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# Differences in sound absorption of samples with periodic porosity produced using various Additive Manufacturing Technologies

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## ABSTRACT

With a rapid development of modern Additive Manufacturing Technologies it seems inevitable that they will sooner or later serve for production of specific porous and meta-porous acoustic treatments. Moreover, these new technologies are already being used to manufacture original micro-geometric designs of sound absorbing media in order to test microstructure-based effects, models and hypothesis. In the view of these statements, this work reports differences in acoustic absorption measured for porous specimens which were produced from the same CAD-geometry model using several additive manufacturing technologies and 3D-printers. A specific periodic unit cell of open porosity was designed for the purpose. The samples were measured acoustically in the impedance tube and also subjected to a thorough microscopic survey in order to check their quality and look for the discrepancy reasons.

Keywords: Sound absorption, Additive Manufacturing Technologies

## 1. INTRODUCTION

Although standard materials for acoustic treatments are still very competitive, there is a need for novel acoustic materials and meta-materials which can meet specific requirements, or simply, are better optimised for particular noise conditions. One of the most important features of porous materials – responsible for their sound absorbing performance – is their micro-geometry. Tools for the microstructure-based modelling of sound absorbing media seem to be well-established now [1, 2, 3, 4] and they should allow for design of optimised periodic micro-geometries of novel acoustic treatments. On the other hand, there is still a need for further development and experimental validations, especially, in the case of the designed porous media with complex microstructures. Finally, technological issues linked with fabrication of such novel porous materials with designed morphology should be investigated. Modern Additive Manufacturing Technologies [5, 6, 7, 8] can be considered as suitable for prototyping of samples of novel materials and other numerically-designed material samples for experimental validation of the developed acoustic models and their implementations. However, the possible influence of each 3D-printing technology should be first investigated.

This work proposes two periodic geometries of open porosity, which can be 3D-printed (using various Additive Manufacturing Technologies) in the form of porous samples with the well-known (designed) morphology. The 3D-printed samples are measured for their acoustic absorption coefficient; the results are compared and discussed with respect to some specific features related to the manufacturing technologies.

## 2. PERIODIC POROSITY AND MANUFACTURING OF POROUS SAMPLES

### 2.1. Periodic porous geometry

Two cubic periodic porous cells were designed for the purpose of this research. In both cases, the periodic porosities are fully open and are composed of spherical pores linked with short cylindrical channels.

The first porous cell is very simple: it contains a single spherical pore which is linked with identical pores of the adjacent cells through very short (horizontal or vertical) channels of the same size. The pore diameter is $0.9L$ and the channel diameter is $0.4L$, where $L = 5$ mm is the size of cubic cell. This One-Pore Cell (OPC) is depicted in Figure 1(a) in two versions: the first one is with the pore centred inside the cube, and in the second one (which is periodically-shifted by $0.5L$ in the vertical direction) the pore centre is at the centre of top and bottom faces of the cubic cell. The latter cell version was set into a $6 \times 6 \times 12$ 3D-array, from which a cylindrical shape was cut out as depicted in Figure 1(b). The height of the cylinder is $12L = 60$ mm, whereas its diameter was set to (nearly) 29 mm, which is the nominal internal size of the dedicated impedance tubes used for acoustic measurements. In fact, the diameter was set to 28.9 mm, 28.8 mm, or 28.7 mm, depending on the 3D-printing device and technology used for sample fabrication so that each cylindrical sample fits well inside the impedance tube. In particular, in the case of metal samples the diameter was set to 28.8 mm and these samples could still be wrapped in tape to fit tightly inside the tube without scratching it.

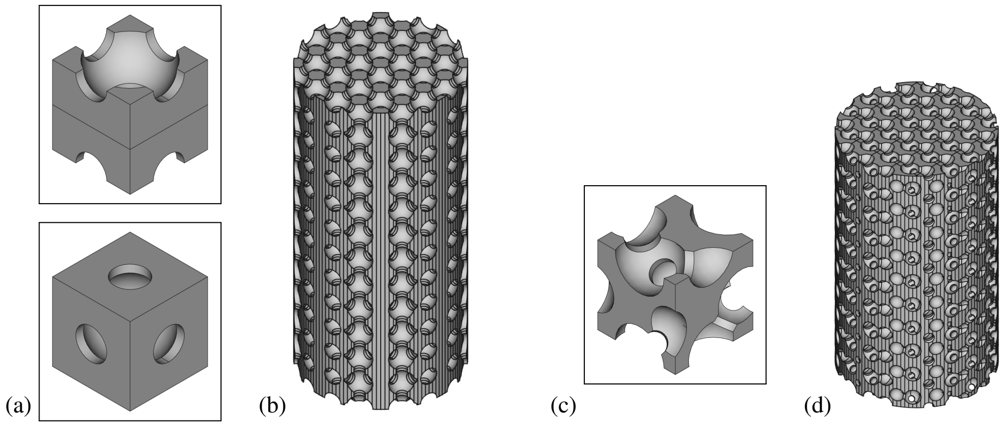


Figure 1. The geometry of periodic cells and the porous cylinders constructed from them: (a) the periodic cubic cell with a single spherical pore – the original and periodically shifted version (on top); (b) the cylindrical geometry for the One-Pore-Cell (OPC) sample; (c) the periodic cubic cell with four different spherical pores; (d) the cylindrical geometry for the Four-Pore-Cell (FPC) sample.

The second porous cubic cell is depicted in Figure 1(c). Its size is also set to $L = 5$ mm. The cell contains four pores of different diameters, namely, equal to $0.68L$, $0.60L$, $0.58L$, and $0.53L$. The pores are interlinked with short channels. Such porous geometry was obtained by modifying a periodic assembly of pores generated automatically by the algorithm described in [9]. The Four-Pore Cell (FPC) was set into a $6 \times 6 \times 10$ 3D-array, from which a cylindrical shape was cut out in the same way as in the case of the simpler cell, only now the length of cylinder is $10L = 50$ mm. The geometry of porous cylinder is shown in Figure 1(d).

From the cylindrical porous geometries – like the ones depicted in Figure 1(b,d) – STL files were generated and used by various slicer software dedicated to different 3D-printing devices which served for manufacturing of porous samples as discussed below.

### 2.2. 3D-printing technologies and 3D-printed samples

Five different Additive Manufacturing Technologies [5, 6] and six 3D-printing devices were used to fabricate the designed porous samples from different materials [8], namely:

**FDM:** Fused Deposition Modelling also known as Fused Filament Fabrication (FFF) with polymer Acrylonitrile butadiene styrene (ABS) filament as material with 3D-printers **(1)** *Zortrax M200* and **(2)** *FlashForge Creator PRO*;

**DMLS:** Direct Metal Laser Sintering of metal (aluminium) powder with 3D-printer **(3)** *EOSINT M280*;

**SLS:** Selective Laser Sintering of polymer powder with 3D-printer **(4)** *Sinterit Lisa* (only for an FPC sample);

**SLA:** Laser Stereolithography with epoxy resin as material and 3D-printer **(5)** *FormLabs Form2*;

**UV LCD:** Ultraviolet curing of epoxy resin using LCD matrix with 3D-printer **(6)** *Zortrax Inkspire* (only for an OPC sample).

10 porous samples were fabricated using these 3D-printers and the STL files of the geometries shown in Figure 1 and descried above, namely, 5 OPC samples and 5 FPC samples, because the UV LCD printer *Zortrax Inkspire* was used only for an OPC sample, while the SLS printer *Sinterit Lisa* was used only to manufacture one FPC sample.

The OPC samples are depicted in Figure 2 and also in Figure 3 where a magnified view of the top face of the high-quality SLA sample is also presented. All samples are cylindrical and they fit very well inside 29 mm impedance tubes, though the metal sample is wrapped in a tape to avoid scratching the tube. The height of all OPC samples is 60 mm.

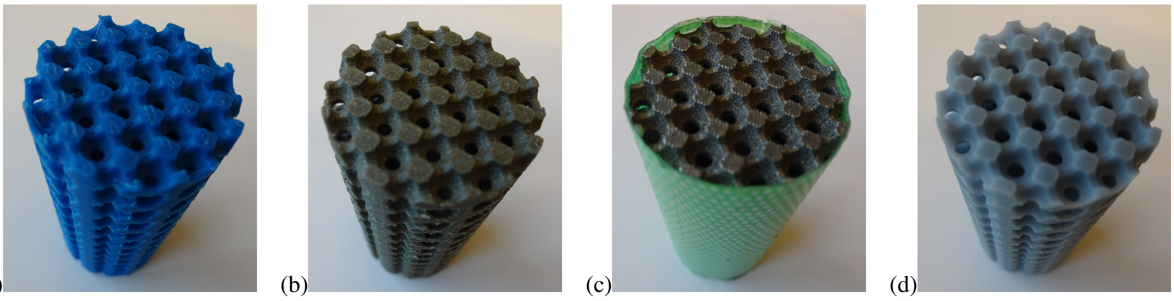
(a) (b) (c) (d)

Figure 2. OPC samples (height 60mm) for 29mm impedance tube, fabricated using various **Additive Manufacturing Technologies** and *3D-printers*: (a) **FDM** – *Zortrax M200*, (b) **FDM** – *FlashForge Creator PRO*, (c) **DMLS** – *EOSINT M280* (aluminium sample wrapped in tape), (d) **UV LCD** – *Zortrax Inkspire*.

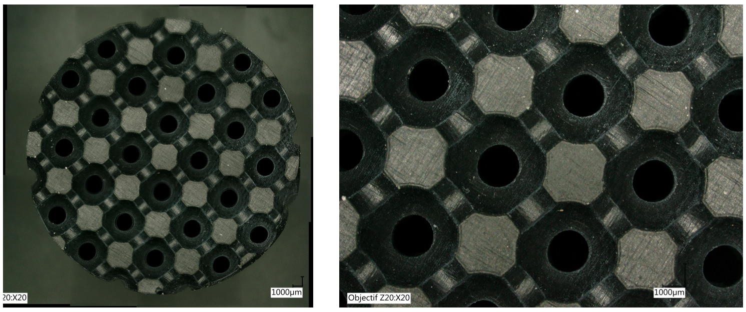


Figure 3. A polymer resin OPC sample (height 60mm) for 29mm impedance tube, fabricated using the **SLA** technology with *FormLabs Form2* 3D-printer: top face view and a zoom

The FPC samples are shown in Figures 4 and 5. Additionally, Figure 6 compares zoomed surfaces of two FPC samples manufactured with FDM technology, but using different devices (*Zortrax M200* and *FlashForge Creator PRO*). A magnified view of the top face of the FPC sample fabricated from epoxy resin using *FormLabs Form2* SLA-technology printer is shown in Figure 5. All FPC samples are in the form of 50 mm long cylinders and they fit very well inside 29 mm tubes, though again, the metal sample is wrapped in tape to protect the tube from scratching.

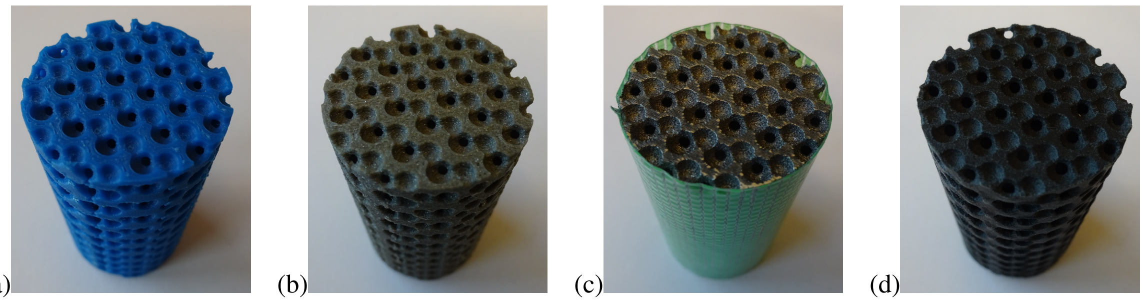
(a) (b) (c) (d)

Figure 4. FPC samples (height 50mm) for 29mm impedance tube, fabricated using various **Additive Manufacturing Technologies** and *3D-printers*: (a) **FDM** – *Zortrax M200*, (b) **FDM** – *FlashForge Creator PRO*, (c) **DMLS** – *EOSINT M280* (aluminium sample wrapped in tape), (d) **SLS** – *Sinterit Lisa*.

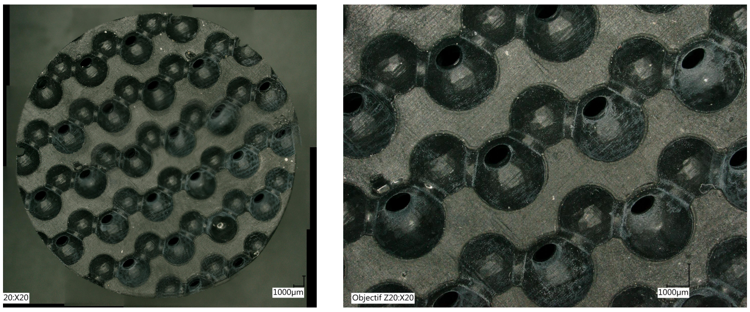


Figure 5. A polymer resin FPC sample (height 50mm) for 29mm impedance tube, fabricated using the **SLA** technology with *FormLabs Form2* 3D-printer: top face view and a zoom.

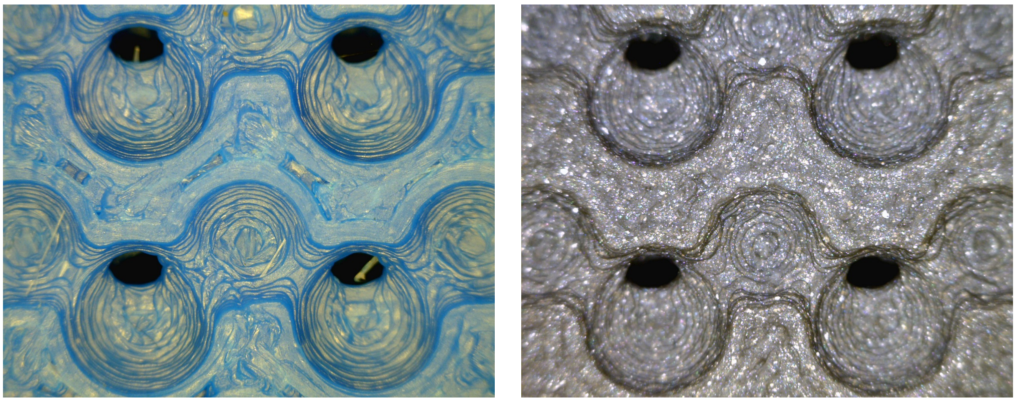

Figure 6. Comparison (zoom) of top faces of two FPC samples manufactured using the **FDM** technology but different 3D-printers: *Zortrax M200* (left) and *FlashForge Creator PRO* (right).

# 3. MEASUREMENTS OF SOUND ABSORPTION

## 3.1. Results for One-Pore-Cell samples

Sound absorption for all porous samples was measured in 29 mm impedance tubes (at 3 laboratories) in accordance with the Two-Microphone Transfer Function Method [10]. Figure 7 presents the results for 5 OPC samples in the frequency range reaching 6.4 kHz. The following observations can be reported.

- In general, the curves of the measured acoustic absorption coefficient are quite similar for all samples. In particular, three peaks in sound absorption are observed at about 1 kHz, 3.1 kHz, and 5.2 kHz.
- Nevertheless, some differences between the results from different samples are noticeable, especially, in the case of one of the FDM samples (the one 3D-printed with *Zortrax M200*) for which the absorption at the two first peaks and also between the peaks is slightly larger than for the other samples. One of the reasons may be a much rougher surface of this sample – see Figure 6 where it is compared with a smoother surface of the other FDM sample.
- The absorption curves for both resin samples, that is, the ones manufactured using SLA and UV LCD technologies, are very similar, in fact, nearly identical, although these samples were manufactured and measured independently at two different laboratories. For these samples the absorption at the peaks and between them is slightly lower than for the other samples, perhaps, because the surfaces of these samples are very smooth, see Figures 3 and 2(d).
- The "high-quality" FDM sample – which was 3D-printed with *FlashForge Creator PRO* after some laborious tests and trials with different ABS filaments and 3D-printing parameters – absorbs acoustic waves in a way similar to the smooth resin samples, though the absorption at the peaks is slightly higher for the FMD sample.
- At frequencies below 3.5 kHz, the absorption curve measured for the aluminium sample (*EOSINT M280*) is very similar to the result obtained for the "high-quality" FDM sample (*FlashForge Creator PRO*), however, at higher frequencies it tends to be closer to the absorption curve of the other FDM

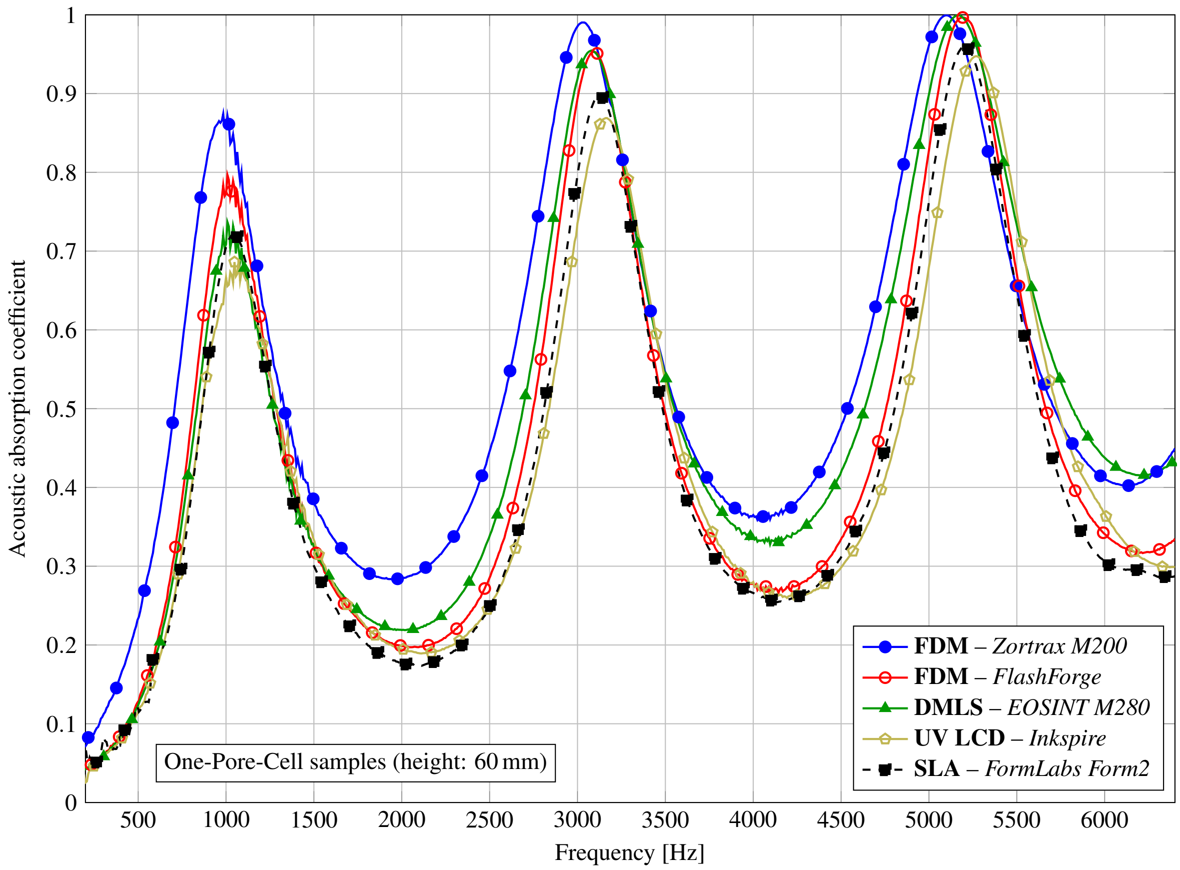


Figure 7. Sound absorption for 60 mm-long cylinders of porous periodic OPC samples

sample (*Zortrax M200*). The sintered metal surface is rather rough (in a specific way, quite different than the roughness of FMD samples), however, one should be aware of the fact that the absorption results measured for the metal sample may also be influenced by the soft wrapping tape.

### 3.2. Results for Four-Pore-Cell samples

Figure 8 compares the acoustic absorption coefficients measured for 5 FPC samples. These are the results of standard sound absorption measurements, that is, for the samples directly backed by a rigid wall (i.e., by a rigid piston or other rigid termination of an impedance tube). Additionally, for 4 FPC samples (SLS, SLA, and 2 FDM ones) the sound absorption was also measured in configurations with an air cavity between the back face of the sample and the backing rigid termination of the impedance tube. The results for the porous samples with the 20 mm air cavity are shown in Figure 9, while the absorption of the samples backed with the 40 mm air cavity are compared in Figure 10. The following is observed.

- The absorption curves are very similar in the whole frequency range below 4 kH (or 4.5 kHz) – for all FPC samples, except for the metal one which was wrapped in a soft tape (the curve for this sample is presented only in Figure 8). Even this absorption curve, however, is rather similar to the other curves at frequencies below 3 kHz.
- The discrepancies between the results obtained for different samples increase above 4.5 kHz, although even there some curves tend to be similar in a moderate way.
- In the considered frequency range (up to 6.4 kHz) there are four absorption peaks (the first two at about 800 Hz and 2.6 kHz) – for the measurements *without* backing air cavity. As expected, the presence of an air cavity shifts all peaks to lower frequencies, so that an additional (the fifth) peak appears below the frequency-range limit (see Figure 10).

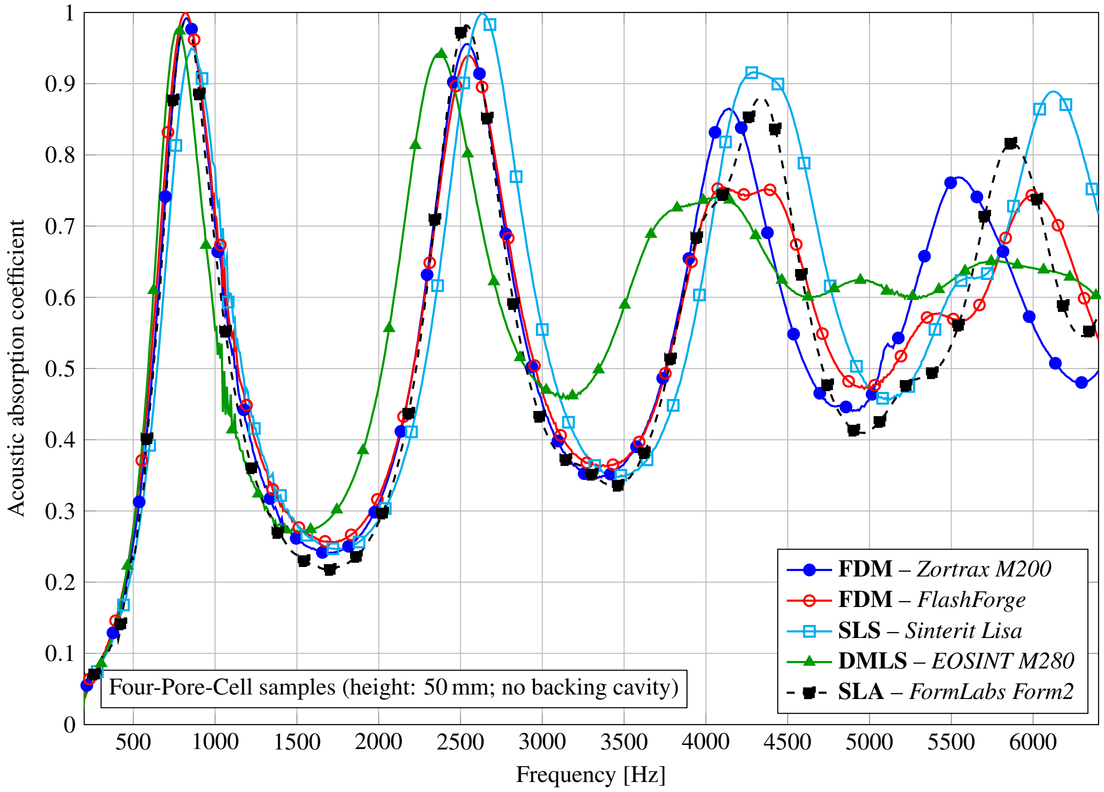


Figure 8. Sound absorption for 50 mm-long cylinders of porous periodic FPC samples backed by a rigid wall (i.e., no air cavity)

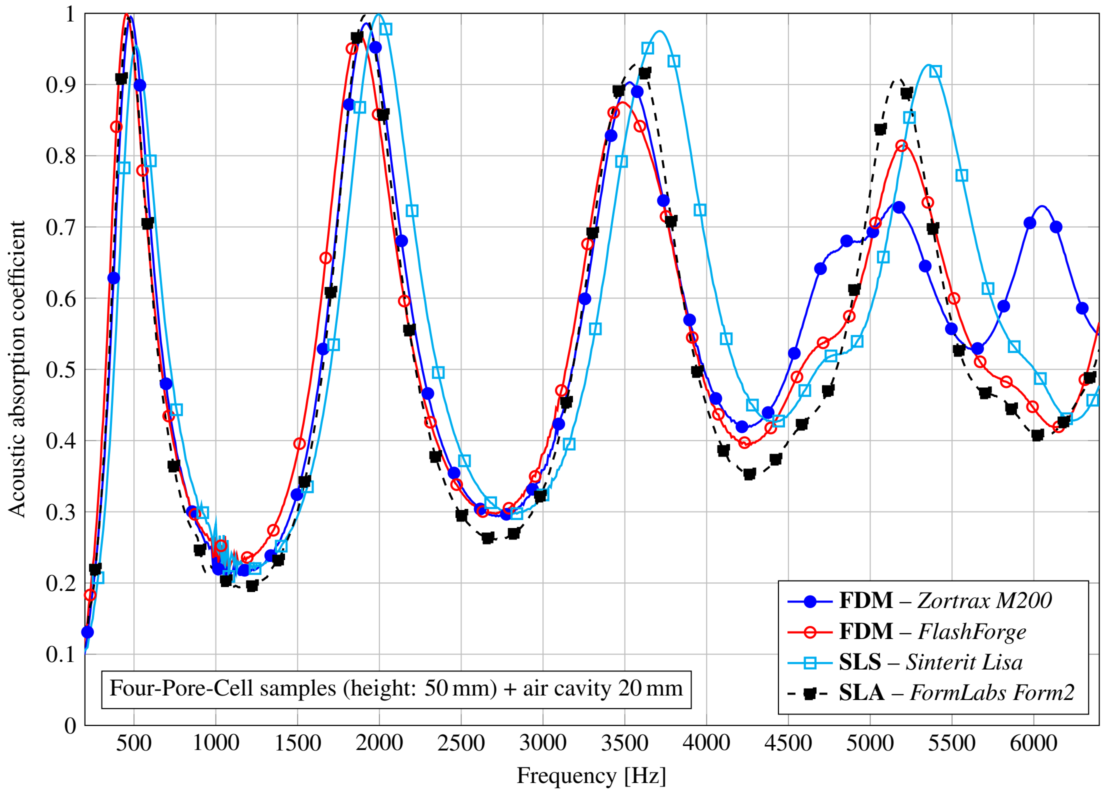


Figure 9. Sound absorption for 50 mm-long cylinders of porous periodic FPC samples backed with 20 mm air cavity (between a sample and the rigid wall)

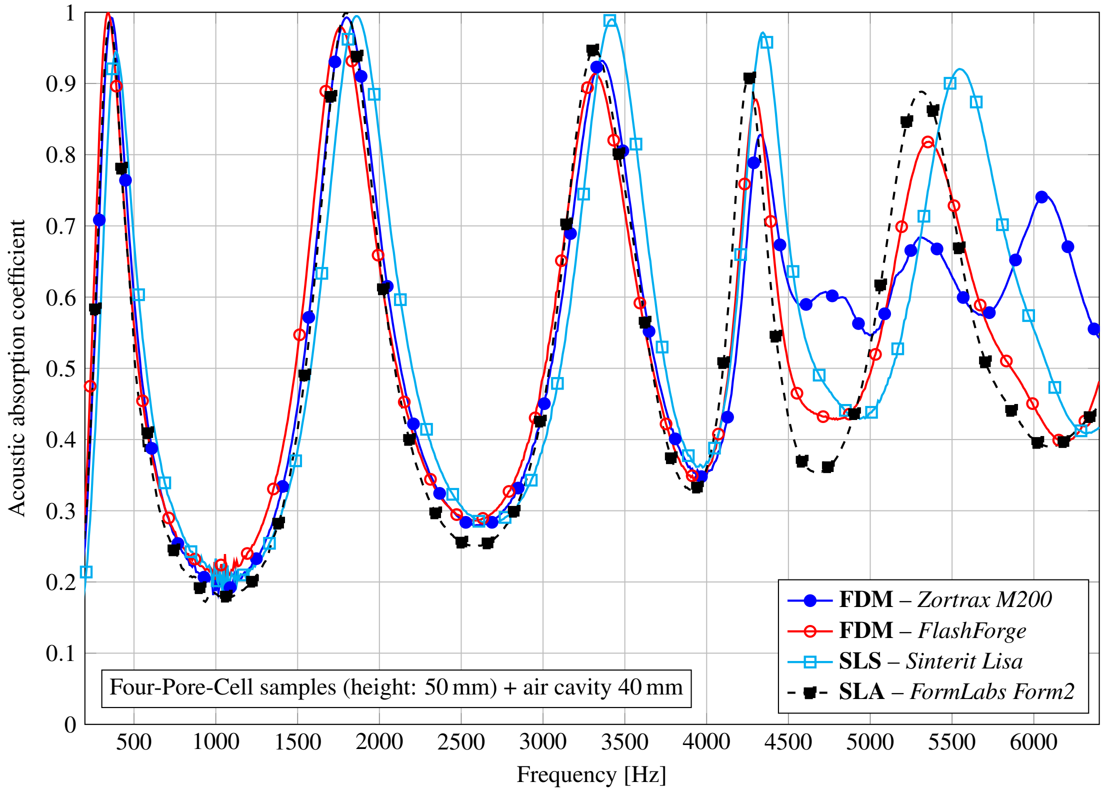


Figure 10. Sound absorption for 50 mm-long cylinders of porous periodic FPC samples backed with 40 mm air cavity (between a sample and the rigid wall)

## 4. FINAL REMARKS

- Although the samples were manufactured independently at different laboratories and by using various Additive Manufacturing Technologies, the measured sound absorption curves are similar or very similar for all OPC samples in the whole considered frequency-range (up to 6.4 kHz), and also for more morphologically complex FPC samples in the frequency range below 4.5 kHz.
- The corresponding results obtained for the epoxy resin samples (SLA and UV LCD), the "better-quality" FDM samples, and the SLS sample tend to be very similar to each other (i.e, with better agreement than to the other results), which can be related with the quality of these samples.
- The sound absorption measured for the FPC metal sample is significantly different above 3 kHz than the corresponding results for the resin or polymer samples. However, this can be caused by the soft wrapping tape which was applied for the metal sample to protect the impedance tube from scratching.

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