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Effect of Adding Perlite and Carbon Nanotubes on Noise Absorption of Plaster Panels

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Abstract: With the development of sound pollutants, modern life is full of unwanted noises which are generated inside or outside of buildings and can be annoying for residents and these problems are always felt more with increased urbanization and the use of thin stone blades separators and transmission of noise from one room to another. Thus, the use of acoustic materials to counter and mitigate noise in the building is necessary. In the meantime, plaster as one of the most common building materials can be used in combination with perlite and carbon nanotubes as a proper adsorbent of sound in buildings. Accordingly, the objective of this study is to assess the degree of sound absorption by the plaster, plaster-perlite, plaster-carbon nanotubes, plaster-perlite-carbon nanotubes using conversion function in impedance tube in accordance with ISO standard number 10534-2. Empirical studies and experimental results showed that Plaster with a thickness of 12 mm can singly absorb up to 36% of noises. The results also suggest that adding perlite and carbon nanotubes results in improved sound absorption capability of plaster panel in frequency range of 100-6300 Hz, in a way that up to 65% sound absorption was observed by combining plaster perlite and up to 75% sound absorption was observed by combining. Finally, the maximum sound absorption in this study was obtained to be about 84% with simultaneous use of combination of carbon nanotubes, perlite and plaster.

Key words: Carbon nanotubes, perlite, acoustic, plaster panel, Iran

INTRODUCTION

Unpleasant sounds are one of the most important problems of today's human life which have severe effects on human health. Sound-absorbing materials are used in various industries such as construction, automotive, transportation and factory environments among which soft porous foams with open structure are generally considered as one of the most common sound absorbers. Most of these absorbent materials are heavy, hard and thick which have caused restrictions in application. In recent years, the use of new materials to increase efficiency and also overcome the weaknesses of conventional adsorbents have attracted much attention in the scientific and industrial communities. Increase of a very small percentage of nanomaterials such as nanoparticles, nanofibers and nanotubes will lead to a significant improvements in the acoustic properties of matter without negative effects such as increasing weight and volume due to having extraordinary properties such as infinitely small size, high length to width ratio and high specific surface area. On the other hand, the use of these nano composites can improve other material properties such as thermal, mechanical and anti-fire properties (Gao *et al*., 2016; Zhang *et al*., 2016; Smirnov *et al*., 2016; Wu and Chou, 2016). Ayub and colleagues evaluated the acoustic adsorbent behavior of Carbon Nano Tubes (CNT) to compare the performance of sound absorption of nanofibers and old porous materials. They carried out the experiments using the impedance tube to measure the acoustic absorption coefficient of carbon nanotubes arranged in vertical rows. The results showed that using 3 mm rows of carbon nanotubes in frequencies of 125-4000 Hz provides the ability of 10% absorption.

Orfali has evaluated the effect of adding carbon nanotubes and silicon oxide nanopowders in the acoustic behavior of poly-urethane composite materials. The results have shown that adding 2% of carbon nanotubes and silicon oxide powders until the frequency range of 1600 Hz increases the acoustics and sound absorption properties of polyurethane. Especially, carbon nanos can be effective in sound absorption and improving acoustic

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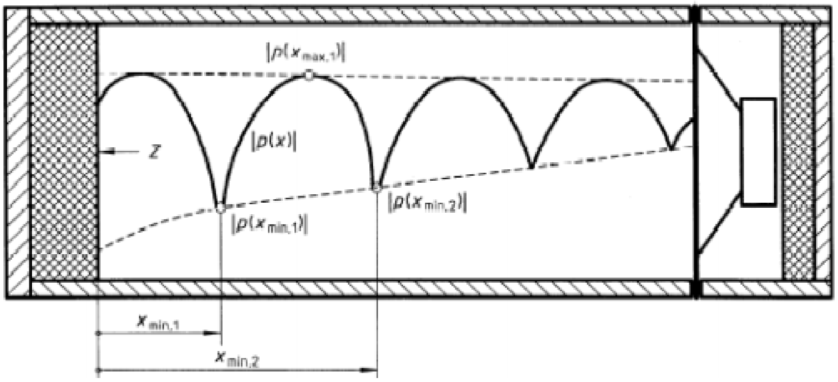


Fig. 1: Standing wave pattern in the test tube

properties by filling porous materials such as plaster mold or polyurethane foam (Chena *et al*., 2006; Mahfuz *et al*., 2004).

Previous studies (Tiuc *et al*., 2016; Eskandari *et al*., 2015; Yilmazer and Ozdeniz, 2005; Lu and Viljanen, 2011) indicate the acoustic behavior of nanoparticles in porous materials (such as polyurethane foam, plaster and concrete). Those results also showed that the highest sound absorption has been achieved in frequency range of 100 Hz. They found that the thermal stability, Mechanical properties and noise reduction of obtained nanocomposites improve only for a small percentage of these nanotubes. It has been shown in a research that the use of polyurethane nanofiber layer a nonwoven substrate reduces the weight of produced insulation up to 25% in addition to increasing sound absorption. In this study, Plaster panels have been prepared using multi-walled carbon nanotubes in the amount of 5.0% wt and pearlite in the amount of 5.0% wt and plaster panel has been cut in the next step in form of layers with the thickness of one centimeter and then the average sound absorption has been measured at different frequencies.

Determination of sound absorption coefficient and impedance in impedance pipes

Method of using standing wave ratio: The purpose of this document is determining a method to determine the sound absorption coefficient, reflection coefficient and surface impedance or surface admittance of materials and objects. These values are determined for vertical collision of sound through evaluation of standing pattern of plane wave in the tube which is generated through superposition of plane sinusoidal collision wave with plane wave reflected from test object. This method can be used to determine the sound absorption coefficient of sound absorbers for perpendicular collision of sound. In addition this method can be used to determine the surface acoustic impedance or acoustic surface admittance of sound-absorbing materials. This method is very suitable for parametric studies and design of the sound absorbers because it requires only a small sample of absorbent materials. Impedance tube method can be used to determine the reflection coefficient as well as impedance or admittance. Sound has vertical collision with the surface of object. The reaction chamber method (in ideal conditions) determines the sound absorption coefficient in Random Collision of sound. The Impedance tube method depends on the existence of a plane sound wave which determines exact values in these conditions.

Application of test tube: The test object is installed on one side of a straight, rigid, flat and firm Impedance tube (Fig. 1). Sinusoidal sound wave (pi) is generated by a speaker at the other end of the tube. Superposition of $p = p_i+p_r$ of incident wave p_i with wave reflected from the test object creates a standing wave pattern in the tube. Evaluating the measured quantities (in linear or logarithmic scale) of Sound pressure ranges continues until minimum pressure (s)$|P_{max}|$. (One or several) and maximum pressure (s)$|P_{max}|$. These data are enough to determine sound absorption coefficient. In addition, $x_{min,1}$ distance is the first sound pressure until the reference plane in $x = 0$ (which is usually the plane in which surface of test object is placed) and the wavelength of the sound should be determined in a way that reflection coefficient r and impedance Z or admittance be $G = 1/Z$.

Basis of sound waves: According to assumption, Collision Sound wave (p_i) is plane with time synchronized with frequency of (f) and angular frequency of $\omega = 2\pi f$ without weakening and aligned with the tube axis impedance (negative x):

$$P_i(x) = p_0 e^{jk_0 x}$$

$$k_0 = \frac{\omega}{v_0} = \frac{2\pi f}{v_0}$$

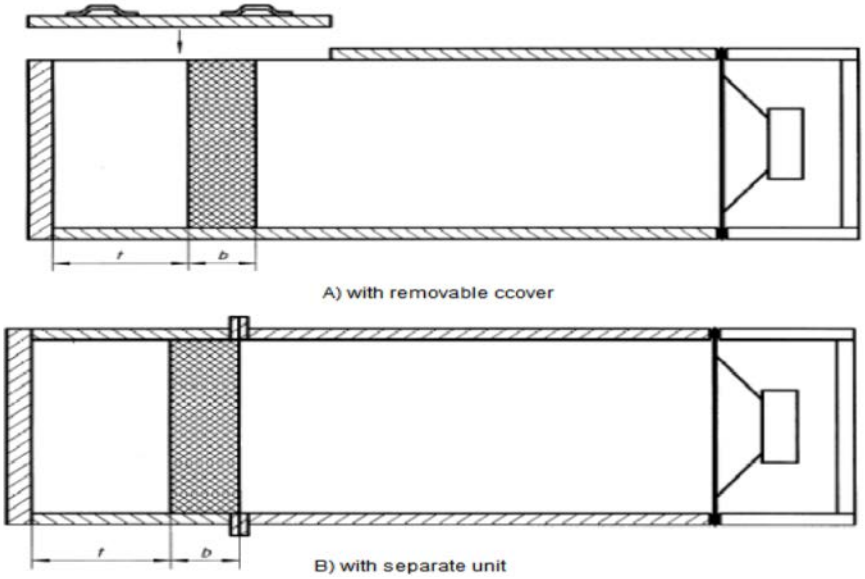


Fig. 2: test holder

In which p_0 domain is optional. So, wave reflected from test object which has the reflection coefficient of r is:

$$P_r(x) = r.p_0.e^{-jk0x}$$

Particle velocity of waves (with positive counting in the negative direction of x, Fig. are respectively:

$$V_i = \frac{1}{Z_0} p_i(x)$$

$$v_r(x) = -\frac{1}{Z_0} p_r(x)$$

The first impedance (in negative direction of x) in standing wave is:

$$X(x) = \frac{p_i(x) + p_r(x)}{v_i(x) + v_r(x)} = Z_0$$

$$\frac{p_i(x) + p_r(x)}{p_i(x) - p_r(x)}$$

The test equipment: Test equipment consisted of an impedance tube, a test sample holder, a test microphone, a tool to move and deploy test microphone, equipment for signal processing for microphone signal, speaker, a signal generator, probably an absorber terminal in impedance tube and a thermometer. Holder has been integrated with impedance tube or it is a separating unit which has been fixed securely to one side of tube during measurement (Fig. 2 for possible deployments). Length of sample holder should be large enough so that test objects can be installed on the back with needed air distance.

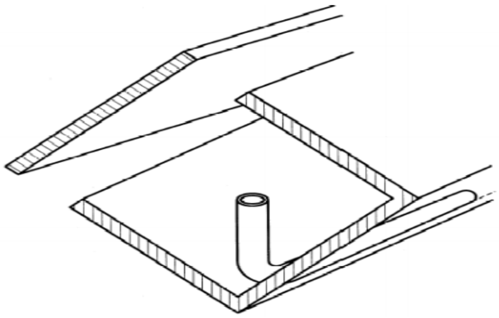
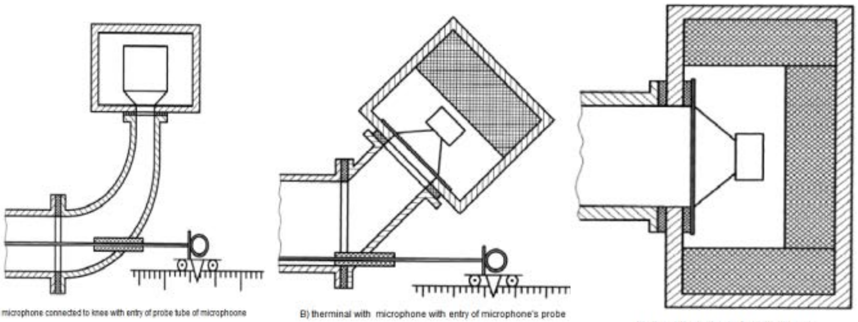


Fig. 3: Probe tube of microphone in the corner of impedance tube

Probe tube Installed in the center must be kept in a horizontal impedance tub in a way that probe tube is prevented from bending because it may cause higher sound amoods. Holders should not be close to sound pickup valve. The microphone or probe tube may be freely hung in impedance tube in a vertical Impedance tube with install section in the head down. In a right-sided impedance tube, tube can be rotated at an angle of about 45° around the axis (Fig. 3) and probe can be placed in the bottom corner, then holders can be removed.

The accuracy of tool to move probe microphone and read acoustic center position of it must be ± 0.5 mm. this tolerance may increase to maximum tolerances of ± 2 mm for frequencies below 300-50 Hz. Placement of microphone must be independent of the direction of the microphone (without orientation in the opposite direction). Signal processing equipment consist of an



C) microphone connected to knee with entry of probe tube of microphoone

B) therminal with microphone with entry of microphone's probe

A) direct therminal of microphone

Fig. 4: different types of microphone base

amplifier, a filter, a pressure gauge or sound flush (constant to reference pressure but optional) and preferably a continuous writer for standing wave pattern. Impedance tube terminal on the opposite side of sample holder must be a shell speaker (or speaker for pressure chamber for high frequencies be with tentacle as transmitter to impedance tube). Speaker's shell surface (or output of tentacle) should cover at least two-third of impedance tube's cross-section. Speaker's axis may be coaxial with pipe, or oblique, or connected to tube through knee (Fig. 4) so that a suitable space is created for inlet of probe tube.

Signal generator consists of a sinusoidal oscillation generator, a power amplifier and probably a frequency counter. Accuracy of regulating and reading frequency must be better than 2%. This matter also applies for tolerances of uncontrolled changes of frequency during the measurement.

MATERIALS AND METHODS

Test methods' theory

Specifications of reference plane: The first step in measuring the reflection coefficient or impedance after installation of the test sample is determining the reference plane ($x = 0$). This plane is usually the surface of test object. But if the test object has a surface profile, the reference plane must be placed at a distance in front of test object. In the final step, evaluation of the reflection coefficient or impedance can be converted to plane by calculations which are properly determined through structural measures of object.

Distance of reference plane and the first minimum from the surface of test object which in this case is used for evaluation should not be less than twice the diameter of the round pipes or maximum lateral size for right-sided tubes. It is even recommended for plane test objects which are seemingly homogeneous that minimums which are placed in this distance do not be used for evaluation (False stimulation to higher Amood; changing acoustic center of probe near the surface of object).

Specifications of frequencies: Range of work frequency must be covered with frequencies which preferably do not have steps wider than a third of synchronize. If it is possible, according to ISO 266 standard, use frequencies with central band frequencies a third of synchronize. Other frequencies may be required to reveal resonances to resonance test objects.

Determination of wavelength and attenuation: Speed of sound (c_0) in tube is determined prior to measurement, using which wavelengths of measurement frequencies are obtained. This determination of should be done in a tube with rigid terminal. Determination of attenuation of tube (meaning $k''_0\lambda_0/4$) must be done in the same initial measurement in tube with rigid terminal. Wavelength and attenuation determined in this way to measure frequencies can be used for all next evaluations with condition that tube or temperature do not change.

Selection of signal range: The signal range should be chosen in a way that it can be preferably more than 10 dB and at least 5 dB higher than background noise in deepest minimum pressure in that frequency.

Determination of sound absorption coefficient: The standard procedure method consists of measurement of amplitude of each frequency $|p(x_{min,1})|$ and location of the first $x_{min,1}$ minimum as well as amplitude $|p(x_{max,1})|$ of fist maximum. Calculate the following equation using these data:

$$Sl = \left|p\left(x_{max,1}\right)\right| / \left|p\left(x_{min,1}\right)\right|$$

And then, find the amplitude $|r|$ of reflection coefficient through equation A-13 with $n = 1$. Finally, find absorption coefficient of α through equation (Tiuc *et al*., 2016). For the inspection measurements, $|P_{max}|$ and $|P_{min}|$ are respectively measured in first minimum and maximum and then the sound absorption coefficient, α is calculated from equation.

Determination of reflection coefficient: The standard procedure consists of measurement of domain in each frequency $|p(x_{min,1})|$ and location of $x_{min,1}$ first minimum as well as domain of $|p(x_{max,1})|$ first maximum. Calculate the following equation using these data:

$$Sl = \left|p\left(x_{max,1}\right)\right| / \left|p\left(x_{min,1}\right)\right|$$

Then, $|r|$ amplitude of reflection coefficient is evaluated. Then, Φ phase is calculated

Determination of impedance: Start the measurement and evaluation procedure for reflecting coefficient and then evaluate normalized impedance of z through equation. Multiply the result by special impedance to find dimensioned impedance of Z. the amount of is obtained in Pa.s through the following equation. In which, T temperature during measurement is in Kelvin.

Determination of admittance: After determination of impedance of Z, admittance of G = 1 / Z is obtained by the following equation:

$$Z_0 = p_0 c_0 = 7064 / \sqrt{T}\,(\text{pa.s}) / m$$

In which T temperature during measurement is in Kelvin.

Determination of admittance After determination of impedance of Z, Admittance of G = 1 / Z is obtained by the following equation:

$$G = G + jG'' = \frac{Z' - jZ''}{Z'^2 + Z''^2}$$

Converting reflection coefficient and impedance: Reflection coefficient of r and impedance of z are determined for the reference plane of x = 0 based on procedure described in paragraph 8. If the surface of object is in x = -D, reflection coefficient of r and impedance should be corrected for distance of D. the converted reflection coefficient in any x position is determined as follows:

$$\begin{aligned} rx &= p_r(x) / p_i(x) = r e^{-2jk0x} \\ &= r\left[\cos(2k_0x) - j.\sin(2k_0x)\right] \end{aligned}$$

If x =-D, then Components of reflection coefficient converted to the object's surface are:

$$\begin{aligned} r(-D) = &\left[r'.\cos(2k_0D) - r''.\sin(2k_0D)\right] + \\ &j\left[r''.\cos(2k_0D) - r'.\sin(2k_0D)\right] \end{aligned}$$

Normalized impedance of z (x) which has been corrected for position x from x = 0 and normalized impedance in it is z is calculated as follows:

$$Z(x) = \frac{Z(x)}{Z_0} = \frac{z.\cos k_0 x + j.\sin k_0 x}{\cos k_0 + j.z.\sin k_0 x}$$

Thus, impedance, the normalized in x = -D object's surface is:

$$z(-D) = \frac{z'}{(\cos k_0 D + z''.\sin k_0 D)^2 + (z'.\sin k_0 D)^2} +$$

$$\frac{j\left[z'(\cos^2 k_0 D - \sin^2 k_0 D) - \right.}{1 - z'^2 - z''^2 \sin k_0 D.\cos k_0 D}$$

$$(\cos k_0 D + z''.\sin k_0 D)^2 + (z'.\sin k_0 D)$$

Sound absorbers

Ranking sound absorption: The objective of determining this standard is determination of a method using which values related to frequency of sound absorption coefficient can be converted to a Single number.

The single number ranking determined in this standard can be used to determine regulations and also to describe the characteristics of acoustic sound absorber products for common applications in offices, hallways, classrooms, hospitals, etc. this standard is applicable only if cases of using it cover the entire frequency range of reference diagram. If only a part of this range is considered, considering products which only have good sound absorption in this range is more appropriate. If a narrower frequency range is desired, since the low limit of in this standard is 250 Hz one point bad frequency ranking lower than this frequency is not suitable. If low frequencies are considered, then we should refer to full chart of sound absorption coefficient.

Applicable sound absorption coefficient: Applicable sound absorption coefficient (α_{pi}) for each one point band of i is calculated from the arithmetic mean value of α_{i1}, α_{i2} and α_{i3} one-third point sound absorption coefficient:

$$\alpha_{Pi} = \frac{(\alpha_{i1} + \alpha_{i2} + \alpha_{i3})}{3}$$

Weighted sound absorption coefficient: Values of α_{pi} mentioned in Table 1 are used based on reference diagram (Fig. 5) to calculate weighted sound absorption coefficient of α_w. the reference diagram sliders toward measured value in 0.05 steps until the sum of unwanted deviations is less than or equal to 0.10. Adverse deviation in a specific frequency occurs when measured value is less

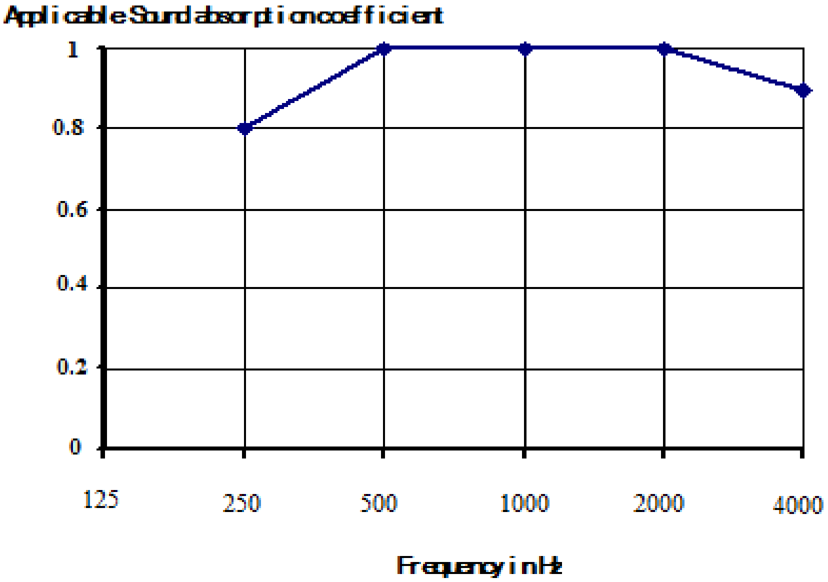


Fig. 5: Reference diagram for evaluation of weighted sound absorption coefficient of α_w

Table 1: Values of reference diagram for evaluation of weighted sound absorption coefficient of α_w

Frequency (Hz)	250	500	1000	2000	4000
Value of reference diagram	0.80	1.00	1.00	1.00	0.90

than the reference diagram. Deviations should only be considered in unwanted direction. Weighted sound absorption coefficient of α_w are defined in form of sliding reference diagram in the frequency of 500 Hz.

Form symbols: Whenever applicable sound absorption coefficient of α_{pi} with the value of 0.25 or more is higher than slide reference diagram, one or more form symbols are added to α_w in the parentheses. If additional absorption occurs in frequency of 250 Hz, Index L is used, if it occurs in frequency of 500 and 1000 Hz, index M is used and if it is in frequencies of 2000 Hz and 4000 Hz, index H is used.

RESULTS AND DISCUSSION

Values of $\alpha_{S:}$: Values of sound absorption coefficient in one third point band frequency (α_S) are drawn on a diagram. Frequency is set on x axis in logarithmic scale and values of α_S are set on y axis in linear scale. Distance of each point on x axis must be 15 mm and for each 0.20 of absorption coefficient on y axis, the distance should be 10 mm.

Values of α_p: Values of applicable sound absorption coefficient (α_p) are drawn on a diagram. Frequency is set on x axis in logarithmic scale and values of α_p are set on y axis in linear scale. Distance of each point on x axis must be 15 mm. Y axis is graded from α_p= 0- 0.1 and x axis is graded in one point bands from 125-4000 Hz.

Values of α_w and form symbols: Weighted Sound absorption coefficient (α_w) is calculated to two decimal places and form symbols in parentheses are expressed after α_w. The following sentence should be added whenever form symbol is provided:

"It is strongly recommended that this single number ranking be used along with the full diagram of sound absorption coefficient which can be accomplished upon request".

The depth of structure is determined for each diagram of α_p and each value of α_w for all products which have test object installed behind them (Fig. 6).

Empirical studies:

Preparation of plaster panel: Three types of panels containing plaster, plaster-perlite, plaster-carbon nanotubes were made with respect to the following conditions. To prepare plaster panel, some plaster were poured into water container and were stirred for 5 min with a mechanical stirrer. Upon starting solid phase entry, the mixture is poured into a mold with a diameter of 100 mm in order to come up completely and form the final structure of panel. To prepare plaster perlite and plaster-carbon

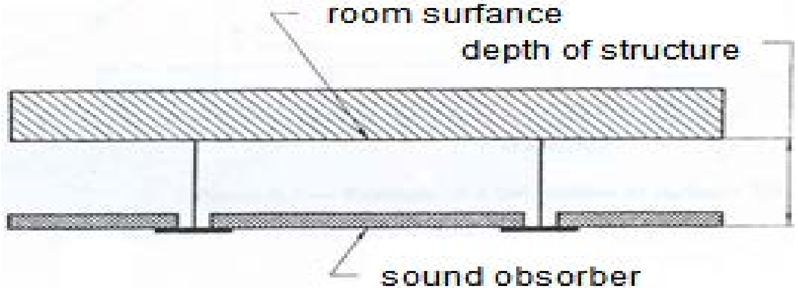


Fig. 6: specifications of structure’s depth

Fig. 7: Test sample

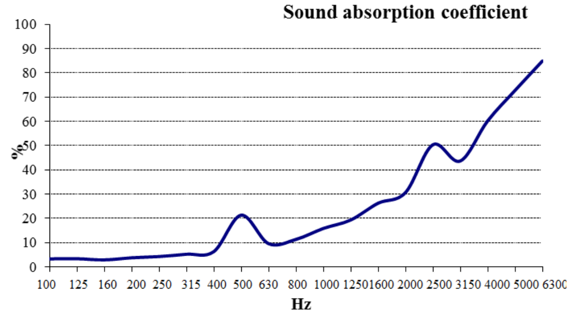


Fig. 8: Sound absorption coefficient

Table 2: Average sound absorption coefficient of samples in frequency range of 100-6300 Hz

Sample	Wt% of carbon nanotubes	Wt% of perlite	Average sound absorption coefficient
1	-	-	0.24
2	0.05	-	0.47
3	-	0.5	0.39

nanotube panels, initially plaster and perlite or plaster and carbon nanotube were mixed together and were poured into a water container as before and were stirred for 10 minutes with a mechanical stirrer (Fig. 7).

Measurement of sound absorption coefficient: Impedance tube method is used for this purpose which consists of a tube, two places for microphones and a digital frequency analysis system and is used to determine coefficient of sound absorption by sound absorbers in vertical collision of sound. In conversion function method which has also been used in this research, plane waves are generated by a sound source at one end of the tube and decomposition of interference field caused by audio signal hitting the sample and reflected from it is done by measuring the acoustic pressure at two fixed locations using an installed microphone and then the mixed acoustic transfer function is calculated and absorption is calculated in vertical collision.

Table 2 as well as sound absorption curves in Fig. 8 shows the increased sound absorption ability of panel due to adding carbon nanotube. In general, mechanism of sound absorption by porous adsorbents caused by converting energy of sound waves to heat energy due to movement of these waves in irregular routes within these materials and moving panel walls and friction with them as well as reflections and multiple scattering from walls and edges of panel’s cavities. Adding perlite to plaster and eventually creating plaster -perlite panel increases the sound absorption capability compared to plaster panel.

In this research, plaster panels have been initially prepared using carbon nanotubes and / or perlite and the average sound absorption coefficient of prepared nanocomposite foams have been measured in frequency range of 6300-100 hertz in the next step.

CONCLUSION

Now a day, use of nanopowders in building structures in order to improve the acoustic properties of construction materials has been focused on by building and construction industries. Thus, the effect of using carbon nanotubes and perlite in sound absorption properties and improvement of acoustic performance of plaster panels has been evaluated in this research. The results show that layers of carbon nanotubes provide better acoustic absorption with same volume and thickness. In other words, use of carbon nanotubes as light acoustic adsorbent is from of nano-fibers in different conditions is recommended. The following conclusions can be drawn from this study according to evaluations:

- Sound absorption capability of plaster panel increases by adding perlite and carbon nanotubes
- Effect of increased sound absorption capability due to the addition of perlite is higher than nanotube

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