. Sci. Eng. A* 557, 17-28.

Muehleisen, R. T. (2005). "Measurements and empirical model of the acoustic properties of reticulated vitreous carbon," *J. Acoust. Soc. Am.* 117(2), 536-544.

Nguyen, T., Zavarin, E., and Barral, E. M. (1981). "Thermal analysis of lignocellulosic materials. 1. Unmodified materials," *J. Macromol. Sci., Part*. C 20(1), 1-65.

NTP (2011). *Report on Carcinogens, Twelfth Edition*, U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program.

Ramadevi, P., Sampathkumar, D., Srinivasa, C. V., and Bennahalli, B. (2012). "Effect of alkali treatment on water absorption of single cellulosic abaca fiber," *BioResources* 7(3), 3515-3524.

Reddy, N., and Yang, Y. (2011). "Novel green composites using zein as matrix and jute fibers as reinforcement," *Biomass and Bioenergy* 35, 3496-3503.

Rouette, H. K. (2001). *Encyclopaedia of Textile Finishing*, Springer, pp. 766.

Saheb, D. N., and Jog J. P. (1999). "Natural fiber polymer composites: A review," *Adv. Polym. Technol.* 18(4), 351-363.

Saw, S.K., Purwar, R. Nandy, S., Ghose, J., and Sarkhel G. (2013), "*Fabrication, characterization and evaluation of Lufffa cylindrical fiber reinforced epoxy composites*," *BioResources* 8(4), 4805-4826.

Shen, J., Xie, Y. M., Huang, X., Zhou, S., and Ruan, D. (2012), "Mechanical properties of luffa sponge," *Journal of the Mechanical Behaviour of Biomedical Materials* 15, 141-152.

Shen, J., Xie, Y. M., Huang, X., Zhou, S., and Ruan, D. (2013). "Behaviour of luffa sponge material under dynamic loading," *International Journal of Impact Engineering* 57, 17-26.

Shen, J., Xie, Y. M., Zhou, S., Huang, X., and Ruan, D. (2014), "Water-responsive rapid recovery of natural cellular material," *Journal of the Mechanical Behaviour of Biomedical Materials* 34, 283-293.

Shoshani, Y., and Yakubov, Y. (2001). "Use of nonwovens of variable porosity as noise control elements," *International Nonwovens Journal* 10(4), 23-28.

Simon, F., and Pfretzschner, J. (2004). "Guidelines for the acoustic design of absorptive devices," Noise and Vibration Worldwide.

Sgriccia, N., Hawley, M. C., and Misra, M. (2008). "Characterization of natural fiber surfaces and natural fiber composites," *Composites: Part A* 39 1632-1637.

Su, W.-C., and Cheng, Y. S. (2009). "Deposition of man-made fibres in human respiratory airway casts," *J. Aerosol Sci.* 2(18), 270-284.

Yang, H.-S., Kim., D.-J., and Kim, H.-J. (2003). "Rice straw- wood particle composite for sound absorbing wooden construction materials," *Bioresource Technology* 86, 117-121.

Yang, H.-S., Kim, D.-J., Lee, Y.-K., Kim, H-J., Jeon, J.-Y., and Kang, C.-W. (2004). "Possibility of using waste tire composites reinforced with rice straw as construction materials," *Bioresource Technology* 95, 61-65.

Yang, W., and Li, Y. (2012). "Sound absorption performance of natural fibres and their composites," *Sci. China Technol. Sci.* 55(8), 2278-2283.

Yilmaz, N., Powell, N., Banks-Lee, P., and Michielsen, S. (2012). "Hemp-fibre based nonwoven composites: Effects of alkalization on sound absorption performance," *Fiber. Polym.* 13(7), 915-922.

Zou, Y., Huda, S., and Yang, Y. (2010). "Lightweight composites from long wheat straw and polypropylene web," *Bioresource Technology* 101, 2026-2033.

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