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Development Sandwich Wall Panel by Using Recycled Paper for Thermal and Acoustic Properties

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Abstract: Every month, about 57,000 tonnes of paper are dumped in Malaysian landfills. Thus, this thesis aimed to recycle paper waste combined with resin as a binder to produce a Middle core of Sandwich Wall Panel (SWP), thereby minimizing environmental contamination caused by waste material disposal. The study's objective is to determine an optimum ratio of paper waste and resin and evaluate the materials' physical, acoustic, and thermal conductivity. The study's objective is to determine an optimum ratio of paper waste and resin and evaluate the materials' physical, acoustic, and thermal conductivity. According to the result, the density of 30 mm panel paper is 475.93 kg/m^3, while that of 15 mm has a density of 437.40 kg/m^3. For the impedance tube test, the results show that panel paper is more inclined to high frequency of 0.730 Hz for 30 mm and 15 mm panel paper reaches 0.626 Hz at a distance of 1000 Hz - 5000 Hz. Then, based on the result found 30 mm panel paper has a thermal conductivity of 0.012 Wm/K and a thermal conductivity of 15 mm is 0.011 Wm/K. Comparing to the rice husk, the maximum values are about 0.74 and 0.91 while paper panel the best maximum values sound absorption coefficient is about 0.730 and 0.679 at 1000 Hz to 1000 Hz to 5000 Hz. Due to the difference in thickness between the two materials causing the paper to be less efficient than a rice husk. The proportion was (67.00 %) recycled paper and (33.00 %) resin was used as the binder in SWP manufacturing. Sound absorption and thermal conductivity are affected by thickness density. Density improves efficiency. In other words, panel paper can be used for sound absorption but must be improved to match the rice husk's performance.

Keywords: Sandwich Wall Panel, Panel Paper, Waste material, Density, Sound Absorption, Thermal Conductivity

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1. Introduction

The sandwich wall panel is constructed of three distinct materials that are put together to form a single panel. Sandwich wall panels are used in a variety of construction applications, including the construction of building walls. Sandwich wall panels are also known as composite panels due to their composition of several materials. Sandwich wall panels are named for the arrangement of the panels. The panels are made up of three fundamental components: two outward-facing layers and a thick core; the two outer panels serve as the sandwich's "bread," while the core contains the meat. [1] This project focuses on the core of the sandwich wall panel, which uses recycled paper to create a new product in the Sandwich Wall Panel project. Wastepaper contributes to low-cost, eco-friendly, and thus sustainable design. In India, just a small percentage of paper gets recycled each year. This means that the rest is still disposed of, mostly ending up in landfills for slow degradation and capacity consumption of dumpsites. Conservatively speaking, it takes about 15 trees to make 1 ton of paper [2]. As it is recycled material, there is a benefit in embodied energy due to reutilization. It has good thermal and sound insulation properties. [2] Thermal testing is a method of testing a materials ability to operate safely at different temperatures. Data gathered by thermal tests allow users of products to understand its safe operating limits, as well as gain more information about the material’s general characteristics and potential lifespan. [3] While, Acoustics is the study of sound, noise, and vibration. Understanding the acoustical performance of your product is important because windows, doors, and walls in a house need to diminish the transfer of unwanted sound into living areas. Acoustical testing helps diminish high levels of noise from traffic, neighbors, and other sources. Acoustical testing helps product manufacturers determine these values. [4]

This review are done to identify the previous researchers who studied sandwich wall panel by using paper. It also to anylyze the density, sound absorption coefficient and thermal conductivity for the product sandwich wall panel by using paper and to propose the best properties of using paper as core in sandwich wall panel.

2. Materials and Methods

There are various ways of research method, testing and procedures in testing the panel, but to achieve the objective of this study, only three methods has been focused that is by evaluate the test such physical, acoustical and thermal conductivity. Therefore, in this part, it will explain about the process used along with an overview so that it is more detailed. Figure 1 shows the methodology chart for this study.

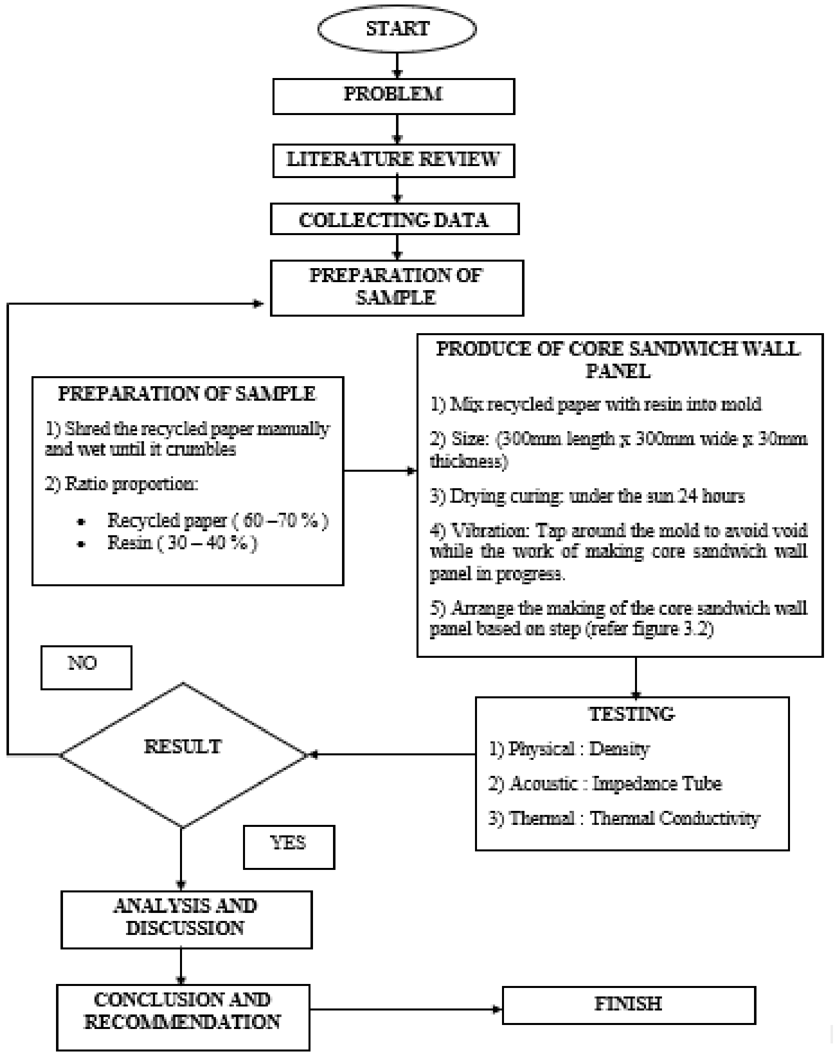

Figure 1: Methodology chart

2.1 Materials

In this study there are 3 materials used in Middle core for Sandwich wall panel such recycle paper, Resin and Wire mesh.

2.1.1 Recycled Paper

Paper is made of cellulose fibers, which are combined with a number of chemicals that determine the properties and quality of the paper, as well as chemicals for bleaching the cellulose. Paper and cardboard make up a significant portion of total waste, accounting for roughly 10% of total municipal solid waste [6] . As already known, paper and its waste are easily degradable in nature and recyclable.

2.1.2 Resin

Resin is the name given to a two- component natural organic compound that exists in liquid form. When resin is combined with a hardener a chemical reaction takes place binding the molecules of the resin forming a solid, durable plastic substance. Resin can be molded into various shapes and forms and is used in many DIY, or craft projects but is also used in industrial and commercial projects.

2.1.3 Wire Mesh

Wire mesh, also known as wire cloth or wire fabric, is an extremely versatile product that has thousands of different applications throughout the world. Edward J. Darby & Son, Inc. prides itself on maintaining one of the most complete and extensive wire mesh inventories in the United States. There are endless combinations of opening sizes and diameter wires that can be produced, either in a woven or welded construction.

2.2 Trial Proportion

In the study to make the product of the middle part of the sandwich wall panel, there are several proportions done to find the suitable proportions of combination of recycled paper and resin samples as shown in the Table 1.

Table 1: Proportion of combination of recycled paper and resin samples

Samples	Picture	Proportion	Result
1		67:33 Paper Recycled and Resin	The combination of Recycled Paper and Resin as binder is in good condition and there is a honeycomb on the top and bottom surfaces of the object
2		50:50 Recycled Paper and Resin	The combination of Recycled Paper and Resin as binder is in good condition but too dense and lacking some honeycomb on the upper and lower surfaces of the object
3		70:30 Resin and Recycled Paper	The combination of Recycled Paper and Resin as binder in good condition has honeycomb on the top and bottom surfaces of the object but is too dense and the use of excessive resin.

2.3 Methods

In order to obtained data, 3 tests have been performed including physical density, sound absorption and thermal conductivity as mentioned in the passage below

2.3.1 Density

Bulk density is the ratio of the total mass of the sample and its volume. Figure 2 shows Physical test to identify the density on Paper panel.

Figure 2: Density Test

2.3.2 Sound Absorption Coefficient

Sound absorption coefficient can be tested through AED 1000 Acoustic Tube Impedance Tube with two fixed microphones shown in Figure 3.

Figure 3: Impedance Tube Test with two fixed microphones

2.3.3 Thermal Conductivity

The square panel of 300 x 300 mm x 30 mm and 300 x 300 x 15 mm of Recycled Paper shows the sample testing and the sample was produced in the laboratory in Figure 4.

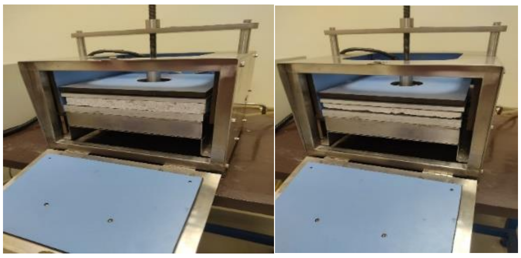

Figure 4: Thermal Conductivity Test

2.4 Equations

In this study there are several calculations, among which are involved are physical density and thermal conductivity

2.4.1 Physical Density

The sound absorption coefficient was increased as the density of the sample increase. The samples with 300 mm x 300 mm panel, 100 mm and 29 mm diameter were cut out randomly and weight. A few observations were taken for each sample and expressed in kg/m3. A density used to be calculated by using the following equation:

$$Density = \frac{M}{V} \qquad Eq. 1$$

Where M is mass, and V is volume.

2.4.2 Thermal Conductivity

The thermal conductivity K-value coefficient can be calculated by applying the following equations:

$$K = \frac{qx}{A(\Delta T)} \qquad Eq. 2$$

Where, K is thermal conductivity, q is the amount of heat tranfer, x is thickness of sample, A is area of sample and ΔT is temperature difference.

The heat transfer rate can be calculated by rearranging the heat flow density equation:

$$Q = -\frac{q}{A}$$

$$q = Q(A) \quad Eq.3$$

where, q is heat transfer rate, Q is heat flow density, and A is area of sample.

In order to determine the thermal resistance of samples, it can be calculated by using the equation:

$$Rth = \frac{q}{A} \quad Eq.4$$

Where, Rth is thermal resistance, ΔT is temperature difference, and Q is heat flow density.

3. Results and Discussion

In this chapter discussed an examining the data allows for analysis and discussion. To determine whether the experiment material can replace the available material on-site, a comparison of the experiment sample and the availability sample is required. To achieve the result, two different thickness 30 mm and 15 mm of the Middle Core Paper of the SWP sample was created. Three types of testing were performed to determine the results: physical, acoustic, and thermal. Also comparing the performance between paper panel and rice husk.

3.1 Physical Density

The differences between 30 mm and 15 mm paper thickness samples are collected from the result. The weight of the 30 mm paper thickness is 1,285 kg, the sample volume is 0.0027 m^3, and the scrub density is 475.93 kg/m^3. While the 15 mm paper thickness weighs 1.006 kg, the sample volume is 0.0023 m^3 and the bulk density is 437.40 kg/m^3.

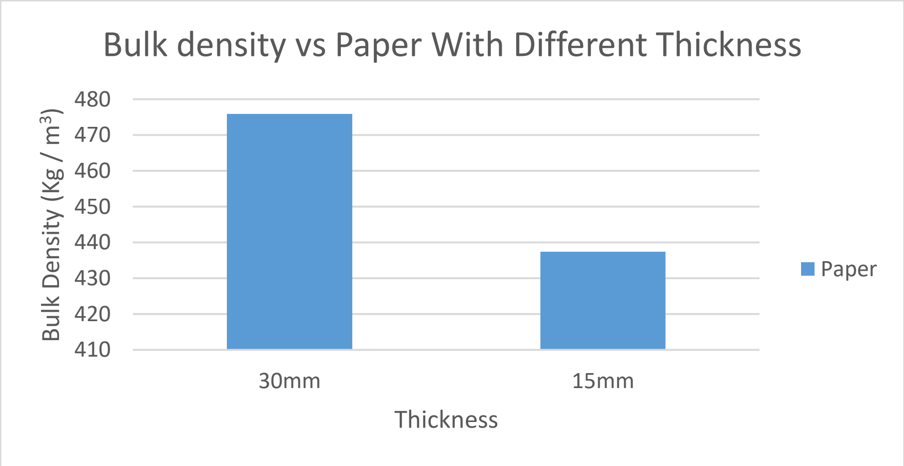

Figure 5: Bulk density on different thickness of paper

Each paper sample varies in weight and volume, as shown in Figure 5. the results of the results, the absorption of the paper affects each test performed such as physical test, thermal conductivity and even sound. For example, from a sound test, the thicker the thickness and weight of the paper core swp, the better its ability to absorb sound. Similarly with thermal testing, the thicker the thickness and weight of the paper core swp, the better its thermal resistance

3.2 Sound Absorption Coefficient

The absorption coefficient ranges between zero and one, one meaning no sound energy is reflected and the sound is either absorbed or transmitted [10]. Based on the Figure 6 Shown Paper panels with thicknesses of 30 mm and 15 mm have been tested for sound absorption. Best reading at low-frequency of sound absorption is only performed at 0.1, and for high-frequency less than 0.7. This may be due to a honeycomb on the edge of the panel paper that makes the sound on the test penetrate on the edges of the paper.

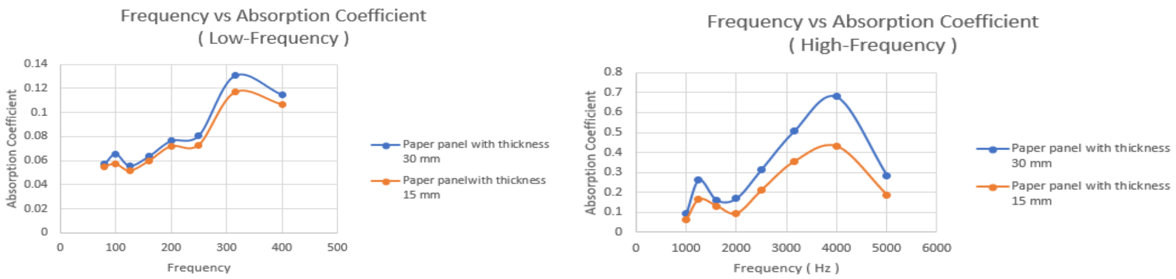

Figure 6: Paper panel with 30 mm thickness vs Paper panel with 15 mm thickness through Low-Freqeuncy and High-Frequency

3.2.1 Low-Frequency and High-Freqeuncy

The best sound absorption coefficient for paper panel with thickness of 30 mm is 0.131 while the best sound absorption for paper panel with a thickness of 15 mm is 0.117. The 80 Hz to 400 is the range for low-frequency. In this test frequency peak at 315 Hz for both samples. Figure 4.6 shows the average performance in the range of 80 Hz to 400 Hz. Panel paper with 30 mm thickness shows a better average performance of sound coefficient than 25 mm thickness of the paper panel.

The best sound absorption coefficient for paper panel with thickness 30mm is 0.730 while the sound absorption coefficient for paper panel with thickness 15 mm is 0.626. The 1000 Hz to 5000 Hz is the range for high frequency. In this test frequency peak at 5106.25 Hz for both samples. Figure 4.8 shows the average performance in the range of 1000 Hz to 5000 Hz. Paper panel with thickness shows the better average performance of sound absorption coefficient than 15 mm thickness of paper panel. Based on the data obtained from the test of sound absorption, it is seen that paper panels are more prone to high-frequency.

3.3 Thermal Conductiviy

The square panel of 300 x 300 mm x 30 mm and 300 x 300 x 15 mm of Recycled Paper shows the sample testing and the sample was produced in the laboratory. In this test, the two samples were used. The purpose was to identify the level and quality of the samples. The materials based in Table 1 shows Paper panel with thickness 30 mm and 15 mm. It also shows an interesting result since the thermal conductivity value obtained from both materials is lower than 0.05 W/mK. The that obtained obviously achieved the requirement needed for insulating materials and needs to be studied due to their availability of the sources.

Table 2: Comparison between 30 mm and 15 mm thickness of paper in terms of thermal properties

Thickness of Paper	Density(Kg/m^3)	Thermal conductivity(W/mK)
30 mm	476	0.012
15 mm	437	0.011

Based on Table 1 shows the results of the study between the paper panel thickness of 30 mm and 15 mm. as can be seen the thermal conductivity of 30 mm paper thickness is 0.001 more readings than 15 mm paper due to the thickness of the paper. it can be seen that the density on the paper affects the thermal conductivity. It is clear that 15 mm thick paper is better than 30 mm paper.

3.4 Comparison Between Paper and Rice Husk

Rice husk and paper, is known to be one of the recycled wastes. In this case, rice husk is widely used in the building sector, for example as a building sector, sound absorbers and insulation materials. Following that, previous research discovered numerous attractive advantages of its features. [8]

3.4.1 Density and Thermal conductivity between paper panel and rice husk

Table 3: Paper and Rice husk on Density and Thermal Conductivity

Materials	Density (Kg/m^3)	Thermal conductivity (W/mK)
Paper 	475	0.012
Rice Husk 	170	0.070

The materials based in Table 2 shows Paper and rice husk also showed and interesting result since the thermal conductivity value obtained from both materials is lower than 0.08 W/mK. Their value was not as low as requirement needed for insulating material and needs to be studied because of their availability of the sources. By comparing paper and rice husk, shows that paper has a greater opportunity to be replaced with the artificial materials since their thermal conductivity value is quite similar to the artificial materials listed in Table 4. This is due to different structures of each material and conditions implemented by the researchers might affect the thermal conductivity value of the materials. Other than that, multi-layers structures with another material also give an impact on insulation properties.

Table 4: List of density and thermal properties, description of fibres with typical insulation materials [7]

Materials	Density (Kg/m^3)	Thermal conductivity (W/mK)
Rock wool	40 - 200	0.033 – 0.040
Extruded Polystyrene (EPS)	15 - 35	0.031 – 0.038
Expanded Polystyrene (XPS)	32 - 40	0.032 – 0.037
Kenaf	30 - 180	0.034 – 0.043
Sheep wool	10 - 25	0.038 – 0.054

3.4.2 Sound Absorption Coefficient of Paper Panel and Rice Husk

Figure 8 shows the maximum values are about 0.74 and 0.91 measured respectively at 1700 and 5300 Hz for the maximum thickness of 3.5 cm. (Buratti et al., 2018). While figure 7 shows the best maximum values absorption coefficient for paper panel with thickness 30 mm is 0.679 and 0.730 measured respectively at 1000 Hz to 5000 Hz is the range for high frequency. Due to difference that occurs between these two materials is not very significant because the element thickness on the rice husk exceeds 0.5 mm compared to the paper panel. in other words, panel paper is also suitable to be made functional for sound absorption and also needs to be further improved to achieve the best data obtained level such as rice husk

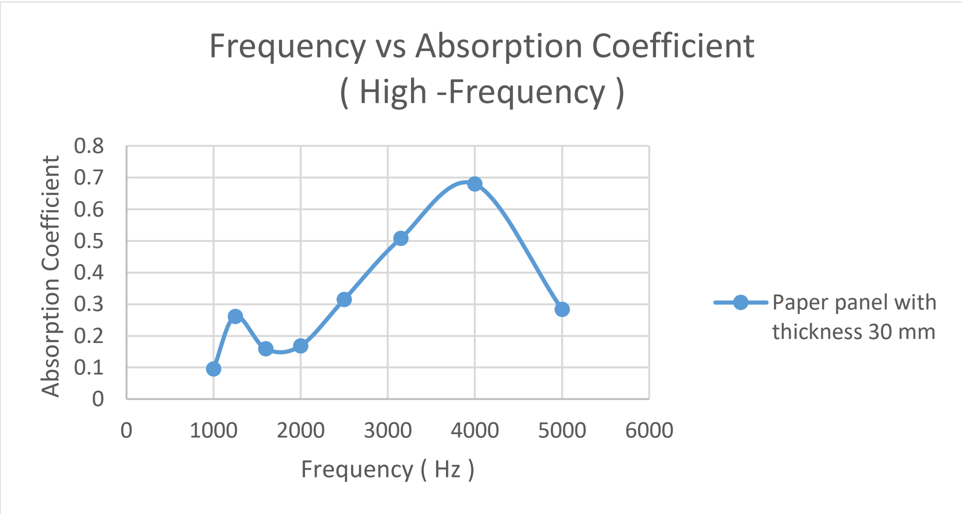

Figure 7: Sound absorption coefficient of the paper panel

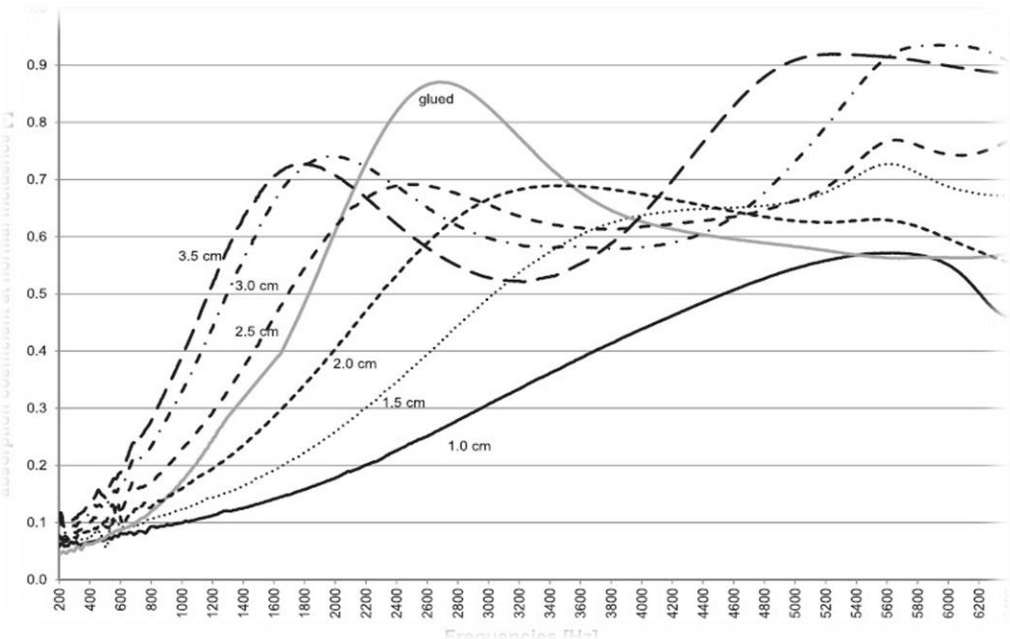

Figure 8: Sound absorption coefficient of the rice husk by different thickness [8]

4. Conclusion

All objectives have been achieved, the first objective of the sandwich wall panel middle core samples, the optimum proportion was (67.00 %) paper and (33.00 %) resin binder. This proportion was chosen because the panels produce less honeycomb, have strong structures, and can be used as insulating materials. Bulk density proves that a material's thermal conductivity and sound absorption can be affected by its density.

The second objective, the result for density test show 30 mm thick panel paper with a density of 475.93 kg/m^3 and 15 mm with a density of 437.40 kg/m^3 gave different impacts in terms of sound absorption and thermal conductivity tests. Then, the result for sound coefficient at low and high frequencies was determined using a 100 mm and 29 mm Impedance Tube. Paper panel with 30 mm has a high sound absorption coefficient at high frequency and better than 15 mm of paper panel. The thickness may cause the effect of the properties itself. Next, for the result of thermal conductivity, 30 mm and 15 mm paper panels, paper with a thickness of 30 mm has 0.001 higher thermal conductivity than 15 mm paper. The density affects the thermal conductivity of the paper.

The third objective, to compare the existing rice husk product, 30 mm thick high-frequency paper is close enough. Also, for 30mm and 15mm paper compared to rice husk, the result gives a good vibe because it's thermal. The thermal conductivity K-value is similar to artificial materials' thermal conductivity, such as Rock wool, EPS, XPS, Kenaf, and Sheep wool.

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