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Nanomembranes and Urban Vehicles: A Simple Way to Minimize Urban Noise †

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Abstract: Urban noise is considered a growing problem in major cities around the world. This paper explores the development of a nanomembrane-based material for noise attenuation. The experimental results show that a combination of acoustic foam and nanomembranes can act as a Helmholtz resonator. The average sound absorption coefficient was around 90%, with peak frequencies varying from 2400 Hz to 4000 Hz. The average thickness of the nanomembranes was approximately 5.0 µm, while the acoustic foam was 13 mm thick. The mean noise reduction, around 10 dB, depends on the morphology of the nanomembranes, their thickness, and their pore size.

Keywords: nanomembranes; acoustics; urban noise attenuation

1. Introduction

As noted by de Paiva Vianna et al. [1], the World Health Organization (WHO) identified urban noise as a pollutant and potential health hazard in the early 1970s. The primary source of urban noise is road traffic, as examined by Hao et al. [2], who observed its link to sleep deprivation. Sorensen et al. [3] connected long-term exposure to urban noise with an increased risk of type 2 diabetes. McBride et al. [4] identified the spectral content of tire–pavement noise as falling within the 500 to 1500 Hz range. Van Renterghem et al. [5] found that urban park noise frequencies range from 2500 Hz to 8000 Hz, influenced by traffic. Shin et al. [6] associated road traffic noise, common in Toronto, with cardiovascular diseases, hypertension, and diabetes among residents.

Calixto et al. [7] defined allowable noise levels in various urban locations, based on factors such as construction type and traffic flow. Faulkner and Murphy [8] measured noise levels across different urban areas in Dublin. Similarly, Nascimento et al. [9] conducted a comparable study in Goiânia, Brazil, a city with a population of 1.3 million and noise levels greater than 60 dB (A). Dublin recorded road noise levels exceeding 55 dB (A).

Urban noise's harmful effects on humans requires mitigation strategies, such as developing novel noise attenuation materials for urban areas. This paper discusses the development of a hybrid material, which combines two dissimilar microstructures to tailor acoustic behavior, potentially reducing health issues among urban populations.

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2. Materials and Methods

The technique utilized for synthesizing nanomembranes in this study was electrospinning. In this research, the polymeric solution used during electrospinning consisted of poly (vinylidene fluoride-co-hexafluoropropylene) (PVdF-HFP) at a concentration of 12% w/w. Acetone and dimethyl–formamide (DMF) were mixed at a ratio of 40/60 w/w as solvents. This solvent combination not only reduced the solution's viscosity but also facilitated rapid solvent evaporation. The flow rate of the polymeric solution through the 18G needle was maintained at 1.0 mL/h. The optimal voltage-to-distance gap ratio was determined to be 10 kV/cm for effective nanofiber formation [10]. A morphological analysis of the nanofibers was conducted using a high-resolution scanning electron microscope (SEM), FEG-Quanta 200 FEI. The experimental matrix outlined in Table 1 was designed not only to examine the impact of carbon nanotubes (CNTs) and surfactant (SDBS), but also to investigate the influence of surface tension reduction on the morphology of the nanofibers. The acoustic material used in this study was Basotect® UL (BASF Corporation, Florham Park, USA), specifically melamine foam with a density of 6 kg/m^3 and a thickness of approximately 0.5 inches (around 13.0 mm). The melamine foam was combined in series with the nanomembranes. Acoustic tests were conducted following ASTM C 384 standards [10] using an impedance tube to evaluate frequencies ranging from 0 to 5000 Hz, chosen to encompass the urban noise spectrum, typically between 500 and 4500 Hz.

Table 1. Nanomembranes' manufacturing features.

Group ID	PVdF-HFP [% *w*/*w*]	CNT [% w]	SDBS [ppm]	SDBS [%w]
E1	12	0.00	--	--
E2	12	0.20	--	--
E3	12	0.20	100	--
E4	12	0.20	--	0.20

3. Results and Discussion

Leão et al. [11] discussed how acoustic properties are directly linked to the microstructural morphology of materials. To investigate these correlations between nanomembrane microstructure and overall acoustic response, a detailed morphological analysis was conducted; see Table 2. SEM observations from groups E1 to E4 are depicted in Figure 1a–d.

Table 2. Key dimensions for each nanomembrane group.

Group ID	Fiber Diameter [nm]	Porous Diameter [µm]	Thickness [µm]
E1	216.68 ± 55.71	1.36 ± 0.27	7.80
E2	130.01 ± 23.23	1.24 ± 0.32	4.68
E3	188.67 ± 20.04	1.72 ± 0.47	6.79
E4	146.68 ± 26.66	1.76 ± 0.45	5.28

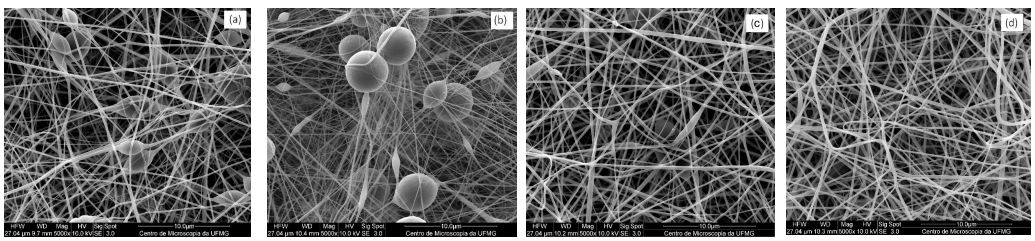


Figure 1. SEM observations: Cases E1–E4. (**a**) Case E1; (**b**) Case E2; (**c**) Case E3; (**d**) Case E4.

The addition of CNTs leads to a decrease in fiber diameter due to the increase in electrical conductivity. However, as discussed by Leão et al. [11], the bead formation was due to the increase in viscosity due to CNT addition. Bead formation was not observed in Figure 1c,d. This phenomenon occurs due to a reduction in surface tension between the needle's internal walls and the solution, induced by the addition of the surfactant SDBS. As discussed by Mahesh and Mini [12], nanomembranes' morphological changes can influence the overall system (foam + nanomembrane)'s acoustic behavior, as the combined materials act as a Helmholtz resonator. Table 3 shows the results obtained, while Figure 2a,b describe each group's acoustic behavior over a wide frequency range.

Table 3. Acoustic properties of each nanomembrane group.

Group ID	Peak Absorption Coefficient [a.u.]	Peak Frequency [Hz]	Peak Noise Drop [dB]	Mean Noise Drop [dB]
E1	0.85	2388	19.81	11.16
E2	0.89	3006	20.34	11.45
E3	0.90	3435	20.44	11.21
E4	0.91	3996	21.58	10.27

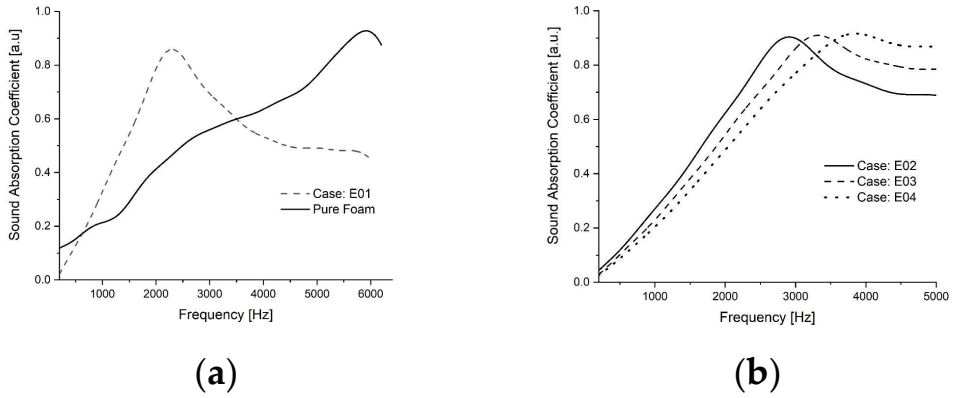


Figure 2. Sound absorption coefficient as function of frequency. (**a**) Case E01 and foam; (**b**) Cases E02, E03, E04.

According to Roca-Barcelo et al. [13], the noise map ranged from 45 dB to 65 dB near the Congonhas airport. By using such new material as acoustic insulation for public transportation, e.g., buses, it is possible to reduce the noise inside by at least 10 dB. The reason for such good performance is the combination of melamine foams and nanomembranes, which acts as a Helmholtz resonator, making it an an innovative and cost-effective solution, as nanomembranes are easy to create.

4. Conclusions

The concept of a Helmholtz resonator was successfully applied to create a new class of material with high capacity of sound absorption. This new innovative concept based on the series association of nanomembranes (~5.0 µm) and acoustic foam (13 mm) not only provided an average sound absorption coefficient around 89%, but also peak frequencies varying from 2400 Hz to 4000 Hz. The mean noise drop, around 10 dB, is dependent on the nanomembranes' morphology, their thickness, and their pore size. By applying this new material to urban buses in downtown São Paulo, the average noise in a radius of 5 km from Congonhas airport can be reduced from 55 dB (A) to <45 dB (A). The environmental benefits of such a material are clear.

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