A study of Acoustics Performance on Natural Fibre Composite

Musli Nizam Yahya¹, Mathan Sambu², Hanif Abdul Latif³ and Thuwaibah Mohd Junaid⁴

¹Noise and Vibration Analysis Research Group, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor,
²Dept. of Mechanical Engineering, Faculty of Engineering, Nilai University, 71800, Nilai, Negeri Sembilan, Johor.
³SI Acoustic Sdn Bhd, Seksyen U5, Bandar Pinggiran Subang, 40170, Shah Alam, Selangor.
⁴Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor

Coresponding author: musli@uthm.edu.my

Abstract. Natural fibres are fibre that can be directly obtained from an animal, mineral, or vegetable sources. Recently natural materials are becoming good alternatives for synthetic material as they provide good health to greener environment. The purpose of this study is to investigate and compare the acoustic characteristics of natural fibres; Kenaf fibre, Ijuk fibre, coconut coir and palm Oil frond. During the processing stage, each fibre is reinforced with 60:40 weight ratio of natural rubber (NR) separately. The fibres are then compressed after the natural rubber (NR) treatment into circular samples, of 28 mm and 100 mm diameters respectively. The thickness of each sample is fixed at 50mm. The acoustical performances were evaluated by using an impedance tube instrument. The frequency peak value of Kenaf is obtained in a range of 700 Hz – 800 Hz, while for coconut coir is at 1000 Hz – 1075 Hz frequency range. Palm oil frond gives high frequency at 850 Hz – 1200 Hz. However, Only Ijuk has obtained the highest frequency range of 3200 Hz – 3400 Hz. The results demonstrate that these fibres are a promising light and environment-friendly sound absorption material as they are ready to replace the common synthetic fibre.

1. Introduction
In this era, sound control in a building or in human living space has improved considerably. Following the progress, technology has improved the control of room interior’s sound quality, but at the same time, the balance of the development and application of advanced materials should also be considered. Besides that, there are some hazardous sounds that have become much more complex and serious for human life [1]. Therefore, a thin, lightweight and low-cost material that will absorb sound waves at wider frequency regions are strongly desired [1]. In common building structure industry, usage of synthetic materials for sound absorption panel are still a regular practice for them. But using synthetic material can cause pollution to the environment and health in a very short time [2]. Due to that, many researchers are interested in natural based materials rather than using synthetic materials. Fibres that can be obtained from fauna and flora are naturally bio-degradable, non-harmful and less hazardous to
human health and the environment including low safety risk in their process [2]. Moreover, in sustainable chart, natural fibres are leading. Several researches investigated the capability on the performance of natural fibres uses as acoustic absorber. Nevertheless, sound absorption properties $\alpha$, of natural fibres are not investigated much and there is very less information about them.

Many studies focused on a similar group of natural fibres, which have been discovered and suggested to be used as acoustical panel. Coconut coir fibre has good sound absorption at higher frequencies, but less value for the lower frequencies, the same goes for oil palm fibre [3][4][11]. Higher noise absorption of oil palm is due to its higher density [5]. Coir has higher absorption coefficients from middle to high frequency range of 1400 Hz to 6300 Hz that were revealed by S. Mahzan and A. A. Zaidi studies [6]. D'alessandro and Pispola [7] used Kenaf (Hibiscus Cannabinus) and blankets of recycled polyester (PET) fibres to make sound absorption panels. The acoustic properties results of both samples concluded that the absorption level is good at the frequency range of 1000 Hz to 5000 Hz with the average of 0.8. In the case study of Lindawati Ismail [8], Ijuk (Arenga Pinnata) are tested at 40 mm thickness and the obtained sound absorption coefficients were good for the medium to high frequency which is from 2000 Hz to 5000 Hz within the value range of 0.75 – 0.90. Dried paddy straw fibres are also used as a sound absorption panel by Y. Abdullah and A. Putra [9]. The result obtained was at 1500 Hz has an average absorption coefficient of 0.8 which contained carboxymethyl cellulose (CMC) as a binder. At the same time, the researcher also found that the performance at low frequencies can be increased by increasing the composition of the CMC binder [9][10].

This research aims to study about sound absorption coefficient on few selected natural fibres that are easily obtained around ASEAN countries. The chosen natural fibres are Kenaf fibre, Ijuk fibre, Palm oil frond and coconut coir. The sound absorption coefficient test samples are made of natural latex rubber as a binder and the listed natural fibre as raw materials on fixed ratio of 60:40. Acknowledged by the previous researchers, Urea formaldehyde and Polypropylene are used as reinforcing agent that contains chemical behavior. However, it could affect and pollute the environment in the long run [2][8][9][10]. So far, not many studies are done on natural sound absorption properties by using pure latex rubber as a binder. Also in this study, the thicknesses of this sample are fixed according to the global standard of acoustic synthetic panel’s thickness size, which is 50 mm. Normally an optimum level acoustic performance is found at the range between 1000-5000 Hz with the average absorption coefficient of 0.8 [2].

2. Materials Preparation

The raw fibres are obtained from local factories and farm. After chopping and crushing into average length 10-20 mm, the raw fibres that contain cellulose layer and unwanted properties are soaked in the alkaline treatment of sodium hydroxide 2% (NaOh) for 24 hours to remove this dirt. Then the fibres are heated up to 80°C for 2 hours to remove the alkaline wetness. By using the weight percentage calculation, the ratio combination of 60:40 of fibre and NR are measured in gram capacity. Both fibre and pure latex are mixed well and filled up into a cylindrical mould. The composite mould was relocated into a hot press machine which was heated up to 130°C. The pressure of the machine is initially set to 15 bars for 10 minutes. These parameters are constant for each sample. The size of the samples followed the impedance tube diameter (following ASTM E1050-09), but the thicknesses are fixed at 50 mm as shown in Figure 1 and Figure 2.
3. Normal incident measurement

The sound characteristic test of Kenaf, Ijuk, palm oil frond and coconut coir that are reinforced with pure latex are studied in this work. The testing was done using Impedance Tube Method (ITM) by applying standard two-microphone transfer function that is based on ASTM E1050-09. The small impedance tube kits consisted of a 28mm diameter tube (small tube for high frequency), a sample holder, and an extension tube of the same diameter. The large impedance tube kit consisted of a similar tubular apparatus with a diameter of 100mm (low frequency). The small and large tube setups were used to measure different acoustical parameters and later the large and small tube measurements were combined to determine the sound absorption coefficient $\alpha$, for the frequency range of 1Hz – 4500 Hz as shown in Figure 3.

4. Results and Discussion

4.1. Sound absorption coefficient of Ijuk

Samples of Ijuk fibre with and without NR were prepared for sound absorption performance testing. Every sample are recognized as 0%, 20%, 30% and 40% of NR mixed and fixed in 50mm thickness. The values of the sound absorption coefficient of each sample were illustrated in the line graph for easier observation and determination of each sample’s result. Figure 4 demonstrates the sound absorption coefficient of each sample with different percentages of NR. Almost all results that were obtained from impedance tube measurements reached optimum absorption coefficient value at low and high frequency. Even every sample’s results showed a similar pattern that is categorized in porous absorbers as claimed by author Jacobsen & Mingzhang [11]. Samples with 0% and 20% of NR on Ijuk fibre have good sound absorption coefficient compared to 30% and 40% of NR binder composition.
The sound absorption increased with frequency and reaches an optimum value at 1375 Hz. It almost reached 0.9 absorption coefficient values at a higher frequency from 3000 Hz to 4500 Hz for without NR (0%) binder sample. For other samples which contained different percentage as 20%, 30%, and 40% also gave good optimum absorption value at low and high-frequency ranges. Almost all samples gave slight drop performance at mid-range frequencies, 1500 – 3000 Hz. The absorption coefficient value dropped gradually till 0.6 then increased back after entering the high-frequency range. From the graph in Figure 4, it shows the characteristics of the sample, 20% NR is the good sound absorber at low and high frequency due to the high value for sound absorption. Even at mid-range level, this sample does not extremely drop its absorption coefficient performance compared to other samples. This sample is a good sample of membrane or panel absorber which changes over sound energy as a result of bending deformations associated with the vibrations of the panel which are excited by the incident sound [12]. Sound absorption for sample Ijuk without NR or as 0% NR has the increasing sound absorption coefficient, $\alpha$ proportional with frequency for the value around 0 to 1500Hz. It produces the highest sound absorption coefficient at value 0.92. At high frequency, the sample has approximately similar coefficient of sound absorption to the low frequency is 0.98. That means it performs well at high and low frequencies. But in mid-range frequency, the absorption coefficient dropped dramatically till 0.65 compared to samples which were prepared with NR. This finding can be used as the initial result for Ijuk fibre to compare with other samples or fibres in future work. What is fascinating in this graph is that while contrasting samples between with and without NR, samples that contain NR gave better an absorption coefficient values. The results also show that natural rubber makes the absorption coefficient value shift towards low frequency. This is due to the fact that the air trapped between porous layer and back plate creates resonance, which moves the absorption coefficient peaks towards low frequency and more poured sample moves further towards low frequency.

4.2. Sound absorption coefficient of Kenaf

The sound absorption coefficient of the sample Kenaf fibre with natural rubber mixture is determined based on various binder percentages. The results are graphically described in Figure 5. As illustrated in Figure 5, the sound absorption coefficient is frequency dependent. Kenaf sample with 0% NR result’s pattern of absorption coefficient value increased in low range frequencies at almost 0.84 and dropped slightly at mid-range frequencies. At high frequencies, it gradually increased back and reached the peak absorption coefficient of 0.91 at 3750 Hz. The trend of the result shows that Kenaf 0% NR which only contained fibre had much porous which is suitable for absorber panels. A similar observation was noticed for the Ijuk 0% NR sample in Figure 5. In contrast, samples of 20%, 30% and 40% NR give similar pattern result but different from 0% NR Kenaf sample pattern. The samples with NR contain increased massively on low range frequency before 1000Hz reached more than 0.9 absorption coefficient value. In entering the stage of mid-range frequencies, the absorption coefficient values had steep drop till between 0.7 and 0.6 then increased slowly at high frequencies. Kenaf samples with NR contain diversified from Ijuk with NR samples. Nevertheless, the increments of absorption coefficient values in low range frequency are remarkable. Among the samples, Kenaf with 20% NR reached top absorption coefficient value 0.97 at 875Hz. This significant result shows that this Kenaf sample has potential usage as low frequency’s absorber panel. Although the performances dropped at mid-range and diminished slightly at high frequency, it is still capable to be used as good absorber because the absorption coefficient range is still in high absorptive character which referring to Rossing et al. [13]. The samples of Kenaf 30% NR and 40% NR, are still capable to be used as sound absorber but poor performance at high frequency compared to Kenaf 20% NR. The reason behind these drop performances is the influence of physical properties character. Regards to this influence comparison will be examined in the upcoming section.
4.3. Sound absorption coefficient of coconut coir

Figure 5 depicts the effectiveness of NR mixture and without mix on coconut coir for acoustical performance in term of sound absorption coefficient. Similar with previous fibres containing NR mixture, Coconut coir samples labelled as 20% NR, 30% NR, 40% NR and 0% NR which contains only Coir fibre. The trend line in Figure 5 describes that panel with natural rubber addition had excellent sound absorption characteristics at low range frequency, matching to non-NR mixture contain a sample; 0% NR. Sample with Coir 20% NR, 30% NR and 40% NR accomplished the peak at 900 Hz to 1100 Hz with maximum absorption coefficient of 0.97, 0.95 and 0.95 respectively, whereas sample without binder 0% on maximum 0.90 at 4000 Hz. As noticed in Figure 4.11, 0% NR sample nearly similar like the sample of Ijuk and Kenaf 0% NR. The wave pattern with a slender drop at mid-range frequency illustrates that this sample under the porous category which damps the travelling sound wave [14]. The results of the past study by Hosseini Fouladi et al. [15] using Coir at 50mm gives the parallel result with Coir 0% NR sample in this study. Apart of it, it can concluded that Coir without any binder or composite will give the identical result even the preparation method are not the same. While comparing the result between the coconuts coir samples with NR as a binder, all the three samples’ results are different in the tiny range of differentiations. As stated earlier, all the three samples, 20% NR, 30% NR and 40% NR reached the peak of maximum absorption coefficient at low range frequency but large gaps in the range of high frequencies in-between. From that, Coconut coir sample with 20% of NR advanced in the comparison of acoustical performance while having better sound absorption coefficient value in high range frequencies than other samples. Although the Coconut coir 30% NR and 40% NR have minor poor performance compared to 20% NR, it can observed that both samples’ result shift earlier towards low range frequencies. It consequences of physical characteristics of the Coconut coir samples with NR makes the result inconstant. Concerning that influence of physical properties on samples will be analysed in the upcoming section.

4.4. Sound absorption coefficient of palm oil frond

Like previous natural fibres in this study, acoustical performance of palm oil frond is also one of the novelties in this study which intermixes with NR. Based on the several NR mixing percentages, the sound absorption coefficient of palm oil frond determined by prepared sample and it is demonstrated in Figure 5. It shows that the Palm oil frond 0% NR which the sample were only prepared with the fibre only gives optimum absorption coefficient value at low and high range frequencies. The pure palm oil frond fibre’s sample with 0% reaches optimum absorption coefficient 0.92 at 3800 Hz at high frequency. The similar result observation was noticed for the previous natural fibres; 0% NR samples...
of Ijuk, Kenaf and coconut coir. A previous study on palm oil fibre and date palm fibre by Al Rahman et al. [16] also found out the similar trend curve results for the both sample thickness at 50mm. On the other hand, results of sound absorption coefficient by samples with 20% NR, 30% NR and 40% NR of Palm oil fibre shows greater result than the 0% NR sample. Referring to Figure 5, samples made of palm oil frond with 20%, 30% and 40% get to peak 850 Hz to 1200 Hz with a maximum sound absorption coefficient of 0.98, 0.97 and 0.96 respectively. All the three samples with NR, increased towards their peak absorption coefficient with tiny range gaps only; from 100 Hz to 1000 Hz. After the low frequency while entering to mid-range, all three samples with NR mix, had slope drop performance from 0.95 averages till 0.6 absorption coefficient value. Almost 30% of absorption performance dropped and a steadily increased in high range frequency. Concerning on outline of the results, physical properties of the samples also play its influences to optimize the absorption coefficient values. All samples of palm oil frond gave good absorption coefficient but samples with NR binder gave better absorption coefficient towards low frequency. Like the previous natural fibre’s results, 20% NR sample of palm oil frond fibre have the potential to become the best selection in acoustical performance.

5. Conclusion
This study shows that by using the impedance tube test method to determine sound absorption coefficients of selected natural fibres have been successfully carried out. Samples of sound absorber have been made from Kenaf, Ijuk, coconut coir and palm oil front which went through a 2% alkaline treatment. The experiment showed that these natural fibres can be a good alternative sound absorber compared to synthetic fibres. The thickness of each 50mm natural fibre showed the optimum level of sound absorption coefficient value of more than 0.7. The performance at higher frequency can be improved by increasing the mixing ratio of fibres and binder. These will be investigated in the future work.

Acknowledgement
The author would like to thank Universiti Tun Hussein Onn Malaysia for the support of this research

References
[1] Xiang, H., Wang, D., Liua, H., Zhao, N., & Xu, J. (2013). Investigation on sound absorption properties of kapok fibers. Chinese Journal of Polymer Science, 31(3), 521–529.
[2] Abdullah, Y., Putra, A., Effendy, H., Farid, W., & Ayob, M. (2011). Dried Paddy Straw Fibers as an Acoustic Absorber: A Preliminary Study. International Journal of Renewable Energy
[3] Mwaikambo, L., & Ansell, M. (1999). The effect of chemical treatment on the properties of hemp, sisal, jute and kapok fibres for composite reinforcement. 2nd International Wood and Natural Fibre Composites Symposium 1999. 1-16

[4] Nor, M. J. M., Amin, N., Zulkifli, R., Fouladi, M. H., & Ismail, A. R. (2009). Analysis on sound absorption of natural coir fiber using delany-Bazley model, International Conference on Mechanical Engineering 2009, 26–28.

[5] Alrahman, L. A., Raja, R. I., Rahman, R. A., & Ibrahim, Z. (2014). Comparison of Acoustic Characteristics of Date Palm Fibre and Oil Palm Fibre, 7(8), 1656–1661.

[6] Mahzan, S., & Zaidi, A. A. (2010). Study on sound absorption properties of coconut coir fibre reinforced composite with added recycled rubber. International Journal of Integrated Engineering 2010.

[7] F. D’ Alessandro and G. Pispola 2005. Sound Absorption Properties of Sustainable Fibrous Materials in an Enhanced Reverberation Room. The 2005 Congress and Exposition on Noise Control Engineering.

[8] Ismail, L., Ghazali, M., Mahzan, S., & Zaidi, A. (2010). Sound absorption of Arenga Pinnata natural fiber. World Academy of Science, Engineering and Technology 2010. 601–603.

[9] Abdullah, Y., & Putra, A. (2014). Investigation on sound absorption coefficient of natural paddy fibers. International Journal of Renewable Energy Resources 3 (2013), 8-11

[10] Yang TL, Chiang DM, Chen R. Development of a novel porous laminated composite material for high sound absorption. Journal of Vibration and Control 2001, 7(5), 675–8.

[11] Jacobsen, R. & Mingzhang, F. (1993). A method of measuring the dynamic flow resistance and reactance of porous materials. Applied Acoustics, 39(4), 265-276.

[12] Sakagami, K., Kiyaman, M., Morimoto, M. & Takahashi, D. (1996). Sound absorption of cavity backed membrane: A step towards design method for membrane type of absorbers. Applied Acoustics, 49(3), 237 – 247

[13] Rossing, T.D., Moore, R.F., Wheeler, P.A., Huber, D.M. & Runstein, R.E (2009). The science of sound/ Edition 3. Addison Wesley

[14] Blackstock, D.T. & Atchley, A.A (2001). Fundamental of Physical Acoustics. The journal fo Acoustical Society of America, 109(4) 1254

[15] Hosseini Fouladi, M., Ayub, M. & Jailani Mohd Nor, M (2011). Analysis of coir fiber acoustic characteristic. Applied Acoustics, 72(1), 35-42

[16] Al Rahman, L., Raja, R.I., Rahman, R.A., Ibrahim, Z. et al. (2014). Comparison of acoustic characteristic of date palm fibre and oil palm fibre. Research Journal of Applied Science, Engineering and Technology, 7(8), 1656-1661