EFFECT OF THE COMPOSITE TEMPERATURE AND HUMIDITY TEST ON THE SOUND ABSORPTION COEFFICIENT OF FIBROUS MATERIALS USED IN AUTOMOTIVE APPLICATIONS

BADANIE WPŁYWU STARZENIA MATERIAŁU W WYNIKU DZIAŁANIA TEMPERATURY I WILGOTNOŚCI NA WSPÓŁCZYNNIK POCHŁANIANIA DŹWIĘKU MATERIAŁÓW DŹWIĘKOCHŁONNYCH STOSOWANYCH W MOTORYZACJI

PIOTR BIAŁKOWSKI[1], ŁUKASZ ZAPART[2], BOGUSŁAW KRĘŻEL[3]
BOSMAL Automotive Research and Development Institute Ltd.

Summary

In this article an attempt to determine the effect of composite temperature and humidity test on the sound absorption coefficient for commonly used materials in vehicles is described. Three types of fibrous materials were selected. The absorption coefficient was determined for material samples and then the materials were tested with composite temperature and humidity test. After the test, the sound absorption coefficient was measured again. The difference between the absorption coefficients before and after the test shows the actual effect on the sound absorption. An impedance tube was used to determine the absorption coefficient. Results are presented in graphs and tables for three types of fibrous materials. The method of measurement is described and conclusions are drawn.

Keywords: sound absorption coefficient, absorber materials, acoustic, impedance tube

[1,2,3] Instytut Badań i Rozwoju Motoryzacji BOSMAL Sp. z o.o. ul. Sarni Stok 93, 43-300 Bielsko-Biała
piotr.bialkowski@bosmal.com.pl; lukasz.zapart@bosmal.com.pl; boguslaw.krezel@bosmal.com.pl tel. 33 8130454

Streszczenie

W pracy przedstawiono próbę określenia wpływu temperatury i wilgotności na współczynnik pochłaniania dźwięku materiałów powszechnie stosowanych w samochodach. Do badań wybrano trzy rodzaje materiału włóknistego. Dla próbek materiału wyznaczono współczynnik pochłaniania dźwięku, a następnie próbki te poddano złożonej próbie temperatury i wilgotności. Po wykonaniu testu temperaturowo-wilgotnościowego ponownie wyznaczono współczynnik pochłaniania dźwięku. Różnica pomiędzy współczynnikami pochłaniania przed i po teście przedstawia rzeczywisty wpływ temperatury i wilgotności dla danej próbki materiału. Do wyznaczenia współczynnika pochłaniania dźwięku wykorzystano rurę impedancyjną. Wyniki przedstawiono w formie wykresów i tabel dla danego materiału. Opisano przebieg pomiarów oraz powstałe wnioski.

Słowa kluczowe: współczynnik pochłaniania dźwięku, materiały dźwiękochłonne, akustyka, rura impedancyjna

1. Introduction

The sound absorption coefficient describes the acoustic absorption of the interior of a vehicle. Long-term influences of environmental factors occurring in vehicles such as vibration, humidity, temperature or exposure to exhaust gas can affect the structure of the sound absorbing materials covering elements inside the vehicle, and thus the sound absorption coefficient.

A review of the scientific literature on this issue shows that relatively few studies have been published describing the impact of the above mentioned environmental factors on the sound absorption coefficient. In fact, manufacturers are focused on meeting the acoustic requirements of new materials, rather than anticipating changes in materials' acoustic parameters over time.

The influence of the environmental factors occurring in vehicles during typical vehicle operation on acoustic properties is not controlled. Materials are only tested prior to aging tests. For this reason, a vehicle even a few years old can change its acoustic properties if subjected to unfavorable environmental factors.

The sound absorption coefficient is also a low priority compared to other requirements related to the automotive applications, hence the problem of sound absorption is not often described in publications. Nevertheless, there are few studies related to this topic [1].

In this article an attempt to determine the effect of some environmental factors on the sound absorption coefficient for commonly used fibrous materials in vehicles is described. For this purpose normal incidence sound absorption coefficients of samples of the materials, before and after aging tests, were measured in the range of 80-5000 Hz in 1/3 octave bands (range of narrow band spectrum 50–6600 Hz). The tests were carried out on materials used in components of the vehicles' interiors.

The sound absorption coefficient was measured according to (ISO 10534-2, 1998), the method covers the use of an impedance tube, two microphone locations and a transfer-function method [2].

2. Environmental factors occurring in vehicles

The most important environmental factors that may affect the properties of materials absorbing sound inside vehicles are: humidity, temperature and contamination like exhaust gas, dust, dirt, liquids (oil, water), dust [3], as well as wood dust [4]. Vibrations can also be an additional factor. These environmental factors have an influence on the faster aging of the material.

Due to the increasing number of vehicles on the world's roads, the problem of the impact of the road surface (asphalt) on traffic noise has recently been seriously addressed. Low-noise surfaces are increasingly used. This type of surface loses its acoustic properties over time, so from a few year ago, many studies have been published on the impact of pollutants on the sound absorption coefficient of asphalt [5]. On the other hand, there have been few publications on the impact of the above mentioned environmental factors on the sound absorption coefficient of fibrous materials used in automotive applications.

Publications related to the influence of similar factors on other properties, such as heat transfer [6] or pollutants, not related to the automotive applications, are more common [7].

3. Tested objects

Fibrous materials, characterized by very good acoustic properties, are commonly used in automotive applications. Three types of such material were used in the tests: two materials 25 mm thick ('blue poroso' and 'green poroso') and one material approximately 7 mm thick ('thin poroso'). Three samples of each material were cut in order to determine the dispersion of measurements. The samples were cut using special rotating cutters of 100 mm and 30 mm diameter (fig.1). The dimensions of the samples are determined by the impedance tube used in the test. This allows covering the full frequency range of 50-6600 Hz (this is the measuring range of the impedance tube and the most important range for absorber materials in vehicles).

The physical properties of the tested material samples are shown in table 1.

Fig. 1. Samples: ø100mm – left view, ø30mm - right view (from up: blue poroso, green poroso and thin poroso)

Table 1. Physical properties of tested material samples

Sample	No.	Thickness [m]	Diameter ø100 mm		Diameter ø30 mm	
			Mass [kg]	Density [kg/m³]	Mass [kg]	Density [kg/m³]
Blue poroso	1	0.025	0.01654	84.2	0.00144	81.5
	2	0.025	0.01754	89.3	0.00160	90.4
	3	0.025	0.01847	94.1	0.00144	81.5
	mean	**0.025**	**0.01752**	**89.2**	**0.00149**	**84.5**
Green poroso	1	0.025	0.01515	77.1	0.00118	66.8
	2	0.025	0.01422	72.4	0.00131	74.1
	3	0.025	0.01441	73.4	0.00088	49.7
	mean	**0.025**	**0.01459**	**74.3**	**0.00112**	**63.5**
Thin poroso	1	0.007	0.00574	104.4	0.00062	125.9
	2	0.007	0.00592	107.6	0.00060	120.7
	3	0.007	0.00671	122.1	0.00054	109.9
	mean	**0.007**	**0.00612**	**111.4**	**0.00059**	**118.8**

4. Methods of tests

4.1 Determination of the sound absorption coefficient

An impedance tube (AFD 1000–AcoustiTube, SinusMesstechnik GmbH) was used to determine the sound absorption coefficient. The impedance tube includes:

- a tube with inner diameter 30mm and 100mm,
- two microphones GRAS (46BD ¼" ICP),
- a speaker module and amplifier.

The method of determining the sound absorption coefficient is based on the ISO 10534-2 norm. Apparatus for determining the sound absorption coefficient is shown in fig. 2. A scheme of the impedance tube with symbols appearing in formulas (1) ... (4) is shown in fig. 3.

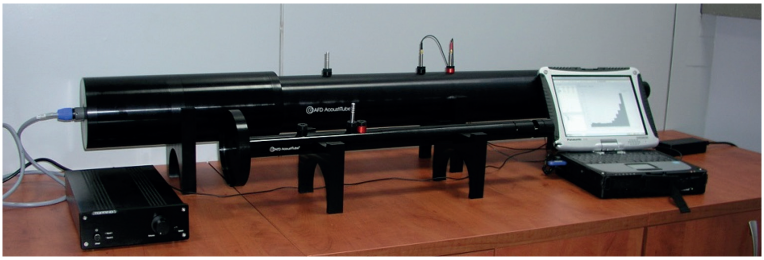

Fig. 2 Apparatus for determining the sound absorption coefficient – impedance tube

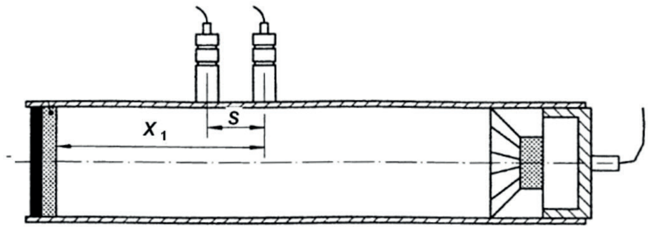

Fig. 3 Scheme of impedance tube [2]

The Complex Reflection Coefficient according to ISO 10534-2 [2] is defined as follows:

$$r = \frac{H_{12}-H_l}{H_R-H_{12}} e^{2jk_o x_1}, \quad (1)$$

where:

H_{12} – complex acoustic transfer function,

H_l – transfer function of incident sound wave,

H_R – transfer function of reflected sound wave,

k_0 – complex wave number,

x_1 – distance from the test sample to the centre of the further microphone.

The transfer function of the incident sound wave is defined as follows (2):

$$H_l = \frac{p_{2l}}{p_{1l}} = e^{-jk_o(x_1-x_2)} = e^{-jk_o s}, \quad (2)$$

where:

x_1 – distance from the test sample to the centre of the further microphone,

x_2 – distance from the test sample to the centre of the nearest microphone,

p_{2l} – the sound pressure of the incident wave in the second position of the microphone,

p_{1l} – the sound pressure of the incident wave in the first position of the microphone,

The transfer function of reflected sound wave is defined as follows (3):

$$H_R = \frac{p_{2R}}{p_{1R}} = e^{jk_o(x_1-x_2)} = e^{jk_o s}, \quad (3)$$

where:

p_{2R} – the sound pressure of the reflected wave in the second position of the microphone,

p_{1R} – the sound pressure of the reflected wave in the first position of the microphone, Sound absorption coefficient:

$$\alpha = 1 - |r|^2 = 1 - r_r^2 - r_i^2, \tag{4}$$

where:

r_r – real part of complex acoustic reflection coefficient,

r_i – imaginary part of complex acoustic reflection coefficient.

4.2 Composite temperature and humidity test

In this paper the effect of composite temperature and humidity test on the sound absorption coefficient was determined. For this purpose, the results of the sound absorption coefficient presented in 1/3 octave bands were compared before and after the composite temperature and humidity test.

The composite temperature and humidity test was carried out in accordance with the following sequence:

- 20 hours at -40 °C,
- 2 hours at + 23 °C and 50% RH,
- 20 hours at + 90 °C,
- 2 hours at + 23 °C and 50% RH,
- 20 hours at + 50 °C and 95% RH.

Test parameters were determined based on the analysis of environmental standards and tests used in research of materials in the automotive applications.

Each sample was conditioned at room temperature for 24 hours before and after the composite temperature and humidity test.

5. Results

The sound absorption coefficient was measured before exposure to temperature and humidity cycles. For each large sample (ø100 mm), three measurements were made in two frequency bands (1/3 octave bands): 80-250 Hz (low frequency LF) and 315-1600 Hz (high frequency HF). For small samples (ø30 mm) were also made three measurements, but only in one frequency range (1/3 octave bands): 2000-5000 Hz (HF). Such a number of measuring ranges covers the entire previously mentioned range of the narrow band spectrum 50-6600 Hz.

Before each measurement, the sample was removed from the tube and re-installed to minimize errors due to imprecise mounting in the impedance tube. The repeatability of results (included in the determined values of type A uncertainty) showed that the effect of fixing the sample on the final result was minimal.

The sound absorption coefficient was measured after exposure to temperature and humidity cycles using identical boundary conditions (position of the sample face with respect to the microphones, re-installing the samples for every measurement, performing three measurements).

Two of the three types of material were found to increase their volume (thickness) due to the temperature and humidity to which they were exposed. It should be noted that the thickness measurement of this type of material is quite uncertain due to its surface (measuring accuracy was about 1 mm, so for the material that is 7 mm thick, the error is about 14%). Changes of thickness and density in samples due to temperature and humidity are summarized in table 2 and table 3.

Averaged graphs were made on the basis of the obtained results from three samples (total of 9 measurements). Results for measurements before and after the temperature-humidity test are presented in fig. 4. Graphs of changes in the sound absorption coefficient as a function of frequency are presented in fig. 5. The summary results are presented in table 4.

Table 2. Changes in sample thickness due to temperature and humidity

Sample	No.	Sample ø100mm			Sample ø30mm		
		Thickness before test [mm]	Thickness after test [mm]	Change [mm]	Thickness before test [mm]	Thickness after test [mm]	Change [mm]
Blue poroso	1	25	31	6	25	30	5
	2	25	35	10	25	32	7
	3	25	35	10	25	30	5
	mean	**25**	**34**	**9**	**25**	**31**	**6**
Green poroso	1	25	26	1	25	26	1
	2	25	26	1	25	27	2
	3	25	26	1	25	26	1
	mean	**25**	**26**	**1**	**25**	**26**	**1**
Thin poroso	1	7	7	0	7	7	0
	2	7	7	0	7	7	0
	3	7	7	0	7	7	0
	mean	**7**	**7**	**0**	**7**	**7**	**0**

Table 3. Changes in sample density due to temperature and humidity

Sample	No.	Sample ø100mm			Sample ø30mm		
		Density before test [kg/m³]	Density after test [kg/m³]	Change [%]	Density before test [kg/m³]	Density after test [kg/m³]	Change [%]
Blue poroso	1	84.2	67.9	-19.4%	81.5	67.9	-16.7%
	2	89.3	63.8	-28.6%	90.4	70.6	-21.9%
	3	94.1	67.2	-28.6%	81.5	68.0	-16.7%
	mean	**89.2**	**66.2**	**-25.7%**	**84.5**	**68.9**	**-18.5%**
Green poroso	1	77.1	74.2	-3.8%	66.8	64.2	-3.8%
	2	72.4	69.6	-3.8%	74.1	68.6	-7.4%
	3	73.4	70.6	-3.8%	49.7	47.8	-3.8%
	mean	**74.3**	**71.5**	**-3.8%**	**63.5**	**60.3**	**-5.1%**
Thin poroso	1	104.4	104.4	0.0%	125.9	125.9	0.0%
	2	107.6	107.6	0.0%	120.7	120.7	0.0%
	3	122.1	122.1	0.0%	109.9	109.9	0.0%
	mean	**111.4**	**111.4**	**0.0%**	**118.8**	**118.8**	**0.0%**

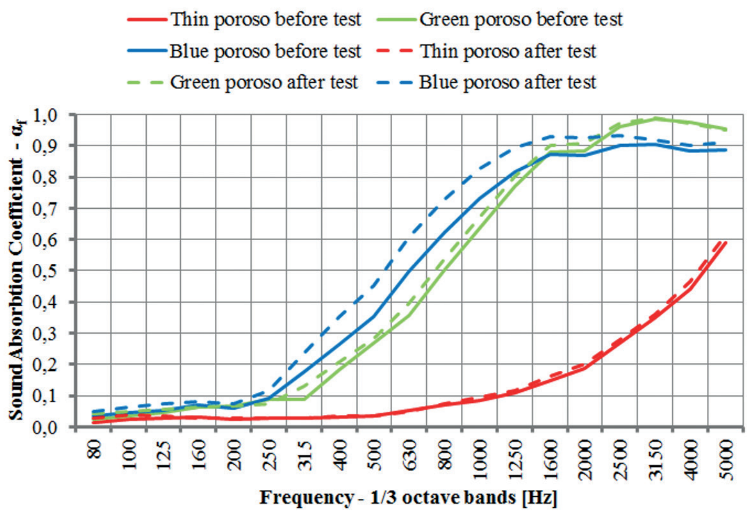

Fig. 4 Results of the sound absorption coefficient presented in 1/3 octave bands – before and after the composite temperature and humidity test

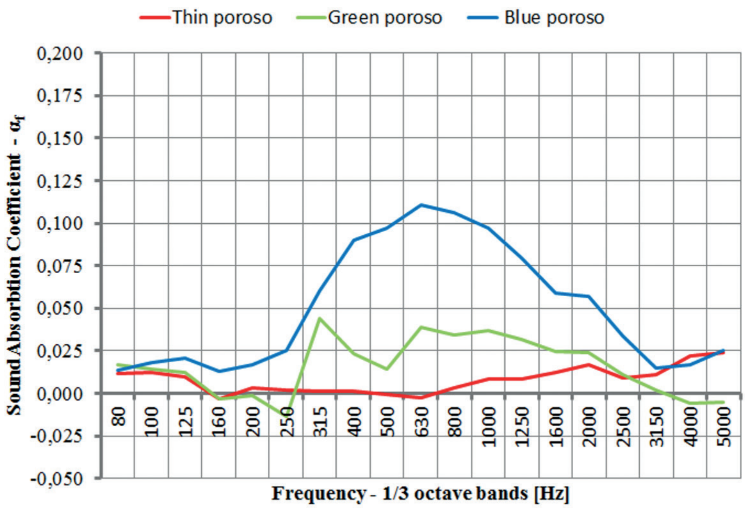

Fig. 5 Changes in the absorption coefficient

Table 4. Summary of sound absorption coefficient measurements

Sample	Freq. [Hz]	Before test α_1			After test α_2			Change α_2 - α_1		
		Thin poroso	Green poroso	Blue poroso	Thin poroso	Green poroso	Blue poroso	Thin poroso	Green poroso	Blue poroso
100 mm LF	80	0.016	0.024	0.035	0.027	0.041	0.049	0.012	0.017	0.014
	100	0.026	0.036	0.045	0.038	0.051	0.063	0.012	0.014	0.018
	125	0.027	0.045	0.054	0.037	0.058	0.075	0.010	0.013	0.021
	160	0.031	0.065	0.07	0.028	0.062	0.083	-0.003	-0.003	0.013
	200	0.025	0.067	0.058	0.028	0.066	0.075	0.003	-0.001	0.017
	250	0.027	0.086	0.092	0.029	0.073	0.118	0.002	-0.014	0.025
100 mm HF	315	0.027	0.087	0.176	0.029	0.131	0.237	0.002	0.044	0.060
	400	0.033	0.185	0.264	0.034	0.208	0.354	0.001	0.023	0.090
	500	0.035	0.268	0.354	0.034	0.282	0.45	-0.001	0.015	0.097
	630	0.052	0.358	0.497	0.049	0.397	0.608	-0.003	0.039	0.111
	800	0.07	0.503	0.621	0.073	0.537	0.727	0.003	0.034	0.106
	1000	0.086	0.635	0.731	0.094	0.672	0.828	0.008	0.037	0.097
	1250	0.109	0.769	0.815	0.117	0.8	0.894	0.009	0.032	0.080
	1600	0.149	0.878	0.871	0.161	0.902	0.93	0.012	0.025	0.059
30 mm HF	2000	0.186	0.883	0.869	0.203	0.907	0.925	0.017	0.024	0.057
	2500	0.268	0.959	0.899	0.278	0.97	0.933	0.009	0.011	0.034
	3150	0.35	0.987	0.903	0.361	0.988	0.917	0.011	0.002	0.015
	4000	0.443	0.977	0.884	0.465	0.971	0.901	0.022	-0.006	0.017
	5000	0.591	0.954	0.886	0.615	0.949	0.911	0.024	-0.005	0.026

For the above measurements, uncertainty of measurement type A related to the dispersion of measurement results was determined,. For materials: 'thin poroso' and 'green poroso', the maximum uncertainty was 0.022 and for material 'blue poroso' was 0.050. Due to the comparative nature of the research, type B uncertainty (related to measuring equipment) was not determined.

6. Conclusions

The research shows that the sound-absorbing material subjected to temperature and humidity tests corresponding to those found in cars in everyday use not only does not lose its acoustic properties, but also there is a chance of sound absorption increase (in the case of a 'blue poroso' this can be a noticeable increase). This is probably related to the simultaneous increase in volume and hence porosity.

It can be concluded that the changes in the sound absorption coefficient for 'thin poroso' and 'green poroso' are within determined uncertainty range.

The change in absorption coefficient is not constant over the entire frequency range. For materials 25 mm thick ('blue poroso' and 'green poroso'), the biggest differences in the sound absorption coefficient can be observed in the range of 315 Hz to 2 kHz. It is logical that if above 2 kHz the absorption coefficient is above 0.9, then it can't be increased much beyond that point. For the third material ('thin poroso'), the sound absorption coefficient increased with increasing frequencies up to the upper range (in the range of 800 Hz to 5000 Hz). This is probably due to its low thickness.

The third material ('thin poroso') changed its absorption coefficient the least with practically no increase in thickness. The material of the blue poroso changed its density by a maximum of about 29%; the 'green poroso' a maximum of about 7% while the density of 'thin poroso' remained practically unchanged.

References

[1] Patton H W. Smart Acoustic Material for Automotive Applications, Center for Engineering Education and Practice Annual Progress Report, March 2005.

[2] ISO 10534-2:1998, Acoustic. Determination of sound absorption coefficient and impedance in impedances tubes – Part 2: Transfer-function method.

[3] Liu J, Herrin D. Effect of Contamination on Acoustic Performance of Microperforated Panels, SAE Int. J. Passeng. Cars – Mech. Syst. 4(2):1156-1161, 2011, doi:10.4271/2011-01-1627.

[4] Wertel S J. Experimental analysis of noise reduction properties of sound absorbing foam, A Research Paper Submitted in Partial Fulfillment of the Requirements for the Master of Science Degree With a Major in Risk Control.

[5] Krivanek V, Pavkova A, Togel M, Jedlicka J, Cholava R. Cleaning Low-Noise Surfaces as a Basic Condition for Improving Pavement's Acoustic Absorption Capability.

[6] Firkowicz-Pogorzelska K. Metodyka określania wartości obliczeniowej współczynnika przewodzenia ciepła materiałów budowlanych, Prace instytutu techniki budowlanej - kwartalnik nr 3 (119) 2001.

[7] Chrisler V L. Effect of paint on the sound absorption of acoustic materials, U.S. Department of commerce national bureau of standards research paper RP1298, Part of Journal of Research of the National Bureau of Standards, Volume 24, May 1940.