Exploration of Sound Absorption Properties of 3D-Printed Hybrid Materials through Impedance Tube Measurements

DOI: 10.61782/fa.2023.1121

EXPLORATION OF SOUND ABSORPTION PROPERTIES OF 3D-PRINTED HYBRID MATERIALS THROUGH IMPEDANCE TUBE MEASUREMENTS

Louena Shtrepi[1*] **Elena Badino**[1] **Vaia Tsiokou**[2]
Arianna Astolfi[1] **Anna Karatza**[2]
[1] Department of Energy, Politecnico di Torino, Italy
[2] BioG3D SMPC, Athens, Greece

ABSTRACT

Additive manufacturing technologies can be used to produce innovative and efficient acoustic materials that can be designed with tailored complex inner structures and topological surfaces to address specific frequency-related acoustic problems. These fabrication techniques can facilitate the production of hybrid materials, which combine sound absorption and diffusion properties. This is usually achieved by combining porous layers with irregular hard elements. This contribution focuses on the sound absorbing performances of 3D printed hybrid acoustic materials (HAM) and explores the challenges associated with their characterization in an impedance tube. The effects of the combined hard and porous layers have been investigated on two comprehensive examples that can serve as benchmark. Both layers have been obtained by printing the same material, i.e., thermoplastic filament (Ø 1.75 mm) PLA.
It was found that the sound absorption properties of the tested HAM samples are significantly influenced by many factors, namely by the open-porous material structure, the sample thickness, and the presence or absence of a hard layer on top of the porous one. This information can provide useful insight to further optimize the design of HAMs to improve their sound absorbing performances.

Keywords: *3d-printed materials, hybrid surfaces, sound absorption coefficient, impedance tube.*

[*]***Corresponding author***: *louena.shtrepi@polito.it*

1. INTRODUCTION

Sound can be considered as important as any other architectural aspect that contributes to the indoor and outdoor well-being. It can be shaped through design principles which are supported by new manufacturing technologies exploring more complex structure [1]. Therefore, state of the acoustic measurement methods needs to be further tested for innovative complex structures. The aim of this paper is to explore the sound absorption properties of customizable 3D printed hybrid acoustic materials (HAMs) through measurements in impedance tube.
In the current state of the art, the normal incidence sound absorption coefficient of different 3D printed porous sound absorbers has been presented through measurements in the impedance tube [2-6] or predicted through theoretical models [3-5]. For these novel porous 3D printed materials, the focus has been the analyses of the effects of the 3D printing techniques used for their fabrication [6] on the accuracy of the measurements of the sound absorption coefficients. In particular, the work in [6] presents a Round Robin test on the influence of different Additive Manufacturing technologies (e.g., FFF, SLS, SLM, LCD), materials (e.g., PLA, ABS, polyamide or aluminum powder, photopolymer resin) and 3D printing devices. The analyses have been performed on the measured sound absorbing performance of porous samples designed with two different cellular structures. Different impedance tubes with variable diameters in different laboratories have been used. The study highlights compatible results. However, some discrepancies were reported, due to:

a) shape and surface imperfections, or microporosity, induced by the manufacturing process;
b) imperfect matching between tube and sample diameter;

c) different geometric details present at the circular edges of the samples, based on cellular design and sample diameter.

These previous studies have focused on porous sound absorbing materials composed of 3D printed lattice micro-geometry with specific thicknesses. To the best knowledge of the authors no previous investigation was found on 3D printed materials combing sound absorbing and diffusing properties, i.e., "hybrid" acoustic materials (HAMs). They are generated by combining a porous layer designed for absorption with surface irregularities that promote sound diffusion [7].

In the present study, samples with surface irregularities in the form of variable patterned stepped thickness have been considered. The selected cylindrical samples are a representative portion of an entire rectangular area of an irregular surface pattern.

This contribution focuses on the sound absorbing performance of 3D printed HAMs and explores the variation of the sound absorption coefficient when different degrees of irregular steps are introduced on a cellular 3D printed foam. To this aim, two samples with the same top configuration but with different foam thicknesses have been tested and compared (Figure 1, a). Moreover, a comparison on the two samples foam properties has been investigated to highlight any possible differences in the 3D printing process.

2. METHODS

The tested samples (C1 and C2) are composed by a foam core and an irregular structure on top of it forming three steps oftop coating indicated as 3T in the denominations of the samples. Sample C1 has an overall thickness of 70 mm (C1_3T_70) and sample C2 of 50 mm (C2_3T_50). The foam core is a customized structure based on a gyroid pattern. The top surfaces were printed as a compact layer (infill pattern of 100% density) of 2 mm thickness. The testing specimens were fabricated in a dual-nozzle Raise3D Pro2 Plus FFF unit, employing a commercial thermoplastic filament (Ø 1.75 mm) colorFabb Light-Weight PLA (LW PLA) Natural. Pictures of the samples are shown in Figure 1, a. It should be noted that each top coating step has been indicated as 3T, 2T and T; the foam steps have been indicated as 3F, 2F and F. All the tested samples have been obtained by cutting each step progressively.

The measurements were performed on samples with a diameter of 35 mm using the impedance tube HW-ACT-TUBE (Siemens, Munich, Germany), equipped with two ¼'' flush-mounted GRAS 46BD (GRAS, Holte, Denmark) microphones. Figure 1, b shows two of the samples inside the impedance tube, C1_3T_70 and C1_F_27. The denomination of the samples shows for the first part C1 and C2 indicating the main sample, then the letters T (Top coating) and F (Foam) are used to indicate the upper surfaces configuration, and finally the thickness of the sample is included (_70, _50,_47 and 27 mm) The diameter of the samples could perfectly match the inner diameter of the tube, which limited any effects of the mismatch between these two dimensions.

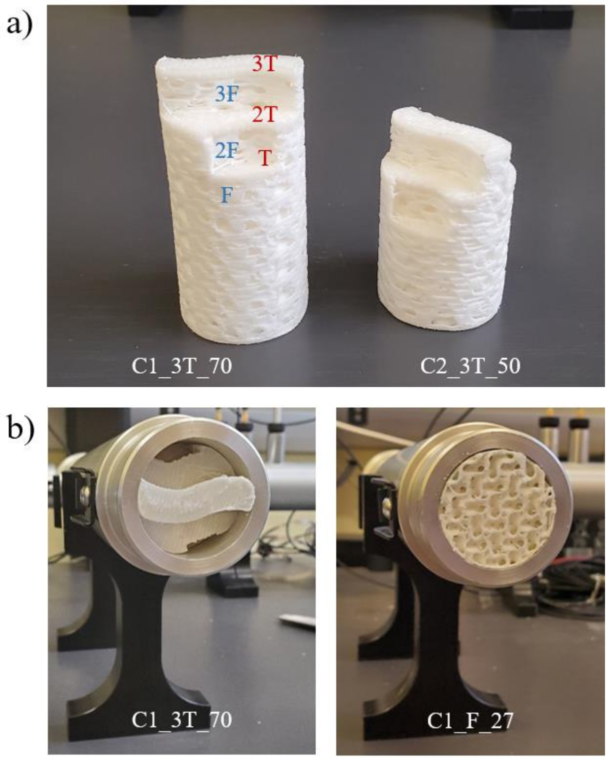

Figure 1. a) Tested samples C1 and C2, and b) impedance tube sample C1_3T_70 and C1_F_27 positioning.

The goal of the measurement campaign was to assess the effect of the top cut out surfaces and foam core on C1 and C2 samples and to compare the performance of the two samples. To this aim the original sample C was sectioned by removing using a coping saw (Figure 2):

a) the top coating surfaces: 3T (C1_3T_70 and C1_NT_70). This samples are presented in Figure 1, a;

b) the foam core of the 1st step (the upper one, C1_3T_70 and C1_3F_70; C2_3T_50 and C2_3F_50) and the 2nd one (the middle one, C2_2T_50 and C2_2F_50);
c) the effect of the sole foam (F) core was assessed considering a thickness of 47 mm (for C1_F_47) and of 27 mm (for C1_F_27 and C2_F_27).

The same procedure could not be performed on the 3rd step, given its the very limited dimensions (indicated as T in Figure 1, a).

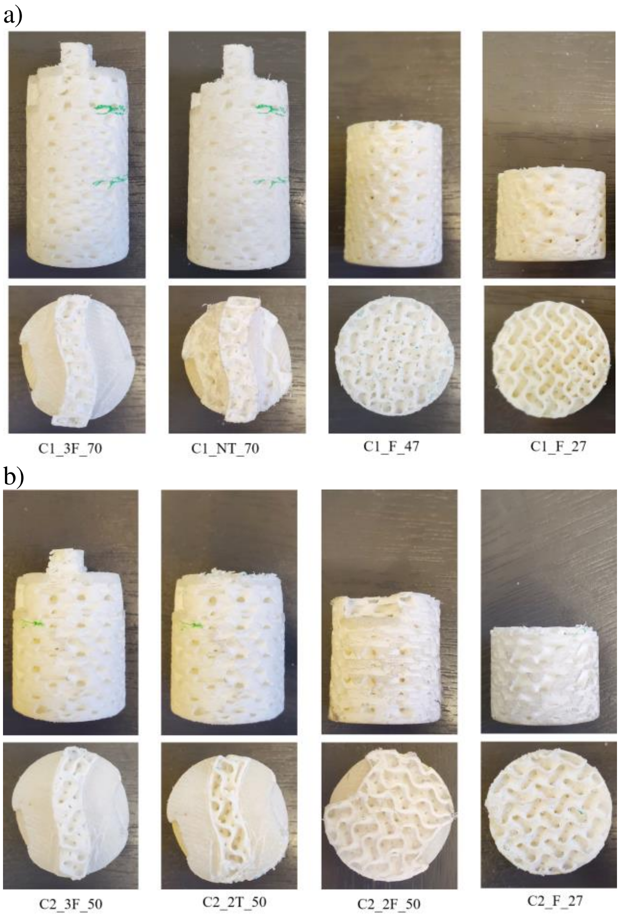

Figure 2. Configurations of the tested samples a) C1 configurations and b) C2 configurations.

3. RESULTS

The results of the measurements of the one third-octave bands sound absorption coefficients have been presented in Figures 3-5.

a) The overall effect of the top coating surfaces could be observed (Figure 3) by comparing the curves representing the samples C1_3T_70 and C1_NT_70. The sample without coating (C1_NT_70) shows a frequency shift from 800 Hz to 1000 Hz for the first maxima and from 2500 Hz to 3150 Hz for the second maxima, while the minima is preserved at 2000 Hz. Moreover, the first maxima of the C1_NT_70 results in lower values of sound absorption coefficient by ≈0.1; conversely, the second maxima results higher by the same amount compared to the C1_3T_70 one.

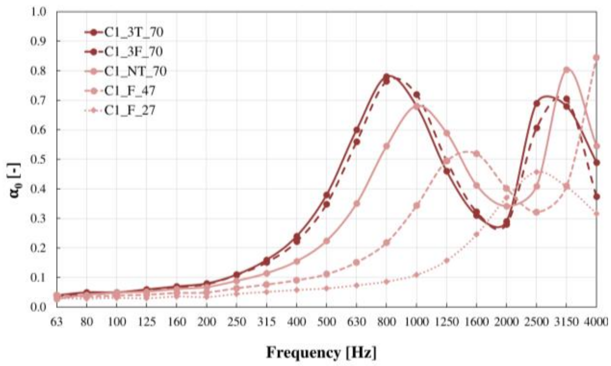

Figure 3. Sound absorption coefficient of the C1 samples.

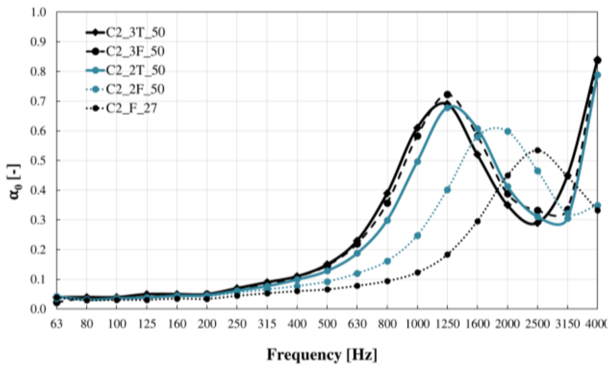

Figure 4. Sound absorption coefficient of the C2 samples.

b) The effect of the foam core of the 1st step (the upper one) could be observed by comparing samples C1_3T_70 with C1_3F_70 (Figure 3) and C2_3T_50 with C2_3F_50 (Figure 4). In both cases the differences between the two samples seem to be quite small and the effect of the first top coating layer results very limited. For the 2nd top coating step, i.e., the middle one, the effects could be observed by comparing C2_2T_50 with C2_2F_50 (Figure 4). In this case it is shown that the differences are more evident both as shift in the maxima and minima. Given this shift, the values of the sound absorption are lower up to 1600 Hz for the C2_2F_50 sample and result higher for the range 1600-3150 Hz. Moreover, comparing the curves presented in Figure 3 for C1_F_47 (i.e., pure foam with almost 50 mm thickness) and Figure 4 for C2_3T_50 and C2_3F_50, it can be observed that there is a slide shift in towards lower frequencies and an approximate increment from 0.5 to 0.7. Figure 5 depicts an extract of these three curves for an easier comparison.

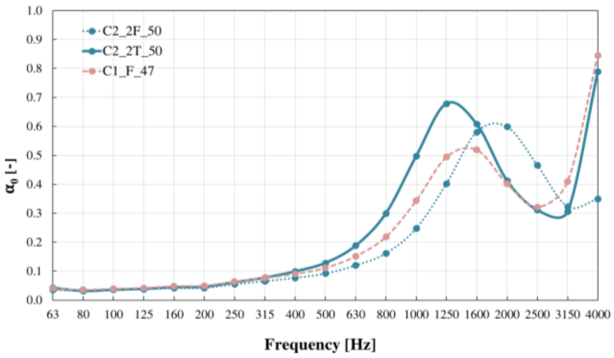

Figure 5. Sound absorption coefficient of C1 and C2 with similar foam thickness, i.e., C1_F_47, C2_3T_50 and C2_3F_50.

c) the effect of the sole foam (F) core was assessed considering a thickness of 47 mm (for C1) and of 27 mm (for C1 and C2). It can be observed (Figure 6) a shift in the sound absorption maxima from 1600 Hz to 2500 Hz when the sample thickness is reduced from 47 to 27 mm. The curves are very similar for both C1 and C2 27 mm samples presenting also the same frequency peak at 2500 Hz. However, the C1_F_27 sample peak presents slightly lower values. These differences might be due to the irregularities and dissimilarities in the 3D printed foam structure.

When considering the HAMs (C1_3T_70 and C2_3T_50), the peak values, due to the first frequency of resonance of the porous material (i.e. quarter-wavelength f_0 =c/4d, where c=343,1 m/s at 20°C and d equals the material thickness), are generally observed at 800 Hz, in the case of the 70 mm thick samples, and at 1250 Hz, in the case of the 50 mm thick ones. These frequencies are lower (by one or two one-third octave bands) than those expected from the f_0 formulation provided above (i.e., 1225 and 1715 Hz for the 70 mm and 50 mm thicknesses, respectively). This shift at lower frequencies is observed in a similar way when a coupling of perforated panels and Helmholtz resonators with porous materials is performed [7]. The peak values, due to the first frequency of resonance of the porous material when considering the foam core only are generally observed at 1600 Hz, in the case of the 47 mm thick samples, and at 2500 Hz, in the case of the 27 mm thick ones. These frequencies are lower (by one-third octave bands) than those expected from the f_0 formulation provided above (i.e., 1824 and 3175 Hz for the 70 mm and 50 mm thicknesses, respectively).

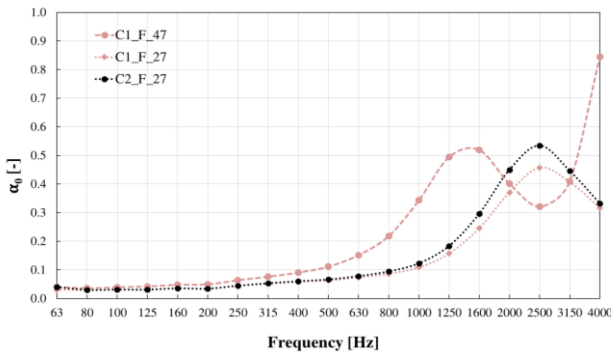

Figure 6. Sound absorption coefficient of the foam core with a thickness of 47 mm and 27 mm.

4. CONCLUSIONS

In the present study, 3D printed hybrid acoustic materials with surface irregularities in the form of variable patterned stepped thickness have been considered. The sound absorbing performance has been measured on two different thicknesses of 3D printed HAMs and the variation of the sound absorption coefficient when different degrees of irregular steps are introduced on a cellular 3D printed foam has been provided. The results highlight the benefits at lower frequencies due to the combination of top coating rigid layers with a foam layers. They also show possible variability of the sound absorption coefficient due to the 3D printing irregularities of the foam in samples with the same thickness.

Further investigations could be performed on other irregular configurations and also exploring the sound diffusive properties. Moreover, advanced simulation methods (e.g., FEM) could be used to investigate the design parameters in more systematic way.

5. ACKNOWLEDGMENTS

We thank Leonardo Catalano and Farid Jafari (Politecnico di Torino) and Efstratios Kroustis (BioG3D) for the technical support of the project.
The experimental activities presented in this paper were carried out as part of the H2020 project "iClimabuilt - Functional and advanced insulating and energy harvesting/storage materials across climate adaptive building envelopes" (Grant Agreement no. 952886).

6. REFERENCES

[1] E. Badino, L. Shtrepi, and A. Astolfi: "Performance-Based Design: A Brief Overview of the Opportunities and Limits in Current Practice," *Acoustics*, no. 2, pp. 246–278, **2020.** doi:10.3390/acoustics2020016.

[2] M. Vasina, K. Monkova, P. P. Monka, D. Kozak, and J. Tkac: "Study of the Sound Absorption Properties of 3D-Printed Open-Porous ABS Material Structures," *Polymers,* no. 12, 1062, **2020.** doi:10.3390/polym12051062.

[3] Z. Liu, J. Zhan, M. Fard, and J. L. Davy: "Acoustic Properties of Multilayer Sound Absorbers with a 3D Printed Micro-Perforated Panel," *Applied Acoustics,* no. 121, 25–32, **2017**. doi:10.1016/j.apacoust.2017.01.032.

[4] X. Cai, Q. Guo, G. Hu, and J. Yang: "Ultrathin Low-Frequency Sound Absorbing Panels Based on Coplanar Spiral Tubes or Coplanar Helmholtz Resonators," *Appl. Phys. Lett.,* no. 105, 121901, **2014**. doi:10.1063/1.4895617.

[5] R. Aslan, and O. Turan: "Gypsum-Based Sound Absorber Produced by 3D Printing Technology," *Applied Acoustics*, no. 161, 107162, **2020.** doi:10.1016/j.apacoust.2019.107162.

[6] T. G. Zieliński, K. C. Opiela, P. Pawłowski, N. Dauchez, T. Boutin, J. Kennedy, D. Trimble, H. Rice, B. Van Damme, G. Hannema, et al.: "Reproducibility of Sound-Absorbing Periodic Porous Materials Using Additive Manufacturing Technologies: Round Robin Study," *Additive Manufacturing*, no. 36, 101564, **2020.** doi:10.1016/j.addma.2020.101564.

[7] T. J. Cox, P. D'Antonio: "*Acoustic Absorbers and Diffusers: Theory, Design and Application*," 3rd ed.; Taylor & Francis: Abingdon-on-Thames, Oxfordshire United Kingdom, 2017; ISBN 978-0-367-65841-0.