World Applied Sciences Journal 31 (Applied Research in Science, Engineering and Management): 40-44, 2014
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2014.31.arsem.522

Experimental Study on the Effect of Compression on the Sound Absorption of Date Palm Fibers

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Abstract: This paper presents an experimental investigation on the effect of compression on the sound absorption properties of a date palm fiberl. The experiments were carried out using an impedance tube. The material was tested for 1, 1.3 and 2.5 compression rates. The results show that the values of absorption coefficient for the uncompressed sample (30 mm) are small at low frequencies, rising with increasing frequency and exhibiting a significant peak. When the sample is compressed to 23 mm or nominal rate of 1.3 the sound absorption improved after frequency 2500 Hz with a slight decrease in the range of 1500 Hz and 2500 Hz. However, a further compression to 12 mm or increasing the nominal compression rate to 2.5 reveals an overall lower performance of the sample compared with the compression rate of 1.3. Simulation was performed using Delany and Bazley model for sound absorption of the panel using modified and unmodified flow resistivity. The simulation results show that the trend of the panel in sound absorption when using the modified flow resistivity is more closed to the trend of the experimental results.

Key words: Date palm fiber · Impedance tube · Sound absorption · Compression · Simulation

INTRODUCTION

Natural fibers can be obtained from stems, leaves, roots, fruits and seeds of plants. The most famous sources of natural fibers are cotton, palm, sisal, kenaf, flax, arecanut and banana. These fibers have been used to manufacture reinforced plastics, strings, cords, hats, cables, ropes, mats, brushes, baskets and bags [1]. Natural fibers have been investigated for other applications such as automotive lining and noise absorption panels.

Sudan has plenty of agricultural waste products such as palm date fiber. These fibers have some advantages such as they are renewable, cheaper, abundance, nonabrasive and show less health and safety concern during handling and processing. Mineral fibers such as glass fiber, rock wool, or asbestos have been used extensively in acoustical applications. However, the health hazard associated with asbestos fibers is now well known and this type of material is no longer widely used. Other man-made mineral fibers are not known to be as hazardous as asbestos but there are concerns with possible health effects and it is standard practice to take safety precautions when installing or handling fiberglass or rock wool.

The date palm is one of the most cultivated palms around the world. The main date producing countries are Saudi Arabia, Iraq, Iran, Egypt, Pakistan, Algeria and the Sudan. The date palm in Sudan is mostly along the Nile in the Northern part of Sudan [2]. The fiber in the date palms can be obtained from leaves, the stem and the trunk [3]. Date palm fibers have been investigated for different applications such as domestic wastewater treatment and as wetted pads in evaporative cooling [4, 5].

The growing concern about the health risks of using glass or mineral-fiber materials as sound absorbing panels has motivated researchers to develop sound absorption panels from natural fibers.

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Many researchers developed acoustical composite boards using natural agricultural wastes [6,7]. Yang *et al*. introduced rice straw-wood composite boards for sound absorption purposes, which are more porous than other wood-based materials [6]. Ersoy and Kucuk [8] investigated the sound absorption properties of tea leaf fiber as an industrial waste material. The sound absorption of coir fiber from coconut was investigated extensively in the Acoustic Laboratory at the Universiti Kebangsaan Malaysia. The studies covered both experimental observations in reverberation room [9] and using impedance tube [10]. The investigation on the acoustical properties of the date palm fibers has started at the University of Khartoum by conducting simulation studies based on the measured flow resistivity [11].

The effect of compression on the sound absorption of fibrous materials used in automotive industry was studied by Castagnède *et al*. [12]. They reported that the compression of a porous layer affects the acoustical parameters such as porosity, characteristic lengths, tortuosity and flow resistivity. The aim of this research is to study the effect of compression rate on the sound absorption coefficient of date palm fibers panel.

MATERIALS AND METHODS

Date Palm Fiber: The date palm fiber used in this research is collected from the sheathing leaf base, which surrounds the stem of the date palm tree (Figure 1). It has a netted structure that is covered by soft tissues. It is collected from the tree and dried remove any excess moisture. The fiber is combed to remove the pulp, which is present on the fiber surface. The average diameter and the average density of the fibers are 0.408 mm and 919 kg/m3, respectively.

The date palm fibers samples were prepared using two plastic moulds. The moulds are different sizes equivalent to the diameters of the impedance tubes to cover the low and high frequency range of measurements. The low frequency range of the 100 mm impedance tube is 0 to 1000 Hz and the high frequency of 1000 Hz to 5000 Hz is obtained using the 28 mm diameter impedance tube. Figure 2 shows the plastic moulds and samples of date palm fibers for both sizes.

The sample used for this research was initially of thickness and density of 30 mm and 77 kg/m3, respectively. The sample was then compressed to 23 mm and 12 mm to obtain different compression rates. The compression rate *n* is defined as:

Fig. 1: Date palm netted structure

Fig. 2: Plastic moulds and date palm fiber samples

$$n = t_o/t_n \quad (1)$$

Where,

t_o is the original thickness of the date palm fiber sample
t_n is the thickness of the sample after compression.

Therefore, the compression rate for the samples in case of 23 mm and 12 mm are 1.3 and 2.5, respectively. Whereas the compression rate of the original sample of 30 mm thickness, which is the reference, is 1. The sound absorption of the three different compression rates was measured.

Sound Absorption Measurement: Sound absorption properties of a material can be measured using either reverberation rooms or impedance tubes. In this research the experiment was conducted using two impedance tubes of 28 mm and 100 mm diameters, noise generator, two

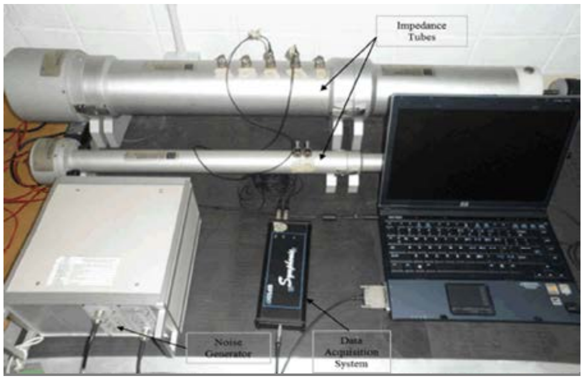

Fig. 3: Sound absorption experimental set-up

channel data acquisition system 01 dB, two ¼ in microphones type GRAS-40BP in each tube, software package SCS8100. The measurements were made based on ISO 10534-2 standard (1998). The microphones' sensitivity was calibrated using calibrator type GRAS-42AB at 114 dB level and 1 kHz. Figure 3 shows in a Photo of the system. A random noise was transmitted into the tubes using noise generator. Interior sound pressure spectrum was measured by the two microphones and transfer functions between them were calculated. The acoustical absorption coefficient was calculated from these transfer functions and distances between the microphones and date palm fiber sample. The frequency span of experiment was 100–5000 Hz with 3 Hz resolution. Before running the experiment the two impedance tube microphones were calibrated relatively to each other using the standard switching technique. This was based on mounting the sample in the sample holder and conducting the measurement to make sure that the sound field inside the tube is well defined.

Delany and Bazley model [13]: The theoretical sound absorption analysis for the date palm fiber sample used in this study was performed using Delany and Bazley model [13]. The model predicts the sound absorption coefficient (α) based on the frequency and the flow resistivity of the material. The model was derived by empirical equations for the complex propagation coefficient ($\tilde{A}$) and the complex characteristic impedance (Z_c) of the material which may be written as:

$$Z_c = \rho_o c_o [1 + 0.0571 * E^{-0.754} - j * 0.087 * E^{-0.732}] \quad (2)$$

$$\Gamma = \frac{\omega}{c_o}[1 + 0.0978 * E^{-0.700} - j * 0.189 * E^{-0.595}] \quad (3)$$

where:

C_o= speed of sound in air (m/s)
j = unit imaginary number = $\sqrt{-1}$

$$E = \frac{\rho_o * f}{\sigma}$$

σ = the flow resistivity

The sound absorption coefficient is given by:

$$\alpha = 1 - |R|^2 \quad (4)$$

with

$$\frac{Z_c \coth(\Gamma b)}{\rho_o c_o} = \frac{1 + R}{1 - R}$$

Flow resistivity of date palm fiber sample was estimated using the following empirical equation [14]:

$$\sigma = 490 \frac{\rho_{bulk}^{1.61}}{d_{fiber}} \quad (5)$$

where:

$\rho_{bulk}^{1.61}$ is the bulk density of the fiber
d_{fiber} is the date palm fiber diameter

However, according to Castagnède *et al*. [12], for a 1D compression rate the flow resistivity of the porous materials varies as follows:

$$\sigma_c = n\sigma \quad (6)$$

Where σ_c is the flow resistivity due to compression.

RESULTS AND DISCUSSION

The variation of sound absorption coefficient against frequency for date palm fiber sample at normal incidence as measured by the impedance tube is shown in Figure 4. It can be observed that the values of the sound absorption coefficient for the uncompressed sample of 30 mm are small at low frequency range, rising with increasing frequency but exhibiting a significant peak. The results show a peak of 0.52 in the sound absorption coefficient at 3160 Hz for date palm fiber. The performance of the fiber in sound absorption for different value of

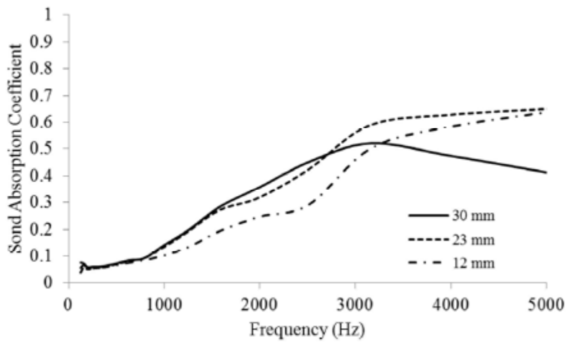

Fig. 4: Sound absorption coefficient for the date palm fiber samples of compression rates of 1(30 mm) 1.3 (23 mm) and 2.5 (12 mm)

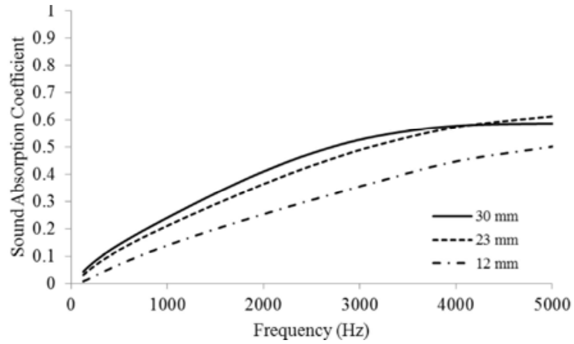

Fig. 5: Simulation of sound absorption coefficient for the date palm fiber using unmodified flow resistivity

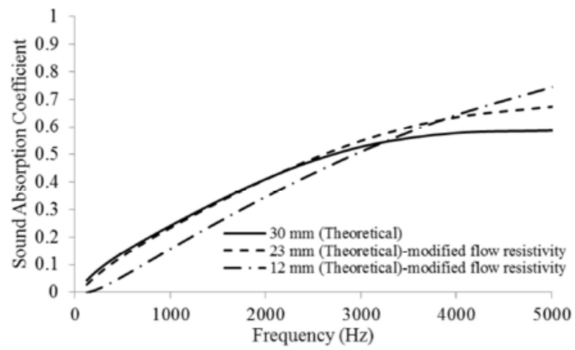

Fig. 6: Simulation of sound absorption coefficient for the date palm fiber using modified flow resistivity

frequencies is considered low which is probably due to the low density (high porosity) of the date palm fiber sample used for testing. The figure also shows the performance of the compressed configurations. When the sample is compressed to 23 mm or nominal compression rate of 1.3 the sound absorption improved after frequency 2500 Hz with a slight decrease in the range of 1500 Hz and 2500 Hz. However, a further compression to 12 mm or increasing the nominal compression rate to 2.5, the overall performance is less than the performance of the sample when the compression rate is 1.3. The improvement of the sound absorption when the compression rate is 1.3 is due to the variation of the physical parameters which are all in the right direction. The compression makes the apertures of the media small which improve the flow resistivity of the sample [15]. However, for the compression rate of 2.5 the decrease in the sound absorption coefficient could be attributed mainly to that the large variation of the flow resistivity. This results in a difficulty for the sound energy to be transmitted to the porous media and hence high sound reflection seems to occur. Therefore, there is a limitation for the compression rate beyond which the performance of the date palm fiber panel in absorbing the sound will be low.

Simulation was performed using Delany and Bazley model [13] for the date palm fiber panel to show the effect of the performance of the panel in sound absorption for the modified and unmodified flow resistivity as indicated by Eq. 6. The simulation results for the sound absorption for the unmodified and modified flow resistivity cases are shown by Figures 5 and 6, respectively. As can be observed the trend of the panel in sound absorption when using the modified flow resistivity (Figure 5) is more closed to the trend of the experimental results. This indicates that the approximation suggested by Castagnède *et al*. [12], can be used to simulate the sound absorption of compressed porous panel.

CONCLUSIONS

In this paper the effect of compression on the sound absorption properties of a date palm fiber panel was investigated. The material was tested for 1, 1.3 and 2.5 compression rates. The results show that the values of the sound absorption coefficient for the uncompressed sample (30 mm) are small at low frequencies, rising with increasing frequency and exhibiting a significant peak of 0.52 in the absorption coefficient at 3160 Hz. When the sample is compressed to 23 mm or nominal rate of 1.3 the sound absorption improved after frequency 2500 Hz with a slight decrease in the range of 1500 Hz and 2500 Hz. Increasing the nominal compression rate to 2.5 shows an overall lower performance of the sample compared with the compression rate of 1.3. Therefore, there is a limitation for the compression rate beyond which the sound absorption coefficient is decreased.

ACKNOWLEDGMENT

The authors would like to thank the Universiti Kebangsaan Malaysia for sponsoring this research under project GGPM-2012-073.

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