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WASTE MATERIALS FOR ACOUSTIC INSULATION IN INDUSTRIAL ENVIRONMENTS

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ABSTRACT

Noise pollution in industrial and construction settings poses serious health risks, such as hearing loss and stress-related illnesses, underscoring the need for sustainable mitigation strategies. This study explores the application of bio-materials and recycled waste products for acoustic insulation to tackle this challenge. Noise levels measured near the Fitting Shop, Rajshahi University of Engineering & Technology, averaged 87.03 dBA, far exceeding the WHO-recommended limit of 65 dBA. Luffa, a natural bio-material, reduced noise by 12%, while foam achieved an 8% reduction. A combination of luffa and foam improved noise reduction by 15%. Further research developed a geotex-foam-geotex three-layer composite, demonstrating a maximum noise reduction of 25%, outperforming geotex alone at 12.75%. Proposed for enclosing sound-generating equipment, this structure incorporates vibration absorbers and exhaust silencers, combining active and passive noise control methods. This study underscores the potential of eco-friendly, cost-effective materials for reducing industrial noise pollution, enhancing acoustic comfort, and fostering sustainable workplaces.

INTRODUCTION

Industrial activities are a major source of environmental noise pollution, posing significant risks to ecological health and worker safety [1]. According to the World Health Organization (WHO), over 1 million healthy life years are lost annually due to noise exposure [2]. In industrial settings, excessive noise affects nearby communities and creates hazardous conditions for workers, leading to hearing loss, tinnitus, stress, and other health complications [3]. Prolonged exposure to high noise levels is also linked to cardiovascular diseases, sleep disturbances, and psychological stress, with up to 33% of workers in some environments experiencing hearing loss [3], [4]. The WHO identifies noise levels above 65 dBA as harmful, yet many industrial environments, including the construction site near the Fitting Shop at the Rajshahi University of Engineering and Technology, regularly exceed this threshold [5].

The pressing need to address industrial noise pollution has prompted research into various control strategies, ranging from traditional materials like concrete and foam to advanced methods such as active noise control (ANC) and passive noise control (PNC) [6]. While ANC uses sound waves to counteract noise, PNC relies on materials that block or absorb sound. However, conventional approaches often involve environmentally harmful materials, such as synthetic foams and polymers, sparking interest in more sustainable alternatives [7]. Eco-friendly solutions using bio-materials and recycled waste products are gaining traction due to their potential for acoustic insulation and reduced environmental impact.

Traditional noise control methods, such as insulation and damping, provide partial solutions but face limitations in cost, space efficiency, and performance across different frequencies [8]. Additionally, the reliance on non-renewable and non-recyclable materials raises environmental concerns [9]. As a result, there is growing interest in renewable, biodegradable materials, which show promise for sound absorption, though their application in industrial settings remains underexplored [10], [11].

This research is driven by the need for sustainable, cost-effective solutions to industrial noise pollution. High noise levels not only jeopardize workers' health and productivity but also disrupt ecosystems and contribute to environmental degradation [12]. Conventional methods, while effective to an extent, are resource-intensive and environmentally unsustainable, highlighting the necessity for alternative approaches.

The study focuses on developing a noise barrier system using bio-composite materials derived from natural and recycled waste products. Materials such as luffa and geotextiles, known for their sound-absorbing properties, are investigated for their potential in acoustic insulation. While the study emphasizes passive noise control methods, structural parameters will be optimized for maximum noise reduction, cost-effectiveness, and sustainability. The system’s effectiveness will be validated through practical implementation in industrial environments, where noise levels will be measured to assess its real-world applicability.

By leveraging bio-materials and recycled waste products, this study aims to develop a sustainable noise control system that mitigates industrial noise pollution while promoting environmental sustainability and worker well-being. Standardized methods, such as the impedance tube technique, will evaluate the acoustic performance of selected materials, providing a foundation for scalable and practical noise control solutions.

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.

Field Noise Measurement

The study was conducted in a construction site behind the machine shop at Rajshahi University of Engineering & Technology, where noise pollution levels were measured and analyzed. The study area measured 100m x 60m, and noise measurements were taken at 20 different allocated points throughout the site as shown in Figure 1. The measurement process utilized a digital sound level meter mounted on a wooden stand 1.5 meters above the ground (Average height of humans), located near various noise sources within the area as illustrated in Figure 2. This setup ensured consistent and reliable data collection across all points.

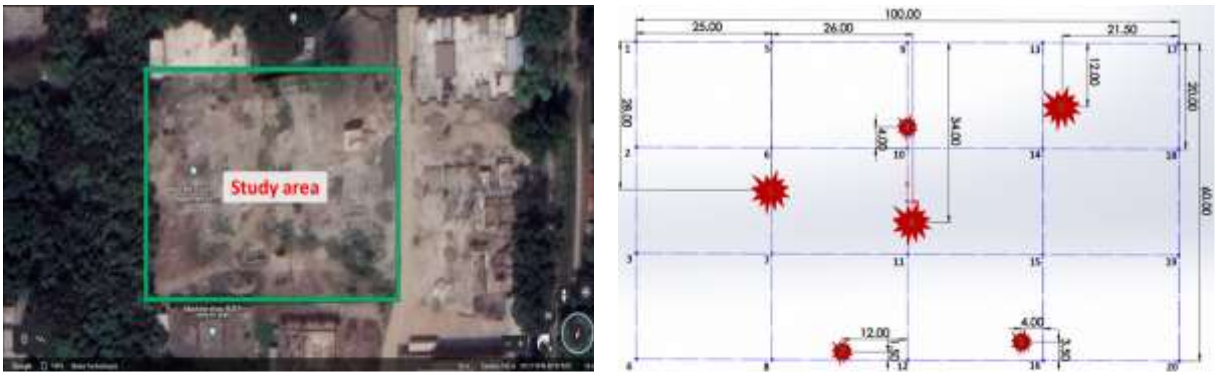

Figure 1 Study area (100m x 60m) of sound measurement.

Noise levels were recorded during working hours, with measurements focusing on both maximum and minimum sound levels, as well as calculating the average noise level for the entire study area. The digital sound level meter was positioned at equal distances from the sound sources, and the sound intensity was recorded in decibels (dB) at each allocated point.

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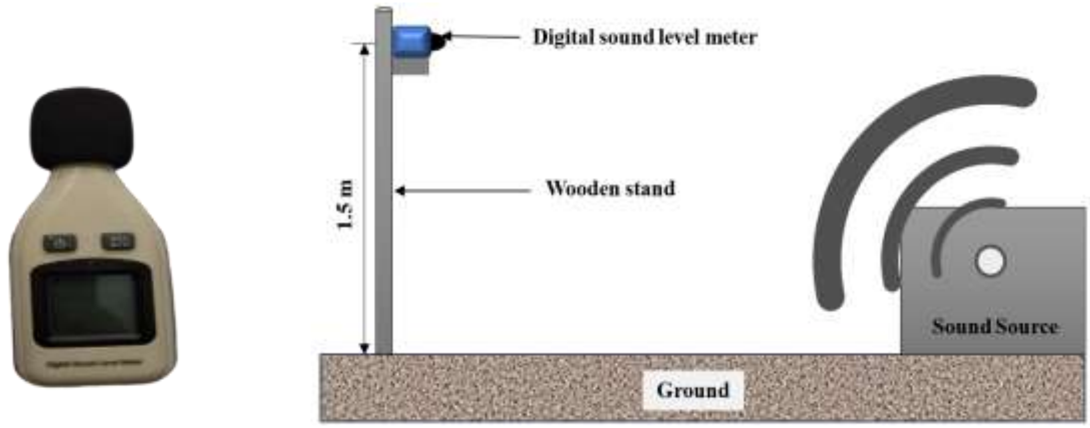

(a) (b)

Figure 2 (a) Digital sound level meter. (b) Schematic diagram of the data taking process.

Frame Making

The frame structure is the foundation for the sound barrier system, providing the physical support for the composite materials used for noise reduction. The frame was constructed using mild steel rods due to their durability and ability to provide sufficient structural integrity as shown in Figure 3. The materials used in this frame are stated below-

1. A 10 mm x 10 mm square rod was selected for the main frame to ensure adequate support for the sound barrier system.
2. A circular rod with a 5 mm diameter was used for reinforcing specific sections of the frame.
3. A 240 mm x 240 mm glass with 5 mm thickness was incorporated into the structure to assess the impact of transparent materials on sound propagation and reduction.

Figure 3 Fabricated frame structure.

Composite Fabrication

The noise barrier system primarily utilized natural and recycled materials such as geotextile and foam. 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

1. Luffa: A natural fibrous material known for its porous structure, ideal for sound absorption [13].
2. Foam: A synthetic material effective at absorbing high-frequency sounds [14].
3. Geotex: A recycled material that provides structural integrity and absorbs mid-frequency noise [15].

Procedure

1. Material Selection: For each composite sample, the chosen materials (luffa, foam, and geotextile) were selected based on their individual acoustic properties. The materials were combined in different configurations to assess their noise reduction capabilities. The layered approach aimed

to create synergy between materials, with geotextile providing a robust outer layer, luffa serving as a sound-absorbing core, and foam acting as an absorber of high-frequency sound waves.

2. Preparation and Cleaning: The geotextile and PVC samples were collected and thoroughly cleaned to remove impurities. These materials were then cut into square shapes measuring 240 mm × 240 mm to match the frame size, ensuring uniformity across all samples.
3. Layering and Assembly: Initially, the geotextile was sewn onto the frame, and its Noise Reduction Coefficient (NRC) value was measured at varying frequency levels. Next, a three-layer composite was created by sandwiching PVC material between two layers of geotextile. The layered configuration was secured using stainless steel clamps to maintain structural integrity during testing.
4. Curing: The layered materials were bonded using epoxy resin, chosen for its superior adhesion and structural durability. The assembled samples were cured at room temperature (25°C) for 24 hours in a controlled environment with humidity levels maintained between 40%–50% to prevent warping and ensure robust bonding between layers [16].
5. Testing Procedure: The NRC values were measured again for the three-layer composite as a function of frequency. During the testing, the upper portion of the frame was covered with transparent glass to simulate real-world conditions and ensure precise measurements.
6. Sample Variants: Several material combinations were tested for noise reduction efficiency, including Sample 1: Luffa only.
   Sample 2: Foam only.
   Sample 3: Luffa + Foam.
   Sample 4: Geotextile only.
   Sample 5: Geotextile-Foam-Geotextile; three-layer structure with foam as the middle layer and geotextile as the outer layers. (as shown in Figure 4)
7. Composite Testing: The Geotextile-Foam-Geotextile composite was tested for its enhanced noise absorption capabilities. The frame provided structural stability and allowed accurate simulation of the composite's performance under industrial noise conditions. The setup ensured consistency in testing and reliable performance evaluation as shown in Figure 4.

(a)

(b)

Figure 4 (a) Geotex-Foam-Geotex composite structure. (b) Experimental setup for closed enclosure.

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.

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) [17].
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.

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].

Interpretation and Practical Significance of NRC Values

The NRC provides a simplified, averaged value that indicates the material's overall sound absorption performance across the tested frequencies. The interpretation of the NRC values is crucial for understanding how effective each material would be in practical noise control applications:

- NRC values close to 1 indicate excellent sound absorption across the frequency range, making the material suitable for environments with high noise pollution. Such materials are ideal for use in industrial settings where broad-spectrum noise reduction is required, particularly where machinery operates at varying frequencies.
- NRC values between 0.5 and 0.75 suggest moderate sound absorption. These materials may perform well in specific noise environments, such as those dominated by mid-frequency sounds (e.g., 500 Hz to 1000 Hz).
- NRC values below 0.5 indicate limited sound absorption, where the material might reflect more sound than it absorbs. These materials may be more effective when combined with others to form a layered composite structure that targets a wider range of frequencies [19].

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.

1. 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 Figure 5.
    - 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).

Figure 5. Experimental setup for impedance tube method.

2. 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.
3. 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.

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 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 Rajshahi University of Engineering & Technology. 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(Daytime) and 50 dBA(Nighttime) in Bangladesh [20].

From the graph in Figure 6, 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.

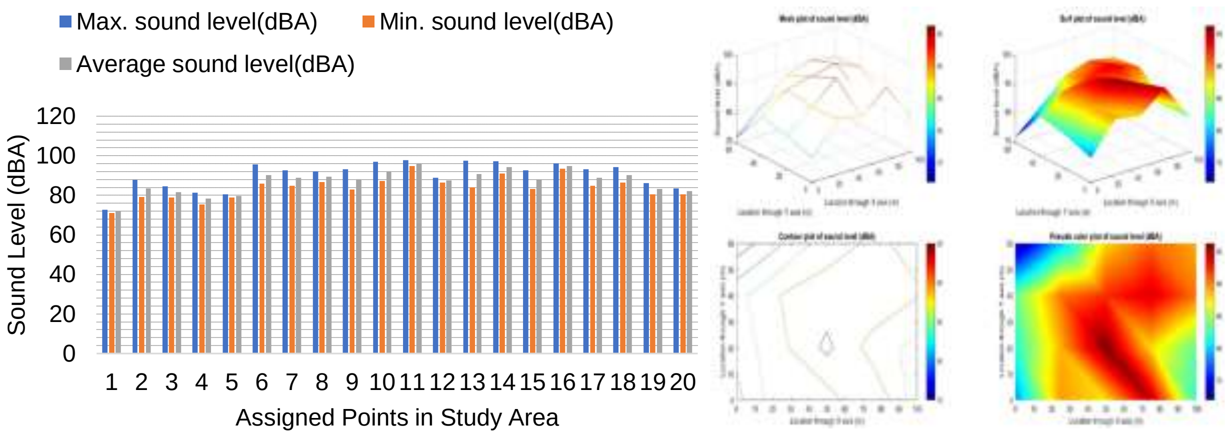

Figure 6. Recorded sound intensity in the locations in the study area.

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 Rajshahi University of Engineering & Technology's machine shop. The measured noise level at Rajshahi University of Engineering & Technology aligns with general findings in industrial settings globally, where noise levels frequently surpass safe limits, posing risks to worker health and well-being.

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 [21]. The key findings from the laboratory tests are shown in Figure 7.

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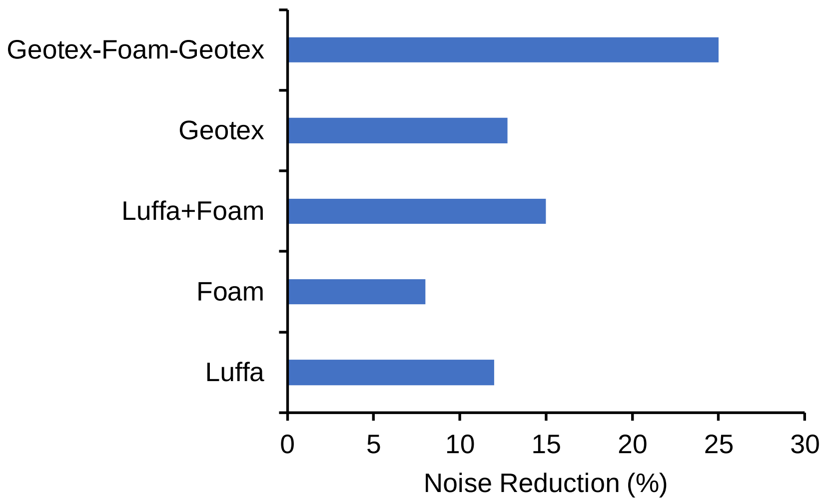

Figure 7. Percentage of noise reduction for different materials.

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.

- Luffa: Achieved a noise reduction of 12%, making it a moderately effective natural material for sound absorption. Luffa's performance, while reasonable, indicates that natural materials alone may not be sufficient for high-performance noise reduction in industrial settings, especially at high noise levels like those recorded in the field.
- Foam: Produced a lower noise reduction of 8%, likely due to its limited ability to absorb mid-to-low frequency noise. Foam is generally more effective at absorbing high-frequency sounds, and its reduced performance in this study suggests that it is best utilized in combination with other materials, particularly for environments with a broader range of frequencies.
- Geotex: Achieved a noise reduction of 12.75%, showing that this recycled material has decent sound-absorbing properties, but performs best when integrated into a layered structure. Its slightly better performance compared to luffa indicates that recycled materials like geotex can be more effective when used strategically in composite structures.

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 Rajshahi University of Engineering & Technology'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 Figure 8 where it can be used to mitigate noise coming from different instruments like generators, pumps etc.

The real-world noise measurements at Rajshahi University of Engineering & Technology's machine shop, combined with the laboratory findings, highlight the potential for applying these bio-composites and waste materials in industrial environments. The average noise level recorded at Rajshahi University of Engineering & Technology (87.03 dBA) was significantly above safe thresholds, underscoring the need for effective noise control strategies. Implementing the Geotex-Foam-Geotex composite as a noise barrier in such settings could potentially reduce noise levels by up to 25%, bringing the average noise closer to safer limits (around 65-70 dBA). This reduction could significantly decrease the risk of noise-induced hearing loss and improve the overall health and well-being of workers in industrial environments. A proposed schematic diagram of the sound barrier in industrial settings is shown in Figure 8.

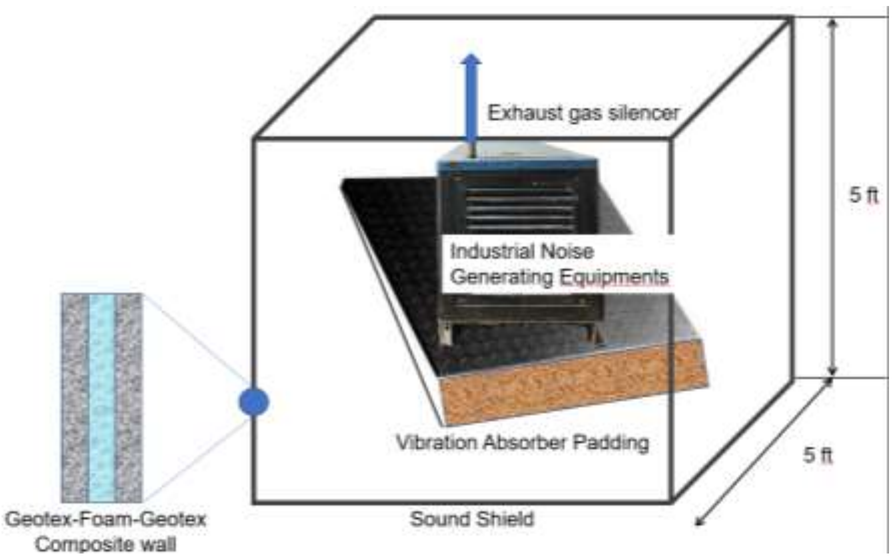

Figure 8. Proposed schematic diagram of the sound barrier in industries.

Moreover, using sustainable materials like geotex (recycled material) and luffa (natural bio-material) aligns with the growing demand for eco-friendly engineering solutions. The environmental impact of traditional noise control materials (such as synthetic foams and polymers) is a key concern, as these materials often have limited recyclability and contribute to pollution. In contrast, bio-composites and recycled materials offer a more sustainable alternative, reducing waste while maintaining effective noise control.

CONCLUSIONS

This study investigated the potential of sustainable materials, such as luffa, foam, and geotextile, in developing an effective noise barrier system to address industrial noise pollution. The research highlighted the urgent demand for eco-friendly noise control solutions, particularly in industrial environments where noise levels frequently exceed safe limits. Field measurements conducted at the machine shop of Rajshahi University of Engineering & Technology recorded an average noise level of 87.03 dBA, significantly surpassing the recommended daytime threshold of 65 dBA. These findings underscore the critical need for effective noise reduction strategies to protect worker health, enhance productivity, and mitigate the broader environmental impacts of noise pollution.

The noise reduction capabilities of bio-materials and recycled materials were evaluated through both field measurements and laboratory experiments. Among the tested configurations, the Geotextile-Foam-Geotextile composite demonstrated the highest performance, achieving a 25% reduction in noise levels. This layered structure significantly outperformed individual materials, such as luffa (12% reduction) and foam (8% reduction). A combination of luffa and foam improved noise reduction to 15%, further highlighting the benefits of material combinations for sound insulation. The Geotextile-Foam-Geotextile composite excelled by effectively absorbing sound across a broader frequency range, proving the value of multi-layered configurations.

The study also emphasized the advantages of using sustainable materials in industrial noise control. Recycled materials like geotextile and natural bio-materials like luffa present promising alternatives to traditional synthetic noise control solutions, which often have a higher environmental impact and limited recyclability. The findings demonstrated that bio-composites and recycled materials can be effectively integrated into noise barrier systems, providing robust sound insulation while promoting environmental sustainability. This approach aligns with the global push toward greener engineering practices, reducing dependency on non-renewable and resource-intensive materials.

However, several limitations should be acknowledged. The study focused on a specific set of materials and configurations, and the results may not be fully applicable to all industrial settings or noise frequencies. Additionally, testing was conducted under controlled conditions that may not accurately reflect the diverse and dynamic challenges of real-world industrial environments. The long-term durability and performance of the materials under varying environmental conditions, such as high humidity and temperature fluctuations, were not comprehensively explored.

Future research should aim to optimize noise barrier designs with sustainable materials for broader industrial applications. It will be essential to investigate the long-term durability of bio-composites and assess their performance under diverse environmental stresses. Furthermore, exploring advanced eco-friendly materials, such as bio-composites and nanomaterials, could offer enhanced sound absorption properties. Combining passive and active noise control methods should also be examined to maximize noise reduction in high-noise environments. Addressing these challenges will improve the effectiveness of noise barrier systems and support more sustainable industrial noise control practices.

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