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Recycling of Textile Waste Into Sound-Absorbing Acoustic Plates

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Abstract. **The textile waste problem is a significant concern both in Latvia and globally. The textile industry, particularly the fashion industry, is considered one of the most polluting industries, generating a substantial amount of waste. Worldwide, the production of textiles has been on the rise due to population growth and increased consumption, leading to a significant increase in textile waste generation. The management of textile waste is crucial for ensuring sustainability and minimizing environmental impacts. Recycling and reusing textile waste are essential strategies for implementing a circular economy model and reducing the environmental hazards associated with textile production and disposal. One way we can reduce the amount of textile waste in landfills is to create new products from this waste by intercepting it before it ends up in landfills. The aim of this study is to develop sound-absorbing acoustic plates using textile waste. Experiments with textile waste started in January 2024, beginning with the acquisition of textile waste. The textile obtained for the experiment was sourced from the waste management company in Latvia's North Vidzeme, which collects clean textile waste from residents. In the next stages, textile waste was shredded, and slabs were formed using a compactor. Textile processing into a finer fraction was carried out using an industrial shredding machine. A mixture of water-based glue, an isotonic solution (containing boric acid and sodium borate), PVA glue, and sodium bicarbonate was used as a binder for making the plates. The created plates were tested for acoustic properties in the laboratory. The absorption coefficient of the acoustic plate at the best performance level (1250 - 3500 Hz) ranged from 1.14 to 1.6. This is consistent with the fact that non-separated textiles were used.**

Keywords: Circular economy, Sound-absorbing materials, Sustainable textile, Waste recycling.

I. INTRODUCTION

In an era prioritizing sustainability, innovative solutions are emerging to recycle waste materials into valuable resources. One focal point is the recycling of textile waste, offering dual benefits: waste reduction and resource optimization [1]. Among the myriad applications of recycled textiles, the conversion into sound-absorbing acoustic panels stands out as a promising option with substantial environmental and practical impacts [2].

Textile waste, comprising discarded clothing, upholstery, and production remnants, presents a significant challenge to global waste management systems [3]. Given that the textile industry ranks among the world's largest waste producers, finding effective ways to repurpose these materials is imperative for minimizing their environmental footprint [4]. At the same time, demand has increased for noise control solutions across various environments – from office buildings to education and music studios as well as industrial settings. This underscores the necessity for innovative acoustic materials [5], [6], [7].

Materials employed in the construction industry for the purpose of thermal insulation and noise management predominantly consist of inorganic and synthetic compounds, including glass wool, stone wool, and

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polystyrene. Although these materials provide a low level of thermal conductivity and display remarkable sound absorption characteristics, the environmental repercussions stemming from their manufacturing procedures can be substantial. Furthermore, depending on variables such as fiber dosage, dimensions, and resilience, they may also have an impact on human health and overall well-being [8], [9].

This article delves into the recycling of textile waste into sound-absorbing acoustic plates, elucidating technological advancements, environmental benefits, and practical applications of this pioneering approach. Through a comprehensive examination, our aim is to underscore the potential of textile waste recycling as a sustainable solution to both environmental challenges and acoustic requirements across diverse fields.

The aim of this study is to develop sound-absorbing acoustic plates using textile waste.

II. Materials and Methods

The textile waste for the experiment was obtained from the Latvian North Vidzeme Waste Management Company, which collects clean textile waste from residents. This textile waste was sorted to avoid the various metal, plastic and solid non-textile admixtures that are sometimes found in textile clothing (see fig. 1).

Fig. 1. Sorting of textile waste

After grading operations, the textile waste was shredded. They were shredded into fractions ranging from 5 to 20 mm, an industrial shredder was used to shred the textile waste - Shred-Tech ST-25 (see fig. 2). The Industrial Shredder is equipped with a set of sturdy and resilient blades that have been specifically engineered to penetrate effortlessly through various products and materials. These formidable blades possess the capability to effortlessly disintegrate voluminous loads, reducing the materials into fragments. Each blade boasts a diameter of 19,7 cm, ensuring an ample amount of robustness to effectively shred textile.

Fig. 2. Shredding of textile waste

The shredded textile was then mixed with a binder in the ratio Binder : textile = 1 : 3 (see fig. 3). A mixture of water-based glue, an isotonic solution (containing boric acid and sodium borate), PVA glue, and sodium bicarbonate was used as a binder for making the plates. The following binder proportions were used – 0.2 (water-based glue) : 0.05 (isotonic solution) : 0.6 (PVA glue**)** : 0.02 (sodium bicarbonate).

Fig. 3. Mixing of binders and textiles

To create the plate, a wooden mould measuring 150 x 250 mm and 30 mm thick was made and the mass was laid into it. Finally, a wooden lid was placed on the mould and pressed together with a vise. The drying time of the plate was 24 hours. After the binder had dried, the mould was opened and the plate removed (see fig. 4).

Fig. 4. Sound-Absorbing Acoustic Plate

In order to assess the sound absorption capabilities of textile acoustic palates, we utilized the AFD 1000 – Sound Absorption Tube Set (see fig. 5), an impedance tube manufactured for industrial purposes. This particular equipment was specifically designed to accurately determine the sound absorption coefficients across a frequency range that extends from 100 Hz to 4000 Hz. The initial stage of the sample measurement process involved the preparation of the textile acoustic panels. To ensure consistency in the testing, circular cutouts with diameters of 40 mm and 100 mm were obtained, thus guaranteeing uniformity in both size and shape (see fig. 6). Subsequently, the prepared circular cutouts were meticulously positioned within the impedance tube setup. Particular attention was given to ensuring precise alignment and secure placement of the sample within the testing chamber, thereby minimizing any potential sources of error. Once the panels had been securely positioned, the testing procedure commenced. This involved subjecting the panels to controlled sound waves that spanned the specified frequency range of 100 Hz to 4000 Hz. The impedance tube was responsible for generating these sound waves, effectively simulating real-life acoustic conditions.

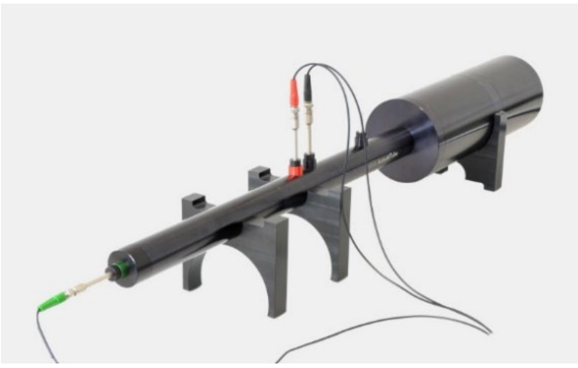

Fig.5. Sound Absorption impedance tube [10]

Throughout the testing process, the impedance tube accurately measured the sound absorption characteristics of the samples at various frequencies within the designated range. This meticulous measurement process facilitated the acquisition of precise absorption coefficient values. Stringent efforts were made to maintain consistent testing conditions and mitigate any external factors that could potentially impact the results during the sample measurement process. This rigorous approach ensured the reliability and validity of the sound absorption data obtained from the impedance tube testing.

Fig. 6. Circular cutouts with diameters of 40 mm and 100 mm

Statistical data analysis was performed using the Krustkal-Wallis test. We investigated the sound absorption properties of various samples using Nemenyi's procedure for multiple pairwise comparisons. The data presented in the results offers a descriptive overview of the sample frequencies, sum of ranks, and mean of ranks for each group, providing insights into their relative performance in sound absorption.

The Kruskal-Wallis test is used to compare two or more independent samples of equal or different sizes. It helps to determine whether a sample is drawn from the same distribution, thus grouping the data. This technique was used to analyse sound absorption coefficient and frequency distribution data for samples.

Before analysing the data, the frequencies at which the sound absorption coefficient was measured were divided into three parts. The first part - low frequencies (100-250 Hz), the second part - medium frequencies (315-1000 Hz), and the third part high frequencies (1250-4000 Hz). This was done in order to compare the data and results in a more accurate and transparent way.

The experimental data were compared with the sound absorption coefficients of rockwool and mineral wool. The sound absorption coefficients of mineral wool at different frequencies were obtained from a study published by Jan Sikora and Jadwiga Turkiewicz [11]. The absorption coefficients of rockwool at different frequencies were obtained from Rockwool Ltd, a rock wool manufacturing company [12].

III. RESULTS AND DISCUSSION

The results show sound absorption coefficients at different frequencies in the range from 100 to 4000 Hz. The highest sound absorption coefficient is observed at 3000 Hz, where it is 0.16. The lowest sound absorption coefficient is observed at 100 Hz, where it is 0. The best sound absorption performance of the developed plate is at frequencies between 1250 and 3500 Hz (see Fig. 7)

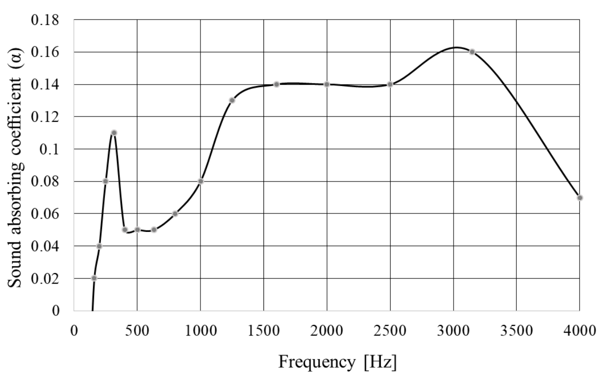

Fig. 7. Sound absorption coefficients for sound - absorbing acoustic plate at frequencies from 100 to 4000 Hz

Nemenyi's procedure for multiple pairwise comparisons for low frequencies (100-250 Hz). The following results were obtained (see Table 1):

- Sound-Absorbing Acoustic Plate: This sample has a frequency of 5, resulting in a sum of ranks of 5 and a mean of ranks of 1.0. Sample Sound-Absorbing Acoustic Plate belongs to Group A.
- Mineral wool: With a frequency of 5, Sample Mineral wool accumulates a sum of ranks of 12 and a mean of ranks of 2.4. It is associated with both Groups A and B.
- Rock wool: Sample Rock wool, also with a frequency of 5, has the highest sum of ranks at 13, translating to a mean of ranks of 2.6. It belongs exclusively to Group B.

TABLE 1 MULTIPLE PAIRWISE COMPARISONS USING NEMENYI'S PROCEDURE (TWO-TAILED TEST) FOR SOUND ABSORPTION COEFFICIENTS AT LOW FREQUENCIES (100-250 HZ)

Sample	Frequency	Sum of ranks	Mean of ranks	Groups	
Sound-Absorbing Acoustic Plates	5	5.000	1.000	A	
Mineral wool	5	12.000	2.400	A	B
Rockwool	5	13.000	2.600		B

A box plot of the sound absorption coefficients at low frequencies (100-250 Hz) can be seen in Fig. 8.

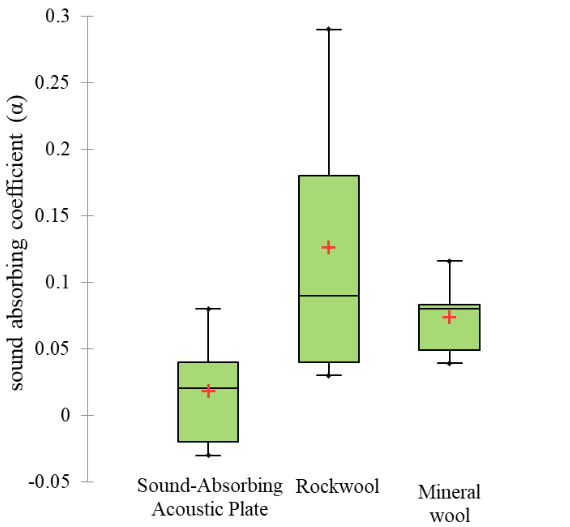

Fig. 8. Sound absorption coefficients at low frequencies (100-250 Hz)

Nemenyi's procedure for multiple pairwise comparisons for medium frequencies (315-1000 Hz). The following results were obtained (see Table 2):

- Sound-Absorbing Acoustic Plate: This sample has a frequency of 6, resulting in a sum of ranks of 6 and a mean of ranks of 1.0. Sample Sound-Absorbing Acoustic Plate belongs to Group A.
- Mineral wool: With a frequency of 6, Sample Mineral wool accumulates a sum of ranks of 12 and a mean of ranks of 2.0. It is associated with both Groups A and B.
- Rock wool: Sample Rock wool, also with a frequency of 6, has the highest sum of ranks at 18, translating to a mean of ranks of 3.0. It belongs exclusively to Group B.

TABLE 2 MULTIPLE PAIRWISE COMPARISONS USING NEMENYI'S PROCEDURE (TWO-TAILED TEST) FOR SOUND ABSORPTION COEFFICIENTS AT MEDIUM FREQUENCIES (315 - 1000 HZ)

Sample	Frequency	Sum of ranks	Mean of ranks	Groups	
Sound-Absorbing Acoustic Plates	6	6.000	1.000	A	
Mineral wool	6	12.000	2.000	A	B
Rockwool	6	18.000	3.000		B

A box plot of the sound absorption coefficients at low frequencies (315-1000 Hz) can be seen in Fig. 9.

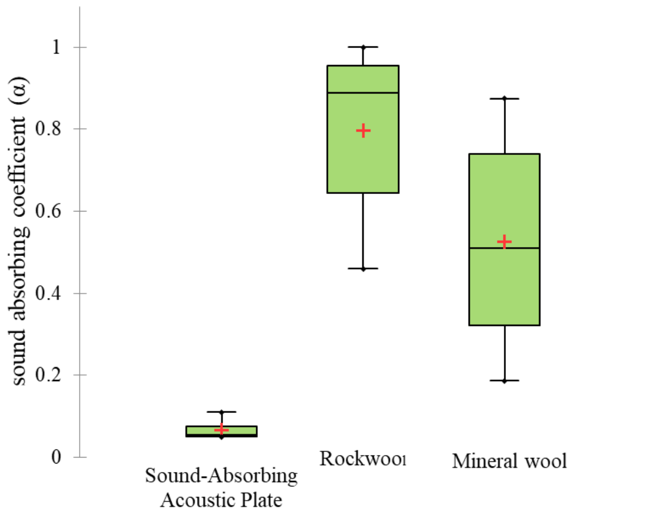

Fig. 9. Sound absorption coefficients at medium frequencies (315 - 1000 Hz)

Nemenyi's procedure for multiple pairwise comparisons for high frequencies (1250-4000 Hz). The following results were obtained (see Table 3):

- Sound-Absorbing Acoustic Plate: This sample has a frequency of 6, resulting in a sum of ranks of 6 and a mean of ranks of 1.0. Sample Sound-Absorbing Acoustic Plate belongs to Group A.
- Mineral wool: With a frequency of 6, Sample Mineral wool accumulates a sum of ranks of 12 and a mean of ranks of 2.0. It is associated with both Groups A and B.
- Rock wool: Sample Rock wool, also with a frequency of 6, has the highest sum of ranks at 18, translating to a mean of ranks of 3.0. It belongs exclusively to Group B.

TABLE 3 MULTIPLE PAIRWISE COMPARISONS USING NEMENYI'S PROCEDURE (TWO-TAILED TEST) FOR SOUND ABSORPTION COEFFICIENTS AT HIGH FREQUENCIES (1250 - 4000 Hz)

Sample	Frequency	Sum of ranks	Mean of ranks	Groups	
Sound-Absorbing Acoustic Plates	6	6.000	1.000	A	
Mineral wool	6	12.000	2.000	A	B
Rockwool	6	18.000	3.000		B

A box plot of the sound absorption coefficients at low frequencies (315-1000 Hz) can be seen in Fig. 10.

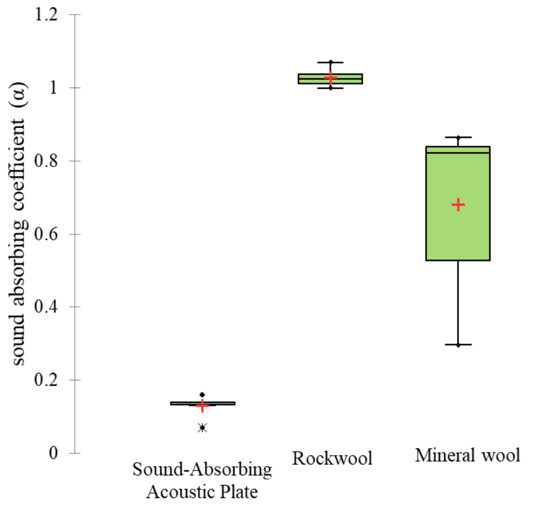

Fig. 10. Sound absorption coefficients at high frequencies (1250 - 4000 Hz)

Sound absorption coefficients for sound-absorbing plates made of textile waste were investigated in several studies. Rubino et al. found that composite panels made of 100% wool waste fibres had absorption coefficients higher than 0.5 from 500 Hz and higher than 0.9 from 1 kHz on [2]. Vejelis et al. examined waste from the production of woollen yarns and found that soft boards made from this waste had sound absorption coefficients ranging from 0.4 to 0.9 at a board density of 40 kg/m3 [13]. While in our study, at the best performance level (1250 - 3500 Hz), the absorption coefficient ranged from 1.14 to 1.6. This is consistent with the fact that non-separated textiles were used.

IV. CONCLUSIONS

This study investigated the sound absorption properties of the developed plates, highlighting their effectiveness in attenuating sound waves at different frequencies. Our results show that the material composition, density and surface structure have a significant influence on the sound absorption performance. Porous materials such as rock wool and mineral wool showed better sound absorption performance over a wide range of frequencies than our sound absorbing board. The developed plate needs to be refinished, its porosity and surface texture improved and the properties of the binder used improved. These improvements have the potential to bring the results much closer to good sound absorbing materials.

Furthermore, the results obtained underline the importance of taking into account environmental factors and specific requirements when selecting materials for sound absorption. Future research could explore new sustainable material formulations and advanced manufacturing techniques to further improve sound absorption performance.

By adopting a proactive stance towards the sustainable recycling of textile waste, we can open up opportunities for innovation, job creation and societal development. Continued research and concerted efforts are imperative to promote systemic change and a more sustainable future for the textile industry and beyond.

V. ACKNOWLEDGMENTS

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