Modification of Noise Reduction by SiO_2 Nanocomposite: The Case of Earplugs

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Abstract: - When applying different control measures fail to reduce noise exposure to a safe level, using hearing protection devices (HPDs) becomes necessary. The study's aim was to investigate the effect of SiO_2 nanoparticles on the noise reduction efficiency of PVC earplugs. PVC polymer of type S-60 as the main matrix and SiO_2 with a size of 30 nm were used. The PVC / SiO_2 nano-composite was mixed at a temperature of 160 ° C and 40 rpm and samples with 0, 0.2 and 0.5 weight percent of SiO_2 nanoparticles were prepared. Samples of earplugs with PVC / SiO_2 nanoparticles (0.2; 0.5% by weight), when compared to raw earplugs, showed the noise attenuation at low frequencies (125-500 Hz) almost the same as that of the raw earplugs. At high frequencies (2-8 kHz), however, the noise attenuation performance of earplugs with SiO_2 nanoparticles increased significantly ($P < 0.05$). The results of the present study showed that samples with SiO_2 nanoparticles show a stronger noise attenuation at higher frequencies compared to samples without nanoparticles.

Keywords: - Earplug, Nanocomposite, Noise Reduction

1. INTRODUCTION

When applying different control measures fail to reduce noise exposure to a safe level, using hearing protection devices (HPDs) becomes necessary. Their lower price in comparison to technical engineering controls makes them a feasible choice with acceptable efficiency. Considering the worn-out industrial facilities and their economic problems in developing countries, the need for more cost-effective means of maintaining the health of workers is well known [1]. As result, HPDs with higher efficiency are required. The major properties of HPDs are comfort and an adequate noise reduction rate. Employees' training and motivation to apply HPDs safely voluntarily are also determining factors of success [2, 3]. The lower weight and sufficient noise insulation factors of these devices are stated by researchers as the main comfort component when using HPDs [2, 4]. A high level of noise attenuation and a high level of comfort are therefore essential determinants of a good HPD [4, 5]. The noise reduction index is a common factor used to describe the amount of noise that is attenuated by an HPD. This factor is often used to estimate the actual exposure of workers [6]. High attenuation rates (45 - 50 dB) are recommended in work environments with noticeably high noise levels. In this regard, regulating agencies like National Institute for Occupational Safety and Health (NIOSH) sometimes mandate the use of earplugs and earmuffs at the same time to enhance the rate of noise reduction. These systems are known as dual hearing protection (DHP). Although, when using DHPs, discomfort and other problems occur, leading this type of hearing protection program to fail [7, 8]. Accordingly, improving the noise attenuation of HPDs through a new design is desirable while at the same time allowing for improved comfort [9]. Nanoparticles such as titanium/silicon dioxide are of interest because of their good soundproofing properties, their low weight and their proven properties for improving mechanical and thermal properties when added to polyurethane foam [10-12]. It can therefore be accounted that the application of these materials in HPDs has a bright future. NIOSH has announced "The application of nanomaterials and nanotechnology in the field of occupational health and safety" as an emerging research need [13, 14]. This study aims to apply the nanocomposite of polyvinyl chloride / SiO_2 to make a laboratory-scale prototype earplug and to examine the earplug in different situations to determine its noise attenuation behavior.

2. PROBLEM FORMULATION

The S-60 type PVC polymer (Abadan Petrochemical Co, Iran) was used as the matrix in the study. Its mass flow rate and melt densities were 1.4 g/10 min and 0.52 g/cm^3, respectively. SiO_2 nanoparticles were applied as nano-fillers (VK-SP15 via Xuancheng Jingrui New Material Co. (China)). The size and surface area of the SiO_2 nanoparticles were 15 nm and 200±50 m^2/g, respectively.

2.1. Sample preparation

The PVC / SiO_2 nanocomposite was made by the melt blending process using a twin-screw extruder. Then it was mixed at a temperature of 160 ° C and 40 rpm. The prepared material was dried for further steps. In the study, samples of 0, 0.2 and 0.5 percent by weight were made of SiO_2 nanoparticle concentration. The samples were pressed into a mold measuring 10 mm in diameter, 25 mm in length and 5 mm in thickness.

2.2. Insertion Loss Measurements

A common measure of acoustic performance that is of interest when attenuating noise in hearing protection devices is the insertion loss (IL), which is defined as follows:[14, 15]

$$IL= 20 \log (P/P0) \text{ (dB)} \quad (1)$$

where, P= sound pressure level measured at the location of interest with earplug on (dB)

P0= sound pressure level measured at the same location with earplug removed (dB)

An acoustic test fixture (ATF) was used to measure the attenuation performance of HPDs [6, 16]. Figure 1 illustrates a laboratory setup of ATF. The white noise signal was generated by micro lab loudspeakers. The noise signal was measured with a calibrated sound level meter (TES, Taiwan) accompanied by a frequency analyzer. The measurements took place in the 1/3 octave band from 31.5 Hz to 8000 Hz. The American National Standards Institute (ANSI S12.42-2010) and the International Organization for Standardization (ISO / TS 4869-5: 2006) recommendations were used to ensure the accuracy of the experimental study conditions [17, 18]. Noise attenuation tests for earplug samples were performed on 3 groups of these nanocomposite HPDs with 5 earplugs in each group. To ensure the accuracy of the measurements, one of these 3 groups was a sample without added nanoparticles (pure PVCs). The sound pressure level differences were calculated as the IL of the HPD at each frequency.

Figure 1. Laboratory acoustical test fixture of the present study with three sample earplugs which tested one by one, a: Pure PVC, b: Sample with 0.2 wt%SiO_2, c: Sample with 0.5 wt%SiO_2

3. PROBLEM SOLUTION

Table 1 presents the results of the mean and standard deviation of sound reduction in 3 categories of earplug samples with different loading of SiO_2 nanoparticles. According to the results of table 1, it was found that in the case of the sample containing 0.2 wt% of silica nanoparticles, at frequencies of 2000 to 8000 Hz, the ability to reduce the noise was improved between 4 to 10 dB compared to the raw sample. These conditions were also observed in samples containing 0.5 wt%. Besides, the comparison between samples with 0.2 wt% and 0.5 wt% SiO_2 revealed just ≤1 dB noise reduction.

Table 1. Average of insertion loss (dB) and standard deviation in samples

		125 Hz	250 Hz	500 Hz	1KHz	2KHz	4KHz	6KHz	8KHz	Sample Weight gr
Pure PVC	IL	23.9	17.9	19.5	22.4	25.1	22.6	27.7	25.4	1.73
	SD	0.8	0.5	0.4	0.6	1.1	0.4	0.5	0.9	0.08
Sample with 0.2 wt% SiO_2	IL	25	18.1	19.7	21.8	35.5	26.2	35.4	37.6	2
	SD	0.1	0.4	0.5	0.5	0.1	0.5	0.4	0.4	0.07
Sample with 0.5 wt% SiO_2	IL	24.6	17.8	20.4	22.1	34	25.8	35.4	38.1	2.09
	SD	0.1	0.1	0.1	0.3	0.1	0.1	0.2	0.1	0.03

The results of the noise reduction (NR) measurement of earplugs containing zero and 0.2% by weight of silicon dioxide are presented in figure 2. The NR of earplugs with 0.2 wt% SiO_2 nanoparticles compared to raw earplugs showed that the noise attenuation at low frequencies (125-500 Hz) was almost the same as that of the earplugs without any nanoparticles.

At frequencies of 2000, 4000 and 8000 Hz between pure PVC and earplugs with 0.2 wt.% SiO_2 nanoparticles, the NR differences of 10, 4 and 12 dB, respectively, were observed which had a significant difference ($P < 0.05$).

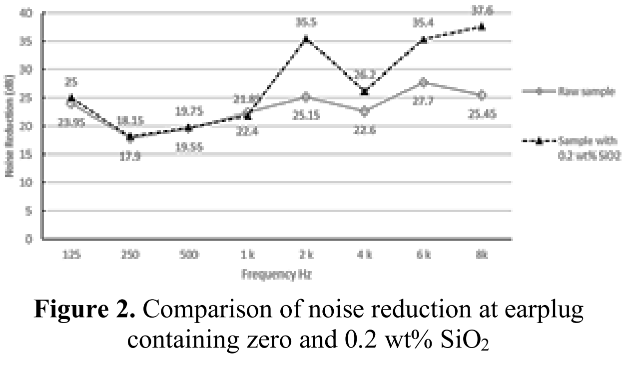

Figure 2. Comparison of noise reduction at earplug containing zero and 0.2 wt% SiO_2

The results of the noise reduction measurement of earplugs containing zero and 0.5% by weight of silicon dioxide are presented in figure 3.

The maximum NR at the frequency of 8 kHz in earplugs with 0 and 0.5 wt% SiO_2 nanoparticles were 25.4 and 38.1 dB, respectively.

Also, the minimum NR at the frequency of 250 Hz in earplugs with 0 and 0.5 wt% SiO_2 nanoparticles were obtained as 17.8 and 17.9 dB, respectively. At frequencies from 125 to 1000 Hz the noise attenuation was almost the same for both earplugs, but at high frequencies (2-8 kHz) the NR performance for the earplugs with 0.5 wt% SiO_2 increased significantly ($P<0.05$). And the difference of NR ranged from 4 to 13 dB.

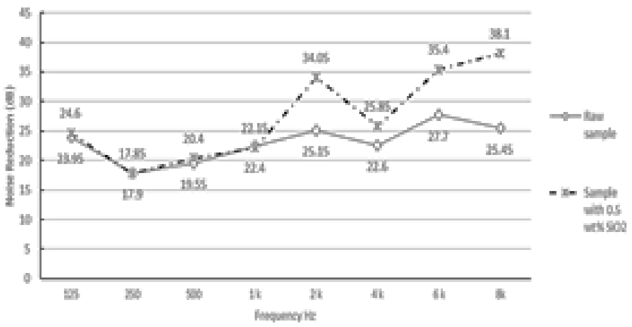

Figure 3. Comparison of noise reduction at earplug containing zero and 0.5 wt% SiO_2

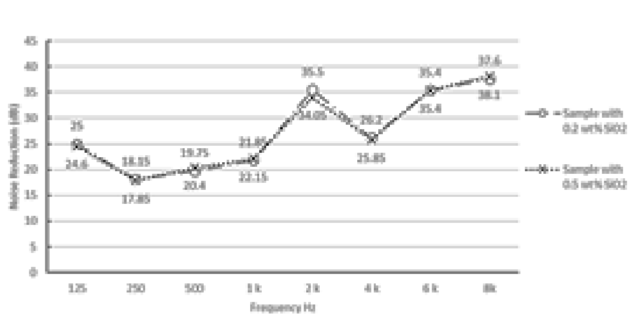

Figure 4. Comparison of noise reduction at earplug containing 0.2 and 0.5 wt% SiO_2

In a comparison between earplugs with a loading of 0.2 and 0.5% by weight SiO_2 nanoparticles, the results showed that no significant difference could be observed in any of the frequencies. The range of difference of NR between the same frequencies was small and amounted to 1.5 dB (Fig. 4).

4. CONCLUSIONS

This study compared the mean noise attenuation of two different contents of nanoparticles of SiO_2 /PVC earplugs with the noise attenuation of pure PVC earplugs to determine the effect of SiO_2 nanoparticles in combination with conventional PVC earplugs on the insertion loss. The results showed that the addition of SiO_2 nanoparticles to pure PVC earplugs can increase their insertion loss to a significant level ($P < 0.05$). Also for higher frequencies above 2000 Hz, higher noise reduction efficiency of nanocomposite earplugs was observed. Yan and Kim (2014) also confirmed a higher efficiency of nanocomposite earplugs [19].

Besides, the noise reduction efficiencies achieved at frequencies below 1 kHz, which are similar to those of pure PVC earplugs, suggest that earplugs, like earmuffs, have poor noise attenuation at low frequencies [9]. Lee et al., (2013) reported that with adding nano-silica content to polyurethane foam, the sound absorption ratio increased over the entire frequency range [20].

This finding is similar to the present study. In another study by Zhao et al., (2020) on the structure and properties of polyurethane foam modified with SiO_2 nanoparticles, the results showed that the combination of polyurethane and nanoparticles increased the sound absorption properties of nano-composited polyurethane and improved its noise attenuation efficiency to a significant level at higher frequencies [21].

The same improvement in the case of sound insulation efficiency of various nanocomposites when compared to pure conventional materials, are reported by other studies [13, 19, 22]. Khanouki and Ohadi also studied the acoustic performance of SiO_2 nanoparticles and stated that the sound absorption ability of nanocomposite was significantly higher that of pure polyurethane [23].

The results of this study showed that samples with silicon dioxide nanoparticles had more pronounced noise reduction properties at frequencies of 2000, 4000, 6000 and 8000 Hz compared to samples without nanoparticles (pure PVC).

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