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Original Paper

Investigation of The Acoustic Properties of Nonwoven Fabrics Associated with Nanofiber Mat

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Abstract

Undesirable noise has become a paramount issue that has been focused on by researchers of various fields worldwide. Nonwovens are used as sound insulation materials due to their low production cost and small specific gravity. Nanofiber mat has the potential to improve the acoustic properties of traditional materials without adding weight and size. The ability of the nonwoven incorporation with nanofiber mat for acoustic application is addressed in this paper. Five electrospun nanofiber mats were produced on spunbonded nonwoven fabric from four different polymers. Finally, traditional spunbond-meltblown-spunbond (SMS) sandwich structures were formed nonwoven with nanofiber mats. It was found that sandwich structures associated with nanofiber mats showed higher sound absorption coefficient and transmission loss at low and medium frequency (Hz) sound levels, as well as high-frequency sound levels. Among all the polymers, TPU (thin), consisting of nanofibrous mat sandwich structure, had nearly 42% higher sound absorption coefficient and 75% higher sound transmission loss at 6.3 kHz frequency than the based SMS structure. The study also revealed that nanofiber diameter had a positive impact on the acoustic performance properties of the final sandwich structure. Morphological characterizations of nanofiber mats for different polymers were also investigated by Scanning electron microscope (SEM) and FibraQuant 1.3 software.

Keywords: Sound absorption, sound transmission, nanofiber, nonwoven, electrospinning, air permeability.

1. Introduction

The noise refers to all sounds that are undesired. These are created by vibrations and spread evenly on air in the form of sound waves. A persistent or serious noise nuisance can adversely affect a person's performance or even lead to illness. So, it is important to develop sound insulation materials to combat noise nuisance since the invention of the engine in the industrial revolution. Nonwoven fabrics are extensively utilized as sound insulation materials due to their porous structure. The air molecules rub against each other there and against the fibers of the structure, which converts the kinetic energy of the molecules into heat through friction losses. This reduces the sound field that occurs or, to put it another way, the noise level drops [1]. Nonwoven fabrics exhibit good sound absorbers at high frequencies due to their low density but have less efficiency at low and medium frequencies [2]. Low-frequency noises are generally difficult to absorb due to their long wavelength [3]. Researchers around the world are discovering new applications for nanofibers. Various studies [4–8] were done on the application of nanofiber mat at acoustic materials and found the ability of sound absorption at a wide range of frequency, especially at low and medium frequency. Liu et al. investigated sound absorption in electrospun membranes with different back cavities. They revealed that electrospun membranes based on polyacrylonitrile, thermoplastic polyurethane, and thermoplastics polyester elastomer have good acoustical performance at low and medium frequency ranges (100–2500 Hz) [9].

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In the literature, several researchers studied and recorded the acoustic properties of nonwovens [10–14]. Çelikel and Babaarslan investigated the sound absorption performance of SMS type composite nonwoven. In their study, five different gsm (g/m^2) of meltblown nonwoven layers were used with either homocomponent (100% PET) or bicomponent (90% PET and 10% CoPET) filaments spunbond layers. The study revealed that composites composed of bicomponent sounbond layer were more effective as sound absorbers than other structures [15]. Another study investigated the feasibility of using polyurethane and polyacrylonitrile nanofibers with conventional polyester and wool nonwovens. The results discovered that nanofiber layers with nonwovens improved the acoustic properties of composite materials [16]. Rabbi et al. [17] discovered the effect of nanofiber and PET nonwoven layers number, the surface density of nanofibrous mat on the sound absorption properties by response surface methodology. Nanofibrous mat was produced from PAN and PU polymers, and PAN showed higher sound absorption than PU polymers. The study also revealed that sound absorption properties improved with the increasing nanofiber layers number, or its surface density increased. The study performed by Iannace [18] aimed to investigate the effect of sound absorption coefficient on various types of porous materials like glass, wool, kenaf, foam, polyester, and felt coated with a layer of nylon 6 nanofibers. The results showed that adding nanofiber mat with traditional porous materials improved the sound absorption coefficient at low and medium frequencies. Gayathri et al. [19] investigated the sound absorption and other behaviors of polyurethane foam modified with nano-silica, nano clay, and crumb rubber fillers. Polyurethane-based porous composites were synthesized in this study using in situ foam polymerization with fillers. The sound absorption coefficient of polyurethane foam with fillers increased from 0.5 to 0.8.

Although several studies on the acoustics properties of nonwovens and nanofibrous mats have been published to date, none of them, according to the authors' knowledge of the literature, reveal the acoustic properties of SMS nonwovens in conjunction with nanofibrous mat. In this study, acoustic properties of SMS type multilayer nonwoven incorporated with nanofiber mat produced from four different polymers PAN(Akkim), PVDF (Kynar 761), PVDF (Kynar 2801), TPU (BASF elastollan) were investigated. In all the cases, 230 gsm SMS nonwoven was used as base material, and 5 gsm nanofiber mat from four different polymers worked as associate materials to produce final sandwich (five layers) structures. Test sens's Impedance tube was used at low and high frequency to determine the best sandwich structure as insulation material.

2. Materials and Methods

2.1. Preparation of SMS nonwoven

In this study, 230 gsm SMS nonwoven fabrics were used as base material, with top and bottom spunbond layers and a meltblown nonwoven layer in the middle formed the final ultrasonic edge bonded three-layered structures. The thickness of ten specimens from the 230 gsm SMS sample was measured with a Käfer measuring instrument in compliance with the NWSP 120.6.R0 (15) nonwoven thickness standard. The recorded mean values of thickness and nonwoven (SMS) fabric density are listed in Table 1 with properties of nonwoven layers. Fabric density (g/cm^3) was estimated by dividing the fabric weight (g/cm^2) by the fabric thickness (cm).

Table 1. Properties of nonwoven layers

Type of layer (SMS)	Fiber content	Fiber diameter (µm)	Bonding	Basic weight of layers (gsm) (S^1/M^2/S^1)	Basic total weight (gsm)	Average thickness (mm)	Fabric density (g/cm^3)
Spunbonded	Polypropylene	23	Thermal	17	230	2.59	0.09
Meltblown	Polypropylene	2-4	-	196			
Spunbonded	Polypropylene	23	Thermal	17			

Keys: S^1= Spunbond layer, M^2= Meltblown layer

2.2. Nanofiber mat production

Nanofiber mats were produced by NanoSpinner24 (Inovenso) electrospinning system from PAN (Akkim), PVDF copolymer (Kynar 2801), PVDF homopolymer (Kynar 761), TPU (BASF Elastollan) polymers separately with surface density of 5 g/m^2 each where all the cases, 17 gsm spunbonded polypropylene(PP) nonwoven was used as a substrate. The electrospinning process parameters and preparation of polymer solution are listed in Table 2 and Table 3, respectively. After layering the nanofiber mat within three (3) layered nonwoven, a sandwich structure (Figure 1) was produced by pressure. Composite sample (sandwich) specifications of 230 SMS nonwoven with different polymers nanofiber mat are given in Table 4.

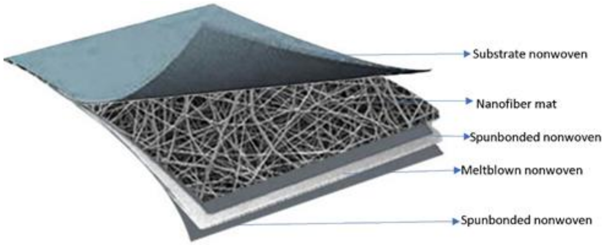


Figure 1. The sandwich structure of a prepared sample

Table 2. Process parameters of nanofiber mat production

	Production parameters (2 Syringe pumps were used for the production of nanofiber mat)					
Polymer	**Homogeneity**	**Collector Drum (RPM)**	**Spinning distance (mm)**	**Voltage (KV)**	**Nozzle**	**Flow rate (ml/hr)**
PAN (Akkim)	20 mm/s, 130 mm	200	193	32	20 G	1.45
PVDF (Kynar 2801)			203	35	23 G	0.90
PVDF (Kynar 761)			193	38	20 G	1.10
TPU (BASF Elastollan) (Thin)			203	32	23 G	0.60
TPU(BASF Elastollan)(Thick)			193	34	20 G	1.10

Table 3. Preparation of polymer solution (100 ml)

Polymer	**Amount of polymer (w/w %)**	**Solvents (w/w)**	**Surfactants (gm)**
PAN Covinylacetate	12.0% Polymer	88% DMF	×
PVDF (Kynar 2801)	15.0% Polymer	10.0% Acetone 75.0% DMF	×
PVDF (Kynar 761)	15.5% Polymer	14.5% Acetone 70.00% DMF	×
TPU (BASF Elastollan) (Thin)	16.5% Polymer	13.92% MEK 69.58% DMF	0.9 gram CTAB (in 100 gram)
TPU (BASF Elastollan)(Thick)	14.0% Polymer	70.00% DMF 16.00% Ethyl acetate	×

*CTAB: Hexadecyltrimethylammonium bromide *DMF: Dimethylformamide *MEK: Methyl Ethyl Ketone

2.3. Nanofiber mat production

The air permeability values of the SMS nonwoven materials with or without nanofiber mat were measured by applying 200 Pa pressure through a 20 cm^2 test area of the material. The air permeability of five specimens has been measured from each SMS nonwoven fabric with or without nanofiber mat by Prowhite (EPO8M) air permeability tester according to NWSP 070.1.R0(15) standard, and the average value has been determined.

Table 4. The studied proprieties abbreviation

Type (Sandwich structure)	Substrate (PP)	Polymer (Nanofiber mat)	Nonwoven (SMS) gsm
A	×	×	230
A1	17 gsm spunbond nonwoven	PAN (Akkim)	230
A2		PVDF (Kynar 2801)	
A3		PVDF (Kynar 761)	
A4		TPU (BASF Elastollan) (Thin)	
A5		TPU (BASF Elastollan)(Thick)	

2.4. Determination of sound absorption coefficient and transmission loss

TestSens sound Tube HF-ABS/STL was used to determine sound absorption coefficient and sound transmission loss properties of samples according to the ISO 10534-2 (Transfer Function Method) and ASTM E2611(4-pole Transfer Matrix Method), respectively. Samples were prepared and placed in the tube according to inner diameter 30 mm for the smaller tube and 100 mm inner diameter for the larger tube. The sound absorption coefficient is a dimensionless ratio of sound energy absorbed to sound energy incident. As a result, it theoretically has a maximum value of 1. Therefore, the effectiveness of acoustic insulation material will be improved with the coefficient increase. A loudspeaker was used at one end of the tube to generate a random broadband signal ranging from 50 Hz to 6.4 kHz to determine the sound absorption coefficient. The test specimen was placed in front of the backplate at the end of the impedance tube. The incident and reflected sound waves were measured using two fixed microphones positioned vertically on the tube [20].

On the other hand, sound transmission loss is the difference in sound pressure level between the source and receiver sides. An additional tube extension impedance tube was attached with four microphones (2 in front of the test specimen and 2 behind it) to calculate the sound transmission loss. In addition, a 100 mm diameter tube was set up for frequency range from 50 Hz to 1.6 kHz, and a 30 mm diameter impedance tube was installed for the frequency range 500 Hz to 6.4 kHz to determine the sound transmission loss of samples. Testsens software v2.7.4 was used to calculate the sound absorption coefficient and sound transmission loss for frequency 50 to 6400 Hz [21]. Figure 2 represents the general view of the measurement system.

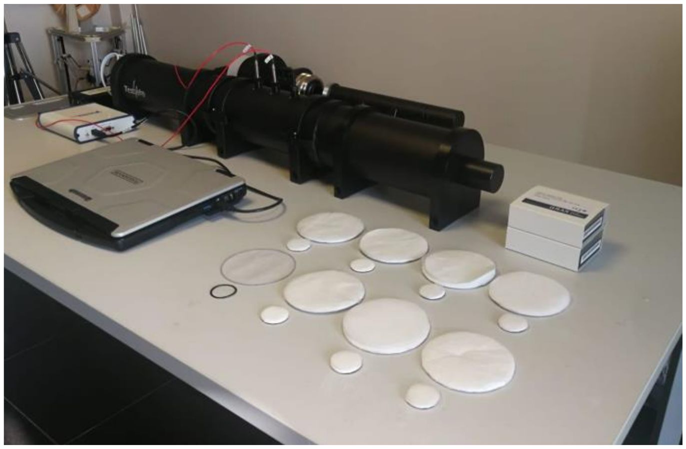


Figure 2. The general view of the measurement system

3. Results and Discussion

3.1 Surface morphology of nanofiber mat

The surface morphology of five nanofiber mats generated from four different polymers was investigated by SEMocsope Desktop Scanning Electron Microscope (Model: IEM 11) at an accelerating voltage of 20 KV. FibraQuant 1.3 software was used to determine the nanofiber diameter by 200 measurements. SEM images of nanofiber mats are depicted in Figure 3. From the morphological characteristics of nanofiber mats, nanofiber mat contains TPU(Thin) polymer found finest nanofiber diameter. It can be one of the main reasons for more sound absorption coefficient and high sound transmission loss at different frequency levels. Table 5 represents the nanofiber mat properties.

Table 5. Nanofiber mat properties

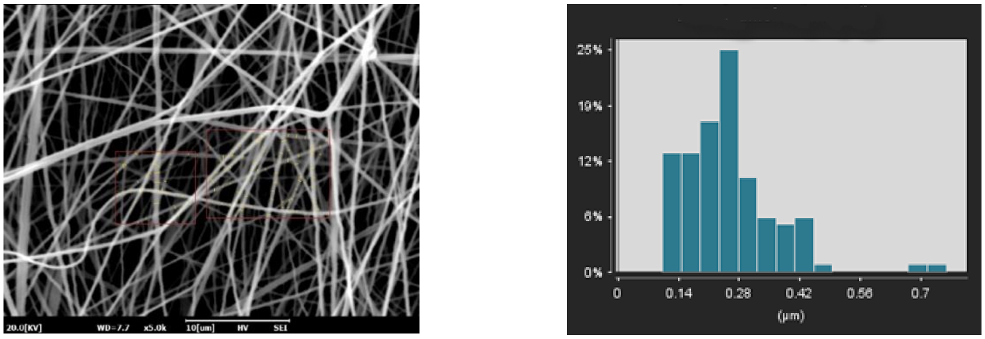
Polymer	**Fiber Diameter (nm)**			**Average orientation (°)**	**Area Coverage (%)**
	Average	**Std dev**	**Median**		
PAN Covinylacetate	251	0.108	251	70	16
PVDF (Kynar 2801)	166	0.075	159	90	9
PVDF (Kynar 761)	361	0.126	361	103	21
TPU (BASF Elastollan) (Thin)	154	0.067	142	80	18
TPU (BASF Elastollan) (Thick)	283	0.120	253	92	24

3.2. Surface morphology of nonwoven layers

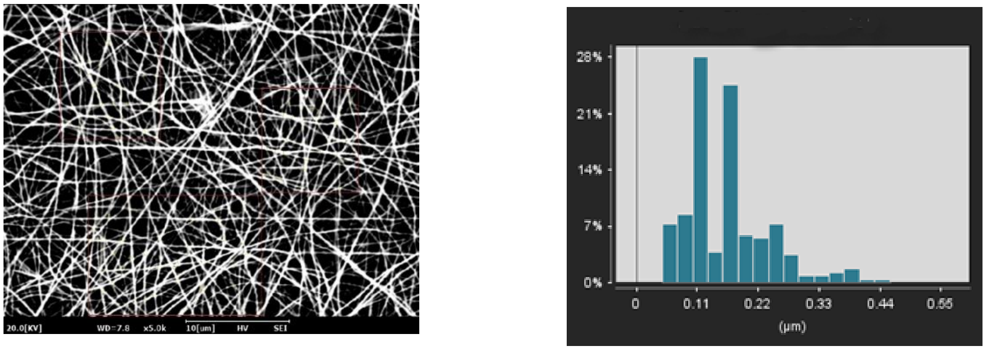
Scanning electron microscope (SEM) images of 17 gsm of PP spunbond and 196 gsm melblown layers are shown in Figure 4 and Figure 5, respectively, with their corresponding diameter distribution. The average fiber diameter was calculated from the 200 measurements. Table 6 represents the fiber properties used in this study. Image processing J and origin Pro software were used to determine the polypropylene fiber diameter and frequency distribution of diameter, respectively.

Table 6. Properties of fiber used for nonwoven layer and substrate

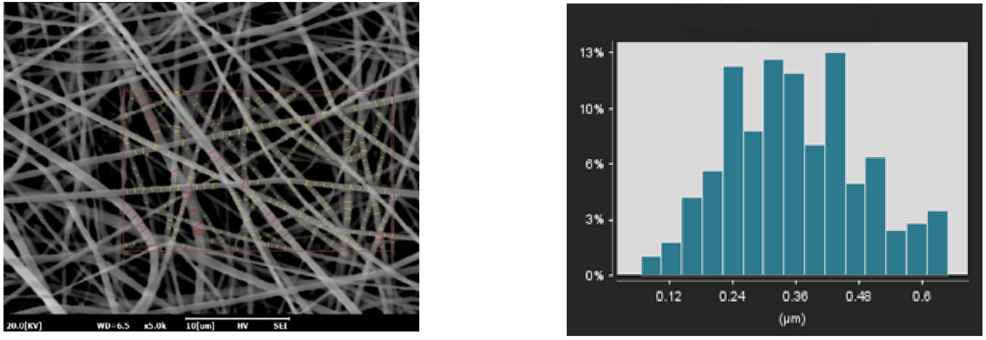
Type of layer	**Fiber content**	**Fiber diameter (μm)**			**Fiber diameter (nm)**
		Average	**Std Dev.**	**Median**	**Average**
17 gsm PP spunbond	Polypropylene	16.97	2.68	17.20	16,970
196 gsm meltblown	Polypropylene	2.47	1.08	2.17	2,470



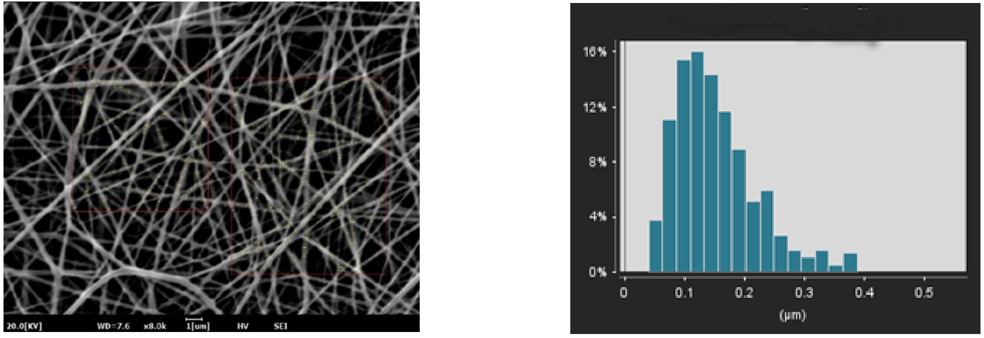
(a) PAN Covinylacetate



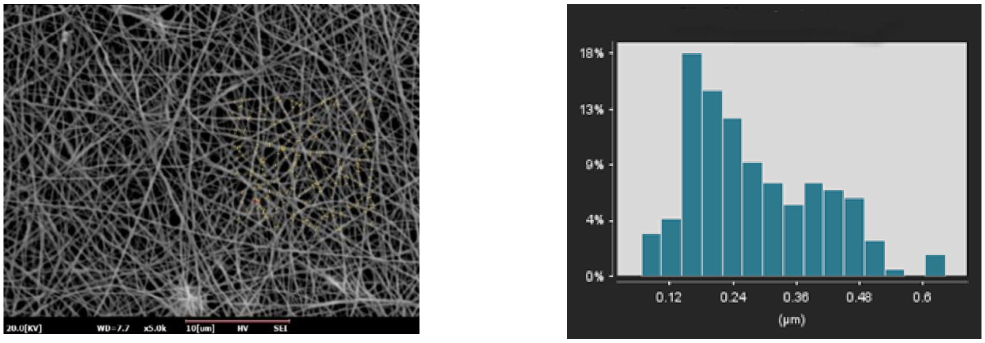
(b) PVDF (Kynar 2801)



(c) PVDF(Kynar 761)



(d) TPU (BASF Elastollan) (thin)



(e) TPU (BASF Elastollan) (thick)

Figure 3. Surface morphology (left) and diameter distribution (right) of different polymers nanofibrous mats

3.3. Acoustic performances of composite structures

Figure 6 provides the sound absorption coefficient of composite structures produced from five different nanofibrous mat layers. From the results, it was observed that nanofibrous mat with SMS nonwoven improved the sound absorption coefficient at low and medium frequency sound levels as well as high-frequency sound levels for all types of polymers. For example, in the case of TPU (thin) and TPU (thick) nanofibers layer, the sound absorption coefficient was increased by 30% and 15%, respectively, at 6.3 kHz frequency level. On the other hand, PVDF copolymer and homopolymer nanofibrous mat composite structures at the same frequency level improved sound absorption coefficients around 17% and 9%, respectively. It was revealed that the PAN polymer consisting of a nanofibrous mat showed less sound absorption coefficient than the other four polymers nanofibrous mat.

From Figure 7, it can be conspicuously seen that nanofibrous mat consisting of sandwich structures also improved the sound transmission loss at medium and high-frequency sound levels. After adding PAN, PVDF (thin), PVDF (thick), TPU (thin), and TPU (thick) nanofibrous mat with SMS nonwoven sound transmission loss increased 30%, 59%, 33%, 75% and 62% respectively. The unique properties of nanofiber mat, i.e., their small fibrous diameter, corresponding high specific surface area, and high porosity, are responsible for this. Without a nanofibrous coating, the SMS layer nonwoven showed less sound absorption coefficient and loss of sound transmission at different frequency levels. From the test results, it was revealed that TPU (thin) polymer nanofiber mat with SMS nonwoven structure exhibits more sound absorption coefficient (0.68) and sound transmission loss (15.24 dB) compared to PVDF and PAN polymers. It was also found that thinner nanofiber diameter positively impacts acoustic properties compared to thicker nanofiber diameter. Sound transmission loss is largely determined by its mass. For every doubling of mass per unit area of any impermeable materials, sound transmission loss will be increased by 6 dB [22]. As a result, nanofibrous mat incorporation with SMS nonwoven could open up a new market for sound insulation materials without increasing the gsm of nonwoven fabrics.

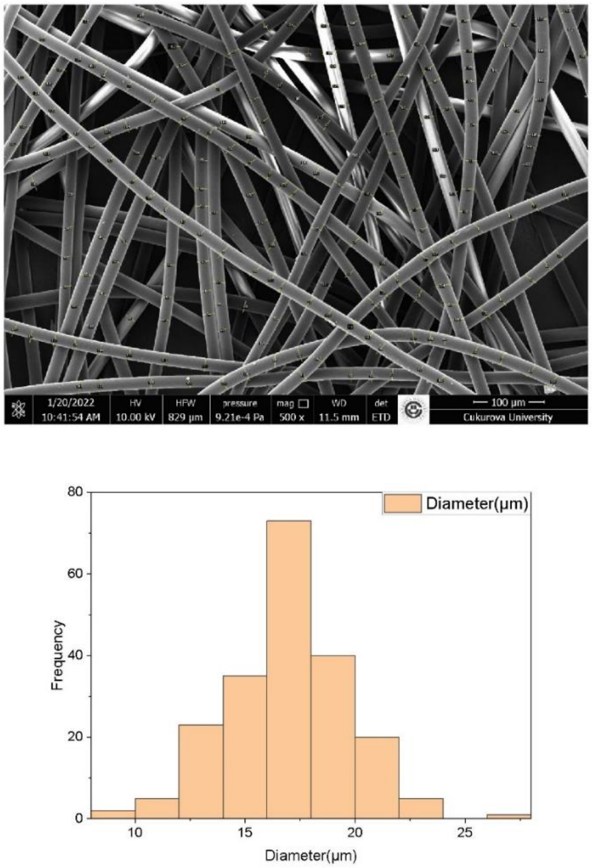


Figure 4. Surface morphology of the 17 gsm of PP spunbonded nonwoven (top) and diameter distribution (bottom)

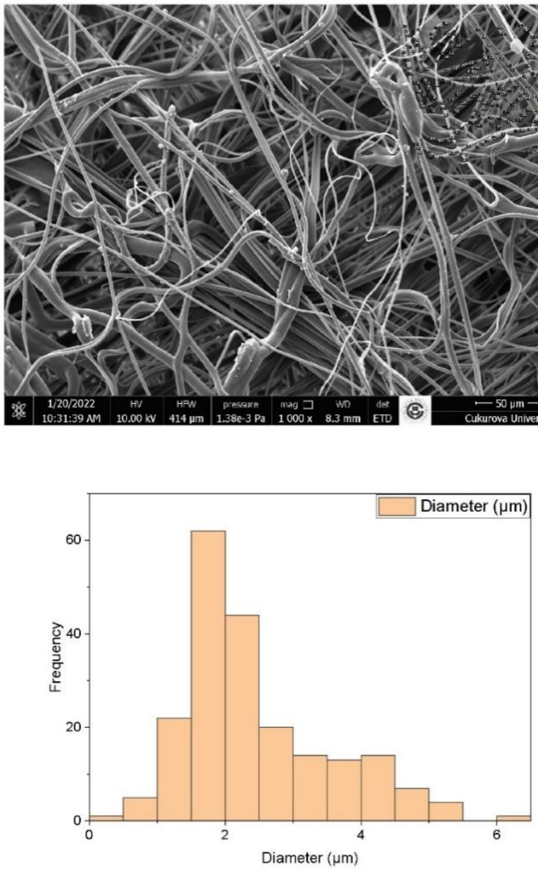


Figure 5. Surface morphology of the 196 gsm meltblown nonwoven (top) and diameter distribution (bottom)

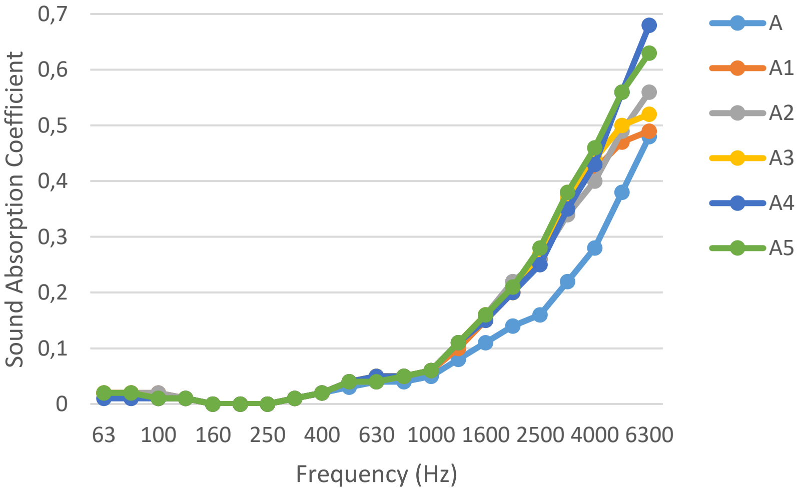


Figure 6. Sound absorption coefficient for different sandwich structures (1/3 octave band)

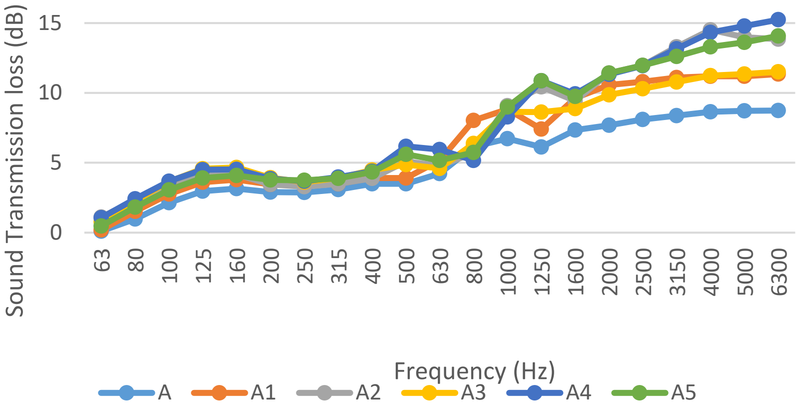


Figure 7. Sound transmission loss for different sandwich structures (1/3 octave band)

3.4. Air permeability of composite structures

Air permeability is an important metric for sound insulation material to determine thermal and acoustic properties. Higher air permeability results cause higher sound transmission; as a result of this, there is less sound insulation [11]. The air permeability of nonwoven samples was measured with and without nanofiber mat is shown in Figure 8 for different polymer's nanofiber mat sandwich structures. The error bars were calculated from the standard deviations of the air permeability of sandwich structures. The nanofiber mat offers more rooms and a longer, tortuous path along which the air must flow. Thus, the sandwich structure becomes more airflow resistant, resulting in low air permeability. As a result, lower air permeability was achieved, confirming the relationship between this significant parameter and sound insulation capability. According to the results, the sandwich structure from PVDF (Kynar 761) polymer nanofibrous mat presented more air permeability due to the coarser (361 nm) fiber diameter.

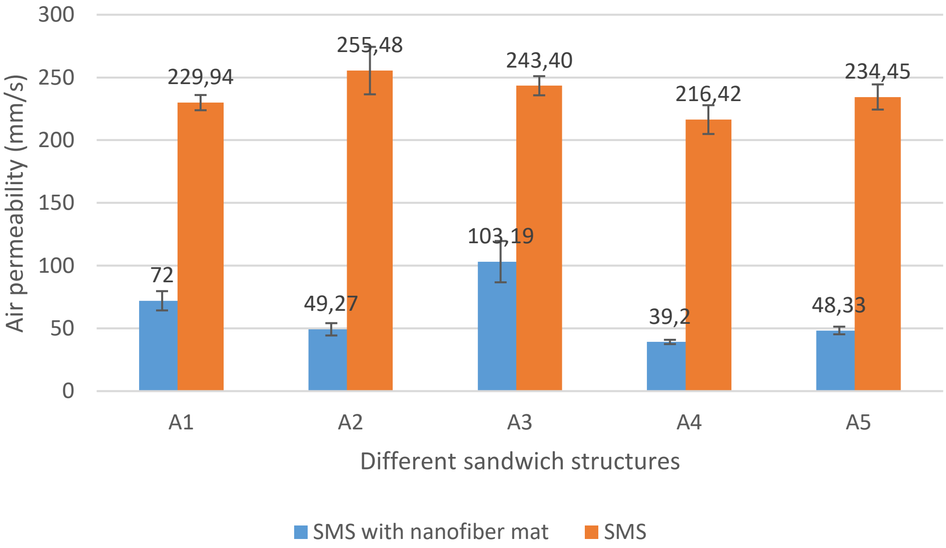


Figure 8. Air permeability of Sandwich structure of samples with and without nanofiber mat

4. Conclusions

The performance of the acoustic properties was determined with the traditional SMS nonwoven material and then coating this one with a nanofibrous mat produced from four different polymers. It was observed that nanofiber mat sandwich structures improved the sound absorption coefficient and sound transmission loss at low and medium frequency sound as well as at high-frequency levels. Among all the nanofiber mats, TPU (Thin) polymer nanofiber mat sandwich structure exhibits the highest sound absorption coefficient (0.68) and sound transmission loss (15.24 dB) compared to other polymers sandwich structures. In addition, the study found that the nanofiber diameter had a positive impact on the acoustic properties of sandwich samples. TPU thin diameter (154 nm) comprised of nanofibrous mat enhances sound absorption coefficient and transmission loss as much as 1.5 and 1.75 times, respectively, at 6.3 kHz frequency compared to SMS based nonwoven fabric. The air permeability results obtained in this study with or without nanofiber mat are comparable to those obtained by other studies. These novel materials could be utilized in refrigerators, dishwashers, washing machines, concert halls, theaters, cinemas, large-scale sports stadiums, and the automotive and aerospace industries, where weight reduction is needed to increase fuel/energy efficiency. These findings are noteworthy because of the improvement of sound absorption and transmission loss simultaneously and could be beneficial to researchers and the sector that works on acoustic materials.

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