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CONSIDERATIONS ON THE MANUFACTURING OF SOUND ABSORBING MPP SAMPLES FOR THE IMPEDANCE TUBE

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Abstract: *In the present paper some aspects of the manufacturing of microperforated panels (MPPs) for creating MPP samples are presented. MPP samples are used in impedance tubes to asses and improve the sound absorption coefficient of various sound absorbing structures. MPP materials like Aluminum, polycarbonate, plywood and cardboard are under observation. They can be used with sound absorbing materials of various thickness and perforations of different patterns and sub-millimeter holes in diameter. Laser cutting and drilling, laser engraving and drilling and 3D printing samples were manufactured and shown by images. The influence of the deviations from the cylindrical shape on the absorption coefficient will be assessed in the future.*

Key words: *MPP sample manufacturing, impedance tube, sound absorption coefficient*

1. INTRODUCTION

Micro-perforated panels (MPP) are known for their sound absorbing qualities, being an alternative to the fibrous or porous sound absorbing materials like mineral wool, glass or polyester fibers. This is a different class from previous developed classical panels with perforation diameter of couple millimeters to centimeters. MPPs were first developed by Maa, [6], [7], [8], including the mathematical model to predict the MPP acoustic impedance and the sound absorption coefficient. A MPP consists of a thin panel of about one millimeter in thickness or less and it has micro-perforations of sub-millimeter holes in diameter (typically 0.05 to 0.8 mm) displayed in different patterns (matrix, triangular) within the perimeter of the panel. The sound absorption is based on Helmholtz resonance mechanism.

Micro-perforated panels can be used to create different structures to achieve sound attenuation at various frequencies. MPPs with ultra-micro perforations of diameter less than 100 μm (ultra-MPPs) may have great potential to become a wideband sound absorber in high frequency range.

The sound attenuation or the sound absorption coefficient at a given frequency can be determined by using the impedance tube and the calculations defined in ISO 10534-1 and 10534-2.

The diameter of the micro-perforations, the distance between micro-perforations, thickness of the MPP and the length of the cavity of air behind the MPP are contributing factors in influencing the value of the sound absorption coefficient at the specific frequency of the incident sound.

Different micro-perforated panel absorbers can be categorized in terms of the coupling mode as single or conventional MPP absorbers, serial-coupled MPP absorbers, parallel-coupled MPP absorbers and serial-parallel-coupled MPP absorbers, studied by different authors, [3], [9], [10], [11], [12], [13]. Several layouts of the MPPs are presented in the sequel.

A single cavity MPP absorber is the simplest MPP structure that can be made and consists of one MPP and a cavity of air of a given length D

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between the MPP and a rigid termination, as presented in Figure 1, [3].

A serial-coupled MPP absorber is a type of MPP absorber that consists of two MPPs placed one after the other with a cavity of air of length D1 between them and a cavity of air of length D2 between the MPP2 and a rigid termination, as presented in Figure 2, [3].

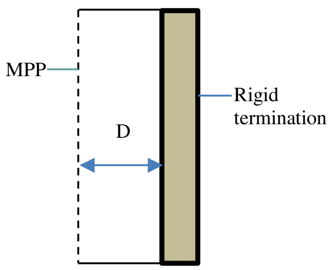

Fig. 1. Schematic of a single MPP absorber

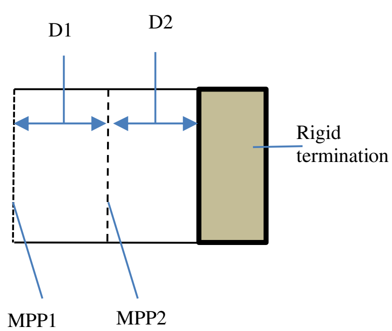

Fig. 2. Schematic of a serial-coupled MPP absorber

A parallel-coupled MPP absorber or an inhomogenous MPP [9], is a type of MPP absorber that consists of two MPPs placed in parallel one with the other and both with the same cavity of air of length D between them and a rigid termination, as presented in Figure 3, [3].

In Figure 4 an example of a parallel-coupled MPP absorber is presented, [9].

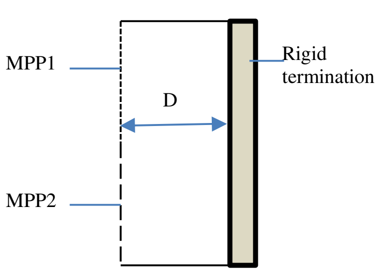

Fig. 3. Schematic of a parallel-coupled MPP absorber

A serial-parallel-coupled MPP absorber is a type of MPP absorber that consists of two MPP absorbers placed in parallel one with the other: one absorber that has a single MPP (MPP3) that is backed by a cavity of air (with length D3) and a serial-coupled absorber that is formed by MPP1, MPP2 and the cavities of air with the lengths D1 and D2, as presented in Figure 5, [3].

Fig. 4. Inhomogenous MPP

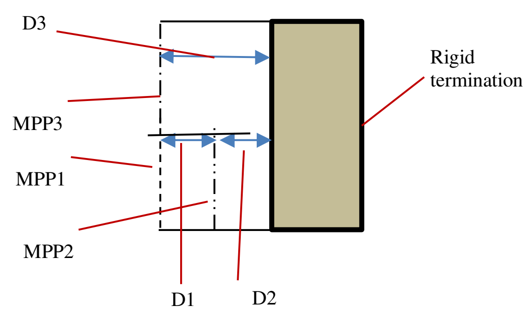

Fig. 5. Schematic of a serial-parallel-coupled MPP absorber [3]

The normal absorption coefficient for the mentioned MPPs is developed based on the electric acoustic analogy.

The fabrication methods of MPPs include CNC milling, laser drilling, micro-electro-mechanical systems (MEMS) technology, 3D printing and others. CNC milling of paperboard (cardboard) having the mass per area above 250 g/m^2 and thickness over 0.03mm is at low cost.

Similar situation is for PET, PVC where the holes result more regular with sharp edges which is not the case to the cardboard MPPs [17].

When the fabrication by using machining or CNC milling is not possible because of the small diameter of the micro perforations, the MEMS technology is to be chosen. This technology have great potential to create MPPs with a wideband frequency sound absorber in high frequency range.

Laser drilling apart from laser cutting or laser engraving is offering precision of the cylindrical hole, a diameter starting from 0.05mm, allowing good laser beam manipulation and a depth to diameter ratio up to or even greater than 10:1 [20].

An alternative approach to manufacture microperforated panels is the application of additive manufacturing or 3D printing technology. Sailesh et al. [14] explored the Fused Filament Fabrication (FFF) 3D printing based technology to fabricate micro-perforated panels with circular perforations having six different types of cross-section variations. The material used is Poly Lactic Acid (PLA) which is a bio-degradable material.

In the sequel, considerations on some of the manufacturing processes for MPP samples for impedance tube are presented.

2. FABRICATION OF MPP SAMPLES

The micro-perforated holes on the MPP surface are treated as thin cylindrical tubes when computing the impedance of the MPP. The length of the tubes is much shorter comparing to the wavelength of the sound absorbed. In Table 1, MPP samples with a thickness (t) of 1 mm, with matrix arrangement (samples 1M, 2M, 6M) and triangular arrangement at 60° between two micro-perforations in two rows (samples 1T, 2T, 6T) arrangements of the micro-perforations of different diameters (d) and different distances between the geometric centers of two adjacent micro-perforations (b) are presented, similar with samples in [4], [5], [13].

In the present paper MPP samples were made using several manufacturing processes: laser cutting, laser cutting with drilling, drilling and 3D printing.

2.1 Laser cutting and drilling

Samples with characteristics presented in Table 1 were made by using Amada LC 2415 Alpha III laser cutting machine with FANUC controller at a sample diameter of 104 mm (one set) and samples of 99.2mm diameter (a second set) from a sheet of aluminum with thickness of 1 mm (for two slightly different impedance tube diameters). The micro-perforations were made at smaller diameters (1M and 1T at 0,3 mm, 2M and 2T at 0,6 mm; 6M and 6T at 0,8 mm), then enlarged at the diameters from Table 1 by using a proper drill. The diameter of the sample is 99,2 mm in order to fit the impedance tube inner diameter [4].

Table 1

Geometric parameters of samples

Sample	Thickness t [mm]	Diameter d [mm]	Distance b [mm]
1M	1	0,5	3
1T			
2M		0,8	6
2T			
6M		1	8,8
6T			

In Figure 6 sample 6M made by using the process described above is presented.

Fig. 6. Sample 6M , Aluminum, sheet

In Figure 7 a micro-perforation of sample 6M captured with PG 2000 camera at 7x magnification is presented.

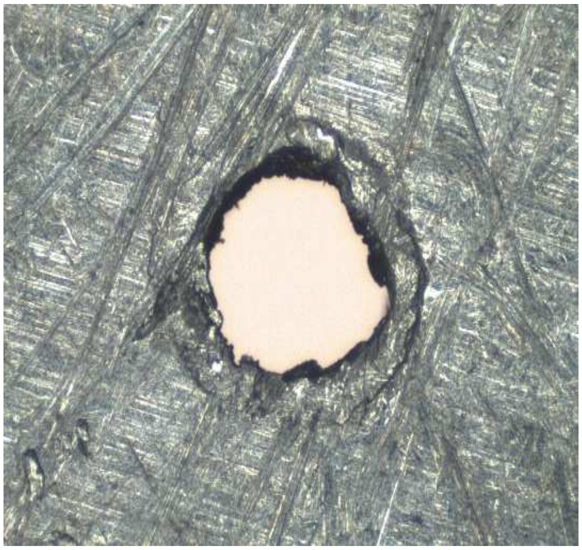

Fig. 7. Micro-perforation of sample 6M using laser cutting and drilling, Aluminum sheet

2.2 Laser engraving

In Figure 8 sample 1M made from plywood with a thickness of 3 mm made by using a laser engraving machine is presented.

Fig. 8. Sample 1M made from plywood

In Figure 9 a micro-perforation of sample 1M made from plywood with 3 mm thickness captured with PG 2000 camera at 7x magnification is presented.

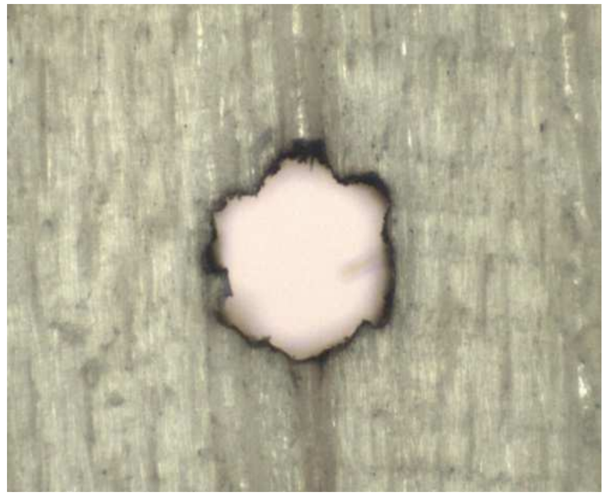

Fig. 9. Micro-perforation of sample 1M made from plywood with thickness of 3 mm using laser engraving

In Figure 10 a micro-perforated panel made from polycarbonate with a thickness of 1 mm, micro-perforations with diameter of 0.5 mm and the distance between micro-perforations of 3 mm is presented. The sample was made using Golden Laser engraver with laser power 60 W.

In Figure 11 a micro-perforation of sample 1M made from polycarbonate (PC) sheet with 1 mm thickness captured with PG 2000 camera at 7x magnification is presented.

Fig. 10. Sample 1M made from polycarbonate with thickness of 1 mm

Fig. 11. Micro-perforation of sample 1M made from PC with thickness of 1 mm using laser engraver

In Figure 12, sample 1M made from polycarbonate specially designed to be cut by a laser engraver is presented. It was made by using GoldenLaser engraver with laser power of 93 W.

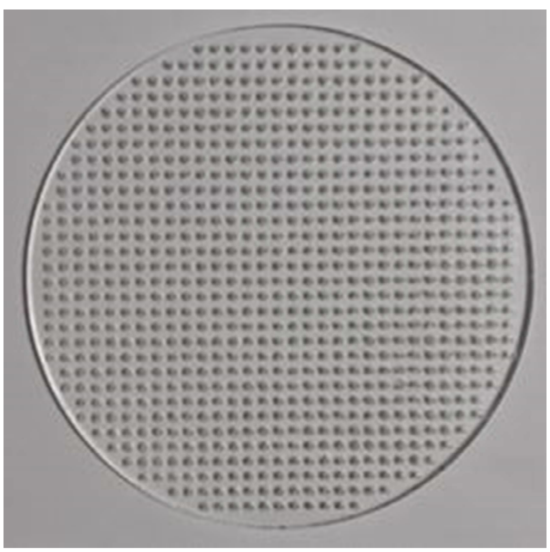

Fig. 12. Sample 1M made from laser polycarbonate with thickness of 3 mm

In Figure 13 a micro-perforation of sample 1M made from polycarbonate with thickness of 3 mm captured with PG 2000 camera at 7x magnification is presented.

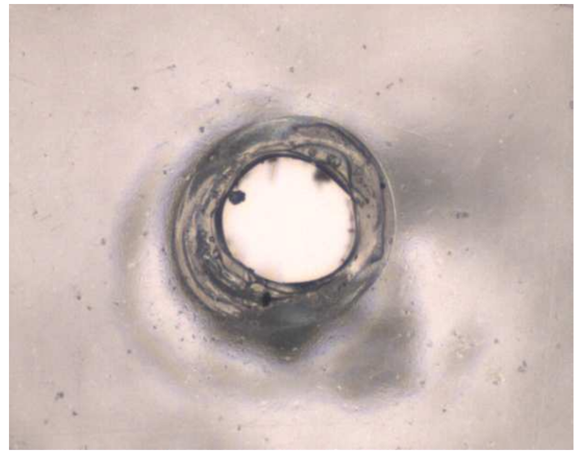

Fig. 13. Micro-perforation of sample 1M made from polycarbonate with thickness of 3 mm

2.3 Drilling

In Figure 14, sample 2M made from cardboard of a cover of address agenda with a thickness of 2.2 mm is presented.

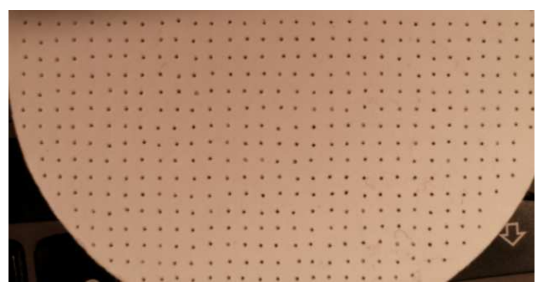

Fig. 14. Sample 2M made from cardboard with thickness of 2.2 mm

In Figure 15 a close-up of the micro-perforations of sample 2M is presented.

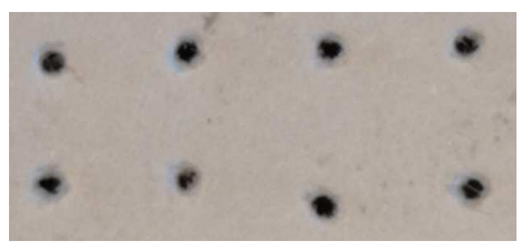

Fig. 15. Close-up of micro-perforations of cardboard sample 2M

2.4 3D Printing

Additive manufacturing or 3D printing represents an alternative technology to build structures layer-by-layer using computer-aided design. It can produce easily any shape, and overcomes conventional manufacturing limitations.

Liu et al. [2], has been proposed an easy way of producing MPPs. In their research was investigated the acoustic absorption capability of a multilayer micro-perforated panel whose front layer is produced applying stereolithography (SLA), a 3D printing based technology.

The manufacturing process applied in this study is Multijet Printing (MJP), also known as Material Jetting (MJ) which is an inkjet printing process that uses piezo printhead technology to deposit photocurable plastic materials, layer-by-layer. MJP deposits droplets of photoreactive material that solidify when subjected to ultraviolet (UV) light.

The micro-perforated panel part has been designed by using a computer aided design software. The thickness of MPP is $t = 1\ mm$, the outer diameter is $\mathrm{D} = 78\ \mathrm{mm}$, the hole diameter is $\mathrm{d} = 0.6\ \mathrm{mm}$ and the hole spacing is $\mathrm{b} = 5\ \mathrm{mm}$.

After designing, a Standard Triangle Language (STL) file format is uploaded into the 3D printing machine, a standard commercial ProJet MJP 2500 Plus printer. The uploaded file is optimized by the 3D Sprint, an exclusive software used for managing the additive manufacturing process. This software slices the solid part into layers which are then printed on top of each other onto a flat platform.

The part material used for printing is an ultraviolet curable plastic named Visijet M2R-CL. The mechanical properties of this material are presented in Table 2.

Table 2

Mechanical Properties of Visijet M2R-CL material

Tensile Modulus (MPa)	Tensile Strength (MPa)	Elongation at Break (%)	Density (g/ccm)
1500-2000	35-45	20-30	1.16

The complete printed part is consisting of two materials: part material and support material. The part is adhered to the flat platform by means of the support material, which is a wax based material called VisiJet M2 SUP used to fill voids and other non-freestanding features. UV lamps flashes to solidify materials creating a fully cured plastic parts.

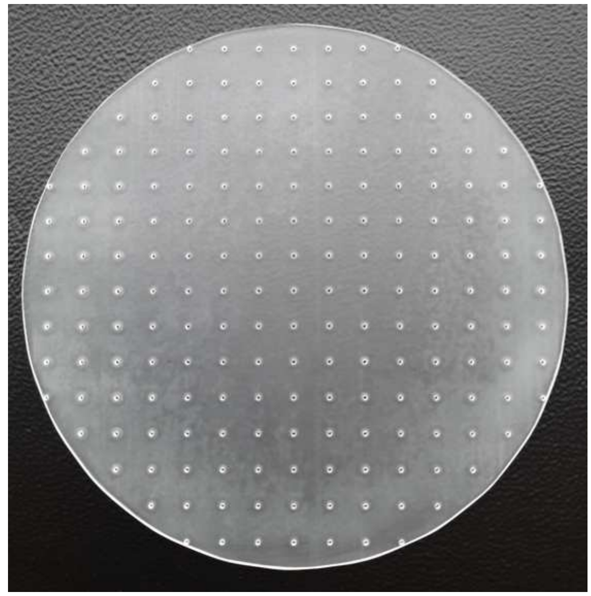

Fig. 16. The 3D printed MPP sample

After printing process there are some post processing steps that must be followed in order to ensure a successful and usable part. The first step is to place the build plate with part attached in a freezer for a few minutes; this cool the parts and will enable the part to separate from the build place. Once part has been removed, the support material needs to be removed from the part; this can be done in MJP Easy Clean system by using a hands-free process.

The printed micro-perforated panel are presented in the Figure 16 and 17, where can be seen that the perforations are not perfectly circular in shape.

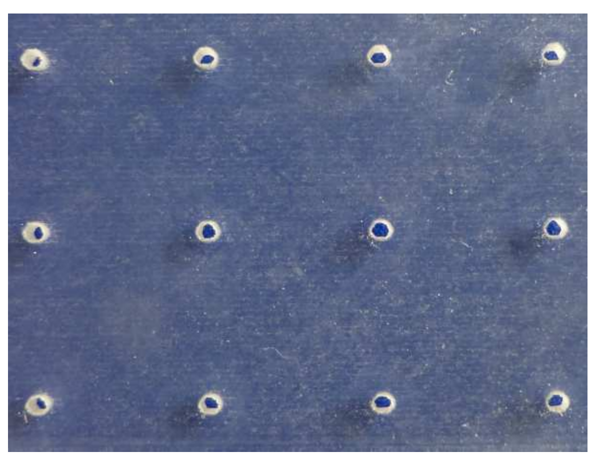

Fig. 17. The perforations of 3D printed MPP sample

3. CONCLUSION

MPPs from diverse materials like Aluminum, polycarbonate, plywood and cardboard and thickness of one to a couple millimeters were manufactured by using several manufacturing processes.

Fabrication of metallic MPPs could be costly and difficult to realize because of the holes small size (sub-millimeter). Micro-perforation drilling on Aluminum is acceptable (Fig.7).

For the MPP made of plywood with laser engraving, the perforation quality is acceptable, too (Fig 9). The micro-perforations on the specially designed to be cut by a laser engraver polycarbonate resulted of good quality in terms of the deviation from a cylindrical surface.

For the cardboard MPP, the perforations with drilling (Fig. 15) are obtained without problems in terms of the drill integrity and the perforation quality is acceptable. The perforation wall unevenness may improve the sound absorption coefficient.

The advanced three dimensional printing technique, called Multijet Printing, was introduced to manufacture MPP for acoustic absorption. The feasibility of using 3D printing process and curable plastic material to produce MPP at a relatively low prototype cost was presented, as well.

The measurement of sound absorption coefficient of mentioned MPP samples is under observation in terms of variations from cylindrical shape coming from fabrication process. These MPP samples are used with an air layer and in combination with fibrous materials and air layers in order to design sound absorbing structures that cover specific needs.

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4. REFERENCES

[1] Liu, J., *Estimation of effective parameters for micro perforated panel absorbers and applications*, Applied Acoustics 75 (2014).

[2] Liu, Z., *Acoustic properties of multilayer sound absorbers with a 3D printed micro perforated panel*, Applied Acoustics 121 (2017).

[3] Lu, C.H., *Comparison analysis and optimization of composite micro-perforated absorbers in sound absorption bandwidth*, Acoustics Australia (2018) 46:305-315.

[4] Lupea, I., *Sound absorption coefficient measurement set-up by using Labview and a simple impedance tube*, Acta Technica Napocensis, Series: Applied Mathematics, Mechanics, and Engineering, Vol. 62, Issue IV, November, 2019

[5] Lupea, I., Stremtan, A., *Considerations on the acoustic panel absorber,* Acta Technica Napocensis, Vol.56, 2013.

[6] Maa, D.Y., *Theory and design of micro perforated sound absorbing constructions*, Sci. Sin., 17, 55–71 ,1975 .

[7] Maa, D.Y., *Microperforated panel wideband absorber*, Noise Control Eng. J., 29, 77–84, 1987.

[8] Maa, D.Y., *Potential of microperforated panel absorber*, J. Acoust. Soc. Am., 104, 2861–2866, 1998.

[9] Mosa, A. I., *Theoretical model of absorption coefficient of an inhomogeneous MPP absorber with multi-cavity depths*, Applied Acoustics 146, pp.409–419, 2019.

[10] Qian, Y., J., *Investigation on micro-perforated panel absorber with ultra-micro perforations*, Applied Acoustics 74 , 2013.

[11] Qian, Y., J., *A note on the fabrication methods of flexible ultra-micro-perforated panels*, Applied Acoustics 90 , pp. 138–142, 2015.

[12] Qian, Y., J., *Pilot study on wideband sound absorber obtained by adopting a serial-parallel coupling manner*, Applied Acoustics 124 , 2017.

[13] Stremţan, A., Garai, M., Lupea, I., *Micro-perforated panels and sound absorption*, Acta Technica Napocensis, Series: Applied

Math. and Mechanics, Vol. 55, Issue III, 2012.

[14] Sailesh, R., Yuvaraj, L., Pitchaimani, J., Doddamani, M., Chinnapandi, L.B.M., *Acoustic behaviour of 3D printed bio-degradable micro-perforated panels with varying perforation cross-sections,* Applied Acoustics, November 2020.

[15] Tayong, R., *On the variations of acoustic absorption peak with flow velocity in Micro-Perforated Panels at high level of excitation*, The Journal of the Acoustical Society of America 127(5):2875-82 , May 2010.

[16] Toyoda, M., *Prediction of micro-perforated panel absorbers using the finite-difference time-domain method*, Wave Motion , 2019.

[17] Xie, D., et al*., Flexible micro-perforated panels prepared by CNC machining*, IOP Conf. Ser.: Earth Env. Sci. 358 042013, 2019.

[18] SR EN ISO 10534-1:2002 *Acoustics. Determination of sound absorption coefficient and impedance in impedance tubes. Part 1: Method using standing wave ratio.*

[19] ISO 10534-2 - *Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes. Part 2: Transfer-function method.*

[20] https://www.spilasers.com/application-drilling /laser-drilling-metal/

Metode de manufacturare a mostrelor MPP pentru măsurare absorbţiei acustice cu tubul de impedanţă

Rezumat: *În prezenta lucrare sunt prezentate câteva mostre de panouri micro-perforate (MPP) confecţionate din aluminiu, policarbonat, placaj şi carton. Acestea sunt folosite pentru masurarea coeficientului de absorbţie sonoră cu tubul de impedanţă. Micro-perforaţiile sunt realizare prin găurire cu laser şi/sau burghiere cât şi prin printare 3D. Cilindricitatea perforaţiilor şi netezimea pereţilor acestora sunt acceptabile si dependente de metoda de fabricaţie, putând fi îmbunatăţite. Se pune de asemenea problema exploatării prezenţei bavurilor după gaurire pentru creşterea absorbţiei acustice, aspect care va fi observant în viitor prin măsurare. Mostrele confecţionate în combinaţie cu straturi de materiale fibroase şi de aer vor fi folosite pentru proiectarea unor structuri fonoabsorbante cu un profil dorit al variaţiei coeficientului de absorbţie cu frecvenţa.*

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