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Investigation of Acoustic Properties of Polymer Nanocomposites Polymer Regarding Combined Sound Absorption and Insulation Characteristics

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ABSTRACT

Introduction: Nowadays multiple techniques have been developed to noise control. One the most important way is the control based on sound absorption and insulation. The purpose of current study was to improve the acoustic properties of soft polyurethane foam regarding combined sound absorption and insulation characteristics.

Materials and Methods: Polyacrylonitrile and polyvinylidine fluoride nanofibers are fabricated using solution electrospinning technique. Nano-clay particles (montmorillonite, 1-2 nm in diameter) were purchased from Sigma-Aldrich, Inc. Experimental design was prepared using Design-Expert ver.7 software. The 50 samples of nanocomposites were fabricated on the basis of experimental run. The measurement of sound transmission loss and the absorption coefficient was conducted using BSWA SW477 550005 Impedance Tubes according to the standard ASTM E2611-09 and ISO10534-2, techniques. Response surface methodology (RSM) with central composite design (CCD) was applied to optimize the conditions to produce nanocomposites for each frequency range.

Results: The polymer nanocomposites had the higher combined sound transmission loss and the absorption coefficient than pure polyurethane foam. Their combined transmission loss and the absorption coefficient in the low, middle and high frequency range was 02.02, 1.91 and 2.53 times higher than the pure polymer. The combined transmission loss and the absorption coefficient in all frequency ranges have been increased by increasing the thickness of the composites and air gap. At a thickness of 2 cm, the combined composites, sound transmission loss and the absorption coefficient increased with the increase of content of both nanofibers. The highest combined transmission loss and the absorption coefficient was observed when mass fraction of nanofibers was in at its maximum level.

Conclusion: This study showed that the adding nano-clay particles, polyacrylonitrile and polyvinylidine fluoride nanofibers to polyurethane foam can lead to increased sound transmission loss and the absorption coefficient. The obtained optimized nanocomposite can be applied to noise control where requiring the absorption as well as reduction of sound transmission.

Keywords: Noise, transmission loss, absorption coefficient, Polyurethane, nanofiber, nanoparticle

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1.Introduction

Noise control based on the absorption and isolation is an effective engineering control method. In this approach, by increasing in surface absorption coefficient, the level of sound reflection would decrease and the total sound level would drop down. In addition, with appropriate insolation, a less exposure level would happen to noise among the workers. In the case of using acoustic tile as sound absorption with insolation properties, it could shift sound field to free field around the source. Meanwhile a dramatic increase cab be seen in transition loss in other areas. Among the polymers, polyurethane was chosen for this study because of its lowcast, ease of foaming and high porosity. Nanofibers Polymer also cause more damping of the sound due to the creation of tortuous path for the sound transmission and increased contact area. It has been shown that addition of nanoclays in polyurethane foam can improve the sound absorption level at all frequencies, especially at low frequencies. Therefore, the present study aimed to assess the acoustic properties of polyurethane containing nanofibers and nanoclays regarding combined sound absorption and insulation characteristics [1].

2. Materials and Methods

Polyacrylonitrile and polyvinylidine fluoride nanofibers were produced using solution electrospinning technique. Nano-clay particles (montmorillonite, 1-2 nm in diameter) was provided from Sigma-Aldrich, Inc. Experimental design was prepared using Design-Expert ver.7 software. The 50 numbers of nanocomposites samples were produced on the basis of experimental run. To make the nanocomposites samples, electro spun polyacrylonitrile (PAN) nanofiber (NF) and polyvinylidine fluoride (PVDF) NF were added to the polyols with methylene diphenyl diisocyanate (MDI) system. It was stirred with a magnetic stirrer for two hours and placed in an ultrasonic for 30 minutes. The polyols containing PAN and PVDF nanofibers were mixed with isocyanate containing clay nanoparticles inside the mold and the desired composites were made using a mechanical [2].

After making the test samples, the average combined noise transmission loss and absorption coefficient (considering 70% absorption coefficient value and 30% transmission loss value) in three frequency bands (low, medium and high) was measured using tube impedance device. The measurement of sound transmission loss and the absorption coefficient was done using BSWA SW477 550005 Impedance Tubes according to the standard ASTM E2611-09 and ISO10534-2.

At first, each sample according to the mean and standard deviation was standardized for each sample set

to obtain the optimized test sample in terms of combined sound transmission loss and the absorption coefficient, due to the high dispersion rate of the transmission loss compared to the absorption coefficient and their non-coherence, Then, the sample with highest absorption coefficient and transmission loss was selected as the optimized sample. Standard score (Z) determine scores relative to the mean.

To determine the combined transmission loss and absorption coefficient of the sound are performed as follows: Combined transmission loss and absorption coefficient of the sound = 0.7 Z (absorption coefficient)+0.3 Z (transmission loss). Response surface methodology (RSM) with central composite design (CCD) was applied to optimize the conditions to produce nanocomposites for each frequency range.

3.Results

The diameter of PAN NF and PVDF NF was 85± 20nm and PVDF NF 96±20 nm, respectively. An example of the forms of nanofibers and nanoparticles used in nanocomposites is shown in Figure 1.

Design Expert software proposed a linear relationship between combined absorption coefficients and transmission loss and input variables (weighting percent of nanoclays and nanofibers, foam thickness and air gap distance) at low frequencies, two-factor relationship model (2FI) at middle frequencies and a quadratic relationship model at high frequencies. To increase the validity of the models provided by Design-Expert, the combined absorption coefficients and transmission loss the factors which were not statistically significant, were excluded from the model. Design-Expert software was used to predict optimal combinations using input variables to achieve maximum, minimum, or specific amount of response variables. After obtaining the relevant results, optimization for the combined absorption coefficients and transmission loss was done with using Design-Expert software. Table 2 presents some solutions at different levels of response variables that had combined high absorption coefficients and transmission loss at low, mid and high frequencies.

Figure 2 shows the influence of thickness and air gap on the combined absorption coefficients and transmission loss in the low, mid and high frequency bands. The combined absorption coefficients and transmission loss increase with increasing foam thickness and air gap. This increase id higher for low and mid frequency than high frequency.

According to the results, as the air gap increases, the absorption coefficient increases at low, mid and high frequencies. The results also showed that increasing the foam thickness and distance at the mid and low frequencies had a higher effect on the absorption coefficient and transmission loss than the high frequencies. The air gap behind the sample can be effective in absorbing the acoustic energy at mid and low frequencies, with increasing the acoustic energy absorption at long wavelengths, as a result. Resonance phenomena also occur at lower frequencies by creating an air gap behind the absorber, resulting in better absorption of sound at low frequencies. The results of study showed that using PAN NF with clay nanoparticles or PVDF NF in composite didn't have the combined absorption coefficients and transmission loss. One reason can be that PAN NF gas low density and, consequently, being too bulky, disrupts foam formation if used concurrently with other fillers. What is more the overuse of fillers reduces cell volume, which can reduce absorption and transmission loss at low frequencies [3-5].

The highest combined absorption coefficients and transmission loss occurs at 1 cm thickness when PAN NF has the highest weighting percent and PVDF NF has the lowest percent but at 2 cm thickness the coefficient of absorption and coefficient of transmission occurs when PVDF NF and PAN NF have the highest weighting percent. At high thickness, the sound waves collide with many nanofibers, which increases the combined absorption coefficients and transmission loss [6]. The nanoclay along with one of the nanofibers increases the density of foam. That is due to may be the increase in mass transmission loss in the control region for the high effect of clay nanoparticles and thickness on the increase in combined absorption coefficients and transmission loss at mid frequencies. As the thickness doubles, the surface density doubles. In this area, dB6 transient doubling of surface density or frequency increases [7].

When fillers are placed in the cell or inside the foam, the energy loss in the form of heat can be increased because the wall of cell or foam must improve the deformation caused by sound waves. The combined highest absorption coefficients and transmission loss occur when both nanofibers are at their maximum weighting percent [8]. These results show that at higher thicknesses, the sound waves are more affected by nanofibers and also the use of nanofibers with clay nanoparticles partially increases the combined absorption coefficients and transmission loss.

4.Conclusion

The polymer nanocomposites had the higher combined sound transmission loss and the absorption coefficient than pure polyurethane foam. Their combined transmission loss and the absorption coefficient in the low, middle and high frequency range was 02.02, 1.91 and 2.53 times higher than the pure polymer. By increasing the thickness of the composites and air gap, the combined transmission loss and the absorption coefficient in all frequency ranges were increased. At a thickness of 2 cm, the combined composites, sound transmission

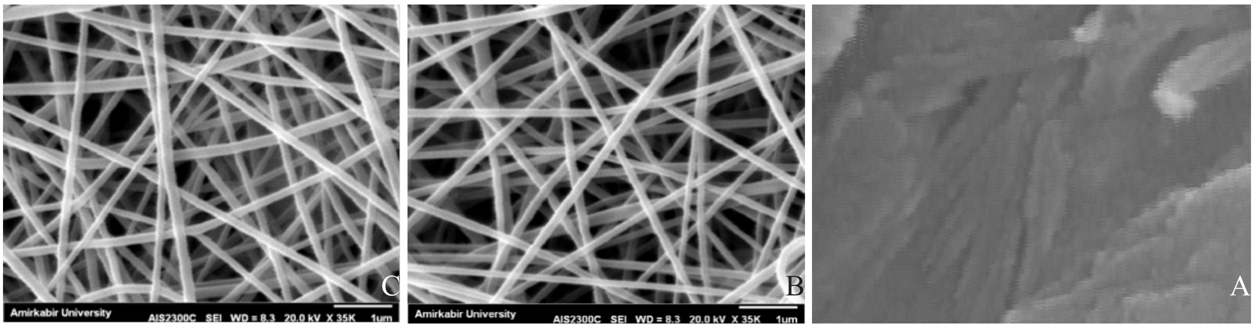

Fig. 1. SEM taken from nanofibers and nanoparticles A: Clay nanoparticles b: PAN NF C: PVDF NF

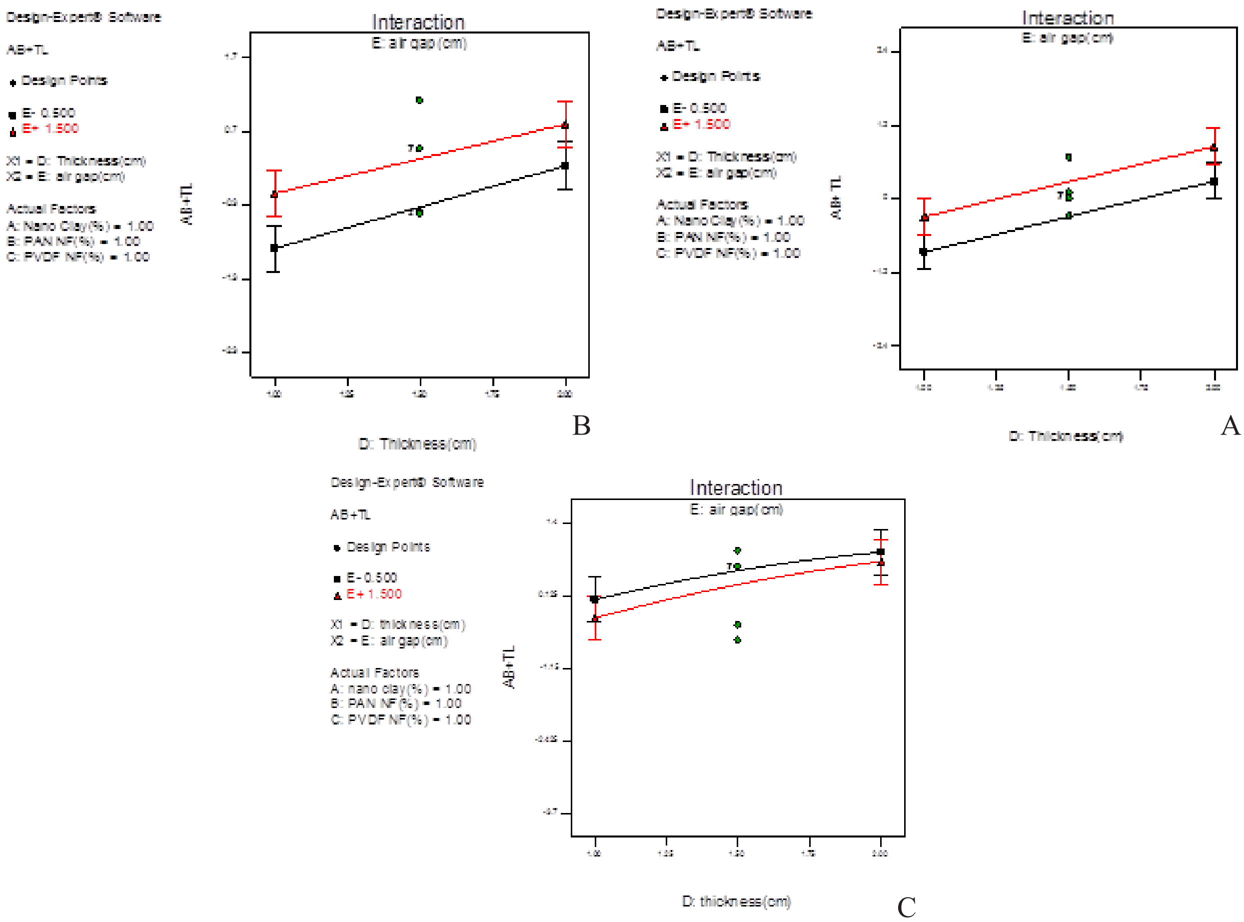

Fig. 2. Influence of air gap and thickness on absorption coefficients and transmission loss coincidently A: Low frequencies B: Mid frequencies C: High frequencies

loss and the absorption coefficient was increased with the increase of content of both nanofibers. The highest combined transmission loss and the absorption coefficient was observed when mass fraction of nanofibers was in at its maximum level.

This study showed that adding nanoclay particles, polyacrylonitrile and polyvinylidine fluoride nanofibers to polyurethane foam can lead to increas sound transmission loss and the absorption coefficient. The obtained optimized nanocomposite

Table 1. Models obtained at different frequencies

frequency	Model type	Equation
low	Linear	(AB+TL)* =+0.001-0.11A** +0.047B*** -0.15C**** +0.58D*****+0.29E******
middle	2FI	(AB+TL)=+0.0012-0.10A+0.041B-0.19C+0.51D+0.33E-0.36AB -0.21AC-0.041AE-0.30BC+0.046BD+0.24CD-0.046DE
high	quadratic	$(AB+TL)=+0.37-0.018A+0.072B+0.15C+0.46D-0.12E$ $+0.13AC+0.13AD-0.088BC+0.062BD+0.023BE+0.057CD$ $+0.039DE-0.53A^2+0.034B^2+0.064C^2-0.093D^2+0.073E^2$

absorption coefficients and transmission loss coincidently * A-nanoclay(%)** B-PAN NF(%)*** C-PVDF NF(%)**** D-thickness(cm) ***** E-Air Gap(cm) ******

Table 2. Some Proposed Solutions to Optimize the absorption coefficients and transmission loss coincidently in Different Frequency Bands by Design-Expert Software

frequency	Nano clay (%)	PAN NF (%)	PVDF NF (%)	Thickness(cm)	Air Gap(cm)	absorption coefficients
low	0.5	1.5	52/0	2	1.5	1.16
middle	0.5	1.32	0.5	2	1.5	1.15
	0.55	1.5	0.5	2	1.5	1.39
	0.5	1.5	0.5	1.96	1.34	1.3
high	1.08	1.47	51.	2	0.5	1.23
	1.11	1.23	1.5	2	0.5	1.19

can be applied for noise control in the environment where simultaneously requires the absorption and the reduction of sound transmission.

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