# ACOUSTICAL CHARACTERISTICS OF OIL PALM MESOCARP

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## ABSTRACT

Oil palm Mesocarp from oil palm tree is an abundant natural fiber which found in Malaysia. This work was carried out to investigate the sound absorption coefficient of the oil palm Mesocarp fiber also categorized as porous material. These natural fiber were intermixed with Polyurethane (PU) as binder. Various binder percentages are; 10%, 20%, 30% and 40% used. The measurement of sound absorption coefficient was done by using analytical and experimental method where Johnson-Champoux-Allard model as analytical and Impedance Tube Method experiment respectively. This study also investigated the physical properties of the prepared samples. PU compresses the fiber gaps tightly causing the pores closed and consequently resulting in lower flow resistivity and porosity. The viscous characteristic length and density were inversely towards the value of flow resistivity and porosity. It shows that increase of binder percentage produced more compacted (denser) material and thereby, stiffness of the material was affected. The result of Johnson-Champoux-Allard model predicted the absorption coefficient very well and similar to the experimental. The sample with 10% PU binder shows the greater performance in most of low to mid frequency range. However, sample with 20% PU binder reach the high value of sound absorption of 0.99 at 1000 Hz. Finally, it can be concluded that oil palm Mesocarp can be classified as sound absorption material which accomplished in this research and shows that, it's capable to be used as sound absorption panel in various applications.

**Keywords:** sound absorption, natural fiber, oil palm mesocarp, noise reduction coefficient, Johnson-Champoux-Allard.

## INTRODUCTION

There have been several studies in the literature reporting that the increasing interest in green technology is widely used to replace the synthetic fiber with agro waste and agro forest obtain materials for sound absorption purposes. Additional, natural fibers are increasingly being used in many products such in automotive, interior lining for apartments, aircraft, ducts and bio-composite products. The general reason for using natural fiber as basic material according to (Zhu et. al., 2013) was due to low density, biodegradable and low cost. Furthermore, there are a lot of advantages possessed by natural fibers where there is renewable, abundance, non-abrasive and less health and safety concern during handling and processing (Khedari *et al.*, 2003).

Regarding to environmental concerns, researchers have now driven their concern to find the replacement or renewable materials instead of producing acoustical panel using non-renewable materials. There are several product of sound absorption panels have been commercialized in the market. The common acoustical panels are made from synthetic fibers such as glass wool, rock wool and asbestos. Furthermore, (Asdrubali, 2006) identifies some of these materials known to be hazardous to our health and also contributes higher to Global Warming Potential (GWp) kg $CO_2$. In 1967, the European Council Directive stated that the synthetic fiber has some disadvantages where the fiber can lay down in the lung alveoli and cause skin itchy (European Council Directive, 1967).

Over a decade ago, the expanding of oil palm plantation was bringing Malaysia as a well-known in the producing of palm oil in the global market. About 5 million hectare of area is used as oil palm plantation. There are about 57% of total production occurs in west

Malaysia and 99% in Sabah (Malaysia Palm Oil Board, 2011). A large portion of these fibres in the nation are left abandoned. Nearly 22% of fiber created from oil palm industry declared as waste (Badri et. al., 2005). Forest Research Institute of Malaysia (FRIM) and Malaysian Palm Oil Board (MPOB) has conducting fundamental research for many years to find the potential of using oil palm residues as raw materials for various applications.

A preliminary study on acoustical performance of oil palm Mesocarp, Kenaf, Ijuk, and Coir natural fibers was investigated previously in Acoustic and Vibration Research Group laboratories at Universiti Tun Hussein Onn Malaysia by (Latif *et al.*, 2015; Sambu *et al.*, 2015). Those studies covered with the effect of air gap, thickness and different binders; Polyurethane and Latex.

Porous type sound absorbing materials are widely used in acoustical control engineering. The porous absorber is used to avoid a resonance of the air cavity. If the cavities of the resonance are not eliminated by damping, sound will pass easier though the partitions and the sound absorption will be poorer. Porous absorbers are any material where sound propagation occurs in a network of interconnected pores in such a way that viscous effects cause acoustics energy to be dissipated as heat (Cox and D'antonio, 2009). Fouladi *et al.*, (2011) study the acoustical characteristics of coir fiber as a porous material. Result described that increasing of the thickness will improve the lower frequencies. Zulkifli *et al.*, (2008) investigate the multi-layer coir fibers and his observations were done in reverberation room and simulation approach using WinFLAG[TM] as a support. Flow resistivity of porous absorption was covered depth in the literature by (Bies and Hansen, 1980; Beranek, 1992, 1971; Ingard, 1994). Their study encased an efficient review of the utilization of flow

resistance evidence and signified solution to the utility information of wide range acoustical problems.

Ballagh, 1996 discovered there are close empirical relation between bulk density, fiber diameter and flow resistivity. He proposed two empirical equations to determine flow resistivity based on the relationships. Delany and Bazley, (1970) stated that the fiber size and bulk density is the main factors influencing the flow resistivity. Miki, (1990) modified the Delany and Bazley models to make it more applicable and discussed form physical reliability. He also identify new empirical model generalized with respect to the porosity, tortuosity and the pore shape factor ratio (Miki, 1990).

However, to the best of author's knowledge, no report has been found so far using oil palm Mesocarp fiber in acoustic absorption application. The effect of various percentage binder, decides the ideal acoustic performance is additionally discovered in this research. The measurement of internal properties of porous absorbents such as flow resistivity, tortuosity, porosity, and characteristic length also will be discussed in this study.

## MATERIAL SELECTION AND PREPARATION

### Raw material
Among the alternative material resources, agricultural waste like oil palm Mesocarp is selected for the experiment, which known as lignocellulose material. The oil palm Mesocarp fibers were used for experiment and characteristics is obtained from oil palm mill after press station. Before used, the materials have to undergo several pre-treatment processes. Then the samples were prepared in cylindrical shape with two different diameters of 28mm and 100mm for high and low frequency measurement range, respectively. The samples used for this study was initially of thickness of 50 mm as shown in Figure-1.



**Figure-1.** Sample of oil palm mesocarp.

### Polyurethane
Combination of this sample, polyurethane (PU) as a binder could provide a great approach for the improvement of its mechanical properties. Until now, PU remains as one of the popular resins in composite studies and were carried out by several researchers that have been using PU as a binder in their study (Badri *et al.*, 2005;

Mahzan *et al.*, 2010; Asdrubali *et al.*, 2008; Stankevičius *et al.*, 2007). The polyol resin and maskiminate that used to prepare PU were obtained from local chemical supplier. The mixing of those chemical were formulated based on mixing ratio 1:11 that were recommended by data sheet of the chemical. Four percentages of binder samples were used to mix with the oil palm Mesocarp separately i.e. 10%, 20%, 30% and 40%.

## METHODOLOGY
Two type of model were utilized for acoustical analysis of oil palm Mesocarp fiber in normal incidence. First one was using impedance tube method; experimental method that enables to know the incident absorption coefficient and surface impedance. Secondly, the Allard & Atalla, (2009) analytical model that possible to describe the acoustical behaviour of porous material was applied. Both method were depend on five macroscopic parameter elements where flow resistivity ($\sigma$), porosity ($\varepsilon$), tortuosity ($k_s$), viscous ($\Lambda$) and thermal ($\Lambda'$) characteristics lengths. These are mainly required measurements for those involved in this research.

### Experimental measurement using impedance tube method
The impedance tube contains of two combination tube (SBS9020B "Kundt Tube"); 28mm diameter and 100mm, two 1⁄4 in microphone type GRAS-40BP for pressure microphones and GRAS-26AC for preamplifier, two channel data acquisition system 0.1 dB and SCS8100 (software). This tubes configuration represents the basis; standard system setup for sound absorption coefficient (SAC) and impedance measurements uses 2 microphones – transfer function method. The calibrator was Larson Davis CAL 200. The test performed using the ASTM E1050-98. This experiment run at Noise and Vibration Laboratory, Universiti Tun Hussein Onn Malaysia. According to user manual, recommendation using the microphone position that label with M1 and M2 or M1 and M3. The transfer function method consist the position of microphone with the ratio of pressure, $H_{12} = p(z_2)/p(z_1)$ where $z_1$ and $z_2$ are the position of the microphones. Cox and D'antonio, (2009) stated that there are restrictions on the microphone spacing. The microphone spacing must not too close or too far together; the change in pressure will be too small (lower limit) and the pressure measured at upper frequency (upper limit), respectively.

### Johnson-Champoux-allard model
This model is acknowledged to the phenomenological theoretical model of porous absorbents. Several researchers have been engaged in the generating of the models. The combination work between Johnson, (1987), Allard and Atalla (2009) and Allard and Champoux, (1993) in development of this approach produce a simple phenomenological model where the acoustic wave propagates only in the air saturated pores and the medium can be considered as porous material of rigid frame. In generally, density and bulk modulus are the

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two parameters which necessary in this model. The effective density can be expressed as follows:

$$\rho_e = k_s \rho_0 \left[ 1 + \frac{\sigma \varepsilon}{j\omega\rho_0 k_s} \sqrt{1 + \frac{4jk_s^2 \eta\rho_0\omega}{\sigma^2\Lambda^2\varepsilon^2}} \right]$$

(1)

The bulk modulus of the fluid that saturates the pores of the material is in fact the frequency dependent effective modulus of porous material with rigid skeleton. According to Johnson-Champoux-Allard model, the effective bulk modulus of the air in the material is given by:

$$K_e = \frac{\gamma P_0}{\gamma - (\gamma - 1) \Big/ \left( 1 + \frac{8\eta}{j\Lambda'^2 N_P \omega\rho} \sqrt{1 + \frac{j\rho\omega N_p \Lambda'^2}{16\eta}} \right)}$$

(2)

Where $\gamma$ is for air as the ratio of specific heat capacities ($\approx 1.4$), $\omega$ is angular frequency, $P_0$ is atmosphere pressure, $\eta$ is viscosity of air, $\rho_0$ is density represented value in air where ambiguity might otherwise arise $N_p$ is the Prandtl number can be expressed as follows:

$$N_p = \left( \frac{\delta_v}{\delta_h} \right)^2$$

(3)

$$\delta_v = \sqrt{\frac{2\eta}{\rho\omega}}$$

(4)

$$\delta_h = \sqrt{\frac{2\eta\kappa}{\rho c_p \omega}}$$

(5)

$\delta_v$ and $\delta_h$ is the thickness size of viscous and thermal boundary layer, respectively. $\kappa$ is thermal conductivity of air and $c_p$ is the specific heat capacity of air at constant pressure. In this research, the fiber structure (rigid frame) was assumed as elastic cylindrical fibers and considered the layer of porous material with identical parallel pores perpendicular to the surface (normal incidence). After determined the Equation-1 and 2, the impedance and propagation wavenumber for porous absorber is possible to determine.

The characteristic impedance $Z_c$ and the complex wave number $k$ in a pore are given by:

$$Z_c = (K_e \rho_e)^{1/2}$$

(6)

$$k = \omega \left( \frac{\rho_e}{K_e} \right)^{1/2}$$

(7)

The viscous characteristic length can be found using the following formulation:

$$\Lambda = \frac{1}{2\pi rl}$$

(8)

Where $r$ is radius of fiber and $l$ is total length of fiber. The total length of fiber can be defined as:

$$l = \frac{1}{\pi r^2 \left( \frac{\rho_{bulk}}{\rho_{fiber}} \right)}$$

(9)

Where $\rho_{bulk}$ and $\rho_{fiber}$, bulk density and density of the fiber, respectively. In this researcher, the sample will mix with the PU and the binder will covered the fiber surfaces. According to the Johnson-Champoux-Allard approach, new radius of fiber, total length of the fiber and viscous characteristic length of mixed fiber were developing as:

$$r_{mix} = r_{fiber} + (r_{fiber}\,\varepsilon)$$

(10)

$$l_{mix} = \frac{1}{\pi r_{mix}^2}$$

(11)

$$\Lambda_{mix} = \frac{1}{2\pi r_{mix}\, l_{mix}\, \varepsilon}$$

(12)

**Measurement of internal properties within porous absorbents**

There will be empirical and semi-empirical approaches to determine the characteristic parameters of the material. It is necessary to set down the five important and fundamental quantities that used to determine the acoustic behaviour of porous absorbent.

**Flow resistivity measurement**

For oil palm Mesocarp, the following empirical Equation-15 derived by Ballagh, 1996 will be implementing in this study. Ballagh, 1996 found that a close relationship between flow resistivity, bulk density and fiber diameter.

$$\rho = 490 \frac{\rho_{bulk}^{1.61}}{d_{fiber}}$$

(13)

$\rho_{bulk}$ is bulk density and $d_{fiber}$ is diameter fiber. Each fiber is assumed as perfect cylindrical shape. Fouladi

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*et al.*, (2011) has already proved that Equation-14 used to predict the flow resistivity.

## Porosity measurement

Various laboratory techniques are available to calculate porosity. The porosity of each sample can be determined as follows Equation-16 by measuring two variables where pore volume $V_p$ and bulk volume $V_b$.

$$\varepsilon = \frac{V_p}{V_b}$$

(14)

$$V_p = \frac{(W_s - W_d)}{\rho_s}$$

(15)

$$V_b = \frac{W_s - W_i}{\rho_s}$$

(16)

Where $W_s$ is weight of sample (saturated), $W_d$ is weight of the sample (dry), $W_i$ is weight of sample immersed (saturated) and $\rho_s$ is density of saturating liquid. Tortuosity of each sample will calculate following empirical equation according to Umnova, (2001). The empirical formulation is:

$$k_s = \frac{1}{\sqrt{\varepsilon}}$$

(17)

## RESULT AND DISCUSSIONS

A number of 20 single fibre, pick out from the sample were selected to obtain an average for diameter of oil palm Mesocarp. Optical microscope was be used to measure the diameter of each fibre. Mettler Toledo's analytical balance density kit tester were measured the density in accordance with Archimedes principle. In Johnson-Champoux-Allard model, viscous characteristic length was calculated based to physical properties of oil palm Mesocarp that were defined in Equation-9. While, thermal characteristic length $\Lambda' = 2\Lambda$ (Allard and Atalla, 2009; Cummings and Beadle, 1994). From the observation, the effect of after adding percentages of PU binder is not much significant to the diameter of fiber. The diameter for each fiber between with and without PU binder was 147.13 $\mu$m and 245.89 $\mu$m. The result of porosity, density, flow resistivity, tortuosity and characteristic length of oil palm Mesocarp with and without PU binder showed in Tables-1. The calculated acoustic absorptions using the impedance tube method and Johnson-Champoux-Allard model are shown in Figure-2-6.

As shown in Table-1, the result shows that the flow resistivity, porosity and tortuosity decreases by increasing the percentages of PU binder. It indicated that the PU binder had covered more hollow space within samples. The binder wads the fiber tightly causing the pores closed and consequently resulting in lower flow resistivity and porosity. The viscous characteristic length and density were inversely to the flow resistivity and porosity value. It shows that more percentages of binder produced more compacted (denser) the material and the stiffness of the material were affected. However, it also describes that the sample had high frequency viscous and thermal interaction between the fluids. In previous studies, (Badri *et al.*, 2005; Mahzan *et al.*, 2010; Asdrubali *et al.*, 2008; Stankevičius *et al.*, 2007) percentages of binder was change the physical properties of samples. This behaviour is in agreement to the fact that by adding more percentage of binder will increase the diameter of fiber and indirectly affect the other physical properties of fiber. In addition, the physical properties of sample were affecting between each other (Ingard, 1994; Cox and D'antonio, 2009; Nor *et al.*, 2010).

**Table-1.** Physical characteristics of oil palm Mesocarp with and without PU binder.

| Percentages of binder (%) | Flow Resistivity (N s m$^{-4}$) | Porosity (%) | Tortuosity | Viscous characteristic length ($\mu m$) | Thermal characteristic length ($\mu m$) | Density of the fiber (kg/m$^3$) |
|---|---|---|---|---|---|---|
| 0 | 37415.52 | 0.847 | 1.087 | 97.81 | 195.62 | 246.65 |
| 10 | 17201.09 | 0.882 | 1.065 | 582.37 | 1164.74 | 266.79 |
| 20 | 17566.14 | 0.801 | 1.117 | 613.73 | 1227.46 | 283.88 |
| 30 | 15594.63 | 0.766 | 1.143 | 629.27 | 1258.54 | 291.73 |
| 40 | 21439.48 | 0.639 | 1.251 | 700.15 | 1400.3 | 310.16 |
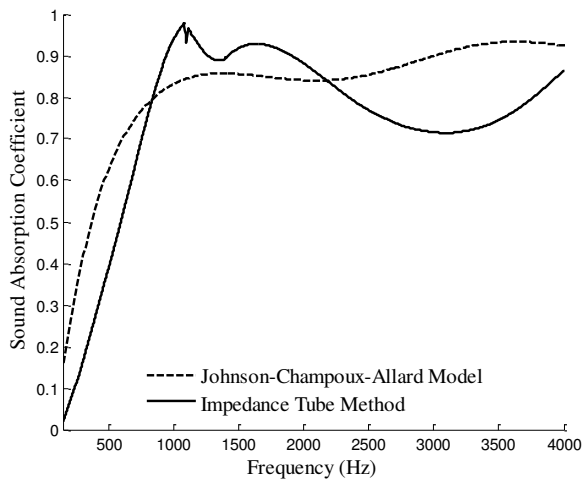
**Figure-2.** Sound absorption coefficient for sample with wt% 0 PU binder.
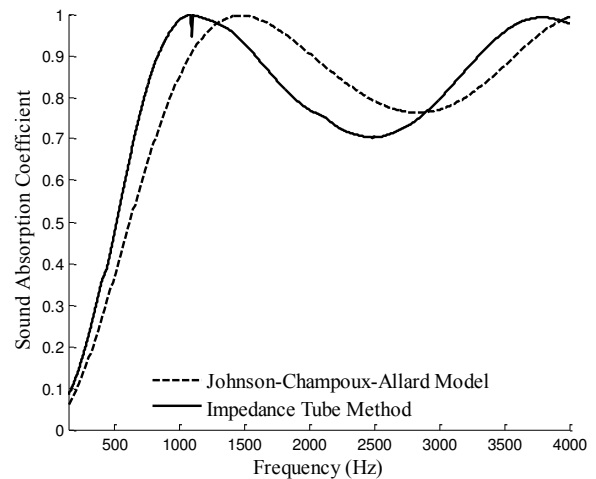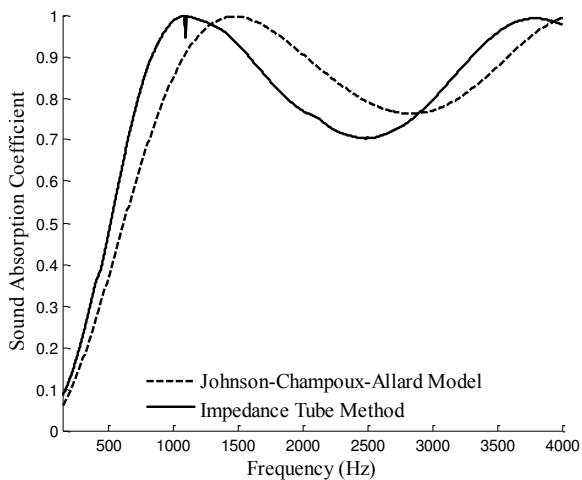


**Figure-5.** Sound absorption coefficient for sample with wt% 30 PU binder.
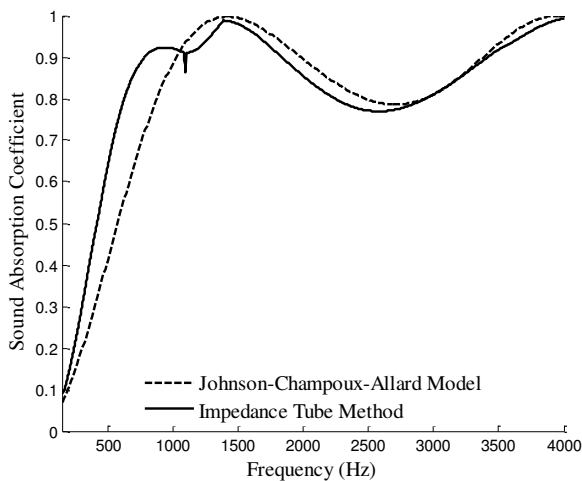


**Figure-3.** Sound absorption coefficient for sample with wt% 10 PU binder.
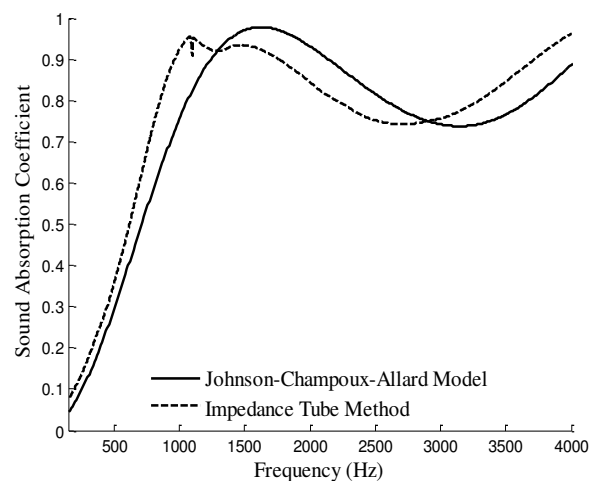


**Figure-6.** Sound absorption coefficient for sample with wt% 40 PU binder.

As shown in Figures-2-6, Johnson-Champoux-Allard model were predicted the absorption coefficient to the similiar. However, the Johnson-Champoux-Allard model cannot predict the peak values accurately. In order to measure the performances of the both graph, a comparison between the impedance tube method and the Johnson-Champoux-Allard Model was shown in Table-2. The prediction error rate ($e$) between impedance tube method and Johnson-Champoux-Allard Model was calculated by Equation-18.

$$e = \frac{|mean_e - mean_p|}{mean_e}$$

(18)



**Figure-4.** Sound absorption coefficient for sample with wt% 20 PU binder.

Where, $mean_e$ and $mean_p$ are the mean of the experimental and prediction. Table-2 shows that each mean of Johnson-Champoux-Allard model is slightly higher than the mean of impedance tube method. However, the Johnson-Champoux-Allard model can predict the pattern of sound absorption correspondingly.

Therefore, the error between impedance tube method and Johnson-Champoux-Allard results are less than 16% for most of the graph. It indicated that the result of impedance tube model and Johnson-Champoux-Allard model is acceptable.

**Table-2.** Percentages error between ITM and Johnson-Champoux-allard model.

| Percentage of binder | Mean of impedance tube method (SAC) | Mean of johnson-champoux-allard model (SAC) | Error (%) |
|---|---|---|---|
| **0** | 0.72 | 0.84 | 16 |
| **10** | 0.80 | 0.82 | 2 |
| **20** | 0.75 | 0.80 | 6 |
| **30** | 0.73 | 0.77 | 7 |
| **40** | 0.71 | 0.78 | 9 |

Figures-2-6 also shows the variations of SAC against frequency for oil palm Mesocarp with different percentages of PU binder. In general, all samples demonstrated higher SAC at mid-high frequency range with the average of sound absorption above 0.5. The SAC at first increase from under 0.2 to about 0.9 until 1500 Hz, but then decrease to about 0.7 to 0.8 from 1500 to 2500 Hz and increase to reach approx. 1 in 4000 Hz. The sample with 10% PU binder show the greater performance in most of low to mid frequency range. However, sample with 20% PU binder reach the high value of sound absorption of 0.99 at 1000 Hz. The result illustrated the sample with PU binder improve the low frequency range and indicated that the cavity resonances are removed by damping, at the resonant frequency sound are not easier though the partitions, and so low frequency were be better. The porous material will be most effective at mid-high frequencies when flow resistivity have a low enough either wise no dissipation occurs (Cox and D'antonio, 2009). According to the Bies and Hansen (2009), the result in table 1 still in the optimum flow resistivity value which is ranging from 10000 and 40000 Nsm$^{-4}$. The PU shows improvement on the low frequency range because of this membrane effect give greater depth to the resonant structures and the interconnected pores of the sample prevent the energy.

## CONCLUSIONS

In this research, acoustic absorption of oil palm Mesocarp was investigated with and without PU binder by different percentages. Impedance tube method is employed to obtain the acoustic absorption characteristics by experimentally. Analytical method was also conducted to support the analyses. Johnson-Champoux-Allard model was based on wave transmission including few of microscopic characteristic. Additionally, the mean of prediction error rates between both of method are noticed as low as 16%. It shows that the experimental results are acceptable and accurate. From the analytical proof of experimental outcomes, it is robust evident that sound absorption of sample with PU binder can be calculated using the Johnson-Champoux-Allard model. The results demonstrate that PU binder has a positive and significant effect on the physical properties. Moreover, intermix of PU in lignocellulose fibre material not only used as a binder but also improves the SAC. The 10% of PU binder showed optimum SAC in most of low to mid frequency range. According to the environmental, it is important to know the material conditions that the absorbent will be subject. Oil palm Mesocarp was able and will be sufficiently robust overtime and not instance because of superior of its physical properties. The PU binder also will avoid fungus grows that could effects to the panel become clogged and prevent fibers being lost within the ventilation system. However, the percentage of PU binder must be low enough, because the PU binder help prevent sound entering the porous absorbent. Finally, it can be concluded that the sound absorption material of oil palm Mesocarp as a material that capable to be used for sound absorption panel in various applications.

## ACKNOWLEDGEMENT

## REFERENCES

Allard, J. and Atalla, N. 2009. Propagation of sound in porous media: modelling sound absorbing materials 2e. John Wiley and Sons.

Asdrubali, F. 2006. "Survey on the Acoustical Properties of New Sustainable Materials for Noise Control".Euronoise, 30.

Asdrubali, F., D'Alessandro, F. and Schiavoni, S. 2008. Sound absorbing properties of materials made of rubber crumbs. Journal of the Acoustical Society of America, 123(5), pp. 3037.

ASTM E1050-98. Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and A Digital Frequency Analysis System.

Badri, K. H., Othman, Z. B. and Razali, I. M. 2005. Mechanical properties of polyurethane composites from oil palm resources. Iranian Polymer Journal, 14(5), pp. 441-448.

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

Beranek, L. L. and Vér, I. L. (Eds.). 1992. Noise and vibration control engineering (pp. 146-149). New York: John Wiley and Sons.

Beranek, L.L. (ed.) 1971. Noise and Vibration Control. New York: McGraw Hill, Chapter 7.

Bies, D. A. and Hansen, C. H. 1980. Flow resistance information for acoustical design. Applied Acoustics, 13(5), pp.357-391.

Bies, D. A. and Hansen, C. H. 2009. Engineering noise control: theory and practice. CRC press.

Cox, T. J. and D'antonio, P. 2009. Acoustic absorbers and diffusers: theory, design and application. CRC Press.

Cummings, A. and Beadle, S. P. 1994. Acoustic properties of reticulated plastic foams. Journal of sound and vibration, 175(1), pp.115-133.

D. L. Johnson, J. Koplik and R. Dashen. 1987. Theory of dynamic permeability and tortuosity in fluid-saturated porous media", J. Fluid Mechanics, 176, pp.379–402.

Delany, M. E. and Bazley, E. N. 1970. Acoustical properties of fibrous absorbent materials. Applied acoustics, 3(2), pp.105-116.

European Council Directive 67/548/EEC of 27 June 1967. On the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances, Official Journal of the European Union, 196, 1-98, 16th August 1967.

Fouladi, M. H., Ayub, M. and Nor, M. J. M. 2011. Analysis of coir fiber acoustical characteristics. Applied Acoustics, 72(1), pp.35-42.

Ingard U. 1994. Notes on sound absorption technology. New York: Noise Control Foundation.

ISO 10534-2-1998. Acoustics: determination of sound absorption coefficient and impedance in impedance tubes. Part 2: Transfer-function method.

Khedari, J., Charoenvai, S. and Hirunlabh, J. 2003. New insulating particleboards from durian peel and coconut coir. Building and environment, 38(3), pp. 435-441.

Latif, A. H., Yahya, M. N., Rafiq, Sambu. M., Ghazali, M. I and Hatta, M. M. N. 2015. A preliminary study on acoustical performance of oil palm mesocarp natural fiber. Applied Mechanics and Materials, 774, pp. 247-252.

Mahzan, S., M Ahmad Zaidi, A., Arsat, N., NM Hatta, M., I Ghazali, M. AND Rasool Mohideen, S. 2010. Study on sound absorption properties of coconut coir fibre reinforced composite with added recycled rubber. International Journal of Integrated Engineering, 2(1), pp.29-34.

Malaysia Palm Oil Board. Oil Palm Planted Area: 1975 - 2011 (Hectares). Economics and Industry Development Division.

Sambu, M., Yahya, M. N., Latif, H. A., Hatta M. M. N. and Ghazali, M, I. 2015. The acoustical characteristics analysis on different type of natural fibers. Applied Mechanics and Materials, 774, pp.242-246.

Mechanics User Manual, Acoustic Material Properties Measurement System, SCS9020B "Kundt/T60/TL Tubers".

Miki, Y. 1990. Acoustical properties of porous materials. Generalizations of empirical models. Journal of the Acoustical Society of Japan (E), 11(1), pp.25-28.

Miki, Y. 1990. Acoustical properties of porous materials. Modifications of Delany-Bazley models. Journal of the Acoustical Society of Japan (E), 11(1), pp.19-24.

Nor, M. J. M., Ayub, M., Zulkifli, R., Amin, N. and Fouladi, M. H. 2010. Effect of different factors on the acoustic absorption of coir fiber. Journal of Applied Sciences, 10, pp.2887-2892.

Software User Manual, Acoustic Material Properties Measurement System, PRO-KIT 517 and PRO-DUO/TL for SCS9020B "Kundt/TL Tubes".

Stankevičius, V., Skripkiūnas, G., Grinys, A. and Miškinis, K. 2007. Acoustical characteristics and physical-mechanical properties of plaster with rubber waste additives. Materials Science, 304-309.

Umnova, O., Attenborough, K. and Li, K. M. 2001. A cell model for the acoustical properties of packings of spheres. Acta Acustica united with Acustica, 87(2), pp.226-235.

Y. Champoux and J. F. Allard. 1991. Dynamic tortuosity and bulk modulus in air-saturated porous media", J. Appl. Phys., 70, pp.1975-9.

Zhu, J., Zhu, H., Njuguna, J. and Abhyankar, H. 2013. Recent development of flax fibres and their reinforced composites based on different polymeric matrices. Materials, 6(11), pp.5171-5198.

Zulkifli, R., Mohd Nor, M.J., Ismail, A.R., Nuawi, M.Z., Abdullah, S., Mat Tahir, M.F., Ab Rahman, M.N. 2009. Comparison properties between coir fibre and oil palm fibre. European Journal of Scientific Research. Vol. 33, No 1, pp. 144-152.