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The effect of moisture content on sound absorption of expanded perlite plates

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Abstract

Expanded perlite is a porous, lightweight, fire resistant and moisture retaining material with sound and thermal insulation properties. In this research, acoustical behaviour of plates made of expanded perlite was studied experimentally. Since these plates are used for sound absorption, the acoustical parameter selected for this study is ''sound absorption coefficient''. Preliminary experiments indicated that moisture reduced the sound absorption coefficient on plates and there is not much significant difference between the dry and 50% humid conditions. However, there is a significant difference in acoustical properties for the 50–95% humid conditions. Thus, this interval was studied in detail. A number of expanded perlite plates having different mixtures were prepared and tested. It was observed that, coating the expanded perlite particles with sodium silicate increased the moisture resistance, and the addition of mineral fibres into the mixtures increased the strength and sound absorption coefficient of the plates.

Keywords: Perlite; Building materials; Acoustics; Sound absorption coefficient

1. Introduction

Perlite is a siliceous volcanic rock, which expands by 10–30 times its original volume when heated up to 700–1200 °C. In situ and prefabricated building materials made of expanded perlite are used widely as thermal insulation materials. It is used in other industries as filler, filter, abrasive and moisture retaining material. Expanded perlite, with its open pore structure, is also very suitable as a sound absorbing material. It is used mostly in spray form in paints and plastering for acoustical purposes [1]. However, moisture retaining properties of perlite restricts its usage. Shields, Sabatier, Hickey and Wang studied the effect of moisture on granular material for some other purposes [2,3]. The effect of moisture on plates made of perlite has not been considered in the literature from architectural design point of view. It is possible to use these plates in any auditorium or moist space like indoor swimming pool, in order to reduce reverberation time. The aim of this study is to determine the sound absorbing properties of plates made of expanded perlite in moist environments.

2. Experimental study and methods

The initial stage of this research was to find out, whether the moisture affects the acoustic properties of the plates made of expanded perlite and how it might be possible to produce plates with both sound absorbing and moisture resisting properties. It is known that, for a moisture-proof material with good sound absorbing properties; porous admixtures with high tortuosity, low flow resistance and water repelling qualities are needed [4,5]. Thus, four different types of plates, with five samples from each type were prepared as shown in

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Table 1
The mixing ratios and the production processes of the sample plates

Code and the definition	Mixing ratio	Production process
PCP Perlite–cement plate	1.3 m^3 Perlite 150 kg Cement 300 l Water	Firstly expanded perlite and cement are mixed dryly. After adding water the mixture is cast to a steel mould
SPCP Sodium silicate coated Perlite–cement plate	1.3 m^3 Sodium silicate coated perlite 150 kg Cement 300 l Water	Expanded perlite granules are coated with Na_2SiO_3 and sieved through a 4 mm sifter. Prepared particles are mixed with cement, and after adding water it is cast in a steel mould
PTCP Perlite–rock wool–cement plate	1.3 m^3 Perlite 1.3 m^3 Rock wool 150 kg Cement 500 l Water	Firstly, rock wool fibers, expanded perlite and cement are mixed dryly. After adding water the mixture is cast in steel mould
SPTCP Sodium silicate coated Perlite–rock wool–cement plate	1.3 m^3 Sodium silicate coated perlite 1.3 m^3 Rock wool 150 kg Cement 500 l Water	Expanded perlite granules are coated with Na_2SiO_3 and sieved through a 4 mm sifter. Prepared particles are mixed with rock wool and cement dryly. After adding water the mixture is cast in a steel mould

Table 1. The plates were prepared from the commercially available perlite aggregates of 0–3 mm particle size with different mixing ratios. In SPCP and SPTCP plates, expanded perlite granules were coated with sodium silicate in order to increase the moisture retarding property of the plates. In PTCP and SPTCP plates, rock wool was used to increase the durability and the porosity of the plates.

In the preparation of the plates, care was taken to follow the standards of cement-based component production like mixing, casting and curing processes. The mixtures were cast into a steel mould and compressed with a vibrator to produce 30 mm thick plates with 90 mm diameter. In order to avoid shrinkage, the samples were placed in a water vessel, with their surfaces facing down and completely under water, and were kept so for 7 days. At the end of 7 days, in order to dry in a stabilized environment, they were put into the climate chamber, where the temperature was kept at $23 \pm 2\,^\circ C$ and the relative humidity at 50% ± 5. In order to find out their dry weight the samples were dried at $105 \pm 5\,^\circ C$ until there was no change in their weight. First, various tests were made to find the physical characteristics of these plates. Then the prepared plates were kept in the climate chamber at different humidity conditions and their sound absorption coefficients were measured in a two-microphone impedance tube.

2.1. Preliminary testing of the plates

The following tests were made on the physical characteristics of the plates made of expanded perlite.

2.1.1. Density

Density is the weight divided by the overall volume including the holes and pores. Dry density (ρ_d), wet (saturated) density (ρ_w), and the density of the natural humidity conditions (ρ_n) are given in Table 2.

The results show that the weight of sodium silicate coated and fibre added plates became heavier. Water saturated plates became twice heavier than the dry ones, indicating that they have porous structure.

2.1.2. Mass density

Mass density (ρ') is the weight divided by the bulk volume (V_B) excluding the volume of the holes and pores. For this purpose, the plates were ground and put into a Le Chattelier balloon to find the bulk volume. The results are given in Table 3.

The mass densities which were found to be 3.22–3.51 g/cm^3 are very close to the mass density of cement (2.95–3.15 g/cm^3). Using cement as the binding material has been effective on this result. By comparing the plates between each other, it was seen that, the process of coating the perlite granules with sodium silicate increased the pore volume and the process of adding fibres increased the void volume but not the bulk volume.

2.1.3. Porosity and effective porosity

Porosity (P) is the ratio of void volume (V_v) to the overall volume (V). Effective porosity is the difference between wet (saturated) density (ρ_w) and dry density (ρ_d). The results of the tests are given in Table 4. The porosity of plates made of expanded perlite are between

Table 2
Density of sample plates

	95% Confidence Interval					
Sample plate code	Diameter (mm)	Thickness (mm)	V (volume) (cm^3)	Natural humidity density, ρ_n (g/cm^3)	Dry density, ρ_d (g/cm^3)	Wet (saturated) density, ρ_w (g/cm^3)
PCP	89.4 ± 0.47	29.0 ± 0.47	180.22 ± 5.69	0.44 ± 0.03	0.43 ± 0.03	0.94 ± 0.05
SPCP	88.0 ± 0.91	28.7 ± 0.53	174.77 ± 4.83	0.50 ± 0.06	0.47 ± 0.01	1.026 ± 0.0
PTCP	88.4 ± 0.90	28.0 ± 0.90	172.14 ± 7.84	0.54 ± 0.02	0.55 ± 0.02	1.103 ± 0.0
SPTCP	87.5 ± 1.22	28.9 ± 0.24	174.05 ± 4.52	0.54 ± 0.07	0.52 ± 0.01	1.099 ± 0.0

Table 3
Mass density of sample plates

	95% Confidence Interval				
Sample plate code	Diameter (mm)	Thickness (mm)	Volume, V (cm^3)	Bulk volume, V_B (cm^3)	Mass density, ρ' (g/cm^3)
PCP	89.4 ± 0.47	29.0 ± 0.47	180.22 ± 5.69	3.01 ± 0.233	3.51 ± 0.022
SPCP	88.0 ± 0.91	28.7 ± 0.53	174.77 ± 4.83	3.15 ± 0.392	3.22 ± 0.061
PTCP	88.4 ± 0.90	28.0 ± 0.90	172.14 ± 7.84	3.62 ± 0.269	3.43 ± 0.246
SPTCP	87.5 ± 1.22	28.9 ± 0.24	174.05 ± 4.52	3.38 ± 0.157	3.35 ± 0.149

Table 4
Porosity and effective porosity of sample plates

	95% Confidence Interval					
Sample plate code	Dry density, ρ_d (g/cm^3)	Wet density, ρ_w (g/cm^3)	Effective porosity, P_e	Volume, V (cm^3)	Void volume, V_v (cm^3)	Porosity, P (%)
PCP	0.43 ± 0.03	0.94 ± 0.05	0.505 ± 26	180.22 ± 5.69	176.6 ± 5.5	97.99 ± 0.12
SPCP	0.47 ± 0.01	1.03 ± 0.03	0.552 ± 26	174.77 ± 4.83	171.3 ± 4.7	98.05 ± 0.07
PTCP	0.55 ± 0.02	1.10 ± 0.04	0.550 ± 33	172.14 ± 7.84	169.1 ± 8.0	98.23 ± 0.19
SPTCP	0.52 ± 0.01	1.10 ± 0.02	0.570 ± 17	174.05 ± 4.52	170.9 ± 4.4	98.18 ± 0.22

97% and 98%. However, the effective porosity of the plates are in the range of 0.50–0.57. The effective porosity is more important in the propagation of sound in porous media and SPTCP has the highest value.

2.1.4. Air permeability

Air permeability is the amount of air passing through a plate under the air pressure difference, and it is another significant parameter in sound absorption. Air permeability tests on plates were performed by Porous Materials Inc., USA by the use of the Capillary Flow Porosity-meter according to ASTM F-316-86 and F-778. The result is given in Fig. 1. Permeability of SPTCP is higher than PCP because coating of perlite granules with sodium silicate and adding of fibres increased the void volume of the plates. Thus they became more sound absorbent.

2.2. Measuring sound absorption coefficients of the plates in moist environment

2.2.1. Climate chamber

A climate chamber shown in Fig. 2 was designed and constructed to moisturize sample plates made of expanded perlite. The dimensions of the climate chamber are 800 × 500 × 500 mm^3 and its upper section is transparent and constructed with Plexiglas. As this chamber is used in a room where all environmental conditions can be controlled, no thermal insulation is needed on the Plexiglas surfaces. The upper section has a temperature sensor connected to a thermostat, a humidity sensor connected to a hygrostat and a fan circulating hot and cold air within the chamber. The microprocessors of the thermostat and the hygrostat have the ability to make six programs one after

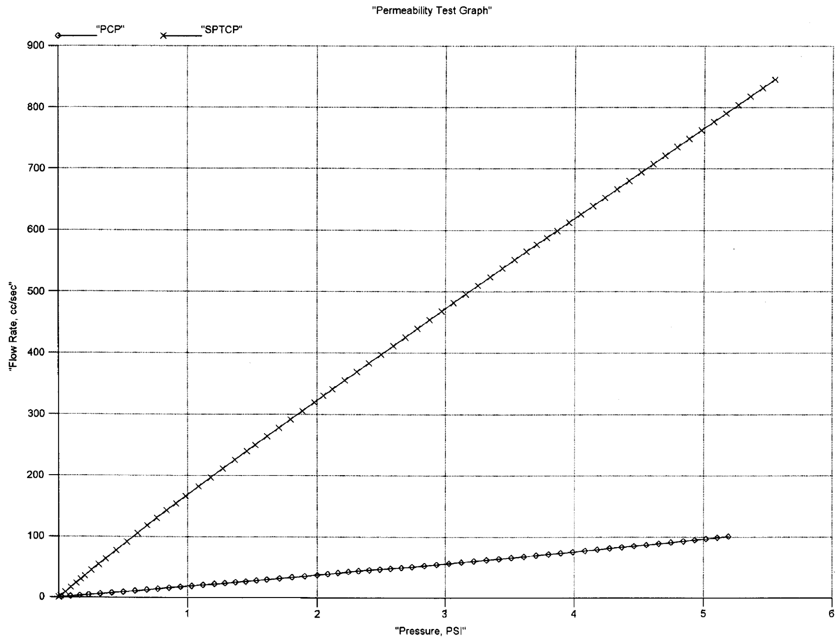

Fig. 1. Permeability tests of PCP and SPTCP.

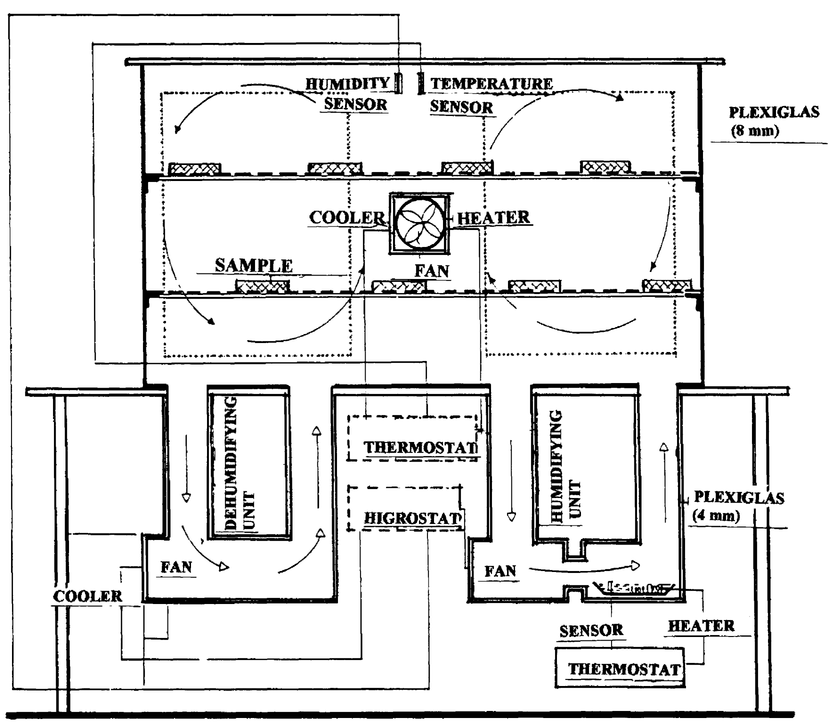

Fig. 2. Sectional diagram of the climate chamber.

the other. Within the upper section there are two perforated shelves on which the samples are put and through which air circulation is provided. The lower section of the climate chamber has two parts. One of them is for increasing and the other is for decreasing the humidity. Both of them have separate connections to the upper section. The working temperature range is 5–40 °C and humidity range is 10–98% for the climate chamber.

2.2.2. Computer controlled two-microphone impedance tube

There are several methods for the measurement of sound absorption coefficients [6–10]. It was necessary to

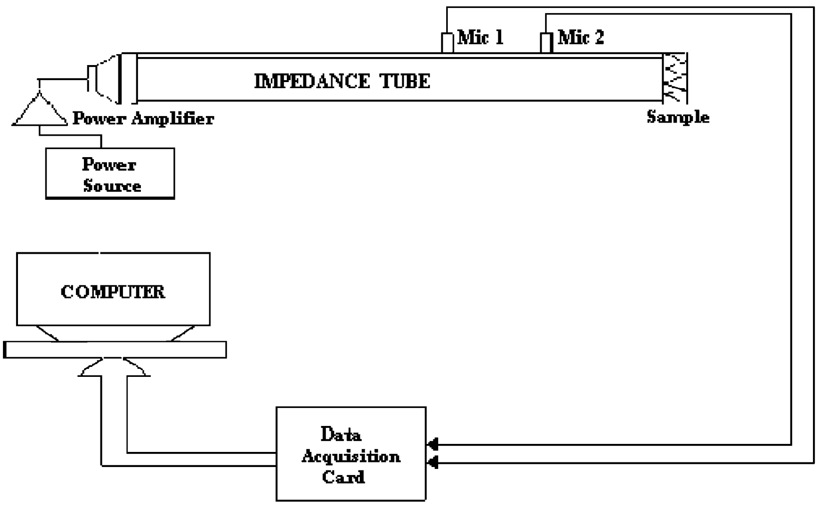

Fig. 3. System scheme of two-microphone impedance tube.

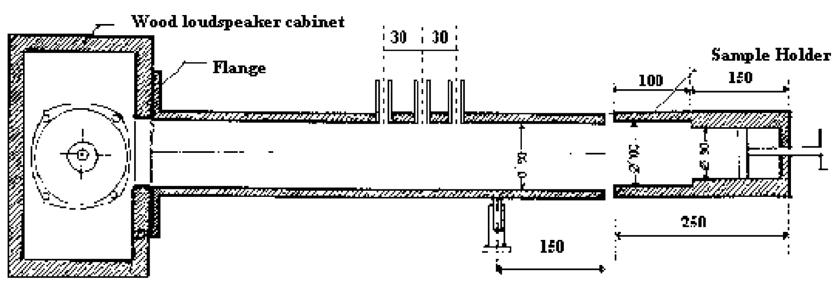

Fig. 4. Section and dimensions of two-microphone impedance tube.

make quick measurements without changing the moisture conditions of the sample plates. It was decided to employ a "two-microphone impedance tube" under computer control because with this method it is possible to work with relatively small samples. The method was proposed by Seybert and Ross [11] and developed by Chung and Blaser [12,13].

The system is composed of five parts. They are computer, computer input–output units, sample holder, impedance tube, pink-noise generator and microphones. The system is shown schematically in Fig. 3.

The impedance tube is a steel tube with a test specimen at one end and a loudspeaker at the other. Two $\frac{1}{4}$" microphones with 60 mm spacing are mounted outside the wall of the tube. For communication with the computer, a data acquisition card was used. The interior section of the tube is circular and has a diameter of 90 mm. Thickness of the tube is 10 mm, so the outside diameter of the tube is 100 mm. The length of the tube is 1000 mm (Fig. 4).

$\frac{1}{3}$-Octave band absorption coefficients of the specimens are measured between 300 and 1800 Hz. The upper measurement limit for this tube is 1894 Hz. The transfer responses of microphones are collected at each frequency, and then sound reflection and absorption coefficients are calculated by the following equations, respectively:

$$r = (Ge^{jkd} - 1)/(1 - Ge^{-jkd}),$$

$$\alpha = 1 - |r|^2,$$

$$k = 2\pi/\lambda,$$

where r is the sound reflection coefficient, α is the sound absorption coefficient, k is the sound propagation constant, G is the transfer response between the microphones, d is the distance between the microphones, and λ is the wavelength.

2.2.3. *Sound absorption coefficient of plates made of expanded perlite*

Preliminary experiments showed that moisture reduced the absorption coefficient on these plates. It was found that there was no significant difference in terms of sound absorption coefficient, between the dry and 50% humid conditions. However, there is a significant difference in acoustical properties for the 50–95% humid conditions [14,15]. So, it was decided to study in this interval in detail.

Sound absorption coefficients of the samples were measured under various humidity conditions. These are;

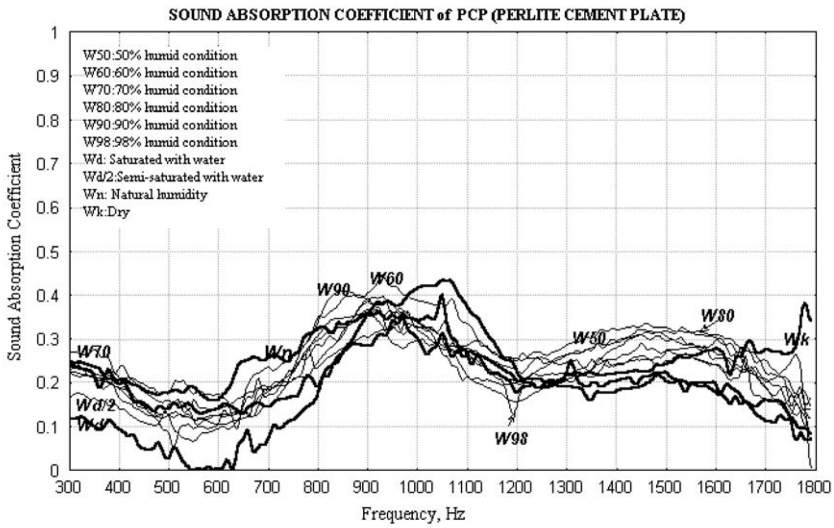

Fig. 5. Sound absorption coefficients of PCP (perlite–cement plate).

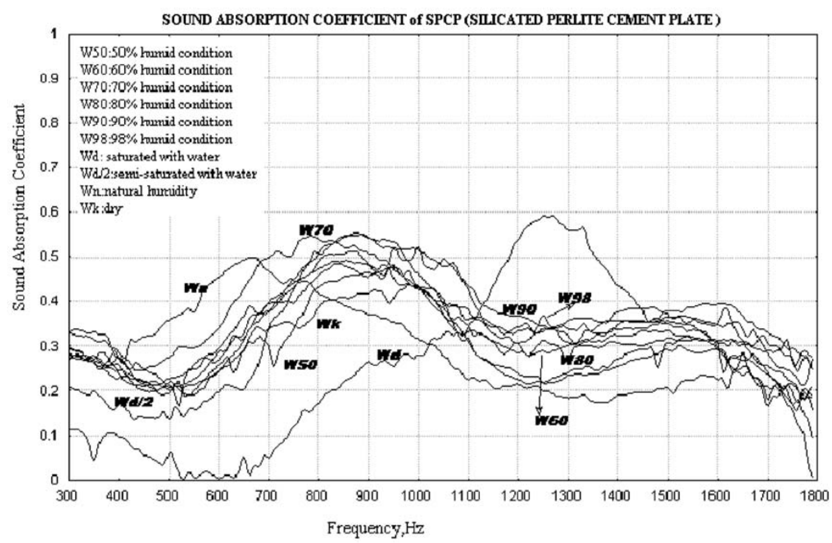

Fig. 6. Sound absorption coefficients of SPCP (sodium silicate coated perlite–cement plate).

dry (W_k), under natural humidity conditions (W_n), after being saturated with water (W_d), after being semi-saturated with water ($W_{d/2}$), after being kept under 50%, 60%, 70%, 80%, 90%, 98% relative humidity conditions (W_{50}, W_{60}, W_{70}, W_{80}, W_{90}, W_{98}) between 300 and 1800 Hz frequencies. Semi-saturated with water means 50% of the pores are filled with water, water content will be different when kept under 50% relative humidity up to the equilibrium state. Results are given in Figs. 5–8.

3. Findings and discussion

As seen in these figures, in terms of sound absorption coefficient in moist environments SPCP is better than PCP, SPTCP is the best plate among all the tested plates. The coating of perlite granules with sodium silicate closes the open pores thus the water retaining property is reduced [16]. However, this process causes the micro-size granules to stick to each other and produces new open pores. Thus the plate does not loose its sound absorption property.

Another disadvantage of the plates made of expanded perlite are their low durability. The addition of mineral fibres into the mixture improved a number of features. It increased the durability, as well as gas permeability and the sound absorption coefficients of the plates because fibres introduced new open pores to the material.

Regarding the porous structure of the plates, their porosity was measured as 97–98%, whereas their effective porosity was measured as 0.50–0.57. The difference between the porosity and the effective porosity indicates the presence of the unconnected and

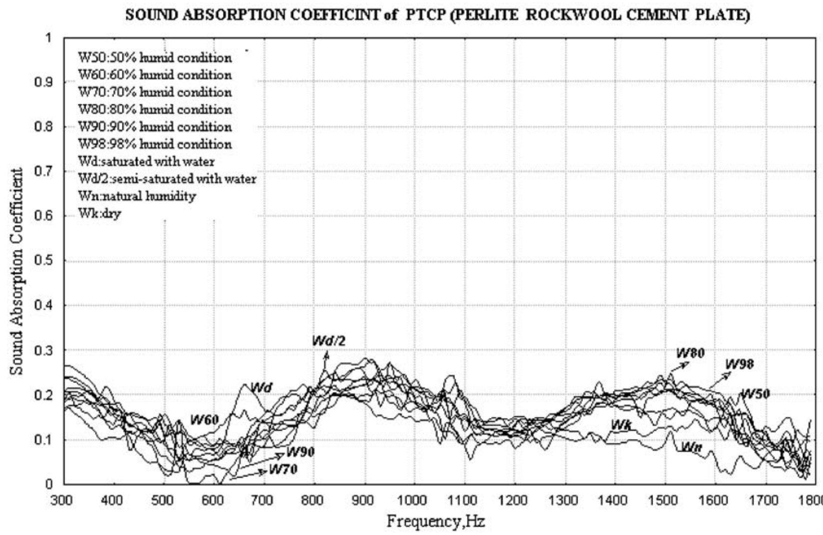

Fig. 7. Sound absorption coefficients of PTCP (perlite–rock wool–cement plate).

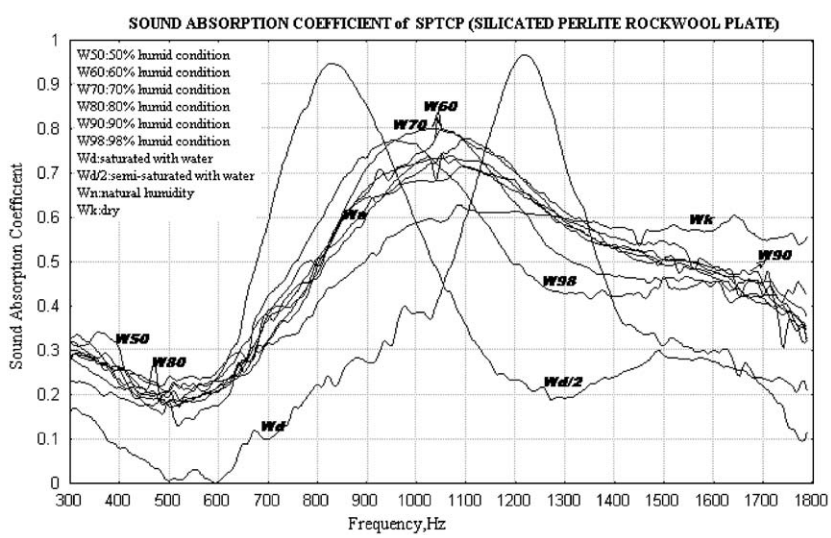

Fig. 8. Sound absorption coefficients of SPTCP (sodium silicate coated perlite–rock wool–cement plate).

impermeable capillary pores. The effective porosities of SPCP and SPTCP turn out to be higher than those of the other plates, showing that, coating of perlite granules with sodium silicate, enlarges the granule size and thus decreases the surface contact area between the particles. At the same time, SPCP and SPTCP are more sound absorbent than PCP and PTCP, because a portion of the sample plate which is active in transmitting the sound has been increased. The addition of a fibrous material increases the connection between pores. The effect of this capillary structure on sound absorption coefficient in moist environments will be studied by the authors in future.

The difference in sound absorption coefficient between the dry and 98% humid condition of the samples is between 10% and 30%. When the plates are saturated with water, this difference increases between 40% and 60% on average. When the plates are moisturized by keeping them in humid conditions, their sound absorption coefficients are close to the values of plates under dry and natural humid conditions. However, when they are kept under 98% relative humidity conditions until the equilibrium state, they behave as sound reflectors. It is also concluded that, by soaking the plates in water and thus saturating them, instead of leaving them in 98% relative humidity condition of the climate chamber, their sound absorption coefficients are reduced. However for some frequencies the measured sound absorption coefficients show significant increase. The reason for is that water cannot penetrate some of the tiny pores due to the surface tension. When the sound waves of certain wavelength enter these pores, the pores absorb the sound energy like a resonator and therefore the sound wave which cannot exit the pore is absorbed.

While the plates were being moisturized, they were continuously weighed with a sensitive balance. It took 10 h to reach a stable weight, corresponding to W_{50}, from the dry condition. After this it took another 20.5 h to reach to W_{80}. Between W_{80} and W_{90} 24 h, and between W_{90} and W_{98} 32 h were needed. It was observed that the plates were moisturized at a relatively short time, but it took a long time to dry. This indicates that despite the measures taken, plates will have some pores which will retain water.

4. Conclusions

An experiment was performed in order to determine whether the porous structure and moisture retaining properties of perlite results in any changes in its acoustical properties. During the preliminary experiments, it was found that, when the plates were moisturized and especially when saturated with water, their sound absorption coefficients were reduced. In order to increase their resistance to moisture without changing their acoustical properties, plates with different mixing ratios were prepared. Parameters indicating the acoustical and hygroscopic properties, were tested on those plates.

The plate proving to be the best among all is the SPTCP (Silicate coated Perlite, Rock wool, Cement Plate). It is more durable than the others, has a higher vapour permeability and has the greatest number of connections between the pores. Its porosity, permeability and the other properties yielded a favourable sound absorption coefficient even in very humid environments.

An important finding of the research is that, moisture resistance of the plates made of expanded perlite, can be improved by adding special mixing materials and also by using various mixing ratios without decreasing their acoustical properties.

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References

[1] Harris DA. Noise control manual. New York: Van Nostrand Reinhold; 1991 [chapter 9–21].

[2] Hickey CJ, Sabatier JM. Choosing biot parameters for modelling water-saturated sand. J Acoust Soc Am 1997;102(3): 1480–4.

[3] Shields FD, Sabatier JM, Wang MJ. The effect of moisture on compressional and shear wave speeds in unconsolidated granular material. Acoust Soc Am 2000;108(5)(P1):1998–2004.

[4] Attenborough K. Acoustical characteristics of rigid fibrous absorbent and granular materials. J Acoust Soc Am 1983;73(3): 785–99.

[5] Ingard U. Sound absorption technology. NY: noise control foundation; 1994.

[6] ASTM. Standard test method for sound absorption and sound absorption coefficient by the reverberation room method. ASTM C 423, American Society for Testing and Materials; 1990.

[7] ASTM. Standard test method for impedance and absorption of acoustical materials by the impedance tube method. ASTM C 384, American Society for Testing and Materials; 1990.

[8] Allard JF, Champoux Y. In situ two-microphone technique for the measurement of the acoustic surface impedance of materials. Noise Control Eng J 1989; 15–23.

[9] Powell JG, Houten J. A tone-burst technique of sound-absorption measurement. J Acoust Soc Am 1970;48(6): 1299–303.

[10] ASTM. Standard test method for impedance and absorption of acoustical materials using a tube, two microphones, and a digital frequency analysis system. ASTM E 1050, American Society for Testing and Materials; 1990.

[11] Seybert AF, Ross DF. Experimental determination of acoustical properties using a two-microphone random excitation technique. J Acoust Soc Am 1977;61(5):1362–70.

[12] Chung JY, Blaser DA. Transfer function method of measuring in-duct acoustic properties, I. Theory. J Acoust Soc Am 1980; 68(3):907–13.

[13] Chung JY, Blaser DA. Transfer function method of measuring in-duct acoustic properties, I. Experiment. J Acoust Soc Am 1980; 68(3):914–21.

[14] Yílmazer S. Behaviour of acoustical plates made of expanded perlite in moist environments. International Noise 96. 25th anniversary congress, Liverpool, UK: 1996. p. 939–42.

[15] Yílmazer S. Perlitli Akustik Plakalarín Nemli Ortamlardaki Davraníşlarí (Behaviour of Acoustical Plates Made of Expanded Perlite in Moist Environments). PhD thesis, Karadeniz Technical University Science Institute, Trabzon; 1998.

[16] Raleigh WJ. Silicone emulsions for treating silicate particulate matter. NY: US Patent; 1979.