ARPN Journal of Engineering and Applied Sciences

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PRELIMINARY STUDY ON ACOUSTICAL AND PHYSICAL CHARACHTERISTICS OF KENAF (HIBISCUS CANNABINUS) USING NATURAL RUBBER AS BINDER

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ABSTRACT

Natural fibres are significantly used as reinforcements for the manufacture of low-costing and lightweight polymer composites; other advantages include innoxiously to human, easily obtain, and have a higher capacity of biodegradability. Therefore, researchers divert their attentions to find sustainable and eco-friendly materials such as natural fibres to be an alternative sound absorber. This paper discusses the use of natural fibre from the Kenaf fibre (Hibiscus Cannabinus), that eligible as sound absorber. This selected natural fibre is famous among the South East Asia countries and has a wide plantation. Sound absorption properties of this natural fibre have been investigated. Kenaf fibres are treated with alkaline treatment 2% individually to remove the unwanted dirt's and bind with various percentages, 40%, 30%, 20% and 0% of natural rubber (latex). The thickness of each sample is kept constant at 50mm only. To obtain the sound absorption, the Kenaf fibre samples was measured using impedance tube. The measured values from impedance tube were compared with the empirical model Delany- Bazley in order to investigate sound absorption`s prediction result. In addition, bulk density, porosity and flow resistivity were also been examined. The result shows that Kenaf reach the maximum absorption coefficient value towards low frequency with fibre samples bind with natural rubber whereas fibres without the binder reach at high frequency range of 4000 Hz and above. In this preliminary study of the natural fibre i.e Kenaf fibre, it is shows that the fibre is a promising light and environment-friendly sound absorption material.

Keywords: natural fibres, kenaf, sound absorption, physical, delany-bazley.

INTRODUCTION

Currently, synthetic fibres such as glass wool, poly foams and ceramic are being widely used as acoustic material because of their high stiffness and strength properties (Rout *et al.* 2001). These synthetic materials also offer good acoustical performance. However, synthetic fibres have serious disadvantages in terms of initial processing cost, recyclability, energy consumption and machine abrasion (Bledzki *et al.* 2012). Another negativity of these synthetic sound absorber materials are the damage done on human's health and environment, such as lung problems and non-biodegradable. Hence, new research are being conducted to find an alternative material to synthetic absorbers due to the high demand for new sound absorbers material, such as natural fibers (Kabir and Wang, 2011). Introduction of bio fibres known as natural fibres from annually renewable resources are gaining interest to be used as reinforcement in polymer composites to provide benefits to the environment with respect to the degradability and utilization of renewable materials (Cox and D'Antonio, 2009).

There are various types of natural fibers today, with many more variety to be found. Some examples of fibres which are already in use include ramie, hemp, jute, sisal, bamboo, banana, and okra fibers. These natural fibres are light weight, high specific modulus, non-toxicity; friendly processing and absorbed CO2 during their growth becomes the attractive features (Rokbi *et al.* 2011). Anyhow the mechanical properties of natural fibre's composites are much lower than those of the synthetic fiber composites (Saikia, 2010), (Sule, Isa, Ameh, Ajayi, and Omorogbe, 2014). Furthermore, these green sources of fibres are biodegradability, less hazardous to human health and cheaper in cost. Moreover, in sustainable chart, natural fibres are in leading. Several researches investigate the capability on the performance of natural fibres as an acoustic absorber.

Among acoustical research on natural fibres, Arenga Pinnata which is known as Ijuk is a waste fibre from sugar palm plantation. This thick black fibre contain high tensile properties naturally and gives good result on sound absorption at high frequency (Ishak *et al.* 2013). Coir is a under category of lignocellulose natural fiber. The coir fiber is relatively waterproof and is the only natural fiber resistant to damage caused by salt water (Harish *et al.* 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 by 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). Nevertheless, sound absorption properties α, of natural fibres bind with natural rubber (latex) are not investigated much and there are very less information about them in terms of physical properties. Therefore this investigation was carried out to review the use of Kenaf fibre (Hibiscus Cannabinus) to replace synthetic fibre in making acoustical applications.

Natural fibre like kenaf is an alternative replacement for synthetic fibre in acoustical purpose because of its fiber properties, especially its bast fibers (outer fibers) which are low in cost and density, good toughness, suitable for recycling, acceptable strength properties and biodegradability (Saad and Kamal, 2013). Moreover it's also in category of fibrous material that are obtains naturally.

METHODOLOGY

In this paper, two methods were used for acoustical analysis of Kenaf fibre bonded with natural rubber 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 kenaf fibres such as bulk density, porosity, tortuosity, flow resistivity, and fibres structure character are investigated.

Material Preparation

Kenaf fibres are obtained from Lembaga Kenaf dan Tembakau Negara (LKTN) in Malaysia. The fibres are washed using water to remove the unwanted shells, damaged bast and dirts. After a good wash, the fibers are soaked in alkaline treatment for 24 hours to remove cellulose layer and unwanted properties of the raw fibres. The fibres are then dried using oven to remove the alkaline wetness. Then Kenaf fibres were bind together with natural rubber in various percentages of 40%, 30%, 20% and the rest without binder which are labeled as 0%. All the samples are fabricate at constant thickness of 50mm, that following the standard thickness of synthetic acoustic panel that available in 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).

Physical Measurement

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 Equation.1. Where, W_d is dry sample weight in gram; W_s sample that saturated in water and ρ_w density of water.

$$\rho_s = \frac{W_d}{W_d - W_s} - \rho_w \tag{1}$$

Figure-1. The prepared Kenaf sample with natural rubber binding.

Porosity

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

$$\phi = \frac{W_d}{W_s} \tag{2}$$

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 fiber material placed in a tube. The flow resistivity calculated using Equation. 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 fiber, d_{fibre} (Hosseini Fouladi *et al.* 2011).

$$\sigma_{exp} = \Delta p / VL \tag{3}$$

$$\sigma_{est} = 490 \ \rho_{bulk}^{\ 1.61} / d_{fibre} \tag{4}$$

At 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.

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Morphological Characteristics

The possibility of forming binder`s bonding at the interface is mainly dependent on the surface morphology and treatment of the fibre. Hence microscopic analysis of fibre surface topology deserves outmost significance in fibrous composites (Sreekala *et al.* 2000). Morphological analysis was accomplished to observe the comparison between topology and fiber pullout of the samples using Scanning Electron Microscope (SEM) Model JEOL JSM-7600F and Digital Microscope Scan, Model NIKON LV150NL. This advanced scanning analyzer helps to understand the characteristics before and after pre-treatment of the samples. The physical changes are also clearly observed here. More that, digital microscope identifies the samples structure that mixed with natural rubber.

Acoustical Measurement

Normal Incidence Sound Absorption Coefficient

Sound absorption 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 fiber 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. This test method covers the use of an impedance tube, also known as standing wave apparatus, for the measurement of impedance ratios and the normal incidence sound absorption coefficients of acoustical materials. 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 α, for the frequency range of 1Hz - 4500 Hz as shown Figure-1 (Sambu *et al.* 2015).

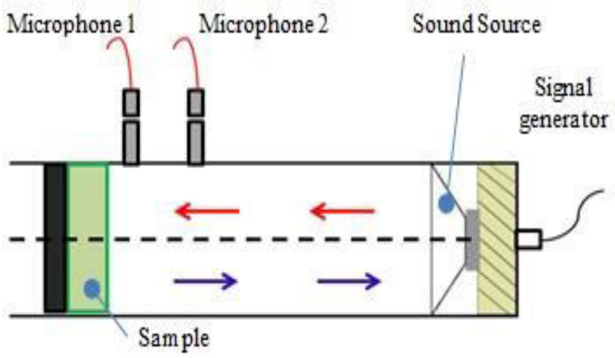

Figure-2. Schematic diagram of impedance tube.

Empirical Model Delany-Bazley

The first empirical model equation for equivalent fluids provided by Delany-Bazley based by measured on acoustical properties. These model method are applicable for many noise control materials (Jones and Kessissoglou, 2015). Delany-Bazley also revealed that the bulk acoustic properties could be used to find the normal surface impedance of a sample of material, and hence its absorption coefficient especially on porous materials. Moreover this empirical model is the fastest prediction and effective because the measurement are not dimensionalised (Kirby, 2014). Even Delany and Bazley together explored that their model is significant to fibrous media where the porosities are close to 1.0 (Delany and Bazley, 1970). This first empirical model is chosen for this study as it easily considered with few parameters of fibrous material such as bulk density and the air flow resistivity. Also, this paper is just the preliminary study based on Delany-Bazley model to make an investigation practice for Kenaf fiber bind with natural rubber and supportive result for the impedance tube result of sound absorption. Considering the effects of porous materials with porosities close to one on acoustic absorption, and can be presented as follows:

$$k_c = k_a\left[1+0.0978\left(\frac{\rho_a f}{\sigma}\right)^{-0.7} -j0.189\left(\frac{\rho_a f}{\sigma}\right)^{-0.595}\right] \quad (5)$$

$$Z_c=Z_a\left[1+0.057\left(\frac{\rho_a f}{\sigma}\right)^{-0.734} -j0.087\left(\frac{\rho_a f}{\sigma}\right)^{-0.732}\right] \quad (6)$$

$$c_c=\frac{\omega}{k_c}, \qquad \rho^c=\frac{k_c Z_c}{\omega}, \qquad f=\frac{\omega}{2\pi} \quad (7)$$

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 Equations. 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 ρ_a f/σ from 0.01 to 1 are also obtained and stated in Table 1for this Kenaf study.

Table-1. Physical characteristics of Kenaf fiber that mix with natural rubber.

Natural Rubber (wt%)	Density (kg/m^3)	Porosity	Average Diameter (μm)	Air flow resistivity, σ_{exp} (NSM^{-4})	Air flow resistivity, σ_{est} (NSM^{-4})
40	837.5	0.66	18.78	30063.77	33827.61
30	716.1	0.79	17.32	24798.57	26644.36
20	613.2	0.83	15.02	15223.31	18948.54
0	304.5	0.78	12.81	6572.63	6731.14

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 Kenaf fibre when the pretreatment 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.

Physical Characteristics Analysis

Bulk Density Influence: Bulk density is a significant parameter that sound absorption materials often concern about. For instance, when defining the insulation or sound absorption within a double wall system the density is usually specified to ensure the partition will achieve the required performance (Mcgrory, Cirac, Gaussen, and Cabrera, 2012), (Mcgrory *et al.* 2012). The result listed in Table 1 shows, increase of Kenaf bulk density from 30.45 kg/m^3 that is 0% binder to highest density 83.75 kg/m^3 at 40% of binder mixed; which mean more percentage of binder, results in higher density. Different behavior of sound absorption happens in variable bulk densities, since the bulk density has great influence on the porosity of fibrous material fabrications.

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. Referring to that, values of porosity is steadily increasing while the percentage of binder mixed with Kenaf fibres decreases. Sample 10 to 12 with 0% binder shows the highest value in porosity. That indicates the pores and micro gaps are more random. With the 20% of natural rubber in Kenaf fibre, it allows more gaps exist compare to samples that holding 40% of natural rubber as binder. This is due to higher percentage of binder covers up and dissolves in the pores and micro gaps inside the samples.

Airflow Resistivity Influence: In all ordinary forms of porous sound absorbing materials, the viscous resistance or know as flow resistance of air in the porous material has an important influence on the sound absorption mechanism (Rey *et al.* 2013). Referring 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 show much different when compared by numerical value. As for the physical character, density, porosity and airflow resistivity are the inbound parameters which plays an important role in acoustical performance. From the obtained results that presented at Table-1, one can observe that there are some relations with these four parameters. In all prepared Kenaf fiber samples, increase in bulk density of the sample results in an increase in flow resistivity and reduction in porosity. It reveals that the pore and structure of the samples are increasing when the natural rubber binder usage getting lower. Figure-3(c) and 3(d) can display the differences between with and without structural binder of the sample. More pore and micro gaps happens towards low percentage of binder. When more pores and gaps appear airflow or viscosity also get thrown in to plays their role. The same incident occurs when sound wave passes throw the sample and dissolves between the gaps.

Morphological Observation: The surface morphology of raw and treatment Kenaf fibres was analyzed by scanning electron microscope (SEM). In terms of Kenaf fibres level of smoothness and roughness, it's expected that the untreated fiber will differs from the treated fibers. Figure-3(a) and (b) displays the treated and untreated Kenaf. As can be observed from the image, alkaline treatment analysis reveals that it will remove the impurities of Kenaf fibres. By referring to Figure-3, it can see that (b) have a smoother surface as compared to (a). Furthermore, the treatment also has effect on the fiber, such as increase in the amount of cellulose exposed on the fiber surface and increase in surface roughness. This condition helps by creating better interlocking between binder and fiber. Figure-3(c) and (d) shows the Digital Microscope Scan photographs of prepared samples' surfaces upon different modifications. This is strong evidence for the physical microstructural changes occurred to the Kenaf samples surface. Porous structure is observed in both with and without binder combination under compression preparation method. Sample in Figure-3(c) has more pores and micro gaps as compared to (d) which are bonded to the natural rubber that melt and interlock together. The white minuscule net-like look is the image of natural rubbers bonded with Kenaf fibres. This shows that the natural rubber hold together and interlock with Kenaf very well. The higher the percentage of natural rubber in the sample, the stronger the bond acquired. But this also causes the samples to be poor in acoustical performance because the pores and micro gaps are already filled up by the natural rubber.

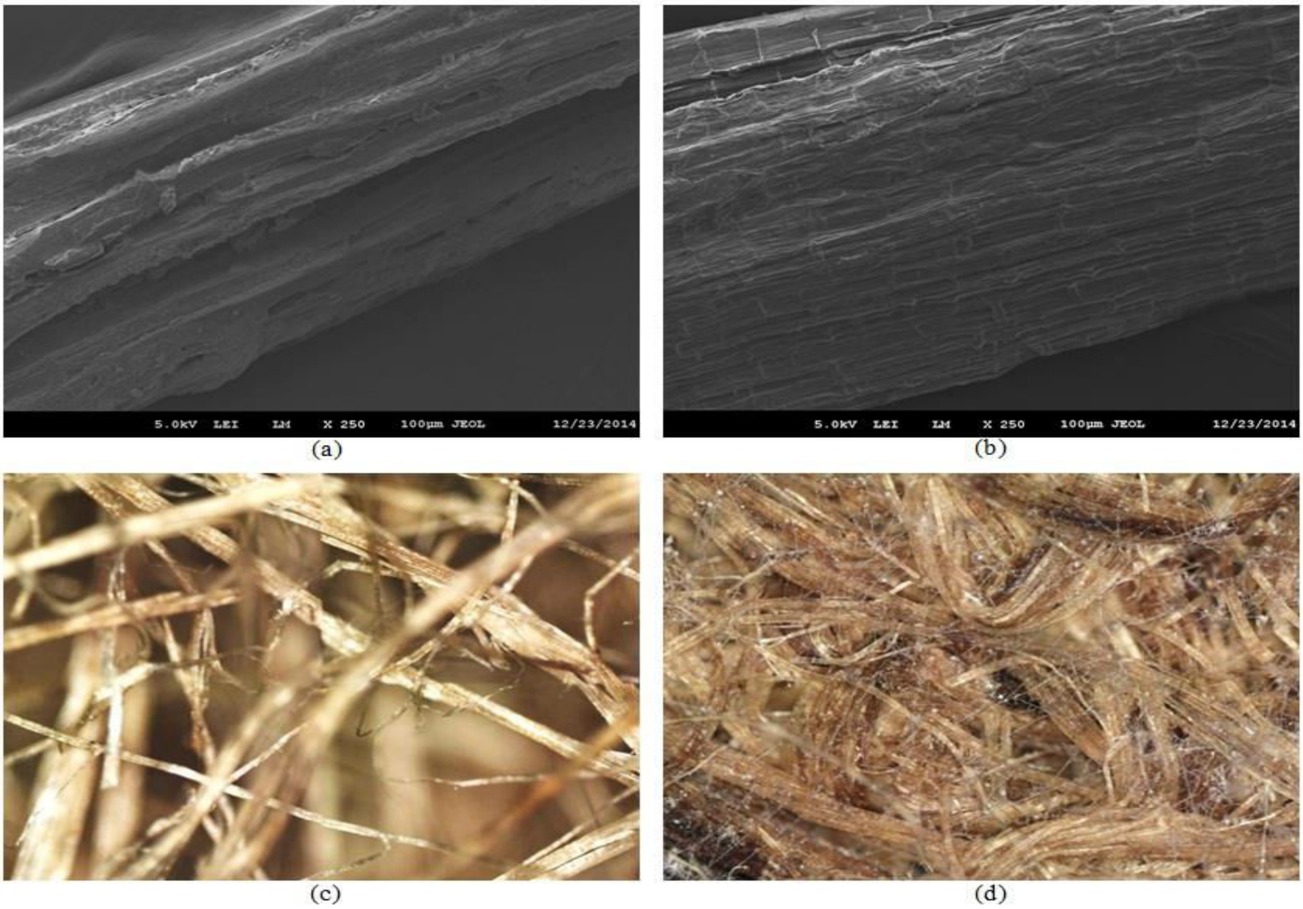

Figure-3. Scanning electron micrographs of the fibre surfaces (a) Raw untreated Kenaf fibres, (b) Alkaline treated, Digital Microscope Scan (c) Without natural rubber binder, (d) With natural rubber binder.

Acoustical Characteristics Analysis

Sound absorption coefficient of Kenaf bind with natural rubber: The sound absorption coefficients of Kenaf, Hibiscus Cannabinus fibres bonded with natural rubber are measured from impedance tube test on four various percentages of binder that covers from low to high frequencies are as shown in Figure-4. In this study, the binder percentage varies from 0%, 20%, 30% and 40% but all samples have constant 50mm thickness. The sound absorption coefficient are dependent variables of the sound frequency (Hao, Zhao, and Chen, 2013). Therefore, the absorption coefficient frequency Hz, curves were plotted by the mean values of three samples for each binder percentage groups. As shown in Figure-4, the 0% binder sample`s result shows a different pattern compare to other contained natural rubber samples. The alkaline treated pure fibre sample`s gives a result of wave pattern that covers up both mid-low and high frequency. At 1500Hz and above 4500Hz frequency, it achieves nearly 0.9 in sound absorption coefficient. Although they are good coefficient values, still in low frequency below 1000Hz, the value slowly improve towards better coefficient as compared to samples bonded with natural rubber. The samples that merged with binder give a very good absorption coefficient results compared to Rockwool at same thickness. This natural rubber mixed porous samples shows more than 0.8 value of absorption coefficient at lower frequency, 1000Hz in their results. Among the three samples of 40%, 30% and 20% of natural rubber bind between Kenaf fibres, the 20% of natural rubber gives the high absorption with distinct peaks with an absorption coefficient value of 0.98 that appeared around 875Hz for

VOL. 11, NO. 4, FEBRUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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50mm thick sample layer. Hence it can be concluded that 20% of the binder, has a good airflow resistivity and porosity which also stated in Table-1. That proves that Kenaf fibre bonded with natural rubber capable use for low frequency application. Not only that, character of natural rubber makes the samples granular and porous, which gives a good absorption in low frequency, good interlocking and bonding between the Kenaf fibres.

Empirical Model Delany-Bazley prediction comparison: The verification of using empirical model Delany-Bazley was carried out to compare the experimental, impedance tube method for 0% and 20% binder mix samples only. This is due to the fact that 20% category sample gives the optimum and high potency in absorption coefficient value compare to other two percentages of 40% and 30% while 0% of binder gives the exact acoustical character of Kenaf fibre. The prediction and experimental result for both samples are plotted together in Figure-5. According to the result obtained in Figure-5, the measured plots fall fairly well with empirical prediction. The profiles of the both graphs are almost the same. Empirical result of 0% has more similarity with the experimental result compare to the 20% graphs. Still the 20% prediction result gives better agreement with experimental measurements although the profile is larger than experimental. However, the results also show that empirical model unable to predict the resonance peak at exact frequency. This may be due to the frame resonance and also Delany-Bazley model did not consider bulk modulus of elasticity. But the empirical results achieve the optimum value for sound absorption coefficient experimental result for category samples 0% and 20%. This shows that Delany-Bazley model is capable to use and to identify the preliminary founding of acoustical performance before proceeding to experimental stage that require cost and time.

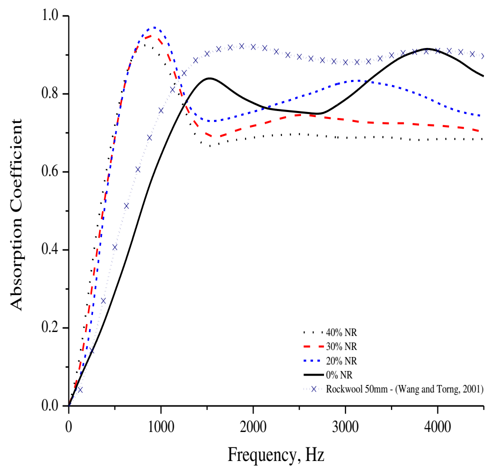
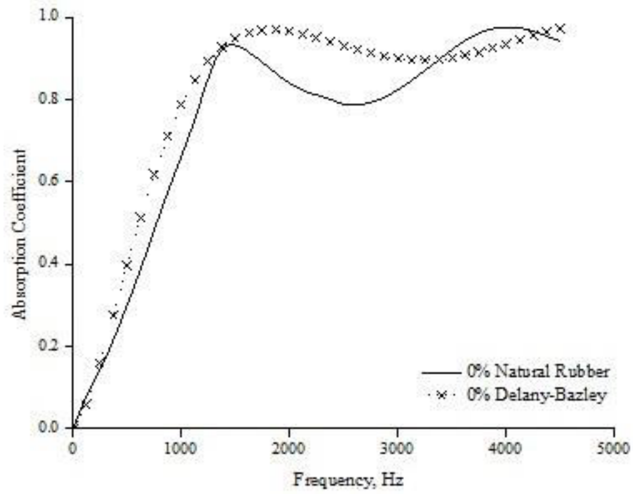
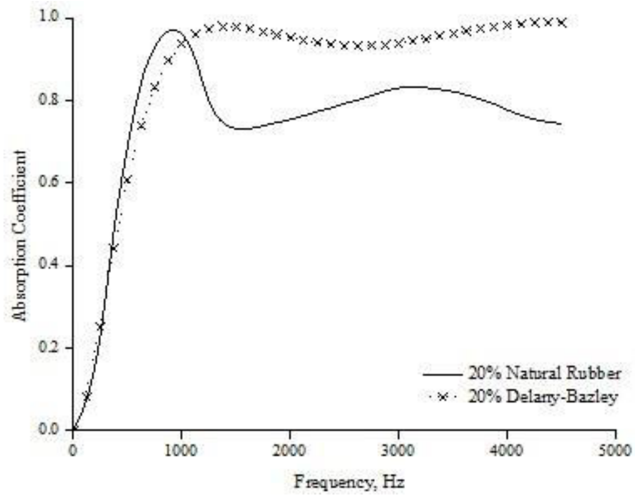


Figure-4. Acoustic absorption coefficient of Kenaf fibre binds with natural rubber and Rockwool (synthetic fibre).



(a)



(b)

Figure-5. Acoustic absorption coefficient of experimental and empirical model prediction on Kenaf binds with natural rubber, (a) Result of 0% natural rubber (b) Result of 20% natural rubber.

CONCLUSIONS

In this investigation the sound absorption coefficients of Kenaf fibre reinforced with natural rubber as binder have been tested. Analyses from this study give an overall knowledge about the factors and influence that are able to enhance the absorption of Kenaf fiber. The results in term of physical and acoustical, indicates that both plays an important role in the improvement of sound absorption. The effect of density and porosity of this porous material made from natural fibre distinctly promotes acoustic absorption with decreasing natural rubber`s binder percentage; 20% binder more sound absorb compare to more percentage 40% of natural rubber. But, increasing the percentage of binder with Kenaf fibre, increases the airflow resistivity value and slightly move the absorption peak towards lower frequencies. Treated pure Kenaf fiber sample seems to give well absorption characteristics because of porosity increment due to more pores and gap that allows sound dissolved and absorb without reflect compare to samples with binder. These results reveals that more strategically designed layers and configurations of Kenaf fiber could increase the sound absorption value.

An empirical model by Delany-Bazley for theoretical prediction also has been obtained. It can justify the overall trend of the Kenaf fibre`s absorption spectrum. It's just a preliminary assumption to understand the normal incidence of Kenaf fibre`s acoustical performance. For accurate prediction of overall absorption including the frame resonance, more sophisticated with additional physical measurements model like Johnson-Allard (Allard, 1992) or Wilson model (Wilson, 1997) can be used.

ACKNOWLEGEMENTS

The authors acknowledge the financial support by the Malaysian Ministry of Education and Universiti Tun Hussein Onn Malaysia. (No. 1461: Identifying Sound Characteristics of Natural Fibres Using Room Scale Model)

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