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An experimental study for evaluating the sound absorption coefficient of polylactic acid electrospun nonwoven

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Abstract. Noise pollution is becoming more prevalent, and it is currently the world's third most serious pollution problem. In recent years, nanofibers have achieved great interest in acoustics applications for noise control. Electrospun nonwovens can enhance acoustic insulation goods by enhancing the sound absorption coefficient, reducing material thickness, and diminishing material weight, giving them a strategic advantage. Polylactic acid (PLA) polymer has sparked a lot of attention as a potential textile material for a sustainable future. In this study, nonwoven mats of PLA were prepared by electrospinning with various amounts of deposition time (30, 60, and 120 min). The electrospun layers was coated on the PP nonwoven and used samples with different thicknesses of textile materials. The measurements of the absorption coefficient have been performed with the impedance tube in the frequency range of 500 Hz-6400 Hz. The test results were compared with measurements carried out on PP nonwoven without the layer of nanofibers. Electrospun samples that are quite thin were found to be particularly effective at high frequencies. This study demonstrated that the sound absorption property of a textile material that does not have sound-absorbing properties could be improved simply by coating with electrospinning using PLA polymer.

Keywords: sound absorption coefficient, polylactic acid, electrospinning, coating, noise pollution.

1. Introduction

Noise, or unwanted sound, is one of the most common environmental pollutants and is a growing problem across the world. In 2020, the European Environment Agency (EEA) report estimated that 100 million people in Europe were influenced by noise pollution and pointed out a significant impact on human health. [1, 2]. Consequently, both industry and academia are interested in noise-absorbing materials as a way to reduce the harmful effects of noise. This necessitates the design of novel materials. Electrospun nanofiber materials are one of the most promising and alternative materials, with several benefits such as high porosity, small pore size, and high surface area [3, 4].

Electrospun nonwovens have been examined for the preparation of highly useful sound absorbers due to their ease of manufacture, numerous material selection, and adjustable method. Electrospinning is a fascinating method for technological applications because of its strong control over fiber structure, flexibility, cost-effectiveness, easy modifiability, and scalability [3-5]. The advantages of electrospun

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nanofibrous mats as sound-absorbing have been indicated in studies focused on polymers such as polyvinyl alcohol (PVA) [6-12], polyvinyl alcohol/polyethylene oxide (PVA/PEO) [8, 11], polyvinylpyrrolidone (PVP) [13-14], polyamide (PA) [15-17], polyacrylonitrile (PAN) [18-20], polyurethane (PU) [21-26], polyvinylidene fluoride (PVDF) [27-29], polystyrene (PS) [30], polyester [31], silicon dioxide (glass wool) [32] were studied.

The manufacture of ecologically friendly textiles is critical for both the environment and the economy. PLA is one of the most often used aliphatic polyesters in green textiles applications because of its compostability, renewability, biocompatibility, market availability, outstanding tensile strength, and stiffness comparable to certain commercial oil-based polymers [33, 34].

Despite all the advantages highlighted above, the sound absorption property of PLA polymer has not been investigated. The sound absorption ability of PLA electrospun nonwovens coated on a sheet of polypropylene (PP) nonwoven was examined in this work.

2. Experimental study

2.1. Materials

PLA (Ingeo 6201D) beads were purchased from NatureWorks LLC (Minnesota, USA). Acetone is supplied by Eurochem Sp. z o.o (Katowice, Poland). Dichloromethane is provided by POCH Basic (Gliwice, Poland).

2.2. Preparation of Electrospun Mats

PLA solution for electrospinning was prepared by dissolving 10% (w/v) PLA in mixed solvents dichloromethane/acetone (1:1, v/v) over a magnetic stirrer. Electrospinning was done at an applied voltage of 23 kV, a distance from the needle tip to the target of 25 cm, and a flow rate of 10 mL h^{-1}. The electrospun web was collected on a drum collector (circumference = 1 m) wrapped in a nonwoven fabric at 35 rpm (Figure1.). The process was performed for 30, 60, and 120 min to obtain samples with different thicknesses.

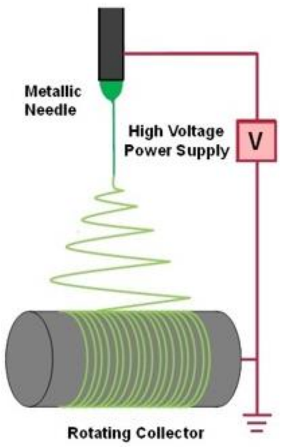

Figure 1. Scheme of electrospinning device.

2.3. Measurements

Scanning electron microscopy (SEM) was conducted using a Nova™ NanoSEM 230 microscope (FEI Company, USA). The thickness of electrospun nonwoven was measured using a Checkline J-40-V (Electromatic Equipment Co. NY, USA). Sound absorption coefficients of the samples were measured with an impedance tube device (Brüel&Kjaer). Measurements in the range of 500 Hz to 6400 Hz were carried out from the samples.

3. Results and Discussion

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3.1. Morphology of electrospun mats

The morphology of PLA electrospun nonwoven textiles were evaluated using SEM, as illustrated in Figure 2. The average diameters of electrospun fibers were 1.16 ± 0.63 μm. Table 1. shows the thickness of PLA electrospun coated and uncoated (reference) nonwoven fabrics.

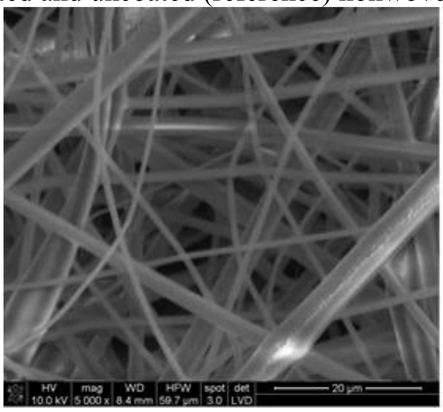

Figure 2. SEM image of electrospun fibers.

Table 1. Thickness of the electrospun mats (mean ± standard deviation).

Electrospun nonwoven	Thickness (mm)
Uncoated sample	1.01 ± 0.03
1 face-30 min coated sample	1.04 ± 0.02
1 face-60 min coated sample	1.05 ± 0.01
1 face-120 min coated sample	1.06 ± 0.07
2 face-30 min coated sample	0.97 ± 0.02
2 face-60 min coated sample	1.04 ± 0.06
2 face-120 min coated sample	1.22 ± 0.04

3.2. Sound absorption coefficient of PLA electrospun mats

The average sound absorption coefficient was larger than 0.2, referred to as sound-absorbing material [11]. Figure 3 shows the sound absorption coefficient curves calculated for the samples produced in uncoated, 1-sided coated-30-60-120 min, and 2-sided coated-30-60-120 min. The sound absorption coefficient of the uncoated PP nonwoven (reference) was the lowest and had a value of about 0.1 at the low and mid-frequencies, at high frequencies, it increases to 0.16 at 6300 Hz. The highest sound absorption coefficient of the 1-sided coated-30 min and 2-sided coated-30 min has the value of about 0.18 and 0.20 at high frequencies. The highest sound absorption coefficient of the 1-sided coated-60 min and 2-sided coated-60 min has the value of about 0.19 and 0.22 at high frequencies. The production time of electrospinning was 60 min, it was observed that the samples exhibited low sound absorption characteristics, especially in the range of 4000-6400 Hz. The highest sound absorption coefficient was measured as 0.27 and 0.43 for the samples produced in 1-sided coated-120 min and 2-sided coated-120 min. In the measurements made from the samples obtained by increasing the production time to 120 min, a significant improvement is observed in the 3500-6400 Hz range. It is to be expected that the sound absorption coefficient values weight increases as production time increases. Because the thickness increases the sound wave propagation path, more sound energy is provided, which is converted into heat [35].

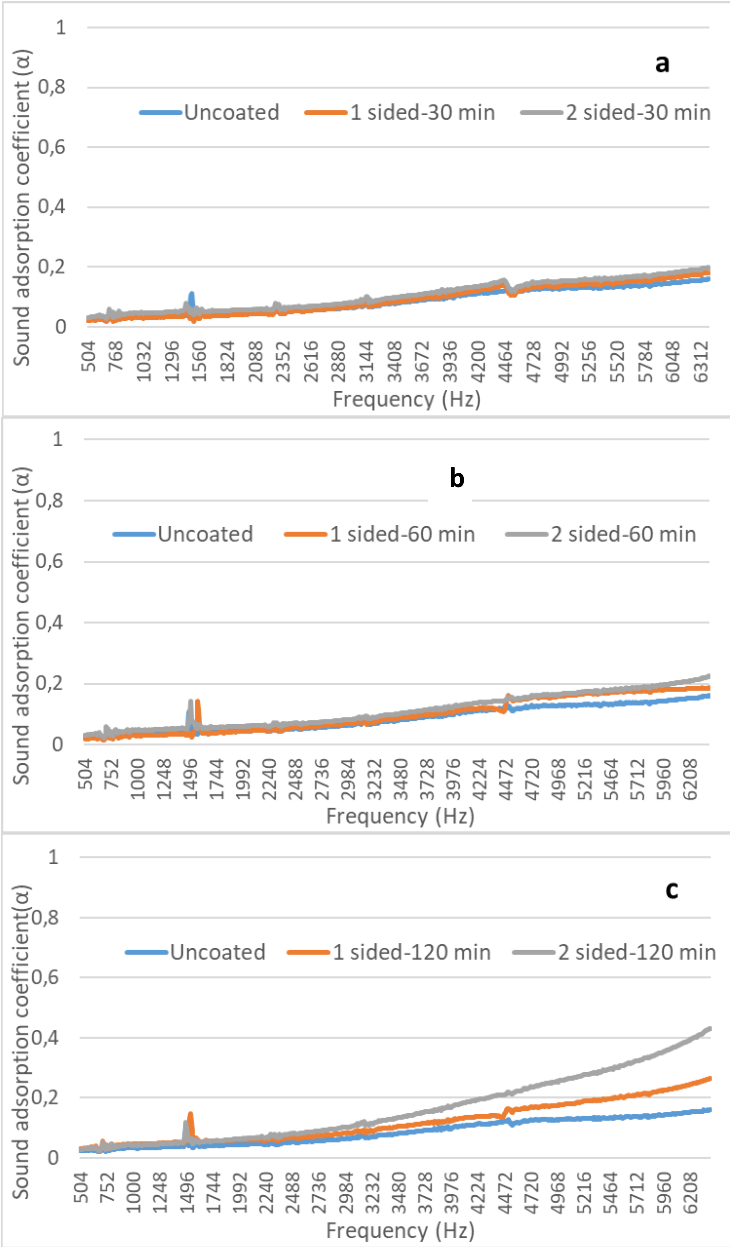

Figure 3. Comparison of the sound absorption coefficients of uncoated, 1-sided coated and 2-sided coated samples with different deposition time (a) 30 min, (b) 60 min and (c) 120 min.

4. Conclusion

The study presents an evaluation of electrospinning coating time the sound absorption coefficient of bio-based and biodegradable PLA nonwoven mats. The PLA fibers produced were smooth and bead-free with ultrafine. To investigate the effect of the production time of electrospinning on the PP nonwoven, production times (30 min, 60 min, and 120 min) of the coating were applied. The absorption coefficient of 2-sided120 min coated sample reaches absorption coefficient values of 0.2 and 0.4 in frequency ranges of 3500 and 6400 Hz. Electrospinning coating with PLA polymer is thought to be an environmentally friendly and cost-effective method of adding new properties to materials that do not have sound absorbing properties.

It is revealed that the PLA electrospun mat has an impact on the sound absorption performance. These eco-friendly materials can be used as a hushed automobile door, hatch, wheel arches, headliner, and trunk.

References

[1] European Environment Agency, Number of Europeans exposed to harmful noise pollution expected to increase, https://www.eea.europa.eu/highlights/number-of-europeans-exposed-to, (accessed on 2 February 2022).

[2] Hammer M S, Swinburn T K, Neitzel R L 2014 Environmental noise pollution in the United States: developing an effective public health response Environmental Health Perspect 122 115-119.

[3] Madushika J W A and Lanarolle W D G 2022 A review on novel approaches to enhance sound absorbing performance using textile fibers The Journal of The Textile Institute 113 341-348.

[4] Li X, Peng Y, He Y, Zhang C, Zhang D, Liu Y 2022 Research progress on sound absorption of electrospun fibrous composite materials Nanomaterials 12 1123.

[5] Bihola D and Amin H N 2015. Application of nano material to enhance acoustic properties Engineering Science and Futuristic Technology 1 (12) 1-9.

[6] Mohrova J and Kalinova K 2012 Different structures of PVA nanofibrous membrane for sound absorption application Journal of Nanomaterials 643043.

[7] Gao B, Zuo L, Zuo B 2016 Sound absorption properties of spiral vane electrospun PVA/nano particle nanofiber membrane and non-woven composite material Fibers and Polymers 17 (7) 1090–6.

[8] Liu H and Zuo B 2018 Structure and Sound absorption properties of spiral vane electrospun PVA/PEO nanofiber membranes Applied Sciences 8 296.

[9] Kucukali-Ozturk M, Nergis B, Candan C 2018 Design of layered structure with nanofibrous resonant membrane for acoustic applications Journal of Industrial Textiles 47 (7) 1739-56.

[10] Elkasaby M A, Utkarsh U, Syed N A, Rizvi G, Mohany A, Pop-Iliev R 2020 Evaluation of electro-spun polymeric nanofibers for sound absorption applications AIP Conference Proceedings 2205 020042.

[11] Liu H and Zuo B J 2020 Sound absorption property of PVA/PEO/GO nanofiber membrane and non-woven composite material Journal of Industrial Textiles 50 (4) 512-525.

[12] Shen J, Lee HP, Yan X 2022 Sound absorption performance and mechanism of flexible PVA microperforated membrane Applied Acoustics 185 108420.

[13] Avossa J, Branda F, Marulo F, Petrone G, Guido S, Tomaiuolo G C 2018 Light electrospun polyvinylpyrrolidone blanket for low frequencies sound absorption Chinese Journal of Polymer Science 36 (12) 1368-74.

[14] Del Sorbo G R, Truda G, Bifulco A, Passaro J, Petrone G, Vitolo B, Ausanio G, Vergara A, Marulo F, Branda F 2019 Non monotonous effects of noncovalently functionalized graphene addition on the structure and sound absorption properties of polyvinylpyrrolidone (1300 kDa) electrospun mats Materials 12 108.

[15] Na Y, Agnhage T, Cho G 2012 Sound absorption of multiple layers of nanofiber webs and the comparison of measuring methods for sound absorption coefficients Fibers and Polymers 13 348-1352.

[16] Park, M, Park, H K, Shin H K, Kang D, Pant B, Kim H, Song J K, Kim H Y 2019 Sound absorption and insulation properties of a polyurethane foam mixed with electrospun nylon-6 and polyurethane nanofibre mats Journal of Nanoscience and Nanotechnology 19 3558-3563.

[17] Ulrich T, Arenas J P 2020. Sound Absorption of Sustainable Polymer Nanofibrous Thin Membranes Bonded to a Bulk Porous Material Sustainability 12 2361.

[18] Xiang H F, Tan S X, Yu X L, Long Y H, Zhang X L, Zhao N, Xu J 2011 Sound absorption behavior of electrospun polyacrylonitrile nanofibrous membranes Chinese Journal of Polymer Science 29 (6) 650–7.

[19] Kucukali-Ozturk M, Nergis F B, Candan C 2018 Design of electrospun polyacrylonitrile

DOI: 10.54254/2755-2721/7/20230395

nanofiber– coated nonwoven structure for sound absorption Polymers Advanced Technologies 29 1255-1260.
[20] Salehi F, Avanaki M J, Nouri M J 2021 An investigation into the designing of fibrous sound absorption materials incorporated with nanofibers: A case study of a multi-layered material composed of PET nonwoven and PAN nanofibers Journal of Industrial Textiles 1-10.
[21] Rabbi A, Bahrambeygi H, Shoushtari A M, Nasouri K 2013 Incorporation of nanofiber layers in nonwoven materials for improving their acoustic properties Journal of Engineered Fibers and Fabrics 8 (4) 36-41.
[22] Bahrambeygi H, Sabetzadeh N, Rabbi A, Nasouri K, Shoushtari A M, Babaei M R 2013 Nanofibers (PU and PAN) and nanoparticles (Nanoclay and MWNTs) simultaneous effects on polyurethane foam sound absorption Journal of Polymer Research 20 (2) 72-82.
[23] Rabbi A, Bahrambeygi H, Shoushtari A M, Nasouri K 2014 Manufacturing of PAN or PU nanofiber layers/PET nonwoven composite as highly effective sound absorbers Advances in Polymer Technology 33 (4) 1-8.
[24] Özkal A, Çallıoğlu F C, Akduman Ç 2019 Development of a new nanofibrous composite material from recycled nonwovens to improve sound absorption ability Journal of Industrial Textiles 11 (2) 189-201.
[25] Zhao-Xuan D, Wang Y 2021 Optimization and characterization of polyurethane electro-spun nano-membranes used for the surfaces of sound absorbent multi-layer sheets Journal of Macromolecular Science Part B 60 (9) 647-662.
[26] Karaca N, Yüksek I, Uçar N, Önen A, Baydogan M, Kirbas C 2021 Experimental analysis of sound absorption effect of specially developed elastomeric thin thermoplastic polyurethane sub-micron fibre web layers placed on rigid layer and flexible layers Plastics, Rubber and Composites: Macromolecular Engineering 50 507-515.
[27] Wu C M, Chou M H 2016 Polymorphism, piezoelectricity and sound absorption of electrospun PVDF membranes with and without carbon nanotubes Composites Science and Technology 127 127–133.
[28] Wu C M, Chou M H 2016 Sound absorption of electrospun polyvinylidene fluoride/graphene membranes European Polymer Journal 82 35-45.
[29] Wu C M, Chou M H 2020 Acoustic–electric conversion and piezoelectric properties of electrospun polyvinylidene fluoride/silver nanofibrous membranes eXPRESS Polymer Letters 14 (2) 103-114.
[30] Karaca N, Yüksek İ Ö, Uçar N, Önen A, Kirbaş C 2021 Sound absorption and thermal insulation properties of composite thermoplastic polyurethane/polystyrene (TPU/PS) nanofiber web and TPU nanofiber web and PS-extracted TPU/PS microfiber web Journal of Industrial Textiles 44.
[31] Özkal A, Çallıoglu F C 2020 Effect of nanofiber spinning duration on the sound absorption capacity of nonwovens produced from recycled polyethylene terephthalate fibers Applied Acoustics 169 107468.
[32] Akasaka S, Kato T, Azuma K, Konosu Y, Matsumoto H, Asai S 2019 Structure-sound absorption property relationships of electrospun thin silica fiber sheets: Quantitative analysis based on acoustic models Applied Acoustics 152 13-20.
[33] Pakolpakçıl A, Draczyński Z, Szulc J, Stawski D, Tarzyńska N, Bednarowicz A, Sikorski D, Hernandez C, Sztajnowski S, Krucińska I, Gutarowska B 2021 An in vitro study of antibacterial properties of electrospun Hypericum perforatum oil-loaded poly(lactic acid) nonwovens for potential biomedical applications Applied Sciences 11 (17) 8219.
[34] Leonés A, Salaris V, Mujica-Garcia A, Arrieta MP, Lopez D, Lieblich M, Kenny JM, Peponi L. 2021. PLA electrospun fibers reinforced with organic and ınorganic nanoparticles: a comparative study Molecules 26 4925.
[35] Panahi M, Tavanai H, Zarrebini M 2015 Preparation of sound absorption on nano-fiber composite mats and ıts absorption property Journal of Textiles and Polymers 3 (2).