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The Comparison of treated coco-husk composite and its applications in architectural interior

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Abstract. This research highlights the acoustical behavior comparison of treated coco-husk fibre reinforced polyesther resin (FRP) on four different treatments. The FRP made of materials with composition of polyesther resin, coco-husk fibre and catalyst as 200 ml, 25 grams and 20 ml respectively. After mixed, the dough was then poured into tabular moulding with 30 mm in diameter. The mouldings were then dismantled and shaped into two thickness groups, two samples in 15 mm and 30 mm for the rest. The method used for this study is the absorption coefficient test refer to the ASTM E-1050-98 with Bruer & Kjaer 4206 impedance tube completed with its pulse- LAN XI utilization. The result is that the best performance was showed by the coco-husk FRP with 15 mm diameter treated with eight half wavelength resonators and additional 10 mm cavity. The sound absorption resulted appeared in wide broadband frequencies comparing to other treated samples. The sound absorption peak reached up to 0.98 at 2.25kHz. This result would be a good address for the interior absorber material for building purposes as described in the end of this paper.

Keywords: **coco-husk FRP; sound absorption; wide broadband frequencies**

1 Introduction

Building materials made of natural fiber local potential has been widely studied. Natural fibers often used are banana midrib, hemp fiber, pineapple fiber, wood fiber, coconut fiber and agave fiber. Several studies have produced acoustic waffle material from coconut fiber and sawdust material produced using a hot press machine specifically designed with waffle plate. These panels have good acoustic performances, because they have absorption coefficients between 0.6-0.8 and Sound Transmission Loss between 32-54 dB[1]–[3]. But the quality of the research product needs to be refined and improved. This research will focus on the acoustic performance of natural fiber materials used as panels in building materials, especially in the acoustic field. In addition, the material treatment for the improvement of material acoustic performance is the most important part of this research.

1.1 Unporous absorber in acoustic

A huge number of studies observed porous absorber materials[4]–[8] and only a few research studied unporous absorber materials. As studied in previous research, coco-husk pressed in hot press machine could have a good performance in both absorption and transmission loss capabilities, but they had paucity in appearance quality. A research conducted by Oliva and Hongisto (2013) observed and compared the impedance tube absorption methods from seven publications on their prediction accuracy. The matrix transfer analyses were used in the frequency range between 100-3150 Hz and the results showed that the Allard and Compoux's method was the best on its prediction accuracy[8]. Studies have verified that the porous materials are valid as absorbers[5], while many unporous material such as composite and bio fibre reinforced polymer need treatment to improve absorption performance.
Many studies has observed the unporous acoustic materials[9]–[11]. A research by Zhou, et al. (2013)[12] declared that dried rubber composited with 7 holed elastomeric polyester had reached its excellent performances on absorption coefficient peak of 0.407 at 2.5kHz and concluded that the absorption properties increased inline with the increment of seven hole elastomeric polyester content. The observation of absorption properties of polymeric composite made of natural fibre was also conducted by Jayamani, et al. (2015)[13].

1.2 The role of coco-husk absorber material in acoustic

Indonesia is an marine country having a lot of coastal regions. Similar to Malaysia, Sri lanka, India, Philiphines, Hawaian Island, Fiji island, they have a huge of coconut trees and plantations[14]. All of coconut

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tree's parts have benefits for human being including the coco-husk in the outer part of the coconut shell.
As an acoustical material, the coco-husk fibre material has a lot of advantages. Many studies have learned about this material[14]–[17]. A research conducted by Zulkifli, et al. (2008)[17] did the comparative study to observe the differences of the absorption coefficient (α) and sound transmissin loss (STL) index between perforated and unperforated panel of natural organic-poly layer coco-husk fibre. The methods used were both reverberation room test and numerical data analyses, while the data based analyses of α and STL refer to ISO-354 (1985) and ISO 717-1 respectively. The results showed that the absorption coefficient ranged of 0.70-0.85 at 500-2.5kHz, while the STL had an average of 20 dB[17]. Other research conducted by Huang,et al. (2013)[18] studied the effectiveness of coco-husk non-woven composite board on the damping performance and thermal insulation. The study compared two kinds of PET/Coconut fibre (CF) composite panels produced by poly-needle-punching technique and laminated by 2D-PETF (2D-polyester non-woven fabric) and 12D-PETF respectively. The result revealed that the absorption coefficient increased by the increment of the coconut fibre content in the composite[18].
The acoustic characteristics of coir/coco-fibre and coco-shell have also been done by researchers[5], [7], [15], [16], [19]. A research conducted by Fouladi, et al. (2011)[16] observed the comparison on absorption coefficient of coco-fibre material between fresh coco-fibre from the wet market and fabricated one with binder. The Delaney-Bazley and Biot-Allard analyses were used to analyze the characteristics of both models, while the experimental data from the impedance tube were used to validate the analytical results. The results showed that the coir fibre from wet market with thickness 20 mm had absorption coefficient average of 0.80 starting from 1.36kHz and the additional thickness can significantly improve the absorption coefficient average. The study has also noted that to increase the durability of coir fibre material, it need coating and lamination to anticipate fungus and flammability as well as to increase the stiffeness.
The uniqueness research was conducted by Indrawati and Suyatno (2017)[15], when they observed innovative panels made of coco-shell in the reverberation room model. The coco-shell has rarely been utilized in acoustical field due to their often wastely in shape, but it was often used as decoration by the craftmans. This study observed the coco-shell creative panel installed in the reverberation room model as both absorber and reflectors. The four types of panels covering the convex and the convay coco-shell panel with perforated and unperforated treatments were investigated. The ISO-354 was used to analyze the acoustical performance of the panels and the result revealed that the absorption coefficient of the convex coco-shell panel is greater than the convay one (at 1kHz and 4kHz) due to the damping phenomenon on the shape to collect, receive and reduce sound energy.
The pure coco-fibre were tested on its acoustical performances by the study conducted by Berardi and Iannace (2015)[5]. As we know, that the coconut trees have many kind of species, they have white, green and brown in their husk, but the Benardi and Iannace's research used only the brown coco-husk for the investigation. The coco-husk has average diameter of 250µm that is bigger than any other natural fibres. The study noted that an airflow resistivity of the coco-husk with thickness of 19 mm and density of 128 kg/m3 was 2.6 kNs/m2, while it had 1.9 kNs/m2 and 1.2 kNs/m2 for the thickness of 29 mm and 42 mm respectively. Lastly, comparing to the Zulkifli,et al.[17] and the Fouladi,et al.[16] the conclusion are verified significantly accurate using the Dellaney-Bazley prediction model. For the sample with thickness 50 mm, the theoritical model was usually accurate in the frequency 2kHz and the prediction was less accurate in the lower frequencies, while for the sample with 100 mm on thickness, the theoritical model was highly accurate in the frequency band of 1kHz and 2kHz and at low frequencies, the measured resonance absorption at 0.5kHz was ignored in the theoritical model, although the model was able to predict a simple absorption in 0.5kHz frequency band.

2 Methods

This study used impedance tube to observe the absorption coefficient of materials. The coco-husk was put from southern part region of central java province where coco-trees (cocos nucifera) become the most important comodity in Indonesia. The coco-husk was collected and dried under two sunny days and then filetered in 0.5 mm. The dough of polyesther resin, coco fibre and methyl ethyl keton peroxide as 200 ml, 25 grams, 20 ml respectively was stirred and poured into tubular moulding with 30 mm in diameter. After 24 hours, the mouldings were dismantled and shaped into two groups in thickness, two samples in 15 mm and 30 mm for the rest of two. The samples were then holed in 8 resonator holes and treated with fibrous layer and air gaps. The group of sample can be identified as listed in the table below:

Table 1. Samples of coco-FRP observed on the absorption test and densities

Thickness	Diameter	Treatment	Code of sample	Density (gram/cm^3)
15 mm	30 mm	Foam, cavity 10 mm	A8HFC1	0.2525
	30 mm	Cavity 10 mm	B8HC1	0.2525
30 mm	30 mm	Foam, cavity 10 mm	C8HFC1	0.2481
	30 mm	Cavity 10 mm	D8HC1	0.2481

The absorption test used the impedance tube of Bruer & Kjaer 4206 equipped with pulse-LAN XI utilization. The procedure of the absorption coefficient test referred to the ASTM 1050-98. Sporadic noise was generated from the loudspeaker in the impedance tube and propagated along the tube before it bowed the samples surface. The transfer function anslysis was used when the two ¼ inch 4187 B&K microphones seized these two incidents, recorded it and tossed wave before it decayed. The energy decayed must be equalled with the absorption performance of the sample material. The H_{12} as the frequence response function and the coefficient of reflection R can be calculated by the following equations[20]:

$$H_{12} = \frac{P_2}{P_1} = \frac{e^{jkh} + e^{-jkh}}{e^{jk(h+s)} + e^{-jk(h+s)}} \quad (1)$$

and then[20],

$$R = \frac{H_{12} - e^{jks}}{e^{jks} - H_{12}} e^{j2k(h+s)} \quad (2)$$

The P1 and P2 represents sound pressure level captured by the two 4187 B&K microphones, while k is number of wave and s is the distance between microphone to sample and the distance between two microphones respectively. The absorption coefficient (α) can be obtained by calculating the R with the following equation[20]:

$$\alpha = 1 - [R]^2 \quad (3)$$

3 Results and discussion

As mentioned in the methods that the absorption coefficient was obtained by using the two microphone B&K impedance tube. The result of the original absorption coefficient of materials before treatment are depicted in the graph and table below:

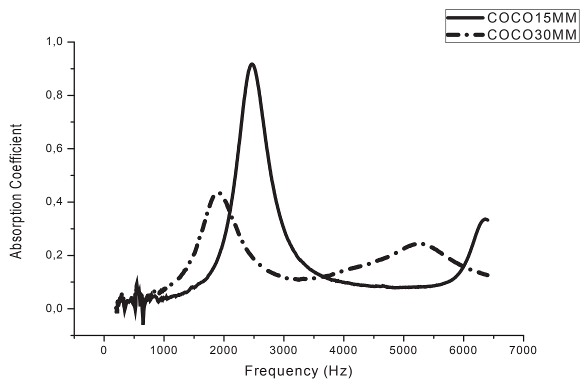

Figure 1. The absorption coefficient result of coco-FRP before treatment

The raw material of the coco-FRP is dried coco-husk and the binder is unsaturated polyester resin with catalyst. The absorption coefficient tends to be similar to the result made by Fouladi,et al. (2016)[16] which the peak of 15 mm coco-husk panel is in 0.92 at 2.5kHz, while the peak of 15 mm coco-FRP is lower than that of the 30 mm coco-FRP. Having lower density than the 15 mm coco-FRP, the 30 mm coco-FRP has its peak of absorption coefficient of 0.41 at 2kHz (see fig.1 and table 2).

Table 2. The absorption coefficient result of coco-FRP before treatment

Frequency (Hz)	Coco-FRP 15 mm	Coco-FRP 30 mm
200	-0,01139	0,00349
256	0,02567	0,02943
504	0,00994	0,01693
1000	0,03926	0,07277
1504	0,07897	0,20597
1752	0,12792	0,37972
2000	0,25914	0,41342
2256	0,62344	0,2768
2472	0,91736	0,19361
2504	0,90604	0,18511
2752	0,54718	0,14012
3000	0,29922	0,11776
4000	0,09943	0,14351
5000	0,08042	0,22513
5504	0,0863	0,22563
6400	0,33286	0,126

The result showed that the coco-FRP with thickness of 15 mm has a greater absorption coefficient because it can qicken the loss of sound energy, while the coco-FRP with thickness of 30 mm saved the sound energy longer than that of the 15 mm coco-FRP.

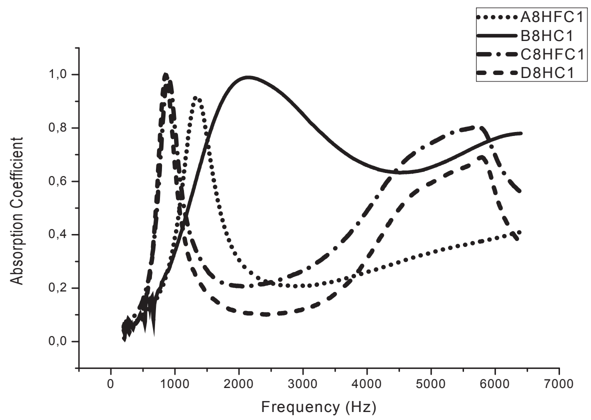

Figure 2. The absorption coefficient result of coco-FRP after treatment with fibrous layer, resonators and cavity

The graph in figure 2 shows four different kind of treatment of both coco-FRP with thickness 15 mm and 30 mm. The absorption performance of the coco-FRP 15 mm was represented by A8HFC1(short dot line) and B8HC1 (continuous one). Although the 15 mm coco-FRP was blocked by fibrous layer (see A8HFC1), its damping performance is lower than B8HC1 because the 8 quarter wavelength resonators performance were covered by the fibrous layer. The 15 mm coco-FRP without fibrous layer (B8HC1) shows the excellent performance with wide broadband frequencies due to the efficacy of the resonators.

Table 3. The absorption coefficient result of coco-FRP after treatment

Frequency (Hz)	A8HFC1	B8HC1	C8HFC1	D8HC1
200	0,05218	0,01249	0,05782	0,04233
256	0,05304	0,04599	0,07031	0,04521
504	0,10073	0,08359	0,16015	0,12262
1000	0,3906	0,33844	0,79816	0,65424
1752	0,44667	0,90737	0,21933	0,13245
2000	0,30554	0,98022	0,20829	0,11148
2256	0,24485	0,98564	0,21013	0,10476
2472	0,22079	0,96166	0,22043	0,10131
2504	0,21894	0,95704	0,22239	0,10154
2752	0,2089	0,91107	0,2404	0,10821
3000	0,20799	0,85075	0,2664	0,12075
4000	0,25939	0,66022	0,48921	0,31083
5000	0,33264	0,65272	0,74323	0,59392
5504	0,36197	0,70639	0,7939	0,65099
6000	0,38658	0,76056	0,69651	0,55919
6400	0,4099	0,77962	0,55944	0,36776

The peak of the 15 mm coco-FRP without fibrous layer (see fig. 2 on B8HC1 and table 3) is 0.96 at 2.5kHz. The absorption behavior of the 30 mm coco-FRP is represented by C8HFC1 (short dash-dot line) and D8HC1 (short dash line). Unlike the 15 mm coco-FRP, both 30 mm coco-FRP samples show similar pattern with poroused 30 mm coco-FRP (a sample covered by fibrous layer) has a little bit greater on damping performance than the one without fibrous layer (D8HC1). The phenomenon occurs because the fibrous layer upgrade the damping performance of the C8HFC1. In other words, the resonators in the 30 mm coco-FRP is not as effective as they are in the 15 mm coco-FRP, because the thicker the sample the longer the energy saved in the materials.

After covered by the fibrous layer (C8HFC1) the absorption coefficient of the 30 mm coco-FRP increased and had its peak of 0.97 at 0.9kHz. On the other hand, the 30 mm coco-FRP without fibrous layer (D8HC1) had only 0.80 at 1.0kHz (see graph in fig. 2 and table 3).

4 Applications in architecture

The application in the architectural design depend on the functional variables in the building. In general, the coco-husk material could be applied in many ways to obtain the best performances in the acoustical parametric aspects. Many studies discussed the design of acoustical materials[21]–[29]. The proposed model was validated by the Finite Element (FE) simulations in the damping performances under normal occurence. The result identified that the damping performances varies and were influenced by the dimension of the resonators and the thickness of the panel. Other study by Azzimi (2017)[30] discuss absorbing materials for building to reduce the noise emitted by traffic, industri and growing population in modern cities. The study suggest three categories of sustainable absorber materials consist of natural materials, recycled materials and mixed-composited materials. A sustainable material themed research conducted by Buratti, et al. (2016)[26] discuss about recycled absorber panels made of paper waste, other scrap material such as wool and non-woven polyester fabric. These materials were tested on their absorption coefficient by the impedance tube methods refer to ISO-10534-2.

Figure 3. The coco-FRP and other natural fibers for building applications

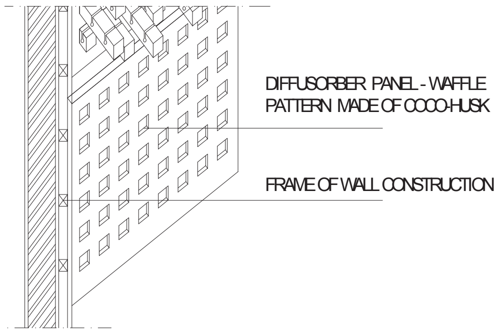

Figure 4. The detail of wall construction with coco-FRP for diffuser-absorber

Figure 3 and 4 describe the application of the coco-FRP in buildings in this research. Refer to the literature review and what have been conducted in the road map of research, it could be noted that the coco-FRP and other innovative product made of coco-husk and coco-shell are very useful for acoustical purposes in buildings and many sciences.

5 Conclusion

This paper hightlights the absorption coefficient performance of four kinds treated coco- Fiber Reinforced Polyester (coco-FRP). The method used in this research was the two microphones procedure of the Bruer & Kjaer 4206 impedance tube method equipped with pulse LAN-XI utilization. Using comparative analyses with graphical visualization of Origin-8, the results revealed that the 15 mm coco-FRP without fibrous layering coded by B8HC1 (in fig.2) is the best performance on the damping behavior. According to the eksperimental data from the impedance tube, it can be concluded that the 15 mm coco-FRP without fibrous layer has a peak of damping performance of 0.96 at 2.5kHz. The eight quarter wavelength resonators have a role to upgrade the absorption performance of the material.

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