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The Potential of Chaff Insulation Panel for Sound Absorption and Thermal Properties

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Abstract: Rice husk is a common agricultural waste product in places where rice is grown. Rice husk (chaff) is an agricultural waste that is not used and will usually be eliminated by burning. If this potential waste is not handled properly, it might cause environmental problems. This study aims to produce insulating material for the energy conservation of the building. The insulating material was prepared from rice husk by mixing with hydraulic lime (binder). Five sample was prepared with different proportional of rice husk and hydraulic lime by using cold and hot pressed. From that, two samples were selected with the ratio of rice husk to lime are 1:4 (Sample A) and ratio 1:3 (Sample B) for further testing. The sample was then investigated for thermal conductivity and sound absorption coefficient. The result obtained for the Sample A is k = 0.088 W/mK and for Sample B is k = 0.077 W/mK. For sound absorption coefficient, α the results were promising for both samples, especially for high frequencies above 2500 Hz, when the maximum values are 0.82 at 3150 Hz for Sample A and 0.85 at 4000 Hz for Sample B, with noise reduction coefficient equal to 0.33 and 0.24, respectively. The chaff insulation panel have a low thermal conductivity and show a better sound insulation than standard gypsum board which recorded 0.85 sound absorption coefficient at 4000 Hz that is near to 1 which make this product a good insulation panel. Comparison with standard gypsum boards also indicates that the Chaff insulation panel is better in terms of thermal resistance and along with acoustic properties.

Keywords: Rice husk, Hydraulic lime, Thermal conductivity, Sound Absorption Coefficient

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1. Introduction

Malaysia generates large agricultural waste, such as rice husks, sugarcane, and palm oil sacks. These compounds frequently cause issues during disposal, resulting in environmental damage. Various research has been done to discover the potential for transforming agricultural waste into a commercially valuable substance. Rice husk is a natural filler with many advantages over inorganic fillers as it is biodegradable, has low cost and is recyclable. However, the dumping of rice husk makes it too complicated to dispose of, so many farmers eventually take a short time by doing open burning. By burning rice husks under certain temperatures and atmosphere, highly reactive Rice husk ash will be obtained [1].

Thermal insulation made from renewable fibers produced from trees, plants, or animals has low environmental impact and production costs. Reduced thermal conductivity is a need for thermal insulation materials, as is resistance to mold and moisture as well as fire resistance. In addition, the effects on the environment and human health must be considered [2]. Hemp fiber insulation, with thermal conductivity of 0.38 to 0.40 W/mK, is one of the best options. It is possible to construct a whole house entirely out of lime-hemp construction material, eliminating the need for bricks or any other form of traditional thermal insulation [3]. Rice husks are one of the most common agro-industrial waste materials. Around the world, about 700 million metric tonnes of rice are produced each year. Burning or transporting it to a landfill can have significant environmental consequences. Some research has shown that rice husk may be used as a component in high-value materials such as thermal insulation and lightweight concrete [4].

Therefore, this study aims to investigate the potential of rice husk as panel insulation for acoustic and thermal. Hence, to identify the suitable ratio between rice husk and hydraulic lime as a binder for insulation panel and to determine the acoustic and thermal properties of the panel. Furthermore, this study also compares chaff insulation panels with standard gypsum board and previous studies. A competitive insulating material must also have solid acoustic performance regarding sound insulation, a low environmental impact, and cheap production cost [5].

1.1 Problem Statement

Malaysia produces substantial amounts of agricultural waste, including rice husks, sugarcane, and palm oil sacks. The disposal of these substances usually causes environmental harm. Recent studies have explored the possibility of repurposing agricultural waste into an economically viable material [1].

Current requirements for building insulation are constantly increasing, not only in terms of the technical properties of the material used but also in terms of the environmental burden. Rice husks, like hemp hurds, will be deemed natural aggregates and repurposed as raw materials in this respect. This opens us the possibility of developing a new construction material from locally sourced agricultural waste. Hemp is grown as a break crop and harvested after four months. Rice husks, on the other hand, do not need to be ground to separate the husks from the hulls since they are utilized as they are [6]. In addition, thermal characteristics of rice husk were studied using the transient heat flow technique and found to be suitable for usage in heat resistant materials [7].

Recently, researchers are looking for new ways to reduce waste in thermal and acoustic contexts. New insulation solutions that use recycled and discarded materials are becoming increasingly prevalent in the marketplace. Products made from sustainable materials give environmental, social, and economic advantages while conserving the environment [8].

1.2 Objective

i. To identify the suitable ratio between rice husk (chaff) and hydraulic lime (binder) for the panels.

ii. To determine the acoustic properties and thermal properties of panels.
iii. To compare the acoustic properties and thermal properties between panels and standard gypsum board.

1.3 Scope of the study and limitation

The study's scope is restricted to:

i. The scope of this investigation is based on a wall insulation panel using rice husk (chaff) and hydraulic lime (binder) to investigate the performance of the process.
ii. Chaff insulation samples were made using a (300 mm x 300 mm) and (100 mm, 28 mm dia.) mould with a thickness of 10 mm, which was hot pressed and cold pressed.
iii. Thermal and sound absorption will be tested with the use of thermal apparatus and an impedance tube, both of which are model HE110 according to ASTM C177 and model AED 1000 according to ASTM E 1050-10, respectively.
iv. During this study, the differences between a 1:4 sample and a 1:3 sample will be evaluated.
v. The result from the data analysis of the samples will be compared with standard gypsum board.

2. Methodology

Figure 1 illustrates a flowchart that might be used to demonstrate the study's research techniques and testing procedure more precisely and efficiently. To conduct this study, a chaff insulation sample will be produced. There will be other samples made if the results are not satisfactory, and this process will be repeated until a satisfactory ratio and result are achieved.

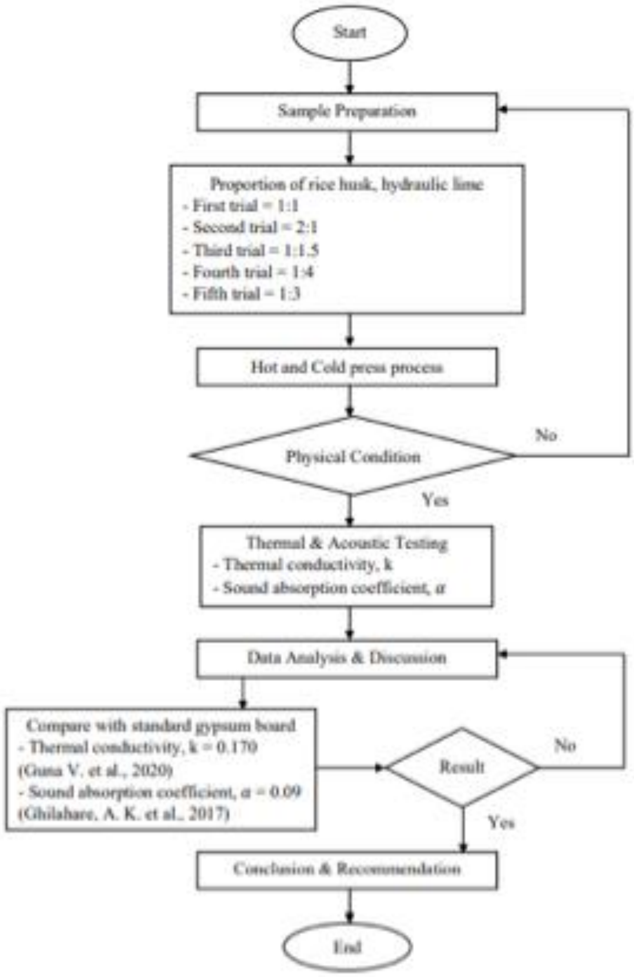

Figure 1: Research flowchart

2.1 Method of data collection

Experiments were conducted in the acoustic room of the Building Services Engineering Technology Laboratory and Composite Engineering Technology Workshop at the Universiti Tun Hussein Onn Malaysia, Pagoh. Hot and cold press machines were employed to compress and dry the mould samples. The quantitative data were compiled, and all sample data were evaluated and debated.

2.2 Raw material preparation

Preparation of samples is critical since it determines the correct proportion and quality. Samples are created when the material preparation procedure is completed. Based on Table 1, several samples were prepared to see which one had the best thermal conductivity and sound absorption coefficient. The samples were compacted in a hot press machine at 100 °C and then moved to a cold press machine to be evenly compacted inside the mould. Figure 2 (a) and Figure 2 (b) shows the raw material for samples preparation.

(a) (b)

Figure 2: (a) Rice husk, (b) Hydraulic lime

Table 1: Proportion of samples

Sample	Ratio	Material	
		Rice Husk	Hydraulic Lime
A	1:4	250 g	1 kg
B	1:3	333 g	1 kg

The method for sample preparation are as follow:

i. Prepare two mix proportions: 1 kg of hydraulic lime, 250 g of rice husk with the ratio of 1:4 and 1 kg of hydraulic lime, 333 g of rice husk with the ratio of 1:3. Mix the proportions and pour mixture into the mould until reach the upper surface.
ii. Next, switch on the hot/cold press machine and setting the pressure and temperature by referring to the manual book. After that, put sample in the hot press machine to be compressed and then transfer sample to cold press machine.
iii. With this method, a compact and smooth surface sample can be easily achieved.

2.4 Thermal Conductivity according to ASTM C177

The thermal conductivity test in this study was conducted using Thermal Conductivity of Building Material Apparatus (Model: HE 110) located at Building Services Engineering Technology Laboratory at UTHM Pagoh campus. The sample's thermal conductivity was determined in accordance with ISO 8302:1991 and ASTM C177 standards by measuring the heat rate required to keep the hot plate at a constant temperature after the cold plate's temperature was controlled using a chiller and steady-state conditions were established. The sample in this study is with a cross section of 300 mm x 300 mm and a thickness of 10 mm, will be sandwiched between two metallic substrates, a hot and cold plate. The temperature of the hot plate was constantly set to 50 °C throughout the experiment. All measurements are displayed on digital indicators as shown in Figure 3. Thermal conductivity value in steady state was calculated by using Eq. 1.

$$\text{Thermal conductivity, k} = -\frac{qx}{A(T_2 - T_1)}\ \text{[W/mK]} \qquad Eq.1$$

Figure 3: Thermal Conductivity of Building Materials Apparatus (Model: HE110)

2.5 Sound Absorption Coefficient Test according to ASTM E 1050-10

Based on Figure 4, the sound absorption coefficient was determined using an AED 1000 acoustic impedance tube with two fixed microphones, in accordance with ISO 10534-2 and ASTM E 1050-10 standards for samples with 100 mm and 28 mm diameters. The value of the air space and the thickness of the supporting material determines how much of the acoustic energy of the incident wave is absorbed by the tested sample.

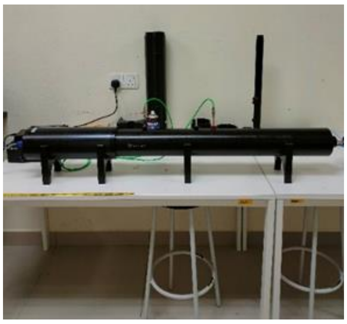

Figure 4: Impedance tube (Model: AED 1000)

3. Data Analysis and Discussion

Data were obtained from two types of testing which are thermal and acoustical testing. Two samples were selected with the ratio of rice husk to lime are 1:4 (Sample A) and ratio 1:3 (Sample B) for further testing from the trial proportion of rice husk and hydraulic lime as discussed in Subtopic 3.1.

3.1 Trial proportions

Trial proportions in this study are important in determining the most suitable ratio of rice husk and hydraulic lime to be used to produce the most compact, great physical panel. In this study, the first three samples were made to configure which is the most suitable ratio to be used in making the wall panel. Then, two samples were made with the suitable ratio for further testing. From Table 3.1, five trials have been made and it shows that samples with the ratio 1:4 and 1:3 were found the best sample.

Table 2: Trial proportions

Trial	Proportion	Method	Result
1	1:1	Hot pressed	A first trial sample casts into the formwork with the manual tamping method. The result for the first trial sample was not great. It is because the surface is too brittle, and the layer of binder can be seen. It shows that the mixture does not well mixed because of too much rice husk.
2	2:1	Hot pressed	Binder has been added. The result for the second trial sample showed the binder overflowing after being removed from the hot press machine. After dried, the sample was split into two parts.
3	1:1.5	Hot pressed	After dried, the result for the third trial sample showed the upper surface was well compacted, but the bottom layer was too brittle.
4	1:4	Cold pressed	Cold press has been suggested. The result show the best condition in terms of surface, durability and compactness.
5	1:3	Cold pressed	A 1:3 ratio samples have been produced and resulting in great physical condition. Then, both successful samples will be analysed and compared with a standard gypsum board.

3.2 Data testing

From the samples trial, two samples ratio were selected for further testing; the ratio of rice husk to lime is 1:4 (Sample A) and 1:3 (Sample B). The thermal conductivity and sound absorption coefficient tests (low and high frequency) were conducted.

3.2.1 Thermal Conductivity

Thermal conductivity was tested by Thermal Conductivity of Building Materials Apparatus (Model: HE110). The result for thermal conductivity is shown in Table 3.2 below.

Table 3: Results for thermal conductivity test

Material:	Rice husk (chaff) + Hydraulic lime (binder)						
Thickness, x:	0.01 m						
Area, A:	0.09 m²						
Sample	**Heat flow density, (W/m²)**	**Hot plate temp., T_h (°C)**	**Cool plate temp., T_c (°C)**	**Temp. difference, ΔT (°C)**	**Thermal conductivity, k (W/m °C)**	**Heat transfer rate, q (W)**	**Thermal resistance, R_{th}**
A	237	57.3	30.2	27.1	0.088	21.33	1.271
B	213	57.4	29.8	27.6	0.077	19.17	1.440

The thermal conductivity of a mixture changes depending on the mixture's composition. The result of thermal conductivity for Sample A is 0.088 W/mK and for Sample B is 0.077 W/mK. Sample B has the lower k-value of 0.077 W/mK than sample A. In previous research, hemp insulating materials exhibit good thermal insulating properties, with the k-value of 0.095 W/mK [9] and for standard gypsum board, the k-value is 0.170 W/mK. So, the thermal conductivity rating of chaff insulation is superior to that of the other types of insulation.

Increased of rice husk concentration led to a reduction in thermal conductivity. Smaller particle fillers have been shown to increase thermal insulation over larger filler sizes, which is a welcome development [10]. On the other hand, Sample B is an excellent insulator because low thermal conductivity materials minimise heat transfer in and out of the building, maximise material capacity and operating expenses, and reduce energy usage.

3.2.2 Sound Absorption Coefficient

Figures 5 and Figure 6 shows the absorption coefficients for each frequency for each sample. Lower frequencies are absorbed by chaff insulation samples, primarily between 80 and 400 Hz, whereas higher frequencies, between 1000 and 5000 Hz, are absorbed by the samples.

The 100 mm diameter test samples were tested to obtain the sound absorption coefficient. Figure 5 shows the sound absorption coefficient curves calculated experimentally for Sample A and Sample B respectively. It was found that Sample A with the lower percentage of rice husk has a higher sound absorption coefficient. The sound absorption values for both samples are not significant (below 0.6) having noise reduction values (NRC) of 0.040 and 0.033, with maximum sound absorption coefficients of 0.077 at 400 Hz and 0.055 at 400 Hz for Sample A and Sample B respectively.

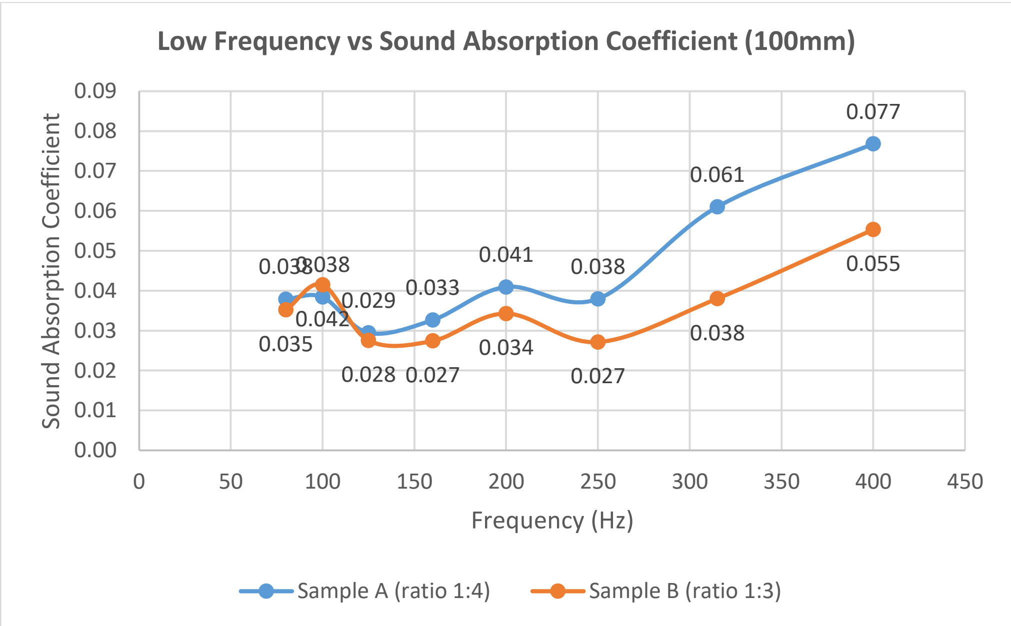

Figure 5: Sound absorption coefficient of low frequency

The 28 mm diameter test samples were tested to obtain the sound absorption coefficient. Figure 3.2 shows the sound absorption coefficient curves calculated experimentally for Sample A and Sample B respectively. It was found that Sample B with the higher percentage of rice husk has a higher sound absorption coefficient. The sound absorption values for both samples are significant (above 0.6) having NRC values of 0.331 and 0.244, with maximum sound absorption coefficients of 0.82 at 3150 Hz and 0.85 at 4000 Hz for Sample A and Sample B respectively. The results were promising, especially for frequencies above 2500 Hz, when the maximum values are 0.82 at 3150 Hz and 0.85 at 4000 Hz, with NRC equal to 0.33 and 0.24 respectively.

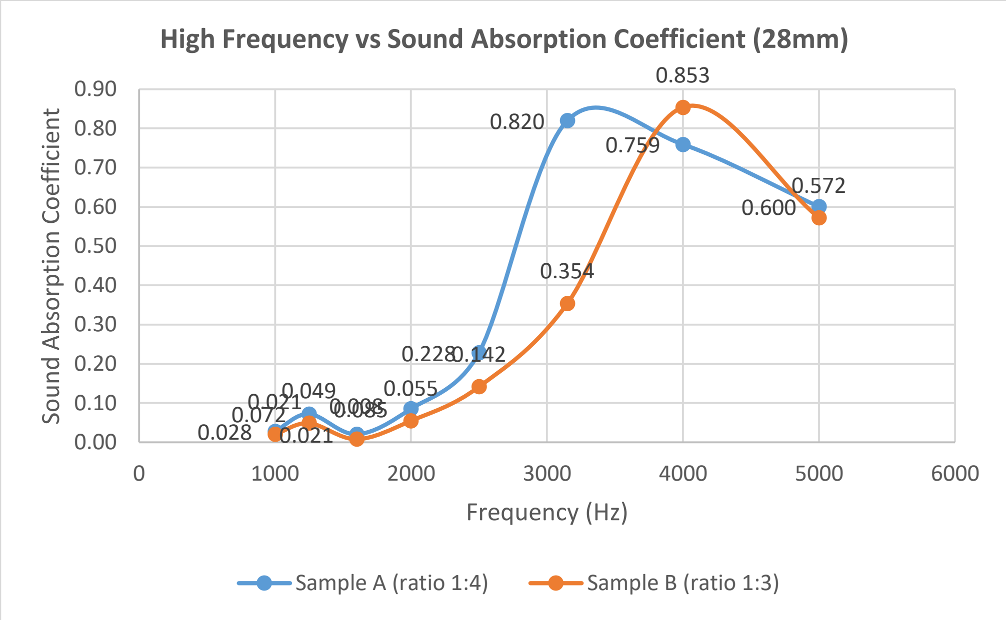

Figure 6: Sound absorption coefficient of high frequency

3.3 Comparison

For both sample, comparison was carried out with standard gypsum board as despite in Table 4. For low frequency, the sound absorption coefficient at 500 Hz for a gypsum board with fibre insulation is 0.050 [11], whereas the sound absorption coefficient at 400 Hz for the chaff insulation panel is 0.077. Therefore, there is no significant difference between the gypsum board and chaff insulation panel regarding the sound absorption coefficient at low frequencies. Next, for high frequency, the sound absorption coefficient of gypsum board at 4000 Hz is 0.09 [11], whereas the sound absorption coefficient of chaff insulation panel at 4000 Hz is 0.85. It shows great potential in terms of sound absorber at high frequency.

Table 4: Comparison between different ratio of chaff insulation and gypsum board

Product / Parameter	Thermal Conductivity, k (W/mK)	Sound Absorption Coefficient, α	
		Low frequency	High frequency
Chaff insulation (1:4)	0.088	0.077	0.82
Chaff insulation (1:3)	0.077	0.055	0.85
Gypsum Board	0.170 (Guna V. et al., 2020)	0.050 (Ghilahare, A. K. et al., 2017)	0.09 (Ghilahare, A. K. et al., 2017)

As a result, rice husk and hydraulic lime-bonded insulation panels are a better and more efficient alternative to gypsum board as a thermal insulator and sound absorber. Chaff insulation might be used as panel insulation because of its low thermal conductivity and high sound absorption. The results demonstrate that the chaff insulation panel may be utilised as a substitute material for thermal resistance and sound absorption in non-structural building applications, such as ceilings, wall sheathing, and interior wall surfaces.

4. Conclusion

Overall, the objectives of this study were accomplished. The ratio of 1:3 of rice husk to hydraulic lime is an excellent thermal resistance. Meanwhile, both ratios (1:3 and 1:4) are promising for sound absorption, especially for high frequencies. Based on the result, chaff insulation has a lower k-value of 0.077 than standard gypsum board k-value of 0.170 in terms of thermal conductivity. For sound absorption coefficient, α, chaff insulation with 0.85 has a higher value than standard gypsum board with 0.09 in terms of high frequency. Comparison with standard gypsum boards also indicates that the Chaff panel is better in terms of thermal resistance and acoustic properties.

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