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EFFECT OF THE INFILL PATTERN ON SOUND ABSORPTION PROPERTIES AND SOME MECHANICAL PROPERTIES OF 3D PRINTED PARTS

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Abstract: *3D printing and eco materials have a particularly wide applicability in many fields and one of these is custom sound-absorbing panels. The architecture of the voids and the infill value or the infill shape has a major influence on the sound-absorbing properties (coefficient α). In this paper, four types of void architectures are studied and three shapes of the infill type using polylactic acid as material and Filament Fused Fabrication technology with 60% infill value. Preliminary best results were obtained for cubic infill with α = 66% at 1000 Hz. The aim is to increase the α value by at least 15% and find the best combination and results, and, to determine the resistance to bending and compression.*

Key words: *3D printing, sound-absorbing panels, α coefficient, eco-materials, polylactic acid.*

1. INTRODUCTION

3D printing is a process used for several decades in industry, where it is also called "rapid prototyping" or RP. This technology appeared in the 1980s, initially being used by companies with massive budgets, such as those in the aerospace industry, or by Formula 1 teams. It was based on a 3D CAD model and was advertised as a "magical process", involving unknown sources such as UV and photosensitive polymers.

This technology today can produce very complex 3D structures with very little or no human input.

Clearly the rapid prototyping activity was not new: even a designer could create the physical 3D model with his hands (based on 2D drawings) faster than any RP system.

Frequently, the application of rapid prototyping technologies in different phases of product development causes an increase in global launch costs. This situation is accepted by decision-makers because:

- confers the advantage of advancing the launch dates and quick installation on the market with the possibility of recovering the investment from the additional benefits achieved.
- the application of these technologies allows the experimentation of the constructive solutions of the designed technological equipment, their validation or, if necessary, their improvement before the necessary changes cause exaggerated increases in the costs of making the final tools.

Additive manufacturing (AM) is a generic name to describe technologies that build 3D objects by adding successive layers of material, whether the material is plastic, metal, concrete or even human tissue [1 - 4].

Through additive manufacturing directly from CAD drawing, the operations and equipment necessary to obtain the devices by classical methods are thus eliminated, the reduction of the manufacturing time of the landmarks, high precision and the replacement/adjustment of the new devices in a much shorter time, which can be translated by higher productivity.

Much research has been reported in the specialized literature regarding the influence of various factors that influence the physical and mechanical properties of 3D printed parts [5, 6], or the thickness, the shape of the inner voids, the value of the infill and so on, depending on the final application [7].

Because noise pollution is a harmful factor that requires improvement measures in terms of the geometric shape of the panels but also the materials, specially designed to have the highest sound-absorbing properties.

Thus, the applicability of AM in this specific field is totally justified by the fact that geometric shapes, no matter how complex, can be obtained under conditions of high effectiveness.

From the study of specialized references, a lot of research is focused on obtaining new materials and on the development of new geometric models obtained through 3D printing [8 - 12].

One factor that influences the sound-absorbing properties is the shape and density of the infill, a fact that has been researched quite extensively [13 – 16].

Another factor that decisively influences these properties is the application angle of the perforations [17, 18], a fact also observed and proven by the authors of the present study.

The field of 3D printing has experienced remarkable growth across various industries, including hobby modeling, advanced medicine, automotive manufacturing, and aerospace engineering [1, 4, 19-21].

Among the different 3D printing technologies available, Filament Fused Fabrication (FFF) using polylactic acid (PLA) material has emerged as the most accessible option in terms of price, quality, and performance [5, 6, 8].

From the study of the specialized literature, we can list several techniques for predicting/simulating sound-absorbing properties like:

- Boulvert et al [22] used Johnson-Champoux-Allard-Lafarge (JCAL) model in order to predict absorption characteristics and draw conclusions about the defects of the 3D printing process;
- Liu, Z.Q.et all [23], measured and theoretically predicted using the transfer matrix method (TMM) of micro-perforated panels (MPP) manufactured by the 3D printing process;
- Opiela, K. C. et all [24], study relatively simple pores (identical, inclined, and parallel) for the analysis of sound absorption and was argued through analytical methods.

The objective of this study was to fabricate sound-absorbing panels using 3D printing technology with PLA material, aiming to achieve high alpha coefficient values.

2. Experimental Section

2.1. 3D-Printed panels

Following the studies in the specialized references in the field, it was concluded that the value and geometrical shape of the infill influences the sound-absorbing properties of the panel [21].

Filament Fused Fabrication technology was employed, utilizing the CreatBot DX Plus 3D printer from Henan CreatBot Technology Limited (Henan Province, China).

A total of 5 sets, each consisting of 3 samples, were produced using different infill values: 20%, 40%, 60%, 80%, and 100%.

The samples were printed with poly(lactic) acid filament, having a diameter of 2.85 mm (supplied by FormFutura VOF, Nijmegen, Netherlands). The samples were circular in cross-section (50 mm diameter) and cubic in infill shape.

The printing process parameters used, and which remained constant for all 3D printed samples were:

- ✓ Layer height: 0.2 (mm).
- ✓ Extrusion width: 0.8 (mm).
- ✓ Perimeters: 2.
- ✓ Infill density: 20, 40, 60, 80 and 100 (%).
- ✓ Print speed: 40 (mm/s).
- ✓ Printing temperature: 240 (ºC).
- ✓ Bed temperature: 50 (ºC).
- ✓ Support type: none.
- ✓ Top layers: 4.
- ✓ Bottom layers: 4.

To assess their sound absorption properties, the samples were tested using the HO-ED-A-03 impedance tube device manufactured by Holmarc, India (Figure 1). The testing was conducted within the frequency range of 500 Hz to 3150 Hz, with the aim of determining the alpha coefficient (α) of sound absorption. The infill geometry of the samples resembled a parallelepiped with a square base.

Fig.1. Impedance tube HO-ED-A-03 type

The results are presented in table 1 as the arithmetic mean of three samples tested from each type of infill and cubic shape.

..Table 1

The value of the α coefficient depending on the infill value

	Infill [%]				
	20	40	60	80	100
α [%]	57	52	**66**	44	41

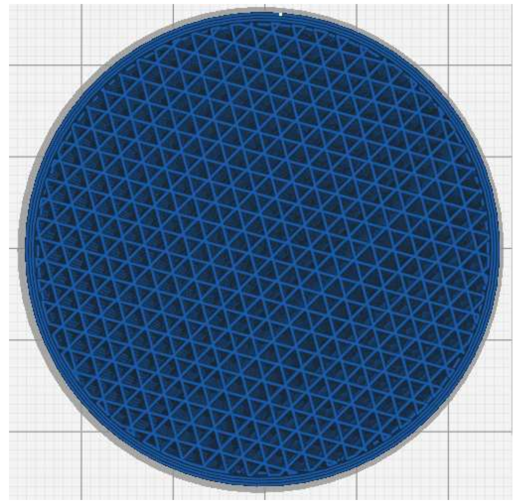
The maximum value of α = 66%, was recorded at the frequency of 1000 Hz and the lowest value was recorded at 100% infill.

Following these preliminary tests and in order to improve the sound-absorbing performance, two more geometric shapes of infill (tri-hexagonal and triangular) were used, as well as the design of four hollow shapes arranged on the height of the panel.

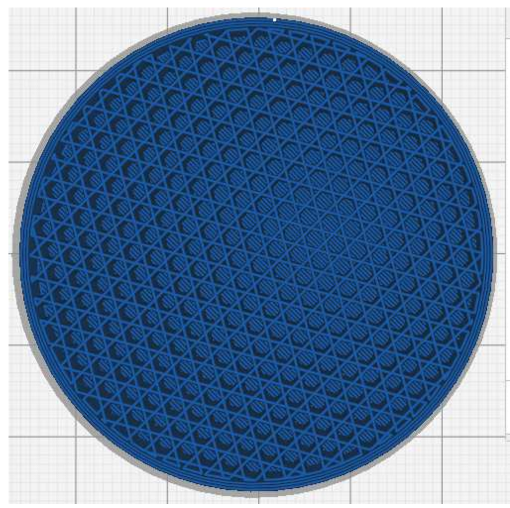
It was decided to choose the infill value of 60% (which had the highest value) and obtain new specimens with three geometric shapes of the infill, geometries presented in figure 2 a, b and c.

2.2. The design of interior voids

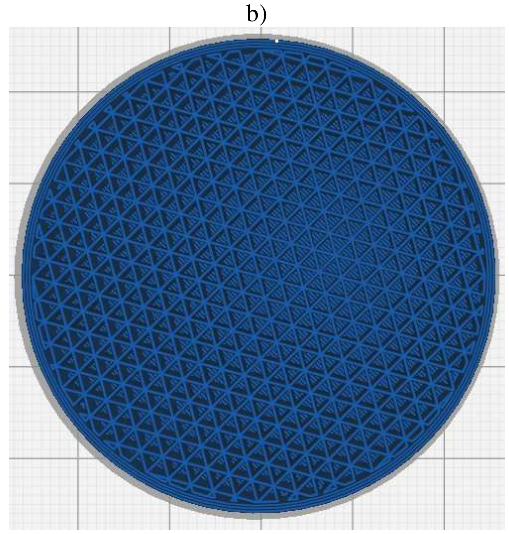
Additionally, for increasing the sound absorption capacity of 3D printed panels, for each geometric shape of the infill, four new types of voids were designed on the height of the sample (shown in figure 3 a, b, c and d), arranged circularly from the center on Φ 6, 10, 15 and 20 mm radius from the center, obtaining 1, 6, 12, 18 and 24 holes (in total 61 on each sample) according to figure 4, using the SolidWorks 2016 software.



a)

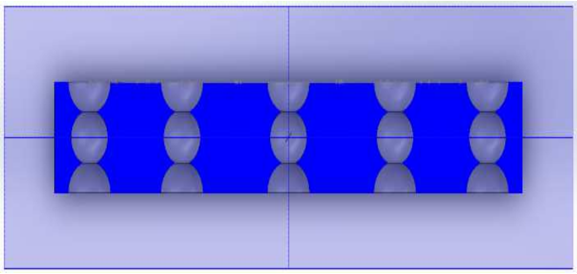


b)

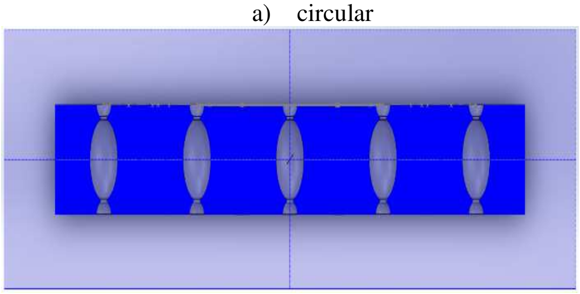


c)

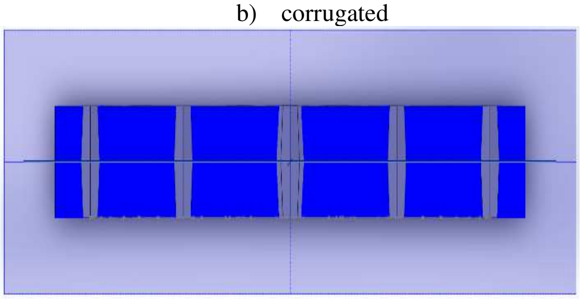
Fig.2. The geometry of the infill: a) cubic; b) tri hexagonal; c) triangular



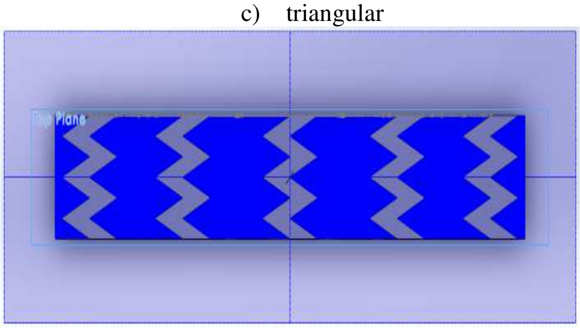
a) circular



b) corrugated



c) triangular



d) zig zag

Fig.3. The new geometry of holes: a) circular; b) corrugated; c) triangular; d) zig zag

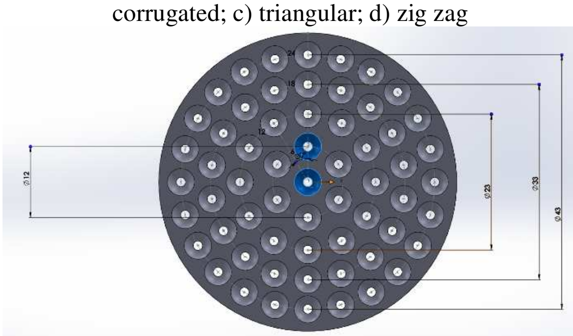


Fig.4. Arrangement of holes at the surface

Figure 5 shows the 3D printed samples used for determining the α coefficient.

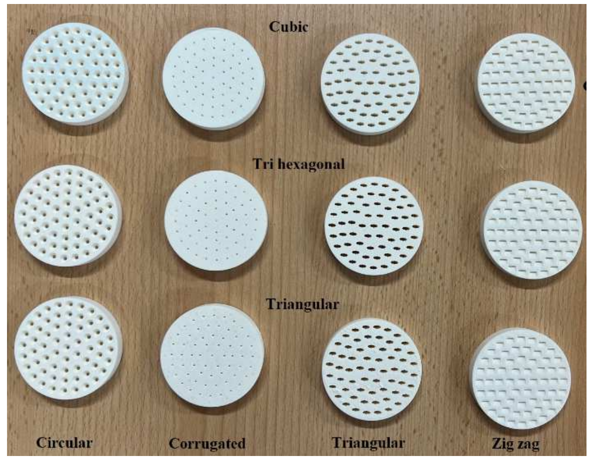


Fig.5. Samples 3D printed

3. Characterization Techniques

3.1. Determination of the sound absorption coefficient

The newly designed variants were physically transposed in samples by 3D printing them and tested using the impedance tube and the results are presented in the figure 6.

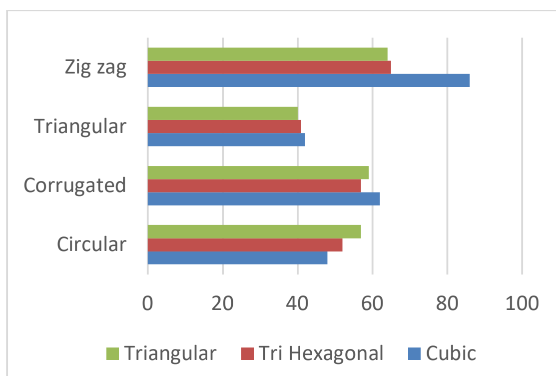
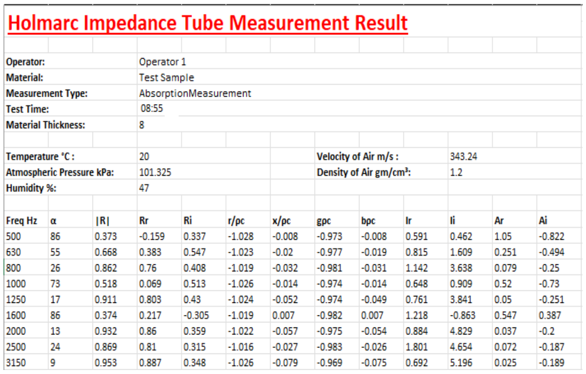


Fig.6. The results obtained for sound absorption

From all the combinations obtained, tested and analyzed, the shape of the gaps proved to have a major influence on the properties of the panels.

Thus, the highest values were determined for the zig zag gaps where α = 86% at 500 and 1600 Hz, and at 1000 Hz α = 73% (figure 7 and figure 8).



Holmarc Impedance Tube Measurement Result

Operator: Operator 1
Material: Test Sample
Measurement Type: AbsorptionMeasurement
Test Time: 08:55
Material Thickness: 8

Temperature °C : 20 | Velocity of Air m/s : 343.24
Atmospheric Pressure kPa: 101.325 | Density of Air gm/cm³: 1.2
Humidity %: 47

Freq Hz	α	|R|	Rr	Ri	r/ρc	x/ρc	gρc	bρc	Ir	Ii	Ar	Ai
500	86	0.373	-0.159	0.337	-1.028	-0.008	-0.973	-0.008	0.591	0.462	1.05	-0.822
630	55	0.668	0.383	0.547	-1.023	-0.02	-0.977	-0.019	0.815	1.609	0.251	-0.494
800	26	0.862	0.76	0.408	-1.019	-0.032	-0.981	-0.031	1.142	3.638	0.079	-0.25
1000	73	0.518	0.069	0.513	-1.026	-0.014	-0.974	-0.014	0.648	0.909	0.52	-0.73
1250	17	0.911	0.803	0.43	-1.024	-0.052	-0.974	-0.049	0.761	3.841	0.05	-0.251
1600	86	0.374	0.217	-0.305	-1.019	0.007	-0.982	0.007	1.218	-0.863	0.547	0.387
2000	13	0.932	0.86	0.359	-1.022	-0.057	-0.975	-0.054	0.884	4.829	0.037	-0.2
2500	24	0.869	0.81	0.315	-1.016	-0.027	-0.983	-0.026	1.801	4.654	0.072	-0.187
3150	9	0.953	0.887	0.348	-1.026	-0.079	-0.969	-0.075	0.692	5.196	0.025	-0.189

Fig.7. Zig zag gaps and 60% infill sample test report

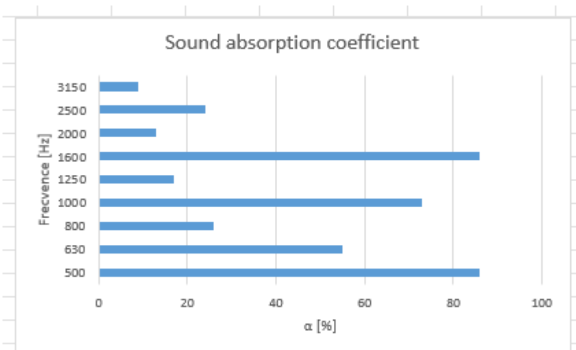


Fig.8. Sound absorption properties at each frequency.

Regarding the zig-zag geometric shape of the infill, the sound waves hit the walls and are lost in the mass of the material, while for the other types of gaps who have a hollow rotation axis, the sound waves pass through over the entire height of the panel.

3.2 Mechanical Tests

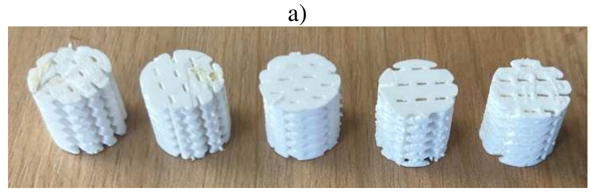
To determine the resistance to bending and compression for these 3D printed panels, the configuration with the maximum α coefficient (86%) was chosen, namely: infill value 60%, cubic infill shape and zig zag hollow shape.

The Universal Testing Machine WDW-150S, a Jinan, China-manufactured equipment, was utilized for the testing procedures. The machine is housed in the C08 research center of Transilvania University in Brasov, Romania.

In figure 7a are presented the bending samples and in figure 7b the compression samples, made according with SR EN ISO 527-3: 2000 / AC: 2003 standard.

For each type of testing, five samples were printed and tested (figure 9a and 9b).

a)



b)

Fig.9. Samples 3D printed for: a) 3-point bending test and b) compression test

The results are presented in Table 2.

Table 2

The mechanical properties of zig zag panel at bending and 3-point bending

Sample / Resistance	1	2	3	4	5
Compression					
R_{bc} [MPa]	149	141	141	143	139
3-point bending					
R_{bb} [MPa]	85	82	83	84	85
f [mm]	4.0	3.8	4.0	4.1	3.9

Where:

- R_{bc} = compression strength in [MPa].
- R_{bb} = bending strength in [MPa].
- f = arrow (maximum bending) before rupture in [mm].

The results obtained in the mechanical tests were uniform and the arithmetic mean is presented in continuation:

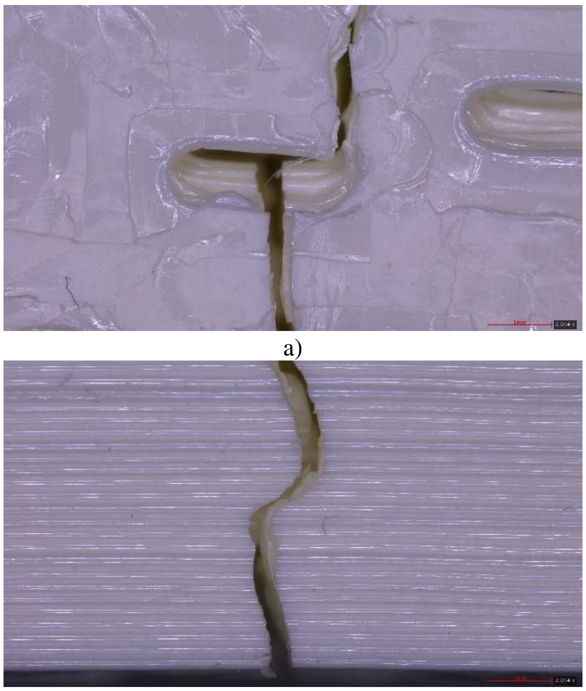
- ✓ R_{bc} = 142.6 [MPa]
- ✓ R_{bb} = 83.8[MPa]
- ✓ f = 3.96 [mm]

Comparing the mechanical test results with the specialized literature [5, 6], it was found that they are close and even higher.

3.3. Surface Morphology Analysis

Images of the fractured composite surfaces were taken using an optical microscope type Leica, Emspira 3 model (Netherlands).

In figure 10a is presented the fracture mode at the surface of the sample, in figure 10b the fracture mode on the height of the sample and in figure 11, the micrograph in section of the sample.



a)

b)

Fig.10. Surface micrograph: a) on the surface; b) on the height

From the analysis of the micrographs presented in figure 10, the following can be observed:

✓ the printing process proceeded in good conditions, a fact proven by the uniformity of the layers on height,

✓ does not show cracks or microcracks except in the tested areas,

✓ no delamination or incomplete layers were observed.

The micrograph in the section of the sample, presented in figure 11, presents only the defects specific to printed PLA, namely triangulations, combined (parallelepipedal) or end defects (where the extrusion head change direction).

Fig.11. Micrograph in section

4. CONCLUSIONS

The main goal, namely that of increasing the sound absorption coefficient from 66% with 15%, was achieved with the help of the configuration: 60% infill value + cubical infill shape + 61 zig zag voids arranged in concentric circles, thus resulting in a coefficient value of phonic absorption α = 86% at 500 and 1600 Hz, and at 1000 Hz α = 73%.

It was determined that the value of 60% of the density of the infill has the best sound-absorbing properties compared to the values of 20%, 40%, 80% and 100%.

It was determined that besides the geometric shape of the gaps, the angle of incidence of the sound on the perforations (gaps) has a major influence on the insulative behavior of the material.

Since the zig-zag perforations do not provide a gap on the central axis as is the case with circular or corrugated perforations, this case resulted in obtaining very good sound-absorbing properties.

The proposed architectural combination presents physical-mechanical properties close to and even greater than those reported in specialized literature.

Even if the other tested combinations proved not to be as efficient, further research can be carried out in order to optimize the results and maybe obtain better results.

The first step in future research is to study how the angle of the triangular and circular gaps from 90º (perpendicular to the surface) is necessary to be modified so that the sound waves are "forced" to hit the walls and be absorbed by the material.

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Efectul modelului de umplere asupra proprietăților fonoabsorbante și a unor proprietăți mecanice a pieselor printate 3D

Imprimarea 3D și materialele eco au o aplicabilitate deosebit de largă în multe domenii printer care și panouri fonoabsorbante imprimate 3D personalizate. Arhitectura golurilor din structura panoului, valoarea infillului sau forma de acestuia au o influență majoră asupra proprietăților de absorbție a sunetului (coeficientul α). În această lucrare, sunt studiate patru tipuri de arhitecturi de goluri și trei forme de tipuri de infill folosind acid polilactic ca material și tehnologia de fabricație cu filament fuzionat cu o valoare de umplere de 60%. Preliminar, cele mai bune rezultate au fost obținute pentru infilul cu formă cubică și anume α = 66% la frecvența de 1000 Hz. Scopul este de a crește valoarea α cu cel puțin 15% și de a găsi cea mai bună combinație și rezultate și de a determina rezistența la încovoiere și compresiune.

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