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DEVELOPMENT OF ACOUSTIC RESONATORS USING RECYCLED PLASTICS

Juraj Potočár[1,2] **Maroa Maaroufi**[3,4] **Stanislav Unčík**[2]
Christ Glorieux[5] **Monika Rychtarikova**[1,2]
[1] KU Leuven, Department of Architecture, Campus Brussels and Ghent, Belgium
[2] STU Bratislava, Faculty of Civil Engineering, Department of Materials Engineering and Physics, Slovakia
[3] Université Paris-Saclay, ENS Paris-Saclay, CNRS, LMT – Laboratoire de Mécanique et Technologie, 91190 Gif-sur-Yvette, France
[4] EPF-Ecole d'Ingénieurs, 55 Avenue du Président Wilson, Cachan 94230, France
[5] KU Leuven, Department of Physics and Astronomy, Laboratory of Soft Matter and Biophysics – Acoustics, Heverlee, Belgium

ABSTRACT

In this contribution, we discuss preliminary research results obtained within the framework of one of the ten individual research projects of the EU-MSCA-DN, "ActaReBuild", which focuses on the development of acoustic resonators based on lightweight concrete using recycled aggregates. In particular, we examine using loose granules of flo-pak plastic as material to fill and absorb sound in the resonator cavity. The sound absorption of the granules was measured in a reverberant room and compared with the sound absorption properties of melamine foam, a common porous material of the same thickness. Also the absorption of a wooden resonator (1) filled with melamine and (2) filled with loose plastics was determined and compared to that of (3) an empty resonator. The results show that adding granules in the cavity leads to an increase in resonance frequency, likely due to their closed pores reducing the effective cavity volume and increasing stiffness. Also broadening of the absorption peak is observed.

Keywords: *resonator, waste plastics, sound absorption*

***Corresponding author**: *juraj.potocar@kuleuven.be*

1. INTRODUCTION

In architectural acoustics, sound absorption plays a key role in regulating the reverberation time, reducing noise levels from sound sources in the room, and improving the overall acoustic quality of a space. By reducing echoes, flutter echoes, and standing waves, sound absorption ensures clarity, comfort, and functionality in various environments, such as auditoriums, offices, classrooms, and recording studios.

In situations when sound containing mid and high-frequencies needs to be absorbed, the usage of porous absorbers is convenient. Typically, the lowest absorbed frequency is the one for which a quarter wavelength corresponds with the distance between the most protruding porous material and the rigid wall behind. In practice, this makes the use of porous materials as absorbers impractical or even impossible for bass frequencies, and the use of resonators becomes necessary. One of the possibilities is the use of a cavity resonator.

Empty Helmholtz resonators exhibit a sharp absorption peak, of which the (typically low) frequency depends on the dimensions of the neck and cavity. The absorption is a consequence of viscous loss effects of the air velocity oscillations in and near the neck. By inserting porous materials, preferably near the neck, additional sound energy is absorbed, broadening the absorption peak.

Besides conventional fibrous and foam-based materials, recycled polymer waste is gaining attention as a promising option for sound absorption. These materials are typically processed into granular form, influenced by factors such as grain size, and internal structure. These variables can significantly affect the acoustic performance across specific frequency ranges. A classification framework for granular absorbents - such as vermiculite, perlite, granulated rubber, and nitrile foam - was introduced by Voronina and Horoshenkov [1]. Studies show that granules obtained from recycled products like tires and cables offer favorable properties for the development of tailored acoustic solutions. Further evidence of the acoustic viability of recycled rubber granulate comes from Swift and Horoshenkov [2], who demonstrated that rubber crumb not only supports broadband absorption but can also be modeled effectively using a semi-empirical approach that captures both viscous and thermal losses in porous structures. Their findings underline the impact of grain shape, flow resistivity, and packing density on absorption characteristics, especially within mid- to high-frequency ranges.

Notably, plastic granulated materials showed effectiveness in providing relatively wide-band sound absorption [3-5]. By adjusting parameters such as granule size and material thickness, one can fine-tune the absorption peak to align with target frequencies. Research by Bumanis et al. on recycled expanded polystyrene granules revealed efficient sound absorption in the range of 600–700 Hz [6].

Although flo-pak granules - EPS-based loose-fill foam products - have been previously evaluated in terms of their mechanical performance [7], their acoustic behavior has not yet been comprehensively studied. In this work, we consider the use of this type of granules in a way to dissipate acoustic energy in the resonator's cavity, compared to foam material - melamine.

2. METHODS

2.1 Samples preparation

Two resonators were used for measurement, made of MDF (medium-density fibreboard) plates. Each of them had internal dimensions of 100x100x7 cm^3 (Figure 1). The thickness of the perforated plate t = 9 mm, with holes at an axial distance of 20 cm and a hole diameter of 25 mm.

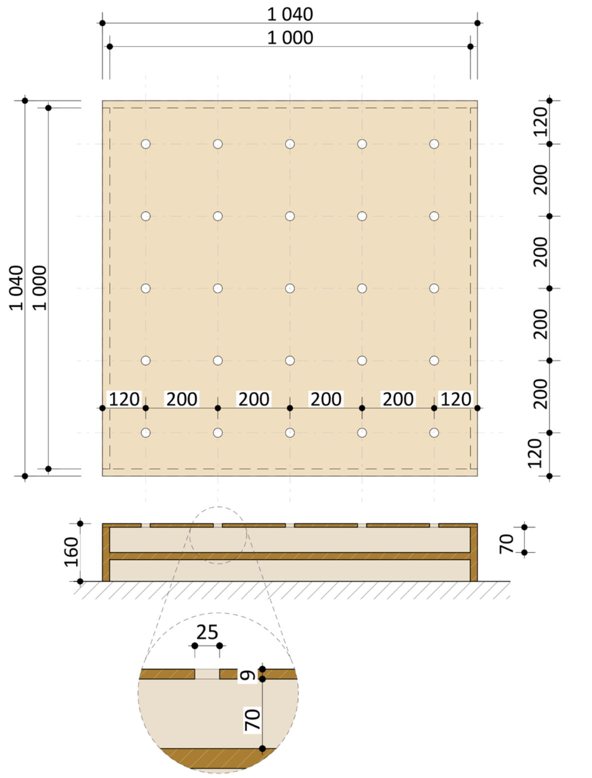

Figure 1. Dimensions of the used resonator (in millimeters)

Two types of porous materials were characterized. The melamine foam (Figure 2a) was used for reference as a well-known open-cell, lightweight foam with a density of approximately 7-11 kg/m³. Melamine foam is widely known for its excellent sound absorption capabilities due to its fine, interconnected pore structure, which enhances sound wave dissipation. The foam used in the study had a dimension of 100x100 cm2 and a thickness of 50 mm.

The sample of main interest consisted of flo-pak granules. The granules have sizes around 10x20x30 mm3, and a variety of different shapes ("S-shape", "8-shape"). The bulk mass density was 4 kg/m³. This type of loose-fill packaging material is commonly used for cushioning and protecting items in boxes during shipping and handling. Granules are made from both expanded PS (EPS) and extruded PS (XPS). It is a lightweight, rigid, and versatile material. Although this material is often made of recyclable PS and can be reused, it rarely happens, and most of it ends up in landfills or incinerators. For this reason, we found it interesting to look for possibilities of reuse in a new context, i.e. as an absorber in acoustic applications.

Figure 2. Detailed view of investigated materials: Left: melamine foam (cylinder cut out of the 50mm thick panel. Right: Selection of flo-pak granules from the 50 mm loose stack

2.2 Reverberant room measurements

The spectrum of the sound absorption coefficient per 1/3 octave band was determined inspired by the conventional ISO 354 method in the reverberant room. While the reverberant room is suitable for ISO 354 measurements (197 m3), due to practical constraints, the sample surface size (2 m²) was lower than the required size (10-12 m2) Measurements were performed by means of impulse response with exponential sweep signal (duration of 23.8 seconds) generated in the room through an omnidirectional loudspeaker. The acoustic absorption of a flo-pak granules (Fig. 4) layer of about 50mm thickness was characterized both in loose form and as cavity-filling material under a 9 mm thick perforated plate with 25 mm diameter holes arranged on a cubic grid with 20 cm interspacing. The melamine reference layer had a thickness of 50 mm and was tested loose and in the cavity configuration. Also, the empty cavity configuration was characterized. The average of measured sound absorption was based on 18 measurements – 6 microphone positions for each of 3 sound source positions.
The temperature, relative humidity, and atmospheric pressure were carefully controlled during the measurement procedure, and taken into account in the analysis.

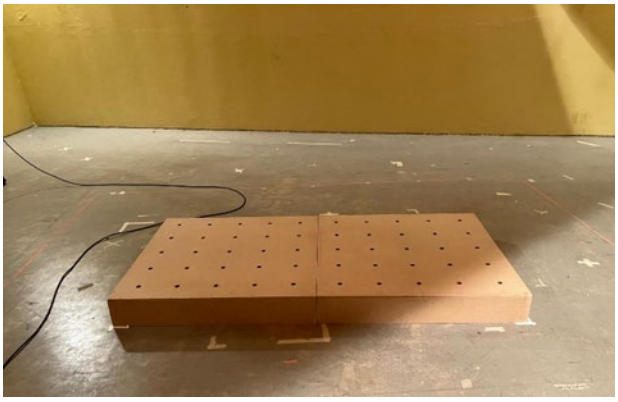

Figure 4. Two adjacent wooden resonators placed in the reverberant room

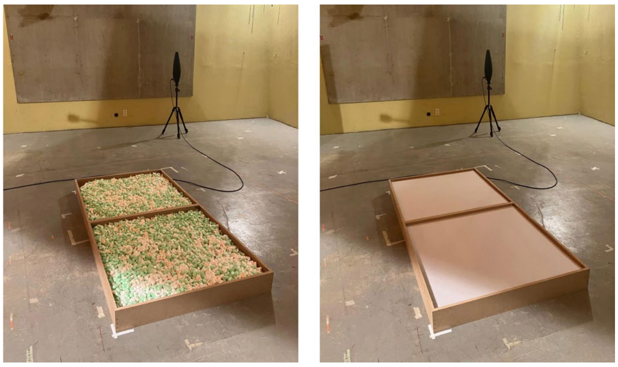

Figure 5. Open resonators with flo-pak granules (left) and melamine foam (right)

3. RESULTS AND DISCUSSION

The sound absorption (α) spectra of the open resonators with porous materials are presented in Figure 5. Melamine foam shows the typical behavior of foam or fibrous porous material, with low α values at low frequencies (α=0.17 at 125 Hz), followed by a gradual increase with increasing frequency, reaching 100% absorption at frequencies of 630 Hz and higher. As expected, due to its much lower porosity and large pores, the absorption of the flo-pak granule layer is substantially lower than the one of the equally thick melamine. Nevertheless, the absorption values between 0.2 and 0.8 across the audio range give the potential for using recycled flo-pak granules for acoustic absorption applications. The weakly pronounced maximum around 1250 Hz, combined with a speed of sound of 340 m/s of the air in the large pores, corresponds with a quarter wavelength of 7 mm, a bit more than 5mm, the nominal thickness of the flo-pack layer.

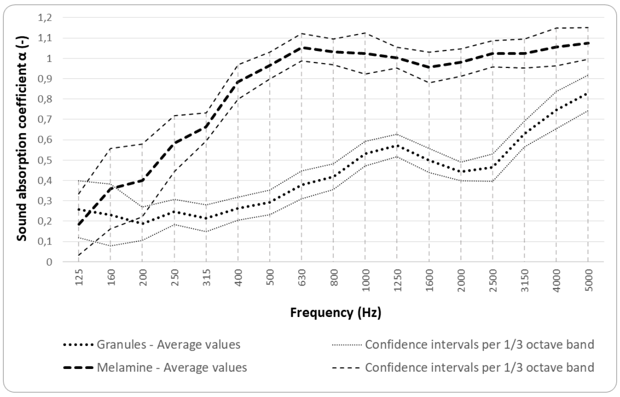

Figure 6. Sound absorption spectrum of a 50 mm layer of melamine foam (dashed line), and flo-pak granules (dotted line)

The α spectra of the perforated panel resonator with different filling conditions are presented in Figure 6. Combining the dimensions of the resonator (Figure 1), its resonance frequency can be calculated as [8]:

$$f_r = \frac{c}{2\pi}\sqrt{\frac{A_{perf}}{A_{panel}\cdot d_{cavity}\cdot t_{eff}}}$$

where c is the speed of sound in air (340 m/s) and teff = t + 2δr = 0,02325 m with $\delta = 0.85(1 - 1.47\varepsilon^{1/2} + 0{,}47\varepsilon^{3/2}) = 0{,}57$. $\varepsilon = A_{perforation}/A_{panel}$ denotes the porosity of the plate. The calculated value of the resonance frequency (140 Hz) is consistent with the sound absorption peak (α=0.55) of the empty resonator in the 160 Hz 1/3 octave band.
Compared to the empty cavity, filling the resonator with flo-pak granules induces a shift towards the 200 Hz-250 Hz 1/3 octave bands, in accordance with the effect of a reduction of the free cavity volume due to the granules. The absorbing function is similar to the one of the empty resonator (α=0.57), but it acts across a wider frequency range.

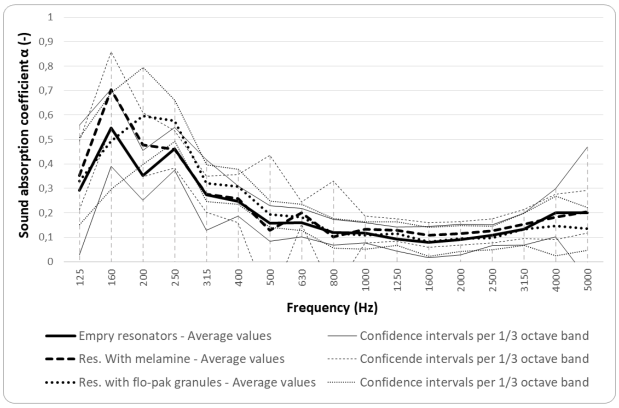

Figure 7. Sound absorption spectrum of the perforated panel resonator with different cavity filling conditions: melamine foam (dashed line), flo-pak granules (dotted line), and empty (solid line)

4. CONCLUSIONS

This study explored the potential of recycled plastics in acoustic resonators, focusing on flo-pak granules as cavity fillings and comparing them to melamine foam. The results confirm that granule filling influences the resonator performance, increasing the resonance frequency (as a consequence of the reduced free volume) and broadening the absorption peak.
As expected, also filling the resonator cavity with melamine increased damping. Still, the overall absorption remained relatively low, possibly due to insufficient perforation or improper placement of melamine (2 cm gap between the melamine and perforation).
The sample dimensions were smaller than the standardized sizes required by ISO norms, which may have influenced the absorption measurements by reducing the overall impact of the material on the acoustic environment. While these recycled materials offer promising applications for sound absorption, challenges remain in optimizing their performance. Future research will focus on refining cavity-filling configurations, analyzing the dynamic stiffness of granules, and conducting larger-scale measurements to assess their viability in real-world noise mitigation solutions.

5. ACKNOWLEDGEMENTS

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