Conference Paper No: PF-02

Sound absorption properties of structures developed using waste materials

N. D. D. D. Senarath*[1], J. A. C. P. Jayalath[1] and D. R. A. Mendis[1]

[1] Department of Physics, University of Peradeniya, Sri Lanka
danudd96@gmail.com*

Abstract

This study investigates the sound absorption coefficients (SAC) of structures developed using coconut shell powder, charcoal powder, and hair. Large amounts of coconut shells and human hair are readily available in Sri Lanka. The study used those to build sound absorption structures (SAS) using natural liquid rubber as a binder. Sample sheets were prepared by varying the volume ratio of the binder and fillers. Samples were tested for their SAC by using the impedance tube for different frequencies within the range of 1000-3500 Hz. Finally, the samples were further improved by changing physical properties such as lowering density, increasing thickness, and increasing porosity with surface roughness and combining layers. A coconut shell powder sample with a 50% volume ratio shows the SAC in the range of 0.80-0.83 for 2500 Hz and 0.85-0.93 for 3000 Hz. Improved charcoal samples, with 1.5 cm in thickness and a volume ratio of 66%, exhibited sound absorption over 60% beyond 2000 Hz, which indicates efficient absorption of incident sound energy without reflections or transmissions. A Hair sample also showed some magnificent SAC of 0.93 at 2500 Hz. A 2 cm thick layering type sample, which combines hair sample layers and charcoal powder sample layers, also shows a SAC of 0.80–0.80 for higher frequencies more fabulous than 3000 Hz. Acoustic materials in the market (thickness > 2 cm) have SAC of 0.20-0.99 for 125-4000 Hz. So, these versatile, cost-effective, eco-friendly SAS are suitable for architectural acoustics, studios, theatres, and the automotive industry due to flexibility, easy preparation, and thin profile.

Keywords

Acoustic foam, Sound Absorption, Sound absorption material, Sound absorption coefficient, Waste materials

Introduction

Sound pollution is a significant environmental issue that impacts human health and well-being. Unlike other types such as water, air, or soil pollution, it is an invisible form of pollution. Excessive noise exposure can lead to health problems like high blood pressure, heart disease, sleep disturbances, hearing loss, and stress. Children are particularly vulnerable. Sound pollution also contributes to social conflicts and family issues. Major sources include vehicle and traffic noise, factory operations, uncontrolled musical shows, and urbanization. The trend of constructing low-cost buildings with thin short walls exacerbates the problem. Smooth walls contribute to increased sound reflection and reverberation within rooms. Addressing sound pollution is crucial for maintaining a calm and healthy environment. This study's main target was to investigate the possibility of discovering confident natural, low-cost, and user-friendly SAS that are made from waste materials such as coconut shells, and human hair.

Global waste production has surged due to economic growth and improved living standards. To address this, researchers are developing sound absorption materials using waste resources like recycled rubber tires, textile waste, wood dust, and green tea residues, offering a value-added solution(Yan et al., 2014; Borlea et al., 2012; Chanlert & Ruamcharoen, 2021; Tiuc et al., 2018; Storodubtseva et al., 2018). We can mitigate environmental harm by repurposing these materials and contribute to sustainable waste management practices. Fiberglass board, glass wool, mineral wool, foam plastic, and wood wool boards are some of the mainly used SAS available in the market. Those have shown SAC between 0.20 – 0.98 for 125-4000 Hz (Materials, 2011; *Sound Absorption Coefficient Chart | JCW Acoustic Supplies*, n.d.).The market price of those materials in one square foot was more than 3-10 $. However, the production cost of these improved sound absorption materials are between 0.5- 1.5 $. So throughout this research, the physical properties of those samples changed by lowering density, increasing thickness, and increasing porosity with surface roughness and combining layers until the SAC increased. All SAC were taken by Impedance tube (Russell, n.d.).

Methodology/materials and methods

In Sri Lanka, there were lots of coconut shells available throughout the country. The selected coconut shells were slightly thicker than usual. The coconut shells were cleaned, ground, dried, and sifted to obtain the powder (Figure 1). It was then mixed with natural liquid rubber in a 1:1 volume ratio, compressed, solidified, milled, and dried to create a uniform sheet. The sheet was cut into samples' size, and their thickness, mass, and diameter were recorded to calculate density. The SAC was measured for high frequencies (1000 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, and 3500 Hz) for a thickness of 1.5 cm. Samples with a thickness of 1.5 cm were drilled with hole spaces of 1.5 cm for different depths (0.7 cm and 1.1 cm), and the SAC was measured for these combinations. Additionally, the SAC was tested by increasing the number of holes (with a hole space of 1 cm) for a depth of 1.1 cm.

Then 40 coconut shells were dried in sunlight for 2 days, cleaned, burned to convert into charcoal, and hammered into charcoal powder. The charcoal powder was sifted through a sieve and mixed with natural liquid rubber in a 2:1 volume ratio. After compression and a day of solidification, the mixture was milled into a uniform sheet, dried under sunlight for 2 days, and cut to sample holder size. The thickness, mass, and diameter were noted, and the SAC was measured at the same high frequency range, for thicknesses of 0.7 cm, 1.1 cm, and 1.5 cm. Similarly, samples with a thickness of 1.5 cm were drilled with hole spaces of 1 cm for different depths (0.7 cm and 1.1 cm), and the SAC was measured for these combinations. Rubber wood dust samples, made by mixing with natural liquid 1:1 ratio, are also used as a reference to check the thickness effect on SAC of samples.

(a) (b)

Figure 1. *(a) coconut shells powder (b) charcoal powder*

Human hair was washed, dried, soaked in rubber liquid, and compressed in a molder. The resulting hair sheet was milled to remove water, dried under sunlight, and cut to sample holder size. Thickness, mass, and diameter were recorded for density calculation. SAC was tested for the same high frequency range at 0.7 cm and 1.5 cm thicknesses. This research investigates the SAC of hair-based samples as sound absorption materials. Then a layer type, 2 cm thick sample (sample C) was made by combining charcoal powder layer and hair layer (Tiuc et al., 2018).This sample C tested for both sides, the one sets of reading set were taken when incident beam fell on hair layer and other set of reading ware taken when incident beam fell on charcoal layer.

Results and Discussion

Coconut shell powder samples

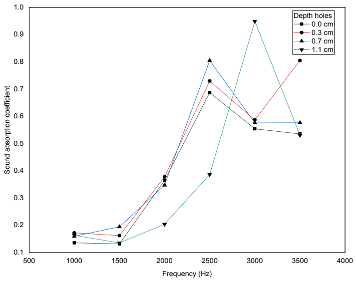

Figure 2. *The graph of the SAC vs frequency for different depths of holes of a 1.5 cm thick coconut powder sample with a 1.5 cm hole space*

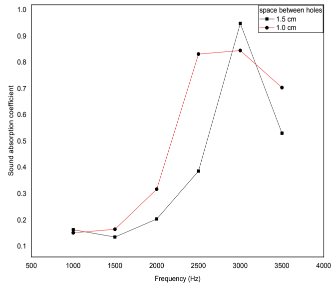

Figure 3. *Variation of SAC for 1.1 cm depth of holes in a 1.5 cm thick coconut powder sample with different hole spaces*

(a) **(b)**

Figure 4. *coconut powder sample (a) without holes, and (b) with holes and space between two holes was 1.5 cm*

Figure 2. illustrates the impact of holes depth on the sample. The sample with holes exhibited a higher SAC than those without holes. This can be attributed to increased surface roughness and reduced total reflection due to the presence of holes. Additionally, the density of the sample decreases with the holes, while the direct sound interaction area of the sample surface increases, resulting in enhanced sound absorption. However, the SAC varied with holes depth, indicating that specific depths of holes corresponded to the highest absorption for different frequencies. Increasing the number of holes or decreasing the hole spacing resulted in higher roughness and density, increasing sound absorption, as shown in Figure 3. There is a direct correlation between the number of holes and sound absorption. However, if the number of holes is increased excessively, the sound wave would transmit through the sample without absorption, indicating a limitation to the increment of holes. Similarly, when the depth of the hole is increased further, SAC is decreased due to the full transmission through holes.

Charcoal powder samples

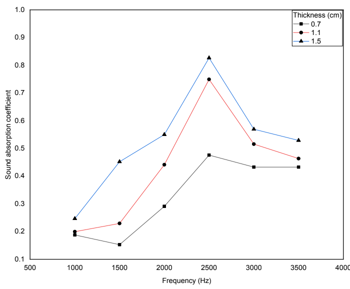

Figure 5*. The graph of SAC vs frequency for different thickness of charcoal powder sample*

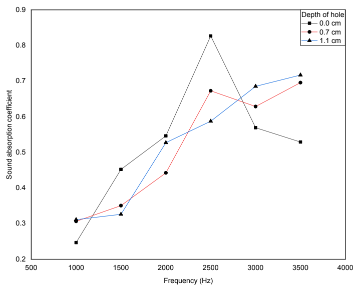

Figure 6. *The graph of SAC vs frequency for different depths of holes of a 1.5 cm thick charcoal powder sample with a 1 cm hole space*

(a) **(b)**

Figure 7. *Charcoal powder sample (a) without holes, and (b) with holes of hole space 1 cm*

Figure 5. illustrates the increased sound absorption coefficient with thicker materials. The 1.5 cm thick charcoal (blue line) demonstrated better sound absorption than to the coconut shell powder sample. Charcoal exhibited the highest absorption coefficient within the 2000 -3000 Hz frequency range. Each sample of 1 cm thick showed a peak in sound absorption coefficient, specifically at 2500 Hz. However, it is essential to note that the readings were not taken continuously because there were no readings within the frequency gap of 500 Hz. *Figure 6.* demonstrates the impact of holes and their depths on sound absorption. The black line represents sound absorption without holes, which showed no significant improvement. However, the sample with holes displayed effective sound absorption within the frequency range of 3000 Hz to 3500 Hz, serving as an example of successful absorption in that specific range. *Figure 8.* Interprit the SAC increased with decreased material density. The densities of the coconut shell powder sample (Red line) and charcoal powder sample (Black line) are 297.24 kg m^{-3} and 203.82 kg m^{-3} respectively. When density decreased, the speed of sound increased. So, the vibration increased, and the thermal energy loss also increased. Therefore, sound absorption should be increased accordingly.

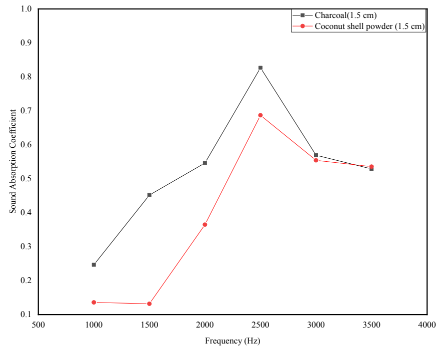

Figure 8. *The graph of SAC vs frequency for different densities of charcoal powder and coconut shell powder sample*

Hair samples

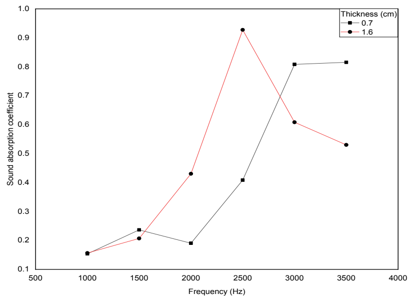

Figure 9. *The graph of SAC vs frequency for different thickness of hair sample*

Figure 9. was a somewhat different set of readings. Here the red line shows the 1.6 cm thick sample and it implies the highest absorption frequency of 2500 Hz. But the black line, which has a 0.7 cm thick sample, suddenly decreased the absorption at 2500 Hz, showings the highest absorption in the range of 3000 Hz to 3500 Hz. This was an unusual incident to the other samples because all other samples imply the highest peak for significant frequency at all thicknesses. Both samples show low absorption for the range 1000 Hz to 2000 Hz. But hair is a fibre-type material and the roughness of the hair sample was high. So, the materials show good performance when absorbing high frequencies between 2500 Hz to 3500 Hz.

Charcoal powder +Hair layer (Sample C)

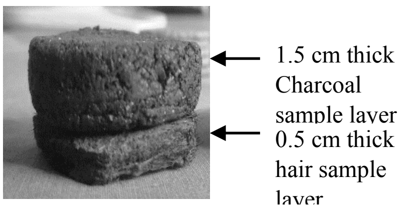

Figure 10.*Two layer Samlple* ***C***

Both materials charcoal and hair had shown good SAC for higher frequencies. The multilayer sample was made by combining a hair sample and a charcoal sample, as shown in *Figure 10*, after considering previous results. So *Figure 11*. implies something essential about sample C, which was the multilayer type sample. Here the sound absorption was checked for both sides of sample C. The black

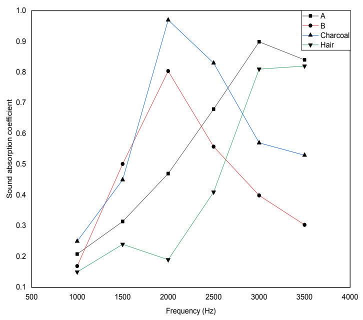

Figure 11. *The graph of sound absorption coefficient vs frequency for both surface of sample **C** , charcoal sample and hair sample*

line of *Figure 11*, which was labelled as A, was the sample whose interacting surface with sound was hair and other side was charcoal. But this has good absorption for the 2500 Hz to 3500 Hz frequency range. This curve was very similar to the hair sample (green line), and has a higher sound absorption coefficient than the hair sample 0.7 cm thick. Similarly, the SAC shown in the red line (B) is the other side of sample C, which means the sound interacting surface was the charcoal. This one show similar behaviour to the charcoal sample (blue line) with a 1.5 cm thickness. But this has lower effective sound absorption than charcoal. This multilayer sample C shows various sound absorptions for various surfaces. At 2000 Hz, the hair sample (0.7 cm thick) shows a drop of sound absorption coefficient less than 0.2, but when combining this hair sample with charcoal, that drop is overcome. *Figure 11.* shows the importance of surface roughness and the value of the hair layer as a surface layer of multilayering sound absorption material.

Conclusion

Various parameters can affect the sound absorption coefficient. The primary characteristics, taken into account in this study were porosity, thickness, surface roughness, and density. It is clearly observed that the sound absorption directly increased with the increment of sample thickness. Though the tested samples have shown somewhat low sound absorption for the frequency range of 1000 Hz to 2000 Hz, more than 0.7 sound absorption coefficient has been shown in the range from 2000 Hz up to 3500 Hz. The number and depth of holes also showed some increment of sound absorption. But it depends from frequency to frequency. The sound absorption direct impacted on the side of the sample with which sound interacts first. After optimizing porosity, thickness, density, hole depth, and hole diameter, sound absorption of materials can be maximized (Amares et al., 2017). Charcoal powder samples interpret effective performance about sound absorption. The thickness of the tested samples was either less than or equal to 1.5 cm, which means that if the thickness increases better sound absorption would be expected from those samples. The hair sample has a good rough surface. So, a hair sample is a better surface for multilayering sound absorption materials. When considering the density of the hair sample (212.31 kg m^{-3}), it has a low density. So that may also be a good reason for the increment in its sound absorption. Multilayering sample C has some good sound absorption coefficients. However, the sound absorption directly impacted on the side with which sound interacts. Due to their adaptability, simplicity of preparation, and thin profile, charcoal powder, hair, and sample C are flexible, affordable, and environmentally friendly sound absorption materials for architectural acoustics, recording studios, home theatres, and the automotive sector (Yan et al., 2014).

References

Amares, S., Sujatmika, E., Hong, T. W., Durairaj, R., & Hamid, H. S. H. B. (2017). A Review: Characteristics of Noise Absorption Material. *Journal of Physics:*

Conference Series, *908*(1). https://doi.org/10.1088/1742-6596/908/1/012005

Borlea, A., Rusu, T., & Vasile, O. (2012). Using particles of recycled rubber when making some soundproofing materials. *Materiale Plastice*, *49*(4), 275–278.

Chanlert, P., & Ruamcharoen, P. (2021). Sound absorption properties of rigid polyurethane foam composites with rubber-wood sawdust as a natural filler. *Journal of Physics: Conference Series*, *1719*(1). https://doi.org/10.1088/1742-6596/1719/1/012062

Materials, A. (2011). Acoustic and Thermal Insulating Materials. *Building Decorative Materials*, 359–374. https://doi.org/10.1533/9780857092588.359

Russell, D. A. (n.d.). *Absorption Coefficients and Impedance*. 1–6.

Sound Absorption Coefficient Chart | JCW Acoustic Supplies. (n.d.). Retrieved July 17, 2023, from https://www.acoustic-supplies.com/absorption-coefficient-chart/

Storodubtseva, T. N., Aksomitny, A., & Saldaev, V. A. (2018). The study of soundproofing properties of wood polymer-sand composite. *Solid State Phenomena*, *284 SSP*, 993–998. https://doi.org/10.4028/www.scientific.net/SSP.284.993

Tiuc, A. E., Vasile, O., Vermeşan, H., Nemeş, O., & Borlea Mureşan, S. I. (2018). New multilayered composite for sound absorbing applications. *Romanian Journal of Acoustics and Vibration*, *15*(2), 115–121.

Yan, J., Kim, M. S., Kang, K. M., Joo, K. H., Kang, Y. J., & Ahn, S. H. (2014). Evaluation of PP/Clay composites as soundproofing material. *Polymers and Polymer Composites*, *22*(1), 65–72. https://doi.org/10.1177/096739111402200110