Technical Notes

Utilizing Hollow-Structured Bamboo as Natural Sound Absorber

Azma PUTRA[1],[2], Fazlin Abd KHAIR[2], Mohd Jailani Mohd NOR[1]

[1] *Centre for Advanced Research on Energy, Vibro Acoustics Research Group?*
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, Durian Tunggal Melaka 76100, Malaysia; e-mail: azma.putra@utem.edu.my

[2] *Faculty of Mechanical Engineering*
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, Durian Tunggal Melaka 76100, Malaysia;
e-mail: fazlinabdkhair@student.utem.edu.my

Studies to find alternative low environmental-impact materials for acoustic absorbers are still progressing, particularly those originated from natural materials. However, most of the established works are mainly focused on the fibrous-type absorbers. Discussion on the non-fibrous-type absorbers is still lacking and this therefore becomes the objective of this paper. Use of bamboo by utilizing its hollow structure to absorb sound energy is discussed here. The normal incidence absorption coefficient was measured based on the length and diameter of the bamboo, as well as different arrangement of the bamboo structure subjected to the incidence sound, namely, axial, transverse, and crossed-transverse arrangements. The trend of absorption coefficient appears in peaks and dips at equally spacing frequencies. For all arrangements the peak of absorption can reach above 0.8. Introducing an air gap behind the bamboo shifts the peak absorption to lower frequency. Covering the front surface of the absorber improves the sound absorption coefficient for axial arrangement by widening the frequency range of absorption also towards lower frequency range. The transverse arrangement is found to have average absorption coefficient peaks of 0.7 above 1.5 kHz. By arranging the bamboo structure with crossed-transverse arrangement, the suppressed absorption peaks in normal transverse arrangement can be recovered.

Keywords: bamboo, hollow structure, acoustic absorber, absorption coefficient.

1. Introduction

Conventional synthetic materials such as glass wools and foams are practically used as sound absorber and thermal insulation materials in building industries. However, analysis done using the life cycle assessment (LCA) study finds that their negative effects to the environment are high and thus natural 'green' and sustainable acoustic materials are now of interest (ASDRUBALI *et al.*, 2012). Using LCA, similar study was also presented by JOSHI *et al.* (2004) where biodegradable, natural fiber composite has much lower environmental impact and is superior than that of the glass fiber composite.

Since the last twenty years, studies on natural fibres for acoustic absorbers have been conducted, and investigations on finding new alternative materials from natural resources are still progressing. WASSILIEF (1996) studied the acoustic properties of compressed wood fibres and flakes. It is found that the absorption coefficient can reach close to unity above 500 Hz with the panel thickness of 75 mm. Mathematical validation with Delaney-Bazley model is also presented. The acoustic properties of natural wool were presented by BALLAGH (1996). For 100 mm thick sample with density of 47 kg/m^3, the normal incidence absorption coefficient is around 0.9 at frequency 0.5–2 kHz. For random incidence test in a reverberation chamber, the absorption coefficient is 0.8 above 500 Hz for sample of thickness 75 mm. The acoustical performance of the wool as sound insulator was also presented from the measurement results of transmission loss and insertion loss.

KOIZUMI *et al.* (2002) studied the bamboo fibre and found that the sample of thickness 50 mm and density of 120 kg/m^3 has similar acoustic character-

istic as the glass wool of density 32 kg/m^3. The absorption coefficient ranges from 0.9 to unity at frequency above 1 kHz. Azevedo and Nabuco (2005) studied the sound absorption of sisal fibres. Results show that for sample thickness of 50 mm and density of 40 kg/m^3, sisal fibres have absorption coefficient greater than 0.8 at frequency above 800 Hz and are comparable with fibreglass of the same thickness and density. Fatima and Mohanty (2011) found that jute fibres with 1% alkali solutions treatment has absorption coefficient of 0.71 at frequency above 500 Hz.

Yang *et al.* (2003) measured the absorption coefficient of rice straw wood particles composite and found that a sample with the specific gravity of 0.4 shows the highest absorption coefficient above 0.6 at the frequency above 2 kHz. A similar study is presented by Stumpf Gonzalez *et al.* (2013) where combination of 50% of waste rice husk with mortars shows a better sound absorption than that of waste from plywood formworks and thermoplastic shoe counters with the absorption coefficient of 0.55 at frequency 2 kHz.

Study on the acoustic characteristics of coir fibres was first conducted by Fouladi *et al.* (2010) by backing the fibrous panel with a perforated plate. The technique is found to reduce the air gap behind the sample required to produce the similar acoustical performance (with a larger air gap). A similar study was continued by Zulkifli *et al.* (2010) by backing the coir fibres with woven cloth cotton. The absorption coefficient of a 20 mm thick sample increases considerably at 1.5–4 kHz.

Ismail *et al.* (2010) showed that *Arenga pinnata* from palm sugar tree has good acoustic properties at the frequency between 2–5 kHz with the absorption coefficient above 0.7 for the thickness of 40 mm. This palm sugar fibre can be categorized as a hard fibre, which has a similar physical characteristics to the coir fibre. That explains why it is difficult to obtain a good absorption coefficient below 2 kHz, unless the thickness of the panel is increased.

Bastos *et al.* (2012) fabricated sound absorber panels from various natural fibres including those from acai, palm, sisal, and coconut. The samples were tested in a scaled reverberant chamber, and results show a good performance of the sound absorption for all fibres. The acai fibre shows the highest absorption coefficient close to unity at the frequency range of 1.25–1.5 kHz.

Asdrubali *et al.* (2014) measured the acoustic properties of various tropical plants namely fern, baby tears, begonia, maidenhair fern, and ivy. Random incidence test in a reverberation room reveals that high density of fern and baby tears are good in absorbing sound with the absorption coefficient of unity at the frequency range of 0.8–1.6 kHz.

Several works have also been discussed on the utilization of wasted fibres or by-product fibres. Erningsih (2009) finds that ramie wasted fibres can have sound the absorption coefficient of roughly 0.7 above 0.5-3 kHz.

Sound absorption from the by-product tea leaf fibres was studied by Ersoy and Kucuk (2009). It is found that 20 mm of thick layers of rigidly backed tea leaf fibres and non-woven fibre materials exhibit almost equivalent sound absorption in the frequency range between 500 Hz and 3.2 kHz.

The potential of paddy wasted fibres as acoustic material was studied by Putra *et al.* (2013a). The effect of density of the paddy fibres on sound absorption properties was investigated. It is discovered that as the fibre weight is increased to 5 grams with a 20 mm thickness (density is increased), the sound absorption coefficient is more than 0.5 above 500 Hz and almost constant at 0.8 in average above 2 kHz. By increasing the density further, considerable reduction of sound absorption is observed as this reduces the flow resistivity. A use of fabric as the facing for the sample is also found to significantly improve the sound absorption. In another study for wasted fibres from the sugarcane bagasse, Putra *et al.* (2013b) shows that a 13 mm thick sugarcane fibre sample can have absorption coefficient of around 0.65 above 1.2 kHz. This is also shown to be comparable with the performance of the glass wool of the same thickness.

The study of natural materials utilizing their non-fibrous structure to absorb sound is still limited according to the authors' knowledge, especially on the unmodified natural material with a hollow structure. The most recent work is presented by Oldham *et al.* (2011) which utilizes the hollow structure of reed to trap the sound energy. Multiple reed stems were arranged so that the cross section of the hollow faced the incident sound. With the 14 cm length of a stem, the absorption coefficient measured in a reverberation chamber is almost unity above 250 Hz up to 4 kHz.

Similar to Oldham *et al.* (2011), this paper presents utilization of the hollow structure of a bamboo as a mechanism for sound absorption. The impedance tube testing was used to measure the normal incidence sound absorption. Samples of bamboo were tested for different lengths of bamboo stem and different hollow diameters.

2. Measurement of normal incidence absorption coefficient

2.1. Materials preparation

Bamboos are well-know plants in Asia and have become the economic and cultural parts of the region. Not only as sources of food, bamboos are also used as

building materials due to their great compressive and tensile strength. Bamboos are also often used as musical instruments and furniture. Samples used in this study are those from the species of *Bambusa Multiplex* which has a relatively small diameter of the stem.

Measurement of the sound absorption coefficient was conducted to investigate the effect of the length of the stem and diameter, and different arrangement of the bamboo structures with respect to the incident sound. The bamboos were cut into length of 2 to 6 cm as in Fig. 1. The bamboo is classified into the small diameter range between 0.2 and 0.4 cm, and to the large diameter range between 0.5 and 0.7 cm, as shown in Fig. 2.

Fig. 1. Samples of bamboo with different lengths of stem.

Fig. 2. Small and large diameter samples of bamboos.

The bamboos were tested in three different arrangements, namely axial, transverse, and cross transverse arrangements shown in Fig. 3. For the axial arrangement in Fig. 3a, the bamboos were placed in the impedance tube such that the hollow cross sections were parallel to the incident sound. The length of the stem thus determines the thickness of the samples.

For the transverse arrangement, the surfaces of the stem were faced towards the incident sound. As seen in Fig. 3b, the stems were cut to fit the diameter of the tube. The bamboos were then arranged layer by layer with the total thickness of also 2 to 6 cm in order to have a fair comparison with the axial arrangement. For the cross transverse arrangement, subsequent layer of the bamboo has a different direction, as shown in Fig. 3c.
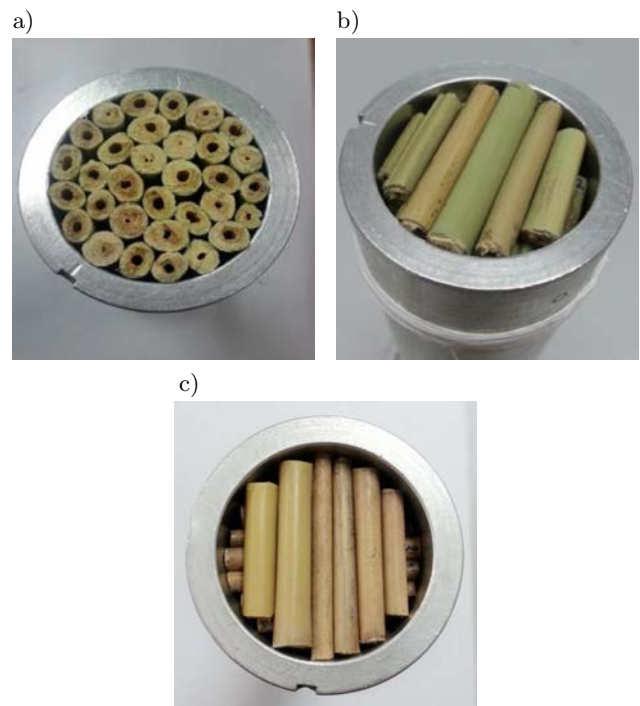
a)

b)

c)

Fig. 3. Arrangement of bamboo in impedance tube: a) axial arrangement, b) transverse arrangement, and c) cross transverse arrangement.

2.2. Experimental setup

The experimental setup using the impedance tube is shown in Fig. 4. It is conducted according to ISO 10534-2 (2001). The diameter of the impedance tube is 33 mm, which can measure the sound absorption coefficient at the frequency of 500 Hz to 4 kHz.
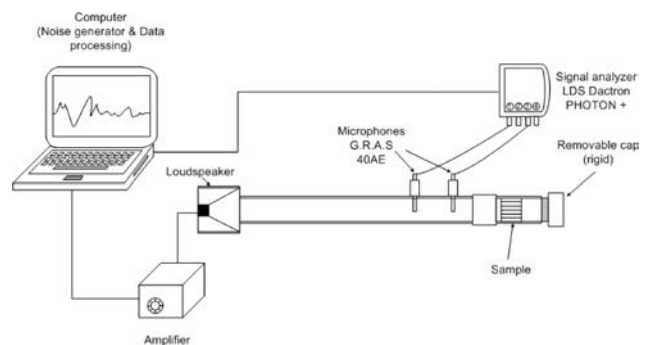

Fig. 4. Diagram of the experimental setup using the impedance tube.

The sample was located at the end of the tube, while a speaker that generated white noise was at the other end of the tube. Two pre-polarized free field microphones with pre-amplifier were located in front of the sample to record the incident and reflected wave signals. The signals were recorded by a digital signal analyzer and the signal post processing in the computer was then performed using the Matlab software.

3. Result and discussion

3.1. Axial arrangement

3.1.1. Effect of diameter and length

A sample of bamboos with two different ranges of diameter as in Subsec. 2.1 were tested in the impedance tube. Results of the absorption coefficient in Fig. 5 show that small diameter bamboos absorb more sound energy than those with a large diameter. With a small diameter, greater quantity of bamboo to fit in the impedance tube increases the absorption of sound energy. The absorption coefficient of 2 cm long bamboos can be seen to achieve 0.95 at 3.6 kHz, and that of 3 cm long bamboos is 0.99 at the lower frequency of 2.3 kHz. The results for mixed diameter samples can be seen to lie between those of the large and small diameter samples.
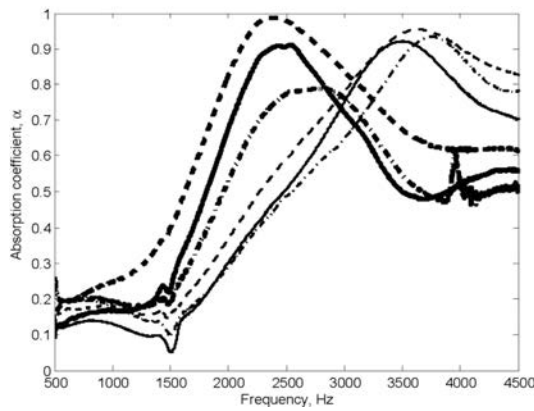
Fig. 5. Absorption coefficient of bamboo with diameter of stem for length 2 cm (thin line) and 3 cm (thick line) and diameter of: $--$ 0.2 to 0.4 cm, $-\cdot-$ 0.5 to 1 cm and — mixed diameter.

Figure 6 clearly shows that as the length of the bamboo increases, the peak of absorption coefficient shifts to the lower frequency. The sound wave in the bamboo behaves like the wave in a circular tube. Each peak co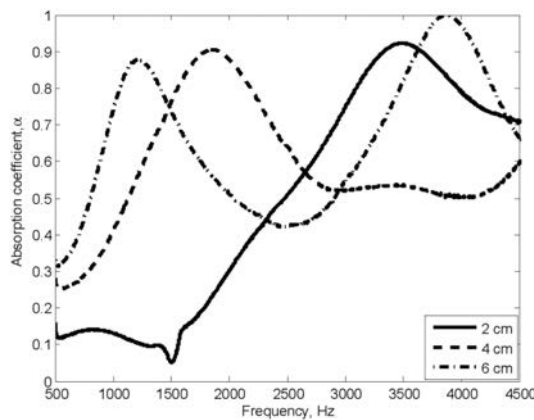rresponds to the quarter of the acoustic wave-length. For example, the first peak at around 1.3–1.4 kHz for the sample of the length of 6 cm corresponds to $\frac{1}{4}\lambda = 6$ cm $\rightarrow f_1 = c/\lambda = 343/(0.24) = 1429$ Hz, where c is the speed of sound in the air, i.e. 343 m/s. The second frequency is at $f_2 = 2f_1$, which is the dip at 2.6 kHz, and the second peak appears again at $f_2 = 3f_1$.

3.1.2. Effect of air gap

The results on the effect of an air gap behind the samples are plotted in Fig. 7 for different stem lengths of 2, 4, and 6 cm. As expected for similar arrangement for natural fiber, the air gap can be seen to lower the frequency of the absorption peak. Introduction of an air gap is useful for controlling the peak of absorption to the low frequency region without having to add the length of the stem. However, the frequency target for sound reduction must be ensured not to fall in the dip area where absorption coefficient is minimum.
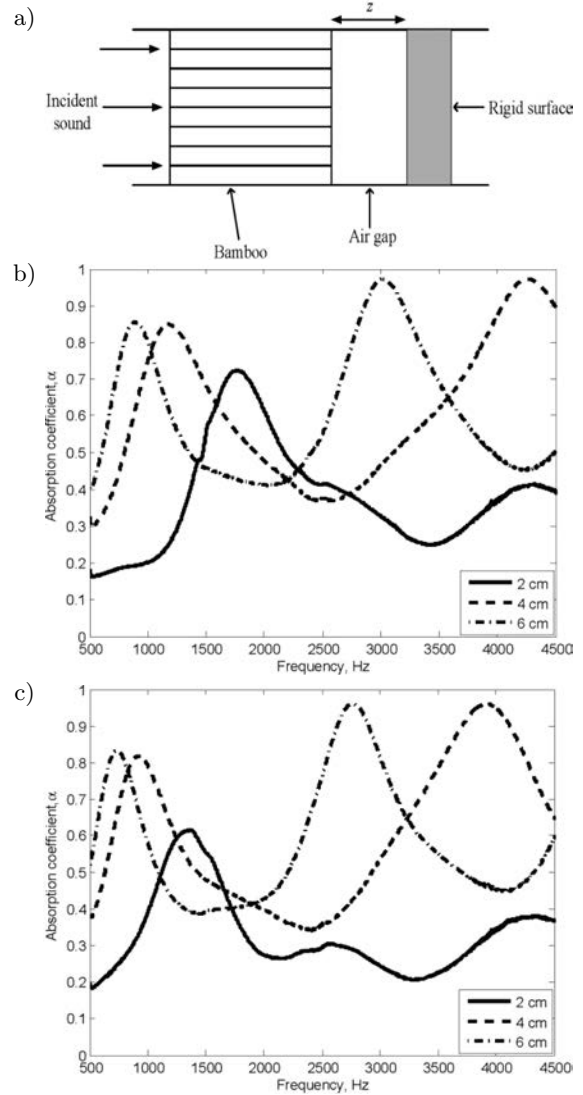

Fig. 7. Absorption coefficient of bamboo in the axial arrangement for different air gaps: a) diagram of the arrangement, b) $z = 1$ cm, and c) $z = 2$ cm.

Fig. 6. Absorption coefficient of bamboo with different stem lengths in the axial arrangement.

3.1.3. Attachment of fabric

The effect of the fabric cover on the acoustic properties of the bamboo samples is also studied. In this experiment the front and/or back surfaces of the samples were covered with non-woven fabric as shown in Fig. 8. The fabric used is known as felt with thickness of 0.2 cm and is commonly used for art works. The purpose of covering the bamboo with felt fabric is not only for artistic purpose, but also for protection, such as to block the way for insects.

Fig. 8. Front and back surfaces of the bamboo absorber covered with fabric.

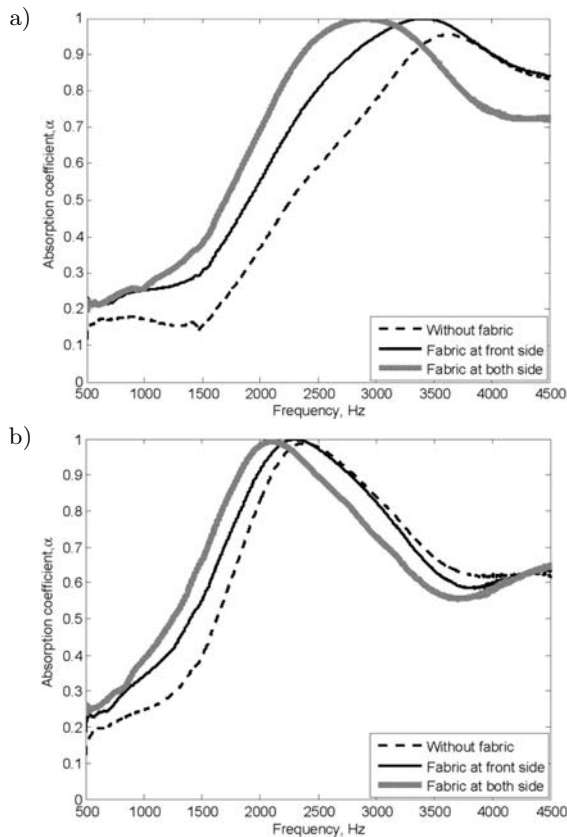Figures 9 and 10 show the comparison of absorption coefficient of bamboo with and without attach-

Fig. 9. Absorption coefficient of a small diameter of bamboo with attachment of a fabric for different stem lengths: a) 2 cm and b) 3 cm.
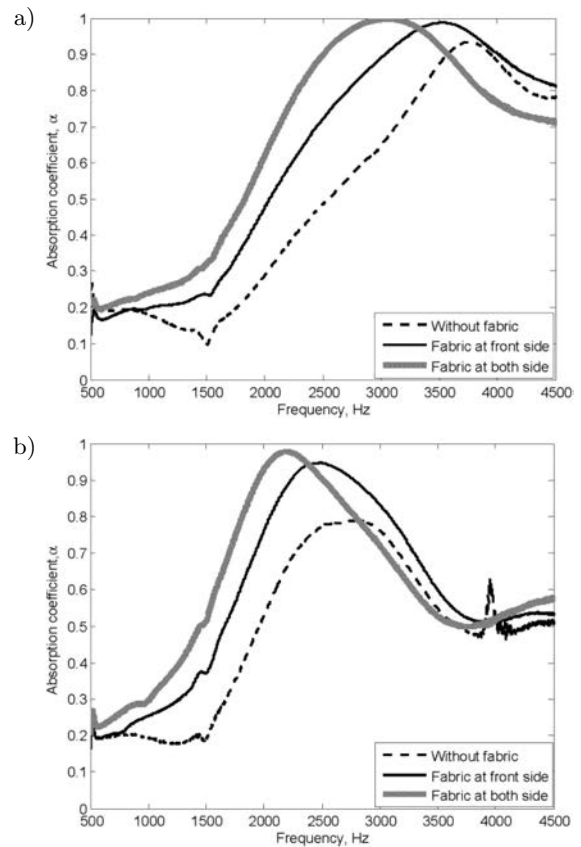

Fig. 10. Absorption coefficient of a large diameter of bamboo with attachment of a fabric for different stem lengths: a) 2 cm and b) 3 cm.

ment of fabric for small and large diameters of bamboo. For the fabric covering only the front surface, the absorption increases at low frequency below the peak frequency and thus improves the bandwidth of absorption ($\alpha > 0.5$). By also covering the back surface, the peak frequency can also be seen to shift to lower frequency range. However, the absorption bandwidth is slightly changed as compared with that from the sample covered on the front surface only.

3.2. Transverse arrangement

3.2.1. Effect of layer thickness and air gap

In transverse arrangement, the sound penetrates between air gap of individual bamboo structures and between the edge of the stem and the impedance tube. Results in Fig. 11 show a similar trend of the absorption coefficient as for the axial arrangement in Fig. 6. The thicker the layer, the lower the peak frequencies of absorption. The quarter-wavelength phenomenon, however, does not apply anymore in this case. As compared to the same thickness in the axial arrangement, the peak frequency in this case is lower about 25%.
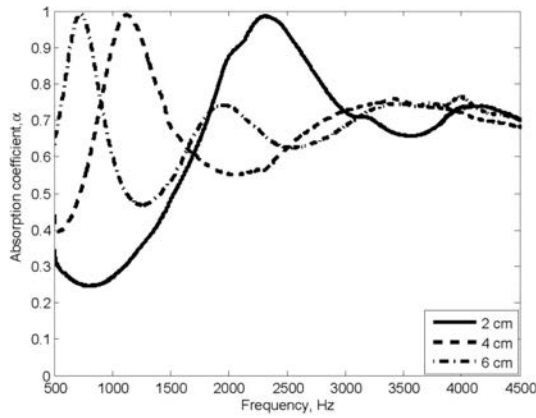
Fig. 11. Absorption coefficient of bamboo for different layer thicknesses in the transverse arrangement.

It can also be observed that for the same length as in the axial arrangement, the dips in the transverse arrangement have a greater level (above 0.5), especially above the second peak frequency. As the absorption peaks above this frequency range are also suppressed, the absorption coefficient is almost flat above 1.5 kHz at value of around 0.7.

For the transverse arrangement, the effect of air gap behind the sample is also tested. Figure 12 shows
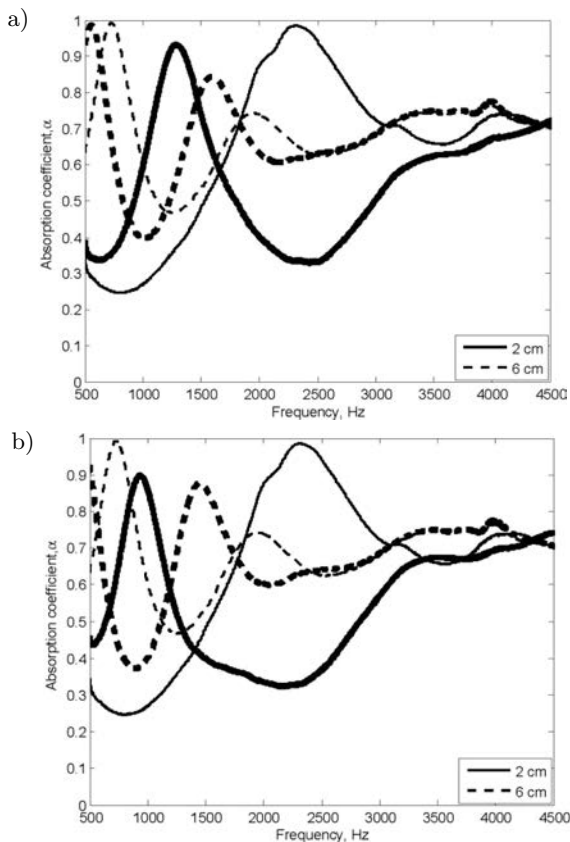

Fig. 12. Comparison of absorption coefficient of bamboo in rigid backing (thin line) and with different air gaps (thick line): a) 1 cm and b) 2 cm.

the comparison of the absorption coefficient of bamboo with the layer thickness of 2 and 6 cm for different air gaps. Similar to the axial arrangement, the greater the air gap, the lower the peak frequency of absorption. However, in this case, the peak absorptions are greater and almost reach unity.

3.2.2. Attachment of fabric

Figure 13 shows the result of bamboo sample in transverse arrangement with the fabric cover. The peak of absorption is slightly shifted towards the lower frequency as the fabric covers were added on the front and back surfaces of the samples. However, in this transverse arrangement, this does not give a significant effect on improving the acoustic performance of the bamboo.
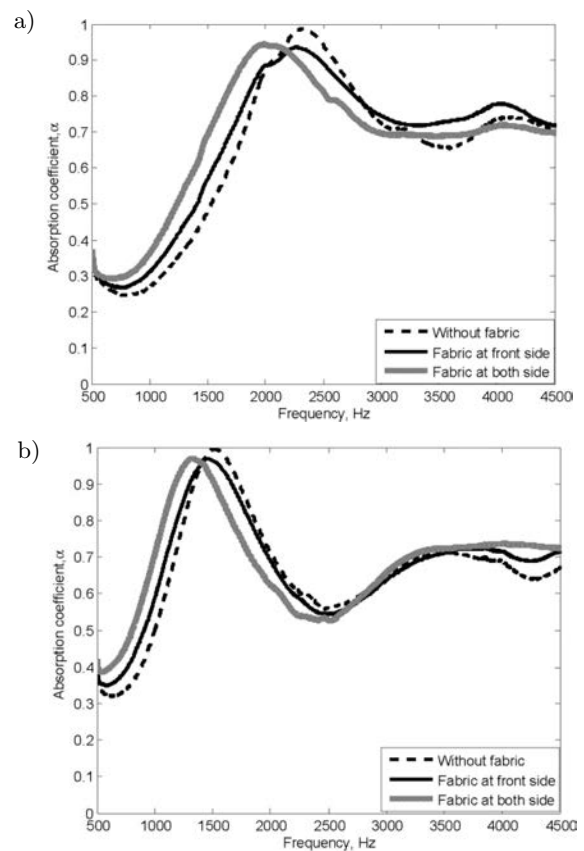

Fig. 13. Absorption coefficient of bamboo in the transverse arrangement with attachment of a fabric for different layer thicknesses: a) 2 cm and b) 3 cm.

3.3. Crossed-transverse arrangement

A crossed-transverse arrangement is aimed at providing a more complex air path inside the sample to increase the absorption coefficient. Figure 14 shows that the results at the first resonant peak are similar to those of the normal transverse arrangement except the crossed-transverse arrangement produces a lower
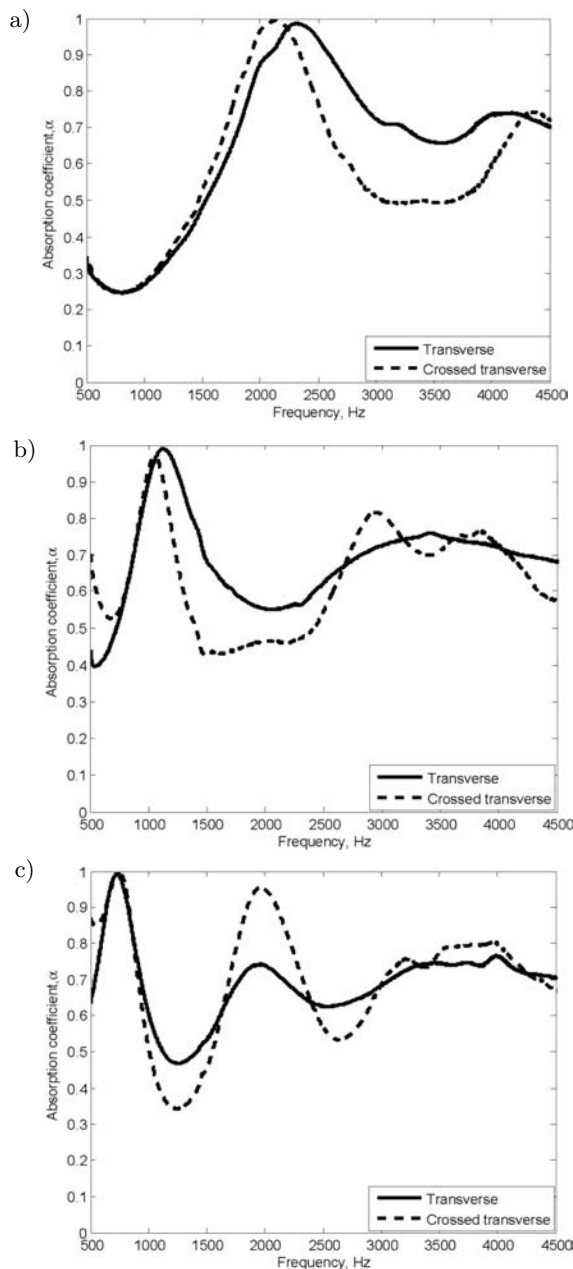
a)

b)

c)

Fig. 14. Comparison of absorption coefficient of bamboo in the transverse and crossed-transverse arrangements for different layer thicknesses: a) 2 cm, b) 4 cm, and c) 6 cm.
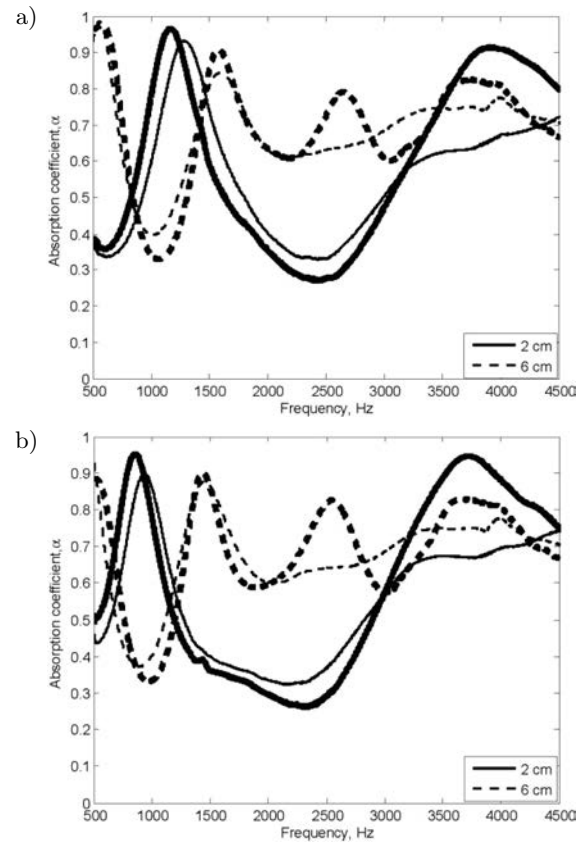
a)

b)

Fig. 15. Comparison of absorption coefficients of bamboo in the transverse (thin line) and crossed-transverse arrangements (thick line) for different air gaps: a) 1 cm and b) 2 cm.

4. Conclusion

The experimental results of the normal incidence absorption coefficient of hollow-structured bamboo reveal that the non-fibrous structure can be an alternative sound absorbing material. For all arrangements of the bamboo inside the impedance tube, the absorption coefficient can reach above 0.8. For the axial arrangement, in particular, the mechanism of sound absorption follows the behaviour of waves inside a circular tube, where peaks of absorption appear at frequencies equivalent to the half-wavelength of the length of the stem.

For the transverse arrangement, the absorption peaks were suppressed above the second peak frequency, but the dips have a greater level of absorption as compared to those in the axial one, which provide almost a flat absorption coefficient of 0.7 above 1.5 kHz. In the crossed-transverse arrangement, these suppressed peaks can be recovered.

It is also found that by covering the front surface directly facing the incidence sound with fabric, the bandwidth of absorption is improved towards lower frequencies, for both axial and transverse arrangements. The absorption peak frequency can also be controlled

dip. However, at the second resonant peak the crossed transverse shows a higher peak, especially as seen for 6 cm stem length in Fig. 14c.

The same phenomenon can also be seen for different air gaps in Fig. 15, where the second resonant peak and those above, which are suppressed in the transverse arrangement, now exist in the crossed-transverse arrangement. A complicated arrangement of bamboos is therefore preferable to increase the sound absorption.

to lower frequency by adding the air gap behind the bamboo.

The results presented in this paper are for condition where sound incidence is normal to the surface of the absorber. To have more representative results as those in practice, results from random incidence test inside a reverberation chamber are of interest.

Acknowledgments

References

1. ASDRUBALI F., SCHIAVONI S., HOROSHENKOV K.V. (2012), *A review of sustainable materials for acoustic applications*, Journal of Building Acoustics, **19**, 4, 283–311.

2. ASDRUBALI F., D'ALESSANDRO F., MENCARELLI N., HOROSHENKOV K.V. (2014), *Sound absorption properties of tropical plants for indoor applications*, Proceedings of the 21st International Congress on Sound and Vibration, China.

3. AZEVEDO L.J., NABUCO M. (2005), *Sound absorption of sisal fiber panels*, Proceedings of the Congress and Exposition on Noise Control Engineering, Brazil.

4. BALLAGH K.O. (1996), *Acoustical properties of wool*, Applied Acoustics, **48**, 2, 101–120.

5. BASTOS L.P., DE MELO G.d.S.V., SOEIRO N.S. (2012), *Panels manufactured from vegetable fibers: An alternative approach for controlling noises in indoor environments*. Advances in Acoustics and Vibration, Article ID 698737, 1–9.

6. ERININGSIH R. (2009), *Ramie fiber composite and ramie waste as natural sound absorber* [in Indonesia], Arena Tekstil, **2**, 1, 1–59.

7. ERSOY S., KUCUK H. (2009), *Investigation of industrial tea-leaf fibre waste material for its sound absorption properties*, Applied Acoustics, **70**, 1, 215–220.

8. FATIMA S., MOHANTY A.R. (2011), *Acoustical and fire-retardant properties of jute composit materials*, Applied Acoustics, **72**, 108–114.

9. FOULADI M.H., AYUB MD., NOR M.J.M. (2011), *Analysis of coir fiber acoustical characteristics*, Applied Acoustics, **72**, 35–42.

10. ISMAIL L., GHAZALI M.I., MAHZAN S., ZAIDI A.M.A. (2010), *Sound absorption of Arenga pinnata fiber*, World Academy of Science, Engineering and Technology, **67**, 804–806.

11. ISO (2011), ISO 10534-2 *Acoustic determination of sound absorption coefficient and impedance tubes part 2: transfer function method.*

12. JOSHI S.V., DRZAL L.T., MOHANTY A.K., ARORA S. (2004), *Are natural fiber composites environmentally superior to glass fiber reinforced composites?*, Composites, **35**, 371–376.

13. KOIZUMI T., TSUJIUCHI N., ADACHI A. (2002), *The development of sound absorbing materials using natural bamboo fibers*, High Performance Structures and Materials, **4**, 157–166.

14. OLDHAM D.J., EGAN C.A., COOKSON R.D. (2011), *Sustainable acoustic absorbers from the biomass*, Applied Acoustics, **72**, 350–363.

15. PUTRA A., ABDULLAH Y., EFENDY H., FARID W.M., SALLEH N.L. (2013a), *Biomass from paddy waste fibers as sustainable acoustic material*, Advances in Acoustics and Vibration, **23**, 1–7.

16. PUTRA A., ABDULLAH Y., EFENDY H., FARID W.M., AYOB R.MD., PY M.S. (2013b), *Utilizing sugarcane wasted fibers as a sustainable acoustic absorber*, Procedia Engineering, **53**, 632–638.

17. STUMPF GONZLEZ M.A., FLACH F., RESCHKE PIRES J., PIVA KULAKOWSKI M. (2013), *Acoustic Absorption of Mortar Composites with Waste Material*, Archives of Acoustics, **38**, 3, 417–423.

18. WASSILIEFF C. (1996), *Sound absorption of wood-based materials*, Applied Acoustics, **48**, 4, 339–356.

19. YANG H.S., KIM D.J., KIM H.J. (2003), *Rice straw-wood particle composite for sound absorbing wooden construction materials*, Bioresource Technology, **86**, 117–121.

20. ZULKIFLI R., ZULKARNAIN, NOR M.J.M. (2010), *Noise control using coconut coir fiber sound absorber with porous layer backing and perforated panel*, American Journal and Applied Sciences, **7**, 2, 260–264.