# The influence of signal type and distance to the sound source on sound transmission through small 3D printed polymer panels

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**Abstract.** The sound insulation of some spaces is possible using panels made of polymer materials manufactured by 3D printing. It is expected that the intensity of the sound signal after passing through a small wall made of polymeric material will be affected by the type of sound signal and the distance at which the sound is received. In the case of previous experimental research, the influence exerted by some parameters of the 3D printing process on the sound insulation capacity of walls made of polymeric materials was largely considered. In the case of the present paper, experimental research was carried out aiming to identify empirical mathematical models capable of highlighting the influence of the sound type and distance on the intensity of the sound signal after passing through the panel. The experimental tests were carried out on equipment designed to investigate different factors' influence on the sound signal's impact when passing through small panels. An empirical mathematical model was identified through the mathematical processing of the experimental results. The empirical mathematical model highlights the influence exerted by the shape of the electrical signal used to generate the sounds and, respectively, the distance between the sound source and the sensor of a sound level meter on the energy absorbed by the small panel from a polymeric material.

## Introduction

Sounds are mechanical vibrations that the human ear can perceive. Human beings can perceive such vibrations if they have a frequency between 20 Hz and 20 kHz and if sounds also have a certain intensity. It should be noted that mechanical vibrations with frequencies in the mentioned range are called *sounds* when they are judged to have a pleasant effect and, respectively, *noises* when the previous condition is not met.

On the other hand, there are practical situations when the intensity of sounds is desired to be as low as possible. For this purpose, it is possible to use enclosures that do not allow the penetration of sound waves from the outside or the exit of such waves to the outside. For this purpose, the walls of the enclosure must have a high capacity to absorb sound waves from the indoor or outdoor environment. Such walls are made in the form of panels made by different manufacturing processes and from different materials, characterized in principle by high sound insulation properties.

Some of the materials used to make the panels are polymers. The development of additive manufacturing processes in recent decades has led to the manufacture of sound insulation panels through these processes. In principle, additive manufacturing involves gradually generating the part to be obtained by depositing successive layers. One of the additive manufacturing processes frequently used today is 3D printing. In this case, the polymeric material in a molten state and advanced through a nozzle is deposited layer by layer as a result of some controlled relative displacements between the nozzle and the table of the equipment on which the gradual generation of the desired part occurs.

By varying the parameters of the 3D printing process, some physical-mechanical properties of the materials of the printed parts can be decisively influenced. This fact led to the idea of researching how, through an appropriate selection of the values of the input factors in the printing process, the sound insulation properties of polymer panels can be improved.

On the other hand, researching the sound insulation capacity of polymer panels involves using appropriate equipment designed, for example, to evaluate the energy of sound waves after they pass through the panels and the influence of different factors on the sound insulation capacity of different materials [1-8].

Thus, Perrot et al. analyzed the acoustic properties of some samples from foams, focusing mainly on the extent to which the internal structure of such materials can affect the sound properties of the cellular foams [1]. They found that the level of absorption of sound waves by materials in the form of foams is directly affected by cell size.

Zahiruddin and Yarlagadda manufactured by 3D printing a polyethylene terephthalate glycol plate with a porosity of 60 % and tested the material's ability to absorb sounds using the impedance tube method [2]. One of the research conclusions was that the plate material has good soundproofing properties for high-frequency sounds.

King and Teo considered the soundproofing possibilities of a room in modern homes. They appreciated that it is possible to improve the ability of materials to absorb sound waves by using materials with optimized structures [3]. Using samples of materials with such structures manufactured by 3D printing, they showed that the produced materials have a high capacity to absorb sounds with frequencies lower than 4000 Hz.

The development of polymer matrix composite materials has led to an expansion of concerns regarding the properties of such materials to absorb sound energy. In a study published in 2021, Sujon et al. concluded that there are great prospects for using polymer matrix composites for sound insulation [4].

In the last decades, the problem of using some polymers as insulating materials from a sound point of view has been a continuous concern of researchers interested in identifying new solutions that allow a better absorption of sound waves [5-8].

In previous research, some of the authors of this paper presented the results of research that focused on the influence of factors such as panel thickness, printing speed, infill percentage, infill pattern, layer thickness, sound frequency, and sound volume on the insulation capacity acoustics of small panels made of plastic materials by 3D printing [9,10]. During these researches, questions were formulated regarding the extent to which the shape of the sound waves or the distance between the wall and the sensor of the pressure sound level measuring device can exert, themselves, a certain influence on the results of some measurements of the sound insulation capacity of the panels manufactured by 3D printing.

Experimental research was developed to highlight the influence exerted by the two factors and possibly the intensity of the influence exerted by the two factors on the evaluation of the sound-insulating capacity of the polymer panels. In the present work, equipment intended for researching the sound insulation capacity of small panels made of polymeric materials was used to highlight the theoretical conditions involved in the generation, propagation, and absorption of sound energy. Later, the experimental research had to provide information on the intensity of the influence exerted by the shape of the sound signal and, respectively, by the distance between the polymer panel and the sensor of the sound pressure level evaluation device on the measurement results.

## Experimental conditions

There are various solutions for generating sounds by converting electrical, hydraulic, etc., energy into mechanical vibrations whose intensity can be increased in various ways. Currently, the most widespread way of generating sounds is based on the use of speakers. In this case, a membrane attached to a coil moves due to the interaction between the electromagnetic field of the coil and the field of a permanent magnet. The variation in the magnitude of the electromagnetic field generated by the coil occurs as a result of the controlled change in the intensity of the current flowing through the coil. The displacement of the membrane leads to the occurrence of air compressions and decompressions, which contribute to the propagation of sounds through the air (Fig. 1). A sensor placed in the direction of sound propagation will receive the pressure variations, allowing both an assessment of the intensity of the sound waves (of their energy) and a possible graphic illustration of the time variation of the sound intensity.

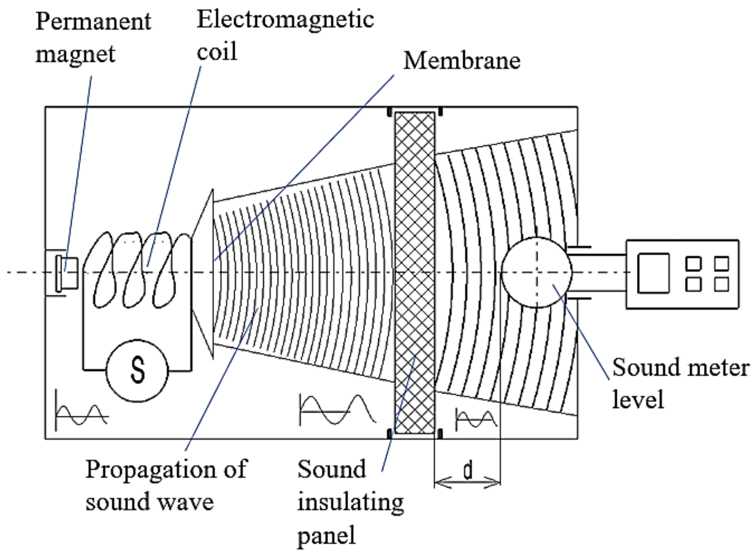


*Fig. 1. Generation, propagation, and absorption of sound waves*

When sound insulation is required, obstacles of materials characterized by a high capacity to absorb sound wave energy are placed along the direction of sound wave propagation. This sound insulation capacity of a certain space is influenced by different properties of the material of the obstacle but also by some characteristics of the sound waves. Such a characteristic can be the shape of the electrical signal used to generate the sounds, the form transmitted by the propagation of the sounds in the air, and the material of the obstacle.

On the other hand, as one moves away from the sound-generating source or the obstacle intended to reduce the energy of the sound waves, it is expected that the intensity of the sounds will decrease due to the absorption of the energy of the sounds by the air layers traveled. The sound level sensor could pick this up.

The so-called *sound impedance tube* is used to investigate the sound insulation capacity of some materials incorporated in small disc-shaped samples. In the case of these tubes, sound waves with known characteristics produced by a sound generator must pass through the disc-shaped test sample. Later, certain characteristics of the sounds passed through the panel are evaluated or recorded using appropriate sensors and devices [11,12].

In its more commonly used variant, the sound impedance tube considers the sounds reflected by the walls and not only the sound waves coming from the sound generator. Also, only relatively small test samples can be inserted into the sound impedance tube. For these reasons, equipment was designed and used to allow the testing of small panels (100x100 $mm^2$) manufactured from polylactic acid (PLA) by 3D printing. The test samples were manufactured on an Ultimaker 3 (Netherlands) printer. The thickness of the test sample was 2 mm. The main parameters of the 3D printing process were the following: printing speed $v$=20 mm/s, infill $i$= 78%, gyroid infill pattern, layer thickness $l$=0.1 mm).

A schematic representation of the equipment can be seen in Fig. 2. The equipment uses a mini audio speaker, which can be operated by existing software on a smartphone. The sounds with known characteristics generated by the mini audio speaker pass through the polymer panel, whose sound insulation properties must be determined. Later, the sounds whose energy has been reduced due to passing through the panel made of polymeric material reach the sensor of a sound level meter. The signal generated by the sound level meter can be sent to a computer, whose software allows the illustration of the evolution of some sound characteristics over time on a monitor screen. The audio minibox, the polymer material panel, and the sound level meter sensor are placed in compartments with wooden walls lined inside with a material that exhibits good sound wave absorption properties. A HY1361-type equipment (China) was used to determine the sound pressure level. The audio mini speaker type Andowl M10 allowed the generation of sounds with different signal shapes. The mini audio speaker received the signal from a smartphone through the Frequency Generator application (produced by LuxDeLux).

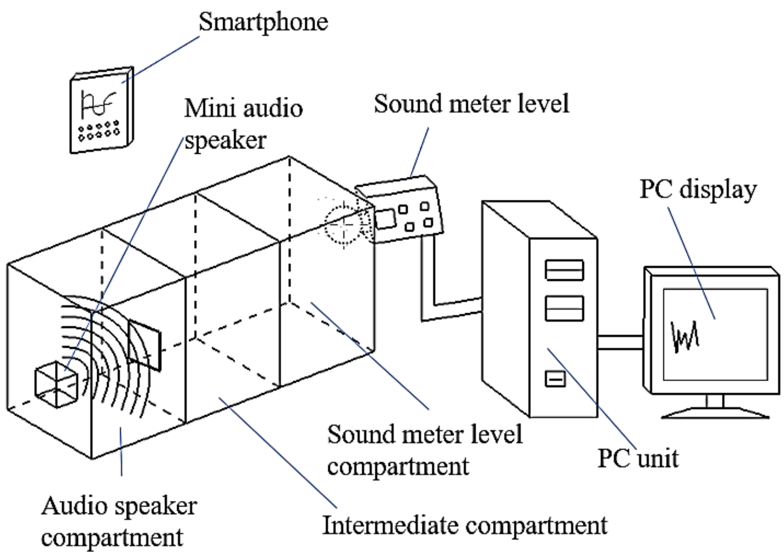


*Fig. 2. Schematic representation of the equipment used to perform the experimental tests*

In the context of some previous research [9,10], for different polymeric materials, empirical mathematical models were determined to highlight the difference in acoustic pressure corresponding to the energy absorbed by the panel made of polymeric material as a function of the thickness *t* of the panel, type *m* of panel material (*m*=1 for polylactic acid, *m*=2 for high-impact polystyrene, *m*=3 for polyethylene terephthalate glycol), printing speed *v*, infill *i*, infill pattern $i_p$, layer thickness *l*, sound frequency *f* and sound volume *s*. Such an empirical mathematical model, established by considering the results obtained for 18 samples, is the following [10]:

$$\Delta p_{ac} = 169.745 - 263.917t + 43.719t^2 + 5.097m - 1.639m^2 - 0.141v + 0.00153v^2 + 0.180i - 0.00177i^2 + 1.311i_p - 0.571i_p^2 - 27.377l + 222.774l^2 + 0.00853f - 3.253 \cdot 10^{-7}f^2 + 0.685s - 0.00480s^2. \quad (1)$$

During the experimental tests aimed at determining the mathematical model corresponding to Eq. (1), the idea appeared to carry out some tests that would allow highlighting the influence of the shape of the electric signal used to generate sound waves and respectively of the distance between the wall and the sensor of sound meter level on the difference $\Delta p_{ac}$ of sound pressure level.

For this purpose, it was used to carry out some experimental tests in which the four types of sound signals generated using the existing software on smartphones and, respectively, two distances *d* between the panel made of polymeric material and the sensor of the sound meter level

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are used. Experimental tests were conducted by the requirements of a factorial experiment with two independent variables (signal shape *s* and distance *d*). Sinusoidal (*s*=1), rectangular (*s*=2), triangular *s*=3), and sawtooth (*s*=4) signals were used. The distances between the panel and the sensor were $d_{min}$=40 mm and $d_{max}$=135 mm, respectively. These last values were established starting from the hypothesis that they will allow highlighting the extent to which the distance *d* could contribute to the reduction of the intensity of the sounds received by the sensor due to the sounds traveling a greater distance.

*Table 1. Performance conditions and experimental results*

| Experiment no. | Input factors | | | Output parameters | | |
|---|---|---|---|---|---|---|
| | Signal shape, *s* | | Distance *d* [mm] | Acoustic pressure level without panel, $I_0$ [dB] | Acoustic pressure level when using polymer panel, $I_p$, [dB] | Difference in acoustic pressure level, $\Delta p_{ac}$ [dB] |
| | Shape | Coded value | | | | |
| Column no. 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | Sinusoidal | 1 | 40 | 117.6 | 97.1 | 20.5 |
| 2 | Sinusoidal | 1 | 135 | 102.4 | 103.8 | -1.4 |
| 3 | Rectangular | 2 | 40 | 117.8 | 98.3 | 19.5 |
| 4 | Rectangular | 2 | 135 | 102.7 | 103.4 | -0.7 |
| 5 | Triangle | 3 | 40 | 117.9 | 97.1 | 20.8 |
| 6 | Triangle | 3 | 135 | 102.1 | 102.7 | -0.6 |
| 7 | Sawtooth | 4 | 40 | 117.5 | 99.6 | 17.9 |
| 8 | Sawtooth | 4 | 135 | 105.5 | 108.8 | -3.3 |

The conditions and the results of the experimental tests are mentioned in Table 1. All results were obtained using a flat panel test sample manufactured from polylactic acid by 3D printing. The fused deposition modeling 3D printing technology was used. In column no. 5 of Table 1, the values of the acoustic pressure level indicated by the measuring device have been entered when the polymer material panel is not placed between the mini audio speaker and the sensor of the measuring device. The values of the acoustic pressure when the polymeric material panel was inserted are those in column no. 6. The differences between the two values of the acoustic pressure level for the same shape of the electrical signal and the same distance between the mini audio speaker and the sensor were entered in column no. 7. These differences are basically due to the sound energy absorbed by the panel material.

**Processing of experimental results**

The experimental results were mathematically processed using software based on the least squares method [13]. According to this software, the adequacy of the empirical mathematical model to the experimental results is achieved using the Gauss criterion [13,14]. The value of Gauss's criterion is determined as a ratio in which the sum of the squares of the differences between the values determined by using the proposed empirical mathematical model and the values of the ordinates of the points corresponding to the experimental results for the same values of the abscissas, is entered in the numerator. The difference between the number of experimental tests and the number of constants in the proposed empirical mathematical model is used as the ratio's denominator. In essence, the lower the value of Gauss's criterion, the more it is appreciated that the proposed empirical mathematical model is more appropriate to the experimental results used.

By using the mentioned software, it was found an empirical mathematical model of the second-degree polynomial type (for which the Gauss sum has the value $S_G$=3.510862):

$$\Delta p_{ac} = 27.948 - 1.0920 s_s + 0.937 {s_s}^2 - 0.201 d, \quad (2)$$

where $s_s$ corresponds to the coding mode of the signal shape (Table 1).

Using the empirical mathematical model defined by Eq. (2), the graphical representations in Figs. 3 and 4 were developed.

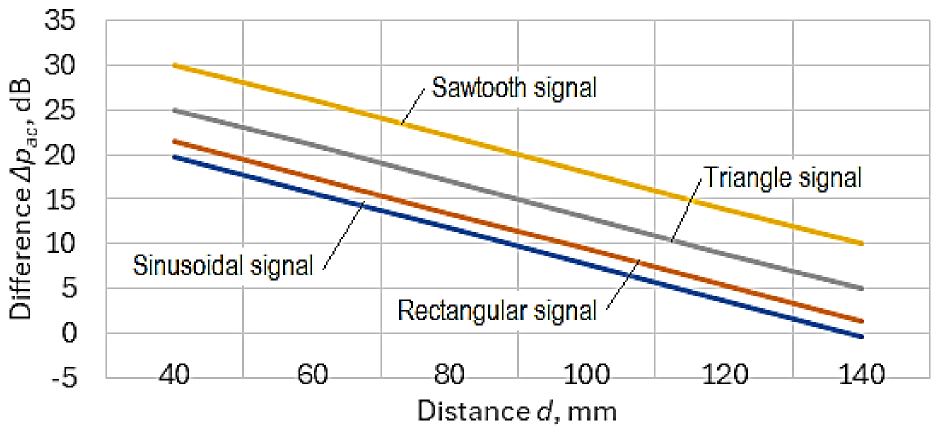


Fig. 3. The influence of the distance *d* between the mini audio speaker and the sensor *of sound level meter for the four shapes of the sound signal, on the difference in acoustic pressure level* $\Delta p_{ac}$

The analysis of the mathematical model constituted by Eq. (2) and the graphic representations in Figs. 3 and 4 allowed the formulation of some observations regarding the influence exerted by the signal shape *s* and by the distance *d* between the sensor of the sound level meter and the mini audio speaker on the difference $\Delta p_{ac}$ corresponding to the energy absorbed by the small dimensions polymer panel.

It is thus found that as the distance *d* between the mini audio speaker and the sensor of the sound meter level increases, there is a decrease in the energy absorbed by the measuring instrument. This fact can be justified by the decrease of the energy that reaches the sensor once the by sound waves of greater distance.

It can also be observed that from the point of view of the influence of the shape of the signal used to generate the sounds, the lowest value of the difference $\Delta p_{ac}$ corresponds to the signal of sinusoidal shape, higher values being registered, in order, for the sinusoidal signal, for the triangle signal and, respectively, for sawtooth signal.

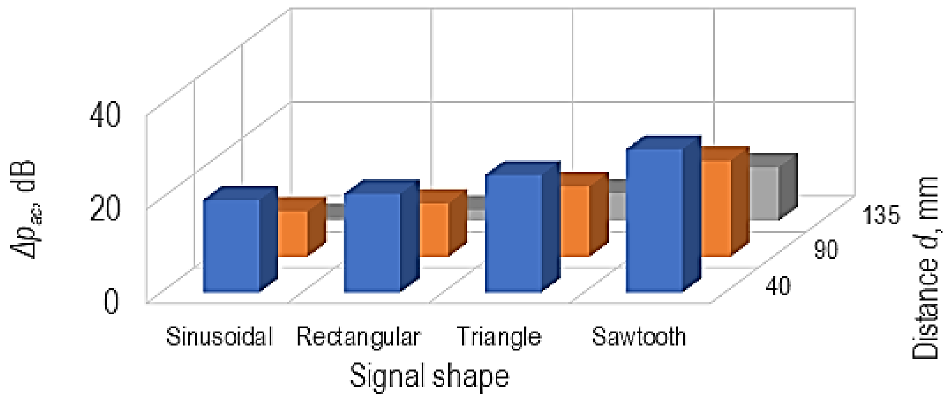


*Fig. 4. The variation of difference in acoustic pressure level, $\Delta p_{ac}$ depending on the shape s of the signal and the distance d*

**Conclusions**

The development of 3D printing technologies has allowed the manufacturing of panels made of polymeric materials that can be used for sound insulation. Several groups of factors are capable of influencing these panels' ability to absorb sound wave energy. The research whose results were included in this paper sought to highlight the influence exerted by the shape of the electrical signal used to generate sound waves and, respectively, the distance between the source of sound vibrations and the sensor of a sound level meter on the difference in acoustic pressure level. The experimental research was carried out using equipment that allows the modification of the input factors considered. The evaluation of the sound insulation capacity of small panels made of polylactic acid was considered. The experimental results were mathematically processed using software based on the least squares method. An empirical mathematical model of the second-degree polynomial type was determined. The model highlights the influence exerted by the two input factors on the difference in acoustic pressure level. As expected, increasing the distance between the source of sound vibrations and the sensor of the sound meter level led to a decrease in the sound energy reaching the sound meter level. In the future, an extension of the experimental research related to the study of the sound insulation capacity is also considered in the case of other polymeric materials. Another possible direction of research could aim to reveal the influence exerted by the internal structure of the polymeric material. This structure can have different aspects by changing the values of the parameters of the 3D printing process.

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