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Thermal and Acoustic Performance of Sago Fine Waste Bricks (SFWB)

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ABSTRACT

Sago fine waste bricks (SFWB) were cement bricks containing sago fine waste (SFW) as a new building material in the construction industry. SFW was utilized to make five brick mixes with partial cement replacement percentages of 2%, 4%, 6%, 8%, and 10% that underwent testing and comparison with control bricks. The mortar mix had a 1:3 ratio, which was consistent with Malaysian brick production regulations. All the specimens had a water-cement ratio of 0.5 and had been cured for 28 days. This work aimed to investigate experimentally the effects SFW had on the strength, thermal, and acoustic properties of mixed cement bricks. According to the results, raising the proportion of SFW decreased the brick's value strength while lengthening the curing procedure increased the brick's strength. However, it complied with the standards for load-bearing constructions. According to Malaysian standard MS1933: Part 1:2007, all bricks satisfied class 1, 2, and 3 load-bearing bricks standards. SFWB had a thermal conductivity of 0.09 to 0.13 W/mK, where the value of heat conductivity was less than standards BS EN 12524, qualifying SFWB as a superior thermal insulator. Samples with higher SFW replacements exhibited higher sound absorption coefficients compared to samples with lower SFW replacements. When the coefficient was less than 0.3, the brick with a lower SFW replacement could not be used in high-frequency conditions. A brick with a coefficient of less than 0.3 absorbed and reflected the sound wave, according to ISO 11654:1997. Based on the results of thermal and acoustic tests, it could be concluded that SFWB were not good sound absorbers but were good heat insulators and suitable for construction in countries with an equatorial climate, such as Malaysia. Overall, SFW had the potential as a novel pozzolanic material in creating more sustainably made bricks that corresponded to the Sustainable Development Goals.

1. Introduction

Cement bricks are widely used in construction, but their extensive production contributes to environmental pollution. One approach to mitigating this impact is replacing cement with more sustainable materials, such as Sago Fine Waste (SFW), a fibrous by-product from sago milling operations [1-3].

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Heat and noise pollution are growing environmental concerns, and porous construction materials provide a practical solution for improving thermal and acoustic insulation. While various agro-waste materials have been studied as partial cement replacements, research on the effect of SFW on the thermal and acoustic performance of cement bricks remains limited [4]. Most existing studies focus primarily on mechanical properties, with less attention given to how SFW influences the combined effects of strength, thermal conductivity, and sound absorption.

Concrete, though widely used due to its durability, often lacks sufficient thermal and acoustic insulation. To address this gap, this study investigates the effect of incorporating different proportions of SFW on the physical, mechanical, durability, thermal, and acoustic properties of cement bricks. The findings will contribute to sustainable construction by identifying an eco-friendly alternative that balances strength, durability, and insulation performance.

2. Literature Review

A space with good acoustics would always be relaxed and comfortable. Since speaking and hearing are the most crucial forms of communication in the area, its acoustic design should be built to maximize the listener's ability to understand speech. Since acoustic quality is one of the key components of effective listening, listeners are now paying more attention to room acoustics [5].

Direct and reflected sounds from the listeners transfer speech in a space. While reflected sound bounces off some surfaces, like walls, before reaching its listeners, direct sound travels directly to its listeners without deviating from its source. When used properly in a silent area, the combination of direct and reflected sound enhances the communication environment [6].

The listeners may have serious abnormalities due to the room's acoustic issues. Stress, anxiety, depression, and other common illnesses are included. These conditions could harm the listener's health [7]. One of the key strategies for sound reduction is sound absorption. The ability to dampen sound wave reflections by material structures is the basis for the acoustic feature of sound absorption.

According to [8], the quantity of acoustic energy lost in a material as a sound wave travels through it is known as sound absorption. A material's sound absorption coefficient (α) is a dimensionless quantity ranging from zero to one over a range of frequencies that quantifies the amount of sound energy absorbed per unit area exposed to the sound.

The sound absorption coefficient is the percentage of a random incident sound energy absorbed or not reflected by a material. It is described as the proportion of sound energy absorbed by a surface to sound energy incident upon it. It also serves as a gauge for the material's capacity to absorb sound. Every material's sound absorption coefficient changes with frequency. The coefficient of material for frequencies of 125, 250, 1000, 2000, and 4000 Hz are typically listed. The symbol for the sound absorption coefficient is α. A higher coefficient value indicates improved absorption (ISO_11654)[9].

Jailani *et al* [10] studied the sound absorption of coconut fibre with a polyester panel board and found that the fibre panel had a good sound absorption coefficient between 0.7 and 0.8 at 1000 Hz to 1800 Hz. On the other hand, [11] conducted a study on sound absorption in bamboo with polyolefin; the result showed that the panel had high sound absorption, which was between 0.8 and 0.9 coefficient.

A brick's porosity and pore size distribution affect its ability to conduct heat, with air trapped in the pores acting as a greater thermal insulator [12,13]. In addition, micro and macropores are produced during the firing process. Hence, adding organic waste to burnt clay brick could increase porosity [14,15]. Therefore, organic waste such as stalks, grape seeds and wine lees [12], bagasse and palmyra fruit fibre [16], wheat straw [13], sunflower seed cake and olive stone flour [17] are more efficiently giving higher porosity after firing compared to incorporation with inorganic waste.

Point of fact, Malaysia is a country in Southeastern Asia with a warm and humid tropical climate throughout the year. According to the Malaysian Meteorological Department, the annual mean temperature as of July 2018 is 29°C with an average daily maximum and minimum temperatures of 34ºC and 24°C, respectively (Malaysian Meteorological Department, 2018). To reduce tenants' suffering from heat at night, the challenge is increasing the building's heat gain [18,19]. Although in the earlier century, the installation of air-conditioning was designed to alleviate unpleasant conditions, the overall energy consumption is predicted to climb substantially [20,21].

Thus, proper construction orientation based on sun exposure and appropriate insulation of building materials should be considered to maintain indoor thermal comfort and reduce energy usage [22]. While choosing a material, remember that it should be both absorbent and capable of storing heat. As a result, the heat flow would rise due to conductivity, pushing the temperature inside beyond what is comfortable [23]. Also, the roof releases heat trapped in the brick wall throughout the night, warming the room. Therefore, to maximize interior and outdoor thermal comfort in the future, building materials with low heat conductivity should be considered during construction.

3. Methodology

This test was conducted to measure the sound level the sample could absorb. A sample size of Ø28 mm was used to measure sound absorption for high frequencies between 0 and 6500 Hz. The apparatus used for this test was the impedance tube model, SCS9020B-Kundt/T60/TL, as shown in Figure 1. This test, which complied with the ASTM E1050 standard, used a tube, two microphones, and a digital frequency analysis system to determine average incidence sound absorption coefficients and standard-specific acoustic impedance ratios for materials.

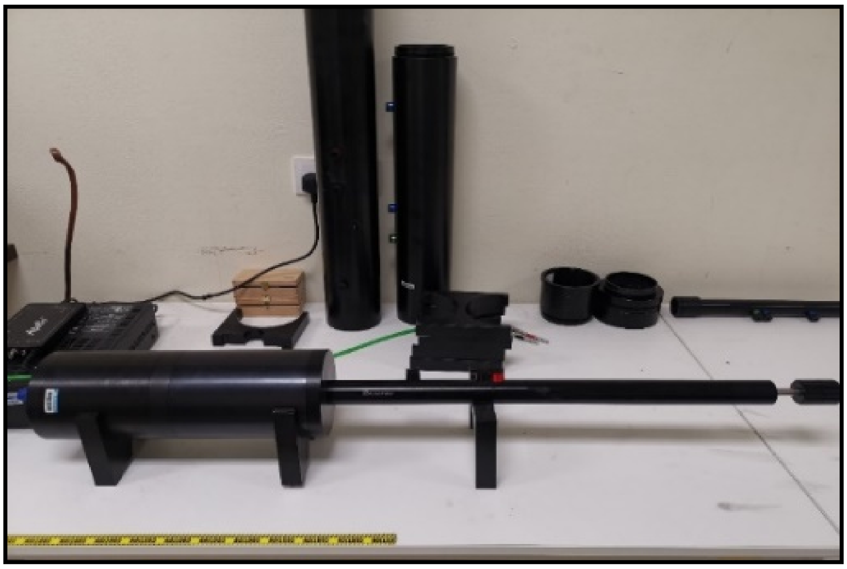


Fig. 1. Impedance tube

The sound absorption test used samples measuring a diameter of 28 mm with a thickness of 65 mm, as illustrated in Figure 2(a). The mould of the sound absorption sample testing is shown in Figure 2(b), while Figure 2(c) shows the sample ready for testing after 28 days of dry curing.

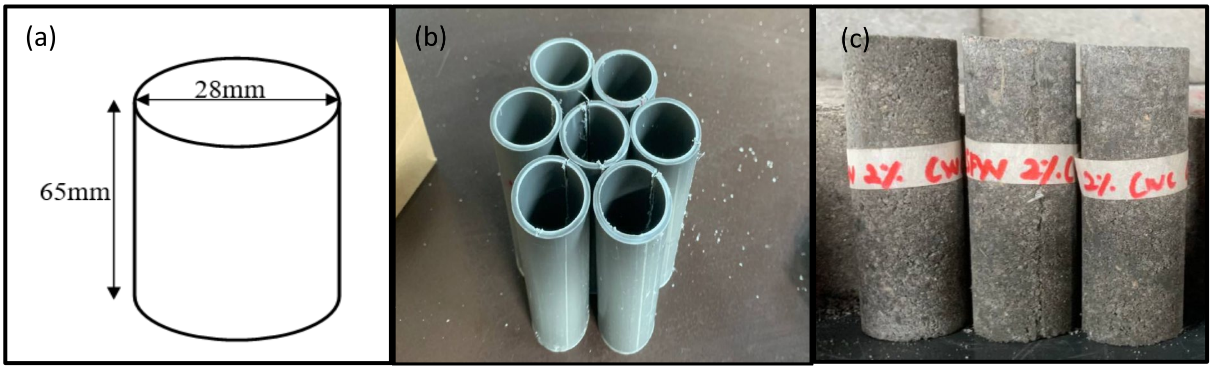
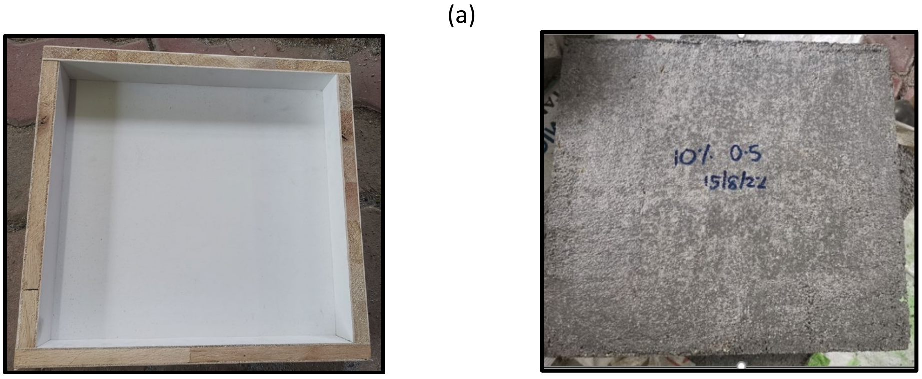


Fig. 2. (a) dimension of samples, (b) pvc pipe as a mould of samples (c) samples ready for testing

Thermal conductivity is the property of a material that reflects its ability to conduct or transfer heat using the standard test method of ASTM C177. This study used a heat flow meter (Solteq Model HE110) to measure the thermal properties of manufactured bricks using two thermoelectric devices, as shown in Figure 3(a). Each device was thermally coupled to a hot and cold plate with a heat transducer. These coupled plates were later thermally in contact with a sample surface and constructed to measure heat flowing through the plate. Thermal conductivity testing was performed on samples 300x300x40mm, as shown in Figure 3(b).

(a)



(b) (c)

Fig. 3. (a) Heat flow meter (b) mould of samples (c) samples ready for testing

Sample as shown in Figure 3(c), plate samples were placed vertically between two brass plates. The testing temperature was set to 24°C. The heat was supplied at the top and made to move downwards to stop any convection within the sample. Measurements were taken after the sample had attained equilibrium, which took about one to two hours per temperature. Every substance had its capacity for conducting and transferring heat. Heat transfer occurred at a lower rate in materials of low thermal conductivity than in materials of high thermal conductivity. The thermal conductivity of a material is explained by the following Eq. (1).

$$\text{Thermal conductivity, K (W/m °C)} = \frac{Qd}{A\Delta t} \quad (1)$$

Where,
Q = amount of heat transfer, Watt (W)
d = distance between two isothermal planes, meter (m)
A = area of the surface, meter square (m^2)
Δt = difference in temperature, °C

4. Result and Discussion

Figure 4 shows the sound absorption coefficient results for samples with various percentages of SFW replacement. The experiment was carried out at frequencies ranging from 0 to 6500 hertz. Frequencies less than 1500 Hz were considered lower frequencies, and 1500 Hz and onwards were regarded as high frequencies.

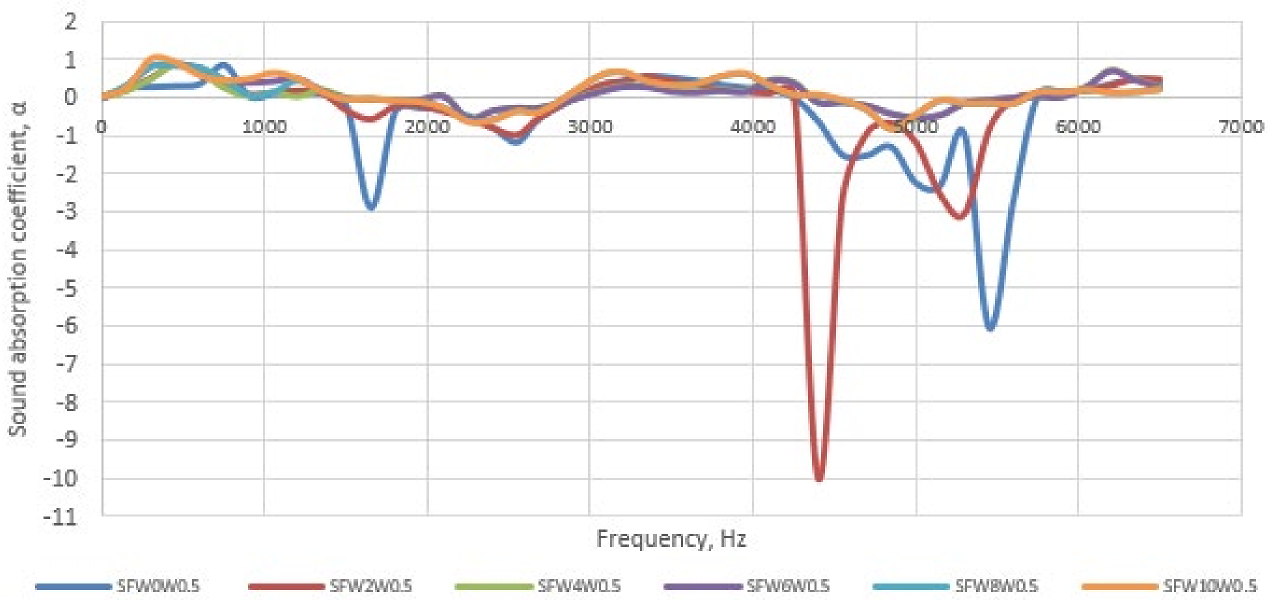


Fig. 4. Sound absorption coefficient

The sample recorded the highest sound absorption coefficient at lower frequencies with 10% SFW replacement with a reading of 0.993 at a frequency of 300 Hz. In comparison, the sample recorded the lowest sound absorption coefficient of 0.018 with 4% SFW replacement at a frequency of 1200 Hz. At the same time, the pattern showed higher sound absorption for samples containing 2%, 4%, 6%, 8% and 10% SFW replacement at a frequency of 450 Hz with coefficients of 0.845, 0.860, 0.855, 0.841, and 0.888, respectively. But for the control sample at 750 Hz, the sound absorption was almost similar in that pattern with a coefficient of 0.874. All the results recorded showed that the coefficients obtained were close to 1, the maximum sound absorption coefficient.

The average of the lower frequencies is 0.21, 0.22, 0.25, 0.41, 0.42 and 0.45 for samples containing 0%, 2%, 4%, 6%, 8% and 10%, respectively. This showed that the sound absorption coefficient can be greater than 0.3 for lower frequencies from 6% onward for replacement SFW. While the average sound absorption coefficient for higher frequencies is negative, SFWB is ideal for buildings with minimal sound absorption but not for use with sound-absorbing structures like acoustic buildings. When the coefficient is less than 0.3, the brick with the lower SFW replacement could not be used in high-frequency conditions. A brick with a coefficient of less than 0.3 absorbs and reflects the sound wave, according to ISO 11654:1997.

The thermal conductivity test was defined as the ability of the material to transmit heat. Therefore, a thermal conductivity test was carried out to determine the thermal conductivity of the samples by using the standard ASTM C177 test method. Table 1 shows the thermal conductivity values of the samples tested using thermal conductivity for building material apparatus utilizing the single plate method for the sample of SFWB. By increasing sago fine waste, the thermal conductivity of the samples fell significantly.

The thermal conductivity of bricks is affected by their firing temperatures, densities, and, thus, porosity [24 ,25]. Referring to Table 1, the thermal conductivity of the brick with 10% SFW is 0.09 W/mK, showing a reduction of 5% compared to the control brick (0.14 W/mK). It coincides with another researcher [26] who used waste material as a substitute in brick mixing. Overall, the SFWB has a thermal conductivity of 0.09 to 0.14 W/mK. Where the value of heat conductivity is less than standards BS EN 12524, SFWB brick qualifies as a superior thermal insulator.

Table 1
Thermal conductivity of the samples

Sample	Heat Flow density, q (W/m^2)	Hot plate temperature T_h (°C)	Cool plate temperature T_c (°C)	Temperature difference, ΔT	Heat Transfer Rate, q (W)	Thermal conductivity, K (W/m °C)	Thermal Resistance, R_{th} (°C/W)
SFW0W0.5	114	57.4	24.20	33.20	10.26	0.14	3.24
SFW2W0.5	94	57.2	27.50	29.70	8.46	0.13	3.51
SFW4W0.5	85	55.0	27.50	27.50	7.65	0.12	3.60
SFW6W0.5	70	54.0	27.90	26.10	6.30	0.11	4.14
SFW8W0.5	69	57.4	27.70	29.70	6.21	0.09	4.78
SFW10W0.5	51	50.2	27.90	22.30	4.59	0.09	4.86

4. Conclusions

Low noise levels are necessary for homes, offices, shopping centers, restaurants, etc. Overall, the results showed that SFWB could be used for the construction of buildings as stated, where the coefficient for lower frequencies was more than 0.3 results for samples more than 6% SFW. Therefore, SFWB is unsuitable for usage in spaces like concert halls, recording studios, lecture halls, and other venues where the quality and understandability of the sound are crucial.

In terms of thermal performance, SFWB exhibited lower thermal conductivity than the control brick, demonstrating its effectiveness as a thermal insulator. Thermal comfort is a key requirement in building design, and materials with low thermal conductivity help maintain stable indoor temperatures while reducing energy consumption. This makes SFWB a promising option for improving thermal insulation, particularly in hot climates like Malaysia.

Beyond its functional benefits, SFWB also offers significant environmental advantages compared to conventional cement bricks. The production of ordinary Portland cement (OPC) is energy-intensive and a major contributor to carbon emissions, whereas incorporating SFW as a partial replacement reduces cement consumption and associated CO_2 emissions. Additionally, utilizing SFW in brick production helps manage agricultural waste that would otherwise contribute to environmental pollution. A life cycle perspective suggests that SFWB could lead to lower embodied energy and waste generation throughout its production and disposal stages. Future research could further analyze its carbon footprint, durability over time, and recyclability to strengthen its role as a sustainable material.

While SFWB provides strong thermal insulation, its sound absorption properties require further enhancement to expand its application to acoustically sensitive environments. Future studies could explore modifications in mix design, pore structure optimization, or blending SFW with other sound-absorbing materials to improve its acoustic performance.

Overall, the use of SFW in brick production contributes to sustainable construction by reducing cement demand, minimizing waste, and lowering environmental impact. By optimizing its acoustic properties and further exploring its lifecycle sustainability, SFWB could become a versatile, eco-friendly alternative to traditional building materials.

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