EXPERIMENTAL STUDY OF 3D PRINTED SAMPLES ACOUSTIC PERFORMANCES

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Porous materials (PMs) are known to have been used since the development of powder metallurgy. The main fields of PM include: filtering, node sealing, cooling, vibration and sound suppression. In particular, PMs are used to muffle the exhaust of technological equipment. PM samples are manufactured by melting, pressing, and also by chemical means, while the structure is difficult to be reproduced again with a high degree of accuracy. Such a 3D printing method as selective laser melting (SLM) allows obtaining samples with a low deviation of the structure (up to 13%) in a wide range of porosity $P=0.3…0.7$. The increase in sound absorption factor and expansion of the frequency range can be achieved by selecting the effective porosity and pores tortuosity coefficient. The high coefficient of normal sound absorption and high manufacturability determine the popularity of application of samples obtained by 3D printing methods in noise suppression designs.

Keywords: porous material, structure, sound absorption, noise suppression, additive technologies

1. Introduction

The challenge of providing new solutions for noise reduction is of great current interest taking into account the constant increase in energy intensity and speed of pneumatic units [1], as well as the tightening of noise regulations [2]. Many scientific papers and standards provide data on the following main ways to reduce noise in pneumatic units and power plants [1,3,4]:

- reducing dynamic source activity;
- noise reduction in the way of its distribution (corrective devices and noise mufflers, sound insulation);
- frequency tuning of the system.

Methods of dealing with noise in the way of its propagation have experienced the greatest development as, in this case, no alteration of design of the unit is required. These methods include, primarily, the use of silencers in the gas-air exhaust ducts as the disturbance of the working medium can freely go outside through those, thus creating the highest sound pressure levels. Metal-based silencers have a lower efficiency loss during operation [1]. The most efficient silencers are considered to be metal-ceramic ones with an acoustic efficiency of about 20 dB in the 1…5 kHz band and they operate at pressures up to 1 MPa [1].
Methods of reducing vibrations through silencers are presented in [4,5,6]. The investigated samples of porous melted material (PMM) can be represented as a passive quadrupole of active resistance R (Figure 1).

![Figure 1: Circuit diagram (a), electrical circuit of the active resistance (b) and its practical implementation in the form of a PMM sound absorber (c)](image)

1– PMM porous absorber, 2 – pipeline

PMs have been widely used since the development of powder metallurgy [7]. The main areas of PM application [1,8] are: filtering, media blending, nodes sealing, transpiration cooling, antifriction and lightweight units, vibration and noise reduction.

In the field of noise suppression, PMs are actively used in pneumatic silencers of the active and combined types [1,3]. Structural, hydraulic, thermophysical, mechanical and acoustic properties of metal-based porous materials which are produced by traditional methods (by melting, pressing, chemically), have a strong dependence on the process of technological heredity, especially on the hereditary component of error [9]. A significant reduction in the hereditary component of the error can be achieved by reducing the number of technological operations [9].

3D printing is similar to powder metallurgy methods and the manufacture of parts by melting is characterized by the following stages [10,11]:

- obtaining initial powder, refining annealing and dispersing of the powder, mixing with other powders;
- molding the powder into a porous blank, drying the mold, additional mechanical processing or temperature treatment;
- preparation for melting: selection of equipment, furnace and melting mode;
- melting;
- post-processing (mechanical and/or physical-chemical) [12].

In this case, the error of the melted part size is affected by the growing number of stages. Among the technologies with a minimum number of operations, 3D printing technology can be distinguished, and SLM technology, in particular [11] which has already proven itself in the production of fluid-operated drive parts [12].

In addition to the methods of powder metallurgy, the main methods of production of elements for sound absorption from metals include pressing and chemical methods [13]. The listed methods are highly dependent on the process of technological heredity, since they have a significant number of operations. An exception is the manufacturing technology of the metal-rubber material (MR), the number of technological operations of which is less than twice than for the technology of obtaining melted metal fibers [8,13]. In this case, the magnitude of the heterogeneity of the structure during the manufacture of MR images does not exceed 10...15%, i.e. the scatter of properties (including acoustic ones) of samples from MR is approximately within the same range.

Therefore, a special feature of 3D printing is its less dependence on the process of technological heredity. 3D printing is different from traditional PM manufacturing methods by being provided with preliminary information about the blank in the form of its 3D model. The advantage of 3D printing for the formation of acoustic parts is as follows:
• a wide range of materials used (metal, plastic, composite);
• geometry simulation for selected tasks at the design stage.

3D printing was tested while manufacturing absorber samples in the form of Helmholtz resonators with internal connections and a labyrinth structure [14]. Polymer samples presented in [15] based on the theory of the "best absorber" show a significantly greater sound absorption (up to two times) in comparison with the sound absorber used in aviation.

The formation of porous metal samples acting as an absorber in active-type silencers is possible by means of 3D printing. The basis of this process lies in the formation of a model with a lattice structure. At the same time, the minimum dimensions of the lattice cells completely depend on the method on which the 3D machine is built (SLM, SLS, FDM, etc.) [10]. The current research is the study of sound absorption of aluminum and steel samples.

Nine PMM samples with different porosity and cell shape were obtained using the SLM method. Samples of PMM were made with h = 15 mm thickness and P = 0.36 ... 0.72 porosity.

In this research we have studied and analyzed acoustic performances of PMM samples and their analogues, as well as the PMM best structure, its parameters and the prospects for using 3D printing for manufacturing noise suppression components.

2. PMM samples manufacturing

The lattice structures selected for manufacturing were designed with special software. The porosity of the models (P) varied within the range (0.36 ... 0.72), the diameter of all samples was established (D=34.5 mm) and is determined by the internal diameter of the impedance pipe, in which the sound absorption of the samples was measured. The first batch of samples (No. 1…9) (table 1) was grown from aluminum alloy AlSi10Mg (Al), and samples No. 1…3 were excluded due to low alloyability and made of more durable nickel alloy VV751P (Ni) (Figure 2).

![Figure 2: An example of a No. 1 PMM sample with a defective and intact structure with a P=0.7 porosity](image)

To manufacture lattice structures of the samples we used an SLM 280HL unit.

Quality analysis of aluminum and nickel alloy PMM samples obtained by the SLM method was carried out on the basis of model cell data (Table 1).
Table 1: Comparison of PMM quality models and samples

<table>
<thead>
<tr>
<th>No. of the sample</th>
<th>Model cell size in mm</th>
<th>Sample cell size in mm</th>
<th>Structure integrity, %</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel alloy V751P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.90</td>
<td>0.90...1.02</td>
<td>100</td>
<td>0.70</td>
</tr>
<tr>
<td>2</td>
<td>0.40...0.47</td>
<td>0.35...0.42</td>
<td>100</td>
<td>0.52</td>
</tr>
<tr>
<td>3</td>
<td>0.13</td>
<td>0.35...0.43</td>
<td>95</td>
<td>0.51</td>
</tr>
<tr>
<td>Aluminium alloy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.80</td>
<td>0.88...0.89</td>
<td>90</td>
<td>0.72</td>
</tr>
<tr>
<td>5</td>
<td>0.64</td>
<td>0.47...0.69</td>
<td>85</td>
<td>0.62</td>
</tr>
<tr>
<td>6</td>
<td>0.41</td>
<td>0.35...0.37</td>
<td>90</td>
<td>0.47</td>
</tr>
<tr>
<td>7</td>
<td>0.83</td>
<td>0.59...0.80</td>
<td>90</td>
<td>0.48</td>
</tr>
<tr>
<td>8</td>
<td>0.66</td>
<td>0.44...0.48</td>
<td>75</td>
<td>0.67</td>
</tr>
<tr>
<td>9</td>
<td>0.24...0.42</td>
<td>0.16...0.28</td>
<td>100</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Samples No.7,9 had up to 70% of pores clogged on the side of the substrate. The maximum deviation of the characteristic sample cell size (410…900 µm) from the model sample for aluminum and nickel alloys does not exceed 13%, e.g. for melted fiber materials the deviation of the characteristic size is about 20%, and the minimal irregularity of pressing (and, therefore, the minimum deviation from a given structure) is characterized by MR porous material. The deviation does not exceed 10…15% [13].

Sample No. 9 has a special feature of the structure in the form of local density concentration areas (Figure 3).

![Model and sample No. 9 images](image)

Therefore, structures with a cell size of 300…500 µm (for the SLM 280 unit) are the most reasonable for the manufacture of samples with a size deviation of no more than 13%. Reducing the size of the cells can be achieved using units with different operating principles [10].

Samples No.1…4, 6,7,9 have a structure that coincides with the model more than 90%.

Thus, the SLM method allows the fabrication of lattice structures from light and heavy alloys. The deviation of the cell sizes of the samples does not exceed 13%. According to [1], the best results in noise reduction are PMs with a porosity of P≤0.75, therefore the rightmost porosity threshold of the produced samples is 0.72, which satisfies the condition of [1].
3. Samples acoustic performances

The main parameter characterizing the acoustic properties of the material is [13,16] sound absorption coefficient which is the ratio of the absorbed and incident energy:

\[
\alpha = \frac{E_{\text{abs}}}{E_{\text{inc}}}
\]  \hspace{1cm} (1)

For a preliminary assessment of the sound-absorbing properties of materials and products, it is allowed to determine the normal sound absorption coefficient [17]. The sound absorption coefficient at normal incidence of a sound wave on a porous material is defined as [18]:

\[
\alpha_N = \frac{4\overline{X}}{(1 + \overline{X})^2 \overline{Y}^2}
\]  \hspace{1cm} (2)

where \(\overline{X}\) is an active component of acoustic impedance, \(\overline{Y}\) is the reactive component of acoustic impedance (with normal incidence of a sound wave on the surface of a material).

According to ISO 10534-2, an impedance method is used for the initial comparison of acoustic performances.

To obtain the acoustic performances of the samples, we used an impedance pipe, as shown in Figure 4. The description of the operation of the unit is given in [19].

\[l_1\] - distance from the sample to the microphone 1, \(l_2\) - distance from the sample to the microphone 2, \(S\) - distance between microphones 1 and 2, \(P_I\) - sound pressure of the wave outgoing from the speaker, \(P_r\) - sound pressure of a wave returning to a speaker.

Figure 4: Experimental unit "Impedance pipe" to assess the acoustic properties of materials.

The frequency range of the impedance pipe is 300…5000 Hz, this is due to the condition of the wave plane [19]. In this regard, all the research results are represented in the designated frequency range. The obtained data of the normal sound absorption coefficient of the samples of aluminum and nickel alloy are shown in Figure 5.
Figure 5: Normal sound absorption coefficient of PMM samples made of aluminum and steel

(h=15 mm)

Samples No.3,6 provide $\alpha_N>0.5$ in the frequency range from -1.9 kHz to 5 kHz (Figure 5) with porosity $P=0.51$ and 0.47 respectively (Figure 6). We have established that samples No. 1,2,4…7 have a tortuosity coefficient of the pores of $a_{tor}=1$, sample No. 8 has $a_{tor} \approx 1$, and No. 3,9 $a_{tor}>1$. According to [8] with $P=(0.84…0.26)$ $a_{tor} \in (1.0…1.5)$, therefore, for No. 3 the refined tortuosity coefficient of the pores $a_{tor}$ will be 1.2.

When analyzing the real part of the acoustic impedance, a range of 400–1000 Hz was allocated in which the PMM samples exert the greatest resistance. In the silencers of technological units, lower PM resistance contributes to a lower pressure drop in it.

According to [17], sound-absorbing materials and units are also characterized by a sound absorption index $\alpha_w$. In literature, the single-digit sound absorption index is calculated by the formula D.A. Bies through noise reduction coefficient NRC [16]:

$$\text{NRC} = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4}. \quad (3)$$
Table 2 shows the sound absorption parameters $\alpha_w$ and the noise reduction coefficient NRC.

Table 2: Sound absorption and noise reduction values

<table>
<thead>
<tr>
<th>No. of the sample</th>
<th>GOST Russian Standard 23499-2009</th>
<th>According to D.A. Bies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\alpha_w^*$</td>
<td>Sound absorbing rating</td>
</tr>
<tr>
<td>1</td>
<td>0.55 (MH)</td>
<td>D</td>
</tr>
<tr>
<td>2</td>
<td>0.85 (LMH)</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>1.00 (LMH)</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>0.60 (LMH)</td>
<td>C</td>
</tr>
<tr>
<td>5</td>
<td>0.85 (LMH)</td>
<td>B</td>
</tr>
<tr>
<td>6</td>
<td>1.00 (LMH)</td>
<td>A</td>
</tr>
<tr>
<td>7</td>
<td>0.7 (LM)</td>
<td>C</td>
</tr>
<tr>
<td>8</td>
<td>1.00 (LMH)</td>
<td>A</td>
</tr>
<tr>
<td>9</td>
<td>1.00 (LMH)</td>
<td>A</td>
</tr>
</tbody>
</table>

*$\alpha_{300}$ is accepted instead of $\alpha_{250}$

According to [17], samples No. 2,3,5,6,8,9 are referred to sound absorption classes A and B. At the same time, the best NRC for samples No. 4, 7. As can be seen from table 1, the single-digit sound absorption parameters $\alpha_w$ and NRC do not have a strict correlation between themselves, therefore the choice of one or another coefficient depends on the purpose of the acoustic material.

4. Discussion and conclusion

Using 3D printing technology to manufacture acoustic parts offers several advantages and disadvantages:
- the speed of manufacturing by the SLM method exceeds that of the traditional "subtraction" technology;
- SLM-method is characterized by a high degree of reproduction of the model with preserving the designed quality and by the ability to manufacture complex-shaped parts;
- high degree of roughness of the synthesized surfaces;
- the need for support material in most cases [10].

Based on the analysis of the quality of the obtained samples, these No. 1…4,6,7,9 should be distinguished as their quality is marked as acceptable while maintaining the model structure of more than 90%. The samples of alloy VV751P (No. 1…3) demonstrate quality of over 95%.

The study of the sound absorption suggests that the best samples from the studied ones can be considered No. 3,6 as having a normal sound absorption coefficient $\alpha_N > 0.5$ in the widest frequency range (1.9…5 kHz).

The sound absorption classes A and B include samples No. 2,3,5,6,8,9. The best NRC are of samples No. 4,7.

For samples obtained by the SLM method, in addition to the cell size and porosity, the $\alpha_{\text{tort}}$ tortuosity coefficient plays an important role in terms of formation of acoustic properties.

We discovered that an increase in the $\alpha_{\text{tort}}$ tortuosity coefficient of the pores leads to a shift of the frequency range to the left and an increase in the normal sound absorption coefficient $\alpha_N$ to 1 (samples No. 3,6).

The use of samples obtained by the SLM method in the construction of sound absorption structures is important due to the high manufacturability and sufficient sound absorption coefficient.

The improvement of acoustic properties of PMM is possible in the following areas:
• search of effective porosity within the range of 0.30…0.55 with $a_{tor} \geq 1.2$;
• search for the optimal tortuosity coefficient of pores.

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**REFERENCES**