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Sound transmission loss from polyvinyl acetate polymer mixed with different porous carbons

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ABSTRACT

The soundproofing properties of microporous activated carbon (AC) and mesoporous carbon nanotube (CNT) in a polymer matrix (polyvinyl acetate, PVA) have been systematically investigated. Analyzed by N_2-adsorption technique, the AC powders are mainly microporous, while the CNT powders consisted of a large number of mesoporous channels. An anechoic termination method is adopted to analyze the sound transmission loss (TL) for PVA-based coatings at different frequencies ranging from 400 to 3000 Hz. Pristine PVA, AC-PVA, CNT-PVA, and AC-CNT-PVA coatings showed average TL values of 24.4, 25.1 and 27.2, and 25.9 dB, respectively. The TL value as an increasing function of mesopore fraction reflects that the mesopore is a major contributor to the improved soundproof performance, while the aid of micropore seems to be minor. The improved TL can be attributed to the fact that the mesopore of CNTs is capable of providing a large number of voids and cavities for air storage, enhancing efficiency of sound absorption and reduces sound vibration. On the basis, the selection of porous carbons plays an important role in determining the soundproof performance of PVA-based coating. This design of soundproof coating delivers a feasible potential as eco-environmental decoration materials due to its good stability, non-toxicity, and excellent soundproof performance.

1. Introduction

Nowadays noise is considered as one of the most lethal form of pollution arising from industrial and technological advancement over the decades [1,2]. According to the World Health Organization (WHO), in the 90s, around 40% of the US citizens experienced a traffic noise level equivalent to 55 dB (decibel) at daytime and 20% experienced a noise level even higher (65 dB) [3]. On the other hand, WHO also reported that above 30% of the population was exposed to 55 dB at night, severely affecting the quality of sleep. The exposure to high noise level, caused by the combined effects of industrial development and increased traffic and population, leads to public health deterioration which includes an increase in the number of patients suffering from high blood pressure and stress. Therefore, keeping human away from sound pollution is a major issue now. There are three different approaches to curb the pollution effects: first turning off the source, which is nearly impossible if anyone lives near the airport, industrial areas or busy roads. The second is stopping the sound from entering the ears by using earplugs. Thirdly, stopping sound in its tracks by using soundproof materials. This approach is very much pragmatic when it comes to making the households soundproof. Soundproof materials are able to reduce the noise either by absorption or reflection of sound energy. Materials like hollow microsphere, porous particle, foam and fiber are ideal for sound insulation applications [1]. A number of studies have been carried out to develop such soundproof materials namely gypsum board on concrete material [4], wood-waste tire rubber composite [5], inorganic particles/polymer composites, including $CaCO_3$/polypropylene [1], hollow glass bead/polypropylene [6], carbon nanotube (CNT)/acrylonitrile-butadiene-styrene [7], carbon black/acrylonitrile-butadiene-styrene [8]. All these studies suggest that the use of soundproof materials has a bright potential in controlling sound pollution problems.

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Generally, activated carbon (AC) is an inexpensive microporous material with high surface area and corrosion resistance, which can be derived from any carbonaceous material. It is a widely used material in variety of fields like energy storages [9], water treatment [10], product purification [11] etc. However, there are few reports on the use of AC for acoustic sound insulation applications. On the other hand, carbon nanotube (CNT), a mesoporous material with a range of applications, has also been reported to have beneficial effects on increasing the performance of soundproof materials [7]. Hence, in this paper, we investigate the acoustic insulation properties of polyvinyl acetate (PVA) filled with microporous AC and mesoporous CNT, forming a composite soundproof coating. The transmission loss (TL) of as-prepared composites was systematically investigated to identify the effects of sound frequency on the soundproof performance. This study would deliver an applicable feasibility of porous carbon materials for an improved soundproof capability of construction materials.

2. Experimental

Commercial AC was purchased from First Chemical Group (Taiwan). Chemical vapor deposition grown multi-walled CNTs were procured from Taiwan Maxwave Co. Ltd. In order to characterize the porous nature of AC and CNTs, an automated adsorption apparatus (Micromeritics, ASAP 2020) was adopted, using N_2 physisorption at −196 °C. Nitrogen surface areas and micropore volumes of the samples were determined from Brunauer-Emmett-Teller (BET) and Dubinin-Radushkevich (D-R) equations, respectively. The amount of N_2 adsorbed at relative pressures near unity has been used to determine the total pore volume, which corresponds to the sum of the micropore and mesopore volumes. The pore size distributions of composites were analyzed by Barrett-Joyner-Halenda (BJH) model. The microstructural morphology of AC and CNTs were inspected by using field-emission scanning electron microscope (FE-SEM; JEOL JSM-5600). The PVA/carbon composite was made according to the following procedure: (i) 28.5 g of PVA and 1.5 g of carbon (AC or CNT) were mixed with a 3D ball mill for 3 min. (ii) The slurry was pasted on calcium silicate plate with a doctor blade. Finally, the film was dried overnight in a vacuum oven at 80 °C.

An impedance apparatus was utilized for analyzing the acoustic TL of PVA/carbon plates. Basically, the apparatus is composed of three parts: an upstream tube with a loud speaker, a removable test sample holder and a downstream tube with a semi-anechoic termination at the end [12], as illustrated in Fig. 1. Herein two cylindrical tubes with an average inner diameter of 15 cm and a length of 120 cm are assembled together. Two pairs of microphones were accurately positioned: one set in the upstream tube and the other in the downstream tube. The distance between the microphone and test sample holder was 15 cm, and the two microphones were positioned 15 cm apart. An urethane foam with a thickness of approximately 3 mm was used as an anechoic termination at the end of downstream tube. The speaker in the upstream tube generated the noise with a frequency range of 400–3000 Hz and the four microphones simultaneously measured the sound pressure.

3. Results and discussion

Fig. 2(a) and (b) show the FE-SEM images of AC at different magnifications. The size of chunk-like AC particles ranges from 80 to 100 μm. On the other hand, FE-SEM images of CNT particles at low and high magnifications are shown in Fig. 2(c) and (d), respectively. As can be seen, one-dimensional CNTs with a high aspect ratio have diameter between 50 and 100 nm and length in micrometer scale. The CNTs seems to form a three-dimensional porous architecture, providing cavities and voids for air trapping.

Table 1 presents the porous properties of AC and CNT, including specific surface area (S_{BET}), pore volume (V_t), volume fraction of micropores (V_{micro}) and mesopores (V_{meso}). The specific BET surface area of AC is more than four times higher than that of CNTs, arising from the fact that the significant fractions of the pores in AC are actually micropores. That is, the AC is composed of micropores, whereas the CNT sample is mainly mesoporous. The AC-CNT composite with a weight ratio of AC to CNT (50: 50) was also analyzed for comparison. It can be seen that the AC-CNT composite has reduced S_{BET}, V_t, and V_{micro} fraction after the introduction of CNTs. To inspect the porosity, the BJH method was adopted to depict the pore size distribution of AC and CNT materials, as presented in Fig. 3. There are one primary peak at pore size <2 nm and one weak peak at *ca.* 3 nm, implying that the pore size distribution of AC falls mainly in microporous range. To the contrary, the CNT powder shows one wide lump within the entire range of 20–50 nm, clearly implicating that CNT is primarily mesoporous in nature. The pore structure of CNTs is presumably due to inner pore of CNTs with opened ends and cavities in CNT aggregation. This reveals that both ends of CNTs are opened, and their inner cavities are accessible to N_2 gas molecules. As expected, the AC-CNT composite is found to have micro- and mesoporous structure.

Generally, the scale of TL by a soundproof material can be estimated, based on an anechoic termination method [8]. The technique is based on a one-dimensional plane wave inside the impedance tubes, where A and B denote the incident and the reflected wave components in the upstream tube, and C and D represent the transmitted and the reflected wave components in the downstream tube, respectively, as shown in Fig. 1. The sound volumes are calculated using the following equation:

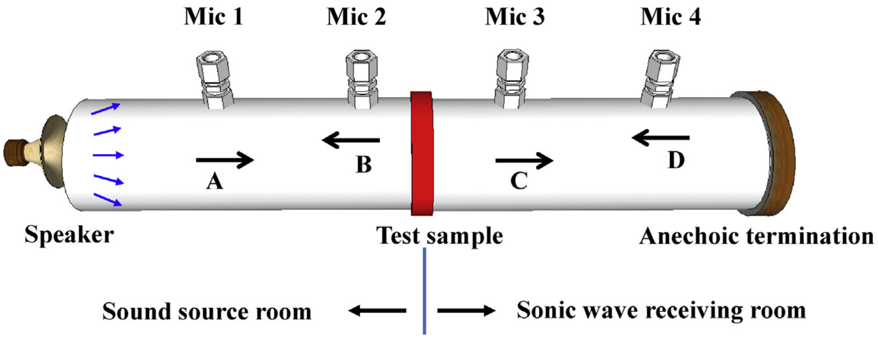

Fig. 1. The schematic diagram of experimental setup for analyzing sound transmission of test sample.