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Sustainable Approaches to Noise Control Using Waste Materials

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Abstract

Noise pollution in industrial and construction environments poses significant risks to human health, leading to hearing loss, stress-related illnesses, and decreased productivity. This study explores sustainable noise control solutions using bio-materials and waste products for acoustic insulation. The noise level at a construction site near the Fitting Shop, RUET was measured at an average of 87.03 dBA, exceeding the WHO threshold of 65 dBA for noise pollution. To address this issue, the research focused on developing a composite noise barrier system using bio-materials. Luffa was identified as a viable bio-material for sound absorption resulting in a 12% reduction in noise levels. Foam alone provided an 8% reduction while combining luffa and foam achieved a 15% reduction. Further investigations into recycled waste materials led to the development of a geotex-foam-geotex three-layer composite structure, which exhibited a maximum noise reduction of 25%, compared to 12.75% with geotex alone. To validate its effectiveness in industrial settings, this geotex-foam-geotex structure is proposed to be used to enclose the sound-generating instruments and incorporate a vibration absorber ground and an exhaust gas silencer. This comprehensive approach, combining both active and passive noise control methods, aims to significantly mitigate industrial noise pollution and enhance acoustic comfort in these environments. Future research will explore the implementation of these noise barriers in real-world industrial applications and further investigate the use of additional bio-materials for acoustic insulation. This study provides a foundation for environmentally friendly and cost-effective noise control systems that promote both human well-being and environmental sustainability.

Keywords: Noise pollution, Bio-materials, Acoustic insulation, Industrial noise control.

1. Introduction

Industrial activities are a significant source of environmental noise pollution, presenting challenges to both ecological health and worker well-being [1]. The World Health Organization (WHO) estimates that over 1 million healthy life years are lost annually due to environmental noise exposure [2]. In industrial settings, noise not only affects nearby communities but also creates hazardous working conditions, leading to hearing loss, tinnitus, stress, and other health issues [3]. Studies show that prolonged exposure to high noise levels in industrial environments contributes to cardiovascular diseases, sleep disturbances, and psychological stress, with the risk of hearing loss reaching 33% in some cases [3], [4]. According to the WHO, continuous exposure to noise levels above 65 dBA is considered noise pollution and poses serious health risks [5]. In many industrial settings, noise often exceeds this threshold, such as at the construction site near the Fitting Shop of the Rajshahi University of Engineering and Technology (RUET).

The urgency of addressing noise pollution has led researchers and engineers to explore various control strategies, from conventional materials like concrete and foam to advanced technologies such as active noise control (ANC) and passive noise control (PNC). While ANC uses sound waves to cancel out noise, PNC relies on materials that absorb or block sound [6]. However, many traditional noise mitigation methods are not sustainable, often using materials with high environmental impact, such as synthetic foams and polymers [7]. This has sparked interest in sustainable approaches that utilize eco-friendly materials, particularly waste products and bio-materials, for noise control.

Traditional methods, such as sound insulation and damping techniques, offer partial solutions but have limitations. They can be costly, space-consuming, and may not be effective across all noise frequencies [8]. Additionally, conventional materials often rely on non-renewable resources and have limited recyclability, raising concerns about their environmental impact [9]. In response, there is growing interest in sustainable approaches using waste materials, which are renewable, biodegradable, and possess promising sound-absorbing properties. However, research on their effectiveness in industrial settings remains limited [10], [11].

This study is motivated by the need for an eco-friendly, cost-effective solution to industrial noise pollution. With noise levels in industrial environments often exceeding safe limits, workers face long-term exposure that affects both health and productivity. While conventional methods are somewhat effective, they are resource-intensive and environmentally harmful. Therefore, alternative noise control solutions that mitigate noise and promote sustainability are essential.

This research aims to develop a noise barrier system using bio-composite materials derived from waste products. Natural materials like luffa and recycled materials such as geotextiles offer the potential for acoustic insulation due to their sound-absorbing properties.

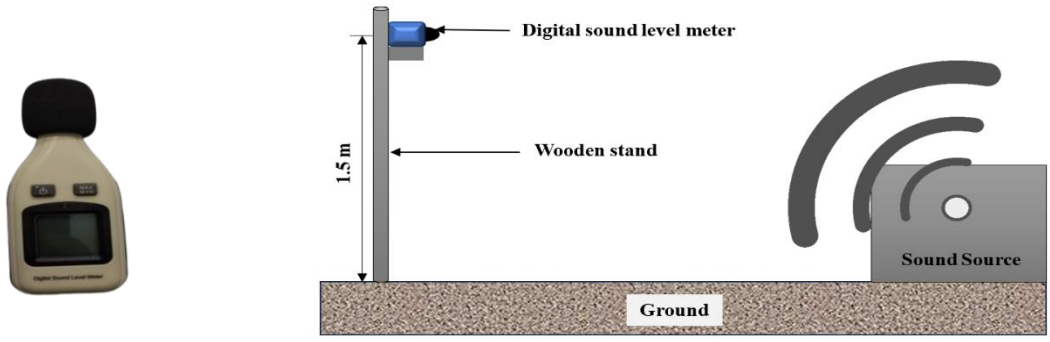
The study proposes the development of a sustainable noise control system utilizing bio-materials and waste products to mitigate noise pollution in industrial environments. Noise levels will be measured at both a construction site and an industrial setting to assess the real-world applicability of the system. Standardized testing methods, such as the impedance tube method, will be employed to evaluate the sound absorption coefficients of the selected materials. Although the study will focus on passive noise control techniques, the system will be designed with considerations for practical implementation in an industrial environment to validate its effectiveness and suitability for reducing noise pollution in such settings.

2. Methodology

The methodology of this study focused on developing a sustainable noise barrier system using bio-composites and waste materials, alongside measuring the existing noise levels in an industrial setting for comparison. Noise reduction capabilities were evaluated through experimental setups, standardized measurement techniques, and field data collection from a real-world industrial environment. This section includes subsections on Field Noise Measurement, Frame Making, Composite Fabrication, Noise Reduction Coefficient (NRC) Calculation, and Experimental Setup.

Measurement of Noise Level

The study measured noise pollution at a construction site behind RUET's machine shop, covering an area of 100m x 60m with measurements taken at 20 points. A digital sound level meter, mounted 1.5 meters above the ground, recorded maximum, minimum, and average noise levels near noise sources as illustrated in Fig. 1. The setup ensured consistent data collection across the site, with sound intensity recorded in decibels (dB).



(a) (b)

Fig. 1. (a) Digital sound level meter. **(b)** Schematic diagram of the data-taking process.

Frame Making

The sound barrier frame was built from durable mild steel rods for strong structural support as shown in Fig. 2. A 10 mm x 10 mm square rod formed the main frame, with 5 mm circular rods reinforcing specific sections. A 240 mm x 240 mm glass panel (5 mm thick) was included to study the effect of transparency on sound reduction. The modular frame was designed to accommodate various bio-composites and waste materials for sound absorption.

Fig. 2. Fabricated frame structure.



The frame was fabricated to accommodate both natural bio-composites and waste materials for sound absorption, providing a modular design that could be adjusted depending on the material being tested.

Composite Fabrication

The noise barrier system primarily utilizes natural and recycled materials such as luffa, foam, and geotex. These materials were selected for their availability, eco-friendliness, and sound-absorbing properties. The fabrication process of the composite materials involved several key steps, described below:

Materials

i. **Luffa**: A natural fibrous material known for its porous structure, ideal for sound absorption [12].
ii. **Foam**: A synthetic material effective at absorbing high-frequency sounds [13].
iii. **Geotex**: A recycled material that provides structural integrity and absorbs mid-frequency noise [14].

Procedure:

i. **Material Selection**: Materials (luffa, foam, and geotex) were chosen for their acoustic properties and combined in layers to optimize noise reduction. Geotex formed the outer layer, luffa the sound-absorbing core, and foam the absorber of high-frequency sound waves.
ii. **Molding and Layering**: Materials were cut to 240 mm x 240 mm, layered, and bonded with epoxy resin for strong adhesion and durability. The Geotex-Foam-Geotex sample used a three-layered configuration and was moulded for shape consistency during curing.
iii. **Curing**: Samples are cured for 24 hours at 25°C and 40-50% humidity to ensure structural rigidity and prevent material warping [15].
iv. **Sample Variants**: Variants tested included single-material samples (luffa, foam, geotex) and combinations (Luffa + Foam, Geotex-Foam-Geotex) to assess noise reduction efficiency.
v. **Composite Testing**: The Geotex-Foam-Geotex composite was tested for noise absorption, and secured within a frame using clamps to simulate real-world industrial noise conditions. This process allowed for a comparison of single-material performance versus composite structures, with the Geotex-Foam-Geotex composite showing the highest potential for sound absorption due to its ability to absorb a wider range of sound frequencies, from low to high. The completed composite structure bound along the frame is shown in Fig. 3, where the three layers are visible.



(a) (b)

Fig. 3. (a) Geotex-Foam-Geotex composite structure. **(b)** Experimental setup for the closed enclosure.

Noise Reduction Coefficient(NRC) Calculation

To determine the effectiveness of the bio-materials in reducing noise, the Noise Reduction Coefficient (NRC) was calculated for each sample. The NRC is a standardized measure that quantifies how much sound a material absorbs, particularly in the mid-range frequencies (250 Hz, 500 Hz, 1000 Hz, and 2000 Hz) [16].
The NRC is given by the following equation:

$$NRC = \frac{\alpha_{250\,Hz}+\alpha_{500\,Hz}+\alpha_{1000\,Hz}+\alpha_{2000\,Hz}}{4} \quad (1)$$

where α is the sound absorption coefficient at specific frequencies. The Noise Reduction Coefficient (NRC) measures a material's overall sound absorption, with values close to 1 indicating excellent absorption suitable for high-noise environments. Materials with NRC values between 0.5 and 0.75 provide moderate absorption, effective for mid-frequency noise, while values below 0.5 indicate limited absorption, making these materials better suited for layered composite structures [17].

Measurement of Sound Absorption Coefficient (α)

The sound absorption coefficient (α) for each material was measured using the impedance tube method, a highly accurate technique for calculating how much sound is absorbed versus reflected when sound waves pass through a material. In this method, sound waves are generated at specific frequencies and directed toward a material sample placed at one end of the tube. The values of α lie between 0 and 1, with higher values indicating better sound absorption [18].

Experimental Setup

The experimental setup for testing the noise reduction capability of the materials involved the use of an impedance tube, a widely recognized method for measuring the sound absorption coefficients of various materials.

i. **Impedance Tube Method**: This method involves generating sound waves at specific frequencies and directing them toward a material sample placed at the end of the tube. The digital sound level meter placed

at the end of the tube measures the reflected and transmitted sound waves, enabling the calculation of the sound absorption coefficient. The impedance tube is shown in the Fig. 4.



Fig. 4. Experimental setup for impedance tube method.

- **Frequency Range**: The materials were tested at frequencies of 500 Hz and 1500 Hz, as these frequencies are commonly encountered in industrial environments and are critical for assessing noise control performance.
- **Sample Testing**: Each material—including luffa, foam, geotex, and composite structures—was tested individually in the impedance tube to measure its respective sound absorption coefficient and Noise Reduction Coefficient (NRC).

ii. **Geotex-Foam-Geotex Composite Testing**: A three-layer Geotex-Foam-Geotex structure was also fabricated and tested using the impedance tube method. This composite structure combined recycled geotex as the outer layers with luffa as the middle layer to enhance noise absorption. The objective was to evaluate how this multi-layered structure compared to single-material solutions in reducing noise levels.

iii. **Data Collection**: The sound absorption coefficients were recorded for each material, and the NRC values were calculated. Additionally, the percentage of noise reduction was calculated for each material and composite structure, providing a comparative analysis of their effectiveness.

3. Results and Discussion

Results

The results of this study provide both laboratory and field data that highlight the effectiveness of bio-composites and waste materials in mitigating noise pollution in industrial environments. The field measurements conducted behind the machine shop at Rajshahi University of Engineering & Technology (RUET) and the laboratory tests on various composite materials form the foundation for this analysis.

Field Noise Measurement Results

Field data collection revealed significant noise pollution levels in the study area behind the machine shop at RUET The average noise level measured across 20 different points during working hours was 87.03 dBA, which is considerably above the standard noise level limits of 60 dBA(Day time) and 50 dBA(Night time) in Bangladesh [19]. From the graph in Fig. 5, it can be seen that the maximum sound intensity was recorded at 96.26 dBA at allocated point 11, with the lowest sound intensity at 71.90 dBA at point 1. These values are concerning, as prolonged exposure to noise levels above 85 dBA can lead to hearing damage and other health issues such as stress, sleep disturbances, and cardiovascular problems, as documented in existing literature. The fact that the average noise level exceeded 85 dBA at most points in the study area reinforces the urgency of addressing noise pollution in industrial environments like RUET's machine shop. The measured noise level at RUET aligns with general findings in industrial settings globally, where noise levels frequently surpass safe limits, posing risks to worker health and well-being.

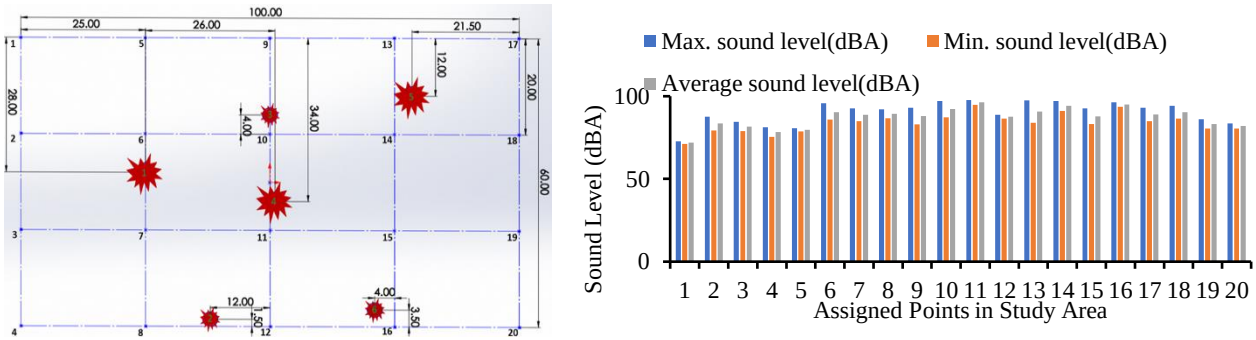


Fig. 5. Recorded sound intensity in the locations in the study area.

Laboratory Testing Results

The laboratory results focus on the Noise Reduction Coefficient (NRC) values and overall noise reduction percentages achieved by different bio-composites and waste materials. The Noise Reduction Coefficient

quantifies how well a material absorbs sound across key frequencies (250 Hz, 500 Hz, 1000 Hz, and 2000 Hz). Mid-range frequencies, particularly between 500 Hz and 1500 Hz, are common in industrial noise environments, making these frequency bands particularly relevant for the study [20]. The key findings from the laboratory tests are shown in the Fig. 6.

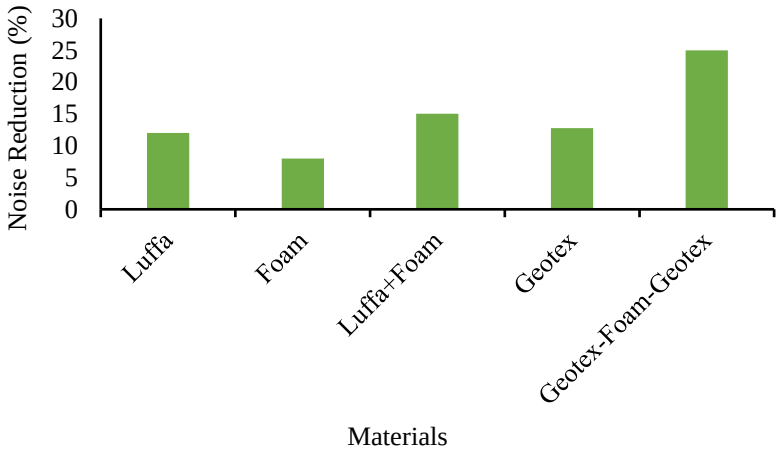


Fig. 6. Percentage of noise reduction for different materials.

The Geotex-Foam-Geotex composite structure achieved the highest noise reduction of 25%, indicating a significant improvement over the performance of individual materials. This result suggests that layered structures that combine materials with different acoustic properties are more effective at reducing noise across a broader frequency spectrum. Geotex is a recycled material that provides structural strength and absorbs mid-frequency sounds, while foam is more effective at absorbing high-frequency noise. The synergy between these materials contributes to the superior performance of the Geotex-Foam-Geotex composite.

The Luffa + Foam combination achieved a 15% noise reduction, which was higher than the individual performance of either material. This demonstrates the advantage of combining materials with different sound absorption mechanisms. Luffa's fibrous structure allows it to absorb sound waves, while foam's porous cellular structure traps air and absorbs sound energy. The combination of these materials, although not as effective as the Geotex-Foam-Geotex composite, provides a notable improvement over using either material alone.

Analysis of Individual Material Performance

Luffa achieved a 12% noise reduction, showing moderate effectiveness but limited suitability for high-noise industrial settings. Foam reduced noise by 8%, performing best at high frequencies, suggesting it works better in combination with other materials. Geotex, with a 12.75% reduction, demonstrated decent sound absorption, particularly effective when used in layered composites.

Comparative Analysis: Layered vs. Individual Materials

The results indicate a clear advantage in using layered materials over individual ones for noise reduction. The Geotex-Foam-Geotex composite outperformed all single-material solutions, achieving a 25% noise reduction. This performance is likely due to the complementary properties of the materials, where geotex absorbs mid-to-low frequency sounds and foam absorbs higher frequencies. The multi-layered structure ensures that sound waves are absorbed more effectively across a wide frequency range, providing better overall noise insulation.

The success of the layered composite structure has important implications for industrial noise control. In industrial environments, noise typically covers a broad spectrum of frequencies. A material that is effective only at specific frequencies may not provide sufficient noise reduction. However, by combining materials with different absorption characteristics, it is possible to create a barrier that is effective across a much wider frequency range, thereby reducing overall noise levels more effectively.

Real-World Application: Noise Control in Industrial Settings

Noise measurements at RUET's machine shop (87.03 dBA) exceeded safe levels, emphasizing the need for noise control solutions. The Geotex-Foam-Geotex composite could reduce noise by up to 25%, bringing it closer to safer levels (65-70 dBA) and improving workers' health. This bio-composite, made from sustainable materials like recycled geotex and natural luffa, provides an eco-friendly alternative to traditional noise control materials, offering effective noise reduction while reducing environmental impact. A proposed schematic diagram of the sound barrier in industrial settings is shown in Fig. 7 where it can be used to mitigate noise coming from different instruments like generators, pumps etc.

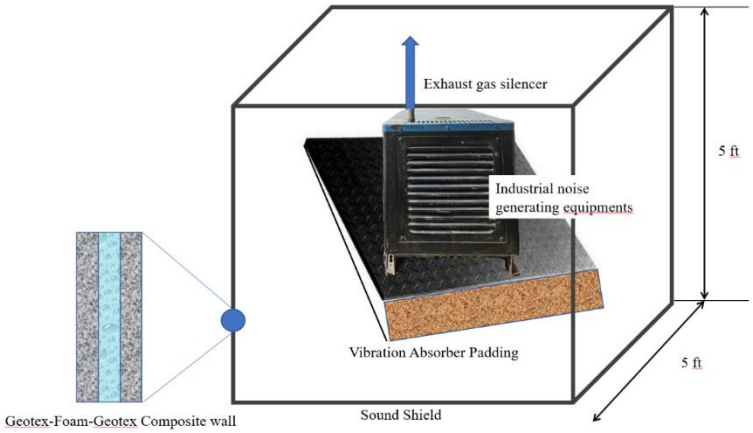


Fig. 7. Proposed schematic diagram of the sound barrier in industries.

4. Conclusions

This study explored the use of sustainable materials, such as luffa, foam, and geotex, in developing an effective noise barrier system to mitigate noise pollution in industrial environments. The research addressed the urgent need for eco-friendly noise control solutions, particularly in the context of industrial noise levels that frequently exceed safe limits. Field measurements at the machine shop of Rajshahi University of Engineering & Technology (RUET) revealed an average noise level of 87.03 dBA, significantly higher than the recommended safe threshold of 65 dBA during the day. This emphasizes the necessity of implementing noise reduction strategies to safeguard worker health and productivity, as well as the broader environmental impact of noise pollution.

The noise reduction performance of bio-materials and recycled materials was thoroughly evaluated using both field measurements and laboratory experiments. Among the tested materials, the Geotex-Foam-Geotex composite structure demonstrated the highest noise reduction capability, achieving a 25% reduction in noise levels. This layered composite structure proved to be significantly more effective than using individual materials, such as luffa or foam, which achieved 12% and 8% reductions, respectively. Combining luffa and foam increased the noise reduction to 15%, highlighting the advantage of material combinations in sound insulation. The Geotex-Foam-Geotex composite further outperformed all other tested configurations, proving the value of multi-layered structures in absorbing sound across a wider frequency range.

The study also underscored the benefits of using sustainable materials for industrial noise control. Materials like geotex, made from recycled products, and luffa, a natural bio-material, offer promising alternatives to traditional synthetic noise control materials, which often have a higher environmental footprint and limited recyclability. The results demonstrate that bio-composites and waste materials can be integrated into noise barrier systems to provide not only effective sound insulation but also promote environmental sustainability. This approach aligns with global trends towards greener engineering solutions, reducing reliance on resource-intensive and non-renewable materials.

Despite these promising results, several limitations must be acknowledged. The study's scope was confined to specific types of materials and configurations, and the findings may not fully generalize to all industrial settings or noise frequencies. The performance of the materials was tested under controlled conditions, which might not fully replicate the diverse and dynamic conditions present in actual industrial environments. Additionally, the long-term durability and performance of these materials under varying environmental conditions, such as high humidity and temperature fluctuations, were not extensively investigated.

Future research should focus on optimizing noise barrier designs using sustainable materials for broader industrial applications. Investigations into the long-term durability of bio-composites and their performance under different environmental stresses are crucial. Additionally, exploring other eco-friendly materials, including advanced bio-composites and nanomaterials, could offer superior sound absorption properties. Combining passive and active noise control techniques should also be examined to maximize noise reduction efficiency in high-noise environments. Addressing these aspects will enhance the effectiveness of noise barrier systems and contribute to more sustainable industrial noise control practices.

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