



THE COMPARISON OF VARIOUS POLYMER BASED NANOFIBERS COATED RECYCLED NONWOVENS ON THE SOUND ABSORPTION PROPERTIES

Scientific paper
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ABSTRACT: In recent years, the development of innovative and eco-friendly acoustic materials is increasingly important for solving noise problems in industrial and architectural areas. This study aims to determine the optimum polymer type for fabricating high performance sound absorbing nanofibers, which are to be coated onto recycled PET-based nonwoven surfaces via the electrospinning method. For this purpose, different polymer/solvent solutions such as polyvinyl alcohol (PVA), polyacrylonitrile (PAN), cellulose acetate (CA), and polyurethane (PU) were prepared. Subsequently, the viscosity, surface tension, and electrical conductivity characteristics of these solutions were investigated. In addition, the morphological structures of the nanofibers were analyzed using Scanning Electron Microscopy (SEM), and their average fiber diameters and uniformity coefficients were determined. Additionally, the air permeability and sound absorption (NRC) properties of 500 g/m² nonwovens coated with different polymer-based nanofibers were compared to an uncoated sample using the impedance tube method. It was found that the nanofiber coating significantly enhanced sound absorption by reducing air permeability from 4502 l/m²/s to 352.8 l/m²/s. Sound absorption tests were revealed that while the NRC value of the uncoated fabric was 0.105, the highest performances were achieved with PVA (0.212) and PAN (0.207) based nanofibers. PVA was selected as the optimum polymer due to its balanced sound absorption across a wide frequency range, bead free and homogenous fiber morphology, and environmental sustainability advantages provided by using DI water as a solvent.

Keywords: Electrospinning, Nanofiber, Recycle PET, Nonwoven, Sound Absorption.

POREĐENJE UTICAJA RECIKLIRANOG NETKANOG TEKSTILA PRESVUČENOG NANOVLAKNIMA NA BAZI RAZLIČITIH POLIMERA NA SVOJSTVA APSORPCIJE ZVUKA



APSTRAKT: U poslednjih nekoliko godina, razvoj inovativnih i ekološki prihvatljivih akustičkih materijala postaje sve značajniji za rešavanje problema buke u industrijskim i stambenim objektima. Ova studija ima za cilj određivanje optimalnog tipa polimera za izradu nanovlakana visokih performansi za apsorpciju zvuka, koja se nanose na površine netkanog tekstila na bazi recikliranog PET-a metodom elektroispredanja (elektrostatičkog ispredanja). U tu svrhu pripremljeni su različiti rastvori polimera i rastvarača, kao što su polivinil-alkohol (PVA), poliakrilonitril (PAN), celuloza-acetat (CA) i poliuretan (PU). Nakon toga, ispitane su karakteristike ovih rastvora poput viskoznosti, površinskog napona i električne provodljivosti. Pored toga, morfološka struktura nanovlakana analizirana je pomoću skenirajuće elektronske mikroskopije (SEM), te su određeni njihovi prosečni prečnici vlakana i koeficijenti uniformnosti. Takođe, svojstva propustljivosti vazduha i apsorpcije zvuka (NRC – koeficijent redukcije buke) netkanog tekstila površinske mase 500 g/m² presvučenog nanovlaknima na bazi različitih polimera upoređena su sa neprevučenim uzorkom pomoću metode impedansne cevi. Utvrđeno je da nanos nanovlakana značajno poboljšava apsorpciju zvuka smanjenjem propustljivosti vazduha sa 4502 l/m²/s na 352,8 l/m²/s. Testovi apsorpcije zvuka pokazali su da je, dok je NRC vrednost neprevučenog tekstila iznosila 0,105, najviša efikasnost postignuta sa nanovlaknima na bazi PVA (0,212) i PAN-a (0,207). PVA je izabran kao optimalan polimer zbog svoje uravnotežene apsorpcije zvuka u širokom opsegu frekvencija, homogene morfologije vlakana bez pojave struktura nalik kapljicama (kuglicama), kao i zbog ekološke održivosti koju pruža korišćenje dejonizovane (DI) vode kao rastvarača.

Ključne reči: Elektroispredanje, Nanovlakno, Reciklirani PET, Netkani tekstil, Apsorpcija zvuka.

1. INTRODUCTION

Sound is an essential part of life; however, noise is an inherent consequence of contemporary urbanization that adversely affects human health. Research shows that excessive noise is the primary cause of behavioral and psychological disorders, decreased efficiency, hearing loss, and various problems, especially in unplanned urbanization areas. In this context, textile materials offer a highly effective solution for noise reduction and the attenuation of acoustic disturbances. In this study, recycled nonwoven fabric are used; these are preferred high-performance materials due to their porosity, reusability, sustainability, and elasticity [1].

Nanofibers show high-performance features due to their small fiber diameter (nm), open pores, high porosity, and large specific surface area (m²/g).

As known from the literature that nanofiber materials dramatically increase the airflow resistance significantly improving sound absorption efficiency particularly at low-to-medium frequencies [2]. The performance of the nanofiber coating is significantly dependent on the specific properties of the polymer used. Therefore, polyvinyl alcohol (PVA), polyacrylonitrile (PAN), cellulose acetate (CA), and polyurethane (PU) polymers



were used to compare optimum sound balance, polymer selection, and fiber homogeneity in this study.

2. MATERIALS AND METHODS

2.1. Materials

In this study, PVA (Aldrich Chemistry, Mw 85,000- 124,000), PAN (Aldrich Chemistry, Mw 150,000), PU (Elastollan 1185 A10, BASF Firm), CA (Aldrich Chemistry, Mw 30,000) were used as polymers; dimethylformamide (DMF) (Fluka Chemika), dimethylacetamide (DMAc) (Fluka Chemika), Deionized (DI) water and acetone (ACE) (Isolab Chemicals) were used as solvents to produce nanofibers. Recycled PET-based nonwoven fabric with a surface density of 500 g/m² was employed as the substrate for the nanofiber coating (UC500).

Table 1: Sample coding according to polymer types (Base Material: 500 g/m² R-PET Nonwoven fabric)

Polymer	Base Sample	Coated Sample Code
PVA	UC500	PVA500
PAN	UC500	PAN500
PU	UC500	PU500
CA	UC500	CA500

2.2. Methods

Polymer solutions of PVA (10 wt%), PAN (7 wt%), PU (14 wt%), and CA (16 wt%) in a DMAc/acetone mixture (1:2, wt/wt) at room temperature were prepared by stirring for 24 hours. The PU and PAN solutions were stirred under heating.

The viscosity, surface tension and electrical conductivity values of the solutions were figured out by a viscometer (Lamy Rheology, B-One Touch Screen), surface tension meter (Biolin Scientific 703), and an electrical conductivity meter (Selecta CD 2005), respectively.

An electrospinning setup consisted of a single needle with a 0.8 mm diameter cut tip, an aluminium collector, a syringe pump, and a power supply (Matsusada, 40 kV). Afterwards, the textile materials were cut into 15x15 cm pieces, and the collector plate was prepared for the electrospinning process. Then, nanofibers were electrospun from the prepared polymer solutions for an equal duration of 30 min onto the base textile materials. The electrospinning process parameters are detailed in Table 2.

Table 2: Process parameters of electrospinning

Polymer / Solvent	Voltage (kV)	Distance between electrodes (cm)	Feed rate (mL/h)	Humidity (%)	Temperature (°C)	Needle Diameter (mm)
PAN / DMF	21.2	19.5	0.65	32	22.8	19.5
PU / DMF	19.9	20	0.9	32	22.2	19.5
PVA/DW	21.7	20	0.5	33	23	19.5
CA/DMAc:Acetone	22	19.5	0.2	32	22.1	19.5



Scanning electron microscope (SEM) (FEI Quanta 250 FEG) and image analysis software (Image J programme) were taken for the fiber morphological analysis and measurement average fiber diameter respectively. To calculate the mean diameter, 100 nanofibers were selected randomly from the obtained SEM images. The nanofibers diameter uniformity was calculated via using the formulas given below 1 and 2 [3]. Then, histogram graphics were originated as a result of this calculation with the help of Microsoft SPSS version 27.

$$A_n = \frac{\sum n_i d_i}{\sum n_i} \text{ (Number average)} \quad (1)$$

$$A_w = \frac{\sum n_i d_i^2}{\sum n_i d_i} \text{ (Weight average)} \quad (2)$$

n_i = fiber number

d_i = fiber diameter

Then, Sound Absorption Coefficient (SAC) and Noise Reduction Coefficient (NRC) values were carried on impedance tube method with ISO 10534-2 standard. Lastly, air permeability was conducted for coated and uncoated textile materials according to the EN-ISO 9237 standard.

3. RESULT AND DISCUSSION

3.1. Polymer Solution Characterization

Polymer solution properties were measured in terms of understanding their effect on fiber spinning performance. In this study, the viscosity, surface tension and electrical conductivity results of the solutions were first determined. According to the obtained results, these values for the prepared polymer solutions are presented in Table 3.

Table 3: Solution Properties of PAN, PU, PVA and CA

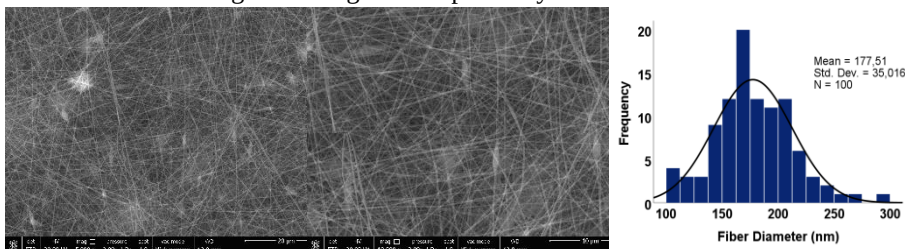
Sample	Viscosity (mPa.s)	Surface Tension (mN/m)	Electrical Conductivity (μ S/cm)
8 wt% PAN / DMF	406,2	35,01	55,5
14 wt% PU / DMF	1850	44,50	1,62
10 wt% PVA / DW	977,8	31,76	728
16 wt% CA/DMAC:AC	625,7	15,60	6,29

According to the table 3, PVA solution exhibited a highest electrical conductivity (728 μ S/cm) and high viscosity (977.8 mPa.s) due to the high polarity and inherent properties of the deionized water solvent. Since the electrical conductivity of polymer solutions is directly related to the number of ions present, the lower conductivity values of the other solutions are attributed to the organic nature of their solvents [4]. Conversely, the PU solution demonstrated the highest viscosity (1850 mPa.s) and the highest surface tension (44.50 mN/m).

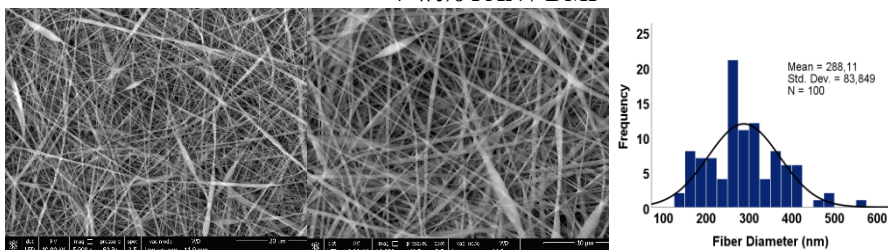
Upon analysis of surface tension values, while PU and PAN solutions had higher values, the CA solution stood out with the lowest surface tension (15,60 mN/m). These combined physical properties are expected to directly influence the average fiber diameters and structural homogeneity observed in the SEM analysis.

3.2. Fiber Morphology Results

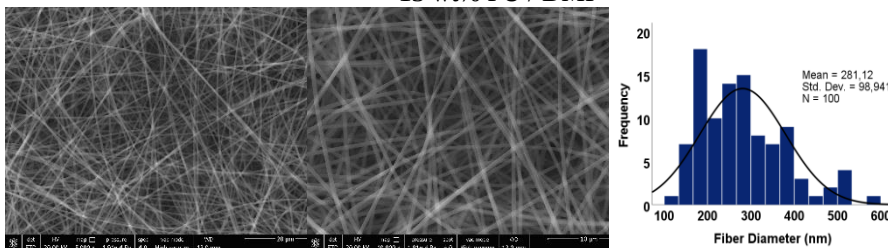
SEM images (5.000x and 10.000x) and fiber diameter histograms of PAN, PU, PVA, CA based nanofibers are given in Figure 1 respectively.



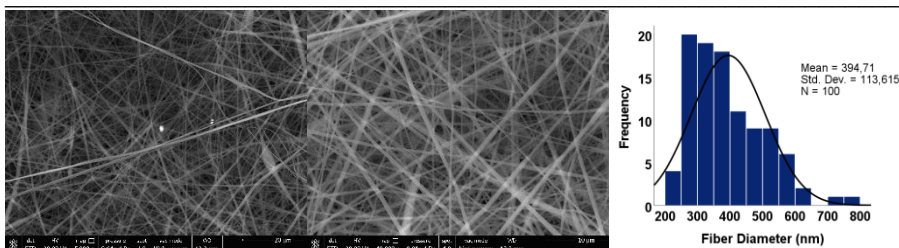
7 wt% PAN / DMF



13 wt% PU / DMF



10 wt% PVA / DI water



16 wt% CA / Dmac: Ace

Figure 1: SEM images (5000x- 10000x) and histograms of PAN, PU, PVA and CA nanofibers produced

When SEM images were analyzed, it was determined that the PAN and PU nanofibers exhibited bead formation, at the concentrations initially specified. However, the PU and PAN solution concentrations were increased to 14 wt% and 8 wt%, respectively, to reach the ideal viscosity, thus bead-free and stable fiber networks were successfully obtained. Conversely, in the 10 wt% PVA/deionized water solution, the high polarity of water resulted in high electrical conductivity (728 $\mu\text{S}/\text{cm}$), while in the 16 wt% CA/DMAC-acetone solution, the optimal combination of process parameters allowed for the direct formation of homogeneous, continuous, and bead-free nanofiber in the initial stage.

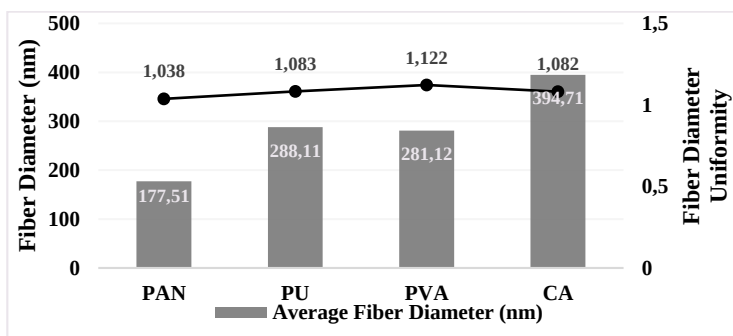


Figure 2: Evaluation of mean fiber diameters and fiber diameter uniformity coefficients (A_w/A_n) of different electrospun nanofibers.

According to the results, the 8 wt% PAN nanofibers exhibited the thinnest average fiber diameter of 177.51 nm and a uniformity coefficient of 1.038, demonstrating the most uniform distribution in the study. The 14 wt% PU nanofibers presented a balanced distribution with a mean fiber diameter of 288.11 nm and a uniformity coefficient of 1.047. On the other hand, the 10 wt% PVA nanofibers reached a mean fiber diameter of 281.12 nm, but exhibited the highest uniformity coefficient of 1.122, confirming the most irregular fiber diameter distribution. Lastly, the 16 wt% CA nanofibers produced the thickest structures in this study, with average fiber diameter of 394.71 nm and a diameter uniformity coefficient of 1.083. In this study, the sound absorption performance of the produced

nanofiber-coated textile materials was determined using a two-microphone impedance tube with the ISO 10534-2 standards (Figure 3).



Figure 3: Impedance tube used in the study

The sound absorption coefficients (SAC) of the uncoated nonwoven fabric (UC500) and the nanofiber-coated samples (PVA500, PAN 500, CA500, and PU500) measured in the 1/3 octave frequency bands are illustrated in Figure 4.

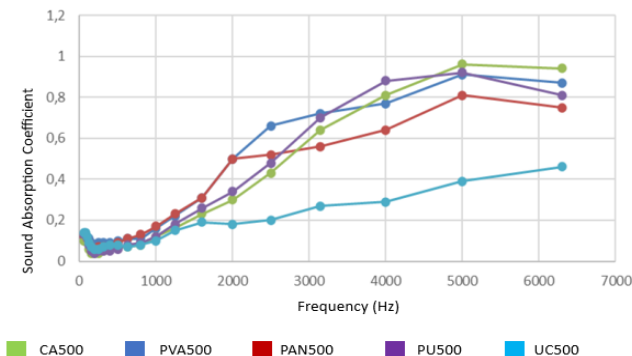


Figure 4: Presents the sound absorption coefficient values of each textile sample before and after coating.

It is seen that nanofiber-coated samples show much better sound absorption than the uncoated UC500 sample, especially between 1000 and 5000 Hz. This frequency range is very important because it represents the most common noises we hear in daily life, such as human voices, phone ringtones, TV sounds, and a baby crying [5]. While the plain nonwoven fabric (UC500) stayed quite low with a maximum value of 0.46, the nanofiber coatings clearly boosted the performance. Specifically, PVA500 and PAN500 reached the highest points with values of 0.92 and 0.91 at 5000 Hz. These results prove that adding a



thin layer of electrospun nanofibers is a highly effective way to block and reduce disturbing everyday noises.

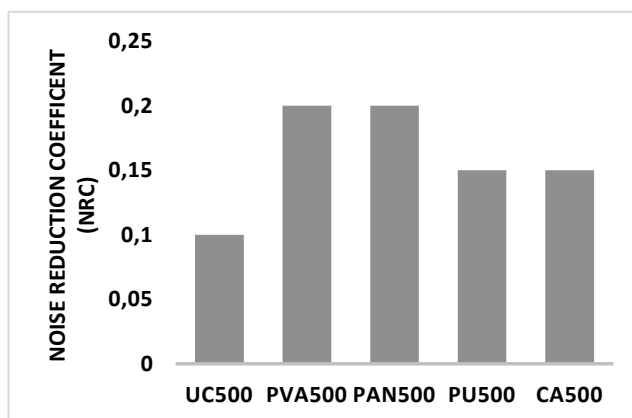


Figure 5: Noise Reduction Coefficient of all samples

According to the graph, NRC value is higher for all nanofiber-coated samples compared to the uncoated UC500 sample. These results clearly prove that adding a nanofiber layer successfully improves the general noise reduction capability of the fabrics. To better understand these sound absorption results, the physical properties of our samples, such as air permeability and thickness are given and compared in Table 4.

Table 4: Air permeability and Cross-section thickness (for total fabric thicknesses) of all samples

Sample Codes	Air Permeability (l/m ² /s)	Cross-section thickness (mm)
UC500	4502	1.684
PVA500	352.8	1.705
PAN500	594.6	1.701
PU500	883.8	1.694
CA500	1974	1.688

According to the results, there is a clear relationship between the fabric thickness and air permeability after the electrospinning coating. The uncoated nonwoven sample (UC500) has the highest air permeability value with 4502 l/m²/s and the lowest thickness of 1.684 mm. When it was analyzed nanofiber-coated samples, their air permeability values are much lower compared to the uncoated sample.



4. CONCLUSION

In conclusion, based on all the experimental findings, PVA was selected as the most suitable polymer for high-performance sound absorption applications. PVA500 provides a well-balanced and steady increase in the sound absorption coefficient from low to high frequencies. This polymer offers a highly effective acoustic solution especially within the 2500–5000 Hz frequency band, which directly represents common daily environmental noises such as restaurant, cafe, and meeting room sounds.

In addition to its sound absorption success, the material properties of PVA play a critical role in this selection. Thanks to its bead-free and highly homogeneous fiber structure, it ensures a stable surface production and reliable sound absorption performance. Furthermore, PVA stands out as an eco-friendly polymer. Since water is used as its solvent, it was strongly preferred by prioritizing environmental sustainability and green chemistry.

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