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ORIGINAL ARTICLE

The Sound Adsorption of Poly Vinyl Chloride Nanocomposites, Consisting of Silica, Zinc oxide, Zeolite A to Noise Pollution Control

BAHRAM KOUHNAVARD

Department of Occupational Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

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ABSTRACT

In the current experimental study, firstly, we seek to synthesize polyvinyl chloride (PVC) nanocomposites, consisting of various additive nanoparticles, including Silica, Zinc oxide (ZnO), and Zeolite A nanoparticles. The size of Silica, ZnO, and Zeolite a nanoparticles were 30±2, 45±5, and 100±5 nm, respectively. Secondly, to investigate the effect of these nanoparticles on sound absorption, density, heat change, expansion, and contraction. Results showed that PVC/Silica 0.51%, PVC/Silica 0.29%, PVC/Zeolite A 6.1%, and PVC/Silica 0.51% had the highest sound absorption coefficient in a frequency of 250, 500, 1000, and 2000 Hz, respectively. Moreover, an increase of Zeolite A and ZnO nanoparticles increases density. However, an increase of Silica nanoparticles decreases density. The heat change experiment showed that an increase of Zeolite A decreases heat change, but an increase of Silica results in higher heat change. It was found that PVC/Silica 0.51% had a minimum contraction and expansion. Consequently, PVC/Silica 0.51%, PVC/Silica 0.29%, PVC/Zeolite A 6.1%, and PVC/Silica 0.51% nanocomposites had the highest sound absorption coefficient in a frequency of 250, 500, 1000, and 2000 Hz, respectively.

Keywords: *Sound adsorption; Poly vinyl chloride; Nanocomposites; Silica; Zinc oxide; Zeolite A*

INTRODUCTION

Nowadays, polymer-based nanocomposites (PBNCs) are widely used in different applications due to highly thermal, acoustic, mechanical, and chemical properties [1-2-3]. Generally, they have higher properties than pristine polymers. Nanoparticles increase thr interfacial contact due to high surface/volume ratio [4]. Therefore, the reaction of PBNCs to sound waves is decreasing the sound intensity both by air friction and scattering of frequencies of sound waves vibration allows the conversion of sound energy into thermal energy.

The developments of sound absorbents based on PBNCs are considered to becoming a subject of efficient panels design for noise reduction, especially for industrial application [7]. There are various sources of noise pollutants in our living and working environments. Noise pollution has become a growing problem to human health due to different adverse

Corresponding author: Bahram Kouhnavard
E-mail: bahramk2011@gmail.com

effects, including hearing loss, sleep disturbance, and psychological disorders [8]. Based on the Occupational Safety and Health Act, high noise levels are very harmful for workers [9]. It leads to not only psychological disorders but also physiological ailments. Many sound proof materials have been designed to minimize the negative impact of sound pollution, such as sound absorbers, sound insulators, sound dampers, and vibration isolators. Among these, sound-absorbing materials are the best way to reduce noises [10]. Soundproofing technologies vary from material to material. However, efficient sound absorbents should be able to prevent sound energy as much as possible at different frequencies. Although various sound absorbers have been used in many industries, such as building, automotive, transport, and industrial environments, a majority of them are not efficient. There is a tendency to use thin, light, and low-cost materials in absorbing sound waves at a wide frequency range [11].

In the current experimental study, firstly, we seek to synthesize polyvinyl chloride (PVC) nanocomposites, consisting of various additive nanoparticles, including Silica, Zinc oxide (ZnO), and Zeolite a nanoparticles. Secondly, to investigate the impact of these nanoparticles on sound absorption, density, heat change, expansion, and contraction.

MATERIALS AND METHODS

In the current study, three nanoparticles were used, including Silica, ZnO, and Zeolite A (Litotech company, German). These nanoparticles were mixed as additives to PVC. The important characteristics of these materials have been presented in Table 1.

Table 1. Important characteristics of materials used in current the study

Materials	Supplier	Characteristics
Silica nanoparticles	Litotech Co, Germany	Size distribution [a]: 30±2 nm Specific Surface Area : 300±25 m^2/g
Zinc oxide nanoparticles	Litotech Co, Germany	Size distribution: 45±5 nm Specific Surface Area : 400±30 m^2/g
Zeolite A nanoparticles	Litotech Co, Germany	Size distribution: 100±5 nm Specific Surface Area : 300±20 m^2/g
PVC	Tabriz Petrochemical Company, Tabriz, Iran.	density = 0.16 g/cm^3, granule size = 2 mm.

[a] The size distribution of these nanoparticles were determined by DLS

Preparation of Nanocomposites:

To prepare different PVC nanocomposites, 136 g of PVC was separately mixed with different contents of nanoparticles. Table 2 shows the exact content of each nanoparticle. All mixed materials were heated inside a cylinder-shaped cast to 400 °C for 60 min. The casts were cooled down at room temperature so that nanocomposites were separated.

Table 2. The exact content of nanoparticles, used for preparation of PVC/nanocomposite

	Silica nanocomposite	Zinc oxide nanocomposite	Zeolite A nanocomposite
Nanoparticle/PVC Ratio (%)	A: 0.14 B: 0.29 C: 0.51	A: 0.94 B: 1.79 C: 2.85	A: 1.9 B: 3.8 C: 6.1

The weight of PVC was 136 g for all nanocomposites.

The Measurement of Sound Adsorption Coefficient:

The sound absorption coefficient was measured using cylindrical nanocomposites with 11 cm diameter and 3 cm thickness. The sound absorption coefficient was calculated based on the four frequencies, including 250, 500, 1000, and 2000 Hz. The sound absorption coefficient was calculated using Equation 1.

$$\text{Sound absorption coefficient} = 1 - (V/I) \quad (1)$$

Where V is a reflected sound intensity and I is an incident sound intensity. Reflected and incident sound intensity was calculated using an acoustic tube (Zysst Fannavar Shargh Co., Iran). The acoustic tube was produced according to ISO 10534 and JIS A1405 [12].

Determination of Density:

To obtain the density of nanocomposites, the weight and volume of each nanocomposite were first obtained by a digital balance and ruler. Then, the density of each nanocomposite was calculated by Equation 2.

$$\text{Density} = m/v \quad (2)$$

Where m is weight and v is volume.

Heat Change Examination:

All PVC/nanocomposites were put in an oven at 70 °C for 1 h. Then, they were removed from the oven, and their temperature was measured by a thermometer after 5 min. Finally, the temperature change was calculated for each nanocomposite, according to Equation 3.

$$\text{The temperature change} = (70 - T) \quad (3)$$

Where T is nanocomposite temperature after 5 min.

Expansion and Contraction Measurement:

Firstly, the diameter of all nanocomposites was separately measured at 25 °C by a ruler. Then, all of them were separately held in an oven (70 °C) and a freezer (0 °C) for 1 h. Finally, the diameter of nanocomposites was separately recorded, and the change of diameter was calculated for each nanocomposite. The expansion and contraction were calculated by Equation 4 and Equation 5.

$$\text{Expansion} = D70\,°C - D25\,°C \quad (4)$$

$$\text{Contraction} = D25\,°C - D0\,°C \quad (5)$$

Where $D_{0\circ}$ C, $D_{25\circ}$ C, and $D_{70\circ}$ C, are the diameter of nanocomposite at 0, 25, and 70 °C.

RESULTS AND DISCUSSION

Sound Adsorption Coefficient of Nanocomposites:

The sound absorption coefficient of PVC/Zeolite A nanocomposites has been shown in Figure 1. In the frequency of 2000 Hz, all PVC/Zeolite A nanocomposites had the same sound absorption coefficient. In the frequency of 1000 Hz, the highest sound absorption coefficient was near 0.9 for PVC/Zeolite A: 6.1% nanocomposite. In the frequency of 500 Hz, the highest sound absorption coefficient was near 0.5 for PVC/Zeolite A: 3.8% nanocomposite (P<0.05). Both PVC/Zeolite A: 1.9% and 6.1% nanocomposites had the same sound absorption coefficient in the frequency of 250 Hz. It must be mentioned that the least sound absorption coefficient was seen in the frequency of 500 Hz for all of them.

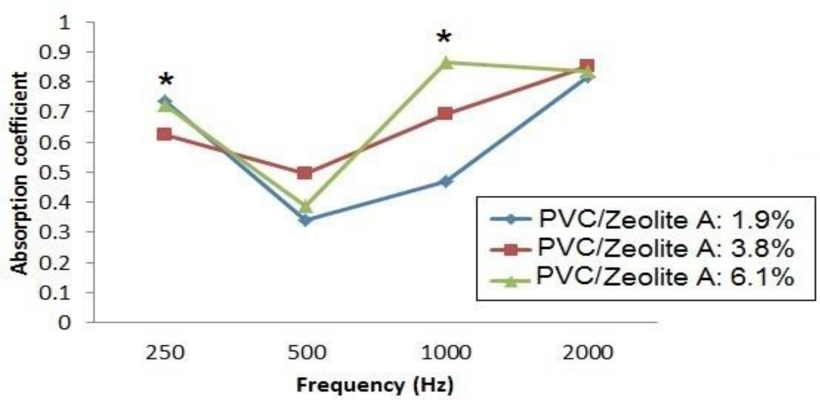

Fig1. Sound adsorption coefficient of PVC/Zeolite A nanocomposites. * P<0.05 compared with others at same frequency, n=3.

The sound absorption coefficient of PVC/Silica nanocomposites has been presented in Figure 2. In frequencies of 250, 1000, and 2000 Hz, the highest sound absorption coefficient was near 0.8, 0.85, and 0.9 for PVC/Silica: 0.51 % nanocomposite ($P<0.05$). In the frequency of 500 Hz, the highest sound absorption coefficient was near 0.4 for PVC/Silica: 0.25% nanocomposite. Note, the least sound absorption coefficient was seen in the frequency of 500 Hz for all of them.

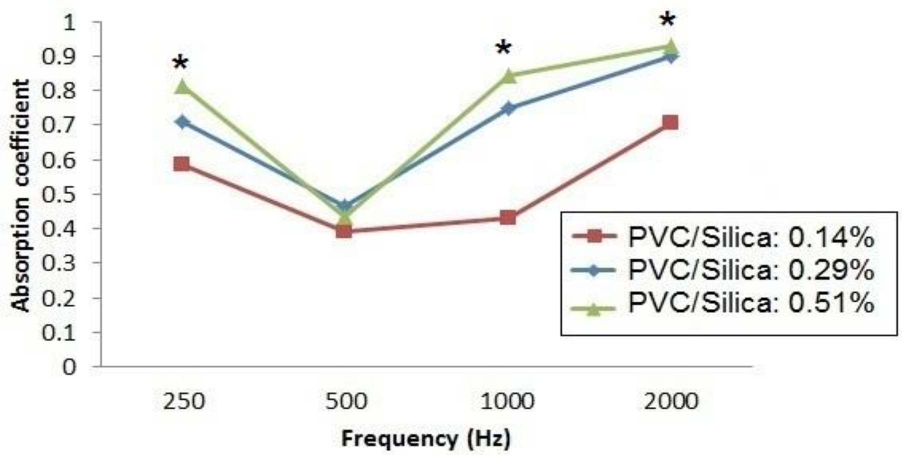

Fig2. Sound adsorption coefficient of PVC/Silica nanocomposites. * $P<0.05$ compared with others at same frequency, n=3.

The sound absorption coefficient of PVC/ZnO nanocomposites has been presented in Figure 3. The highest sound absorption coefficient for PVC/ZnO: 0.94 %, PVC/ZnO: 1.79 %, and PVC/ZnO: 2.85 % nanocomposites was 0.7, 0.8, and 0.7 ($P<0.05$). The least sound absorption coefficient was seen in the frequency of 500 Hz for all PVC/Silica nanocomposites. Thus, sound absorption coefficients did not increase due to an increase in nanoparticles content. It must be mentioned that the best ratio was not the highest ratio.

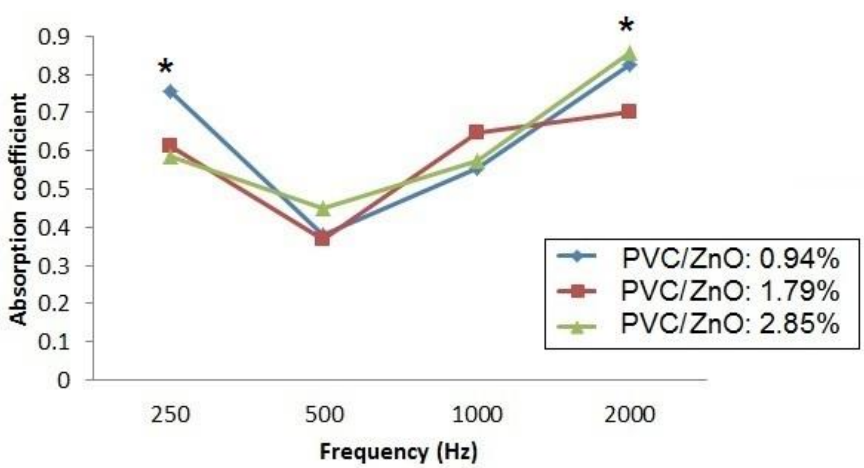

Fig3. Sound adsorption coefficient of PVC/ZnO nanocomposites. * $P<0.05$ compared with others at same frequency, n=3.

Density:

Table 3 shows the density of PVC/nanocomposites, which were used in this study. An increase of Zeolite A and ZnO nanoparticles' content causes to increase in the density. However, in the case of Silica nanoparticles, an increase in content decreases the density.

Table 3. The density of PVC/nanocomposites, which used in this study

Nanocomposite	density (g/cm^2)
PVC/Zeolite A: 1.91%	0.170
PVC/Zeolite A: 3.84%	0.180
PVC/Zeolite A: 6.13%	0.181
PVC/ZnO: 0.94%	0.187
PVC/ZnO: 1.79%	0.198
PVC/ZnO: 2.85%	0.218
PVC/Silica: 0.14%	0.220
PVC/Silica: 0.29%	0.212
PVC/Silica: 0.51%	0.205

Heat Change:

Table 4 shows the heat change of PVC/nanocomposites, which were used in this study. An increase in Zeolite A's content decreases the heat change. In the case of ZnO nanoparticles, the content did not change the heat change. However, an increase of Silica nanoparticles' content increases the heat change.

Table 4. The heat change of PVC/nanocomposites, which used in this study

Nanocomposite	Heat change (°C)
PVC/Zeolite A: 1.91%	32
PVC/Zeolite A: 3.84%	28
PVC/Zeolite A: 6.13%	27
PVC/ZnO: 0.94%	31
PVC/ZnO: 1.79%	31
PVC/ZnO: 2.85%	31
PVC/Silica: 0.14%	28
PVC/Silica: 0.29%	30
PVC/Silica: 0.51%	31

Expansion and Contraction:

Table 5 shows the quantity of contraction and expansion of PVC/nanocomposites. The maximum observed contraction for PVC/Zeolite A was 3.84%, the minimum contraction for PVC/ZnO was 2.85%, and PVC/Silica: 0.51%. Moreover, the maximum observed expansion for PVC/Zeolite A was 1.91%, and the minimum expansion for PVC/Zeolite A was 3.84%, PVC/ZnO: 0.94%, and PVC/Silica: 0.51%. There was no defined pattern with an increase or decrease of nanoparticle content.

Table 5. The quantity of contraction and expansion of PVC/nanocomposites

Nanocomposite	Contraction	Expansion
PVC/Zeolite A: 1.91%	0.1	0.4
PVC/Zeolite A: 3.84%	0.5	0.1
PVC/Zeolite A: 6.13%	0.2	0.2
PVC/ZnO: 0.94%	0.1	0.1
PVC/ZnO: 1.79%	0.2	0.3
PVC/ZnO: 2.85%	0	0.3
PVC/Silica: 0.14%	0.1	0.2
PVC/Silica: 0.29%	0.1	0.3
PVC/Silica: 0.51%	0	0.1

The purpose of the present study was to synthesize PVC/nanocomposites, containing Silica, ZnO, and Zeolite A nanoparticles. Moreover, some physical properties, such as sound absorption, density, heat change, expansion, and contraction were investigated. Both theoretical and experimental studies showed that the presence of nanoparticles in polymers can change their physical and chemical properties [13].

Thus, this study seeks to find answers to the following questions: 1. Which nanoparticles and polymers are better to absorb sound energy? 2. What proportion is needed? In answering the research questions, we used PVC a matrix due to its highly mechanical, physical, and chemical properties. These properties make it suitable for construction of acoustic panels [11]. Therefore, different types of nanoparticles, Silica, ZnO, and Zeolite A nanoparticles were selected to evaluate sound energy absorption. All particles had a small size and a high surface/volume ratio.

Although sound adsorption property is depending on nanoparticle size, shape, and surface/volume ratio, other physical and chemical properties also play an important role. So that, various ratios of nanoparticles were used to investigate the effect of nanoparticle content.

After preparation of PVC/nanocomposites, the sound absorption coefficient was measured in octave bands of 250, 500, 1000, and 2000 Hz, using an acoustic tube, according to ISO 10534 and JIS A1405. The best sound adsorbent in the frequency of 250, 500, 1000, and 2000 was PVC/Silica: 0.51%, PVC/Silica: 0.29%, PVC/Zeolite A: 6.1%, and PVC/Silica: 0.51%. Accordingly, an increase in the content of nanoparticles did not increase the sound absorption coefficient. It could be due to molecular interaction between nanoparticle surface and PVC.

The density of PVC/nanocomposites was also analyzed. The results of this test showed that an increase in the content of Zeolite A and ZnO nanoparticles increases the density. However, in the case of Silica nanoparticles, an increase in the content decreases the density. It could be due to the high porosity of Silica nanoparticles. It must be mentioned that PVC/Silica nanocomposite had a higher density than PVC/ZnO and PVC/Zeolite A nanocomposites. On the other hand, the heat change of nanocomposite showed that an increase in the content of Zeolite A decreases the heat change, but an increase of Silica content increases the heat change. This pattern was in line with sound adsorption properties. Since these nanocomposites may be used in different temperatures, both contraction and expansion are important. It could be due to the impact of the heat change of nanocomposite on the sound adsorption properties. It was found that PVC/Silica: 0.51% had a minimum contraction and expansion. It seems that this nanocomposite was more suitable for hot and cold weather.

Asmatulu et al., in their study, reduced noise in different frequencies by electrospun nanofibers. They showed a high absorption coefficient of nanofibers [12]. The results of Lee et al's., study on polyurethane/Silica nanocomposite foams showed that by increasing Silica's content, the sound absorption increased over the entire frequency. Moreover, a decrease of isocyanate index, cell size, and an increase of the density increase the sound absorption [7]. Xiang et al. analyzed acoustical damping properties of electrospun polyacrylonitrile (PAN) nanofibrous membranes with different thicknesses and porosities. Results proved that the first resonance absorption frequency shifted to the lower frequency with an increase in the back cavity or the thickness of membranes [14]. In a study conducted by Mohrova et al., it was found that the thin nanofibrous layer had higher sound absorption properties than porous fibrous materials. Where, the energy of sound waves was absorbed by the principle of membrane resonance [15]. Gayathri synthesized new polyurethane based porous composites in the presence of nano Silica, crumb rubber, and nano clay. The sound absorption coefficient of nanocomposites increased from 0.5 to 0.8 with increasing of frequency from 100 to 200 Hz. In addition to enhanced sound absorption properties in the low-frequency region, the composite foams exhibited superior thermal and mechanical properties [16]. Bahrambeygi et al. studied the effect of polyacrylonitrile and polyurethane (PU) nanofibers, multi-wall carbon nanotubes, and nanoclay on sound absorption. All nanoparticles improved sound absorption properties [17].

CONCLUSION

It would be interesting to evaluate the application of PVC/nanocomposites in future studies. Thus, the low sound absorption coefficient in the frequency of 500 was a restriction and must be removed by other absorbents. So the efficiency of these nanocomposites, particularly PVC/Silica nanocomposite, must be investigated in a real condition.

Consequently, it was found that PVC/Silica: 0.51%, PVC/Silica: 0.29%, PVC/Zeolite A: 6.1%, and PVC/Silica: 0.51% nanocomposites had the highest sound adsorption coefficient in the frequency of 250, 500, 1000, and 2000 Hz.

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CONFLICT OF INTEREST

There was no conflict of interest.

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