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Effect of Different Factors on the Acoustic Absorption of Coir Fiber

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Abstract: The aim of this study was to explore and analyze the effect of different factors on the absorption of coir fiber using the developed analytical techniques employing Johnson-Allard rigid frame model. Estimated results were verified by the measurements conducted in impedance tube on normal incidence sound absorption of coir fiber. It was found that the developed analytical method can provide a well consistent agreement with the experimental results. Factors that may have positive or negative effect are elaborated in this study. It describes how the physical elements of coir fiber absorber panel can change the absorption behavior. Results obtained show that layer thickness and fiber diameter have a significant effect on the absorption, whereas bulk density does not have any considerable effect. In addition, an example is presented in order to show the approaches of enhancing the absorption utilizing the advantage of modification in the physical elements. It exhibits that properly chosen fibers along with suitable amount of bulk density can increase the absorption for the same layer thickness. It indicates that these analyses can be powerfully exploited to improve the absorption of coir fiber and at the same time maintain a reasonable thickness which would be very efficient for limited space structure. Moreover, these results can serve as a guideline for the future implementation of acoustic absorber using naturally collected coir fiber.

Key words: Acoustic absorption coefficient, coir fiber, layer thickness, fiber size, bulk density, porous material

INTRODUCTION

In practical application, most of the sound absorbing products used in the building construction industry consist of synthetic materials. Because of the dominance of these materials in the commercial market, the study of alternative materials has been limited. However, several research works had been carried out and findings have uncovered potential new materials for sound absorption applications (Wassilieff, 1996; Ersoy and Kucuk, 2009; Dias *et al*., 2007a, b; Dias and Monaragala, 2006). Natural substances are in the center of interest as they are recyclable and easily available source. Malaysia has plenty of agricultural waste such as coconut fiber (*Cocos nucifera*), rice fiber (*Oryza sativa*) and oil palm frond fiber (*Elaeis Guinnesis*) which are abundant and usually burned or used as agricultural by-products (Zulkifli *et al*., 2009a, b). These natural fibers, such as coir fiber, are suitable as a substitute for synthetic fibers for acoustic absorption purposes. Investigation of the sound absorption attribute of coir fiber was initiated by Automotive Research Group laboratories, Universiti Kebangsaan Malaysia (Nor *et al*., 2004; Zulkifli *et al*., 2008, 2009a, b). Thereafter, study was carried out to find out the analytical modeling techniques to characterize the acoustic behavior of coir fiber and experimental observations in impedance tube. Analytical modeling method of coir fiber and the analyses of the absorption behavior can be found in authors' previous works (Fouladi *et al*., 2010a, b; Ayub *et al*., 2010). Studies conducted on coir fiber showed that they have high potential to be used as sound absorption panel (Ayub *et al*., 2009). They can be very useful for various usages in many structural and non-structural applications. However, the effects of different physical factors that may have considerable contribution on the absorption of coir fiber are not explored yet. This current study was aimed to elaborate the effect of different factors such as thickness of the porous layer, bulk densityfiber size of material on the acoustic absorption.

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The study of the acoustical performance of natural substance coir fiber material is important to use it efficiently in applications such as transportation sector, buildings, automotive interior noise, wall lining, room interior surface, muffling system etc. Market demands increases for porous absorbers with the aspirations like lower frequency absorption ability, wide band frequency absorption capacity, thin structure for limited space absorber, specific acoustic absorption spectrum and low cost materials. To achieve these divergent targets and make an optimized absorber using a porous material, it is important to truly understand the relationship between the chemistry, structure, morphology and physical properties of an individual technology concerns to porous material. Therefore, modeling the coir fiber and exploring the effect of different physical and non physical elements on the absorption coefficient is vital and inevitable, since acoustic absorption characteristics have to be enhanced and optimized for commercial use. The main objective of this study is to analyze the effect of different factors on the absorption of coir fiber using the Johnson-Allard rigid frame model.

MATERIALS AND METHODS

Acoustic absorption properties of coir fiber was investigated for natural fresh samples and industrially made fibers mixed with binder in Acoustic Laboratory at Universiti Kebangsaan Malaysia (UKM). Fresh coir fiber samples were collected from fresh coconut husk available in local wet market and then made it dry in open sunny weather. After drying, it was compressed to make the sample using molds. Therefore, fresh coir fiber samples were not processed and sample contains almost same ingredients (including matrix granular part) as it was when collected from local market. Industrial coir fiber was prepared industrially using binder (latex) as a mixer with the fiber to keep it in shape. Samples were collected industrially as a large rectangular sheet and then cut into suitable circular shape for impedance tube.

Johnson-Allard rigid frame model (Allard, 1993) was implemented to estimate the acoustic characteristics impedance and propagation constant of coir fiberhence the absorption coefficient of the porous layer backed with rigid wall. This model was accompanied by some compensation in the physical parameters which was considered to make the model useful for industrially treated coir fiber. It was assumed that binder became parts of fibers, covered their surfaces and filled the porosity between them. Therefore, based on the analyses, it was derived that the new diameter of fiber mixed with binder increased a proportional amount based on the porosity of the material. As a result a new parameter was considered for the diameter of fiber. A detailed analytical calculation procedure along with the experimental validation can be found in authors' previous works (Fouladi *et al*., 2010a, b; Ayub *et al*., 2010).

Experiments were conducted in impedance tube according to ISO 10534-2 (ISO 10534-2 1998) standard and on normal incidence sound absorption of coir fiber. The measurement system included two impedance tubes with diameters 28 and 100 mm each contains two ¼" microphones type GRAS-40BP, plane wave source, dual channel Symphonie (01dB model) real time data acquisition unit and 01dB software package. Calibrator type GRAS-42AB was used for microphone sensitivity calibration at 114 dB and 1 KHz frequency.

Analyses on the absorption of coir fiber were conducted utilizing Johnson-Allard model by varying different physical elements to explore and understand the effect. Comparison between the analytical and experimental results showed that the developed model can consistently provide a well estimation of the absorption coefficient for coir fiber (Ayub *et al*., 2010). Performance of the model was checked more specifically using the mean prediction error rate (Kino and Ueno, 2007). It was observed that the mean error rate shows discrepancies lower than 20% for the prediction of absorption coefficient using Johnson-Allard rigid frame model (Allard, 1993). Results and verifications from the previous findings indicate that developed model can be used efficiently for further analyses. Eventually, rigid frame model is also implemented in this study to estimate the acoustic characteristics of coir fiber in different conditions.

RESULTS AND DISCUSSION

Effect of fiber layer thickness: Figure 1 and 2 illustrate the acoustic absorption of fresh and industrial coir fiber for different thicknesses. Natural fiber has an average absorption of 0.8 for f >1360 Hz, f >940 Hz and f >578 Hz at thicknesses of 20, 30 and 45 mm, respectively. Unlike fresh coir fiber, industrial coir fiber has the average absorption varied within 0.65-0.8 for all sample thicknesses. For instance, 20 mm industrial fiber shows average absorption 0.8 for f >3190 Hz and absorption again decreases in high frequencies.

Industrial fiber with 35 mm thickness has average absorption 0.7 for f>1887 Hz despite a small decline in 3443-4584 Hz frequency band though it is more than 0.65. Similarly, 50 mm sample shows 0.8 for f>1300 Hz and more than 0.7 for 1962-3984 Hz. It shows that increasing coir fiber layer thickness increases the absorption and moves

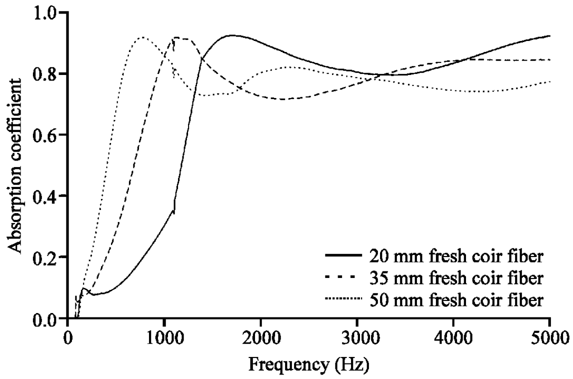

Fig. 1: Experimental results of absorption coefficient for different layer thickness of fresh coir fiber

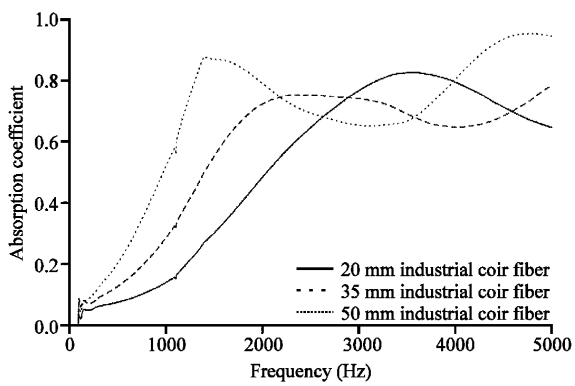

Fig. 2: Experimental results of absorption coefficient for different layer thickness of industrial coir fiber

absorption peak towards low frequency for both cases. Increasing the thickness of material enhanced the sound absorption in lower frequencies having same average absorption coefficient. It indicates that the absorption increases as impinged wave has to go long way through the material and losses its energy. According to absorption phenomena inside a porous material, long dissipative process of viscosity and thermal conductions in the fluid inside the material due to increased thickness improve the absorption.

However, it is observed that fresh coir fiber has better absorption than industrial fiber for the same thickness of the material. This is attributed to the fact of lower moisture content and stiffness effect from binder, which is also addressed in previous research works (Wassilieff, 1996). However, flow resistivity of the fresh coir fiber might also be a reason. It is noted that the flow resistivity of fresh coir fiber is greater comparatively than that of industrial fiber for the same thickness of material. The main factors influencing the flow resistivity of fibrous material are the fiber size and bulk density of the material (Delany and Bazley, 1970). During the preparation of fresh coir fiber, it was found that coir fiber contains some matrix material with the fiber. Extra matrix granular part along with the fiber increased the bulk density of the material, as a result flow resistivity also increased. Nevertheless, fresh coir fiber without any treatment (or binder) can not be used regularly as an absorber for long time period because of the moisture and stiffness effect of the fiber (Wassilieff, 1996). It may decrease the thickness of the porous material later on and change the absorption characteristics as mentioned earlier.

Despite the good acoustical absorption coefficient, coir fiber may not be used commercially in its natural form. It should be mixed with additives to keep it in shape and improve characteristics such as fire retardant, anti-fungus, etc. Here, binder was the only additive utilized by manufacturer to attach fibers together and adding stiffness. These samples had lower acoustic absorption; peaks were flattened and moved to higher frequencies. They exhibited weak absorption at low frequencies and tactics such as adding air gap or perforated plate are necessary to improve this shortcoming. However, these results demonstrate that more strategically designed layers and configurations of coir fiber could increase the noise reduction properties. Therefore, further analysis is conducted only for industrially treated fiber rather than fresh coir fiber.

Effect of bulk density: Absorption coefficient of 35 mm thick industrial coir fiber with varying bulk density is shown in Fig. 3 in order to reveal the effect on sound absorption of coir fiber. Six different mass of the coir fiber sample varying from 20 to 45 g with the duration of 5 g were considered for the circular sample of 100 mm diameter in order to change the bulk density of the material. Figure 3 shows that increasing bulk density of the porous material enhances the absorption of coir fiber and moves the peaks toward lower frequency. Enhancement of absorption occurs due to increased flow resistivity with increased bulk density.

However, the effect is not that much significant as it should be for usual porous material characteristics due to the same layer thickness of coir fiber. It can also be noticed that the profile of the graphs is slightly downward in high frequency with the increased density and the peak is almost in the same position though the additional bulk density increases the absorption. It means that increasing bulk density does not change the position of absorption peak considerably rather it increases the absorption coefficient in that peak position. As long as there is no additional layer (coir fiber or air) with the existing layer, no additional change occurs in the absorption peak. These

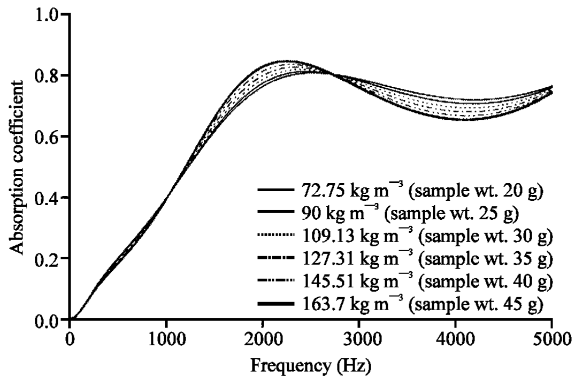

Fig. 3: Numerical simulations of absorption coefficient for 35 mm industrial coir fiber with different bulk density

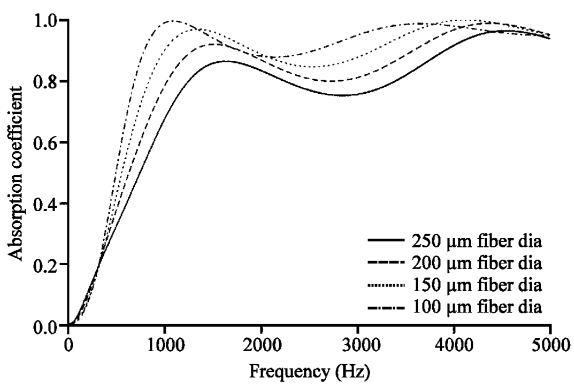

Fig. 4: Simulated absorption coefficient of 50 mm (mass = 34.13 g) coir fiber for different fiber size varying from 250 to 100 μm (original fiber diameter of industrial coir fiber = 252 μm)

results denote that absorber prepared with larger bulk density has a small effect on the absorption of coir fiber. However, increased bulk density can be a useful factor for enhancing the absorption and it should be within a limit which will allow the sound wave to go through the material. Otherwise, there will be a probability of sound wave to be reflected by congested material surface rather than absorption due to compact material.

Effect of fiber size (Diameter): In the previous studies (Sun *et al*., 1993; Koizumi *et al*., 2002; Lee and Joo, 2003) on the various parameters that influence the absorption properties of fibrous material, fiber size was shown to be an important parameter that change the absorption significantly. In this section, effect of coir fiber diameter on sound absorption is investigated and the results are shown in Fig. 4. In the figure numerical simulation of absorption coefficient is plotted for 50 mm thick industrial coir fiber with different fiber diameter varying from 250 to 100 μm. It shows that absorption coefficient changes dramatically with the variation of fiber size. Significant enhancement in low frequency absorption is observed with the reduction of fiber diameter.

This behavior can be attributed to the fact of the changes of two basic material properties; tortuosity and flow resistivity with the change of fiber size as addressed from the previous works (Sun *et al*., 1993; Lee and Joo, 2003). In general, flow resistivity of porous material is inversely proportional to the fiber diameter for a given porosity (Ingard, 1994), whereas tortuosity of the porous material is an indicator of how much tortuous the transmission path of sound wave within the absorbent (Cox *et al*., 2009). Thinner fiber due to reduction of fiber diameter causes the requirement of more fiber to reach an equal volume density for the same thickness. Addition of more thin fibers results in a more tortuous path and higher airflow resistance of the porous materials, which promotes the absorption coefficient and shifts the peak towards low frequency as well. Moreover, thin fiber can move more easily than thick fiber in sound waves which induces vibration in air. It results an increase in airflow resistance by means of friction through the vibration of the air. These results indicate that fiber size plays an important role for the improvement of sound absorption of coir fiber. Since, coir fiber is a natural resource, coir fiber absorber panel may not be prepared with just only by using thin fibers. However, it can be achieved by making the absorber panel with mixing the fine thin fibers with usual thick fibers from the treated coir fiber. It can also be accomplished by mixing the thin fiber from other material (such as man-made fabric, glass or mineral fiber) with the usual coir fiber.

Comparison of absorption performance by modifying the parameters: An example is presented in Fig. 5 to demonstrate how the modification in the fiber size, layer thickness and bulk density can improve the absorption coefficient of coir fiber. As shown in Fig. 5, solid line represents the absorption of 50 mm coir fiber layer in normal condition (fiber diameter = 250 μm and mass of the material = 34.13 g); dotted line shows the absorption plot for the same layer thickness of coir fiber with the only modification in fiber size as 150 μm and same mass of the material (mass of the material = 34.13 g); bold line corresponds to the absorption for 30 mm coir fiber layer with the modification both in fiber size and mass, hence the change of bulk density (fiber diameter = 150 μm and mass of the material = 34.13 g) and dashed line concerns to the case of 30 mm iber layer in normal condition (fiber diameter = 250 μm and mass of the material = 20.48 g). It

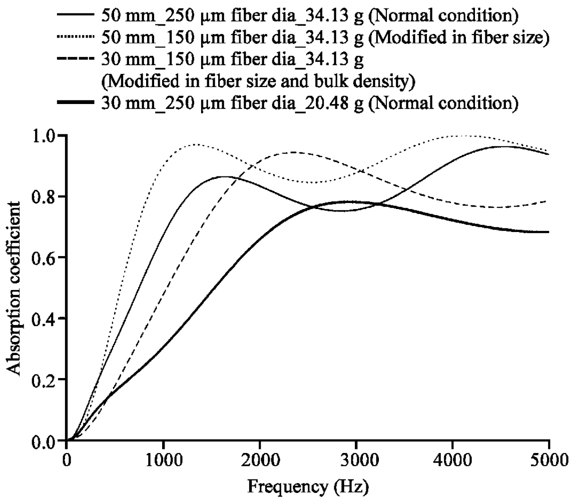

Fig. 5: Simulated results for the comparison of absorption performance among different conditions of coir fiber with the modification in the layer thickness, fiber size and bulk density

shows that decreasing the fiber diameter of 50 mm coir fiber by keeping the same bulk density (mass of the material = 34.13 g) enhances the absorption significantly. The advantage in the modification of fiber size can be utilized to reduce the layer thickness as shown for the case of 30 mm fiber layer with the modification in fiber size and mass of the material. It enables almost similar absorption plot of 50 mm coir fiberat the same time it makes the absorber more suitable for low space structure, whereas 30 mm fiber layer in normal condition shows a very low profile absorption behavior especially at low frequency. Hence it might be an efficient tool to reduce the thickness of acoustic isolators in practical purposes.

CONCLUSION

In this study, analysis have been conducted to explore the elements that may affect the absorption behavior of coir fiber based on the analytical method demonstrated in Authors previous works. In these analyses, Johnson-Allard model were implemented to estimate the surface impedance of coir fiber in different conditions. Variations of acoustic behavior of coir fiber with the change of physical elements such as bulk density, fiber size layer thickness are illustrated. It describes how the different factors can affect the absorption behavior of coir fiber. Results also explore that proper design consideration of absorber with the modification in the parameters can control and change the absorption of coir fiber. An example has been shown to demonstrate the possible way of improving absorption of coir fiber by utilizing the advantages of changing the elements. However, since the coir fiber is collected naturally, its elements can not be changed as it demands for the better absorption. In that case, absorbers can be prepared using those coir fibers chosen with the proper fiber size and thickness among all available fibers.

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