VPS VIBRATIONS IN PHYSICAL SYSTEMS

DOI: 10.21008/j.0860-6897.2025.2.07
Vibrations in Physical Systems, 2025, 36(2), 2025207

Effect of coverage on the acoustic performance of selected porous and fibrous materials

Adam PILCH, **Olaf KREJCZA**

AGH University of Krakow

Corresponding author: Adam PILCH, email: apilch@agh.edu.pl

Abstract Acoustic structures based on fibre slabs must be protected from mechanical damage. It is also important to protect the user from dust, the source of which may be the fibrous material (rock or glass wool). In individually manufactured panels, due to special aesthetic or functional qualities, it is necessary to select alternative coverings to those used in publicly available panels, whence arose the need to analyse different materials that could be used for coverings and determine their effect on the acoustic properties of the base material. The study was carried out analytically, numerically, and experimentally on two different porous materials and one fibrous material. Eleven different coverings were analysed, including four impermeable ones. The results made it possible to demonstrate the magnitude of the effect of the covering material on the sound absorption coefficient of the base material and to develop recommendations for the selection of the covering material depending on the base material.

Keywords: sound absorption, covering, mineral wool, PU foam, melamine foam.

1. Introduction

Porous and fibrous acoustic panels are designed to reduce sounds of medium and high frequencies. Fiber fill made of mineral wool (glass or rock) is highly resistant to fire, hence it can also be used on surfaces above people's heads without additional fire protection. In the case of porous materials (polyurethane foam, or melamine foam), this is unfortunately not possible, due to the lower class of fire resistance. Foams, despite additional fire protection, can only be used on wall surfaces.

One of the most important limitations of mineral wool is its low resistance to mechanical damage and its dustiness. Therefore, it cannot be used without additional protection, especially in areas where the material may come into contact with humans. It is necessary to use protective layers separating the user from the wool fibers, increasing the mechanical resistance of the material, and protecting it from dusting. Coverings made of suitable material further enhance the visual appeal of raw mineral wool, transforming it from a building material into an interior finishing material. Adequate protection of the fibrous material is also necessary when using inside ventilation ducts, where there is an air flow with significant flow velocities. The material used for the coverings must be of high strength to effectively protect the wool fibers from being torn out by the airflow.

Melamine foams, due to their very high porosity and thin pore-forming walls, also have low mechanical resistance. That is why most uses of this type of foam also require protection against mechanical damage. The most mechanically resistant are polyurethane (PU) foams. In the case of appropriately selected foam structure and not too complicated shape, it is impossible to accidentally destroy them due to contact with unsharpened tools. Thus, the protection of the foams mainly performs an aesthetic function.

In mass-produced panels, the most common covering is glass tissue, which, due to its very low thickness and surface weight (e.g., 35 g/m^2), protects only against dusting without providing protection against damage [1]. Much better protection against deterioration is provided by glass fiber fabric used in wall panels [2]. In panels produced on a smaller scale or where greater individualization of the final product is needed, microfiber coverings are used [3].

Previous scientific work on the coating of porous or fibrous materials mainly deals with single combinations of base materials with face materials. In a paper by Witczak et al. [4], six different coverings made of polypropylene or polyester fibers with different woven fabric structural parameters were analyzed. The coverings were characterized by surface densities ranging from 216 to 320 g/m^2. Glass wool with a thickness of 50 mm and a density of 80 kg/m^3 was used as the base material. The high density of the base material resulted in low sound absorption coefficients (maximum α= 0.8 at a frequency of 1000 Hz), so any surface material applied to the surface of the base material improved its acoustic properties. The worst results were obtained for the material with the lowest air permeability and thickness.

In the paper [5], the authors showed that for all tested combinations of coverings made of textured, staple, and twisted polyester yarn types, the best acoustic performance was achieved in each case by plane weave, and the worst by sateen weave.

The present study analyzed 11 different coverings applied to three different porous or fibrous base infills with thicknesses of 30 and 50 mm, which is typical for this type of panel. The study began by determining the sound absorption coefficient in an impedance tube. Then the flow resistance of the base materials and coverings was determined by matching characteristics obtained from measurements and theoretical models. Further, based on the modeling results, the reverberant sound absorption coefficient was determined, and the weighted sound absorption coefficients were determined to allow single-number comparison of the obtained results. Further, the most favorable solutions were indicated both in terms of base materials and coverings and their combinations.

2. Methods

2.1. Measurements

Acoustic measurements were made following ISO 10534-2 standard [6], that is, using the acoustic transfer function method. The tests were conducted for three base samples and 11 coverings. To obtain the required frequency bandwidth used to describe materials in room acoustics, tests were carried out for samples with two diameters: 100 and 29 mm. The results for both sizes were averaged over an overlapping frequency band. A Brüel & Kjær type 4206 impedance tube was used in the tests. Signal generation, waveform collection for the two microphones, and determination of the transfer function and subsequent sound absorption coefficients were performed in the dedicated Brüel & Kjær PULSE software.

2.1. Acoustic modelling

Due to the impossibility of determining the detailed geometric parameters of the base materials or covering materials, the empirical Miki model [7] was used to model the acoustic properties of the structures. Miki model is a modification of the Delany-Bazley empirical model, with the possibility of determining the sound absorption coefficient more accurately, also for lower frequencies. In both cases, the only parameter determining the mechanical properties of a porous or fibrous material is the airflow resistivity σ, from which the characteristic impedance of the material can be determined:

$$Z(f) = 1 + 0.07\left(\frac{f}{\sigma}\right)^{-0.632} - 0.107j\left(\frac{f}{\sigma}\right)^{-0.632}, \tag{1}$$

where f is the frequency. Apart from the $Z(f)$ also propagation constant $k(f)$ is required:

$$k(f) = \frac{\omega}{c}\left[0.160\left(\frac{f}{\sigma}\right)^{-0.618} + 1j + 0.109j\left(\frac{f}{\sigma}\right)^{-0.618}\right], \tag{2}$$

where ω is an angular frequency, and c is the speed of sound in the air.
From these two quantities, the impedance at the surface of the material can be determined:

$$z_1 = Z(f)\cot(k(f)d), \tag{3}$$

and the reflection coefficient:

$$R = \frac{z_1\cos\varphi - \rho c}{z_1\cos\varphi + \rho c}, \tag{4}$$

where φ is the incident angle and ρ is the density of the air.
Finally sound absorption coefficient is calculated using equation:

$$\alpha = 1 - |R|^2. \tag{5}$$

The coverings were modeled as an oscillating membrane with a specific flow resistance:

$$z_2 = z_1 + \frac{j\omega\rho_{\text{cov}}r_{\text{cov}}}{j\omega\rho_{\text{cov}} + r_{\text{cov}}}, \tag{6}$$

where ρ_{cov} is the surface density of the material used for the covering, and r_{cov} is the flow resistance of the covering material.

Measurements were made in the pressure field for a normal incidence acoustic wave. In rooms, the absorption coefficient determined in a reverberation chamber for a random angle of incidence of an acoustic wave for a certain sample size is used for acoustic calculations. The inclusion of these parameters in the numerical model is made possible by taking into account the shape impedance z_r introduced by Thomasson [8]:

$$\alpha_{\text{size}} = 2\int_0^{\frac{\pi}{2}} \frac{4\Re(z_2)}{|z_2 + z_r(\varphi)|^2} \sin(\varphi)\, d\varphi, \tag{7}$$

where φ is the incidence angle of the acoustic wave. Application of equation (7) in some cases gives a sound absorption coefficient above 1.0 because of the limited size of the sample and not perfect diffusiveness of the sound field [9]. Results can be compared with measurements according to ISO 354 standard used in the room acoustics [10]. The single-number evaluation of acoustic structures was based on the weighted sound absorption coefficient α_w determined based on EN ISO 11654 [11].

The flow resistivity of the base materials was determined by comparing the sound absorption coefficient determined from measurements in the frequency range of 100 - 6400 Hz, with a resolution of 2 Hz, averaged to 1/12 octave bands, with the values determined from the model. The comparison consisted of determining the minimum value of the root mean square of the differences between the frequency characteristics. The flow resistance of the covers was also determined by comparison with values from measurements. The previously determined flow resistivity of the base material and the surface mass of the coating were fed into the model.

3. Results

3.1. Parameters of base materials and coatings

Parameters of base materials are shown in Table 1.

Table 1 Parameters of base materials.

Material	Symbol	Thickness [mm]	Flow resistivity [Pa·s/m^2]
Melamine foam	ME30	30	10850
Poliuretan foam	PU50	50	14650
Mineral wool	W50	50	33650

Covering materials were selected to cover a wide range of possibilities used in practice, and to have varying parameters that have a significant impact on the total sound absorption coefficient. All relevant parameters for modeling are summarized in Table 2. The four covering materials presented were impermeable to air – three foils of different thicknesses and Polyester 2, a waterproof material.

Table 2 Parameters of covering materials.

Material	Thickness [mm]	Surface density [g/m^2]	Flow resistance [Pa·s/m]
Cotton	0.91	290	350
Foil 1	0.005	3	∞
Foil 2	0.02	14	∞
Foil 3	0.05	33	∞
Flax	0.48	213	200
Canvas	0.44	246	150
Polyester 1	0.10	53	150
Polyester 2	0.18	100	∞
Corduroy	0.85	323	1300
Upholstery	0.95	320	800
Wool	1.25	470	720

3.2. Results of measurements

Melamine foam with a thickness of 30 mm achieved the lowest sound absorption coefficient, which was a direct result of its smaller thickness than the other materials tested. For the comparatively determined flow resistance of 10850 Pa·s/m^2, high agreement between the model and the measured results was obtained (Fig. 1a). Similarly high agreement was obtained for mineral wool (Fig. 1b), which, due to its greater thickness (50 mm), obtained higher sound absorption values for frequencies of 500 - 1000 Hz.

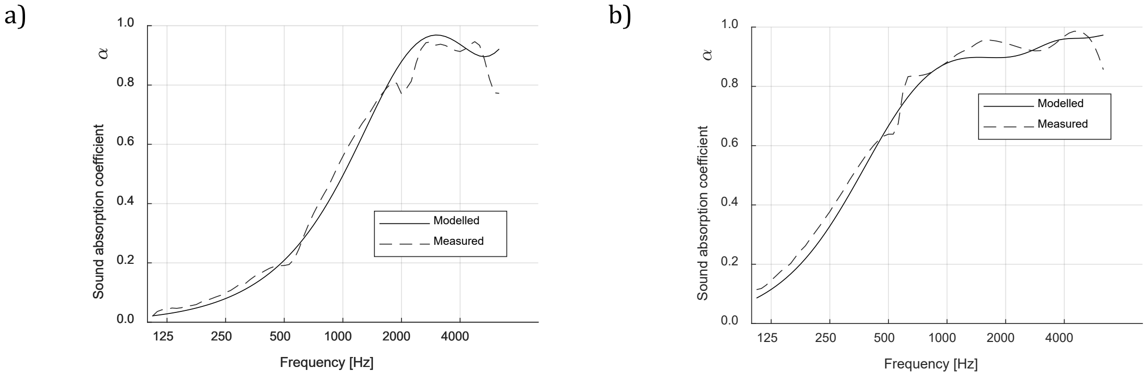

Figure 1. Comparison of modelled and measured values for base materials: a) Melamine foam (ME30), b) Mineral wool (W50). Calculations and measurements for normal incidence acoustic wave.

Comparing the measured results with the values obtained by modeling for combinations of base materials with different coverings, it can be seen that for low frequencies, high agreement was achieved for almost all material combinations (Fig. 2). In the case of air permeable coverings (Fig 2a and Fig 2b), the changes in sound absorption coefficient compared to the value without coverings (Fig. 1) were not significant. For air-impermeable coverings, namely Foils and Polyester 2, changes were observed only for materials with higher surface mass. For materials with low surface mass (Foil 1, 2), the system reduced sound absorption only for the highest frequencies. For the covering made of Polyester 2 with a surface weight of 100 g/m^3, there was a significant deterioration in acoustic properties. The character of sound absorption changed to resonant, and the sound absorption for high frequencies decreased significantly. The resonant frequencies for the subsequent base materials for Polyester 2 were 700 Hz (ME30), 430 Hz (PU50) and 520 Hz (W50).

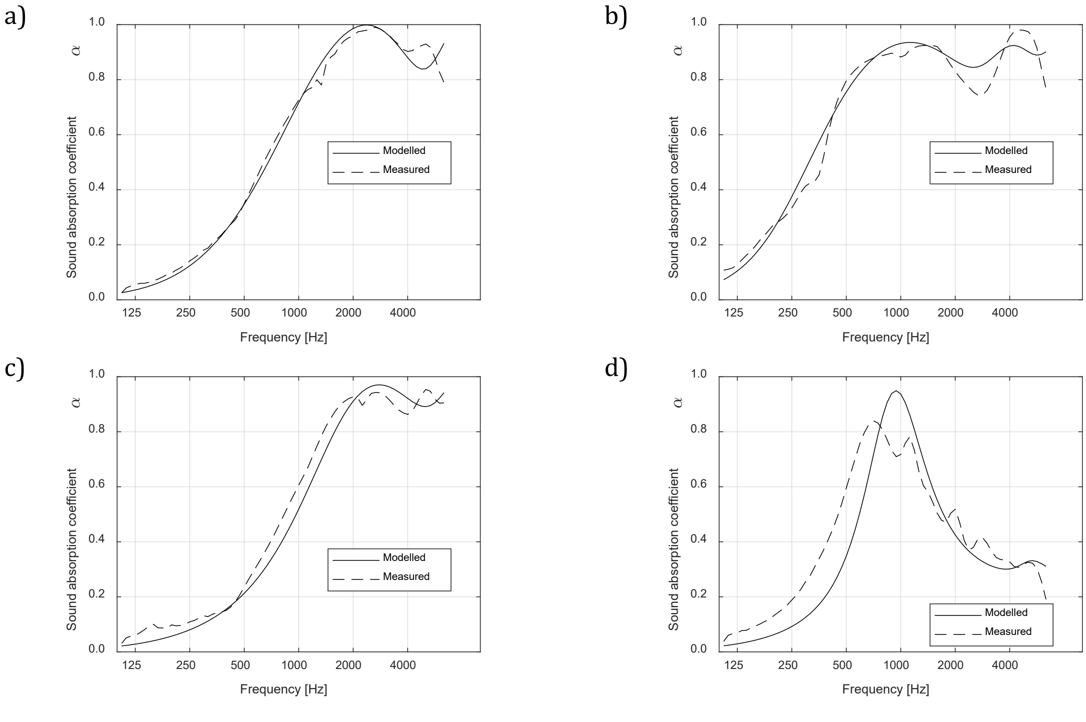

Figure 2. Comparison for modelled and measured values for covering materials with base: a) ME30 + Flax, b) PU50 + Cotton, c) ME30 + Foil 1, d) ME30 + Polyester 2. Calculations and measurements for normal incidence acoustic wave.

3.3. Sound absorption for air-permeable coverings

Based on the calculated results of the flow resistance of the base materials and coverings, comparative analyses were carried out for the different coverings used for the analyzed base materials. Figure 3 shows the results of the reverberant sound absorption (determined for a 3 x 3.5 m measurement sample located in a diffuse field according to equation (7)). Interestingly, in each case, the sound absorption coefficient for the original sample, i.e., without covering, increased after the application of air air-permeable covering. This is mainly due to the small thickness of the sample, and thus the low sound absorption coefficient for the base sample. Values above 1.0 are possible because of the limited size of the sample and not perfect diffusiveness of the sound field. The sample was least affected by materials with low flow resistance (Linen, Canvas, Polyester 1), for which there was an improvement in the mid-frequency range.

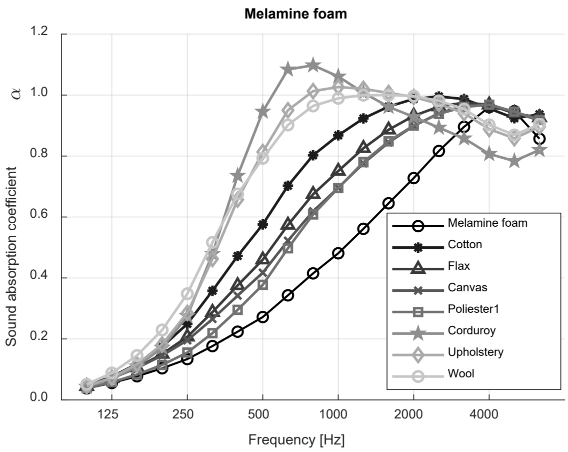

Figure 3. Random-incidence absorption coefficient for Melamine foam with non-airtight covering.

The largest increase in sound absorption coefficient for mid frequencies (500 - 1000 Hz) was for Corduroy, the material with the highest flow resistance (1300 Pa·s/m). However, note the decrease in absorption for the highest frequencies with this type of covering. For the ME30 base material, the most favorable covering turned out to be wool with a flow resistance of 720 Pa·s/m, where an increase in the weighted sound absorption coefficient was achieved from 0.35 for the base material to 0.65.

When air-permeable coverings were used for 50 mm-thick polyurethane foam, a similar trend was observed (Fig. 4). Here again, all air-permeable coverings improved the acoustic properties of the base material, allowing for very high sound absorption at 500 Hz for Corduroy. Again, wool had the greatest impact on improving the weighted sound absorption index, raising this parameter from 0.60 to 1.00, the highest possible value.

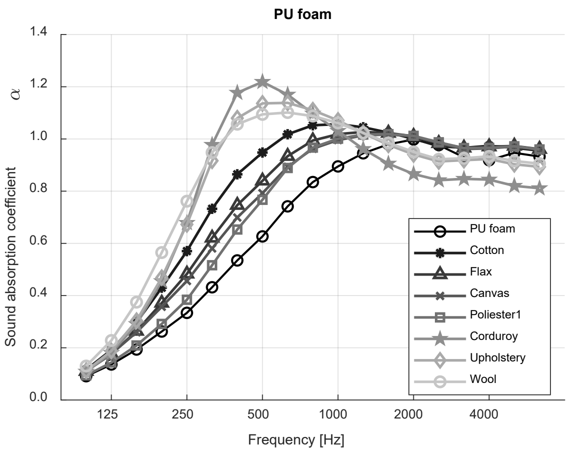

Figure 4. Random-incidence absorption coefficient for Polyurethane foam 50 mm thick with air-permeable covering.

In the case of 50 mm thick mineral wool as a basis material with the highest weighted sound absorption coefficient without covering (Fig. 5), it was not possible to obtain such a large improvement in the index due to its limitation at a value of 1.00. With similar trends as for the other two base materials, the maximum value was obtained for as many as two covering materials (Wool and Upholstery). In both cases, the flow resistance was similar (Wool - 720, Upholstery - 800 Pa·s/m).

Table 3. Weighted random-incidence absorption coefficient α_w for different bases and covering.

	ME30	PU50	W50
w/o	0.35	0.60	0.80
Cotton	0.55	0.85	0.95
Foil1	0.35	0.60	0.80
Foil2	0.35	0.65	0.80
Foil3	0.35	0.65	0.80
Flax	0.45	0.75	0.90
Canvas	0.45	0.75	0.85
Poliester1	0.40	0.65	0.85
Poliester2	0.35	0.40	0.45
Corduroy	0.60	0.90	0.90
Upholstery	0.60	0.95	1.00
Wool	0.65	1.00	1.00

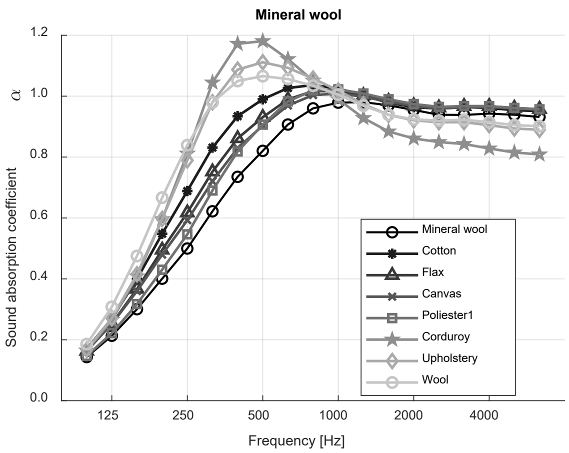

Figure 5. Random-incidence absorption coefficient for Mineral wool 50 mm thick with air-permeable covering.

In the case of air-impermeable materials, the results were more varied, as can already be seen in Table 3. Foils No. 1 and 2, with surface densities of 3 and 14 g/m^2, respectively, did not noticeably affect the characteristics or the weighted sound absorption coefficients. In the case of Foil 3, the single-number values also did not change, while the nature of the curves changed (Fig. 6). A reduction in absorption for high frequencies was observed for all three base materials. For the low-thickness melamine foam with low flow resistivity, the formation of a second resonance was additionally observed for Foil 3 and Polyester 2.

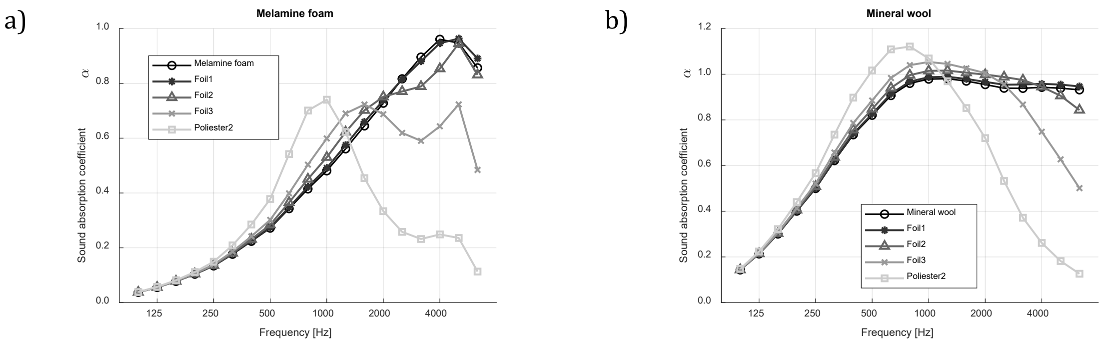

Figure 6. Random-incidence absorption coefficient for base materials with air-impermeable covering: a) base material: melamine foam, b) base material: mineral wool.

To facilitate the selection of air-impermeable material for different base materials, calculations of the dependence of α_w on surface density of covering were performed. The results are shown in Fig. 7. Coverings with surface densities up to about 50 g/m^2 are not destructive to weighted absorption indexes. They can only negatively affect absorptions for high frequencies (Fig. 6). On the other hand, for higher surface densities, the decrease in the single-number index occurs dynamically, reaching values as high as 0.05 for very high surface masses of the coverage.

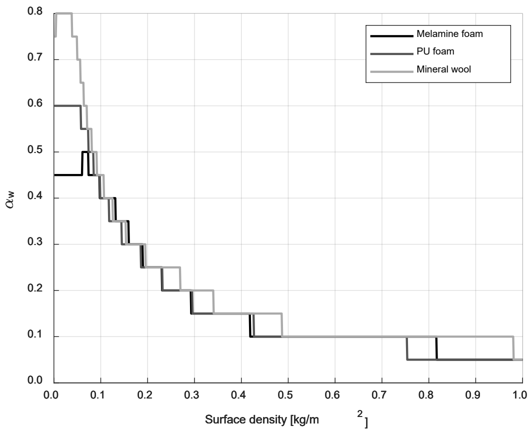

Figure 7. Weighted random-incidence absorption coefficient for different base materials with air-impermeable covering with different surface densities.

4. Conclusions

The research presented here deals with the applicability of coverings made of different types of materials for three selected base materials. The results of the measurements were used to calibrate the numerical models and determine the flow resistance of the materials (both base and covering), which were later used in analytical modeling.

Of the air permeable materials, wool with a surface density of 470 g/m^2 and a flow resistance of 720 Pa·s/m proved to be the most favorable covering. For all base materials, there was an improvement in sound absorption, while for the base with the lowest absorption (30 mm Melamine foam), the increase was the highest.

Among the air-impermeable coverings, it was noted that if the covering has a low surface density (up to about 50 g/m^2), it does not worsen the single-number sound absorption index. It only affects the absorption for high frequencies. Exceeding the value given above can lead to a significant deterioration of sound absorption. In the case of measured samples, a Polyester 2 material with a surface weight of 100 g/m^2 reduced the weighted indices by up to half (in the case of 50 mm Mineral wool).

In summary, the use of coverings on porous and fibrous materials is highly recommended and sometimes necessary. If they are materials with a flow resistance of less than 1000 Pa·s/m, they do not cause deterioration in sound absorption. On the contrary, in many cases, they can improve the performance of the base material if only their flow resistance is properly selected.

Acknowledgments

This work was partly supported by a research subsidy of the Faculty of Mechanical Engineering and Robotics, AGH University of Krakow, no. 16.16.130.942.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

References

1. Glass Fiber Veils V1 & V2 | Isover Technical Insulation; https://www.isover-technical-insulation.com/products/glass-fiber-veils-v1-v2#simple-table (accessed on 2025.04.02)
2. Ecophon AkustoTM Wall A | framed wall absorber; https://www.ecophon.com/uk/ecophon/wall-applications/akusto/akusto-wall-a2/ (accessed on 2025.04.02)

3. FiberMobile DOUBLE-SIDED - Mega Acoustic; https://www.mega-acoustic.pl/sklep/fibermobile/?v=288404204e3d (accessed on 2025.04.02)
4. E. Witczak, I. Jasińska, M. Lao, I. Krawczyńska, I. Kamińska; The influence of structural parameters of acoustic panels textile fronts on their sound absorption properties; Applied Acoustics, 2021, 178, 107964; DOI: 10.1016/J.APACOUST.2021.107964
5. B.T. Samuel, M. Barburski, E. Witczak, I. Jasińska; The Influence of Physical Properties and Increasing Woven Fabric Layers on the Noise Absorption Capacity; Materials, 2021, 14, 6220; DOI: 10.3390/MA14206220
6. ISO 10534-2; Acoustics — Determination of acoustic properties in impedance tubes — Part 2: Two-microphone technique for normal sound absorption coefficient and normal surface impedance, 2023
7. Y. Miki; Acoustical properties of porous materials-Modifications of Delany-Bazley models; Journal of the Acoustical Society of Japan (E), 1990, 11, 19–24; DOI: 10.1250/ast.11.19
8. S.-I. Thomasson; Theory and experiments on the sound absorption as function of the area; Department of Acoustics, Royal Institute of Technology, 1982
9. C. Jeong; Converting Sabine absorption coefficients to random incidence absorption coefficients; J. Acoust. Soc. Am, 2013, 133 (6), 3951-3962; DOI: 10.1121/1.4802647
10. ISO 354; Acoustics — Measurement of sound absorption in a reverberation room, 2003
11. ISO 11654; Acoustics — Sound absorbers for use in buildings — Rating of sound absorption, 1997

© 2025 by the Authors. Licensee Poznan University of Technology (Poznan, Poland). This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).