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Development of Insulation Panel from Recycled Denim Jeans for Thermal and Acoustic Properties

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Abstract

Developing insulation panels made from recycled textiles has become increasingly popular, and many researchers have investigated their thermal and acoustic performance. The aim of this research is to identify the optimum proportions of recycled denim jeans for both acoustic and thermal performance, conducting sound absorption tests using the Sound Reduction Index and thermal conductivity tests to evaluate thermal performance, as well as comparing the results with previous studies on recycled denim jeans-based materials. Thermal conductivity testing was conducted using the SOLTEQ model HE110, while the Sound Reduction Index experiment was used to measure sound absorption coefficients. From the analysis, it was found that jeans panels have a higher density compared to paper and cotton panels, making them the densest among other recycled textile panels. The thermal conductivity testing showed that S2 had the highest value at 0.129 W/m°C, indicating weak thermal resistance, while S1 exhibited good thermal resistance with a thermal conductivity of 0.083 W/m°C. In terms of sound absorption, the recycled paper panel recorded the lowest value at 38.16 dB, whereas the S3 jeans panel achieved the highest value at 50.20 dB, indicating excellent sound absorption or reflection. Therefore, the S3 jeans panel is the better choice for an insulation panel as it absorbs more sound and provides higher thermal resistance. Enhanced sound reduction improves acoustic comfort in buildings, while low thermal conductivity contributes to a more comfortable living environment.

1. Introduction

Indoor Environmental Quality (IEQ) elements include thermal and acoustic comfort in a building is essential nowadays as people spends 90% of their time in building [1]. Heat is a form of energy that influence the environment's temperature and creating sensation of thermal comfort for occupants. Finding optimum proportion of insulation panel is essential to achieve optimum performance of thermal and acoustic properties. In this study, the variables value is the weight of cutting jeans in mixing, while weight of binder remains constant in all proportions.

Thermal insulation is important to maintain and control exchange air indoor and outdoor. Excessively high or low temperatures can cause discomfort to building occupants, makes controlling the temperature is crucial to maintain occupants comfort. To determine the optimum proportions of denim jeans and binder, few testing have done and analysis were made. Thermal conductivity machine was used to measure thermal performance of jeans panels and Sound Reduction method was used to calculate acoustic absorption of jeans panel. Density of each panel with different proportion was calculated to estimate which of the proportion is the optimum.

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Noise from outside of building represent the sound source in acoustic testing and received sounds are collected to measure how much the panels prevent or absorb external noise. According to Bhanap (2013), noise was categorized as an undesirable sound that is perceived as a source of stress and irritation in the surrounding [2]. It is a sound that can irritate and annoying people such as sound of construction machine. Is was important to research a good sound and acoustic insulation.

Synthetic material such as fiberglass, polystyrene, rock wools and others contribute to greenhouse emissions and non-biodegradable that end up at landfill [3]. Some might even causing health problems like skin irritation and respiration problems, some even could cause cancer once contact with synthetics materials that could cause harm to workers and occupants. Synthetic materials have both effect on environment and human body as it was non-renewable and non-disposable properties [4]. Choosing bio-degradable and natural materials is vital to sustain the world from any possible pollution even though the performance as thermal and acoustic properties was better that sustainable materials.

Natural and recycled insulation panels material are widely known and many researchers have investigated this kind of alternatives to change synthetic insulation materials that have many side effect environmentally or human health when exposed to the materials. Denim fabrics demonstrate excellent thermal properties because of their natural fiber content allow this feature enables it to effectively regulate moisture levels while also delivering reliable and consistent thermal performance over time. [10][13]. Denim textiles made from cotton weave that interweaving multiple threads, it is denser than other cotton cloth and the durable nature of denim guarantees lasting strength and resistance to wear [11]. According to Berardi (2015), when denim blended with natural fibers, exhibits sound-absorbing properties, making it an effective material for noise-reducing insulation [12]. All the characteristics of jeans makes it a great choice to investigate recycled insulation panels for thermal and acoustic properties.

The objectives of this study was to identify optimum proportions of recycled denim jeans for acoustic and thermal performance, conduct sound absorption testing using sound reduction index and thermal conductivity testing for thermal performance, and compare the result with previous study on recycled denim jeans based on materials.

2. Methodology

In this chapter, experimental research was conducted to achieve all three objective using research methods. Taken from all many research and articles from past researchers, the most suitable methods, sample size, equipment, and methodology was used in this chapter. **Fig 1** shows the methodology flow chart of development of denim jeans insulation panel for thermal and acoustic performance including testing carried out. Summary of developed samples to testing involve in determine the performance of jeans panel and analysis all the data recorded to determine the optimum insulation before evaluate with other studies.

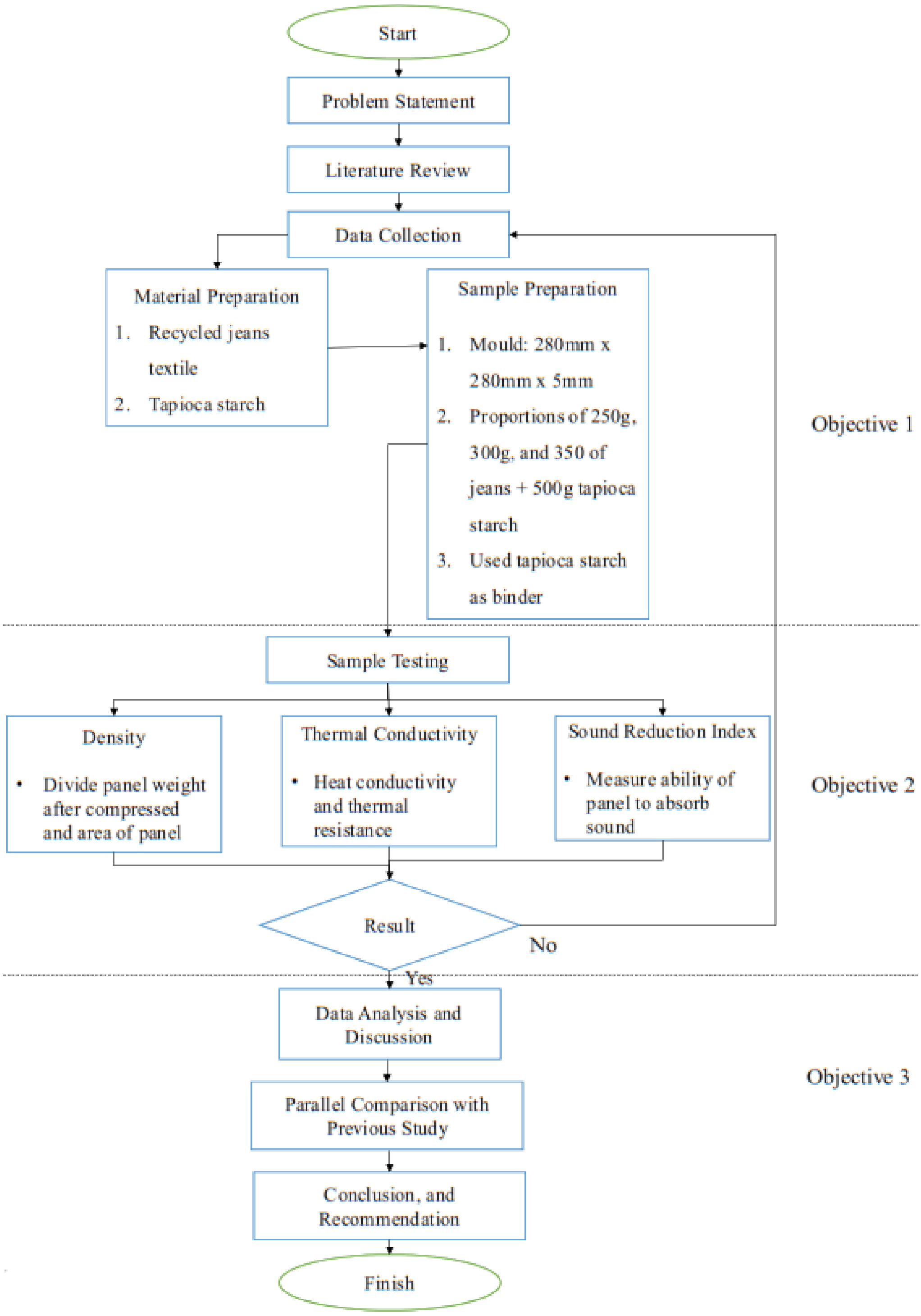

***Fig. 1*: Methodology Flowchart**

The materials preparation taken from cutting the jeans into preferable dimension, in this study, cut dimensions 3mm to 5mm range for any types of jeans. Then, three proportions of jeans insulation panels were developed as shown in **Fig 2** to determine which of the proportion of sample were the best insulation panel. The combination of cut jeans and tapioca starch used ratio 250g, 300g, and 350g of jeans with 500g of tapioca starch, respectively. The proportion of binder mixing was 1:9 with 50g of tapioca starch added to 450g of tap water to make the combination of 500g. Then, to develop the panel, mould size 280mm x 280mm with 5mm thickness were prepared. The jeans were patch layer by layer with binder spread in between layer before compacted using Geotech Testing Hot Press Machine. Compacted panel were weight to determine the density of panels.

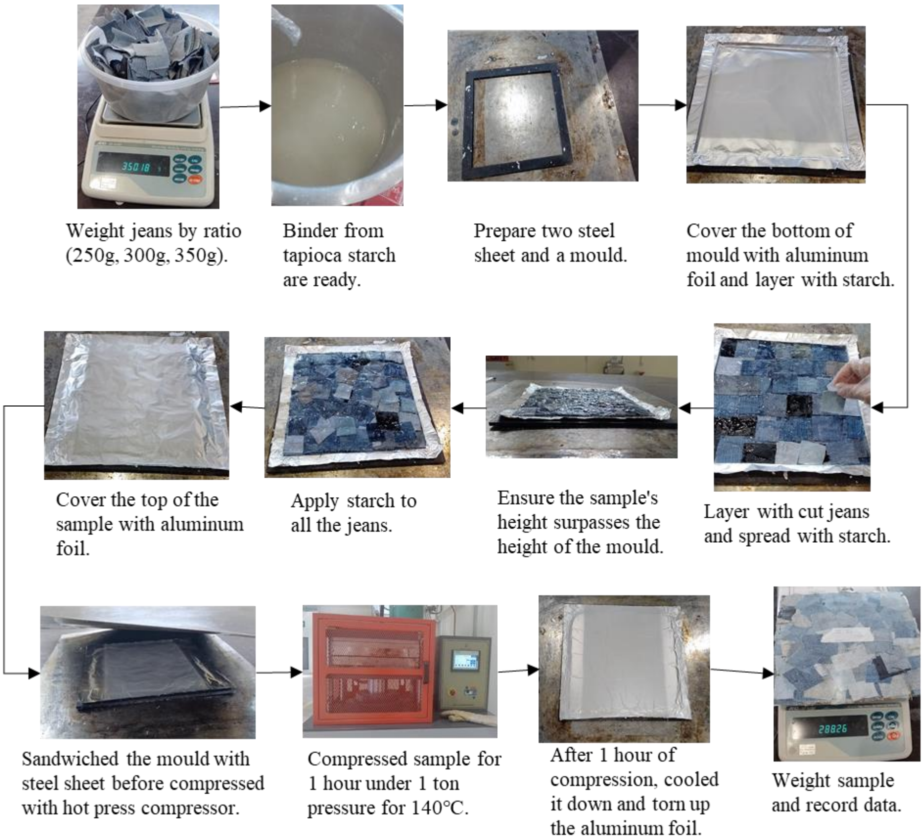

Fig. 2: Process of Samples

After samples were developed, all three samples were tested to determine density, thermal conductivity, and sound reduction of samples to achieve objective 2.

The samples were weight to determine the density of panels using the following equation:

$$\text{Density} = M/V \qquad (1)$$

Where, M was mass of samples and V is sample's volume. The higher the density, the better insulation panels it made. Testing for thermal conductivity using SOLTEQ HE110 Thermal Conductivity apparatus at Building Services Technology Laboratory as in **Fig 3** was conducted. Samples was sandwiched between an electrical heated hot plate maintained at temperature T_h and a cold plate maintained at a lower temperature T_c according to ISO 8302:1991 by measure heat rate until steady-state conditions are reached. Measurement started when hot plate temperature reaches 50^0C and above.

Fig. 3: Thermal Conductivity Apparatus

According to lab sheet on how to use the apparatus, thermal conductivity coefficient can be calculated using following equations:

$$q = \frac{k \cdot A \cdot \Delta T}{x} \tag{2}$$

Where, q is heat transfer rate, k is thermal conductivity, A area of panel in (m^2), x is thickness of panel, and ΔT define as difference in temperature (^{0}C). However, all values in equation 2 already obtained either from the thermal conductivity apparatus or panel itself. Thus, the value that need to be calculated was thermal conductivity, k, by using following equation:

$$k = \frac{q \cdot x}{A \cdot \Delta T} \tag{3}$$

Heat flow density refer to q and the others are the same as equation 2.

$$R_{th} = \frac{\Delta T}{q} \tag{4}$$

While thermal resistance, R_{th} required temperature different (ΔT) and heat transfer rate (q) to calculate.

$$\text{Heat flow density} = -\frac{q}{A} \tag{5}$$

SOLTEQ Thermal Conductivity apparatus would display heat flow density of the sample. However, theoretically, equation 5 was used to calculate heat flow density of samples.

Lastly, Sound Reduction Index was used to measure sound absorption coefficient using three Sound Level Meter and Sound Reduction Box. The test examines the effect of varying distances between the sound source and the receiver, demonstrating that the sound level decreases as the distance increases as the panels reflect or absorb sound waves as shown in **Fig 4**. Total sound meter was used in this experiment; one for read sound source decibels, while two more sound meter attached to the back of box to calculated average receiver sound.

Fig. 4: Sound Reduction Index Apparatus

The sound source used monotone sound to capture constant or stable sound wave throughout the experiment. Each value of sound source and average receiver value at every distance was recorded. The average sound receiver calculated as following equation:

$$Average = \frac{(L1 + L2)}{2} \tag{6}$$

Where, L1 was the reading value of sound meter 1 and L2 was the reading value of sound meter 2. Then, to calculate Sound Reduction Index, minus sending sound's reading with average receiving sound's reading as equation below:

$$SRI = Sound\ source - average\ receiving \tag{7}$$

Results and Discussion

This chapter reveal the result of each testing and discussion on possible reasons aside result obtained.

2.1 Density

Density of samples S1, S2, and S3 presents data of the samples' ratio mass after compressed, volume, and density with constant value is volume of samples, thickness of panels, and starch's ratio. Analyze from the table, samples' density increase as the mass of recycled denim jeans increase. S1 with 250g of recycled denim jeans has the less dense with only 734.7 kg/m³, followed by S2 with 803.6 kg/m³, and the densest panel was S3 with 926.0 kg/m³. Higher density was correlated with better performance on thermal and acoustic properties.

***Table 1*:** Density of Samples

Sample	Mass of sample (kg)	Volume (m³)	Density (kg/m³)
S1: 250:500	0.288		734.7
S2: 300:500	0.315	$3.92x10^{-4}$	803.6
S3: 350:500	0.363		926.0

2.2 Thermal Conductivity

From the result shows in **Fig 5**, S2 shows the highest thermal conductivity with 0.129 W/m⁰C than S1 and S3 with 0.083 W/m⁰C and 0.123 W/m⁰C, respectively. Based on Yousefi (2021), lower density tends to reduce thermal conductivity of panel by trap air within material as it also conducts heat. Audra (2022) had also state that high thermal conductivity signifies reduced resistance to the transfer of heat through the material [6]. S1 shows a great thermal resistance as the thermal conductivity is lower. S3 is a better thermal resistance than S2.

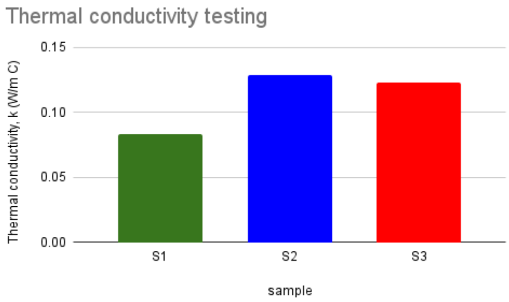

***Fig. 5*:** Thermal Conductivity of Samples

2.3 Sound Reduction Index

Sound reduction results in **Fig 6** of three samples S1, S2, and S3. The highest SPL value was S3 that achieved higher result at distance 1m, 2m, and 3m. the highest SPL data was 50.2dB of S3 at 3m. the lowest data was S1 with 43.6dB at 0.5m, because the panel was least dense that other two panels, make S1 could absorb lower sound wave. Hoda (2009) said that as the density of sample increased, the sound absorption also rose. However, S2 graph was steady and stable throughout the whole distances with little up and down, rather than S3 AND S1. There are many factors affect the result of SRI such as density, porous absorber, and thickness of panel [7].

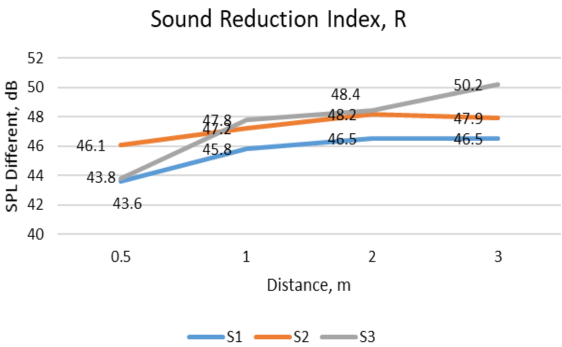

***Fig. 6*:** Sound Reduction Index of samples

2.4 Data Comparisons with Previous Study

As shown in Table 2, three studies were compare using parallel comparison method to determine which insulation panels was better in terms of textile and recycled insulation materials. From the tables shows that recycled jeans panel had the highest density and thermal conductivity rather than studies from Tasnim and Audra result to the thermal and acoustic properties was higher. S2 803.6 kg/m^3 with density of was a good insulation panels in terms of recycled insulation materials with high density, high thermal conductivity, and better sound reduction index.

Table 2: Comparison on Different Properties of Various Sample

Material	Thickness (m)	Density (kg/m^3)	Thermal conductivity, k (W/m^{0}C)	Sound Reduction Index (dB)	Researcher
Recycled cotton + corn starch	0.005	555.77	0.083	-	Tasnim (2023)
		677.78	0.087	-	
Recycled paper + cotton polyester fibers	0.015	174.07	1.42	39.96	Audra (2022)
	0.014	154.60	1.24	38.16	
Recycled jeans + tapioca starch	0.005	734.7	0.083	46.50	This study (2024)
		803.6	0.129	48.20	
		926.0	0.123	50.20	

3. Conclusion

This study has achieved all the objectives for development of recycled denim jeans with tapioca starch. Proportion 7:10 from S3 seems to be the optimum proportion of recycled jeans as an insulation panel result to higher density with 926.0 kg/m^3. The lowest thermal conductivity was recycled jeans and recycled cotton with 0.083 W/m°C, shows that these panel perform best in resistance to heat transfer followed by 0.123 W/m°C and 0.129 W/m°C from S2 and S3 have bit lower ability of resisting heat. Low thermal conductivity directly correlates with higher thermal insulation properties [8]. Sound Reduction Index of recycled jeans was the higher among other two samples of recycled jeans and recycled paper by S1, S2, and S3 values were 46.50dB, 48.20dB, 50.20dB, respectively which was higher than recycled paper sound reduction value. Based on the result, S3 have the best acoustic properties as it was the densest than other panel. High density and compacted structure block sound transmission effectively as the characteristic of jeans itself was strong and durable that prevent sound waves to travel to other medium. The combination of starch enhances cohesion, further reducing sound transmission [9]. Based on the density, thermal conductivity, and sound reduction values, S3 shows a good insulation panel with proportions of 350g recycled denim and tapioca starch and could be improved more in further research.

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