INFLUENCE OF PHYSICAL PROPERTIES ON THE ACOUSTICAL PERFORMANCE OF THE OIL PALM FROND NATURAL FIBRE

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ABSTRACT

The main intention of this research is to investigate the achievability of oil palm frond fibre to be utilized as an acoustical control panel. All the chopped oil palm frond fibre is treated with alkaline treatment (2%) to interfacial bonding between fibre and binder and such treatment was needed to alleviate such problem. Natural rubber (latex) is used as a binder. These samples are varied in the mixing percentage of latex, which are 40%, 30%, 20% and without binder noted as 0%. The physical properties of the fibre which are density, porosity, tortuosity and air flow resistivity were investigated experimentally to show that these properties will affect the value of sound absorption coefficient (SAC). From the result obtained, the sample with a high composition of binder tends to have high density and tortuosity, but less porosity. From the result obtained, the SAC value at the lower frequency (< 500 Hz) increased as the density of the sample increased. However, the SAC value of the higher frequency (> 2000 Hz) decreased as the density of the sample decreased due to the large porosity within them. Furthermore, the results of the SAC tests show that at lower frequency (< 500 Hz), SAC of the sample increases with increasing in density, but tend to decrease at higher frequency (>2000 Hz) for denser samples. Same as density, the SAC value at higher frequency (> 2000 Hz) increased as the tortuosity of the sample increased. However, at lower frequency (< 500 Hz), when the tortuosity of the sample increased, the SAC of the fibre decreased. The oil palm frond fibre can be considered as good sound absorber at high frequency, but cannot be considered as good absorber at lower frequency since the value of SAC is below 0.70. In general, oil palm frond fibre shows that it's suitable as an acoustical panel module at middle frequencies (500 Hz – 1000 Hz) and high frequency sound level which is more than 2000 Hz

Keywords: natural fibres, oil palm frond, sound absorption, physical.

INTRODUCTION

Most of available sound absorbing materials are fibrous materials. Conservatively, synthetic fibres such as fibreglass, glass wool or rock wool are chosen as raw materials for common acoustic manufacturing. These materials offer good acoustical performance. However, they are not sustainable intern of hazardous to human health and gives pollutant emissions (Joshi, Drzal, Mohanty, and Arora, 2004). On global and environmental concerns, material developers are attractive in natural fibre particularly for engineering applications because of lower cost and lower density (Obisung, 2010). Natural fibre composites are likewise asserted to offer some ecological elements for example, diminished reliance on non-renewable energy/material sources, lower toxin emanations, lower greenhouse gas emissions, upgraded energy recuperation, and end of life biodegradability of segments (Jan E. G. van Dam Wageningen University, 2009). These characteristics make the natural fibre as an alternative material considered for sound absorbers.

There are a number of researches and investigations run through on natural fibres as sound absorbing material development has been testified. Acoustical researcher Lindawati inspected acoustic properties of Arenga Pinnata fibre (Ismail and Ghazali, 2010). The fibre indicates great acoustical properties from 2000 Hz to 5000 Hz. Examinations likewise have been made with other natural fibres; coir and oil palm. Arenga Pinnata demonstrates great properties after 2000 Hz, outrageous better than coir fibre yet somewhat lower than palm oil fibre at the normal of 0.7 sound absorption coefficient, SAC. Ersoy and Kucuk have examined sound absorption of natural fibre from tea-leaf fibre and contrasted it with woven fabric material. Result shows that sound absorption of six layers woven textile cloth are slightly comparable to 1cm thick tea-leaf fibre absorber at frequency range between 500 Hz to 3000 Hz (Ersoy and Küçük, 2009).

Natural fibres as coir is a under the category of lignocellulose natural fibre. The coir fibre is relatively waterproof and is the only natural fibre resistant to damage caused by salt water (Harish, Michael, Bensely, Lal, and Rajadurai, 2009). Also investigated on acoustical term; coir gives absorption coefficient value of more than 0.8 (Hosseini Fouladi et al., 2011). Acoustic panel that made from paddy straw are also stated as a good alternative sound absorber among the natural fibres. When it is reinforced with carboxymethyl cellulose, it is reported that the optimum sound absorption coefficient happened under high range frequencies only (Abdullah et al., 2013).

Other than that, a preliminary study on acoustical performance of kenaf fibre which are natural fibre obtain from waste of crop was investigated previously in Acoustic and Vibration Research Group laboratories, Universiti Tun Hussein Onn Malaysia (Sambu et al., 2015). Their study results that kenaf has good potential

character in acoustical properties when exposed to low to high (1 kHz - 4 kHz) within the range of 0.7 to 0.90 sound absorption values.

Nevertheless, sound absorption properties α, of natural fibres bind with natural rubber (NR) are not investigated much and there is very less information about them in terms of physical properties. Therefore, this investigation was carried out to assessment the use of oil palm frond (OPF) fibre to replace synthetic fibre in making of acoustical control applications.

Natural fibre like oil palm frond is an alternative replacement for synthetic fibre in acoustical purpose because of its fibre properties, especially its bast fibres (outer fibres) which are low in cost and density, good toughness, suitable for recycling, acceptable strength properties and biodegradability (Saad and Kamal, 2013). Approximately 22% fibre produced from oil palm industry is a waste. In addition, palm trees not only produce oil but provide a raw material such as oil palm, oil palm trunk, empty fruit bunch, palm kernel shell, palm kernel cake, palm kernel expeller, palm oil mill effluent, dry decanter cake, ash and Mesocarp fibre (Latif, Yahya, Rafiq, Nasrul, & Hatta, 2015).

The acoustic properties of OPF fibres could be similar to wood which is varied with anatomy, density, moisture content and the temperature of the surroundings. For example, a dense wooden structure reflects sound and can easily be made into surfaces that channel sound reflections (Xu, Widyorini, and Kawai, 2005). Oil palm frond is proving an interesting material because of its huge quantities, basic sound absorptive characteristics and environmentally friendly production and disposal (Sihabut and Laemsak, 2010). This fibre is available in Asian countries and easy to obtain. Furthermore, oil palm frond can be easily crushed to chips which are similar to wood particle or fibre and may be used as substitutes for wood based raw materials (Khedari, Charoenvai, and Hirunlabh, 2003). The other advantages of this fibre are renewable, non-abrasive, cheaper, abundance and show less concern with health and safety during handling and processing (Latif *et al*., 2015).

Moreover, it's also in the category of fibrous material which obtains naturally is the main reason to select this oil palm frond fibre as an alternative to synthetic fibre in sound absorption panel.

METHODOLOGY

In this paper, two methods were used for acoustical analysis of OPF fibre bonded with natural rubber (NR) in various percentages at normal incidence sound absorption. First, the normal incidence results obtain using Impedance tube is followed by ASTM E1050, two-microphone method. As a support for the impedance tube result and the fast approximation, Delany-Bazley empirical method was executed. Before performing these tests, physical properties of the OPF fibres such as bulk density, porosity, tortuosity, flow resistivity, and fibres structure character are investigated.

a)　Material preparation

Oil palm frond fibres (OPF) are obtained from local oil palm farm, Parit Raja, Malaysia. The OPF fibres are washed using water to remove the unwanted shells, damaged bast. Water was changed several times in order to reduce the dirt resulted from the retting process. The fibres are soaked in alkaline treatment for 24 hours to remove cellulose layers and unwanted properties of the raw fibres. The fibres are then dried using an oven to remove the alkaline wetness. Then, both OPF fibre and natural rubber are mixed together using mixer machine. The natural rubber mixed in various percentages of 40%, 30%, 20% and the rest without binder which are labelled as 0%. By using a hot compress, all the samples are fabricated at a persistent thickness of 50mm that following the standard thickness of synthetic acoustic panel that available in the commercial market. This is important as it is already known that thickness has influence to sound absorption coefficient of the material from previous researcher (Ismail and Ghazali, 2010).

Figure-1. The prepared OPF sample with natural rubber mixing.

b)　Physical measurement

i.　Bulk density

The specific density of the granular mix is easily determined from the principle of Archimedes (Voronina and Horoshenkov, 2003). The weight of the dry fibre sample was measured and recorded by placing it on the weighing tray first. Then, the same sample was placed in a net bucket which was then dipped fully inside the water and the weight of the immerse fibre sample are also recorded using Eq.1. Where, W_d is dry sample weight in gram; W_s sample that saturated in water and ρ_w density of water.

$$\rho_s = \frac{W_d}{W_d - W_s} \cdot \rho_w$$

(1)

ii.　Porosity

In sound absorption mechanism term, porosity is an important factor that influences the sound absorption.

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Many previous research have declared the importance of porosity on calculating the acoustical absorptive properties of porous material (Biot, 1962), (Latif *et al.*, 2015). Direct measurement of the open porosity was performed using the same Archimedes principle as porosity indicator by using Equation.2.

$$\phi = \frac{W_d}{W_s}$$

(2)

iii. Air flow resistivity

The most high-ranked parameter which used to describe the acoustic absorption character of fibrous material is the air flow resistivity. Those materials in fibrous category are anisotropic and it depends on the air flow direction through the material (Yang and Chen, 2015). There is a close relationship between air flow resistivity, density and porosity. Apart from that, air flow resistivity, σ was measured experimentally using ISO 9053, Determination of airflow resistivity apparatus σ_{exp}, whereby steady air flow is passed through a sample of fibre material placed in a tube. The flow resistivity calculated using Eq. 3 (Wang and Torng, 2001). Moreover, estimation equation σ_{est}, is used to validate each sample towards experimental result and differentiate to both numerical values as shown in Table 1. Estimation Equation. 4 having bulk density of sample, ρ_s and diameter of fibre, d_{fibre} (Hosseini Fouladi *et al.*, 2011).

$$\sigma_{exp} = \Delta p / VL$$

(3)

$$\sigma_{est} = 490 \ \rho_{bulk}^{1.61} / d_{fibre}$$

(4)

In Equation. 3 where the Δp indicate pressure decreases over the sample, steady state velocity V, and the thickness of the sample L which is 50mm as measured.

c) Acoustical measurement

i. Normal incidence sound absorption coefficient

Sound absorption coefficient, SAC by porous material is based on the theory of energy transforming from sound energy to thermal energy. Commonly, porous absorbers such as fibrous minerals wool and glass fibre the acoustic absorption is due mainly to viscous losses as air moves within the pores (Nor, Jamaludin, and Tamiri, 2004). The results of sound absorption were tested using ASTM E1050-09, with the two-way microphone impedance tube method. This method used a tube, two microphones and a digital frequency analysis system. A loudspeaker was placed at one end of an impedance tube and the samples of under test at the other end. The impedance tube set consists of two tubes which are 100

mm diameter for low frequency and 28 mm for higher frequency. For high frequency measurements, the small diameter tubes are connected to the impudence tube and also can act as standalone with its own loudspeaker case while for low frequency measurements, the bigger tube diameter are connected to the impudence tube. Both microphones are connected to the PC which also includes a random noise generator. SCS 8100 software is used to convert the sound wave into the output signal data and also to save the data in frequency range of 10 Hz to 4500 Hz. The SAC experimental progress done at Acoustic and Vibration Research Group laboratory, Universiti Tun Hussein Onn Malaysia. The Kundt model impedance tube used to measure it (Sambu *et al.*, 2015).

Figure-2. Impedance Tube Setup (ASTM E1050-09).

ii. Empirical model delany-bazley

The primary exact model mathematical statement for equivalent fluids gave by Delany-Bazley construct by measured of physical properties. This model system is valid for some commotion acoustics control materials (Jones and Kessissoglou, 2015). Delany-Bazley additionally uncovered that the mass properties could be utilized to locate the typical surface impedance of a specimen of material, and henceforth its absorption coefficient particularly on porous materials. In addition this empirical model is the speediest forecast and successful in light of the fact that the estimation are not dimensionalised (Kirby, 2014). Indeed, even Delany and Bazley together investigated that their model is noteworthy to fibrous media where the porosities are near to 1.0 (Delany and Bazley, 1970). This first experimental model is decided for this study right now considered with couple of parameters of fibrous material, such as, bulk density and air flow resistivity. Additionally, this paper is only the preliminary study in view of Delany-Bazley model to make an examination improve for OPF fibre bond with natural rubber and supportive result for the impedance tube. Considering the effects of fibrous materials with porosities close to one on acoustic absorption, and can be presented as follows:

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Table-1. Physical characteristics of OPF fibre that mix with natural rubber.

Natural Rubber (wt %)	Density (kg/m³)	Porosity	Tortuosity	Air flow resistivity, σ_{exp} (NSM^{-4})	Air flow resistivity, σ_{est} (NSM^{-4})	Differential Error percentage, %
40	872.85	0.62	1.27	37445.47	37430.60	0.03
30	745.56	0.68	1.21	28201.82	26024.30	8.36
20	613.56	0.74	1.16	21107.74	20231.50	4.33
0	227.35	0.85	1.08	18823.03	16952.10	11.04

Where k_a and ρ_a are signified to the wavenumber and the density of air without pressure attenuation separately. The complex wavenumber and empirical material model`s impedance of Delany-Bazley are k_c and Z_c respectively. Here noted that, the formulation of empirical method shown in equation 5-7 is based only on measurement of airflow resistivity σ, which is highly reliant on the chosen fibrous material. Also, these very useful expressions only depend on the (Cox and D'Antonio, 2009). As mention above, this first model is widely accepted and works well for fibrous material over normalized frequency range of $\rho_a f /\sigma$ from 0.01 to 1 are also obtained and stated in Table 1 for this OPF study.

RESULT AND OBSERVATION

This section presents summary of the variable that have been taken into account in this study; density, porosity and air flow resistivity that is influencing the acoustic performance of sound absorption materials. As to understand the structure of OPF fibre when the pre-treatment went through and the appearances of the sample bonded with natural rubber. Moreover, the absorption values are also compared and discuss with the empirical model, Delany-Bazley result.

a) Physical characteristics analysis

Bulk Density Influence: Bulk density is a significant parameter that sound absorption materials often concern about. The result listed in Table 1 shows, increase of OPF bulk density from 233.75 kg/m³ that is 0% binder to highest density 836.65 kg/m³ at 40% of binder mixed; which mean more percentage of binder, results in higher density. Different behaviour of sound absorption happens in variable bulk densities, since the bulk density has great influence on the porosity of fibrous material fabrications (Mcgrory, Cirac, Gaussen, and Cabrera, 2012).

Porosity Influence: For sound absorption, another essential is open pores. To allow energy dissipation by friction, the sound wave has to enter the porous material (Cox and D'Antonio, 2009). On the porosity column in Table-1, each sample`s porosity are stated. Alluding to that, estimations of porosity is consistently expanding while the rate of natural rubber blended with OPF fibres diminishes. 0% binder shows the highest value in porosity;

0.85. That demonstrates the pores and smaller scale gaps are more irregular. With the 20% of natural rubber in OPF fibre, it allows more gaps exist compare to samples that holding 40% of natural rubber as binder. This is because of higher rate of binder conceals and disintegrates in the pores and smaller scale gaps inside the samples.

Airflow Resistivity Influence: In every common type of porous sound absorbing materials, the viscous resistance or know as flow resistivity of air in the porous material has an essential impact on the sound absorption mechanism (Rey, Alba, Arenas, and Ramis, 2013). Discussing to Table-1, airflow resistivity is calculated using two different methods to validate the data that obtained, where one uses experimental method σ_{exp} while the other uses estimation equation σ_{est}. Both results did not demonstrate entirely different when compared about by numerical value. Concerning the physical character, density, porosity and airflow resistivity are the inbound parameters which assume a critical part in acoustical execution. From the gained results that exhibited at Table-1, one can watch that there are a few relations with these four parameters. In all prepared OPF fibre tests, increment in density of the specimen brings about an increment in flow resistivity and decrease in porosity. It uncovers that the pore and structure of the examples are expanding when the natural rubber use getting lower.
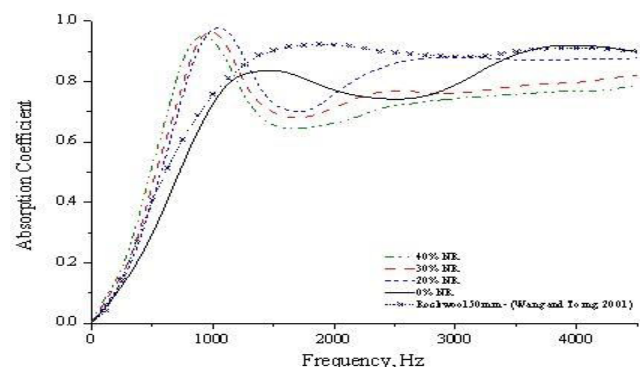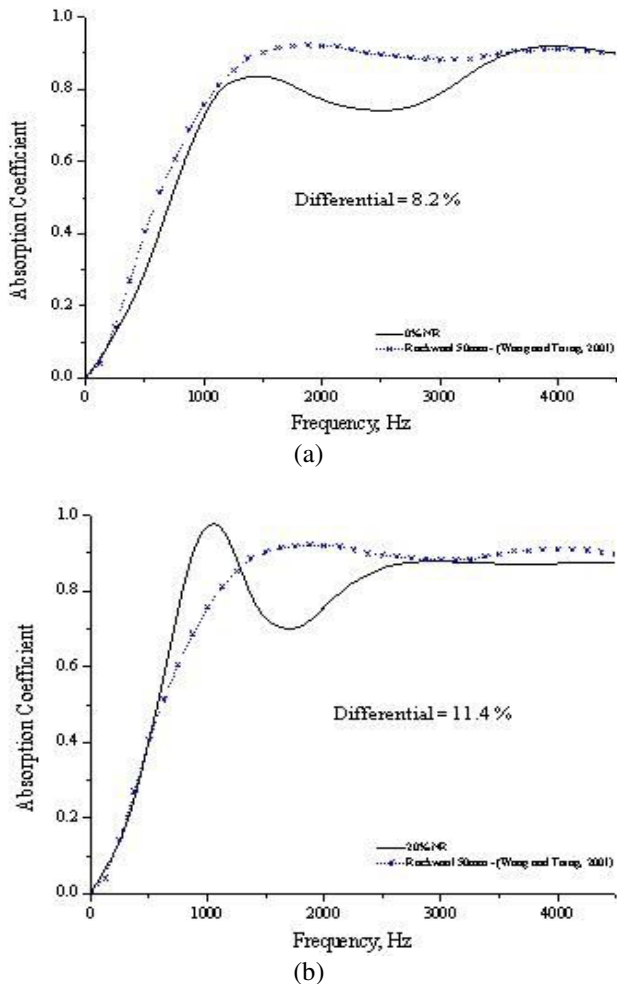

Figure-3. Acoustic absorption coefficient of OPF fibre binds with natural rubber compare with Rockwool (synthetic fibre).

Figure-3(c) and 3(d) can display the differences between with and without structural binder of the sample.

More pore and miniaturized scale holes happen towards low rate of binder. At the point when more pores and gaps show up airflow or viscosity additionally gets into assumes their part. The same occurrence happens when sound wave passes throw the sample and disintegrates between the gaps.

(a)

(b)

Figure-4. Acoustic absorption coefficient of experimental and empirical model prediction on OPF binds with natural rubber, (a) Result of 0% natural rubber (b) Result of 20% natural rubber.

b) Acoustical characteristics analysis

Sound absorption coefficient of OPF bind with natural rubber: The sound absorption coefficients of oil palm frond fibres reinforced with natural rubber are measured from impedance tube test on four different rates of percentage that covers from low to high frequencies; at Figure-3. In this study, the NR rate differs from 0%, 20%, 30% and 40% while all specimens have steady 50mm thickness. The sound absorption coefficient is dependent variables of the sound recurrence (Hao, Zhao, and Chen, 2013). Along these lines, the absorption coefficient on frequency Hz, bends were plotted by the mean estimations of three examples for every percentage rate groups. Based on Figure-3, the graph shows that the OPF fibres have a

SAC toward to 1.0 at both low and high frequency. From the graph, at lower frequency (<500 Hz), the OPF fibre with ratio 20% NR has higher sound absorption coefficient compared to the OPF fibre with ratio 0% and followed by 30% and 40%. However, at middle frequency (500 – 2000 Hz), the values of sound absorption coefficient are different. At range of 500 Hz, the OPF fibre sound absorption coefficient values show the almost same results with sound absorption coefficient at the lower frequency and tend to increase until 1000 Hz. However, after 1000 Hz, the sound absorption coefficient value started to decrease after 1000 Hz except for the sample with ratio 0% which started to decrease at 1500 Hz. At higher frequency, the OPF fibre with ratio 0% has higher sound absorption coefficient compared to the OPF fibre with ratio 20% and followed by 30% and 40%. These results obtained are affected by the density, porosity and tortuosity of the samples. From the result obtained, the SAC tests show that at lower frequency (< 500 Hz), SAC of materials increases with increasing in density but tend to decrease at higher frequency (>2000 Hz) for denser samples. It show that less dense and more open structure absorbs less sound at low frequencies (500 Hz) but performs better at frequencies above than 2000 Hz. Same as density, the SAC value at higher frequency (> 2000 Hz) increased as the tortuosity of the sample increased. However, at lower frequency (< 500 Hz), when the tortuosity of the sample increased, the SAC of the fibre decreased. The samples that merged with binder give a very good absorption coefficient results compared to Rockwool at same thickness (Wang and Torng, 2001). Therefor it can be inferred that 20% of the binder, has a decent air flow resistivity and porosity which like expressed in Table-1. That demonstrates that OPF reinforced with natural rubber utilization for low frequency application. Not just that, character of natural rubber makes the specimens granular and porous, great interlocking and holding between the OPF fibres.

Empirical Model Delany-Bazley prediction comparison: The confirmation of utilizing empirical model Delany-Bazley was completed to analyse with the experimental, impedance tube method for 0% and 20% NR tests only. This is because of the way that 20% test gives the ideal and high intensity in absorption coefficient rate contrast with other two rates of 40% and 30% while 0% sample gives the basic acoustical character of OPF fibre. The prediction and experimental result for both specimens are plotted together in Figure-4. As indicated by the outcome acquired in Figure-4, the measured plots fall genuinely well with empirical model result. The profiles of the both charts are very nearly the same. Empirical result of 0% NR has more comparability with the experimental result compare with the 20% NR results. The differential percentage value just 8.2% for 0% sample and little higher in 20% NR contain samples gives 11.4%. Still the 20% prediction result gives better agreement with experimental measurements although the profile is larger than experimental. Yet, the prediction results accomplish the ideal worth for sound absorption coefficient

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experimental result for samples 0% and 20%. This demonstrates that Delany-Bazley model is competent to utilize and to recognize the preparatory establishing of acoustical execution before continuing to experimental stage that involve cost and time.

CONCLUSIONS

This study shows that the oil palm frond (OPF) fibre is suitable as a sound absorber material at middle frequency (500 Hz – 1000 Hz) and high frequency sound level which is more than 2000 Hz. Even though rock wool; synthetic fibre has higher SAC value compared to some OPF samples, its hazardous to human health which can cause inhalation problem, skin itching and eye pain. Also hazardous to human environment since they are non-biodegradable and not sustainable material. Furthermore, the natural fibres have very low toxicity which is good to protect the environment. There are a few improvement can be done for future research. To make sure these OPF can be commercialize as sound absorber material, an additional tests can be done such as in durability case. Furthermore, fire retardant treatment also can be done. OPF fibre is a natural fibre that has physical properties that influencing the good acoustical properties that giving abilities use as acoustical control material.

An empirical model by Delany-Bazley for hypothetical prediction has been gotten. It can legitimize the general pattern of the OPF fibre`s absorption range. It's only a preparatory assumption to comprehend the normal incidence of OPF fibre`s acoustical performance. For precise forecast of overall absorption including the frame resonance, more sophisticated with extra physical estimations model like Johnson (Allard, 1992) or Wilson model (Wilson, 1997) can be utilized can be used as further work.

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