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Performance of dry rubber foam as a sound absorbing material

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ABSTRACT

The present study aims to investigate the actual sound-absorbing capability of dry rubber foam. Two sound-absorbing foam materials were produced from dry synthetic rubbers known as ethylene-propylene-diene monomer (EPDM) and nitrile butadiene rubber (NBR). The acoustical efficiencies of dry rubber foams and commercially available acoustic foams; polyurethane and melamine were studied. The results showed a significant influence of the sound absorption properties of the different dry rubber foams and acoustic foams. EPDM reached a peak absorption coefficient of 0.94, while NBR peaked at 0.75, both occurring at frequencies below 1500 Hz. In contrast, acoustic foams reached their sound absorption peak at frequencies exceeding 2000 Hz. These properties were governed by the physical and microstructural properties of the foams. This study can be helpful and valuable for designing a dry rubber foam with optimum non-acoustical properties to achieve the desired acoustical properties in various service applications.

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INTRODUCTION

Environmental noise pollution has a significant impact on human health, contributing directly to both physical health and increased mortality rates. In Europe alone, noise exposure is recognized as one of the leading environmental risk factors, accounting for over 10,000 premature deaths annually [1]. Furthermore, noise pollution has been identified as one of the top contributors to the environmental burden of disease [2].

In response, international standards have been established to curb noise pollution through increasingly stringent regulations. For instance, the permissible pass-by noise levels for cars have been progressively reduced from 82 dB(A) in 1970 to 70 dB(A) by 2020 [3]. Building on this momentum, the UN/ECE R51.03 regulation—introduced by the United Nations Economic Commission for Europe—sets an even lower target of 68 dB(A) by 2024 [4]. These rigorous regulatory efforts, combined with the growing need for innovative materials, highlight a promising opportunity to explore advanced noise control solutions. In particular, the development and application of viscoelastic materials such as rubber present a compelling avenue for enhancing acoustic performance in modern environments.

Acoustic materials are engineered to mitigate noise through mechanisms such as sound absorption and sound insulation, and their performance in these domains has been extensively studied. However, the acoustic behavior of viscoelastic materials, particularly rubber foams derived from dry rubber, remains relatively underexplored in the existing literature. Moreover, the relationship between non-acoustical properties and the acoustic performance of dry rubber foam has not been fully understood. This gap underscores the need for an analysis of the non-acoustical characteristics that influence the acoustic properties of dry rubber foam, in order to better understand and optimize its performance for noise control applications

EXPERIMENTAL SETUP

Materials

Four sound-absorbing foam materials as shown in Figure 1 were investigated in this study: two foams fabricated from dry synthetic rubbers, namely ethylene-propylene-diene monomer (EPDM) and nitrile butadiene rubber (NBR), and two commercially available acoustic foams commonly used in the market, namely polyurethane and melamine. Table 1 presents the physical data of the foams studied.

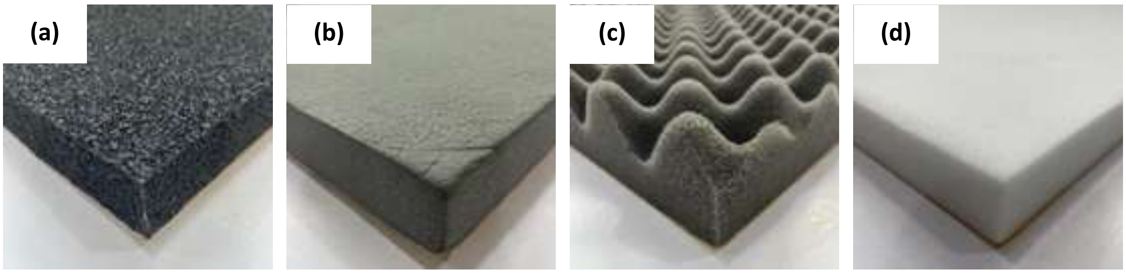

Figure 1. Dry rubber foams: (a) EPDM; (b) NBR, and commercially available acoustic foams: (c) polyurethane; (d) melamine.

Table 1. Physical data of the dry rubber foams and the acoustic foams.

Foam	Nominal Thickness (mm)	Nominal Density (kg/m^3)
EPDM	25	115
NBR	30	65
Polyurethane	45	30
Melamine	30	15

Experimental Procedure

The acoustic properties of the foam materials were measured following ISO 10534-2 [5], which specifies the use of an impedance tube equipped with microphones and a frequency analysis system. The airtight impedance tube consists of a sound source at one end, which generates the incident sound wave, and a test specimen positioned at the opposite end. Two microphones are mounted along the inner wall of the tube to capture the sound pressure at specified locations. Measurements were conducted over a frequency range of 200 to 6400 Hz, with the incident sound wave oriented perpendicularly to the foam's rise direction. To ensure accuracy and repeatability, each test was performed on five separate samples, and the results were averaged to provide representative values.

The microstructure of the foams was analyzed using an in-house method to determine surface morphology via field emission scanning electron microscopy (FESEM). Foam samples were cut perpendicular to the foaming direction and mounted onto specimen stubs using double-sided carbon tape. The foams were then examined with a JOEL JSM-7601F Plus microscope at a magnification of 35×.

RESULTS AND DISCUSSION

Sound Absorption

The sound absorption performance of the dry rubber foams and the acoustic foams is presented in Figure 2. A distinct increase in the absorption coefficient is observed for all tested foams, particularly above 1000 Hz for both polyurethane and melamine foams. This trend is characteristic of low-density, soft porous materials, which typically exhibit enhanced absorption at higher frequencies [6]. Polyurethane foam demonstrated consistent sound absorption above 70% ($\alpha \geq 0.7$) at frequencies exceeding 2000 Hz, while melamine foam exhibited even greater performance, absorbing more than 90% of incident sound ($\alpha \geq 0.9$) within the 2500–4500 Hz range.

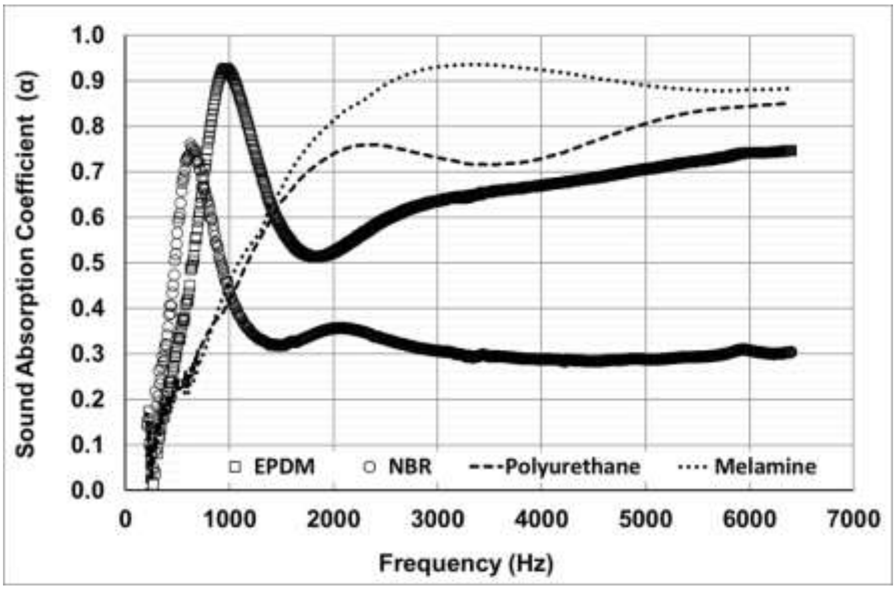

Figure 2. Sound absorption coefficient as a function of the frequency of the dry rubber foams and the acoustic foams.

In contrast, the dry rubber foams, EPDM and NBR achieved their maximum absorption at lower frequencies. EPDM reached a peak absorption coefficient of 0.94, while NBR peaked at 0.75, both occurring at frequencies below 1500 Hz. Beyond these peak points, the absorption coefficients for both rubber foams declined. These results suggest that dry rubber foams are more effective in low-frequency sound absorption, whereas soft porous materials such as polyurethane and melamine foams perform optimally at higher frequencies. The observed differences in acoustic behavior are closely linked to the structural characteristics of the foams, particularly pore size and density, which play a critical role in sound wave dissipation mechanisms [7].

Microstructure

Figure 3 presents the micrographs of the foam samples, revealing distinct structural characteristics. Both polyurethane and melamine foams exhibit open pores on their top and side surfaces. This feature facilitates enhanced sound absorption by allowing incident sound waves to penetrate the material and dissipate the internal vibration. This process converts sound energy into heat through viscous and thermal interactions within the pore structure. These observations are consistent with the high sound absorption coefficients shown in Figure 2. Soft, porous materials are inherently well-suited for sound absorption due to their ability to dissipate acoustic energy effectively.

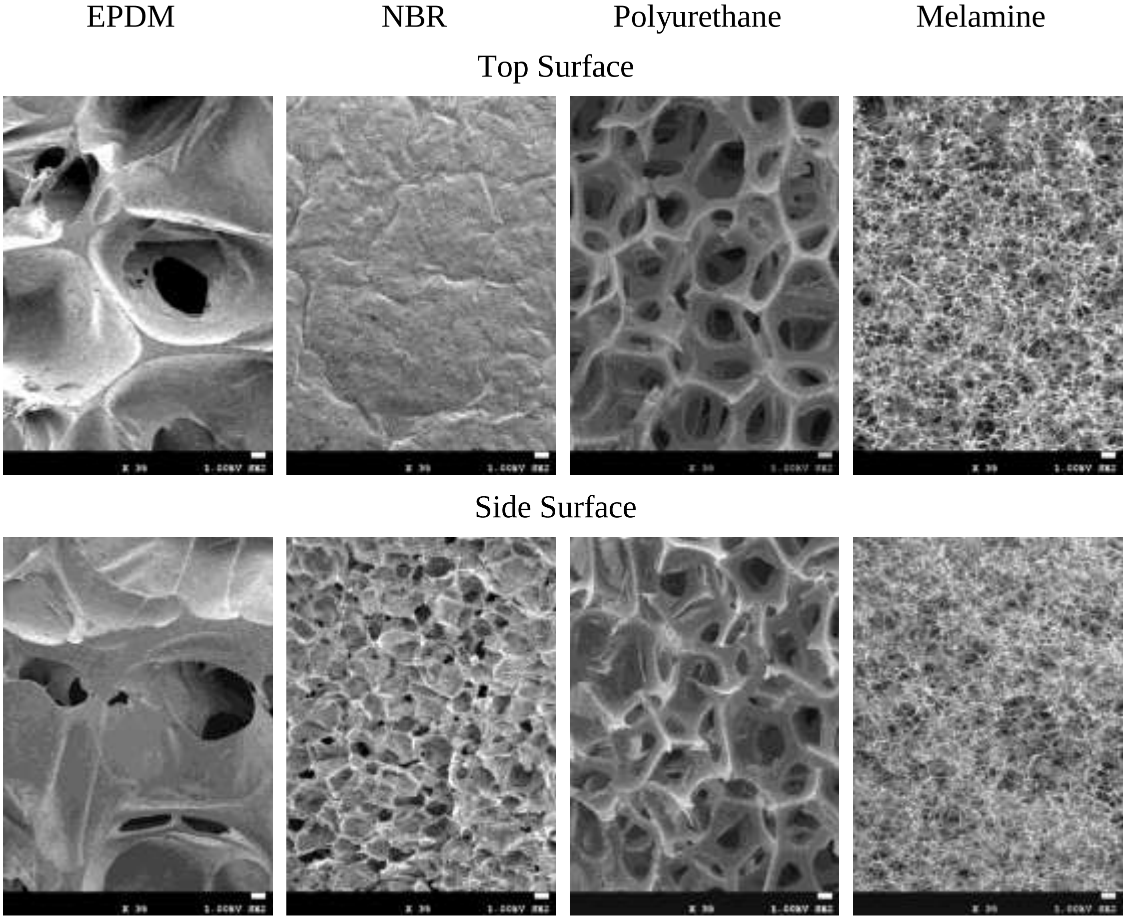

Figure 3. Micrographs of the dry rubber foams and the acoustic foams.

EPDM foam demonstrates a hybrid pore structure comprising both open and closed cells, a characteristic also observed in NBR foam. However, EPDM foam possesses significantly larger pores and lacks a skin layer on the top surface unlike NBR foam, which features a dense outer layer. These structural differences are reflected in their acoustic performance. Both foams exhibit high absorption peaks in the low-frequency range, attributable to the presence of combined open-closed pores. Notably, the larger open pores in EPDM foam enhance its absorption capacity at higher frequencies, whereas the skin layer in NBR foam impedes sound wave penetration, resulting in diminished performance in the high-frequency region. These microstructural features strongly support the acoustic data presented in Figure 2.

CONCLUSIONS

This study systematically investigated the sound absorption capabilities of dry rubber foams, EPDM and NBR, in comparison with commercially available acoustic foams, polyurethane and melamine. The findings highlight different acoustic performance linked directly to each foam's physical and microstructural properties. Polyurethane and melamine foams, characterized by their open-pore structures and low density, demonstrated superior sound absorption at high frequencies, with melamine achieving absorption coefficients above 0.9. Conversely, EPDM and NBR foams were more effective in the low-frequency range, where EPDM outperformed NBR due to its larger pore size and absence of a surface skin layer, enabling improved sound wave penetration. These results confirm that the acoustic efficiency of foam materials is strongly influenced by pore morphology, specifically pore size, openness, and the presence or absence of surface layers. The observed differences in frequency-dependent sound absorption emphasize the importance of tailoring foam microstructures for targeted acoustic applications.

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