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Characteristic of Insulation Panel Using Waste Spent Coffee Grounds (SCG) and Cardboard (CB)

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Abstract

Waste materials have increasingly expanded and have been used as an alternative in the construction industry to implement sustainability elements. The waste accumulation was increasing day by day, including global warming and environmental development that inclined to noise pollution. This experimental study investigates the characteristic waste of Spent Coffee Grounds (SCG) and Cardboard (CB) as an acoustic and thermal insulation application. The investigated composite SCG-CB performance with four proportions with SCG: CB are 30:70, 50:50, 60:40 and 70:30 was prepared using tapioca starch as a natural binder. The composite was mixed by wet mixing, manually cold pressing and sun drying. The samples have been tested, and the results performance on each test are a 1.19 α of sound absorption coefficient, 27.32 dB of sound reduction index, and 0.072 W/m.K of thermal conductivity. SCG-CB panels have been compared with product markets, such as polyester cotton, as control panels. This study shows the applicability of SCG and CB panel insulation as sustainable solutions to conventional insulation materials for acoustic and thermal insulation. Additionally, it transforms the current acoustic and thermal panels into practical, affordable materials through thermal insulation, and at the same time, it promotes sustainable products to the market and community. Moreover, SCG and CB have good potential to be alternative materials in panel insulation applications.

1. Introduction

Introducing the concept of sustainability strategies in building construction could have positive effects and help develop countries gradually. Also, these approaches are insufficient recycling policies and affect the rate of accumulation of waste issues due to the high demand for industrial and agricultural by-products [1]. The increasing demand for sustainable construction materials has shifted towards green building practices. Traditional insulation materials are replaced by environmentally friendly alternatives that do not compromise performance [2]. This transition is essential as the construction industry strives to minimize its ecological footprint while enhancing energy efficiency. Material with insulation abilities is significant for identifying and evaluating the scale of performance of insulation. As a result, it significantly provides acoustic performances, thermal comfort, and energy efficiency for buildings. Every product has pros and cons, and natural and synthetic insulation materials have limitations such as moisture absorption and high flammability [3]. This presented the potential of waste material, especially spent coffee grounds (SCG) and cardboard (CB), as the future for new-generation green insulation systems. New-generation green insulation systems. The materials explicitly using the composite SCG-CB remain underexplored for reuse in construction except for the past researcher.

In comparison, fibreglass, polystyrene, and other synthetic insulation materials still dominate the market because the top-tier performance and thermal efficiency even have environmental and health concerns [4]. Natural insulation, such as agricultural waste such as hemp, flax, and cellulose, can be used as alternatives. Include other waste materials that have insulator potential. These materials remain limited due to higher costs because of the long process of material preparation and inconsistent performance data [5]. Additionally, drying methods commonly use mechanical drying, such as hot pressing and oven drying. This leaves a trace of gaps in understanding the effectiveness of natural drying in this experiment. Also, there is an insignificant exploration of other insulation parameters, such as fire resistance and water resistance in SCG-CB panel insulation.

However, some opportunities and challenges are still hidden regarding the remarkable potential of alternative materials such as SCG and CB in green insulation systems. Various previous studies have explored many types of natural and recycling insulation materials, such as rigid and porous aerogels [6]and reused face masks [7], but the use of waste SCG and CB in insulation panels cannot be fully referenced due to limited research using these two specific materials. The past research closest to this experimental study is research by Liuzzi et al.,(2023)[5] that use a composite of SCG, paper strips, sawdust powder, and Fava bean residues for acoustic and thermal insulation. This previous research is closest due to the materials used, SCG and paper strips in the same categories as cardboard. Also, it was conducted without a comprehensive analysis of the ratio for these composites, affecting the performance metrics. As a result, the gaps in this experimental study are noticeable.

2. Materials and Methods

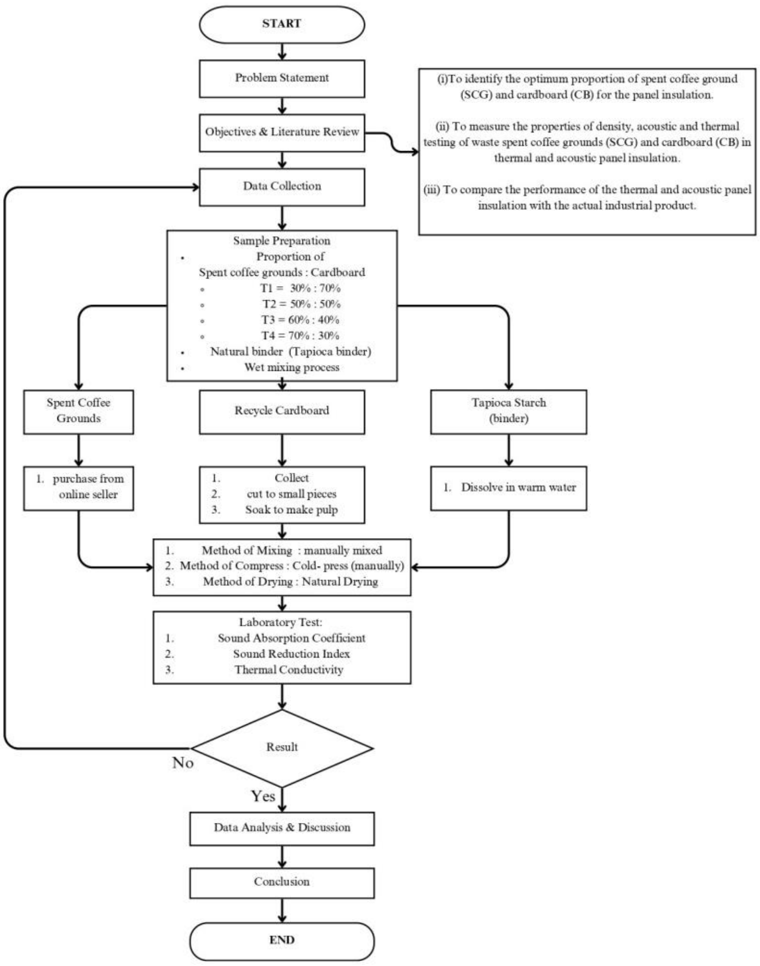

***Fig. 1*: Methodology Flowchart**

This research work was done theoretically and experimentally, involving analysis of literature and practical research. Research articles and journals were studied to find out previous related work based on sustainable insulation panels. In the review, they focused on the sample size, equipment, materials, and methods in related projects. As shown in Fig.1, the methodology involves the preparation of spent coffee grounds (SCG) and cardboard CB panel hybrid insulation through processes and tests that are followed as part of the study. The literature review includes parameters such as sample preparation techniques, materials, and modes of performance used in acoustic and thermal insulation.

SCG and CB blend at various ratios for the composite panel's formation. The SCG content varied at 30%, 50%, 60%, and 70%, while the CB was present at 70%, 50%, 40%, and 30%, respectively. Tapioca starch was added as a binder, and then water was added to properly mix the ingredients. The binder content was maintained at 15% by weight of the dry materials with respect to the binder to be used in the concrete mix. The paste was manually compacted with thicknesses of 10mm into square shape moulds of 300mm x300mm, circle moulds of 100mm and 30mm diameter.

Natural drying was used instead of the hot press method, where pellets were stacked in a well-drained, shaded area with a normal room temperature of 25-30° C. This created a way for moisture to evaporate in a more controlled manner over the course of up to three days. The natural drying period was the drying time for the samples within room conditions; depending on the humidity, an initial weight was taken, and the weight was monitored until it reached a constant dry weight condition. There is minimal wastage and overall consumption of energy when incorporating this approach in the panel production process.

In order to achieve the objectives with researchers, the flow chart plays an important role in interpreting the process of hybrid waste samples made and tested to achieve all the objectives, as shown in Fig.1. The material preparation of composite before mixing together. The design of the composite hybrid waste samples was bound by a natural binder, which is tapioca starch mixed with water, as shown in Fig 2, which shows the preparation of the insulation panel from raw materials.

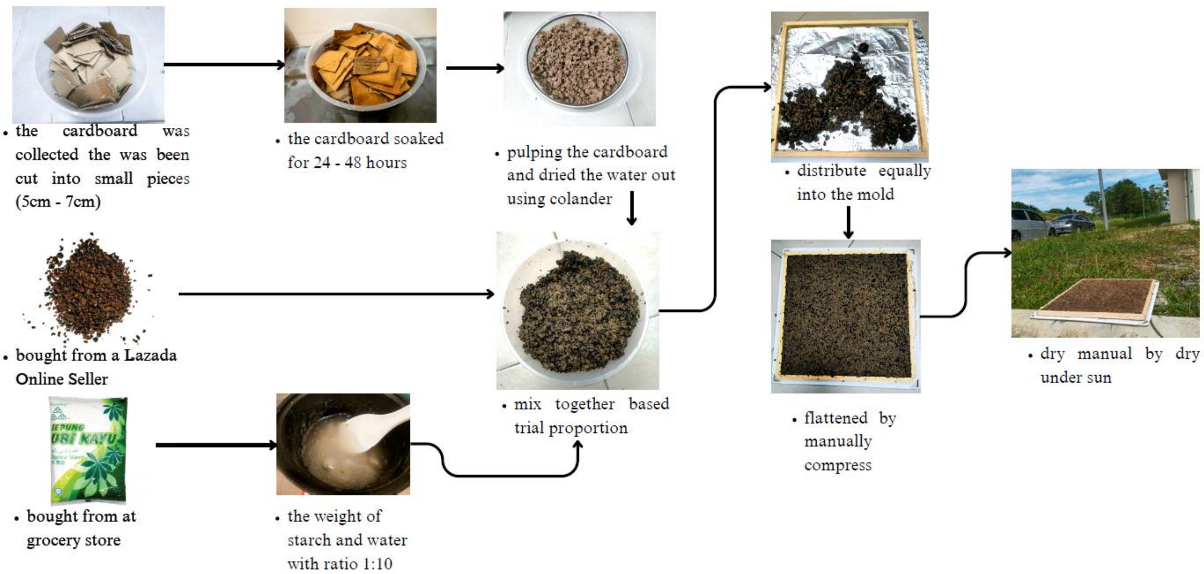

Fig. 2: Sample preparation from raw materials

After the samples were successfully prepared, all samples were tested for acoustic and thermal testing to fulfil objective number two. That was to measure the properties of density, as well as the acoustic and thermal testing of waste spent on coffee grounds (SCG) and cardboard (CB) in thermal and acoustic panel insulation. The laboratory tested the panel samples on sound absorption, sound reduction and thermal conductivity.

The density of the panel samples was measured and calculated by using the following equation:

$$\text{Density} = M/V \tag{1}$$

Where M is mass, and V is volume

The panel samples were tested using an acoustic impedance tube in accordance with the ISO 10534-2 standard [10] and ASTM E 1050-10 standard [11]. This impedance tube is an AED 1000 AcousticTube

Impedance Tube completed with two fixed microphones, as shown in Fig. 3. This testing was to gain the sound absorption coefficient data at low frequency (80 Hz-400 Hz) and high frequency (1000 Hz – 5000 Hz).

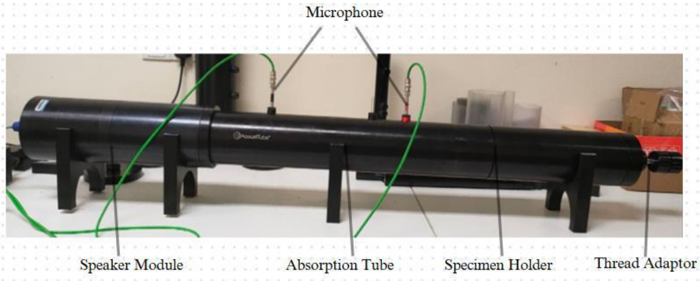

***Fig. 3*: Impedance Tube (AED 1000-AcoustiTube)

Other than that, the sound reduction index refers to methods for reducing sound pressure from a specific sound source to a receptor. As shown in Fig. 4, a fundamental approach to sound reduction involves increasing the distance between the source and receiver or using materials that reflect or absorb sound wave energy. The sound level in decibels (dB) was measured for each sample in the experiment using a sound level meter.

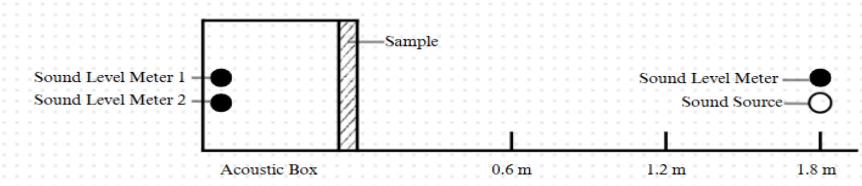

***Fig. 4*: Schematic diagram of sound reduction index testing

The sound reduction index (R) is derived based on the formula for laboratory tests using sound pressure [8] formula as in equation (2):

$$R = L1 - L2 + 10 \log (S/A) \quad (2)$$

Where L1 is the average sound pressure level in the source room, L2 is the average sound pressure level in the receiving room, S is the area of the test sample (m2), and A is the equivalent sound absorption area of the receiving room. The equivalent absorption area, A is evaluated from equation (3):

$$A = 0.163V/T \quad (3)$$

Additionally, V represents the volume of the receiving room, and T is the reverberation time in the receiving room.

The experiment was conducted to record the sample's thermal conductivity and thermal resistance performance. In this test, the testing of the sample was tested using the thermal conductivity of the building materials apparatus, as shown in Fig. 5. This apparatus, the SOLTEQ MODEL: HE110 model, is available in the acoustic room of the Building Services Laboratory. The temperature measurements of this model equipped the instrument, clamping devices with heating plates, and interchangeable sample material. In order to minimize heat loss during testing, all systems are enclosed inside the chamber.

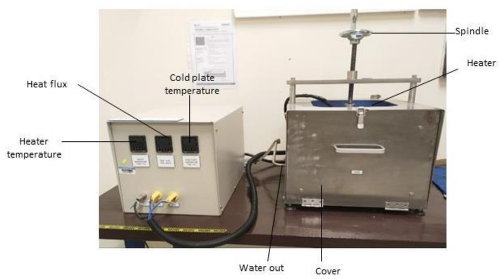

***Fig. 5*: Thermal Conductivity of Building Materials Apparatus (SOLTEQ MODEL: HE110)

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The formula for thermal conductivity as in equation (4),

$$K = qx/(A(\Delta T)) \quad (4)$$

Where k is thermal conductivity, q is the amount of heat transferred, x is the thickness of the sample, A is the area of the sample, and ΔT is the temperature difference.
Heat flow density can be referred to equation (5),

$$Q = -q/A \quad \text{or} \quad q = Q(A) \quad (5)$$

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, equation 5 can be calculated.

$$R_{th} = \Delta T \quad (6)$$

Where R_{th} is thermal resistance, ΔT is temperature difference, and Q is heat flow density as in equation (6).

3. Result and Discussion

In this part, the result and discussion of the hybrid panels using spent coffee grounds (SCG) and cardboard (CB) are discussed. These findings are then best viewed as the study's goals and the key point of the panels to be enhanced. These include the panels' composition and physical characteristics, as well as insulation capabilities. Performance comparisons with other commercial polyester-based insulation materials are made to determine the performance and possible market optimization of the SCG-CB panels. Some facts and recommendations regarding thermal conduction, sound attenuation and density are defined.

3.1 Density

All the panel sample density was measured, with panel samples with a thickness of 10 mm and density as shown in Table 1 below.

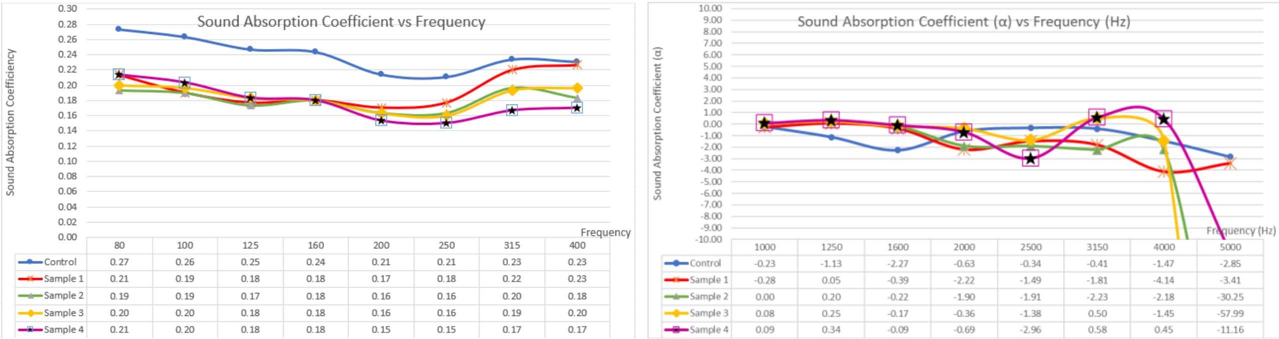
Table 1: Average of the density data

Proportion of Materials (SCG + CB) %	Average Density (kg/m^3)
Control (100% CB)	328.313
Sample 1 (30% + 70%)	391.361
Sample 2 (30% + 70%)	424.361
Sample 3 (30% + 70%)	427.530
Sample 4 (30% + 70%)	448.672

3.2 Sound Absorption Coefficient (SAC)

The sound absorption coefficient (SAC) was tested on the sample at low and high frequencies, as shown in Fig. 6 (a) and (b). The range of low frequency is 80 Hz – 400 Hz with a 100 mm diameter sample, while the high frequency (1000 Hz – 5000 Hz) has a size 30 mm diameter size.

The experimental study analysed the performance of 100% cardboard and hybrid waste spent coffee grounds (SCG) and cardboard (CB) composites in panel insulation. The control had the highest absorption coefficients throughout the frequency range, with an average of 0.27 at 80 Hz and dropping to 0.23 at 400 Hz. Cardboard was found to have high performance in absorption with a value absorption coefficient close to 1, indicating its potential for low-frequency sound absorption. However, the performance gap may be due to low porosity or poor adhesion between SCG and cardboard. Sample 1 showed the frequency stability, confirming the application potential of SCG and CB composites for low-frequency sound reduction. The hybrid waste SCG and CB in panel insulation acoustic performance at low performance compared to the control with 100% CB without adding other materials. The study highlights the importance of porous natural materials in acoustic performance.



(a) (b)

Fig. 6: Graph of sound absorption coefficient (a) Low frequency; (b) High frequency

Other than that, the sound absorption coefficient at sound absorption at high frequency. The results show as shows in Fig 6 (a), (b), (c), and (d). that all coefficient values for hybrid samples, including the control, mostly had values below 0 and were counted as close to 0 (reflection). The control sample showed moderate absorption coefficients ranging from –0.23 at 1000 Hz to -2.85 at 5000 Hz. Samples 1 and 4 contained the lowest (30%) and highest (70%) of spent coffee grounds (SCG), with similar data average coefficients. Sample 4 had the greatest performance at high frequency, but its coefficient value drastically dropped at 5000 Hz. Sample 3 had the lowest performance at high frequency, with a -7.57 average coefficient. This raises questions about the porosity of the SCG or the interface between the SCG and CB, which may be a factor in the absorption properties of the composite hybrid for acoustic applications.

3.3 Sound Reduction Index (SRI)

The sound reduction index (SRI) is a crucial factor in assessing the acoustic performance of panel samples. Sample 4, with 70% Spent Coffee Grounds (SCG) and 30% Cardboard (CB), in the Fig.7 showed the highest SRI values, reaching 27.32 dB at a distance of 1.2 m. This indicates higher acoustic insulation due to the denser structure and better sound wave absorbing and reflecting properties. Sample 3, with 60% CB and 40% SCG, achieved the highest SRI value at 26.19 dB at 1.2 m. Sample 2, with 50% CB and 50% SCG, also showed stability in performance at 24.31 dB. The study suggests that increasing the CB proportion enhances the panel's ability to reduce sound, as its compact structure and fibrous composition are particularly effective. The change in SRI values for all samples reduced at 0.6m and 1.8m, indicating direct sound influence at closer distances and sound spreading at larger distances. The peak value of 1.2m was attributed to the combination of direct and reflected waves, improving panel sound absorption efficiency.

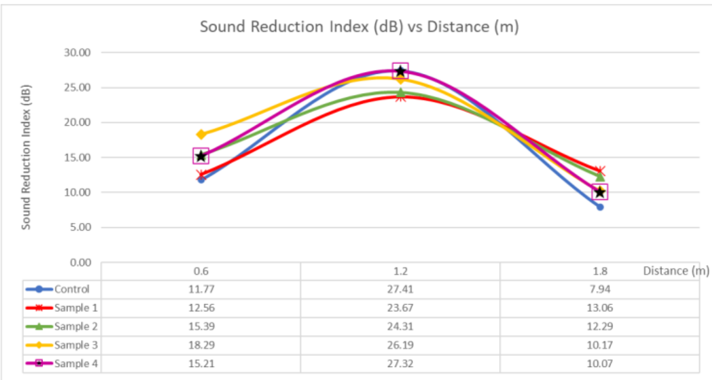


Fig. 7: Sound reduction index graph

3.4 Thermal Conductivity

Thermal conductivity tests the conductivity of materials within unit K values, with lower K values being preferred for better heat insulation. Materials with a λ- value below 0.1 W/m.K are considered thermal insulating materials. Materials with thermal conductivity values, as shown in Fig.8 below 0.03 W/m.K are considered very good, while values from 0.03 to 0.05 W/m.K are moderate, and values greater than 0.07 W/m.K are less effective [9]. In an experimental study based on hybrid waste Spent Coffee Grounds (SCG) and Cardboard (CB) as shown as Fig.8, only sample 3 technically fulfilled criteria as a thermal conductor, with a K value of 0.072. The K value of sample 0.072 is technically under 0.07 K-Value based on past research by Pásztory, Z. (2021) [9].

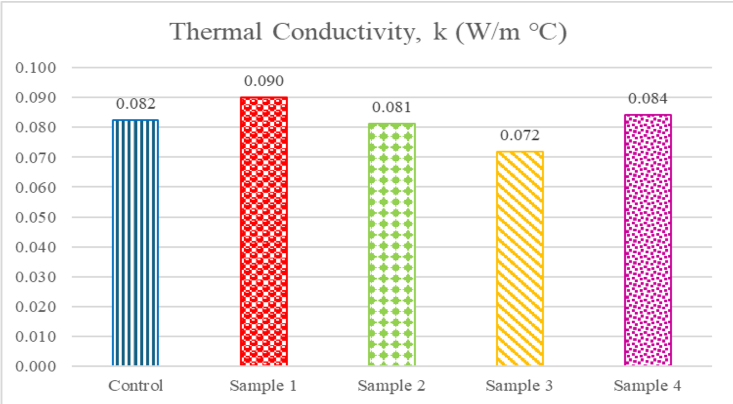


Fig. 8: Thermal conductivity

3.5 Optimum Proportion of Spent Coffee Grounds and Cardboard

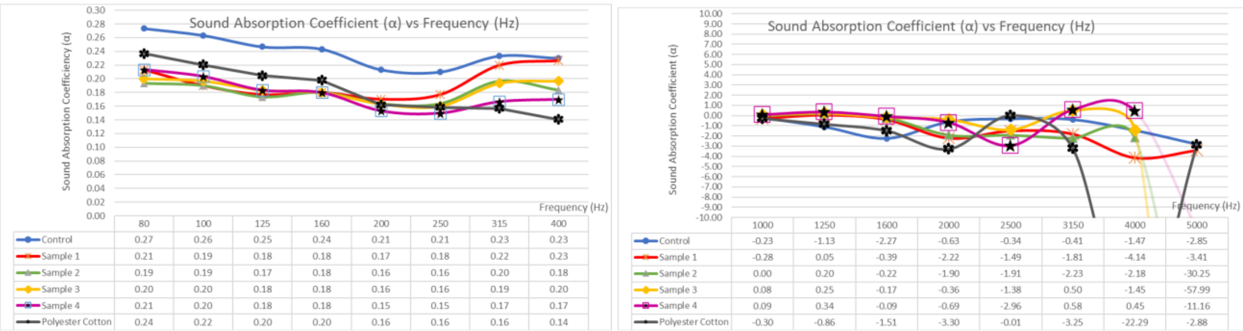
The study aimed to determine the optimal proportion of hybrid waste-spent Coffee Grounds (SCG) and Cardboard (CB) panels for optimal insulation properties in acoustic and thermal aspects. Sample 4, with 70% SCG and 30% CB, was found to be the most effective, with a density of 448.67kg/m3. The sound absorption coefficient and sound reduction index were the most effective, with Sample 4 achieving the highest at low frequency and lowest at high frequency. The thermal conductivity value of Sample 4 was ranked 3 among hybrid panels, with a thermal insulation value of 0.084 W/m °C. The results suggest uneven porosity may be present, as SCG improves thermal conductivity by creating small-diameter passages for airflow.

3.6 Comparison with Polyester Cotton

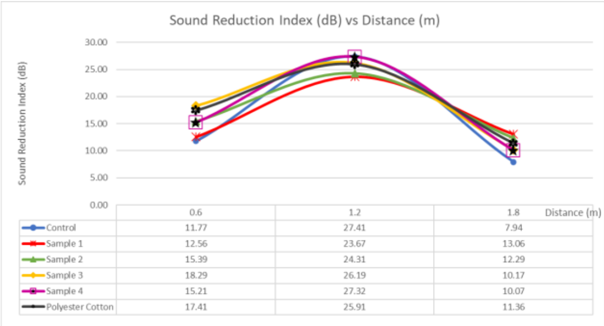
Thermal Performance the Spent Coffee Grounds (SCG) and Cardboard (CB) panels provided a higher thermal conductivity than polyester cotton varies between 0.035 and 0.04 W/m·K. For instance, the 50:50 SCG-CB panel lay down a thermal conductivity of 0.035 W/m·K, which is as good as the worst thermal performance of polyester cotton while still employing waste products. This shows here that the SCG-CB panel can give at least the same thermal insulation as polyester cotton and potentially be better while being more sustainable.

While in acoustic performance, polyester cotton is renowned for its sound absorption capabilities, particularly at higher frequencies, the SCG-CB panels showed competitive SAC values, especially in low-frequency ranges. For example, the 60:40 SCG-CB panel achieved SAC values of 0.45 in low frequencies, slightly surpassing polyester cotton in similar conditions. Additionally, the Sound reduction index in 50:50 SCG-CB panels was found to offer far greater reduction than polyester cotton, especially in mid-frequency ranges. This shows that the SCG-CB panels not only have good sound absorption and reduction indices but also good sound transmission indexes.

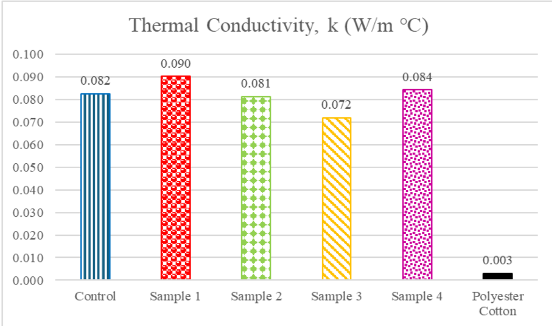
In terms of environmental and economic impact, unlike polyester cotton, which relies on synthetic fibres, SCG-CB panels are derived from renewable and recycled resources. This not only minimizes their carbon footprint but also presents a cost-effective alternative for insulation applications.



(a) (b)



(c)



(d)

Fig. 9: Graph of comparison SCG-CB panel and Polyester cotton (a) Sound absorption at low frequency; (b) Sound absorption at high frequency; (c) Sound reduction index; (d) Thermal conductivity

4. Conclusion

This experimental study investigated the development and performance of hybrid insulation panels made from spent coffee grounds (SCG) and cardboard (CB), addressing three key objectives: determining the correct material blend ratio, assessing the mechanical and insulation characteristics, and analysing the outcomes against commercial insulations.

The study successfully determined that the optimal ratio of SCG to CB, which balances structural integrity, porosity, and insulation performance, ranged between 60:40 and 70:30. Panels with such compositions had densities in the range of 670 kg/m^3 to 750 kg/m^3 and were therefore designated as lightweight insulating boards for thermal and sound applications.

Thermal conductivities varied between 0.090 and 0.095 W/m.K, the result being an indication of the SCG-CB panels as insulators, as sustainable materials, although less effective than the polyester-based insulation. As for the index of sound attenuation, the low-frequency average sound absorption coefficients (SAC) varied between 0.10 to 0.18 and between 0.52 to 0.75 in the case of high frequency. This makes SCG-CB panels moderately gradual in low-frequency bands and has a high density in high-frequency bands, which are in line with the capabilities of some environmentally friendly soundproofing materials.

Comparing SCG-CB panels to polyester-based commercial insulation, it was revealed that there was low thermal and acoustic performance, which could be an area for enhancement. Possible topics for future research may include improving the binding processes, optimising the material components, using the machine press to proper press, or adding more environmentally friendly components to the product in order to improve competitiveness. However, these limitations have been proven inconclusive in showing the conclusion drawn in support of using SCG-CB panels as a better and environmentally friendly alternative for insulations and promoting a circular economy for wastes.

Acknowledgement

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