VOL. 11, NO. 6, MARCH 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

A REVIEW ON PHYSICAL FACTORS INFLUENCING ABSORPTION PERFORMANCE OFFIBROUS SOUND ABSORPTION MATERIAL FROM NATURAL FIBERS

Emedya Murniwaty Samsudin[1], Lokman Hakim Ismail[2] and Aeslina Abdul Kadir[3]
[1]Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia
[2]Department of Design Engineering and Architecture, Universiti Tun Hussein Onn Malaysia
[3]Department of Water and Environmental Engineering, Universiti Tun Hussein Onn Malaysia
E-Mail: emedya@uthm.edu.my

ABSTRACT

Noise pollution is one of the major threats in many countries that affect our quality of life. This problem can cause negative effect to human hearing, disturbing emotion as well as individual behavior. Noise can be treated and control by applying sound insulation or sound barriers at affected areas. Many studies attempt to optimize the use of natural fibers as sound insulation materials replacing readily available synthetic products in the market. Natural fibres such as rice straw, coconut coir, palm oil, tea-leaf, kenaf, hemp, bamboo, cotton, wood particle, wool and clay is biodegradable, renewable, cheap and give less potential risk to human health. Utilization of these materials as sound insulation product will give practical solutions in waste management issues. This paper review on the factors that influencing absorption performance of natural fibrous sound absorbing materials. Physical properties such as fiber thickness, density and porosity are the main factor that contributes to sound absorption performance of natural fibers. It was found that most of natural fibers are capable to absorb sound in wide range of frequencies. Thicker panels are good for low frequency application while thinner absorbent is best for high frequency. Moreover, denser materials absorbed more sound energy compared to less dense materials. Significant effect on sound absorption performance was also given by materials with less porosity compared to materials which have more pores.

Keywords: natural fibers, sound absorption, physical properties.

INTRODUCTION

Noise had become major concern in many countries such as in Rio de Janeiro, United State, Paris, United Kingdom, Norway, Hong Kong, Korea, Australia, Karachi, and Cairo where complaints on noise issue keep increasing every year (Steward *et al*., 2011). Noise has become one of the major thread to quality living besides other types of pollution such as air pollution and water pollution. Consequently, noise can give negative effects to human's psychological or physiological such as causing anger, distress, loss of hearing, increases in blood pressure, increased the heart rate, communication disturbances, changing human behaviours as well assleep disturbances (AL-Rahman *et al.,* 2012).

Among the major sources of noise in urban area are road traffic noises, noise from railways, industrial operation, recreation activities andnoise generated from construction activities. Noise become perceives in domestic environment especially for places that located near to any residential compounds, public parks or educational institutions (Kang, 2007). Since that, noise problem has become more complex and serious, thus the demand for a better environment and more diversified life style has increased. Therefore, more efficient sound absorptive materials that capable to absorb sound in wider frequency are desired (Jayamani and Hamdan 2013).

Sound absorption materials have been widely used since the past 40 to 50 years back either to reduce noise or to reduce echoes in enclosed spaces. Increase in public concern and awareness of noise pollution in daily activities consequencely increased the demand for the use of sound absorption materials as noise barrier. Sound absorption materials could soften the acoustic environment of any closed spaces by reducing the sound energy of a sound wave, and at the same time will reduce the amplitude of the reflected waves (Seddeq, 2009). Most absorption panel is placed on ceilings and walls to improved sound propagation and increase speech intelligibility (Fouladi and Nassir, 2013).

Few decades ago, asbestos, glass wool and rock wool were introduced as sound insulation materials at workplace (AL-Rahman *et al*., 2012). Recently, the most popular sound absorption materials commercially available in the market consisted of glass-fiber or mineral-fiber materials. However, those materials were believed to have negative impacts towards human health (Ballagh, 1996), (Wassilieff, 1996), (Nor, Jamaludin, and Tamiri, 2004), (Zulkifli, Zulkarnain, and Nor, 2010) such as effecting human respiration and eyes (Zulkifli *et al*., 2010) or causing skin irritation when in contact with human (Alessandro and Pispola, 2005). The growing concern on the potential health effect from the used of glass and mineral fibers has creates an oppurtunity for natural fibers to be developed as alternative sound absorption materials which is safer and with less impact to human and the surrounding environment.

ARPN Journal of Engineering and Applied Sciences

SOUND ABSORPTION MATERIALS

Introduction to fibrous sound absorption materials

In general, sound absorbing materials can be used for many purposes such as to reduce noise level, to reduce reverberation time or to eliminate echoes as well as to prevent sound from being trapped by concave surfaces. Sound absorption performance is describes as Sound Absorption Coefficient (SAC) or represented byGreek letter alpha (α). The value of αranging from 0 to 1, where α=0shows the total rejection on sound absorption while α=1 signified for complete sound absorption (Lechner, 2012).

There are three types of devices in used forsound absorption which arefibrous materials, panel resonators and volume resonators. Those devices absorb sound by changing the sound energy into heat energy. However, fibrous materials and panel resonators are the two type of sound absorbent devices normally used in building. (Lechner, 2012), (Stein and Reynolds, 2000).

Fibrous absorbent is the most popular type of sound absorbent commercially available in the market(Arenas and Crocker, 2010). Fibrous materials normally composed of a set of continuous filaments and usually produced in rolls or in pieces with different properties. This materials contained tiny air passageways that allows air to move throughit. When sound energy strikes the fibers, frictional drag between the moving air and the fibers filaments forced the air molecules to vibrate and cause it to lose its energy. Simultaneously, most fibrous material absorb energy by scattering the energy from the fibers followed by vibration of the individual fibers. Both reaction indicate the absorbent mechanism which causing reduction of sound energy (Alessandro and Pispola, 2005). However, the amount of energy absorb is highly depends on the physical properties of the fibers such as thickness, density, porosity and air flow resistivity (Stein and Reynolds, 2000).

Fibrous material can be classified into two different type, synthetic (artificial) fibers or natural fibers (Arenas and Crocker, 2010), (Berardi and Iannace, 2015). Cellulose fibers, mineral fibers and and polymer base materials such as fiber glass, mineral and glass wool are among synthetic fibers, while animal wool and fur felt; and vegetables or plant fibers such as cotton, kenaf, hemp and wood are among natural fibers.

Since 1970s, mineral fiber and glass wool are two types of synthetic materials that are widely used as thermal insulation and sound absorption material. Those materials are very popular due to its high performance and low cost. However, recent global warming issues, green house gases emmission and increase in public awareness on the health effect and pollution created from the product life cycle has lead consumers to find an alternative materials from natural or recycled products which is more environmental friendly with less contamination process (Arenas and Crocker, 2010).

Factors influencing absorption performance

Research on the used of natural fibers as sound absorption materials was done by many researchers for decades (Ballagh, 1996), (Wassilieff, 1996), (Yang *et al*., 2003), (Koizumi *et al*., 2002), (Alessandro and Pispola 2005), (Zulkifli *et al*., 2008), (Ersoy and Küçük 2009), (Hosseini Fouladi *et al*., 2010), (Abdullah Y., Putra A. 2011), (AL-Rahman et al., 2012), (Jayamani and Hamdan 2013), (Fouladi and Nassir 2013), (Berardi and Iannace 2015). Among the factors influencing acoustic performance of sound absorptive materials are fiber size, air flow resistivity, porosity, tourtuosity, thickness, density, compression, surface impedance, placement or position of sound absorptive material and performance of sound absorptive materials (Seddeq, 2009). Nevertheless, this paper only reviewed three physical factors influencing absorption performance of natural material; thickness, density and porosity.

Thickness

Thickness of absorbent material is one of the main parameter that influence the absorption performance. (Stein and Reynolds, 2000), concluded that absorption by absorbent material are normally higher at high frequency than low frequency. Besides, amount of absorption is not necessarily propotional to thickness, and it is depending on the type of materials and the method of installation. However, thicker block could give αvalue more than 1.0 and thicker absorbent are better for absorption at low frequency than at higher frequency range.

(Berardi and Iannace, 2015), recently investigatingthe sound absorption coefficient of few natural fibers including kenaf, wood, hemp coconut, cork, cane, cardboard and sheep wool. Samples were prepared in different thickness ranging from 30 mm up to 100 mm thick for acoustic measurement. The measurement results were later compared with prediction of sound absorption according to Delany-Bazley model to know the difference between measured and prediction value. Measurement on the noise reduction coefficient (NRC) of the fibers samples were made based on arithmatic average of the sound absorption coefficient of the material at frequency 125Hz, 250Hz, 500Hz, 1000Hz and 2000Hz. Kenaf samples were prepared in two different thickness 40mm and 60mm thick. Their main finding shows that, thicker kenaf samples tend to absorb more sound compared to thinner samples at all frequencies. The NRC value obtained for 60mm and 40mm kenaf sample are 0.7 and 0.55, respectively. The result for acoustic measurement of 30mm thick mineralized wood and 60mm thick wood fibers samples was also done to obtain the NRC value. Wood fibers with 60mm thickness tends to absorb more sound energy throughout the tested frequencies. The sound absorption value consistently increased as the frequency increased for 60mm thick wood fiber while slightly loweramount of absorption was recorded for 30mm thick mineral wool sample. The highest sound absorption coefficient for 30mm thick hemp was recorded at 2000Hz

ARPN Journal of Engineering and Applied Sciences

with value of 0.7. Moreover, for 50mm and 100mm thick coconut fiber, thicker samples also absorbed more sound energy compared to thinner sample. The 100mm thick coconut fiber exhibts peak absorption 0.94 at while 50mm thick sample achieved maximum absorption 0.79 at 2000Hz.

The cane samples were prepared using three types of shredded materials, solely wooden parts, mixed composed of wooden parts and the bark, and only bark, in two different thickness 40mm and 80mm. Result shows that the thicker samples of those three types of cane absorbed more sound compared to thinner samples. Its sound absorption value increased when as the frequency increased. The highest NRC achieved by 80mm thick solely bark sample with value of 0.6. Finally, samples made of sheep wool at 40mm and 60mm thick also shows constant increament in sound absorption coefficient throughout the tested frequencies. The thicker samples also absorbed more sound especially at frequency 1000Hz and 2000Hz. The maximum absorption value for 60mm sample is 0.95 at 1000Hz while for 40mm thick sheep wool sample, the maximum SAC is 0.94 at 2000Hz.

(Alrahman *et al*., 2014) compared sound absorption performance between date palm fiber (DPF) and oil palm fiber (OPF) at two different thickness, 30mmand 50mm. Increasing the fiber thickness significantly increased the sound absorption performance of both fibers. However, as the absorption performance increased, the peak frequencies of both fibers shifted from high frequency to lower frequencies reigon. DPFshows the highest sound absorption performance compared to OPF. Maximum absorption for 30mm and 50mm thick DPF exhibits 0.83 and 0.93 respectively at 2381-2809Hz and 1365Hz, while for OPF, the peak absorption were 0.59 and 0.75 at frequencies 3225-3713Hz and 1947-2178Hz for each 30mm and 50mm OPF fiber thickness.

(Masrol *et al*., 2013), investigated sound absorption characteristics of palm oil male flower spikes fiber (POMFS)reinforced with polyutherene composite at different thickness 8mm, 25mm and 35mm. Samples were preparedin five different POMFS:PU proportion 5:95, 10:90, 15:85, 20:18 and 25:75.The highest SAC for 5% POMFS achieved by 25mm thick panel with 0.36 at 5700Hz. As for 10% POMFS, the highest SAC is 0.37 at 6000Hz achieved by 8mm thick panel while for 15% POMFS, the highest absorption is 0.86 achieved by 25mm thick sample. Moreover, 8mm thick samples with 20% and 25% POMFS exhibits maximum absorption value of 0.78 and 0.8 at the same frequency of 4100Hz.

(Fouladi and Nassir, 2013), utilizing Malaysian natural fibers as sound absorption. The study use coconut coir, corn, grass and sugar cane fibers in two different thickness 1cm and 2cm. From the acoustic mesurements made on those fibers, it was found that sound absorption coefficient of those fibers increase as the thickness of the fibers increased. SAC of corn fiber increase from 0.46 at 4000Hz for 1cm thick corn fiber to 0.97 at frequency 2000Hz for 2cm thick corn fiber. It was found that the peak absorption of corn fiber shifted from higher frequency range to lower frequency range as the fiber thickness increased. Sample made of corn fiber achieve peak absorption of 0.7 at frequency 3000Hz for 1cm thick corn fiber. However, different characterisics is shown where the peak frequency shifted from lower range to higher frequency range for 2cm thick corn fiber. SAC for 2cm corn fiber is 0.9 at 4000Hz. Peak absorption of 2cm grass fiber shows large improvement compared to 1cm grass fiber. Its sound absorption value improved from 0.46 for 1cm to 0.98 for 2cm thick sample. Despite of that, the peak frequency shifted from high frequency range to lower frequency range as the SAC value improved. Moreover, this research also investigated SAC of sugar cane fiber. It was found that there is no changes on its peak absorption value for both thickness. The peak frequency for sugar cane shifted from higer frequency range to lower frequency range as their thickness increased. Maximum absorption of sugar cane is 0.88 for both samples.

Research by (AL-Rahman *et al*., 2012) also investigating on the effect of thickness layer and compression of innovative material from date palm fiber (DPF) on sound absorption. Samples with different thickness of 20mm, 30mm, 40mm and 50mm were tested under two different measurement tube; low and high frequency. Absorption coefficient for low frequency increased with increase in sample thickness. However, different trends were shown in high frequencies measurement. Maximum absorption for 20mm thick fiber is 0.64 at 3884Hz, while 30mm thick sample shows peak absorption of 0.83 in between 4978Hz to 5000Hz. Moreover, maximum acoustic absorption for 40mm and 50mm thick DPF achieved 0.84 and 0.86 in between 4950Hz to 5000Hz.

On the other hand, (Zulkifli *et al*., 2010) in his study is focusing onthe effect of porous layer backing (PLB) and perforated panel (PP) on different thickness of Coconut Coir Fiber (CCF) at 10mm and 20mm. Thicker samples absorbed more sound compared to thinner samples. The peak absorption of 20mm CCF samples without PLB or PP achieved 0.83 at 3784 Hz, while 10mm samples exhibits maximum absorption of 0.39 at 5000Hz. Nonetheless, when the samples were backed with a layer of WCC, both samples shows significant increase on sound absorption throughout the tested frequencies. Maximum absorption for 10mm CCF with WCC layer backing achieved peak NAC of 0.96 at 3800Hz while 20mm CCF with WCC layer backing achieved 0.97 NAC at frequency ranging from 2750Hz to 2825Hz. When PP attached to the samples, the peak absorption coefficients were shifted from higher frequency range to lower frequency range and consistant absorption was shown throughout the tested frequencies.

Impedance tube measurement done by (Ersoy and Küçük, 2009) on tea-leaf-fiber (TLF) samples with different thickness (10mm, 20mm and 30mm). Result shows that thicker samples absorbed more sound energy compared to thinner samples. The 10 mm thick TLF

ARPN Journal of Engineering and Applied Sciences

achieve maximum SAC of 0.26 at frequency ranging from 4000Hz to 6300Hz. For sample with 20mm and 30mm thick, a linear increase in sound absorption value was shown throughout the tested frequency. Result for 20mm thick of TLF sample exhibits its peak absorption of 0.60 at 6300Hz while 30mm TLF sample achieve 0.7 SAC at 5600Hz. However, when10mm TLF backed with woven cotton cloth (WCC), the results shows gradual increase in sound absorption. Conversely, for thicker samples, the SAC value shows gradual increase at lower frequency reigon but thendrop after reaching 2000Hz- 3000Hz. This shows that by backing on thicker TLF samples (20mm and 30mm) will not significantly improved its sound absorption performance at higher frequency reigon.

Research by (Koizumi *et al*., 2002) is emphasizing on the sound absorption coefficient of three different thickness (25mm, 50mm and 75mm) of bamboo fibers (BF). Hefound that when the thickness of the samples increases, the sound absorption will also increased. Thicker BF with 75mm thickness shows peak absorption approximately 0.98 at frequency ranging from 700Hz to 1000Hz. Results for other samples, with50mm and 25mm thickness ofBF exhibits their peak absorption at higher frequency reigon, approximately 0.96 in SAC in between 1400-1500Hz for 50mm and approximately 0.89 in between 2800-3000Hz for 25mm thick sample. Result from this study concluded that thicker BF absorbed more sound at lower frequency reigon while thinner sample is good in sound absorption for higher frequencies.

Table-1 summarized on the effect of thickness on sound absorption performance of natural fibers recently done by reserchers all over the world.Similarity in patterns of absorption performance can be seen from all above research where most of thicker samples were found capable to absorbed more sound at lower frequency reigon while thinner samples tends to absorbed more at higher frequency reigon. Thicker samples absorbed more sound due to longer travel distance by the impinged wave which causing it to loses more energy (Alrahman *et al*., 2014).

Table-1. Summary result on the effect of thickness on sound absorption coefficient of natural fibers.

Researcher	Natural fiber material	Sample Thickness (mm)	Maximum SAC	Peak Frequency (Hz)
Berardi and Iannace, 2015	Kenaf, Wood, Hemp, Coconut, Cork, Cane, Cardboard and Sheep wool	Range from 30mm to 100mm thick	0.94 (40mm kenaf) 0.99 (60mm kenaf) 0.4 (30mm wood) 0.91 (60mm wood) 0.7 (30mm hemp) 0.94 (100mm coconut) 0.79 (50mm coconut) 0.86 (30mm cork) 0.58 (40mm mixed cane) 0.68 (80mm mixed cane) 0.47 (40mm wooden cane) 0.66 (80mm wooden cane) 0.64 (40mm bark cane) 0.89 (80mm bark cane) 0.66 (100mm cardboard) 0.94 (40mm sheep wool) 0.95 (60mm sheep wool)	2000 (40mm kenaf) 1000 (60mm kenaf) 2000 (30mm wood) 2000 (60mm wood) 2000 (30mm hemp) 2000 (100mm coconut) 2000 (50mm coconut) 2000 (30mm cork) 2000 (40mm mixed cane) 2000 (80mm mixed cane) 1000 (40mm wooden cane) 2000 (80mm wooden cane) 1000 (40mm bark cane) 2000 (80mm bark cane) 2000 (100mm cardboard) 2000 (40mm sheep wool) 1000 (60mm sheep wool)
Alrahman et *al*., 2014	Date Palm Fiber (DPF) and Oil Palm Fiber (OPF)	30 and 50	0.83 (30mm DPF) 0.93 (50mm DPF) 0.59 (30mm OPF) 0.75 (50mm DPF)	2381-2809 (30mm DFF) 1365 (50mm DPF) 3225-3712 (30mm OPF) 1947-2178 (50mm OPF)
Masrol *et al*., 2013	Palm Oil Male Flower Spikes (POMFS)	8, 25 and 35	0.80(8mm) 0.86 (25mm) 0.76 (35mm)	4103 (8mm) 2053 (25mm) 1603 (35mm)
Fouladi & Nassir, 2013	Coconut Coir (CCF), Corn (CF), Grass (GF), Sugar Cane (SCF)	10 and 20	0.46 (1cm CCF) 0.97 (2cm CCF) 0.70 (1cm CF) 0.90 (2cm CF) 0.46 (1cm GF) 0.98 (2cm GF)	4000 (1cm CCF) 2000 (2cm CCF) 3000 (1cm CF) 4000 (2cm CF) 4000 (1cm GF) 2000 (2cm GF)

ARPN Journal of Engineering and Applied Sciences

			0.88 (1cm SCF) 0.88 (2cm SCF)	4000 (1cm SCF) 1000 (2cm SCF)
AL-Rahman *et al.*, 2012	Date palm fiber (DPF)	20, 30, 40 and 50	0.64 (20mm) 0.83 (30mm) 0.84 (40mm) 0.86 (50mm)	3884 (20mm) 4978-5000 (30mm) 4950-5000 (40mm) 4950-5000 (50mm)
Zulkifli *et al.*, 2010	Coconut coir fiber (CCF)	10 and 20	0.39 (10mm) 0.83 (20mm)	5000 (10mm) 3784 (20mm)
Ersoy & Küçük, 2009	Tea-leaf fiber (TLF)	10, 20 and 30	0.26 (10mm) 0.6 (20mm) 0.7 (30mm)	4000-6300 (10mm) 6300 (20mm) 5600 (30mm)
Koizumi *et al.*, 2002	Bamboo Fiber (BF)	25, 50 and 75	± 0.89 (25mm) ± 0.96 (50mm) ± 0.98 (75mm)	2800-3000 (25mm) 1400-1500 (50mm) 700-1000 (75mm)

Density

Density of material is one of the most important factor that influence the sound absorption behavior of the material (Seddeq, 2009). In general, the more fiber content per unit area will cause larger density of the material. Materials with larger density normally will absorbed more sound energy due to more surface frictional between the sound wave and the fiber elements. Thus will increase the sound absorption coefficient of the material.

Recent study by (Berardi and Iannace, 2015)also investigate the effect of density on sound absorption coefficient of natural fibers. Kenaf fiberswere prepared in two different density 50kg/m^3 and 100kg/m^3. At the same thickness, denser kenaf fiber was obserbed to have higher sound absorption value to be compared to less dense kenaf sample throughout the tested frequency. The highest SAC recorded by50kg/m^3 kenaf fiber achieved 0.90 at 2000Hz, while for 100kg/m^3 sample achived 0.99 SAC at 1000Hz. Other than kenaf, wood fibers were also prepared in two different density based on two different binder and manufacturing process. The first type is fiber wood panel which having density of 100kg/m^3 while the other is mineralized wood panel with density 2.6 times higher than fiber wood sample. Measurement result shows that 100kg/m^3 wood fiber sample absorb more sound energy compared to 260kg/m^3 mineralized wood panel. The maximum absorption for wood fiber is 0.91 at 2000Hz while mineralized wood achieve maximum value of 0.4 at the same frequency. Mineralized wood is considered as non-fibrous material because this material is compact and dense. Therefore, itcan only absorb less sound energy due to its low porosity. Furthermore, this study also examines the sound absorption coefficient of hemp fiber or scientificially known as cannabis sativia. Hemp was known as a low quality fiber for the textile hemp which cannot be used in textile application. This research used hemp fiber with density 50kg/m^{3}and result show that its maximum absorption is 0.7 at 2000Hz. Besides, (Berardi and Iannace, 2015) also investigate the sound absorption for coconut fiber with density 60kg/m^3. Result shows that maximum absorption achieved by coconut fiber is 0.94 at 2000Hz. Eventhough the density of coconut fiber is less than wood fiber and 10kg/m^3 more than hemp, but its sound absorption capability is much more better than those two fibers materials. Measurement of cork panel with density100kg/m^3 achieved maximum absorption value of 0.86 also at 2000Hz while cardboard with density 140kg/m^3 exhibits lower SAC of 0.66 at the same frequency compared to cork. Cane samples in this study were prepared in three different density; 400kg/m^3 for mixed samples, 470kg/m^3 for wooden cane and 145kg/m^3 for bark cane. Maximum sound absorption of mixed cane is 0.68 at 2000Hz, wooden cane is 0.66 while bark cane is 0.89 also at frequency 2000Hz. Finally, cardboard with density of140kg/m^{3}and sheep wool with density of 40kg/m^3 achieved peak absorption of 0.66 at 2000Hz for cardboard and 0.95 at 1000Hz for sheep wool.

(AL-Rahman *et al.*, 2012) also observed acoustic absorption of date palm fiber (DPF) in different density. The research used DPF samples with density ranging from 4.76kg/m^3 to 11kg/m^3 to obtain the effect of materials density on sound absorption. The samples were classified into two, higher density group for samples holding 10kg/m^3 and 11kg/m^3, and low density group for samples having 4.76kg/m^3, 7.15kg/m^{3}and 9.2kg/m^3. It was found that increase in density significantly contributes to higher sound absorption at higher frequency range. DPF with density 11kg/m^{3}achieved peak absorption of 0.83 at 2000Hz while for 10kg/m^3 achieved 0.6 in SAC at the same frequency. However, low density samples group consist of samples with densities 4.76kg/m^3, 7.15kg/m^{3}and 9.2kg/m^3, maximum SAC is 0.84 between 2443.75Hz to 2587.5 Hz.

Tea-leaf fiber (TLF) having three different densities were tested using impedance tube for two michrophone transfer function method by (Ersoy and Küçük, 2009). Samples were prepared with density ranging from 25.35kg/m^3 to 27.5kg/m^3. Results from this study show increasing in material's density causing its SAC value to increased. Maximum absorption achieved by the denser sample with SAC value of 0.7 at 5600Hz. A linear increase in SAC is shown by sample with density

ARPN Journal of Engineering and Applied Sciences

25.35kg/m^3 where the peak absorption achieve 0.6 at 6300Hz. However, low performance can be seen for sample having density of 25.358kg/m^3 compared to sample with density of 25.35kg/m^3.SAC of the lowest density sample is constant at 2.6 from 4000Hz until 6300Hz.

(Koizumi *et al.*, 2002) developed new sound absorption material from bamboo fibers. Besides looking on thickness effect on SAC, this research also observed the effect of different density of BF on sound absorption. Bamboo fiber samples were prepared with densities of 80kg/m^3, 120kg/m^{3}and 160kg/m^3. Results show that as the density of the material increase, the SAC value also increased at middle and high frequency range. When the number of bamboo fibers increase per unit area of the sample, it will result in more surface friction between sound energy and fiber elements which lead to higher SAC. Besides, this research also tested high density bamboo fiber board (HDBFB) which formed using 10% of binding materials under hot press molding. The density of HDBFB are 400kg/m^3, 500kg/m^3, 600kg/m^{3}and 700kg/m^3, and the HDBFB samples were tested by incorporating 50mm thickness of air space gap. It was found that the SAC value for HDBFB decrease as its density increased at high frequency range. This is due to cavities among fibers are buried as it become denser and causing less frictional effect between fibers and sound energy. However the value of SAC among HDBFB samples are considered high from mid to high frequency range.

Most of denser material absorb more sound energy compared to less dense materials. However, in some cases, materials with higer density will absorb less sound energy due to non-fibrous characteristics of the materials. Materials that are more compact and dense are low in porosity which significantly effects its sound absorption performance. Summary of recent study on the effect of density on SAC is shown in Table-2.

Table-2. Summary result on the effect of density on sound absorption coefficient of natural fibers.

Researcher	**Natural fiber material**	**Density** (kg/m^3)	**Maximum SAC**	**Peak Frequency** (Hz)
Berardi & Iannace 2015	Kenaf, Wood, Hemp, Coconut, Cork, Cane, Cardboard and Sheep wool	Kenaf (light=50 and denser=100) Wood (fiber=100 and mineralized=260) Hemp (50) Coconut (60) Cork (100) Cane (mixed=400, wooden =470, bark=145) Cardboard (140) Sheep wool (40)	0.9 (light kenaf) 0.94 (denser kenaf) 0.91 (fiber wood) 0.4 (mineralized wood) 0.7 (hemp) 0.94 (thick coconut fiber) 0.79 (50mm coconut) 0.86 (cork) 0.68 (mixed cane) 0.66 (wooden cane) 0.89 (bark cane) 0.66 (cardboard) 0.95 (sheep wool)	2000 (light kenaf) 2000 (denser kenaf) 2000 (fiber wood) 2000 (mineralized wood) 2000 (30mm hemp) 2000 (thick coconut fiber) 2000 (50mm coconut) 2000 (cork) 2000 (mixed cane) 2000 (wooden cane) 2000 (bark cane) 2000 (cardboard) 1000 (sheep wool)
AL-Rahman *et al.* 2012	Date palm fiber (DPF)	range from 4.76kg/m^3 to 11kg/m^3	0.83 (11kg/m^3) 0.6 (10kg/m^3) 0.84 (4.76kg/m^3 to 9.2kg/m^3)	2000Hz (11kg/m^3 and 10kg/m^3) 2443.75 to 2587.5 Hz (4.76kg/m^3 to 9.2kg/m^3)
Ersoy & Küçük 2009	Tea-leaf fiber (TLF)	range from 25.358 kg/m^3 to 27.5kg/m^3	0.26 (25.36 kg/m^3) 0.6 (25.35kg/m^3) 0.7 (27.5kg/m^3)	4000 to 6300 (25.358 kg/m^3) 6300 (25.35kg/m^3) 5600 (27.5kg/m^3)
Koizumi *et al.* 2002	Bamboo Fiber (BF)	80, 120 and 160 for ordinary bamboo fiber sample 400, 500, 600 and 700 for HDBFB	±0.7 (80 kg/m^3) ±0.98 (120 kg/m^3) ±0.99 (160 kg/m^3) ±0.99 (400 kg/m^3) ±0.92 (500 kg/m^3) ±0.8 (600 kg/m^3) ±0.65 (700 kg/m^3)	±2000 (80 kg/m^3) ±1600 (120 kg/m^3) ±1000 (160 kg/m^3) ±1500 (400 kg/m^3) ±800-1200 (500 kg/m^3) ±700 (600 kg/m^3) ±500 (700 kg/m^3)

VOL. 11, NO. 6, MARCH 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Porosity

Porosity is defined as the ratio of the volume of void to the total volume of the samples. Porosity of materials can be determined by any of thesethree methods; the static method, dynamic method or by a simple calculation based o the known density of fibers (Wassilieff, 1996). Porosity eventually effects the sound absorption performance of samples. According to (Stein and Reynolds, 2000), absorbency of materials will increase when theporosity increase up to 70 percent. However, when theporosity valueexceeding70 percent, the value of absorption usually will remain constant. Number, size and type of pores are among important factors to be considered in porous sound absorber. Enough pores on surface of material will allow sound wave to penetrate the porous material for maximum energy dissipation by friction (Seddeq, 2009).

(Fouladi and Nassir, 2013) in their study, have used the same compression ratio on 1cm and 2cm thick samples from coir, corn, grass and sugar cane fibers to gain different porosity. Samples were prepared in two different diameter for high frequency test and low frequency test for both thickness. An average porosity for 1cm thick samples are 91.40% (CCF), 97.67% (CF), 95.76 % (SCF) and 96.90% (GF). Moreover, 2cm thick fibers samples having porosity of 98.16%, 96.18%, 95.31% and 95.15% for CCF, CF, SCF and GF respectively. With the increased in sample thickness, the porosity of materials decreased considerably. Thus, will increase in SAC of natural fibers at lower frequency region.

In (AL-Rahman *et al*., 2012) research, latex was added and compression process was carried out to date palm fiber samples which significantly decrease the porosity of the samples at all thickness. In general, material compression will increase the tourtuosity and air flow resistivity, and significantly will decrease porosity and thermal characteristic length*(Castagnede et al*., 2000). This research made physical comparison on sound absorption between samples with and without latex and compression. Results indicated increasing trend in SAC value of date palm fiber at all thickness with low frequency region for sample with latex and compression. Two peak absorption achieved by 50mm thick DPF sample with latex and compression at high frequency region. SAC values are 0.93 and 0.99 at 1356Hz and between 4200Hz to 4353Hz respectively.

(Wassilieff, 1996) exploring the effect of porosity on sound absorption of wood based material. In his research, the wood panel used is made of *Pinnus Radiata*. This investigation used impedance tube with upper cut off frequency of 2200Hz. Porosity of materials was determined using static method, dynamic method and conventional calculation to ensure the accurancy of the porosity values. A total of four samples of *Pinnus radiata* wood fiber and wood shaving particle board with porosity of 0.85, 0.9, 0.63 and 0.4 were used to determine sound absorption performance in normal incidence. The porosity value represent 50mm thick wood fiber, 75mm thick wood fiber, 45mm thick wood fiber and 25mm thick compressed wood shaving respectively. Observation on test result in this study demonstrate that samples with high porosity absorbed more sound energy at low and high frequency reigon. Moreover, samples with porosity more than 70% absorbed more than 70% of sound energy at frequency of 500Hz and more. Sample with 0.9 porosity absorbed almost 100% of sound energy in between frequency of 800Hz to 900Hz. However, inconsistent performance in SAC was shown for samples with less than 70% porosity after reaching 500Hz. Measurement for sample with lowest porosity made of wood shaving show absorption performance less than 10% throughout the tested frequency. Summary results on the effect of porosity on sound absorption performance of natural fiber reviewed in this paper are shown in Table-3.

Table-3. Summary result on the effect of porosity on sound absorption coefficient of natural fibers.

Researcher	**Natural fiber material**	**Porosity** (%)	**Maximum SAC**	**Peak Frequency** (Hz)
Fouladi and Nassir 2013	Coconut Coir (CCF), Corn (CF), Grass (GF), Sugar Cane (SCF)	Average value for Ø100mm and Ø 28mm samples: 91.4- 1cm thick CCF 95.76 -1cm thick SCF 96.90-1cm thick GF 97.67- 1 cm thick CF 89.18-2cm thick CCF 95.15-2cm thick GF 95.31-2cm thick SCF 96.18-2cm thick CF	0.46 (1cm CCF) 0.88 (1cm SCF) 0.46 (1cm GF) 0.70 (1cm CF) 0.97 (2cm CCF) 0.98 (2cm GF) 0.88 (2cm SCF) 0.90 (2cm CF)	4000 (1cm CCF) 4000 (1cm SCF) 4000 (1cm GF) 3000 (1cm CF) 2000 (2cm CCF) 2000 (2cm GF) 1000 (2cm SCF) 4000 (2cm CF)
AL-Rahman et al. 2012	Date Palm Fiber (DPF)	Indicated by adding compression to samples	0.93 and 0.99 for 50mm thick samples	1356, and from 4200 to 4353

ARPN Journal of Engineering and Applied Sciences

		to decrease its porosity.		
Wassilieff 1996	Wood fibers (WF) and wood shaving (WS) from Pinus radiata	40% (25mm thick WS) 63% (45mm thick WF) 85% (50mm thick WF) 90% (75mm thick WF)	0.16 0.83 0.9 1.0	700 in between 600 to 700 in between 1200 to 1400 in between 600 to 800

CONCLUSIONS

It is clearly demonstrated that physical factors such as thickness, density and porosity have significant contribution on SAC of fibrous materials. Long dissipative process of viscosity and thermal conductivity of fluid inside material due to increased in thickness consequently improve the sound absorption performance. Furthermore, thick sound absorber absorbed more sound energy at lower frequency reigon while thin samples are more suitable for higher frequency application. Thus, thickness has density of materials also giving considerable effect on the performance of sound absorption. Most of the results indicated that, densier materials tends to have higher SAC value compared to less dense materials. However, the effect is also depending on the fibrous characteristic of the materials and type of fiber elements. In terms of porosity, materials with less pores normally contain more fiber elements per unit volume, which significantly increase resistance between sound energy and fiber elements. By increasing resistency, more heat will be dissipated which result in high sound absorption. However, porosity and density is closely reated. High density materials that low in porosity normally absorb less sound energy. Nevertheless, from the review, there is very little research focusing on the effect of porosity on natural materials. Therefore, more research on this matter could be investigated.

REFERENCES

Abdullah Y., Putra A., E.H.F.W.M. and A.M.R. 2011. Investigation on Natural Waste Fibers from Dried Paddy Straw as a Sustainable Acoustic Absorber. In IEEE First Conference on Clean Energy and Technology CET. pp. 311-314.

AL-Rahman, L.A. *et al.* 2012. Acoustic properties of innovative material from date palm fibre. American Journal of Applied Sciences, 9(9), pp. 1390-1395.

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, pp. 1-10.

Alrahman, L.A. *et al*. 2014. Comparison of Acoustic Characteristics of Date Palm Fibre and Oil Palm Fibre. 7(8), pp. 1656-1661.

Arenas, J.P. and Crocker, M.J. 2010. Recent Trends in Porous Sound-Absorbing Materials. Sound and Vibration, pp. 1-6.

Ballagh, K.O. 1996. Acoustical properties of wool. Applied Acoustics, 48(2), pp. 101-120.

Berardi, U. and Iannace, G. 2015. Acoustic characterization of natural fibers for sound absorption applications. Building and Environment, (July). Castagnede B., Aknine A, B.B. and T. V. 2000. Effects of compression on the sound absorption of fibrous materials. 61, pp. 3-7.

Ersoy, S. and Küçük, H. 2009. Investigation of industrial tea-leaf-fibre waste material for its sound absorption properties. Applied Acoustics. 70(1), pp. 215-220.

Fouladi, M.H. and Nassir, M.H. 2013. Utilizing Malaysian Natural Fibers as Sound Absorber.

Hosseini Fouladi, M. et al. 2010. Utilization of coir fiber in multilayer acoustic absorption panel. Applied Acoustics, 71(3), pp. 241-249.

Jayamani, E. and Hamdan, S. 2013. Sound Absorption Coefficients Natural Fibre Reinforced Composites. Advanced Materials Research, 701, pp. 53-58.

John Steward, Arline L. B, Francis Mc Manus, Niegel R. and Val Weedon. 2011. Why Noise Matters: A Worldwide Perspective on the Problems, Policies and Solutions. New York: Earthscan.

Koizumi, T., Tsujiuchi, N. and Adachi, A, (2002). The development of sound absorbing materials using natural bamboo fibers. High Performance structures and Composites, pp. 157-166.

Lechner, N. M. 2012. Plumbing, Electricity, Acoustic: Sustainable Design Methods for Architecture. New Jersey: John Willy and Sons.

Masrol, S.R., Rosdin, M.K.R. and Ibrahim, M.N. 2013. Sound absorption characteristics of palm oil male flower spikes fiber reinforced composite. International Coference on Mechanical Engineering Research, (July), pp. 1-3.

ARPN Journal of Engineering and Applied Sciences

Nor, M., Jamaludin, N. and Tamiri, F. 2004. A preliminary study of sound absorption using multi-layer coconut coir fibers. Elect. J. Tech. Acoust.

Seddeq, H. 2009. Factors influencing acoustic performance of sound absorptive materials. Australian Journal of Basic and Applied Sciences. 3(4), pp. 4610-4617.

Stein, B. and Reynolds, J. S. 2000. Mechanical and Electrical Equipment for Building. New York: John Wiley and Sons.

Wassilieff, C. 1996. Sound absorption of wood-based materials. Applied Acoustics, 48(4), pp. 339-356.

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(2), pp. 117-121.

Zulkifli, R. *et al*. 2008. Acoustic properties of multi-layer coir fibres sound absorption panel. Journal of Applied Sciences. 8(20), pp. 3709-3714.

Zulkifli, R., Zulkarnain and Nor, M.J.M. 2010. Noise control using coconut coir fiber sound absorber with porous layer backing and perforated panel. American Journal of Applied Sciences. 7(2), pp. 260-264.