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COMPOSITES THEORY AND PRACTICE

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ASSESSMENT OF SOUND ABSORBING PROPERTIES OF POLYURETHANE SANDWICH SYSTEM

The article presents the results of the properties of sound absorbing layer systems produced from recycled polyurethane foams. The sound absorption coefficient values were determined on the basis of the standing waves method in the frequency range from 1000 to 6300 Hz. The average sound absorption coefficient values for the systems produced from the polyurethane foams were α_f = 0.82 (system formed from a foam of an apparent density of 220 kg/m^3), α_f = 0.59 (system formed from a foam of an apparent density of 240 kg/m^3). A comparative of the sound absorption coefficient values of produced chips layered in comparison to single layer foam was also presented. The highest average sound absorption coefficient value was obtained for the layer system formed from a foam of an apparent density 220 kg/m^3. The conducted study of the properties of sound absorbing polyurethane foam allowed selection of a technical solution that can be used to reduce noise in the work environment, and also to expand the possibilities of practical application of polyurethane foams from PU recyclates.

Keywords: **polyurethane materials, sound absorption coefficient, polyurethane sandwich system.**

OCENA WŁAŚCIWOŚCI DŹWIĘKOCHŁONNYCH POLIURETANOWYCH UKŁADÓW WARSTWOWYCH

Przedstawiono wyniki badań właściwości dźwiękochłonnych układów warstwowych wytworzonych z recyklingu pianek poliuretanowych. Wartości fizycznego współczynnika pochłaniania dźwięku określono na podstawie metody fali stojącej w zakresie częstotliwościowym od 1000 do 6300 Hz. Wartości średnie fizycznego współczynnika pochłaniania dźwięku dla układów wytworzonych z pianek poliuretanowych wyniosły α_f = 0,82 (układ utworzony z pianek o gęstości pozornej 220 kg/m^3), α_f = 0,59 (układ utworzony z pianek o gęstości pozornej 240 kg/m^3). Przedstawiono także analizę porównawczą wartości fizycznego współczynnika pochłaniania dźwięku wytworzonych układów warstwowych względem pianki jednowarstwowej. Najwyższą wartość średnią fizycznego współczynnika pochłaniania dźwięku uzyskano dla układu warstwowego utworzonego z pianek o gęstości pozornej 220 kg/m^3. Prowadzone badania właściwości dźwiękochłonnych pianek poliuretanowych spienionych wtórnie pozwoliły na wybór rozwiązania technicznego, które może zostać wykorzystane do ograniczania hałasu w środowisku pracy, a zarazem poszerzać możliwość praktycznego zastosowania pianek poliuretanowych pochodzących z recyklatów PU.

Słowa kluczowe: **materiały poliuretanowe, fizyczny współczynnik pochłaniania dźwięku, poliuretanowe układy warstwowe**

INTRODUCTION

Noise is a factor that accompanies a human-being in everyday life and work, and its excessive emission can cause adverse health effects. The implementation of noise control solutions based on soundproofing materials reduces noise, which is associated with the formation of a proper acoustic climate. In literature topics [1-3], the term "acoustic climate" should be understood as a group of acoustic phenomena that occur in a particular environment, caused by sound sources located in this environment. Thus the acoustic climate is influenced by, e.g.: machinery, equipment, tools or means of transport located in the analyzed environment. The key element in combating the threats of noise is the implementation of legal and technical solutions. The technical method of passive noise reduction is the implementation of barriers to limit noise emission in the form of layered systems made from polyurethane foam secondarily foamed.

In industrial practice, increasingly more materials of sound absorbing properties are used for noise reduction. By absorbers we understand materials made in the form of plates or mats with a suitable decorative texture, which allows its direct use. Absorbers absorb the energy of a sound wave due to their porous or fibrous structure. The absorption is caused by losses in the viscous materials (porous) or friction (fibrous) and internal friction occurring mainly in plastic materials [1-3]. A sound wave that encounters a barrier on its way is reflected from it, can be absorbed by it, and it can penetrate to the other side, as schematically presented in

Figure 1. In the case of soundproofing materials, the desirable physical phenomenon is the greatest absorption of the energy of the acoustic wave, which is converted into thermal energy.

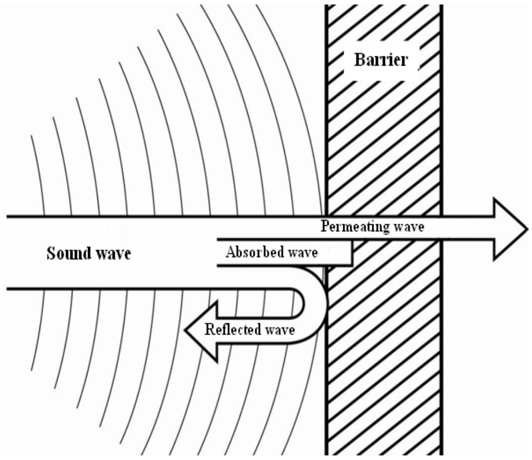

Fig. 1. Sound wave propagation [4]

Rys. 1. Propagacja fali dźwiękowej [4]

MATERIAL CHARACTERISTICS AND RESEARCH METHOD

The study focused on sound absorbing layer systems composed of polyurethane foam secondarily foamed of apparent densities of 220 and 240 kg/m^3 (Table 1). The tested polyurethane foams secondarily foamed are obtained by foaming polyurethane containing a high amount of PU foam recyclates of varying density. The recyclates are in the form of milling grain of a diameter of 5 to 20 mm and come from production waste and post consumer waste. They are of diverse kinds, but only contain soft foam [5].

TABLE 1. **Characteristics of tested material**

TABELA 1. **Charakterystyka badanego materiału**

Symbol of material	Number of layers	Apparent density	Thickness of sample
W-220	1	220 kg/m^3	40 mm
W-240	1	240 kg/m^3	40 mm
UW-220	2	220 kg/m^3	40 mm
UW-240	2	240 kg/m^3	40 mm

Acoustic research was dedicated to layer systems built of secondarily foamed foam of apparent densities of 220 and 240 kg/m^3 and a thickness of 40 mm, which are indicated in Table 1 as W - single layer foam and UW - the layer system formed from polyurethane foam of the same apparent density. A permanent bond was provided by a single layer polyurethane adhesive of a thickness not exceeding 3 mm, for bonding porous materials. The construction of the sandwich system is shown in Figure 2.

The sound absorbing properties of the materials are described by the sound absorption coefficient values, which are expressed by a number less than one unit. The physical absorption coefficient, sound α is defined as the ratio of sound energy absorbed by the tested material to the total energy falling on its surface [6-9]. One of the methods to identify the sound absorption coefficient value of sound absorbing materials is the standing wave method. It allows determining the sound absorption coefficient on the basis of a plane wave in an impedance tube created by imposition of a incident plane sinusoidal wave on the plane wave reflected from a flat surface of the evaluated sample. The scheme of the measurement track to determine the sound absorption coefficients is presented in Figure 3. As a result of the contact between the wave and the surface of the sample, one part of the energy is absorbed and another is reflected from it. The physical sound absorption coefficient is determined based on measurements of acoustic pressures in the p_{max} arrow and p_{min} node of the standing wave, which are proportional to the voltage values read on the microphone amplifier. Determining the sound absorption coefficient is about taking the measurements of voltage and calculating its value based on equation [8-10]:

$$\alpha_f = 1 - \left[\frac{p_{\max} - p_{\min}}{p_{\max} + p_{\min}}\right]^2 = 1 - \left[\frac{U_{\max} - U_{\min}}{U_{\max} + U_{\min}}\right]^2 \quad (1)$$

where: α_f - sound absorption coefficient [-]; p_{max} - maximum sound pressure of standing wave [Pa]; p_{min} - minimum sound pressure of standing wave [Pa] on the measurement amplifier; U_{max} - maximum value of voltage [mV] on the measurement amplifier; U_{min} - minimum value of voltage [mV].

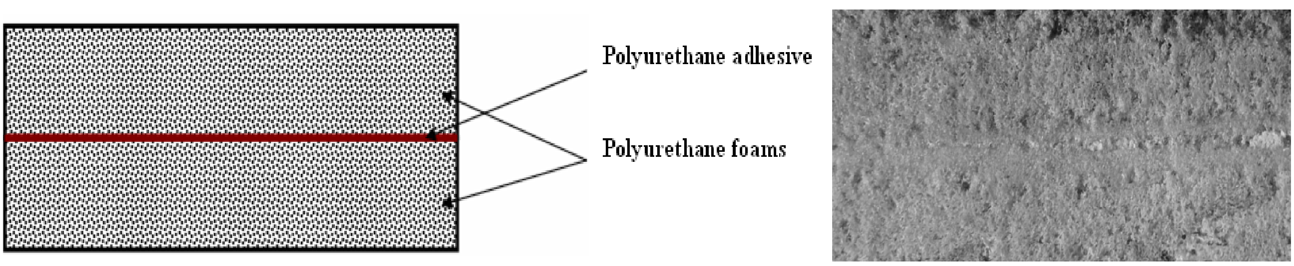

Fig. 2. Construction of sandwich system

Rys. 2. Konstrukcja układu warstwowego

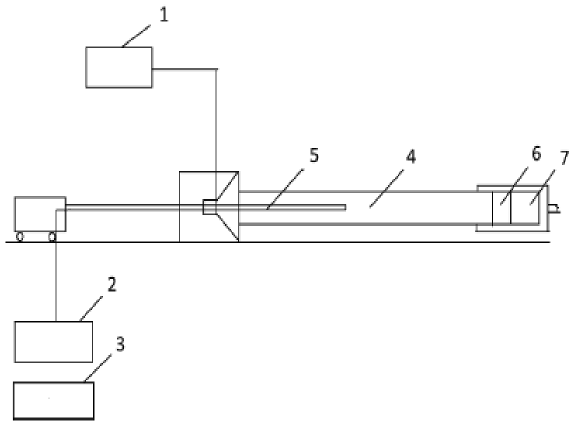

Fig. 3. Measuring path for determining sound absorption coefficient [10]: 1 - acoustic generator, 2 - measuring amplifier, 3 - filter system, 4 - Kundt's tube, 5 - microphone probe, 6 - tested material, 7 - sealing disc

Rys. 3. Tor pomiarowy do wyznaczania fizycznego współczynnika pochłaniania dźwięku [10]: 1- generator akustyczny, 2 - wzmacniacz pomiarowy, 3 - układ filtrów, 4 - rura Kundta, 5 - sonda mikrofonowa, 6 - badany materiał, 7 - krążek uszczelniający

RESEARCH RESULTS AND ANALYSIS

The layer systems tested in the frequency range from 1000 to 6300 Hz are characterized by sound absorbing properties, as indicated by the of sound absorption coefficient values. It is stated that the material has the desired absorbing properties if the value of the sound absorption coefficient is greater than 0.4. The tested systems also have higher values of sound absorption coefficients with respect to a single layer foam, whose sound absorbing properties were also compared with originally foamed foams [9].

For the layer system formed from the foam of an apparent density of 220 kg/m^3, designated as UW-220 (Table 1), the determined average value of the physical sound absorption coefficient is 0.82, which allows including the tested system in the group of sound absorbing materials.

TABLE 1. **Sound absorbing properties of polyurethane materials**

TABELA 1. **Fizyczny współczynnik pochłaniania dźwięku materiałów poliuretanowych**

Kind of material			W-220	W-240	UW-220	UW-240
Sound absorption coefficient α_f	Frequency [Hz]	1000	050	0.46	0.57	0.40
		1250	0.54	0.50	0.71	0.50
		1600	0.62	0.60	0.77	0.58
		2000	0.55	0.49	0.87	0.55
		2500	0.64	0.57	0.93	0.63
		3150	0.61	0.57	0.90	0.61
		4000	0.65	0.59	0.86	0.65
		5000	0.70	0.63	0.88	0.67
		6300	0.76	0.68	0.90	0.71
$\alpha_{f,\ avg.}$			0.62	0.57	0.82	0.59

The tested layer system exhibits sound absorbing properties throughout the whole tested frequency range, i.e. from 1000 to 6300 Hz. The highest set of values of sound absorption coefficient α_f were observed for frequency f = 2500 Hz (α_f = 0.93) and f = 6300 Hz (α_f = 0.90). The UW-220 system at these frequencies absorbs respectively 93 and 90% of the energy of the sound wave. The lowest value of sound absorption coefficient was 0.57, for frequency f = 1000 Hz.

Comparing the sound absorption coefficient values of the layer system indicated in Table 1 as UW-220 in relation to the single layer foam designated as W-220, it was found that this system exhibits higher sound absorption coefficient values. The highest value of α_f for a single layer foam was observed at the frequency of 6300 Hz and amounted to 0.76. The single layer material possesses the desired sound absorbing properties ($\alpha_f > 0.4$), but the average sound absorption coefficient in relation to the layer system is lower by 0.2. Graphic interpretation of the sound absorption coefficient results is shown in Figure 4.

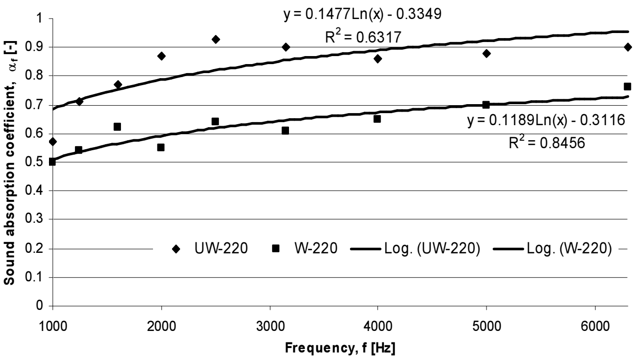

Fig. 4. Dependence of sound absorption coefficient on frequency

Rys. 4. Zależność fizycznego współczynnika pochłaniania dźwięku od częstotliwości

The UW-240 layer system exhibits the desired properties of absorbents, and the average sound absorption coefficient in the frequency range from 1000 Hz to 6300 Hz is 0.59. The highest sound absorption coefficient value was observed for frequency f = 6300 Hz and amounted to 0.71. The layer system indicated as UW-240 shows a lower difference in the average value of sound absorption coefficients with respect to homogenous material than the UW-220 system. The layer system is characterized by higher values of sound absorption coefficient in the frequency range from 2000 to 6300 Hz with respect to homogenous material. For the homogenous material the highest value of sound absorption coefficient was 0.68, for frequency f = = 6300 Hz. Graphic interpretation of the results is shown in Figure 5.

Based on the analysis it was found that the layer systems more effectively absorb the energy of a sound wave in comparison to single layer material in the examined frequency range. The UW-220 and UW-240 systems created by the permanent bond by adhesive polyurethane foams of the same apparent density exhibits the desired properties of sound absorption, as it is evidenced by the sound absorption coefficient value. However, the difference in the absorption coefficient values should be noted, which depends in the case of these materials on their apparent density. An increase in apparent density causes deterioration of the properties of single layer sound absorbing material, as well as sandwich systems. Graphic interpretation of the sound absorption coefficient values for the layer systems is shown in Figure 6.

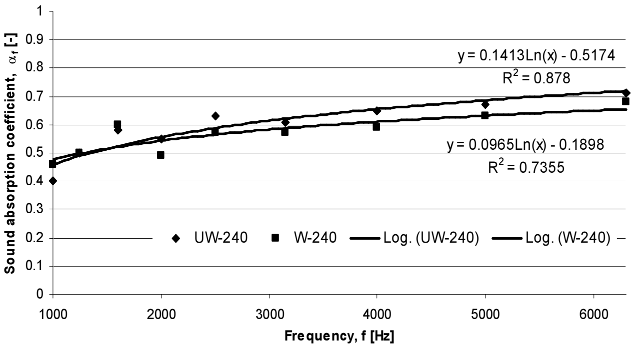

Fig. 5. Dependence of sound absorption coefficient on frequency

Fig. 5. Zależność fizycznego współczynnika pochłaniania dźwięku od częstotliwości

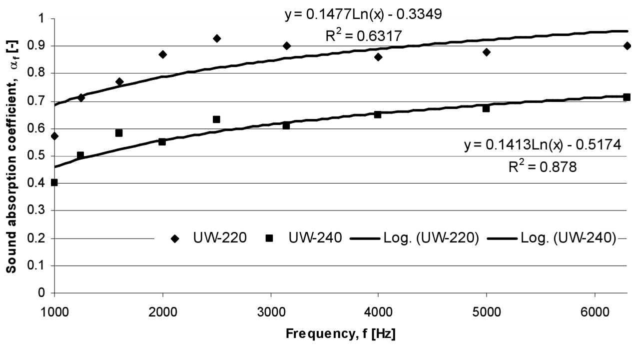

Fig. 6. Dependence of sound absorption coefficient on frequency

Fig. 6. Zależność fizycznego współczynnika pochłaniania dźwięku od częstotliwości

Based on analysis of the obtained results of sound absorbing properties, it was found that single layer materials and layer systems composed of polymers derived from recyclate may be used for the construction of noise control products. The highest average value of sound absorption coefficient was demonstrated by the UW-220 system. The obtained higher average values of sound absorption coefficients of the layered systems, with respect to homogenous material result from the physical phenomena occurring in the porous material and the layer of polyurethane glue. Sound waves in the high frequency range have a shorter length so they are absorbed more easily by the porous material. When falling on the polyurethane foam, they are partially reflected from its surface, and most of all them are absorbed as indicated by the sound absorption coefficient values. In the porous material the sound waves are absorbed and reflected, passing through a complex route. The weakened sound waves hitting the layer of polyurethane adhesive coat partly reflected by it are absorbed and move to the next soundproof layer. In this layer again they undergo the physical phenomena (absorption, reflection) as in the first layer. The process of sound wave propagation in layered systems is schematically shown in Figure 7.

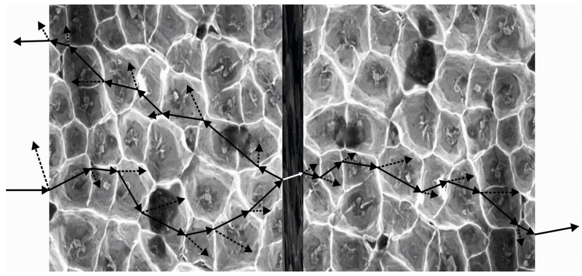

Fig. 7. Propagation of sound waves in sandwich system

Rys. 7. Propagacja fali dźwiękowej w układzie warstwowym

SUMMARY AND CONCLUSION

The developed innovative layer systems of polyurethane foams secondarily foamed can be used to build anti-sound protections. Due to implementation of the adhesive layer between the foam layers, a more complex process of which the incident sound wave will undergo more frequent phenomena of absorption and reflection in layer systems was achieved. In layer systems sound waves underwent the same phenomena as in homogeneous materials, but introduction of the adhesive layer raises the sound absorbing properties of the studied layer systems. This increase is associated with the introduction of an additional layer reflecting and absorbing the energy of the sound wave. Based on the research it was found that:

- material made from PU recyclate exhibits the desired sound absorbing properties, $\alpha_{f,\ avg.} > 0.4$
- layer systems have a greater ability to absorb sound wave energy than the single layer ones
- the polyurethane adhesive layer increases the sound absorption coefficient value in layer systems
- the one-component polyurethane adhesive provides an additional barrier for acoustic waves in layer systems
- the highest average value of sound absorption coefficient was recorded for the UW-220 layer system
- the tested layer systems composed from foamed PU can be used to build noise control products.

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