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Evaluation of acoustic properties of porous asphalt wearing course of a road pavements under laboratory conditions

Ocena właściwości akustycznych warstwy ścieralnej z asfaltu porowatego nawierzchni drogowych w warunkach laboratoryjnych

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Abstract. The use of porous asphalt in the wearing course of a road pavement has a significant effect on reducing tyre/road noise levels. The parameters characterising the acoustic properties of the wearing course are sound absorption coefficient and water permeability. This paper presents an analysis of the results of a study of the sound absorption coefficient and water permeability of porous asphalt mixtures. A significant influence of the air voids content of the mixture on the values of the parameters studied was found.
Keywords: porous asphalt; sound absorption coefficient; water permeability; air void content.

Streszczenie. Zastosowanie asfaltu porowatego w warstwie ścieralnej nawierzchni drogowej istotnie wpływa na obniżenie poziomu hałasu opona/nawierzchnia. Parametrami charakteryzującymi właściwości akustyczne warstwy ścieralnej są współczynnik pochłaniania dźwięku i wodoprzepuszczalność. W artykule przedstawiono analizę wyników badań współczynnika pochłaniania dźwięku oraz wodoprzepuszczalności mieszanek z asfaltu porowatego. Stwierdzono istotny wpływ zawartości wolnych przestrzeni w mieszance na wartości badanych parametrów.
Słowa kluczowe: asfalt porowaty; współczynnik pochłaniania; wodoprzepuszczalność; zawartość wolnych przestrzeni.

Improving the acoustic climate around road routes requires, among other things, the construction of pavements with reduced noise levels. The use of porous asphalt in the wearing course contributes to a reduction in tyre/road noise levels of up to 6 dB(A) [1, 2]. The results of tests on sound absorption coefficient and water permeability as parameters determining the acoustic properties of mineral-asphalt mixtures can provide important information at the stage of pavement design selection. The sound absorption coefficient α describes how effectively a material absorbs an incident sound wave. It takes values between 0 and 1, where 0 is total reflection of the sound wave and 1 is total absorption.

Road surfaces characterised by a high sound absorption coefficient significantly reduce the magnitude of the tyre-rolling noise emission on the pavement, which is the main and largest component of the total car noise emission at driving speeds above 50 kph. Since the highest values of car tyre rolling noise levels on the pavement occur in the frequency range of the middle 1/3 octave bands 630 Hz ÷ 1250 Hz it is recommended that the highest values of the sound absorption coefficient of the wearing course occur in this frequency range [2].

Measurement methods

The best known method for measuring and evaluating the sound absorption coefficient of building materials under laboratory conditions is the standing wave ratio method using a Kundt tube [3]. The test uses an impedance tube with a circular cross-section. The complete set-up consists of two tubes with internal diameters of ϕ100 mm and ϕ30 mm, a microphone probe, an acoustic generator to obtain a standing wave and two third-octave filters at the microphone output to increase the accuracy of the measurement. The test involves placing the sample in a container, determining the acoustic pressures at the arrows and nodes of the standing wave and calculating the physical absorption coefficient.

A certain modification of the Kundt tube method, is the so-called two-microphone method using the transition function described in ISO 10534-2:1998 [4]. The measurements use two microphones mounted in the wall of the impedance tube at well-defined distances L and s from the test sample. By changing the distance s between the two measuring microphones and/or changing the diameter of the tube, the frequency range in which sound absorption coefficient measurements can be made can be varied [5]. During measurements, as in the standing wave ratio method, care must be taken to ensure that the test sample fits and seals well inside the impedance tube [6]. The advantage of this method is its speed and simplicity, hence it has also found application in in situ measurements of the sound absorption coefficient of road surfaces regulated by ISO 13472-2:2010 [7].

Due to the measurement being carried out in the vertical position, the fixed

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measurement frequency range for road surfaces of 250 Hz to 1600 Hz and the requirement to produce a plane wave in the tube, fixed dimensions were introduced: the tube diameter should be 100 mm and the distance between the pair of microphones s = 81±4 mm. The microphone closer to the road surface should be at a distance L ≥ 100 mm from the road surface and the reference microphone should be at a distance greater than three pipe diameters (300 mm). The in situ method is designed for testing smooth pavements with low sound absorption and according to ISO 10844 mainly for pavements with a sound absorption coefficient not exceeding 0.15 [8].

Photo 1 shows the ACUPAVE kit during an in situ pavement measurement. The Spectronics ACUPAVE System consists of an ACUPAVE tube with brackets, a JBL 2426K sound source with threaded mounting plate, ½-inch microphones and brackets, ground mounts, a DT9837A data acquisition and processing module and ACUPAVE software [9].

Photo 1. Spectronics ACUPAVE System – measurement on the road surface
Fot. 1. Spectronics ACUPAVE System – pomiar na nawierzchni drogowej

The Spectronics ACUPAVE System can also be used in the laboratory on cut or prepared samples [6, 10, 11, 12]. At the Bialystok University of Technology, an attachment to the cylindrical tube of the ACUPAVE System has been made that allows sound absorption coefficient tests in the frequency range 315 Hz ÷ 1600 Hz in laboratory conditions according to the two-microphone method [4]. The measuring station consists of a Spectronics ACUPAVE System device connected to an attachment, which is a horizontal tube with a diameter of 100 mm, inside which the test sample is placed (Photo 2). On the outside of the tube is a millimetre scale that fixes

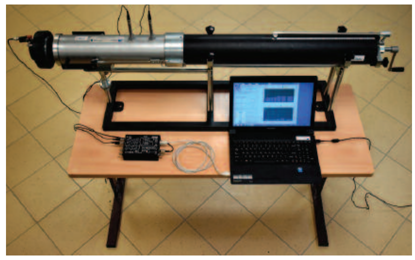

Photo 2. Spectronics ACUPAVE System with attachment – measurement in the laboratory
Fot. 2. Spectronics ACUPAVE System z przystawką – pomiar w laboratorium

the position of the metal piston according to the height of the test sample. The „0" position of the piston is the distance L = 107.95 mm between the test surface of the sample and microphone No. 2 according to ISO 10534-2:1998 [4].

In order to assess the correctness of the measurement set-up and the reliability of the measurements, a validation test of the system was carried out under laboratory conditions, as recommended by [13]. The test consists of measuring a hypothetical part of the impedance of a closed pipe of length L_0 and comparing it with the calculated results. Figure 1 shows a comparison of the measured and calculated impedance values of the pipe used during the measurements for a value of L_0 = 15 cm. The obtained values confirmed good agreement, which means that the measurement system was well set up.

Before the main tests, a comparative analysis of the sound absorption coefficient results of porous asphalt cylindrical specimens with a height of h = 3 cm (W1 and W2) and with a height of h = 5 cm (W3 and W4) was carried out. The analysis was based on test results obtained in a Spectronics ACUPAVE System with an attachment (SA: Bialystok University of Technology) and in a Kundt tube (RK: Department of Mechanics and Vibroacoustics, AGH University of Science and Technology in Krakow). The results shown in Table 1 and Figure 2 confirmed good agreement. This formed the basis for testing the sound absorption coefficient using the Spectronics ACUPAVE System with a constructed attachment on porous asphalt samples under laboratory conditions.

The vertical and horizontal water permeability of road pavements is determined according to EN 12697-19:2020-07 [14]. The test consists of loading cylindrical specimens with a water column of a fixed height of 300±1 mm and measuring the amount of water that seeps through the specimen in vertical or horizontal directions in a measured time.

The vertical water permeability K_v (m/s) is calculated according to the Darcy's formula:

$$K_v = \frac{4 \cdot Q_v \cdot l}{h \cdot \pi \cdot D^2} \quad \text{[m/s]}$$

where:
Q_v – vertical water flow through the sample [m^3/s];
l – sample thickness [m];
D – diameter of the sample [m];
h – current water column height (in the vertical water permeability test) [m].

The horizontal water permeability of the sample K_h (m/s) is determined according to the modified Darcy's formula:

$$K_h = \frac{Q_h \cdot l}{0{,}3 \cdot (\pi \cdot D \cdot l)} \quad \text{[m/s]}$$

where:
Q_h – horizontal water flow through the sample [m^3/s];
l – sample thickness [m];
D – diameter of the sample [m].

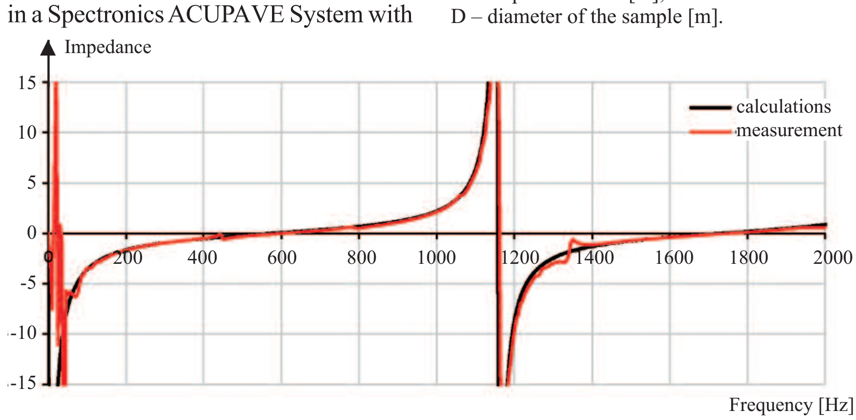

Fig. 1. Results of the validation test of the measuring set
Rys. 1. Wyniki testu potwierdzającego poprawność działania zestawu pomiarowego

Table 1. Sound absorption coefficient values according to Kundt tube (RK) and Spectronics ACUPAVE System (SA) tests
Tabela 1. Wartości współczynnika pochłaniania dźwięku w badaniach rurą Kundta (RK) i Spectronics ACUPAVE System (SA)

Sample	Research apparatus	Sound absorption coefficient for frequencies of the middle 1/3 octave bands							
		315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz
W1 h = 3 cm	SA	0,04	0,05	0,08	0,16	0,37	0,78	0,58	0,27
	RK	0,07	0,10	0,10	0,18	0,31	0,57	0,79	0,49
W2 h = 3 cm	SA	0,05	0,06	0,10	0,18	0,41	0,73	0,55	0,27
	RK	0,08	0,10	0,12	0,19	0,38	0,62	0,70	0,37
W3 h = 5 cm	SA	0,09	0,12	0,21	0,46	0,74	0,43	0,25	0,31
	RK	0,13	0,15	0,24	0,46	0,82	0,60	0,34	0,25
W4 h = 5 cm	SA	0,09	0,13	0,27	0,61	0,62	0,29	0,19	0,28
	RK	0,11	0,19	0,33	0,66	0,77	0,48	0,27	0,29

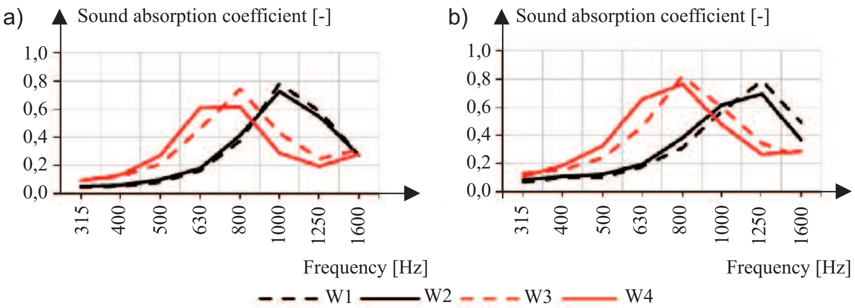

Fig. 2. Sound absorption coefficients: a) SA; b) RK; (black colour: h = 3 cm, red colour: h = 5 cm)
Rys. 2. Współczynniki pochłaniania dźwięku: a) SA; b) RK; (kolor czarny: h = 3 cm, kolor czerwony: h = 5 cm)

According to the provisions of the standard [14], the vertical water permeability of porous pavements ranges from $0.5 \cdot 10^{-3}$ m/s to $3.5 \cdot 10^{-3}$ m/s.

Research and analysis

Tests on sound absorption coefficient and vertical water permeability were carried out in the road laboratory at the Bialystok University of Technology on mineral-asphalt mixtures of the PA5 and PA8 porous asphalt types. In the case of porous asphalt PA5, mixtures with the following air void content were tested: 26.3% (PA5a), 24.4% (PA5b), 21.2% (PA5c) and 15.8% (PA5d), and for PA8: 29.1% (PA8a), 25.4% (PA8b), 20.9% (PA8c) and 16.8% (PA8d). The mixtures tested contained PBM 45/80-65 asphalt in amounts ranging from 5.7% to 6.4% and a cellulose fibre-based stabilising agent in an amount of 0.5% by weight of the total mix.

Sound absorption coefficient tests were carried out using the Spectronics ACUPAVE System with an attachment. After calibration of the measurement set-up, the sample was placed in the impedance tube, properly sealed and the sound absorption coefficient measured. For each mixture, the sound absorption coefficient was measured on 3 cylindrical samples with a diameter of D = 100 mm and a height of h = 4 cm. The results of the analysis of the sound absorption coefficient values depending on the frequency of the sound band and the type of mineral-asphalt mixture are shown in Table 2.

Figure 3 shows a comparison of the sound absorption coefficients determined on PA5 and PA8 mixtures as a function of the air void content and sound frequency.

The results shown in Table 2 and Figure 3 confirmed that the sound attenuation capacity of the mixtures is higher as the higher is the air void content. The mixture with the highest sound absorption capacity in the frequency range 630 Hz ÷ 1000 Hz was the PA8a mixture with the highest air void content (29.1%), followed by the PA5a mixture (26.3%). Of the mixtures with similar air void content (PA5a, PA5b and PA8b), the higher sound absorption coefficient was found on PA5 mixtures. By far the lowest sound absorption coefficients (< 0.2) were determined on PA5 and PA8 mixtures with an air void content of 15.8% and 16.8% respectively. This means that the air void content of the mixture has a significant influence on the sound absorption coefficient. At the same time, there was no clear effect of the maximum aggregate grain size on the sound absorption coefficient.

Table 2. Average sound absorption coefficient values of individual PA5 and PA8 mix types
Tabela 2. Średnie wartości współczynnika pochłaniania dźwięku poszczególnych typów mieszanek PA5 i PA8

Type of mix	Sound absorption coefficient for centre frequencies of 1/3 octave bands ± standard deviation [-] (coefficient of variation)							
	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz
PA5a	0,09±0,00 (5,1%)	0,14±0,01 (6,9%)	0,24±0,02 (10,0%)	0,45±0,02 (4,8%)	0,62±0,05 (8,8%)	0,44±0,06 (14,7%)	0,26±0,02 (9,0%)	0,21±0,00 (2,2%)
PA5b	0,10±0,01 (9,8%)	0,15±0,01 (9,4%)	0,24±0,00 (0,0%)	0,41±0,05 (13,4%)	0,52±0,12 (22,8%)	0,40±0,05 (12,7%)	0,29±0,03 (8,9%)	0,28±0,09 (32,9%)
PA5c	0,12±0,02 (17,6%)	0,18±0,02 (12,0%)	0,26±0,02 (6,3%)	0,32±0,05 (17,2%)	0,29±0,06 (20,1%)	0,24±0,03 (13,9%)	0,20±0,02 (9,6%)	0,21±0,01 (5,8%)
PA5d	0,12±0,04 (36,0%)	0,14±0,06 (40,4%)	0,15±0,06 (38,1%)	0,14±0,05 (36,4%)	0,13±0,05 (35,0%)	0,13±0,03 (25,1%)	0,13±0,03 (24,7%)	0,14±0,05 (38,2%)
PA8a	0,05±0,00 (0,0%)	0,08±0,01 (10,2%)	0,14±0,02 (12,4%)	0,29±0,03 (10,8%)	0,62±0,00 (0,8%)	0,69±0,07 (10,4%)	0,39±0,03 (7,5%)	0,23±0,01 (5,3%)
PA8b	0,09±0,02 (19,6%)	0,16±0,03 (21,1%)	0,29±0,04 (14,0%)	0,43±0,09 (20,1%)	0,33±0,11 (33,3%)	0,21±0,06 (27,7%)	0,15±0,02 (11,1%)	0,14±0,02 (11,7%)
PA8c	0,08±0,00 (6,1%)	0,13±0,01 (9,8%)	0,25±0,03 (13,8%)	0,44±0,04 (8,7%)	0,45±0,00 (1,0%)	0,30±0,03 (10,9%)	0,19±0,02 (8,8%)	0,19±0,02 (11,0%)
PA8d	0,12±0,02 (18,0%)	0,14±0,04 (32,9%)	0,14±0,06 (42,0%)	0,12±0,04 (29,9%)	0,12±0,02 (13,6%)	0,12±0,02 (20,2%)	0,14±0,03 (21,0%)	0,17±0,03 (18,5%)

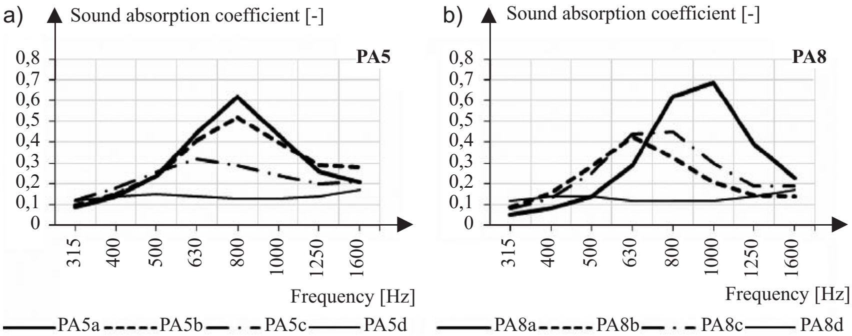

Fig. 3. Sound absorption coefficients determined for: a) PA5; b) PA8 mix types
Rys. 3. Współczynniki pochłaniania dźwięku ustalone na mieszankach: a) PA5; b) PA8

The vertical water permeability of porous asphalt mixtures was tested on samples previously subjected to a sound absorption coefficient assessment. Table 3 shows the values of the K_v coefficient.

Table 3. Water permeability of porous asphalt mixtures
Tabela 3. Wodoprzepuszczalność mieszanek z asfaltu porowatego

Type of mix	Sample number	K_V [m/s]	Mean air void content ± standard deviation [%]
Samples PA5			
PA5a	1	1,16E-03	26,3±0,1
	2	1,30E-03	
	3	0,88E-03	
PA5b	1	0,96E-03	24,4±0,2
	2	0,95E-03	
	3	0,60E-03	
PA5c	1	3,57E-04	21,2±0,1
	2	3,42E-04	
	3	1,75E-04	
PA5d	1	4,68E-05	15,8±0,0
	2	9,07E-05	
	3	1,02E-05	
Samples PA8			
PA8a	1	2,98E-03	29,1±0,4
	2	3,27E-03	
	3	2,13E-03	
PA8b	1	1,44E-03	25,4±0,7
	2	7,36E-04	
	3	1,09E-03	
PA8c	1	1,06E-03	20,9±0,8
	2	1,09E-03	
	3	1,01E-03	
PA8d	1	3,23E-04	16,8±0,5
	2	9,68E-05	
	3	1,83E-04	

Mixtures that had results within the limit values for pavements with good drainage properties were distinguished.

The obtained vertical water permeability coefficients K_v confirmed the significant influence of the air void content of the porous asphalt mixture on its value. More favourable from the point of view of water permeability were the PA8 mixes, which, with an air void content of more than 20%, can be considered as layers with good drainage properties. In the case of the PA5 mix, good drainage properties will be characterised by mixes with an air void content above 24%.

Conclusions

The choice of wearing course for pavement construction is important in terms of reducing the level of sound emitted from traffic. Evaluating the sound absorption coefficient and water permeability of mineral-asphalt mixtures under laboratory conditions will make it possible to assess their acoustic properties. The results of the study confirmed the significant influence of the air voids content on the sound absorption coefficient and water permeability of the porous asphalt mixture.

For PA5 and PA8 mixtures with similar air voids content, higher sound absorption coefficient values were recorded for the PA5 mixture. The results of the tests confirmed that the sound absorption coefficients in the tested mixtures with an air voids content of less than 20% were below 0.20.

It was found that the PA8 mixes were more favourable from a water permeability point of view than the PA5 mixes, as they had good drainage properties at air void contents above 20%. In the case of the PA5 mix, good drainage properties were obtained at air void contents above 24%.

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