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LETTER

Upcycling microfiber waste from wastewater into acoustic panels: a sustainable solution for sound absorption

Sinem Hazal Akyildiz[1,2,*], **Hande Sezgin**[3], **Mustafa Sabri Özen**[2] **and Ipek Yalcin Enis**[3]

[1] Department of Environment, Land and Infrastructure Engineering (DIATI), Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino 10129, Italy
[2] Faculty of Technology, Textile Engineering Department, Marmara University, Goztepe, Istanbul, Turkey
[3] Textile Technologies and Design Faculty, Textile Engineering Department, Istanbul Technical University, Beyoglu, Istanbul, Turkey
[*] Author to whom any correspondence should be addressed.

E-mail: sinem.akyildiz@polito.it

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Abstract

Microfibers (MFs) are released into the environment during the entire life of textile materials, from manufacturing to disposal. It is evident that micro-sized wastes are just as significant as macro-sized ones, and this issue should be prioritized. The use of textile waste in sound insulation materials is increasingly gaining attention. However, conventional sound absorption materials, such as fiberglass, polyurethane, and melamine foams, offer high-performance acoustic properties, but are derived from non-renewable resources and contribute to environmental degradation. This study aims to develop environmentally friendly fibrous sound absorption panels by reusing MF waste generated during textile finishing processes. Waste MFs used within the scope of the study were collected from a textile finishing process' wastewater containing a variety of fibers, including wool, cotton, acrylic, polyamide, polyester, polypropylene, and viscose by filtration method and blended with polyester fiber as a binder. Then, acoustic panels were produced using a hot press technique by varying the panel thickness, density, and binder fiber ratio, and the physical, chemical, morphological, and acoustic properties of these panels were tested. Findings revealed that thickness emerged as a critical factor, with the thickest samples exhibiting the highest sound absorption coefficient (0.9 at 3000 Hz). Moreover, an increase in sample density correlated positively with enhanced sound absorption values, while the binder fiber ratio demonstrated a negative impact. Additionally, all samples exhibited hydrophobic characteristics, showcasing water resistance. The statistical analysis of sound absorption performance was conducted using one-way ANOVA and Tukey's honestly significant difference test, with the results visualized through boxplots. Compared to conventional materials, the developed MF-based panels provide an eco-friendly alternative by reducing reliance on virgin synthetic materials while achieving competitive sound absorption properties. This study enables sustainable waste management in the textile industry and the reuse of MF waste, providing alternative and environmentally friendly solutions to currently used sound absorption materials. While the recyclability and reuse potential of these panels remain promising, further research is needed to evaluate their long-term mechanical performance, resistance to environmental degradation, and practical implementation in real-world applications. Future investigations should focus on optimizing large-scale production processes and assessing the environmental footprint of these materials throughout their lifecycle.

1. Introduction

The textile industry, in addition to producing masses of textile waste, contributes significantly to worldwide microplastic contamination (Li *et al* 2023). Microplastics from textiles, primarily in fibrous form, are released into the environment at various stages, including production, processing, use, and disposal. Most microfiber (MF) release occurs during production (49%), followed by laundry (28%) and use

(23%) (Salvador Cesa et al 2017, Lim et al 2022, Zhang et al 2022). According to the Ellen MacArthur Foundation (2017), over 160 million metric tons of clothing are projected to be sold by 2050, leading to the release of 22 million metric tons of MFs into the oceans from 2015 to 2050.

Although practically every stage of the textile production results in the release of MFs, it is well known that certain procedures have higher MF release according to the machine's working principle and intended applications. To improve the handling or bulkiness of textiles, mechanical finishing processes, including burning, calendering, embossing, and brushing, are frequently utilized. While certain techniques increase MF release, others decrease it. For instance, the fabric's surface is brushed during the raising process to provide bulkiness and smoothness, which results in an excessive number of protruded fibers that may promote MF release. On the other hand, as projecting fibers are eliminated during the burning and calendering operations, the release of MF diminishes (Raja Balasaraswathi and Rathinamoorthy 2021). Biancalani is a textile finishing machine that exemplifies the raising procedure by removing a fiber layer to yield a warm, velvety texture (Senthil Kumar and Sundaresan 2013, Aldalbahi et al 2021). However, the fibers released by this machine interact with wastewater, resulting in higher MF concentrations in the effluent (Carney Almroth et al 2017).

There are various ways to tackle microplastic pollution. One option is to focus on developing textile structures that result in lower shedding (Berruezo et al 2020). It is feasible to reduce the release of MFs during laundry by considering aspects such as weave patterns and fabric design (Luogo et al 2022). Furthermore, pre-washing and vacuum exhaustion at manufacturing facilities can help remove loose fibers before the textiles enter the market, lowering the possibility of shedding during usage. Another approach involves enhancing filtering systems, encompassing both individual households and textile laundries. More effective filters in home washing machines can assist in capturing MFs and preventing their discharge into wastewater (Berruezo et al 2020). Likewise, textile laundries can use filtration technologies that are effective in removing MFs from wastewater before they are released into nature (Stefan et al 2022). Additionally, recycling and reusing textile waste can play an important role in reducing microplastic pollution. While textile waste has traditionally been disposed of through incineration or landfilling, alternative waste utilization strategies have been explored to mitigate environmental pollution and promote sustainability (Harper and Moody 2023). Various recycling approaches have been developed for textile waste, including mechanical recycling, chemical recycling, and bio-based alternatives. Mechanical recycling involves breaking down textile waste into fibers for reuse in nonwoven applications, such as insulation materials, automotive components, and geotextiles (Cao et al 2022, Özdil et al 2023). Chemical recycling, on the other hand, uses solvents or enzymatic processes to depolymerize synthetic fibers, such as polyester, into monomers that can be repolymerized into new textiles (Miao et al 2024). While chemical treatments offer high recovery rates, they often require significant energy inputs and generate secondary waste streams (Juanga-Labayen et al 2022, McCauley and Jestratijević 2023). It is important to investigate techniques for recovering natural and synthetic polymers from textile waste to reduce microplastic emissions during disposal procedures (Juciene et al 2022).

Recently, macro-scaled textile waste has been used in various construction applications, including thermal insulation and sound absorption in buildings, interiors, and vehicles, owing to its environmental benefits and energy-saving potential (Islam et al 2020, Antolinc and Filipič 2021, Samardzioska et al 2023). Studies indicate that recycled textiles can offer superior sound absorption compared to conventional insulating materials (Islam et al 2020). According to Antolinc and Filipič (2021), recycled fibers can be used for a variety of tasks, such as incorporating them into the fabrication of nonwovens or using them as components of composites by applying pressure and heat. In a broader context, the utilization of textile waste as a form of insulating material offers promising opportunities for both energy conservation and ecological sustainability. In a study conducted by Sezgin et al (2021), composite materials were developed by combining waste denim fabric from the textile sector with waste polypropylene/polyethylene bottle caps and containers from the packaging sector. The composite panels were manufactured from shredded cotton wastes and ground plastic wastes distributed through fibrous layers using a hot press machine, with modifications in panel thickness and the type of matrix utilized. The results revealed that the produced composites act like porous materials, and their sound absorption ability improves as the frequency range increases. Moreover, the study by Dehdashti et al (2024) investigated the innovative use of discarded face masks to create sustainable, high-performance panels that enhance thermal and acoustic comfort in buildings. The research highlighted that the fine fibers in the masks that result in higher surface area improve sound absorption and thermal resistance. Finer fibers increase air channel tortuosity, improving thermal insulation and sound wave dissipation and acoustic performance (Karimi *et al* 2022). Research indicates that sound absorption is significantly influenced by the structural properties of materials, including tortuosity (sinuosity of the pore space), porosity, and air flow resistivity. For instance, Ismail *et al* (2019) emphasize that sound absorption in composite materials is primarily governed by air flow resistivity, porosity, and tortuosity, which collectively determine the dissipation of acoustic energy. Similarly, Jayamani *et al* (2015) highlight that the porous structure of fibers plays a crucial role in reducing sound reflection and enhancing absorption, as inter-fiber voids effectively trap sound energy. There have been numerous studies that evaluate macro-sized textile wastes in the literature (Wazna *et al* 2018, Baccouch *et al* 2020, Kamble and Behera 2021, Sezgin *et al* 2021, Ailenei *et al* 2021, Gedif and Atalie 2022, Yalcin-Enis 2023). On the other hand, it is possible to come across very few studies in which microplastic fibers are recycled and used in cement-based construction materials. One of these is a study by Malchiodi *et al* (2022) on the direct recovery of blended finishing textile waste MFs for use in the development of fiber-reinforced cementitious composites with improved thermal insulation and mechanical performance. Results indicated that both environmentally friendly and efficient composite building materials are successfully manufactured, enabling the reduction of almost 4 kg of fine particulate matter per ton of cement paste (Malchiodi *et al* 2022).

Conventional sound-absorbing materials, such as mineral wool, polyurethane, and melamine foams, are derived from non-renewable sources and present significant environmental concerns, including microplastic emissions and toxic chemical release throughout their lifecycle (Astrauskas *et al* 2021, Janlee 2024). Although these materials often exhibit high sound absorption coefficients (SACs), their environmental footprint raises concerns about their long-term sustainability. Additionally, micro/nanoplastic release from conventional sound-absorbing materials—particularly during manufacturing, use, and disposal—poses a significant environmental threat. Synthetic foams have been shown to shed microplastics, contributing to environmental pollution and presenting potential risks to human health (Muralikrishnan 2018).

Despite increasing efforts to mitigate MF pollution through filtration technologies and textile design modifications, there remains a significant gap in research exploring the direct upcycling of microscale fibrous waste into functional materials. While previous studies have demonstrated the potential of macro-scale textile waste for thermal and acoustic insulation, the use of microplastics—particularly MFs—as the primary raw material in polymeric composites remains largely unexplored. Most existing research on microplastic reuse has focused on their incorporation into cementitious composites, with limited studies addressing their acoustic properties or sustainability benefits in polymer-based applications. This study aims to bridge this gap by repurposing waste MFs from textile wastewater into innovative acoustic panels. By systematically investigating the effects of MF composition, thickness, density, and binder ratio on sound absorption performance, this research not only introduces a novel recycling method for textile MFs but also establishes their potential as a viable, eco-friendly alternative to conventional synthetic materials.

2. Materials & methods

2.1. Materials

The MFs examined in this study were collected from the wastewater generated during the fabric raising process carried out with a Biancalani machine at Kadifeteks Textile Company. The fibers removed from the fabric surface during the raising process are released into the wastewater stream via water. All wastewater resulting from wet processes in the facility is collected in tanks as inflow wastewater and then directed to a pre-treatment stage before outflow wastewater. In this study, the wastewater used for MF supply was taken from tanks located at the exit of the raising process but before entering the inflow wastewater. This wastewater contains a variety of fibers such as wool, cotton, acrylic, polyamide, polyester, polypropylene, and viscose. 30 l of wastewater were collected, and sterilization procedures were applied to prevent any potential contamination, including the use of ethanol and distilled water to clean all collection equipment and containers before refrigeration.

In addition to waste MFs, bicomponent, core/shell design, polyester fibers (Co-PET/PET) (supplied from Zhejiang Anshun Pettechs Fibre Co.) with a 4-denier fineness and a low melting temperature (110 °C shell/240 °C core) were used as binders in the production of composites. These polyester fibers were cut into 1–3 mm lengths to facilitate their blending with the waste MFs. Polyester fiber (Co-PET/PET) was selected as the binder due to its low melting temperature, allowing efficient bonding under moderate thermal conditions without excessive thermal degradation. The diverse waste composition necessitates a binder that can integrate effectively across different fiber types while ensuring structural integrity. This makes the polyester binder preferable to biobased alternatives. Similarly, water resistance and durability which stands out as a limitation for bio-based adhesives, are provided by the hydrophobic structure of polyester fiber.

Hydrogen peroxide (H_2O_2, Sigma-Aldrich) and distilled water were used in the pretreatment process

Table 1. Sample codes and compositions. The bold values indicate the parameters varied in each group to analyze the effect of thickness, binder ratio, and targeted density, respectively, while keeping other parameters constant.

	Sample code	Thickness (mm)	Binder ratio (%)	Targeted density (g cm^{-3})
Thickness effect	P5_20_0.075[a]	**5**	20	0.075
	P10_20_0.075	**10**	20	0.075
	P15_20_0.075	**15**	20	0.075
Binder ratio effect	P5_20_0.075[a]	5	**20**	0.075
	P5_30_0.075	5	**30**	0.075
	P5_40_0.075	5	**40**	0.075
Density effect	P5_20_0.075[a]	5	20	**0.075**
	P5_20_0.150	5	20	**0.150**
	P5_20_0.200	5	20	**0.200**

[a] Represents the same sample used for the comparison of all effects.

of separating MFs from wastewater, and ECE detergent (SDL Atlas) was used in the washing process of MFs.

2.2. Methods

2.2.1. Wastewater pretreatment and MF filtration

Initially, 30 l of wastewater were filtered using a 0.7 μm pore-size glass fiber filter (Whatman, 47 mm diameter) to obtain MFs. Filtration of the wastewater from the Biancalani stage was carried out on-site. A total of 5.05 g of MFs were filtered from the wastewater source and stored in a plastic container. Following the filtration stage, the waste MFs were re-introduced to distilled water and subjected to a 5 d pretreatment with 15% H_2O_2 at room temperature. This mild oxidative treatment was applied to remove residual organic contaminants rather than degrade or alter the fiber structure. As demonstrated in previous study (Akyildiz *et al* 2023), this low-concentration H_2O_2 pretreatment does not impact MF integrity or lead to mass loss, ensuring that all collected fibers remained intact. The process effectively eliminated organic matters while preserving fiber morphology, making them suitable for composite panel fabrication. In order to prepare these waste MFs for use in the manufacturing of panels, they were thereafter extensively washed with ECE detergent and rinsed.

2.2.2. Composite panel production

The design parameters of the composite panels were determined as panel thickness, panel density and the binder ratio. A total of seven different samples were produced, the compositions of which are given in table 1 as follows:

- In the first sample group, only the thickness was altered to test the impact of panel thickness while keeping the binder ratio (20%) and density (0.075 g cm^{-3}) constant.
- In the second sample group, the density (0.075 g cm^{-3}) and thickness (5 mm) were held constant while the impact of the altered binder ratio on the final characteristics was investigated.
- In the final sample group, the weight of raw material was increased with a fixed thickness (5 mm) and binder ratio (20%), and the effect of panel density was examined.

The sample with 5 mm thickness, 20% binder ratio, and 0.075 g cm^{-3} density is common for all three categories and was produced once but has been repeatedly intentionally included in table 1 for clarity regarding the comparability of samples.

Before starting production with the hot press, binder fiber was added to the waste MFs at the ratios specified in table 1. In order to distribute the binder fibers homogeneously among the MFs, both the MFs and the binder fibers were mixed again in distilled water and then obtained by filtering. The dried fiber blends were processed under a hot press at 120 °C for 10 min. To ensure reproducibility and consistency in composite panel properties, environmental conditions were controlled during production. The laboratory temperature was maintained at 20 $\pm$ 2 °C, with a relative humidity of 65% $\pm$ 4%. All raw materials were pre-conditioned for 24 h before processing to minimize moisture-related variations in fiber bonding. Additionally, the temperature and pressure of the hot press machine were continuously monitored to ensure uniform polymerization of the binder fibers. These measures were implemented to reduce potential variability caused by uncontrolled environmental factors, which could impact the density, porosity, and acoustic performance of the final composites. In production, a casting mold with sections that allow the desired thickness to be obtained and Teflon paper that prevents sticking were used. Three samples were produced for each sample group to replicate the analysis and ensure consistency in results. Composite samples' production steps are given in figure 1.

2.2.3. Analysis of MFs and composite panels

2.2.3.1. Chemical analysis

The chemical structures of the fibers were thoroughly examined utilizing Perkin Elmer Spectrum 65 Fourier

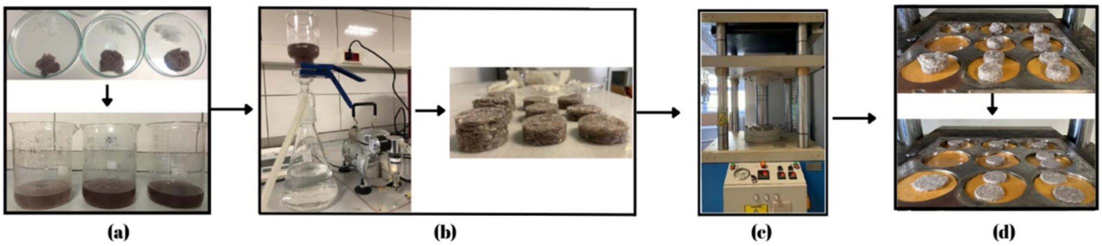


Figure 1. Production of composites samples: (a) mixing pre-determined amounts of microfiber waste and binding fiber in water; (b) performing separate filtrations for each sample to obtain surfaces; (c) hot press; (d) hot pressing process to manufacture composite panels with varying thicknesses; (e) produced composite samples.

transform infrared (FTIR) spectroscopy, operating within the spectral range of 700–4000 cm^{-1}.

2.2.3.2. Microscopic analysis

MFs were observed by Olympus SZ51 optical microscope and the length of MFs were measured from these microscopic images using Image J Program.

2.2.3.3. Physical analysis

A precision balance (0.001 g) was used to measure the weights of the samples, and a caliper was employed to determine their thicknesses. Experimental densities were calculated based on these data and were given along with the mean and standard deviation of all three samples.

2.2.3.4. Acoustic analysis

Measurement of SACs was carried out with an impedance tube (Brüel & Kjaer) with two microphones covering the frequency spectrum from 500 Hz to 6.4 kHz, in accordance with the ISO 10534-2 standard. For this, three different samples from each sample group were cut and tested with a diameter of 29 mm and the results were given as the average value.

2.2.3.5. Water contact angle analysis

To determine the hydrophobicity of the samples, a contact angle measurement system (KSV–CAM 101) based on the fixed drop measurement principle was used and the test was carried out from both sides based on ASTM D7334-08 (2023) standard. Three samples from each sample group were tested and the results were given as average values with standard deviations.

2.2.3.6. Statistical analysis

The statistical analysis of the experimental data was performed to determine significant differences between groups. A one-way analysis of variance (ANOVA) was conducted to assess whether there were statistically significant differences in the mean values among different sample groups. If the ANOVA test indicated significant differences ($p < 0.05$), Tukey's honestly significant difference (HSD) test was applied as a post-hoc analysis to identify which specific groups differed from each other.

Additionally, boxplots were used to visually represent the distribution, median, and variability of the data for each sample group. The boxplots provided insights into potential outliers and the spread of the data, aiding in a comprehensive evaluation of the results. All statistical analyses and visualizations were performed using MATLAB (MathWorks, USA).

3. Results and discussion

3.1. Chemical analysis

Figure 2 shows the raw materials detected as a result of FTIR analysis on MFs through their spectra. According to the results, the MFs found in the wastewater obtained from the outlet of the Biancalani machine are as follows: acrylic, polyester, polypropylene, wool, cotton, viscose, and polyamide. The characteristic peaks proving the existence of these fibers are supported by the literature. Distinctive acrylic peaks include C–H stretching at 2924–2853 cm^{-1}, CN stretching at 2242 cm^{-1}, CO stretching at 1734 cm^{-1}, and C–C stretch in-ring at 1452 cm^{-1} (Abdouss *et al* 2012). For cotton, peaks manifest as O–H stretching at 3300 cm^{-1}, C–H stretching at 2896 cm^{-1}, C=O stretching at 1730 cm^{-1}, C–H bending at 1428 cm^{-1}, and C–C, C–O, and C–O–C stretching at 1060 cm^{-1} (Portella *et al* 2016). In polyamide, key peaks involve N–H stretching at 3293 cm^{-1}, C–H stretching at 2932–2857 cm^{-1}, CO stretching at 1631 cm^{-1}, C–H stretching at 1536–1460 cm^{-1}, and C–N stretching at 1373 cm^{-1} (El-Newehy *et al* 2011). Polyester is marked by C–H stretching at 2968–2908 cm^{-1}, CO stretching at 1710 cm^{-1}, an aromatic ring at 1504–1405 cm^{-1}, carboxylic acid (C–O) at 1242 cm^{-1}, ester (OC–O–C) at 1092 cm^{-1}, and aromatic (C–H) at 719 cm^{-1} (Bhattacharya *et al* 2014). In polypropylene, characteristic peaks encompass C–H stretching at 2950–2918–2836 cm^{-1}, C–H bending at 1456–1376 cm^{-1}, and C–C bending at 1167 cm^{-1} (Prabowo *et al* 2017). Viscose exhibits O–H stretching at 3400 cm^{-1}, C–H

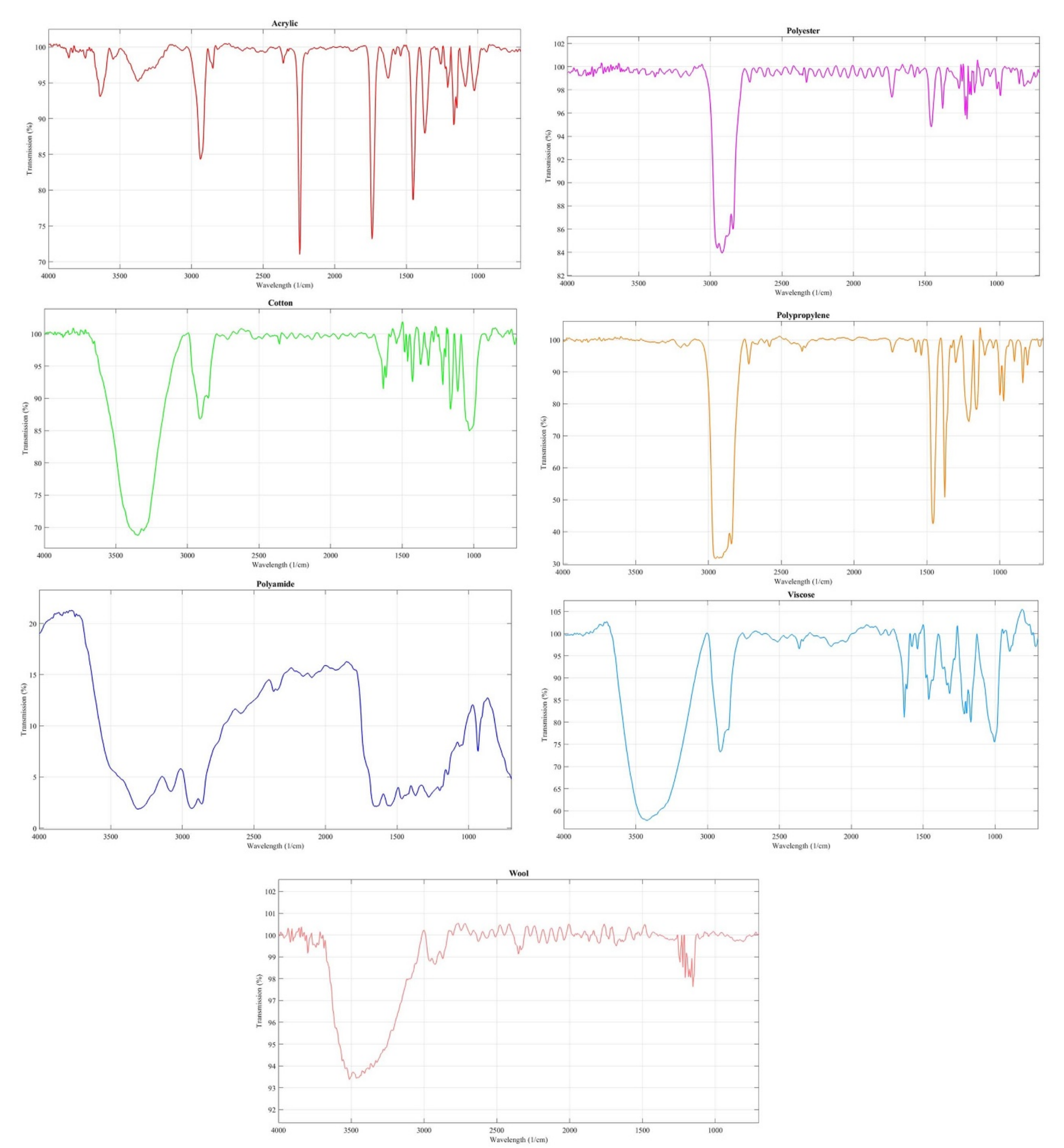


Figure 2. FTIR spectra of detected MFs.

stretching at 2900 cm^{-1}, N–H bending at 1655 cm^{-1}, C–H wagging at 1400 cm^{-1}, and C–O stretching at 1100 cm^{-1} (Rehan *et al* 2019). Wool is characterized by N–H stretching at 3295 cm^{-1}, CO stretching at 1651 cm^{-1}, C–N stretching and N–H in-plane bending vibrations at 1519 cm^{-1}, and C–N stretching and C–O stretching vibrations at 1238–1240 cm^{-1} (Wang *et al* 2016). The detected MFs coincide with the raw materials of the fabrics processed in the company.

3.2. Microscopic analysis

Microscopic images of MFs collected from wastewater are shown in figure 3. The high number of MFs accumulated on top of each other and the fact that they were tangled within themselves (figure 3(a)) caused the fiber length of each MF not to be measured individually. For this reason, measurements were taken on 100 randomly selected fibers (figure 3(b)) to obtain the fiber length distribution graph as seen in figure 4. The results show that the length of MFs ranges from 100 μm to 6 mm. The fiber length distribution plays a crucial role in determining the mechanical performance of the final panels. Shorter fibers (below 500 μm) tend to reduce the mechanical integrity of the panel due to limited fiber entanglement and weaker interlocking. Conversely, longer fibers (above 3 mm) contribute to enhanced mechanical stability by improving fiber–matrix bonding and reinforcing structural cohesion. However, an excess of longer fibers may lead to localized clustering, which could result in uneven fiber dispersion, affecting uniformity in mechanical strength (Kusno *et al* 2023).

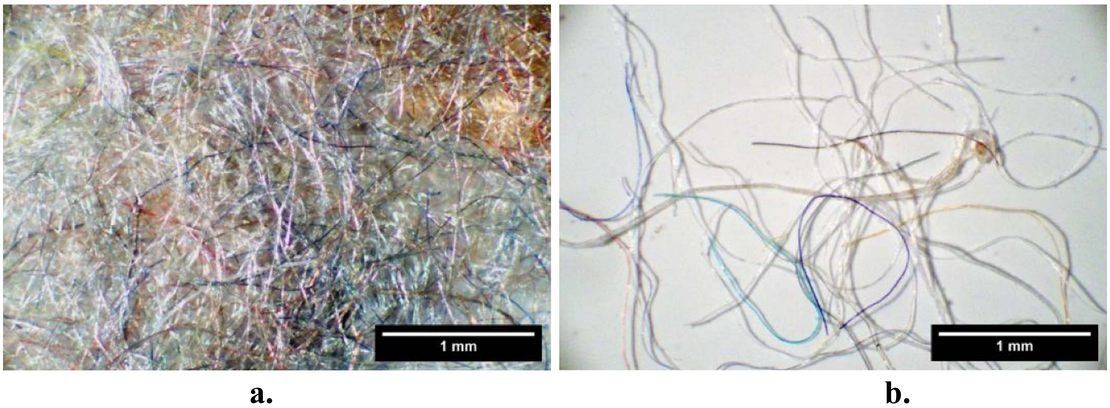


Figure 3. Microscopic images of (a). Accumulated MFs (b). Individual fibers (scale bars indicate 1 mm).

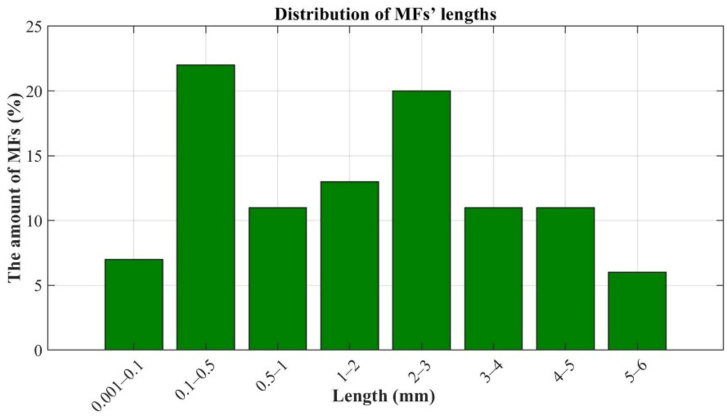


Figure 4. Length distribution of MFs.

Table 2. Experimental densities of composite panels.

Sample code	Experimental density (g cm^{-3})
P5_20_0.075	0.0746 ± 0.020
P10_20_0.075	0.0729 ± 0.013
P15_20_0.075	0.0700 ± 0.015
P5_20_0.075	0.0746 ± 0.020
P5_30_0.075	0.0798 ± 0.011
P5_40_0.075	0.0821 ± 0.010
P5_20_0.075	0.0746 ± 0.020
P5_20_0.150	0.1454 ± 0.023
P5_20_0.200	0.1988 ± 0.026

The observed fiber length distribution in this study provided a balanced structure, ensuring sufficient fiber interlocking without excessive clustering, contributing to both enhanced durability and optimized sound absorption performance.

3.3. Physical analysis

Table 2 presents the experimental densities of the samples. In samples with a constant amount of MFs, decreasing thickness led to an increase in density, aligning with theoretical expectations. For samples where the effect of thickness was examined, although a theoretical density of 0.075 g cm^{-3} was aimed, the actual densities decreased with increasing thickness due to an uneven fiber distribution. This discrepancy suggests potential fiber alignment inconsistencies during the hot press process, leading to localized variations in material compaction. Additionally, minor fiber loss during sample preparation may have contributed to deviations in measured densities. Similarly, in samples with varying binder fiber content, an increase in binder fiber led to a rise in experimental density, which is consistent with the higher density of polyester fibers compared to the MF blend. For the samples produced at target densities of 0.075 g cm^{-3}, 0.150 g cm^{-3}, and 0.200 g cm^{-3}, the experimental results generally matched the planned densities.

3.4. Acoustic analysis and statistical analysis of sound absorption performance

The sound absorption performance of the upcycled MF-based panels was analyzed in relation to their structural properties, including thickness, density, and binder ratio. Figure 5 presents the absorption coefficient comparisons across different samples. The findings confirm that

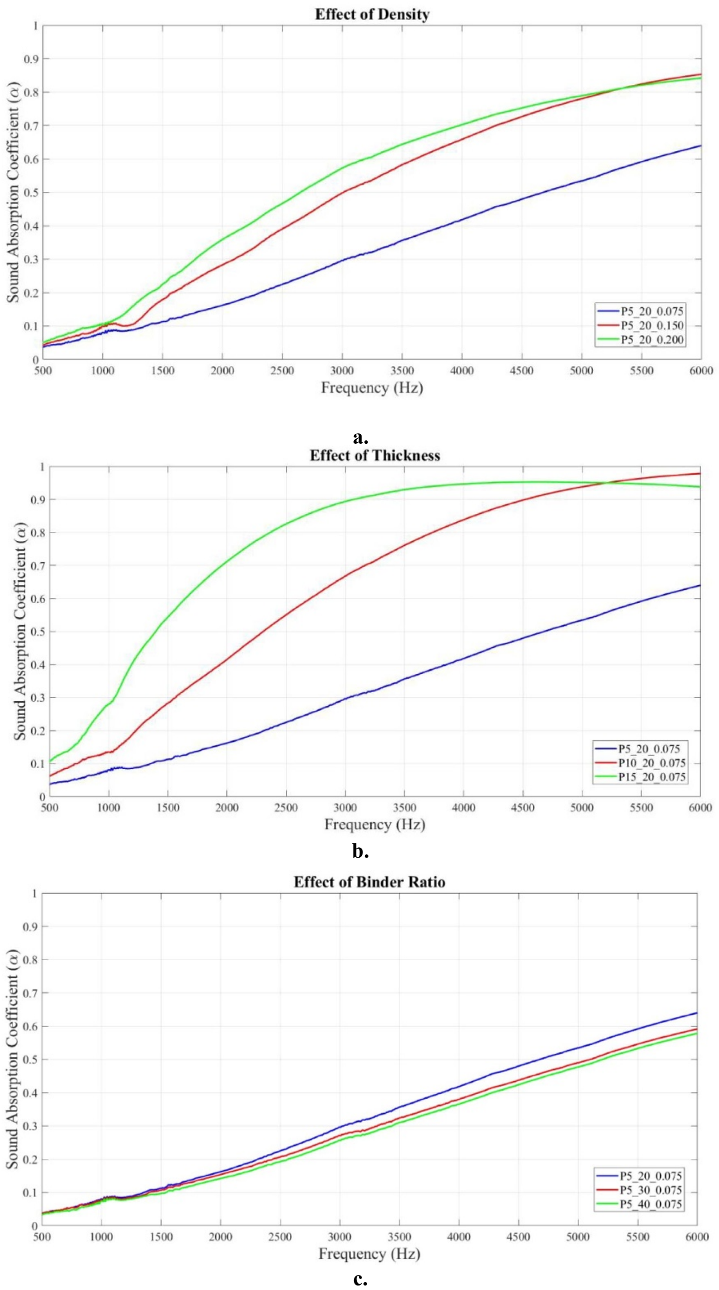


Figure 5. Sound absorption coefficients of the composite panels based on (a). Density, (b). Thickness and (c). Binder fiber ratio effects.

the designed composites exhibit porous material characteristics, contributing to improved sound absorption efficiency at higher frequencies (Chen *et al* 2023).

The effects of density, thickness, and binder ratio were evaluated using one-way ANOVA and Tukey's HSD test, and the results are visualized using boxplots (figure 6). The ANOVA results showed that all three factors had a statistically significant effect ($p < 0.05$) on the absorption coefficient. (p-values: density $= 9.593\,94 \times 10^{-127}$, thickness $= 0$, binder ratio $= 2.044\,23 \times 10^{-08}$). The boxplots in figure 6 highlights the variability and distribution of absorption coefficients across different sample groups. Post-hoc Tukey's HSD test was conducted to identify significant pairwise differences among the groups (table 3).

Density had a strong impact on absorption, particularly in the mid-to-high frequency range. As shown in figure 5(a), higher-density samples (P5_20_0.150 and P5_20_0.200) demonstrated significantly improved absorption, with P5_20_0.200 exhibiting nearly twice the absorption coefficient of the lowest-density sample (P5_20_0.075) around 1500 Hz. This aligns with findings by Sakthivel *et al* (2020), the thermal and sound insulation properties of recycled cotton/polyester chemically bonded nonwovens and found that increasing sample density increased the SAC. It was declared that as density increased, so did the number of fibers per unit area,

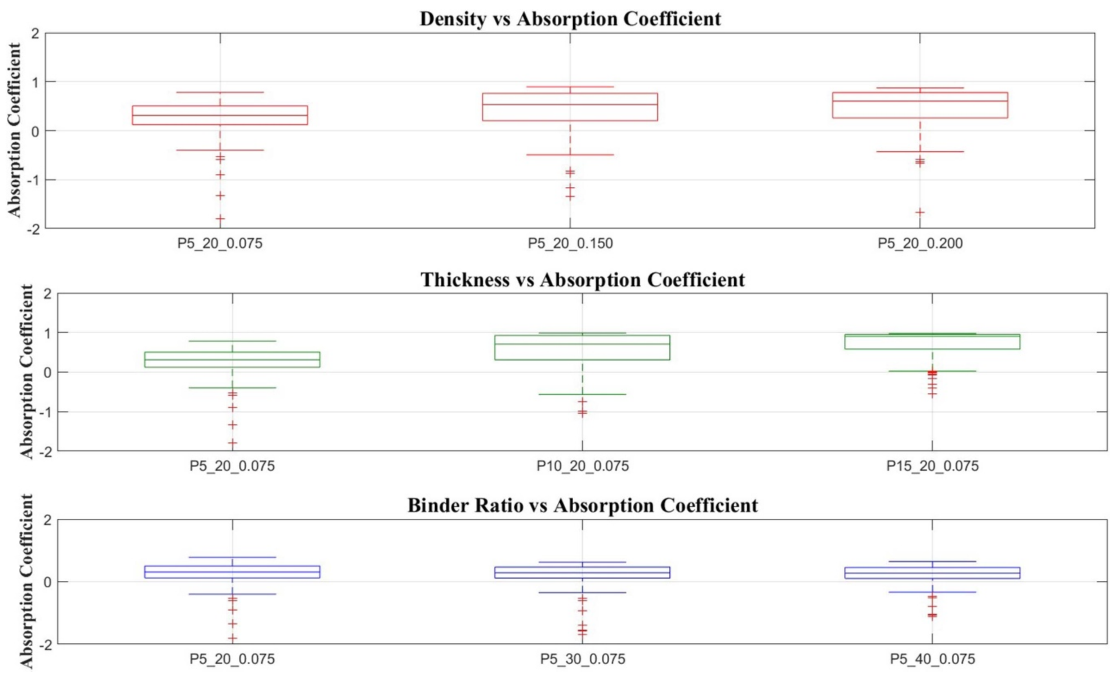


Figure 6. Statistical analysis of absorption performance: boxplots for density, thickness, and binder ratio.

Table 3. Tukey HSD post-hoc analysis for density, thickness, and binder ratio.

Density						
Group 1	Group 2	Mean diff	*p*-adj	CI lower	CI upper	Significant
P5_20_0.075	P5_20_0.150	0,1578	0	0,1384	0,1773	Yes
P5_20_0.075	P5_20_0.200	0,1906	0	0,1712	0,2101	Yes
P5_20_0.150	P5_20_0.200	0,0328	2×10^{-04}	0,0134	0,0522	Yes
Thickness						
Group 1	Group 2	Mean diff	*p*-adj	CI lower	CI upper	Significant
P5_20_0.075	P10_20_0.075	0,2854	0	0,2649	0,3058	Yes
P5_20_0.075	P15_20_0.075	0,4072	0	0,3867	0,4277	Yes
P10_20_0.075	P15_20_0.075	0,1218	0	0,1014	0,1423	Yes
Binder fiber ratio						
Group 1	Group 2	Mean diff	*p*-adj	CI lower	CI upper	Significant
P5_20_0.075	P5_30_0.075	−0,027	0	−0,0417	−0,0124	Yes
P5_20_0.075	P5_40_0.075	−0,0357	0	−0,0503	−0,021	Yes
P5_30_0.075	P5_40_0.075	−0,0086	0,351	−0,0233	0,006	No

resulting in higher sound absorption values in the middle and higher frequency ranges (Sakthivel *et al* 2020). Tukey's HSD test confirmed that P5_20_0.075 was significantly different from P5_20_0.150 and P5_20_0.200, while the latter two exhibited similar absorption performance (table 3).

Thickness emerged as the most dominant factor, with thicker samples, such as P15_20_0.075, achieving significantly higher absorption values across all frequencies. The absorption coefficient for this sample was 3–5 times greater than that of P5_20_0.075 and exceeded 0.9 above 3000 Hz (figure 5(b)). In a study by Bhingare and Subramaniam (2023), the effects of thickness, density, air gap and fiber percentage parameters on the SACs of coconut fiber reinforced composite materials were examined using the Taguchi technique. While the analyzes showed that thickness and density were the most important parameters among these parameters, it was observed that the SAC increased with increasing thickness. It is stated that this situation is a result of the increase in the distance that sound waves travel, resulting in more friction and loss of sound energy (Bhingare and Subramaniam 2023). Tukey's

HSD results showed significant differences among all thickness groups, reinforcing that thicker samples consistently outperform thinner ones (table 3).

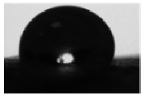
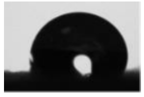
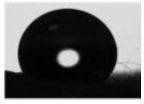
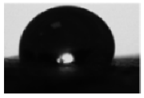
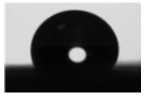
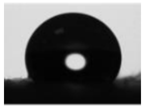
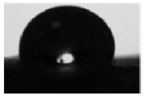
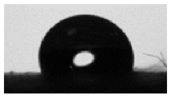
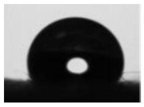
The binder ratio had a less pronounced effect on absorption. While all three samples exhibited a linear increase in the absorption coefficient at higher frequencies, P5_20_0.075, which had the lowest polyester binder fiber ratio, showed the highest absorption. Tukey's HSD test confirmed that P5_20_0.075 was significantly different from P5_30_0.075 and P5_40_0.075, though the difference between the latter two was minimal (table 3).

Overall, thickness emerged as the most influential factor, followed by density, in determining sound absorption performance.

3.5. Water contact angle analysis

Table 4 presents droplet images and water contact angle measurements, confirming that all samples exhibit hydrophobic properties with contact angles exceeding 90° (Jeong and Kim 2023). Hydrophobicity improves with greater thickness, density, and binder ratio. A thicker layer enhances water repellency by creating a more structured and compact surface (Mufti *et al* 2017). Higher density compresses fibers, reducing voids and lowering wettability. Additionally, an increased binder ratio enhances fiber bonding, as the hydrophobic polyester binder minimizes surface water absorption (Sfameni *et al* 2023).

Table 4. Contact angle measurement of samples.

Sample name	Average contact angle ± SD (°)	Droplet images
P5_20_0.075	103.0 ± 1.41	
P10_20_0.075	110.5 ± 0.71	
P15_20_0.075	114.5 ± 0.71	
P5_20_0.075	103.0 ± 1.41	
P5_30_0.075	117.0 ± 1.41	
P5_40_0.075	120.0 ± 0.00	
P5_20_0.075	103.0 ± 1.41	
P5_20_0.150	108.5 ± 0.71	
P5_20_0.200	111.5 ± 0.71	

The hydrophobicity of developed panels is primarily influenced by fiber surface properties, polymer composition, and structural morphology. Polyester fibers, known for their low surface energy, play a critical role in water repellency by preventing liquid penetration (Ji *et al* 2008, Prorokova *et al* 2010). Additionally, fiber distribution, surface roughness, and compaction levels significantly affect water contact angles. A higher binder ratio strengthens fiber bonding, reducing surface voids and creating a denser, less wettable structure. Similarly, increased panel density results in a more compact fiber network with fewer capillary pathways, further limiting moisture infiltration (Scarselli *et al* 2015, Mănăilă *et al* 2020, Odokonyero *et al* 2021).

Through changing the way sound waves interact with or pass through a material; hydrophobic materials may affect the acoustic characteristics of a system. For instance, the addition of hydrophobic chemicals to sound-absorbing materials may improve their performance by lowering the quantity of water that enters the material, therefore impairing its capacity for sound absorption (Cao *et al* 2019). Especially in demanding environmental conditions, the mechanical endurance of these hydrophobic surfaces is especially crucial as it guarantees that the materials preserve their sound absorption characteristics over time (Elliott *et al* 2015).

4. Conclusion

Each year, thousand tons of MFs are released from textiles into the environment, posing a significant risk to both human health and ecosystems. Detecting these MFs, as well as preventing their spread and ensuring their removal, is crucial; however, research in this area remains alarmingly scarce. This study examines the reuse of waste MFs released during a textile finishing process in composite panels for sound absorption purposes. In this context, composite materials were produced using waste MFs containing cotton, wool, viscose, acrylic, polyester, polypropylene, and polyamide with a length range of 100 μm to 6 mm and low melting temperature bicomponent polyester fiber, and the effect of changing parameters on the SAC and hydrophilicity of the material has been examined. The obtained results showed that,

- Among all, the sample coded as P15_20_0.075 has the highest SAC (0.90 at 3000 Hz) due to its highest thickness and it is followed by sample P5_20_0.200 which has the highest density (0.55 at 3000 Hz).
- In contrast to panel thickness and density effect on sound absorption, binder fiber ratio negatively affects the sound absorption properties resulting in the least binder ratio (20%) have the highest SACs (0.30 at 3000 Hz).
- All samples showed hydrophobic properties, with a water contact angle range of 103°–120° providing resistance to surface wetting.

This study introduces a novel approach to repurposing textile waste MFs for acoustic applications, contributing to sustainable waste management in the textile industry. By developing composite materials that address both microplastic pollution and sound absorption, it bridges the gap between environmental concerns and innovative material solutions. The proposed upcycled MF-based panels offer a more sustainable alternative by reducing reliance on virgin synthetic materials. However, further research is needed to assess their long-term stability, durability, and microplastic release potential compared to conventional materials.

While this study provides valuable insights into the development and acoustic performance of these panels, certain limitations must be acknowledged. A key constraint is the lack of long-term experimental data on the release of micro/nanoplastics or chemical substances under real-world conditions. Factors such as humidity, temperature fluctuations, UV exposure, and mechanical wear could affect material degradation, yet these were not systematically examined. Additionally, while the panels exhibit promising sound absorption properties, their durability and stability over time remain uncertain. The environmental impact of their production, use, and disposal also requires further evaluation, particularly in comparison to conventional synthetic sound-absorbing materials.

Future research should focus on accelerated aging tests, fiber emission studies, and leachate analysis to comprehensively assess material sustainability and minimize environmental impact. Given their lightweight structure and acoustic performance, these panels offer a cost-effective and sustainable alternative to conventional materials. Their production can be scaled up using industrial filtration and hot press techniques, making them viable for applications in architectural acoustics, automotive, and sustainable building industries. Addressing these limitations will be essential in validating upcycled MF-based panels as a viable, eco-friendly alternative for soundproofing and noise reduction.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ORCID iDs

Sinem Hazal Akyildiz https://orcid.org/0000-0002-8346-5895
Hande Sezgin https://orcid.org/0000-0002-2671-2175
Mustafa Sabri Özen https://orcid.org/0000-0002-2921-3638
Ipek Yalcin Enis https://orcid.org/0000-0002-7215-3546

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