



INVESTIGATION ON SOUND ABSORPTION OF OIL PALM MESOCARP NATURAL FIBER

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ABSTRACT

Approximately 57% of total production occurs in west Malaysia, 99% in Sabah and about 5 million hectare of area oil palm has been planted. At present, Malaysia is famous in the producing of oil palm in the international market. The oil palm trees are not only provide oil but also raw materials. Among the alternative material resources, agricultural waste like oil palm Mesocarp is selected and known as lignocellulosic materials. In this research, the acoustic absorption of oil palm Mesocarp was measured. The material were mixed with Polyurethane (PU) as binder with four different percentages of 10%, 20%, 30% and 40%. Experimental measurements in impedance tube are used for analysis. Moreover, analytical models namely; Delany-Bazley are conducted to validate the experimental measurements. Results showed that the percentages of binder have positive and significant effects on physical properties. Delany-Bazley model were predicted the absorption coefficient very well in low frequency range. The result also presented that all samples demonstrated higher SAC at mid-high frequency range with the average of sound absorption above 0.5. The sample with 10 percent PU binder shows the best performance in most of low to mid frequency range. The results indicated some potential characteristics of oil palm Mesocarp fiber to be implemented as sound absorption panel.

Keywords: sound absorption, natural fiber, oil palm mesocarp, noise reduction coefficient, delany-bazley.

INTRODUCTION

For over past century, there is a great effort has been made to study about sound absorption panel. Moreover, in recent decades many innovative absorber designs and new ways to measure absorptive material have been achieved. Over this time, the focus of attention is on the use of material for sound absorption purposes. Recent developments in sound absorber have heightened the need for the replacement or renewable materials in making of acoustical panel. The common acoustical panels are made from synthetic fibers such as glass wool, rock wool and asbestos. Despite the fact that glass fiber have excellent not only on physical and mechanical properties but also on sound absorption characteristics, it is difficult to devise suitable disposal methods for them.

Due to the environmental problems, there is increasing concern that some of the synthetic fibers are being major drawbacks. Man-made vitreous fibers refers to group of synthetic, including rock wool, slag wool, glass fiber are widely used as thermal and acoustic insulation material in building and industrial application. Approximately, 27% of mineral wool (glass), 30% of mineral wool (stone) and 40% of foam plastic has been estimated in European building insulation (Schmidt *et al.* 2004). According to recent study found that the man-made fibers exposure significantly to the human related to increased oxidative (Rapisarda *et al.* 2015). A number of epidemiological studies have found an increased risk of human respiratory system cancer when man-made fiber exposed to workers (Berrigan, 2002; Stone, 2004; Mars, 2001).

In recent years, the sustainability has become important issue. These issues have also led to porous absorbers being constructed from natural fiber. Currently,

several researchers have been studying this related issue and findings have revealed the potential of natural fibers as sound absorber material such as coconut fiber (Fouladi *et al.* 2011), bamboo fiber (Koizumi *et al.* 2002), Arenga Pinnata (Ismail *et al.* 2010), Kapok fiber (Veerakumar and Selvakumara, 2012) and Kenaf fiber (Saad and Kamal, 2013). 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, Universiti Tun Hussein Onn Malaysia (Latif *et al.*, 2015; Sambu *et al.*, 2015). Those studies covered with the effect of air gap, thickness and binder; Polyurethane and Latex. Many analysts now agree that the natural fiber has a lot of advantages. Zhu *et al.* (2013), for example, stated that natural fibers have low density, biodegradable and low cost. Moreover, renewable, abundance, non-abrasive and less health and safety concern during handling and processing also become the general reason for using natural fiber as raw material. Oil palm Mesocarp is one of natural fibers that left abundantly. According to (Badri *et al.*, 2005), about 22% fiber produced from oil palm industry is waste. In additional, no research has been found that investigated on the sound absorption characteristic of oil palm Mesocarp. Hence, the objectives of this research are to determine whether oil palm Mesocarp fibers feasible to be applied for acoustical panel.

Porous materials are typically used as sound absorption panel in noise control engineering. The sound propagation found in air saturated rigid frame porous media. In 1970, Delany & Bazley, (1970) published a paper devoted to the impedance and wave propagation properties of fibrous materials. They developed a simple



empirical approach, which involved two parameters; flow resistivity and angular frequency. The empirical approach has been widely used for its good and fast approximation to the solution (Fouladi *et al.* 2011; Cuiyun *et al.* 2012). Miki, (1990) argues that Delany & Bazley model are not capable to use in double layer case. He proved that this model sometimes becomes negative at low frequency range and modified the model with new regression and derivation. In the same year, he define new empirical models with depend on porosity, tortuosity and pore shape factor ratio. In another major study, Biot (1956) produces the theory of propagation of elastic waves in a fluid-saturated porous solid in low and high frequency. Johnson *et al.* (1987), Allard, (1993) and Attenborough, (1971) proposed a analytical method to explain the propagation in porous material and full description on previous method based on Biot (1956) theory.

The aim of this study was to evaluate and validate the potential of oil palm Mesocarp on sound absorption properties. This paper begins by determination sound absorption coefficient (SAC) using experimental method and analytical method. It will then go on to the effect of binder on the physical and sound absorption properties of the samples.

MATERIAL SELECTION AND PREPARATION

Material

Among the agrowaste and agroforest material resources, Oil palm Mesocarp is selected to be as raw material in this study. The oil palm Mesocarp fibers were obtained from oil palm mill after the press station. The fibers have though several pre-treatment processes to removed unwanted material such as 6% content of oil, kernel, nut and shell. In preparation stage, the sample were prepared in cylindrical shape with two different diameters of 28mm and 100mm for high frequency and low frequency range, respectively as shown in Figure-1.

Binder

In this experiment, the raw materials were mixed with four different percentages of polyurethane (PU) which are 10%, 20%, 30% and 40%. The polyol resin and maskimate that used to prepare PU binder was obtained from local chemical supplier and formulated based on mixing ratio 100:110 that were recommended by data sheet. There are numerous of researchers that have been using PU as binder (Badri *et al.*, 2005; Stankevičius *et al.*, 2007; Asdrubali *et al.*, 2008; Mahzan *et al.*, 2010).



Figure-1. Sample of oil palm mesocarp.

METHODOLOGY

Acoustical properties

There are two methods used for acoustical analysis in this study. Firstly, the experimental was performed using impedance tube method (ITM). The experimental was conducted in Acoustic and Vibration Lab, Universiti Tun Hussein Onn Malaysia. Secondly, simple and fast approximately, Delany-Bazley analytical method was implemented. The acoustical properties are calculated based on flow resistivity of the material and the characteristic impedance and propagation coefficient of oil palm Mesocarp were calculated. Moreover, the effect of binder on physical and sound absorption properties will be covered in this study.

Impedance tube method

Two different tube (SBS9020B “Kundt Tube”) was involved in the ITM; 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 01 dB and SCS8100 (software) was contained in the impedance tube. This tubes configuration represents the basis, standard system setup for SAC and impedance measurements (2 microphones – transfer function method). The calibrator was Larson Davis CAL 200. The measurement of SAC has been enshrined into International Standard. The test performed using the ISO 10534-2, ASTM E1050-98 and user’s manual. The user manual recommended 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. There are restrictions on the microphone spacing where the 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 (Cox & D’antonio, 2009).

Delany-Bazley method

This approach used to measure a large number of samples of porous material and contained curve fitting to arrive at relationship describing how the characteristic impedance and propagation wavenumber vary with flow resistivity. The correlations are widely used as they give robust evidence in estimation across quite a wide frequency range. The characteristic impedance Z_c is given by:

$$Z_c = \rho_0 c_0 F_1(X) \quad (1)$$

and the wavenumber k , by:

$$k = \frac{\omega}{c_0} F_1(X) \quad (2)$$

$$\omega = 2\pi f \quad (3)$$



Where ρ_0 is the density of air, c_0 is speed in air and ω is the angular frequency, while,

$$F_1(X) = 1 + 0.0571X^{-0.754} - j0.087X^{-0.732} \quad (4)$$

$$F_2(X) = 1 + 0.0978X^{-0.700} - j0.189X^{-0.595} \quad (5)$$

X is given by:

$$X = \frac{\rho_0 f}{\sigma} \quad (6)$$

Where f is the frequency and σ the flow resistivity of the fibrous material. This method is only applicable when the boundary of X should fall in the range $0.01 < X < 1.0$. The limits of the flow resistivity in the measurement were in the range $1000 \leq \sigma \leq 50000 \text{ Nsm}^{-4}$. Thus, frequency dependent sound speed and density of a highly porous material according to this method can be expressed as follows:

$$C_{eq} = \frac{\omega}{k} = \frac{c_0}{F_1(X)} \quad (7)$$

$$\rho_{eq} = \frac{Z_c}{C_{eq}} = \frac{Z_c k}{\omega} = \rho_0 F_1(X) F_2(X) \quad (8)$$

Physical properties

It is necessary to set down the most important fundamental that determine acoustic properties within absorber, whereas flow resistivity, porosity, tortuosity and density.

Flow resistivity measurement

For this study, equation (9) will be implementing in this study to determine the flow resistivity. According to Ballagh, (1996), there is an unambiguous relationship between flow resistivity, bulk density and fiber diameter. Currently, Fouladi *et al.* (2011) were proved the equation may be used to predict flow resistivity.

$$\rho = 490 \frac{\rho_{bulk}^{1.61}}{d_{fiber}} \quad (9)$$

Where d_{fiber} is diameter fiber and ρ_{bulk} is density of fiber. Each fiber is assumed as perfect cylindrical shape.

Porosity measurement

The porosity of the samples is determined by:

$$\varepsilon = \frac{V_p}{V_b} \quad (10)$$

$$V_p = \frac{(W_s - W_d)}{\rho_s} \quad (11)$$

$$V_b = \frac{W_s - W_i}{\rho_s} \quad (12)$$

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 ρ_s is density of saturating liquid.

Tortuosity measurement

In order to measure the tortuosity, each sample will be calculated using following empirical equation according to Umnova, (2001).

$$k_s = \frac{1}{\sqrt{\varepsilon}} \quad (13)$$

Density of fibers measurement

The density of the fibers will be measured using Mettler Toledo's analytical balance density kit tester accordance with Archimedes principle. This tester makes precise and fast density measurement of samples. The Kits contain a support plate and weighing pan, bracket, glass beakers, thermometer, holders for floating and non-floating solids and a bottle of wetting agent.

RESULTS AND DISCUSSION

Effect of binder on physical properties

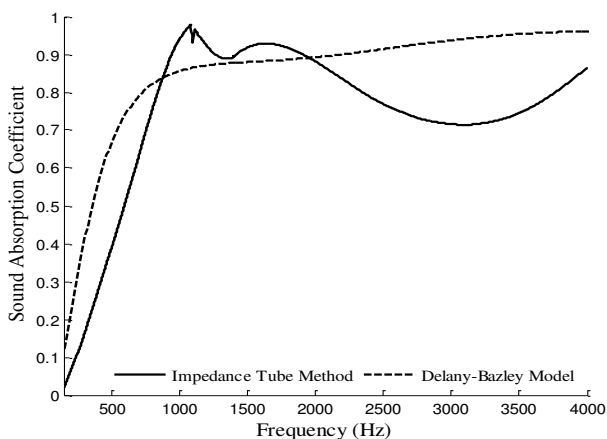
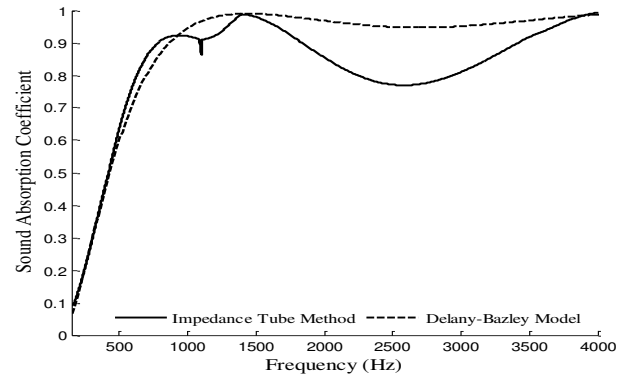
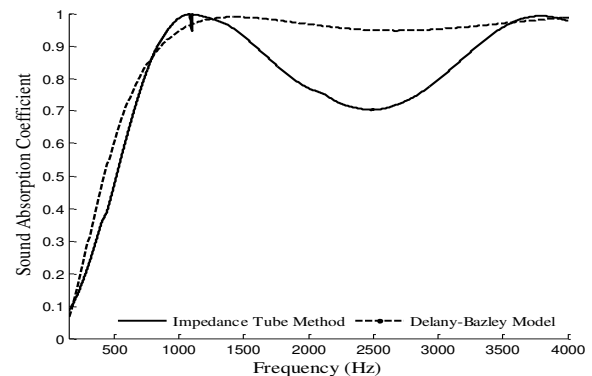
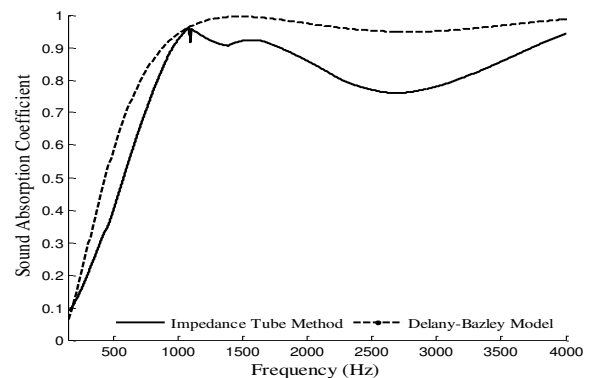
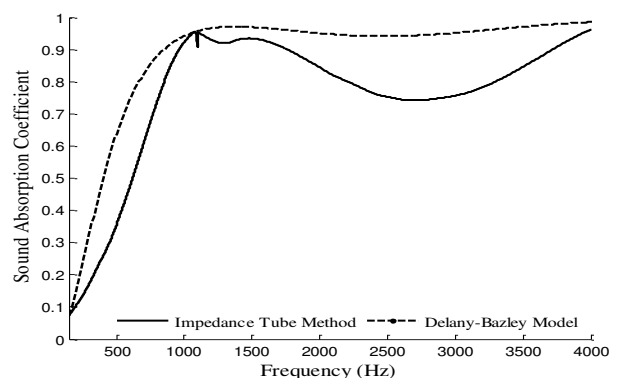
The measured results of physical properties are shown in Table-1. As seen in Table-1, percentages of PU binder were affecting the physical properties of samples. A variation of flow resistivity result demonstrated that the PU binder also effect on the bulk density and the diameter fibers. However, according to the Bies and Hansen, the results are still in the optimum value of flow resistivity which is ranging from 10000 and 40000 Nsm^{-4} . The results also showed that porosity of the samples have strong relationship between porosity and the percentages of binder and fiber. The porosity of the samples decreases by increasing the percentages of PU binder. As the percentages of fiber increase, it means creates more hollow spaces within samples and the binder wads the fiber tightly causing the pores become clogged and consequently resulting to lower porosity. The tortuosity result is inversed to porosity result. The density of samples increases as the percentages of binder were increased. It indicates that the more binders percentages the tighter and compact the material. Overall, it is apparent from these results that the percentages of binder have positive and significant effects on physical properties. However, in this investigation there are several sources for error. The error is the physical condition of the fruit after press station in the oil palm mill, the fruit size and a random arrangement of fibers during material preparation that also could be effect on the physical properties.

**Table 2.** Physical properties of oil palm Mesocarp.

| Percentages of binder | Flow resistivity (Ns/m ⁴) | Porosity | Tortuosity | Density (kg/m ³) |
|-----------------------|---------------------------------------|----------|------------|------------------------------|
| 0 | 37415.52 | 0.847 | 1.087 | 246.65 |
| 10 | 17201.09 | 0.882 | 1.065 | 266.79 |
| 20 | 17566.14 | 0.801 | 1.117 | 283.88 |
| 30 | 15594.63 | 0.766 | 1.143 | 291.73 |
| 40 | 21439.48 | 0.639 | 1.251 | 310.16 |

Acoustical properties

As seen in Figures-2-6, there are variations of SAC against frequency for oil palm Mesocarp with different percentages of PU binder at normal incidence as measured by ITM and Delany-Bazley model. From the graph, we can see that Delany-Bazley model were predicted the absorption coefficient very well in low frequency range. The discrepancy of the prediction might be due to the fact that this model is developed by a simple empirical approach and fast approximate which is using two parameters. However, Delany-Bazley model indicated the overall pattern very well. The result also presented that all samples demonstrated higher SAC at mid-high frequency range with the average of sound absorption above 0.5. The sample with 10 percent PU binder shows the best performance in most of low to mid frequency range. However, sample with 20 percent PU binder reach the high value of sound absorption which is very close to 1 at 1000 Hz. The result demonstrated 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 PU binder 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.

**Figure-2.** SAC for sample without PU binder**Figure-3.** SAC for sample with 10% PU binder.**Figure-4.** SAC for sample with 20% PU binder.**Figure-5.** SAC for sample with 30% PU binder.**Figure-6.** SAC for sample with 40% PU binder.



Effect of physical properties on sound absorption

In order to investigate the effect of physical properties on sound absorption, the noise reduction coefficient (NRC) was implemented. NRC of the samples was calculated according to Equation-14. NRC is a single number rating system for indexing absorption of a material.

$$NRC = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \quad (14)$$

It can be seen from the Table-2, the samples were above 5.0 and this indicated that all samples are highly absorptive (Cowan, 1993). The optimum value for NRC is 0.66 that produced from sample with 10% of PU binder. This value shows that the sample can absorb 66% of incident sound striking them and the rest 60% of incidence sound energy are reflected back into the space or transmitted through. The table also demonstrated that less binder contents give better absorption. On the other hand, this behavior is in agreement to the fact that by adding more percentages of PU binder will affect the physical properties and consequently give high impact on the sound absorption.

Table-2. Influence of physical properties on sound absorption.

| Percentages of PU binder | Flow resistivity (Ns/m ⁴) | Porosity | Tortuosity | Density (kg/m ³) | NRC |
|--------------------------|---------------------------------------|----------|------------|------------------------------|------|
| 0 | 37415.52 | 0.847 | 1.087 | 246.65 | 0.58 |
| 10 | 17201.09 | 0.882 | 1.065 | 266.79 | 0.66 |
| 20 | 17566.14 | 0.801 | 1.117 | 283.88 | 0.60 |
| 30 | 15594.63 | 0.766 | 1.143 | 291.73 | 0.58 |
| 40 | 21439.48 | 0.639 | 1.251 | 310.16 | 0.56 |

CONCLUSIONS

This study set out to investigate the potential of oil palm Mesocarp on sound absorption. This paper also was undertaken to determine the influence of percentage binder on physical and sound absorption properties. Two different methods were implemented to obtain the acoustic properties which is ITM and Delany-Bazley model; experimentally and analytically. The result shows that the Delany-Bazley model applicable to predict overall pattern of sound absorption coefficient. In general, it seems that PU binder not only used as binder but also improves in low frequency range. The 10% of PU binder showed optimum SAC in most of low to mid frequency range. Taken together, the results demonstrated that percentage of binder not only effect on physical properties but also effect on the sound absorption properties. According to the sustainable issue, oil palm Mesocarp was able and will be sufficiently robust overtime and not instance because of superior of its physical properties. Overall, it can be concluded that the oil palm Mesocarp natural fiber shows superior performance and proved that it have the potential to be employed for sound absorption panel in various applications.

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REFERENCES

- [1] Allard JF. (1993). Propagation of sound in porous media. Elsevier Applied Science.
- [2] Asdrubali, F., D'Alessandro, F., & Schiavoni, S. (2008). Sound absorbing properties of materials made of rubber crumbs. Journal of the Acoustical Society of America, 123(5), pp.3037.
- [3] ASTM E1050-98. Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System.
- [4] Attenborough K. (1971). The prediction of oblique-incidence behavior of fibrous absorbers. J Sound Vib, 14, pp.183-91.
- [5] Badri, K. H., Othman, Z. B., & Razali, I. M. (2005). Mechanical properties of polyurethane composites from oil palm resources. Iranian Polymer Journal, 14(5), pp.441-448.
- [6] Ballagh, K. O. (1996). Acoustical properties of wool. Applied Acoustics, 48(2), pp.101-120.
- [7] Berrigan, D. (2002). Respiratory cancer and exposure to man-made vitreous fibers: A systematic review. American Journal of Industrial Medicine, 42(4), pp.354-362.
- [8] Biot MA. (1956). Theory of propagation of elastic waves in a fluid-saturated porous solid. I. Low frequency range. J Acoust Soc Am, 28(2), pp.168-78.
- [9] Biot MA. (1956). Theory of propagation of elastic waves in a fluid-saturated porous solid. II. Higher frequency range. J Acoust Soc Am, 28(2), pp.179-91.
- [10] Cowan, J. P. (1993). Handbook of environmental acoustics. John Wiley & Sons.
- [11] Cox, T. J., & D'antonio, P. (2009). Acoustic absorbers and diffusers: theory, design and application. CRC Press.
- [12] Cuiyun, D., Guang, C., Xinbang, X., & Peisheng, L. (2012). Sound absorption characteristics of a high-



- temperature sintering porous ceramic material. *Applied Acoustics*, 73(9), pp.865-871.
- [13] Delany, M. E., & Bazley, E. N. (1970). Acoustical properties of fibrous absorbent materials. *Applied Acoustics*, 3(2), pp.105-116.
- [14] Fouladi, M. H., Ayub, M., & Nor, M. J. M. (2011). Analysis of coir fiber acoustical characteristics. *Applied Acoustics*, 72(1), pp.35-42.
- [15] Fouladi, M. H., Ayub, M., & Nor, M. J. M. (2011). Analysis of coir fiber acoustical characteristics. *Applied Acoustics*, 72(1), pp.35-42.
- [16] Ismail, L., Ghazali, M. I., Mahzan, S., & Zaidi, A. M. A. (2010). Sound absorption of Arenga Pinnata natural fiber. *World Academy of Science, Engineering and Technology*, 67, pp.804-806.
- [17] ISO 10534-2-1998. Acoustics: determination of sound absorption coefficient and impedance in impedance tubes. Part 2: Transfer-function method.
- [18] Johnson DL, Koplik J, Dashen R. (1987). Theory of dynamic permeability and tortuosity in fluid-saturated porous media. *J Fluid Mech*, 176, pp.379-402.
- [19] Koizumi, T., Tsujiuchi, N., & Adachi, A. (2002). The development of sound absorbing materials using natural bamboo fibers. *High Performance Structures and Composites*, 4, pp.157-166.
- [20] Latif, A. H., Yahya, M. N., Rafiq, Sambu. M., Ghazali, M. I & 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.
- [21] Mahzan, S., M Ahmad Zaidi, A., Arsath, N., NM Hatta, M., I Ghazali, M., & 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.
- [22] Marsh, G. M., Gula, M. J., Youk, A. O., Buchanich, J. M., Churg, A., & Colby, T. V. (2001). Historical cohort study of US man-made vitreous fiber production workers: II. Mortality from mesothelioma. *Journal of Occupational and Environmental Medicine*, 43(9), pp.757-766.
- [23] Mechanics User Manual, Acoustic Material Properties Measurement System, SCS9020B "Kundt/T60/TL Tubers"
- [24] 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.
- [25] Rapisarda, V., Loreto, C., Ledda, C., Musumeci, G., Bracci, M., Santarelli, L., & Cardile, V. (2015). Cytotoxicity, oxidative stress and genotoxicity induced by glass fibers on human alveolar epithelial cell line A549. *Toxicology in Vitro*.
- [26] Saad, M. J., & Kamal, I. (2013). Kenaf Core Particleboard and Its Sound Absorbing Properties. *Journal of Science and Technology*, 4(2), pp.23-33.
- [27] Sambu, M., Yahya, M. N., Latif, H. A., Hatta M. M. N., & Ghazali, M. I., (2015). The acoustical characteristics analysis on different type of natural fibers. *Applied Mechanics and Materials*, 774, pp.242-246.
- [28] Schmidt, A. C., Jensen, A. A., Clausen, A. U., Kamstrup, O., & Postlethwaite, D. (2004). A comparative life cycle assessment of building insulation products made of stone wool, paper wool and flax. *The International Journal of Life Cycle Assessment*, 9(1), pp.53-66.
- [29] Software User Manual, Acoustic Material Properties Measurement System, PRO-KIT 517 and PRO-DUO/TL FOR SCS9020B "Kundt/TL Tubes".
- [30] Stankevičius, V., Skripkiūnas, G., Grinys, A., & Miškinis, K. (2007). Acoustical characteristics and physical-mechanical properties of plaster with rubber waste additives. *Materials Science*, pp.304-309.
- [31] Stone, R. A., Youk, A. O., Marsh, G. M., Buchanich, J. M., & Smith, T. J. (2004). Historical cohort study of US man-made vitreous fiber production workers IX: summary of 1992 mortality follow up and analysis of respiratory system cancer among female workers. *Journal of Occupational and Environmental Medicine*, 46(1), pp.55-67.
- [32] Umnova, O., Attenborough, K., & 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.
- [33] Veerakumar, A., & Selvakumara, N. (2012). A preliminary investigation on kapok/polypropylene nonwoven composite for sound absorption. *Indian Journal of Fibre & Textile Research*, 37, pp.385-388.
- [34] Zhu, J., Zhu, H., Njuguna, J., & Abhyankar, H. (2013). Recent development of flax fibres and their reinforced composites based on different polymeric matrices. *Materials*, 6(11), pp.5171-5198.