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Development of Wall Panels Using Recycled Paper and Cotton Polyester Fibres for Acoustic and Thermal Performance

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Abstract: Noise pollution is one of the environmental problems that cannot be eliminated due to long-term exposure to excessive noise that can cause physical and psychological effects. In building application, an acoustic panel made of fibreglass or mineral wool materials is non-recyclable and poses health risks to occupants. Therefore, two recycled materials: paper and cotton polyester fibres, are used to produce panel boards. The study's objective is to identify the optimum proportion of recycled paper and cotton polyester fibres used in acoustic panels, measure the acoustic and thermal properties, and compare the properties with various materials from previous studies. The wall panels are made of 70.00 % - 90.00 % recycled paper with 10.00 % - 30.00 % cotton polyester fibres by wet mixing with natural tapioca binder composed of 100 g tapioca flour and 1000 mL water before being compressed using Gotech Testing Machine Hot Press Machine. Three samples were tested using an AED 1000 AcousticTube Impedance Tube and Solteq HE110 Thermal Conductivity Apparatus. The optimum proportion was 70.00 % recycled paper 30.00 % cotton polyester fibres. The results showed all samples had densities between 136.67 to 174.07 kg/m^3 with sound absorption coefficients ranging from -0.70 to 0.04 and thermal conductivity k-values from 1.24 to 1.65 W/m °C. It was determined that composite material of recycled paper and cotton polyester fibres were poor quality material to use as acoustic panels because of the poor acoustic and thermal performance.

Keywords: Cotton Polyester Fibres, Recycled Paper, Tapioca Binder, Thermal Conductivity, Sound Absorption Coefficient.

1. Introduction

Noise is classified as an unpleasant sound perceived as a stressor and annoyance in the environment [1]. Noise pollution is one of the most severe environmental problems which can cause physical and psychological effects such as nausea and dizziness and long-term exposure to an excessive amount of

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noise [2]. Therefore, noise control is essential for building an acoustically pleasing atmosphere because of the potential risks it poses to people [3]. Although noise cannot be eliminated, it can be reduced to the appropriate degree to the human ear, whereby minimising its risk as well [4].

Porous, also known as fibrous materials, are the most common and frequently used in the building because of their excellent ability to absorb sound at a low cost compared to other absorbers [5]. According to Xiaoning and Xiong [6], porous materials for noise reduction include inorganic and metallic fibres, synthetic fibres, natural fibres, and nanofibrous membranes.

Synthetic fibres such as fibreglass, glass wool, or rock wool have traditionally been used as raw materials to absorb sound in building applications to minimise noise. Although these materials have good acoustic performance, they are both expensive and non-sustainable [6]. However, these materials are non-recyclable and pose health risks by releasing free fibres that are harmful to workers and future occupants [7][8]. Patnaik et al. [9] also mentioned that these synthetic materials are based on petrochemicals. The demand for environmentally friendly insulation materials is increasing due to the negative impact of synthetic insulation materials [10].

Therefore, the researchers expressed great interest in developing alternative sound absorbers made of natural or recycled materials, which lead to less waste production and less dependence on raw materials [11]. Acoustic and thermal insulation from recycled materials is becoming an interesting alternative due to its good acoustic behaviour, low production costs, good handling, and environmental protection, which can be a sustainable strategy to reduce the environmental impact and the use of virgin material [12][13].

Compared to new fibres, reusing recycled fibres has the advantages of being environmentally friendly and low cost [14]. Küçük and Korkmaz [15] reported that cotton polyester fibres have the highest sound absorption coefficient. Meanwhile, Sim et al. [16] mentioned that paper fibres have a high fibre porosity. This study combines recycled paper and cotton polyester fibres in a starch binder. According to Kadoli et al. [17], tapioca starch creates a transparent film and gel with lower viscosity and high-water retention ability.

The study's objective is to identify the optimum proportion of recycled paper and cotton polyester fibers used in acoustic panels, measure the acoustic and thermal properties, and compare the properties of recycled paper and cotton polyester fibres with various materials from previous studies.

2. Materials and Methods

This study has been conducted using a literature review analysis and experimental research as its research methods. The literatures of articles or journals were obtained from various researchers who have been conducted an experiment or study. The literature was reviewed to determine the sample size, equipment, materials, and methodology used in previous studies related to the research. Figure 1 shows the methodology chart of the development of acoustic panels using recycled paper and cotton polyester fibres, including the testing carried out. According to Figure 1, the parameters summarised by previous studies include sample size, equipment, materials, and methodology used in this research.

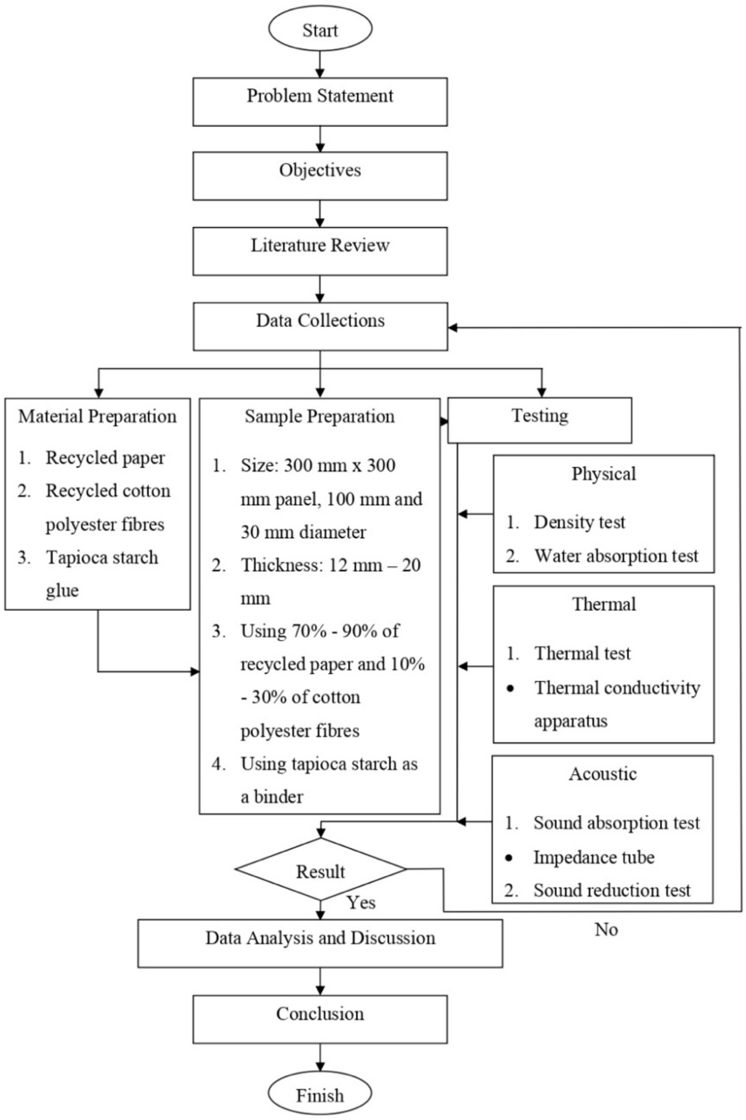

Figure 1: Methodology Flowchart

The process of combination composite samples of various proportions of recycled paper and cotton polyester fibres were developed, as shown in Figure 2. First, the samples were formed by combining 70.00 %, 80.00 %, 90.00 % paper pulp from recycled paper with 10.00 %, 20.00 %, 30.00 % cotton polyester fibres and bonded with 100 g of tapioca flour and 1000 mL of water as a binder [18][19][20]. Then, to develop the samples, square mould sizes 300 mm x 300 mm, 100 mm, and 30 mm diameter with 12 mm – 20 mm thickness were prepared [21]. Next, the samples were compacted using Gotech Testing Machine Hot Press Machine. Finally, the samples were dried using an oven at a high temperature of 105 °C as water evaporates quickly.

Figure 2: Process of The Samples

After the samples were developed, each sample was tested in terms of physical, thermal, and acoustic testing was carried out to determine the density, water absorption, thermal conductivity, sound absorption, and sound reduction of the samples.

The density of the sample was determined and calculated by using the following equation:

$$\text{Density} = M/V \qquad \textit{Eq. } 1$$

where, M is mass, and V is volume.

The water absorption was determined using the water soak method, immersing the samples in water for 2 hours. The water soak method is commonly used to determine an acoustic panel's water resistance. The samples are then examined daily to determine their strength and whether they have been damaged by disassembling [19]. Kolawole et al. [22] stated that water absorption was calculated by using the following equation:

$$\%\ \text{Water Absorption} = W_2 - W_1/\ W_1 \times 100 \qquad \textit{Eq. } 2$$

where, $W_2 - W_1$ is different in weight and W_1 is original weight.

Next, Solteq HE110 Thermal Conductivity Apparatus was used to test the thermal conductivity of the samples. It was determined in accordance with ISO 8302:1991 and ASTM C177 standards by measuring the heat rate required to maintain the hot plate at a constant temperature once the cold plate temperature is stabilised using a chiller and steady-state conditions are reached. The constant temperature of the hot plate during the test was set at 50 °C.

Figure 3: Thermal Conductivity Apparatus

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

$$K = qx/(A(\Delta T)) \qquad \textit{Eq. } 3$$

where, K is thermal conductivity, q is the amount of heat transferred, x is the sample's thickness, A is the area of the sample, and ΔT is the temperature difference. The heat transfer rate can be calculated by rearranging the heat flow density equation:

$$Q = -\, q/A$$

$$q = Q(A) \qquad \textit{Eq. } 4$$

where, q is heat transfer rate, Q is heat flow density, and A is sample area. In order to determine the thermal resistance of samples, it can be calculated by using the equation below:

$$R_{th} = \Delta T/Q \qquad \text{Eq. } 5$$

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

Furthermore, to obtain the sound absorption coefficient data, in accordance with the ISO 10534-2 standard and ASTM E 1050-10 standard, an AED 1000 AcousticTube Impedance Tube with two fixed microphones was utilised. The test is performed at low frequency and high frequency, which ranges from 80 Hz- 5000 Hz. Figure 4 shows the experimental testing Impedance Tube used to obtain the sound absorption coefficient.

Figure 4: Impedance Tube

Finally, data from the sound reduction index is obtained through an Acoustic Box with three Sound Level Meters. The test reduces sound by increasing the distance between the sound source and receiver by using samples to reflect or absorb the sound waves' energy. A Sound Level Meter on the sound source and two Sound Level Meters in the receiving room is used to determine each sample's sound level in decibels (dB). Figure 5 shows the schematic diagram of sound reduction index experimental procedures using an Acoustic Box.

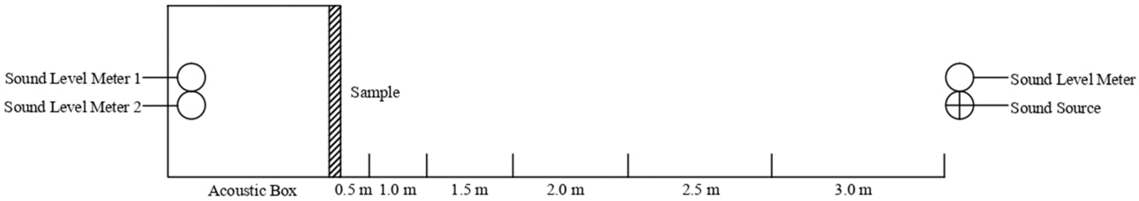

Figure 5: Schematic Diagram of Sound Reduction Index Testing

The sound reduction index (R) is derived using the following formula for laboratory tests using sound pressure [23]:

$$R = L_1 - L_2 + 10 \log (S/A) \qquad \textit{Eq. } 6$$

where, L_1 is the average sound pressure level in the source room, L_2 is the average sound pressure level in the receiving room, S is the area of the test samples (m^2), and, A is the equivalent sound absorption area of the receiving room. The equivalent absorption area, A is evaluated from:

$$A = 0.163V/T \qquad \textit{Eq. } 7$$

where, V is receiving room volume, and T is reverberation time in the receiving room.

3. Results and Discussion

3.1 Density

According to the density measured, samples with thicknesses of 15, 18, and 14 mm showed densities of 174.04, 136.67, and 154.6 kg/m^3, respectively.

3.2 Water Absorption

Table 1: Water Absorption of Samples

Recycled Paper: Cotton Polyester Fibre	Weight (kg)	Water Absorption (kg) Duration (min)		
		5	60	120
Sample 1: 90:10	0.0022	0.0074	0.0081	0.0088
Sample 2: 80:20		0.0077	0.0086	0.0088
Sample 3: 70:30		0.0105	0.0128	0.0144

Based on the water absorption test as shown in Table 1, all samples with the same weight (0.0022 kg) have the highest amount of water absorption. After 5 minutes, sample 3 had absorbed approximately 377.00 % of the water, and within 2 hours, it had absorbed nearly 555.00 %. Sample 1 and sample 2 absorbed up to 236.00 % and 250.00 % of the water respectively after 5 minutes in the water and up to 300.00 % within 2 hours in water. The presence of hydrophilic groups in the materials allows to absorb water or moisture up to 25 times its weight [24][25][26].

3.3 Thermal Conductivity Coefficient

Thermal conductivity results show that sample 2 with an 18 mm thick sample had a thermal conductivity of 1.65 W/m ºC, which was higher than samples with thicknesses of 15 mm and 14 mm, which had 1.42 W/m ºC and 1.24 W/m ºC, respectively. Furthermore, in a study by Hung Anh and Pásztory [27], the thermal conductivity of the samples increased as the water absorption increased. High thermal conductivity indicates a lower resistance to heat transmission through the material.

3.4 Sound Absorption Coefficient (SAC)

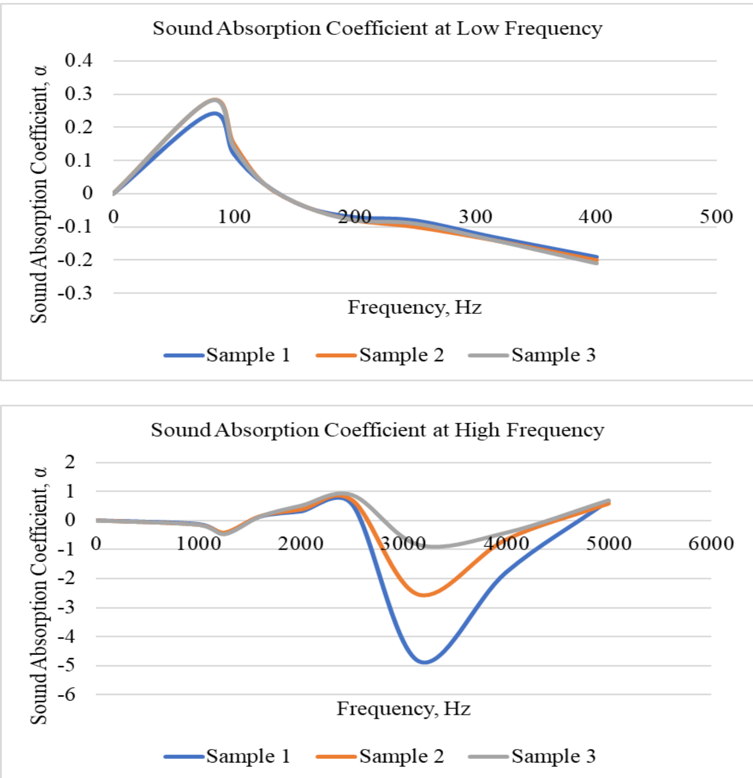

Figure 6: Sound Absorption Coefficient at Low and High Frequency

The sound absorption coefficient at low and high frequencies is shown in Figure 6. At 80 Hz to 400 Hz, the sound absorption averages of 100 mm diameter samples 1, 2, and 3 were -0.02, -0.01, and -0.01, respectively. The average sound absorption of 30 mm diameter sample 1, 2, and 3 at frequencies ranging from 1000 to 5000 Hz was -0.70, -0.25, and 0.04, respectively. The sound absorption coefficient values in all samples were good, especially at low frequencies below 125 Hz and high frequencies between 1600 Hz and 2500 Hz. Sample 3 had the highest absorption coefficients, around 0.87, at 2500 Hz. All samples had low absorbance coefficients because incident sound waves are reflected rather than absorbed. A study by Nandanwar et al. [28] stated that the sound absorption coefficient decreases as density increases.

3.5 Sound Reduction Index (SRI)

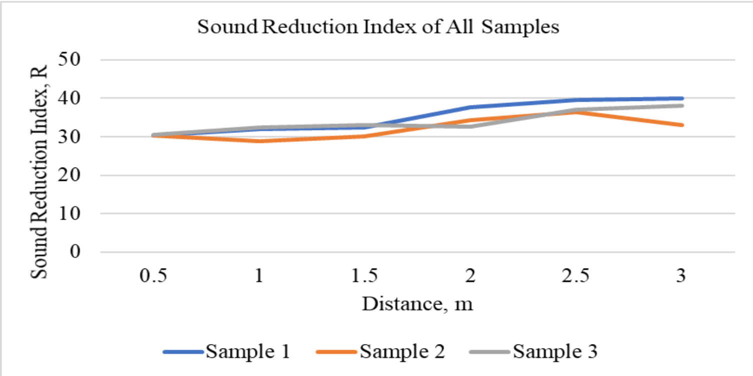

Figure 7: Sound Reduction Index of All Samples

Figure 7 shows the results of the sound reduction index. The sound source was produced about 100 dB to 101.60 dB, and it was transmitted through various proportions of recycled paper and cotton polyester fibres, with the receiving sound source being around 57.65 dB to 69.40 dB. At most distances between the sample and the sound source, sample 1 shows the highest sound reduction with the value obtained was about 39.96 dB at a 3 m. In comparison to the other samples, sample 2 has the most negligible sound reduction value but has the highest sound reduction index of 36.41 dB at a 2.5 m distance. The sound is less easily transmitted at a higher density, as it has a negligible effect on sound energy loss and is thus dampened by airflow resistance [29].

3.6 Optimum Proportion of Recycled Paper and Cotton Polyester Fibres

Based on the results, sample 3 with 70.00 % recycled paper and 30.00 % cotton polyester fibre is the optimum proportion of recycled paper and cotton polyester fibres compared to other proportions. However, sample 3 had the highest water absorption because it comprised of 30.00 % cotton polyester fibre, which absorbed more water after being submerged in the water for 2 hours. Furthermore, when compared to the other samples, sample 3 had the lowest thermal conductivity, showing that the lower thermal conductivity was related to a high density. In terms of sound absorption coefficient, the high density shows more sound reflection than sound absorption. Sample 3's sound absorption value was 0 in the sound absorption results, indicating that sound was reflected. Sound absorption can be improved by increasing the diameter of the fibre and the volume of porosity. The sound reduction of sample 3 was less easily transmitted to the receiving room due to factors such as low porosity volume and high density.

3.7 Comparison with Previous Studies

Table 2 shows the properties of various materials from previous studies. It shows that recycled paper and cotton polyester possess a high density, thermal conductivity, and low sound absorption coefficient compared to other properties except for a study by Ricciardi et al. [21] on waste paper and polyethylene fibres material, where the density of the material was 433 kg/m^3. Recycled paper and cotton polyester fibres were not the most excellent acoustic and thermal performance materials of acoustic panels, but this can be improved by using other materials such as cork, rubber, wood wool, coconut fibres, and recycled wool fibre, polypropylene fibre, etc.

Table 2: Properties of Various Materials from Previous Studies

Material	Thickness (m)	Density (kg/m³)	Thermal Conductivity Coefficient, k (W/m ºC)	Sound Absorption Coefficient, α	Sound Reduction Index, R (dB)	References
Waste Paper + Polyethylene Fibres	0.012 – 0.020	433	0.034 – 0.039	0.23 – 0.38		Ricciardi et al. (2014)
Waste Paper + Polyethylene Fibres	0.018			0.39		Buratti et al. (2016)
Waste Paper + Wool Fibres	0.050			0.59		Buratti et al. (2016)
Hemp Fibre + Cellulose Fibre		30 - 60	0.046 – 0.047			Reif et al. (2016)
Recycled Paper + Cotton Polyester Fibre	0.012 – 0.018	154.60 –174.04	1.24 – 1.65	-0.70 – 0.04	36.41 – 39.96	Irwan (2021)

4. Conclusion

This study has achieved all the objectives for the development of recycled paper and cotton polyester fibres. The experimental results showed that sample 3 with 70.00 % recycled paper and 30.00 % cotton polyester fibres are highly dense, resulted in having the highest water absorption due to the characteristics of recycled paper and cotton polyester fibres which absorb more water after being soaked in water for 2 hours. However, the k-values result with 1.24 W/m ºC in thermal conductivity showed good thermal behaviour compared to other proportions. Furthermore, the sound absorption coefficient of 70.00 % recycled paper and 30.00 % cotton polyester fibres with values of -0.01 in low frequency and 0.04 in high frequency show better performance than the other proportions. The sound reduction for 70.00 % recycled paper and 30% cotton polyester fibres was 38.16 dB as the sound source dropped from 100.50 – 101.30 dB to 60.05 – 68.10 dB as the distance increased. The optimum proportion of recycled paper and cotton polyester fibres was compared to previous research, and it was discovered that 70.00 % recycled paper and 30.00 % cotton polyester fibres were poor quality material to use as acoustic panels due to poor acoustic and thermal performance, but the materials could be improved with further research.

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