Jurnal
Teknologi

Full Paper

PRELIMINARY STUDY ON THE SOUND ABSORPTION BEHAVIOR OF SPENT TEA LEAVES FILLED WITH NATURAL RUBBER LATEX BINDER

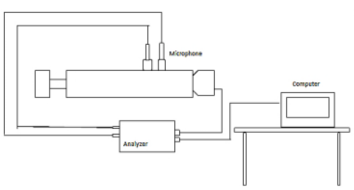
Kylie Wong[a]*, Qumrul Ahsan[a], Azma Putra[b], Sivarao Subramonian[a], Mohd Jailani Mohd Nor[b]

[a]Faculty of Manufacturing Engineering,
[b]Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka

Article history
Received
30 August 2016
Received in revised form
13 November 2016
Accepted
13 March 2017

*Corresponding author
m051510049@student.utem.edu.my

Graphical abstract



Abstract

Nowadays, sound control has been regarded as one of the important requirements for human comfort. For an instance, control of room acoustic enables the room to achieve a good auditive environment for effective speech deliverance and presentations. Synthetic fibers such as glass wool fiber are commonly used for sound absorption. Over the years, it was discovered that synthetic fibers are expensive and possess potential hazard to environment and human health. Therefore, growing attention has been turned to natural fibers as an alternative to synthetic fibers. This paper demonstrates the feasibility of spent tea leaf (STL) fiber as an eco-friendly sound absorbing material. STL fiber is a by-product which was extracted from tea plant. It is unique with fresh aroma and rich in phenolic extractive content. Three different grades of STL fiber were studied and the acoustic property was analyzed in terms of sound absorption coefficient (SAC). Results showed that all the samples obtained maximum SAC above 0.70 at frequency range of 1993-3861 Hz. Furthermore, it was found that finest STL fiber grade exhibits better acoustic performance among others with a maximum SAC of 0.88 at 1993 Hz. Besides, the effect of latex binder on the acoustic property of STL fiber was also analyzed. Results suggest that the types of latex binder did not influence the acoustic performance of STL fiber. The overall results indicate that STL fiber can be a promising environment-friendly sound absorbing material.

Keywords: Spent tea leaves, sound absorption coefficient, impedance tube, latex binder, natural fiber, acoustic properties

1.0 INTRODUCTION

Noise pollution has become severer issues as there has been dramatic increase growth in population and implementation of electrical and mechanical appliances at domestic and industries. The technology development nowadays even more emphasizes the demand of new technologies to control the noise pollution issue.

In general, there are two ways to reduce the noise either by active mediums in which noise generating element is suppressed by the large volume of external energy; or by the passive mediums, sound absorbing material which absorbs the sound wave energy [1]. Sound absorbing material may be classified into three main classes: porous absorbers, membrane absorbers and resonator absorbers [2]. Meanwhile, porous sound absorbing itself can be categorized as cellular, fibrous and granular based in their microscopic configurations. When sound wave incidents normally to the porous sound absorbing material, sound is converted to heat due to the frictional forces between the cell wall and air molecules within the porous material [3, 4].

Conventionally, noise absorbing materials are synthesized by performing non-biodegradable and expensive material such as polymer fibers and glass wool which give rise to health and environmental issues. The fabrication of synthetic fibers emits carbon dioxide, nitrous oxide, methane which is hazardous to human health. Furthermore, synthetic fibers are not skin friendly and may cause discomfort during processing and handling. Investigations reported that synthetic fiber can cause skin irritation and pose danger to human health if they are being inhaled because they can lay down in the lung alveoli [5].

Consequently, the introduction of natural fiber has shown growing interest over last few years. The major reason natural fiber has drawn great deal of attention because it shows ecological advantage while performing acoustical properties. In addition, natural fibers are lightweight, renewable and cost effective.

Natural rubber latex has been commercially available since 1930 and it is claimed as one of the most resourceful nature's products. Fresh latex coming out directly from rubber tree is preserved by using ammonia for long term storage. In year 1914-1918, Philip Schidrowitz has discovered vulcanization of latex by promoting crosslinks of rubber in latex with the addition of sulphur. It is proven that pre-vulcanized natural rubber latex has better mechanical properties especially in terms of tensile strength. This is mainly due the three dimension structure performed by the crosslinks which result in superior retention to stress [6, 7].

Numerous works have been carried out to discuss the use of natural fiber as sound absorbing material. The feasibility of coir fiber as sound absorbing material has been investigated and it was found that coir fiber showed potentials to be an alternative for synthetic based products [8]. Besides, it was discovered that thickness and alkali treatment has positive effect on acoustic performance of jute fiber [9]. Natural fibers such as Betung bamboo and date palm fiber were also studied in terms of the influence of bulk density on the acoustical performance. Different results were obtained where one claimed that lower density sample has better sound absorption properties as it had relatively higher porosity [10]. It was also reported that for the same thickness of sound absorption of materials, the increased in density enhanced the sound absorption performance because higher density resulted in greater airflow resistance [11]. Tea leaf fiber has also been tested and it was found that absorption peak shifted to lower frequency when the thickness of tea leaf fiber material was increased [12]. However, tea leaf fiber is limited when applied to real-world noise problem because it is friable and do not hold in one piece.

This paper emphasizes the acoustic properties of inexpensive and environmental friendly tea leaf fiber filled with natural rubber latex binder sound absorbing material. The purpose of this paper is to explore the possibility of different grades of spent tea leaf which is a by-product from tea plant industries as an alternative to conventional synthetic sound absorbing material.

2.0 METHODOLOGY

2.1 Materials

Spent tea leaf (STL) fiber was extracted from the stalks of the tea plant from BOH Plantations Sdn. Bhd located at Cameron Highland, Malaysia. Figure 1 presents three different grades of spent tea leaf fibers (BHE-SW, BHE-BM and SPE-SW) that were studied in this work. Prior to acoustical test, the spent tea leaf fibers were characterized such as geometry and air flow resistivity. In this work, two different types of natural rubber latex i.e., fresh latex and compounded latex were used as binder to hold STL fiber in shape. The compounded latex is the natural rubber latex which has been pre-vulcanized with the formulation as stated in Table 1. The natural rubber latex was obtained from Rubber, Leisure Products Sdn. Bhd.

(a) (b) (c)

Figure 1 Spent tea leaf fiber (a) BHE-SW, (b) BHE-BM and (c) SPE-SW

Table 1 Formulation of compounded latex

Ingredient	phr
High Ammonia Centrifuged Natural Latex	100.00
Precipitated Calcium Carbonate 50% Dispersion	24.0
Potassium Hydroxide	0.40
Bentonite Clay	0.06
ZnO White Seal	0.13
ZDEC	0.17
Polyphenolic Antioxidant	0.35
Sulfur	0.37

2.2 Dimensional Measurement

Vertical Optical Comparutor was used to determine the length and diameter of STL fiber. The x-direction of the device was used to determine fiber length while y-direction was used to determine the diameter of fiber. The aspect ratio of fiber (ratio of length to diameter) is then determined.

2.3 Flow Resistivity Measurement

AMTEC C522 airflow resistance test system based on ASTM C522 standard [13] was used to define the air flow resistivity of STL fibers. STL samples of 100mm diameter with bulk density of 0.17 g/cm^3 of BHE-SW, 0.19 g/cm^3 of BHE-BM and 0.22 g/cm^3 of SPE-SW were prepared for testing. The average flow resistivity data was obtained from three repeated tests with four flow point 1 to 4 lpm for each test.

2.4 Sample Preparation

Six test samples were prepared prior to the acoustical absorption performance testing. Each of the three different types of STL fibers were mixed with two different types of natural rubber latex (as represented in Table 2).

In preparing a test sample, 3 g of STL fiber was slowly mixed with small amount of latex and left for one hour. Then, the latex-bound-STL fiber was filled in a 33.3 mm diameter hollow metallic mold with metallic stopper at bottom and plunger on top of the mold. The sample was compressed to 20 mm thickness by using manual press machine. The compressed sample was then cured at 100℃ for an hour. Next, the sample was dried in oven to remove moisture contents within the sample. The drying process was repeated until a constant sample weight is obtained.

Table 2 Nomenclature of samples

STL Fiber Grade (without binder)	Sample Nomenclature	
	with Fresh Latex Binder	with Compounded Latex Binder
BHE-SW	BHE-SW(FL)[37wt%]	BHE-SW(CL)[37 wt%]
BHE-BM	BHE-BM(FL) [14 wt%]	BHE-BM(CL) [14 wt%]
SPE-SW	SPE-SW(FL) [8 wt%]	SPE-SW(CL) [8 wt%]

*[ ] - weight percentage of binder content in sample

2.5 Determination of Density and Morphology of Test Samples

The densities of test samples were determined using electronic densimeter. Sample was first placed on the stage to measure the mass. Then, samples was placed and totally submerged into water. The density data obtained were based on Archimedes' Principle.

The surface of the porous material was observed and analyzed under stereo microscope with a magnification of 10x. 30 points of areas of pores on the surface of the sample were measured.

2.6 Acoustical property Measurement

In order to determine the acoustic property of STL fiber, the normal specific sound absorption coefficient was determined by using two-microphone impedance tube (Type 4206) Brüel and Kjær which operates in compliance with ASTM E1050-98. The absorption coefficient of samples was determined at frequency range of 500-4500 Hz. The sample was placed at the end of the tube while a loudspeaker used to produce sound is located at another end of the tube. The sound absorption coefficient was computed from transfer functions and distance between two microphones and test sample. The sound absorption coefficient from the measurement indicates the acoustic energy absorbed by the sample. It is ranged between 0 to 1, where 1 means total sound absorption.

3.0 RESULTS AND DISCUSSION

3.1 Characterization of Spent Tea Leaf Fiber

The physical properties of three different grades of STL fiber are shown in Table 3. Among the three different grades of STL fiber, it was found that BHE-SW is the finest grade fiber as it possesses highest aspect ratio with lowest diameter and length while SPE-SW is the coarsest STL fiber among all.

Table 3 Physical properties of STL fiber

STL Fiber Grade	Physical Properties		
	Average Length (mm)	Average Diameter (mm)	Aspect Ratio
BHE-SW	7.33	0.13	57
BHE-BM	10.45	0.65	16
SPE-SW	9.91	0.98	10

The idea of air flow resistance is the resistance experienced by the air as it propagates through a material. In Figure 2, it is indicated that the increase in flow resistivity is correlated to the bulk density of STL fiber samples.

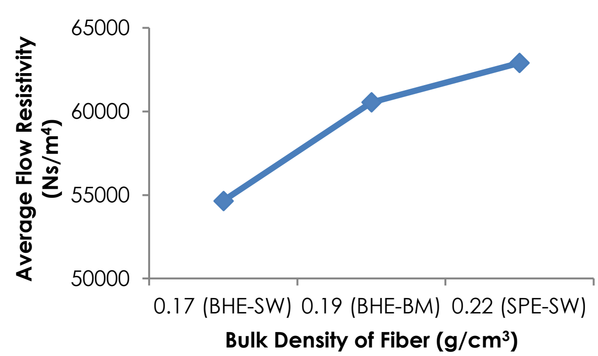


Figure 2 Relationship between the bulk density of STL fiber versus the flow resistivity

3.2 Density and Morphology of Test sample

As may be seen in Table 4, samples made of finest STL fiber BHE-SW result in relatively higher density. This result may be explained by the fact that finer fiber requires greater amount of fiber to reach equal volume of sample for the same thickness.

Similar results were also obtained by from a study and it was explained that the increase in density is due to the increase binder content [14].

Table 4 Densities of test samples

STL Fiber	Density (g/cm³)	
	Fresh Latex Binder	Compounded Latex Binder
BHE-SW	0.920	0.982
BHE-BM	0.840	0.852
SPE-SW	0.766	0.778

Figure 3 presents the surface morphology of STL fiber held by fresh latex. Micrographs of all three samples show open cell or pore structure representing the darker part [15]. Porosity measurement reveals that sample with coarsest fiber possesses largest pore size. The average pore size of SPE-SW sample is 0.18 mm^2 which is 200% greater than the average pore size of BHE-SW sample (0.06 mm^2). It is obvious that the coarsest STL fiber (Figure 3(c)) results in sample with higher porosity while sample with finest fiber (Figure 3(a)) is more compact and has fewer pores.

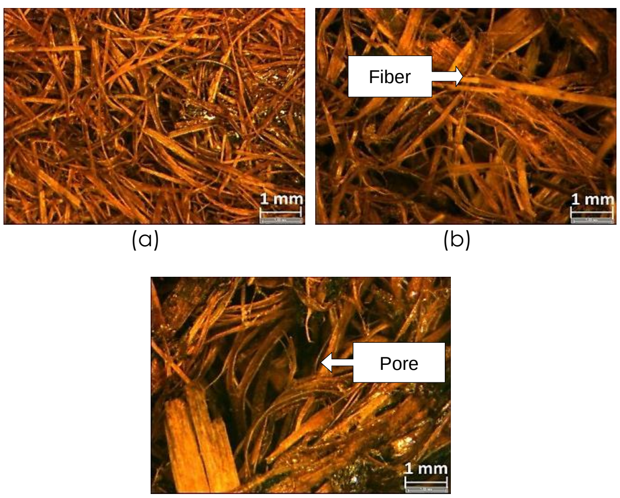


Figure 3 Surface morphology of sample (a) BHE-SW(FL), (b) BHE-BM(FL) and (c) SPE-SW

3.3 Impedance Tube Measurement

The maximum sound absorption coefficient of different STL fiber grades with different binder content are summarized in Table 5.

For sample made of pure fiber, the presented results reveal that STL fiber with finest diameter exhibits highest absorption coefficient among other STL fiber grade. Moreover, it was found that the maximum sound absorption coefficient of finest diameter STL fiber occurred at medium frequency range (1900-2700 Hz) as compared to others (shown in Figure 4). Similar results were also obtained from a study pointing that decrease in fiber diameter promotes sound absorption coefficient [16]. This is due to the fact that thin fiber provides more tortuous path and relatively flexible, thus induces vibration of air molecules causing more sound trapping [10].

Table 5 Maximum sound absorption coefficients of three grades STL fiber with/without latex binder

STL Fiber Grade	Maximum Sound Absorption Coefficient, a		
	No Binder	Fresh Latex	Compounded Latex
BHE-SW	0.94 (at 2648 Hz)	0.86 (at 2014 Hz)	0.88 (at 1993 Hz)
BHE-BM	0.84 (at 3902 Hz)	0.98 (at 2930 Hz)	0.96 (at 3133 Hz)
SPE-SW	0.77 (at 3861 Hz)	0.96 (at 2960 Hz)	0.96 (at 3034 Hz)

It is interesting to note that the introduction of binder to the BHE-SW fiber has lowered the maximum absorption coefficient and peaks were shifted to lower frequency range. Refer to Table 4, both BHE-SW samples with binder has the highest density value among all. This can be mainly attributed that finest BHE-SW possessed higher surface area thus require more binder to hold sample in shape. Conspicuously, the addition of latex binder has blocked most of the pores of the BHE-SW sample, as a result, the absorption performance has been suppressed.

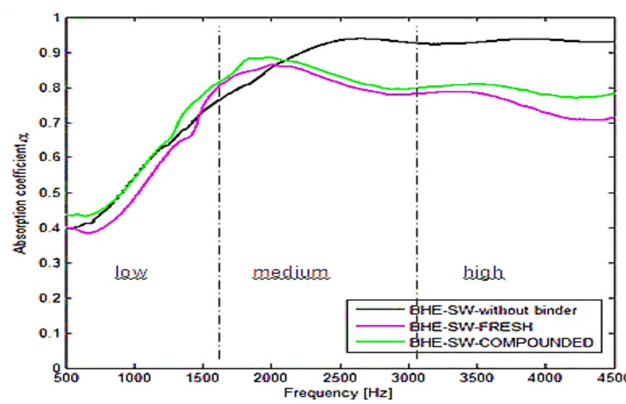


Figure 4 Sound absorption coefficient of BHE-SW using no/fresh/compounded latex binder

Unlike BHE-SW, the introduction of latex binder to BHE-BM and SPE-SW STL fiber showed positive results. As depicted in Figure 5 and Figure 6, the presence of binder in sample has increased the absorption coefficient and peaks were gradually shifted to medium frequency range. A possible explanation for this is that the binder improves the stiffness of fibers. Consequently, sound wave can be effectively dissipated as it travels through the material. As supported by Figure 3, it was shown that sample made of coarser STL fiber exhibits more porosity thus allowing more sound waves to enter the material and dissipated by friction [17].

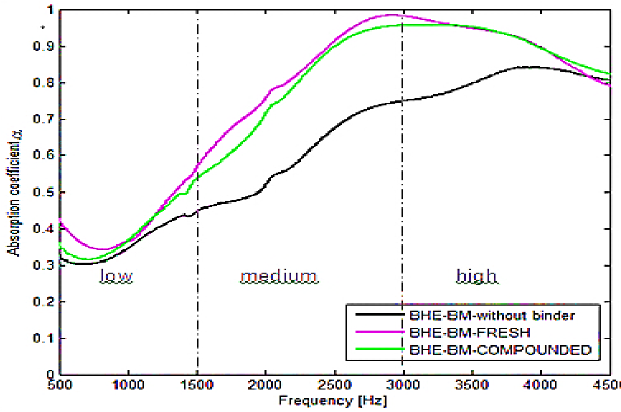


Figure 5 Sound absorption coefficient of BHE-BM using no/fresh/compounded latex binder

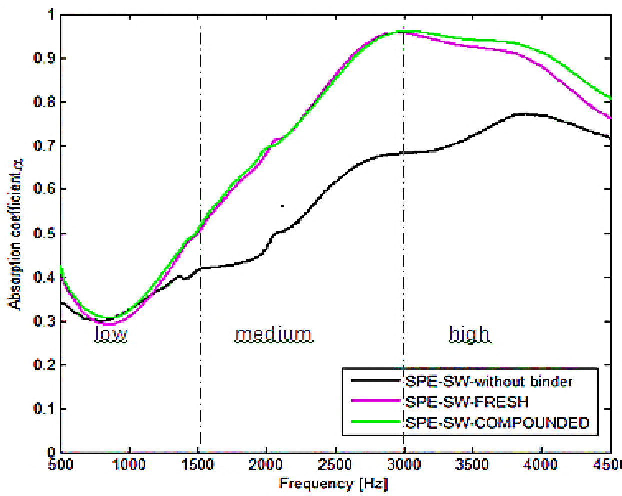


Figure 6 Sound absorption coefficient of SPE-SW using no/fresh/compounded latex binder

Particularly, BHE-SW (finest fiber) predominated among other fibers in term of frequency range. It is observed that the maximum sound absorption coefficient of all BHE-SW samples occurred at relatively lower frequency range. Thus it can be inferred that the finest STL fiber is preferable to be applied in absorbing lower frequency sound.

According to Table 5, the maximum absorption coefficients between samples using fresh latex and compounded latex for each grade of STL fiber were almost similar. Interestingly, each plot shown in Figure 4, 5 and 6 demonstrate almost same trend when different latex binder was used, which indicating that the maximum absorption took place at same frequency range. Thus, it can be deduced that different types of latex binder did not impose significant effect on the acoustic performance of STL fiber.

4.0 CONCLUSION

In conclusion, it has been demonstrated that the fibers which extracted from the by-product of tea plant shows potential as an eco-friendly sound absorbing material. As shown from the above study, it was discovered that the finest STL fiber gives highest acoustic performance among other STL fibers. In addition, the finest fiber got the edge among three STL fibers as it performs better in lower frequency range, which is more susceptible for noise pollution. However, the introduction of binder had slightly suppressed the acoustic performance of the finest diameter. Conversely, the addition of binder has improved the acoustic property of the coarser STL fiber because the binder adds stiffness to the samples, causing the incident sound wave to be absorbed and converts to heat energy more effectively. From the above study, it is also possible to conclude that the types of latex binder do not have effect on the sound absorption properties of STL fibers.

Acknowledgement

The authors gracefully acknowledge the Ministry of Higher Education of Malaysia for their financial support under grant number FRGS/1/2014/TK04/UTEM/01/1 and also Faculty of Manufacturing Engineering and Faculty of Mechanical Engineering of Universiti Teknikal Malaysia Melaka for kind contributions on test facilities.

References

[1] Hung, T. C., Huang J. S., Wang, Y. W. and Lin, K. Y. 2014. Inorganic Polymeric Foam as a Sound Absorbing and Insulating Material. *Construction and Building Materials.* 50: 328-334.

[2] Jacobsen, F., Torben, P., Holger, R. J., Christian,G. A. and Mogens,O. 2011. Fundamentals of Acoustics. *Fundamentals of Acoustics.* 1(31200): 560.

[3] Zhang, C., Li, J., Hu, Z., Zhu, F. and Huang, Y. 2012. Correlation Between the Acoustic and Porous Cell Morphology of Polyurethane Foam: Effect of Interconnected Porosity. *Materials & Design*. 41: 319-325.

[4] Ahsan, Q., Ching, C. P., Yuhazri, M. and Yaakob, B. 2014. Physical and Sound Absorption Properties of Spent Tea Leaf Fiber Filled Polyurethane Foam Composite. *Applied Mechanics and Materials.* 660(2014): 541-546.

[5] Alessandro F. D. and Pispola, G. 2005. Sound Absorption Properties of Sustainable Fibrous Materials in an Enhanced Reverberation Room. *The 2005 Congress and Expostion on Noise Control Engineering*. Rio de Janeiro, Brazil. 07-10 August 2005. 1-10.

[6] Claramma, N. M. and Mathew N. M. 1997. Effect of Temperature on Sulfur Prevulcanization of Natural Rubber Latex. *Journal of Applied Polymer Science*. 65(10): 1913-1920.

[7] Harahap, H. 2006. A Comparative Study on The Effect of Compounded Latex and Diffusion of Curatives on Tensile Properties of Natural Latex Films. *Jurnal Teknologi Proses*. 5(1): 27-30.

[8] Zulkifli, R., Nor, M. J., Tahir, M. F., Ismail, A. R. and Nuawi, M. Z. 2008. Acoustics Properties of Multi-layer Coir Fibers Sound Absorption Panel. *Journal of Applied Sciences.* 8(20): 3709-3714.

[9] Fatima, S. and Mohanty, A. R. 2011. Acoustical and Fire-Retardant Properties of Jute Composite Materials. *Applied Acoustics.* 72(2-3): 108-114.

[10] Karlinasari, L., Hermawan, D., Maddu, A., Martianto, B., Lucky, I.K., Nugroho, N. and Hadi, Y.S. 2012. Acoustical Properties of Particleboards Made From Betung Bamboo (Dendrocalamus asper) As Building Construction Material. *BioResources*. 7(4): 5700-5709.

[11] ALRahman, L. A., Raja, R. I. and Rahman, R. A. 2013. Experimental Study on Natural Fibres for Green Acoustic Absorption Materials. *American Journal of Applied Sciences.* 10(10): 1307-1314.

[12] Ersoy, S. and Küçük, H. 2009. Investigation of Industrial Tea-Leaf-Fibre Waste Material for Its Sound Absorption Properties. *Applied Acoustics.* 70(1): 215-220.

[13] ASTM C522. Standard Test Method for Airflow Resistance of Acoustical Materials. 2003.

[14] Davern, W. A. 1977. Perforated Facings Backed With Porous Materials As Sound Absorbers-An Experimental Study. *Applied Acoustics.* 2(10): 85-112.

[15] Ahsan, Q., Shim, F., Putra, A. and Subramonian,S. 2015. Analysis of Sound Absorption Properties of Spent Tea Leaf. *International Design and Concurrent Engineering Conference 2015*. Tokushima, Japan. 6-7 September 2015. 1-10.

[16] Koizumi, T., Tsujiuchi, N. and Adachi, A. 2002. The Development of Sound Absorbing Materials Using Natural Bamboo Fibers. *High Performance structures and Composites*: 157-166.

[17] Seddeq, H. 2009. Factors Influencing Acoustic Performance of Sound Absorptive Materials. *Australian Journal of Basic and Applied Sciences.* 3(4): 4610-4617.