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(Research Article)

Design and manufacturing of eco-friendly acoustic panels

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Abstract

Noise pollution poses a significant global challenge, prompting a surge in research aimed at addressing this issue. While traditional acoustic panels using synthetic materials are commonly advocated, concerns over their health and environmental impacts have sparked interest in sustainable alternatives. This paper explores the blossoming trend of utilizing waste materials, particularly natural cellulose fibers derived from agricultural byproducts like coir fiber and rice husk, for sound absorption. Embracing the axioms of sustainability, the study investigates the feasibility of replacing synthetic materials with natural fibers to reduce noise reverberations. Natural fibers such as coir, and rice husk or jute offer promising recyclable and biodegradable choices. The present research has achieved the outcomes of "Sustainable Serenity," a project focused on redefining acoustics with aesthetically pleasing, eco-friendly panels. Comprehensive testing demonstrates a reduction in echo by 39% which tends to diminish the corresponding value of 3.2% of conventional gypsum boards. The thermal resistance yielded 82 °C again surpassing the value of 68.7 °C for the conventional panels. Also, the impact strength, water absorption, and carbon footprint of the casted panels compared to traditional panels were evaluated to be applauding. The research highlights the potential of sustainable acoustic panels as a cost-effective, environmentally responsible solution for noise control. The aesthetically appealing design and superior performance of the casted panels with felt coverings underscore their suitability for promoting sustainability while enhancing acoustic environments.

Keywords: Acoustic; Sustainable; Eco-Friendly; Aesthetic; Reverberation.

1. Introduction

Noise pollution has become a major concern worldwide. Many researchers have come forward sharing views and conducting studies on the noise issue. Whilst the majority agrees at some level that the current traditional sound absorption panels using synthetic materials such as glass, mineral wool or polyester fibers are the solution to the noise problems, others on the other hand voice out concerns on the health and environmental impacts of such synthetic materials. Thus, new research on sustainable sound absorption panels is now trending. Natural cellulose fibers which can usually be found in agricultural waste such as coconut husk have proven in previous studies to have the capability to absorb sound.

1.1. Material selection

- The materials are selected upon satisfying the following conditions:
- The material must be well-grained.
- There should be a limitation in terms of water absorption.
- It must be lightweight, which will result in the reduction of the overall weight of the panel.
- It should possess good thermal resistance.

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- It must be cost-effective when compared to the cost of panels available in the market.

2. Methodology.

- Experimental procedure in finding the properties of the basic materials.
- Post-processing of raw materials.
- Designing of patterns/molds of the panels.
- Testing the panels for reverberation, thermal resistance, water absorption and impact strength.
- Results are extracted upon analyses. These results are compared with the conventional panels available in the market.
- A cost comparison between the sustainable panel and the gypsum board is done.

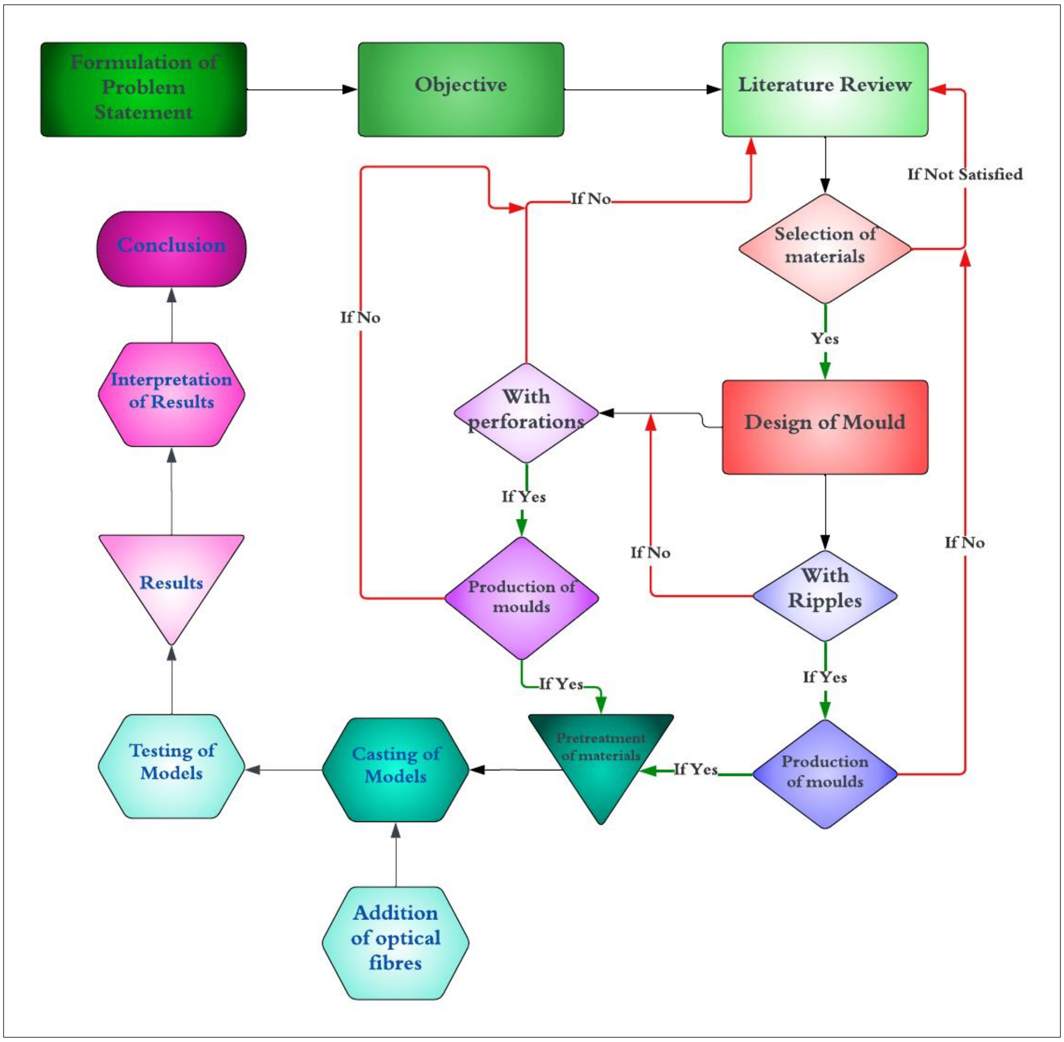

Figure 1 Methodology

2.1. Materials

2.1.1. Rice husk

Rice husk constitutes about 20- 25% of the weight of rice and its composition is as follows: cellulose (45-50%), lignin (25%–35%), silica (15%–25%), and moisture (10%–12%). The bulk density of rice husk is low and lies in the range of 90–150 kg/m3.

2.1.2. Coir Fiber

Coir fiber is the natural fiber extracted from the shell of the coconut. The coir fiber which is a by-product of the coconut industry is acquired from coconut shells treated to remove their organic components.

2.1.3. Gypsum

Gypsum is a very soft mineral that is easily identified by its hardness, cleavage, and white, gypsum may be colored reddish to brown or yellow if impurities are present. Most gypsum occurs as layers of rock containing shale, limestone, or dolostone.

2.1.4. Felt

Natural cotton and polyester felt is a composite material consisting of natural cotton fibers (20- 40%) for softness and sound absorption, and synthetic polyester fibers (60-80%) for durability and moisture resistance.

2.2. Design

- Dimensions of the panel:
- Panel Size = 30cm x 30cm.
- Thickness of the panels = 12mm + 1mm.

2.3. Post-processing of materials

2.3.1. Bleaching of Rice Husk: Sodium Hypochlorite Bleaching

Rice husk was bleached by preparing a bleaching solution by dissolving sodium hypochlorite (NaOCl) in water to achieve a concentration of 5-10% by weight. The rice husk was allowed to soak in the bleaching solution for 1-4 hours for the desired level of bleaching. After the designated soaking time, the bleaching solution was drained and the rice husk was rinsed thoroughly with clean water to remove any residual bleaching agent.

2.3.2. Bleaching of Coir Fiber: Hydrogen Peroxide Bleaching

Coir Fiber was bleached using a bleaching solution by dissolving hydrogen peroxide (H2O2) in water to achieve a concentration of 5-7% by weight. The coir fiber was allowed to soak in the bleaching solution for 24 hours, for the desired level of bleaching. After the designated soaking time, the bleaching solution was drained and the coir was rinsed thoroughly with clean water to remove any residual bleaching agent.

2.4. Casting and manufacturing of panels

A plain silicone mould without any surface patterns was used as the base mould. Small-diameter plastic pipes were introduced to create a perforated design on the acoustic panels. The positions of the multiple small plastic pipe cut pieces were marked on the plain silicone mould using a ruler and pencil to ensure accurate placement and distribution of the perforations in the checkered pattern. The pipe pieces were glued to the marked positions on the plain silicone mould using adhesive one by one. The adhesive was allowed to dry completely, ensuring a secure bond between the moulds.

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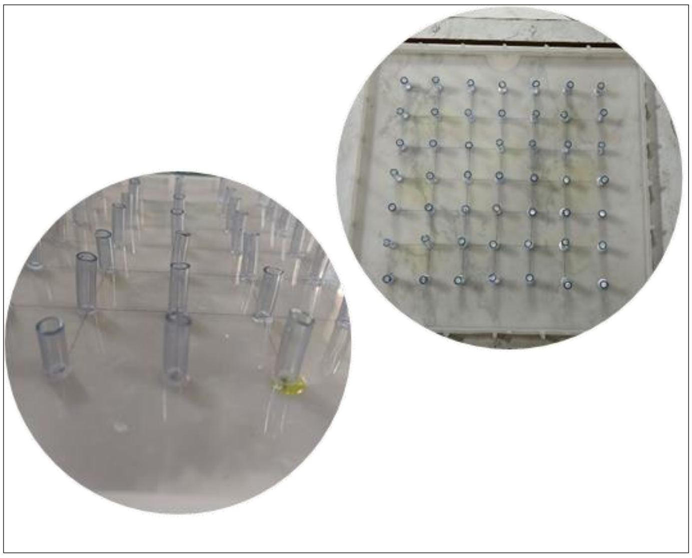

Figure 2 Mould design.

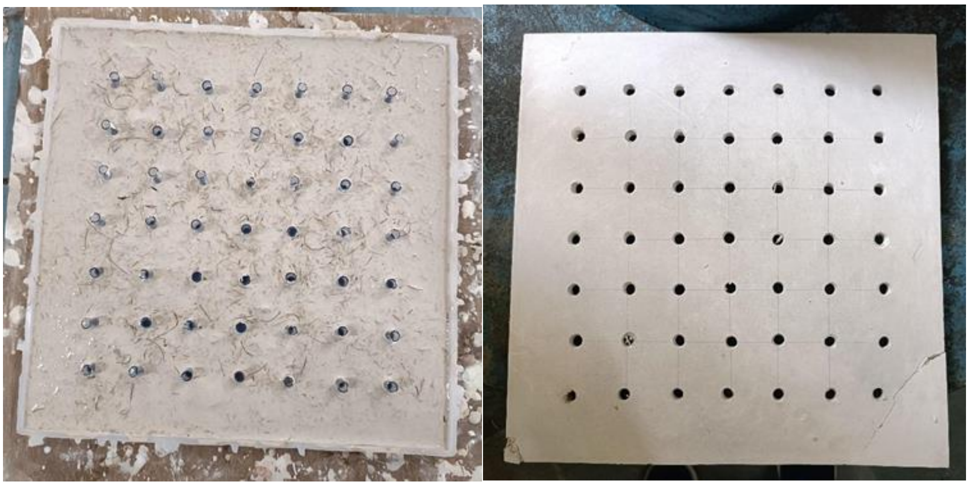

Figure 3 Proposed Acoustic Panels

2.5. Testing of panels

2.5.1. Reverberation Test

Acoustic panels designed for sound diffusion were arranged to form an enclosed box. A source of the test signal (such as a mobile phone or audio interface) is connected to a high-quality speaker system and a high-quality microphone capable of capturing the full frequency range of the test signal is placed. Audio analysis software was used for analyzing the signal.

Table 1 Results of Reverberation Test.

Sample	**Sound reverberation outside the setup(ms)**	**Sound reverberation inside the setup (ms)**	**Difference in Sound reverberation (ms)**	**Efficiency**
S1	893	864	29	3.2%
S2T1	1444	1442	2	0.13%
S3T1	1614	984	630	39%

Three different panel setups were subjected to reverberation testing to evaluate their sound absorption efficiency. The first panel-setup exhibited an efficiency of 3.2%, while the second panel setup had a significantly lower efficiency of 0.13%. However, the third setup, which incorporated acoustic felt material, demonstrated remarkable performance with an efficiency of 39%.

2.6. Thermal Resistance Test

2.6.1. Test Setup

The panel was securely mounted in a horizontal position followed by establishing appropriate boundary conditions. The sides and back of the panel were insulated to minimize heat loss through conduction. A temperature gun was held at a specific location to measure surface temperatures accurately.

Figure 4 Test setup of thermal resistance test.

Table 2 Results of Thermal Resistance Test

Sample	Initial Temperature (℃)	Temperature at Failure (℃)
S1	31	68.7
S2T2	32	82
S3T2	31	81.3

Thermal resistance tests were conducted on three different acoustic panel samples to evaluate their performance under high temperatures. For samples 1 and 2, the initial temperature was set at 31°C, and their final temperatures at failure were recorded as 68.7°C and 81.3°C, respectively. In contrast, the third-panel sample had an initial temperature of 32°C and exhibited a higher final temperature of 82°C before failing.

2.7. Water absorption test

The water absorption test was carried out using samples that were cut out from the cast panels and gypsum boards. A standard test procedure for water absorption of tiles was used referred.

Table 3 Results of Water absorption test.

Sample	Initial Weight(gm)	Final Weight(gm)	Difference in Weight (gm)	Water absorption %
S1	0.034	0.061	0.027	79.41%
S2T3	0.058	0.089	0.031	53.44%
S3T3	0.054	0.08	0.026	48.148%

The cast panel with perforations and felt (S3T3) showed the most reduced water retention rate of 48.148%, making it the best test in terms of water resistance. In differentiation, the routine board (S1T3) had the most elevated water assimilation rate of 79.41%.

2.7.1. Impact strength test

Initially proper support conditions were made utilizing wooden pieces. The panel was fitted such that there would be some space thereunder. Then in the center of the panel, a 520 g ball was dropped with a free drop from 80 cm. Further with the assistance of a digital microscope, the cracks were analyzed.

Crack length is requested to be a most extreme 10 mm. The test is rehashed 3 times for each test. The board composition with no break arrangement of estimate more than 10mm on the surface is classified as having tall affect quality. All tests were arranged as (20 cm × 30 cm–12 mm thickness) and affect test comes about were compared depending on the method.

Table 4 Results of Impact strength test

Sample	Repetition	Test Results			
		Crack numbers (> 10mm size)	Crack Numbers (< 10mm Size)	No Cracks formation	Evaluation of Impact test.
S1T4	1	Yes (3)	Yes (1)	-	Moderate
	2	Yes	Yes	-	Weak
S3T4	1	No	Yes (2)	-	Good
	2	No	Yes (2)	-	Good

Figure 5 Impact strength test result of cast vs conventional panel.

The impact strength test evaluated the gypsum board (S1T4) and the cast acoustic panel (S3T4), two times with different samples. For the conventional gypsum board (S1T4), the first repetition exhibited 3 cracks that were larger than 10mm in size and 1 crack smaller than 10mm, resulting in a moderate evaluation of the impact test. For the next repetition, there was a crack that was larger than 10mm and another crack smaller than 10mm, leading to weak results.

In the cast acoustic panel (S3T4), there were no cracks larger than 10mm that were observed in any of the repetitions. However, there were only 2 cracks smaller than 10mm present in both the repetitions, which resulted in a good evaluation of the impact test.

2.8. Cost Analysis

The results of the cost analysis for the casted acoustic panels made from sustainable agricultural waste materials compared to standard gypsum boards are as follows:

The cost of manufacturing a single-cast aesthetic acoustic panel using sustainable materials like rice husk, coir fiber, and gypsum powder came out to be Rs. 30 per panel. In contrast, the cost of a standard gypsum board available in the Indian or local market is approximately Rs. 60 per panel. Therefore, the proposed acoustic panels made from agricultural waste materials are significantly more economical, with a cost that is only 50% of the price of conventional gypsum boards.

Table 5 Material Quantities

Material	Quantity
Gypsum powder	750 gm
Rice husk	50 gm
Coir fibre	20gm
Sodium hypochlorite (for rice husk)	5-10% by weight
Hydrogen peroxide (for coir fiber)	5-7% by weight

Table 6 Cost of materials

Material	Cost/unit (In Rs.)	Quantity of material used	Cost (In Rs.)
Gypsum	Rs. 11/kg Rs. 220/20kg	750 gm	Rs. 8.25
Rice husk	Mostly free (waste product) Handling charges = Rs. 5/kg	50 gm	Rs. 0.25
Coir fibre	Rs. 40/150gm	20 gm	Rs. 5.33
Sodium hypochlorite (for rice husk)	Rs. 32/200 ml	5-10% by weight For 50gm rice husk	Rs. 2
Hydrogen peroxide (for coir fibre)	Rs. 42/400ml Rs.0.11/ml	5-7% by weight For 20gm coir fibre	Rs. 0.15
Natural cotton felt	Rs. 10/piece	1.25 piece/panel	Rs. 13

Table 7 Total panel cost

Material	Quantity/Panel used	Cost
Gypsum powder	750gm	Rs. 8.25
Rice husk	50gm	Rs 0.25
Coir fibre	20gm	Rs. 5.33
Sodium hypochlorite	5% by weight	Rs. 2
Hydrogen peroxide	7% by weight	Rs. 0.15

Natural felt	1.25 piece	Rs. 13
Total cost =		Rs.28.98 = Rs.30/Panel

Table 8 Cost Comparison

Casted Acoustic panel	**Standard acoustic panel (Gypsum)**
Cost = Rs. 30/panel	Cost = Rs.60/panel

2.9. Carbon Footprint

Carbon footprints are the total greenhouse gas emissions, typically expressed in terms of carbon dioxide equivalents (CO2e), that an individual, organization, event, product, or activity directly or indirectly produces. These emissions contribute to climate change by trapping heat in the Earth's atmosphere, leading to global warming and associated environmental impacts.

Table 9 Carbon Footprints.

Sample	**Calculated Carbon Footprints**
S1. Control specimens	0.169 Kg of CO2 emissions.
S2. Panels without Felt sheet	0.126 Kg of CO2 emissions.
S3. Panels with Felt sheet	0.134 Kg of CO2 emissions.

3. Conclusion

With the use of materials like rice husk, gypsum, and coir fiber, the current study has effectively created an environmentally friendly and sustainable substitute for traditional acoustic panels. The process of innovation has made it possible to create visually appealing perforated designs that are further enhanced by the addition of felt coverings. Surprisingly, the cost estimate showed that felt-casted panels were substantially less expensive than standard gypsum boards, costing only Rs. 30 per panel as opposed to Rs. 60. Extensive testing confirmed that the casted panels outperformed traditional solutions in a number of categories, particularly felt-covered panels. The felt panel turned out to be the best option; it outperformed the usual gypsum boards in reverberation tests, with an efficiency of 39%. Furthermore, this panel demonstrated remarkable thermal resistance, able to sustain temperatures as high as 82°C before failing—a temperature higher than that of a gypsum board, which is 68.7°C. The panel's resilience to moisture-related problems was demonstrated by the water absorption tests. Notably, the casted panels' water absorption rate was approximately 48.148%, which is a significant improvement above the gypsum boards' rate of 79.41%. In addition, the impact testing revealed that the cast panels were remarkably resilient, producing just 1-2 small cracks (<10mm) and no large cracks (>10mm). In contrast, the typical gypsum boards showed larger cracks in both test repeats.

Additionally, the carbon footprint of the cast panels was greatly decreased; panels without felt sheets emitted 0.126 kg of CO2, while panels with felt sheets emitted 0.134 kg. These emissions were subsequently lower than the 0.169 kg of CO2 emissions linked to the gypsum boards. To sum up, our project has effectively created an environmentally friendly, cost-effective, and sustainable acoustic panel solution that not only outperforms conventional options in terms of performance and environmental impact but also has a beautiful look.

Compliance with ethical standards

Acknowledgments

We would like to express our sincere gratitude and appreciation to, Prof. Nilesh Lende, Prof. Aditya Ahirwar, and Prof. Nitin Soni, for their invaluable guidance, support, and encouragement throughout this project.

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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