POTENTIAL APPLICATION OF RECYCLED RUBBER CRUMBS AS SOUND ABSORBING MATERIALS

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ABSTRACT

In this paper, we study experimentally and numerically the acoustical properties of rubber granulates made from the recycling rubber productions. The representative volume element is reconstructed based on the classical algorithm of non-overlapping packing particles. The multi-scale analysis is then used to compute the homogeneous macroscopic transport parameters in the semi-phenomenological model for an acoustic porous media. Several measurements are performed to validate our numerical predictions. Finally, the potential acoustical properties of recycling rubber granular layers with their different thickness and grain sizes are demonstrated.

Keywords: recycled rubber crumb, sound absorption, granular porous material, noise control.

1. INTRODUCTION

Recently, design and selection of sound-insulating/-absorbing structures from both natural and man-made porous materials have been gained great attention in the scientific community. Various methods are proposed to characterize the link between microstructure and macroscopic properties of these materials [1, 2]: analytical, numerical, experimental approaches (for a detailed view see Ref. [3]). It can be stated that: (i) the acoustical properties are highly dependent on the morphology of porous materials (foam, fibrous, granular [2]), (ii) we enable to tailor or archive the derived sound absorption by controlling the geometry of appropriate materials.

Recycling rubber productions (e.g., waste conveyor belts, end-of-life tires) are known within negative economic and environmental impacts due to the difficulty in their disposal and recycling. The utilization of rubber-based structures as a component of functional materials for various fields (construction [4], acoustics [5]) has emerged as a potentially sustainable solution.

This paper demonstrates a potential application of recycling rubber crumbs as sound absorbing materials for noise control purpose by experiment evidence and numerical simulations.

2. METHODOLOGY

2.1. Numerical calculation

2.1.1. Fluid equivalent model of acoustic porous media`

In equivalent-fluid approach, an effective fluid is substituted for a porous medium with the effective density and effective bulk modulus given as (also referred to Johnson-Champoux-Allard-Lafarge (JCAL) model):

$$\tilde{\rho} = \rho_0 \left[\alpha_\infty + \frac{\phi\sigma}{j\omega\rho_0} \sqrt{1 + j\omega \frac{\rho_0}{\eta} \left(\frac{2\eta\alpha_\infty}{\sigma\phi\Lambda} \right)^2} \right], \tag{1}$$

$$\tilde{K} = \gamma P_0 \left\{ \gamma - (\gamma - 1) \left[1 - j \frac{\phi\gamma P_0}{k_0' C_p \rho_0 \omega} \sqrt{1 + j \frac{4 k_0'^2 C_p \rho_0 \omega}{\gamma P_0 \Lambda'^2 \phi^2}} \right]^{-1} \right\}^{-1} \tag{2}$$

where ρ_0 is the air density, P_0 the atmospheric pressure, $\gamma = C_p/C_v$ is the ratio of heat capacities at constant pressure and volume, j is the imaginary unit, η is the dynamic viscosity. Six parameters (ϕ, Λ', σ, α_∞, Λ and k_0') are the geometry and transport factors (see Sec. 2.2.2).

The wave number $\tilde{k} = \omega\sqrt{\tilde{\rho}/\tilde{K}}$ and the normal incidence (NI) characteristic impedance, $\tilde{Z}_c = \sqrt{\tilde{\rho}\tilde{K}}$ are used to describe a homogeneous layer. The complex reflection coefficient of this layer is estimated by, $\tilde{R} = (\tilde{Z}_s - \rho_0 c_0)/(\tilde{Z}_s + \rho_0 c_0)$, in which, c_0 is the sound speed in air, and $\tilde{Z}_s = -j\,\tilde{Z}_c/\phi\,\mathrm{cotg}\tilde{k}L_s$ is the NI surface impedance for a layer of thickness L_s.

Finally, the NI sound absorption coefficient (SAC) of this layer is derived as, $\mathrm{SAC} = 1 - |\tilde{R}|^2$.

2.1.2. Local geometry reconstruction and transport property estimation

Here crumbs are treated as like-spherical particles with Gaussian particle-size distribution (left part of Fig. 1). We reconstruct the representative element volume (REV) based on the dense random packing of poly-sized spheres (middle part of Fig. 1). Dynamically generated distributions of rigid spheres can be used to drive spheres packing towards the close-packed limit. The dropping and rolling algorithm [6] is employed to generate such random close packing.

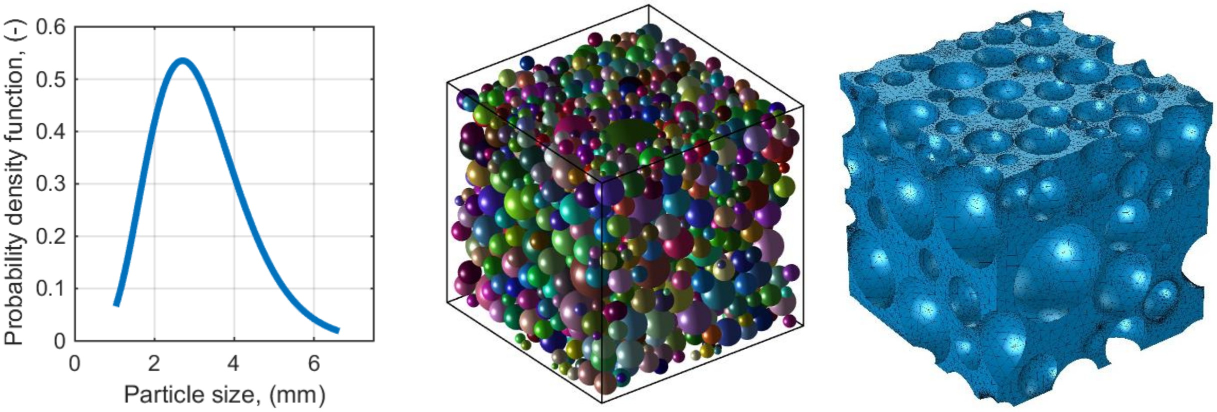

Figure 1. Distribution of sphere size (left) and the corresponding random close packing (middle), and the FE mesh of reconstructed REV with 142 575 tetrahedral elements (right).

JCAL model involves 6 parameters (ϕ, Λ', σ, α_∞, Λ, and k'_0). The porosity ϕ and the thermal characteristic length Λ' are defined from the REV configuration (right part of Fig. 1), and others are computed from the numerical solutions of [3]: (i) the Stokes equations (the static air flow resistivity σ); (ii) the potential flow equations (the high frequency tortuosity α_∞ and the viscous characteristic length Λ); and (iii) the equations of diffusion controlled reactions (the static thermal permeability k'_0). COMSOL Multiphysics® v5.2 is used herein for all multi-scale computations.

2.2. Experimental characterization

In this work, crumbs are manufactured by grinding the rubber products (Fig. 2.a). Here, particle crumb has an average size of $\bar{d}_p$ ~3.2 mm (real grain sizes varying from fine level (< 1.0 mm) to coarser one (> 5.5 mm)). Rubber layers having thickness of 10 ÷ 60 mm were prepared for acoustic experiments. The tests of acoustical property were carried out in a three-microphone impedance tube within a length of 1 m. In order to carry out the tests in a horizontally-positioned tube with an inner diameter of 40 mm, the materials are filled in a small short steel cylinder of 39.75 mm to install inside the tube. Of course, one of the cylinder's end is covered with a steel screen to keep the materials. The tube configuration is shown in Fig. 2.b. The microphones (Mic.) are distributed uniformly along the tube: the distance between Mic. #1 and Mic. #2 is 35 mm and the distance between Mic. #1 and Mic. #3 is 135 mm, and without the cavity or plenum depth. The measurement frequency ranges from 4 Hz to 4500 Hz with a step size of 4 Hz. The measured SACs of nine samples are shown in Fig. 2c (the arrow or the curve thick indicates the increasing value of sample thickness in array [10, 15, 20, 25, 30, 35, 40, 45, 55, 60] mm).

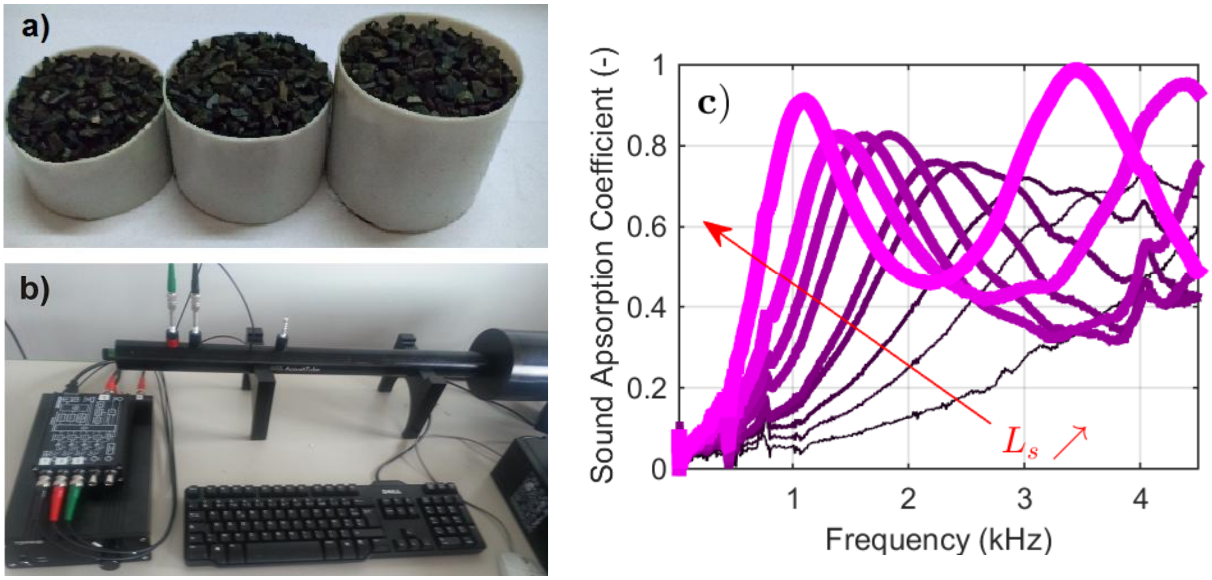

Figure 2. Materials (a), experiment set-up (b), and SACs measured on several samples (c)

3. RESULTS AND DISCUSSION

The interesting SAC of rubber granulates is plotted in Fig. 2.c. In the considered frequency range (<4.5 kHz), with the same configuration of rubber crumbs, we can design the absorbers for low frequency range by increasing their layer thickness. For the first sharp peak of SAC behavior: 10 mm-thick sample shows a peak with SAC of ~0.75 at frequency ~4 kHz, whereas a peak with higher SAC of ~0.91 at lower frequency ~1.1 kHz occurs in the 60 mm-thick sample.

We exam how the numerical computations are in agreement with the experimental data. Several selected samples are used for this purpose. Fig. 3 shows the sound absorption behavior of 4 samples (sub-figures a) to d) for [10, 20, 40, 60] mm-thick layers) obtained from impedance tube test (line) and multi-scale computations (marker). It can be seen from the curves that the numerical framework can predict well the acoustical behavior of real rubber samples.

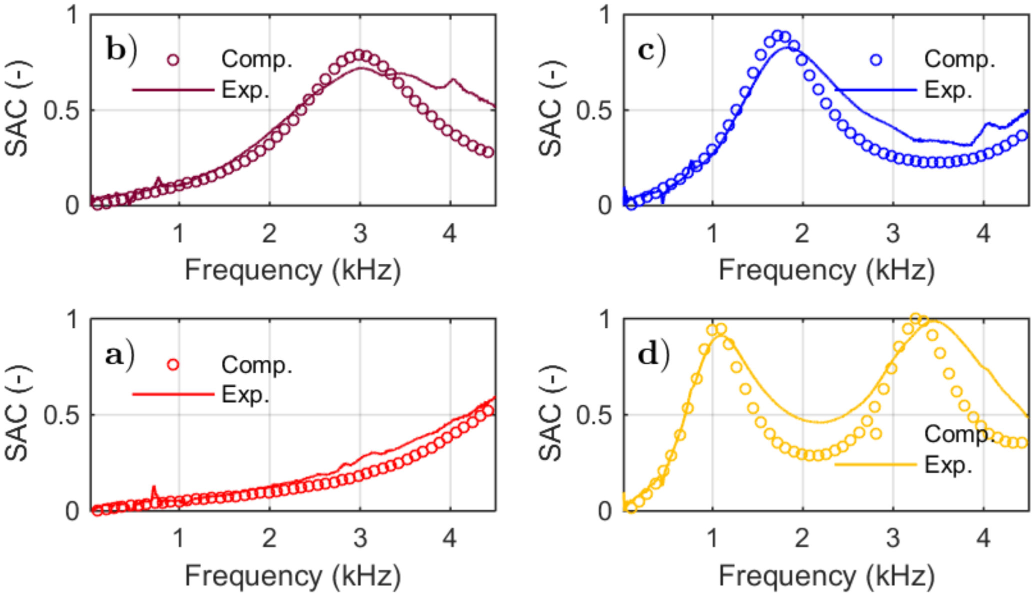

Figure 3. Comparison of SACs obtained from experiments (line) and computations (markers).

Fig. 4 illustrates the numerical results about the effects of both rubber grain size and the absorber thickness on the sound absorption behavior. In Fig. 4.a, we obtain again the same trend of the thickness dependence of the measured SAC mentioned before but with the different $\bar{d}_p$. In detailed, by decreasing the size of the rubber crumbs at ~2.0 mm, the level of sound absorbing can be improved in compared with SACs of crumbs at ~3.2 mm in Fig. 2.c. In the next investigation, as showing in Fig. 4.b, the averaging particle-size value has also strong effects on the SAC curves. With several 60 mm-thick layers based on rubber crumbs having the average size $\bar{d}_p$ varying from 1 mm to 11 mm, the obtained curves show slight differences in terms of the frequency (~1.2 kHz and 3.4 kHz) and the number of sharp peaks. The improvement of SACs in finer crumb layers can be explained by the lower value of the length Λ and the higher value of σ due to the smaller channels in the pore connectivity.

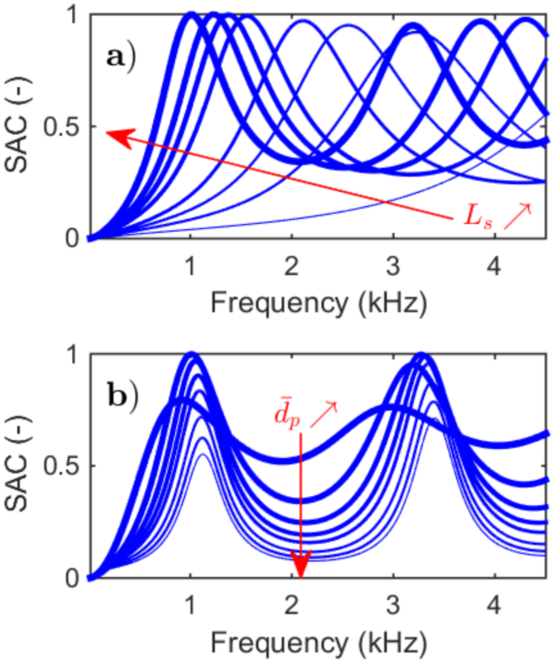

Figure 4. Effects of grain size (a) and layer thickness (b) on SACs of rubber granules

4. CONCLUSION

This present work proposed a numerical-experimental approach for predicting the potential acoustical properties of absorbers made from recycled rubber crumbs. From the obtained results, it can be concluded that: (i) higher value of sound absorption can be achieved in a layer with smaller grain size of crumbs; (ii) increasing the sample thickness provides improvement in SAC and shifts the maximum SAC spectra towards lower frequencies. For practical applications, fabrication and testing samples with other concentrations (i.e., binder, anti-flame) and/or to other non-acoustical properties (e.g., thermal, mechanical) will be considered in the forthcoming work.

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