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Sound Absorption Property of Polyurethane Foam with Polyethylene Fiber

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Flexible polyurethane (PU) foams with varying polyethylene fiber contents were synthesized to improve their acoustic performances. The purpose of this study was to investigate the effects of different polyethylene fiber contents of the PU foams on the resultant sound absorption, which was characterized by the impedance tube technique to obtain the incident sound absorption coefficient. Other parameters related to acoustic absorption performance of polyurethane foams were also measured such as microstructure, porosity and airflow resistivity. In this paper, these parameters were analyzed and compared with those of pure polyurethane foam. The results showed that the acoustic absorption properties of the PU foams were improved especially in the low frequency region by adding polyethylene fiber. When 0.2 g polyethylene fiber was added into the PU foam composite, the sound absorption coefficient is best especially around 125 – 315 Hz. The maximum enhancement in the acoustic properties of the PU foams was obtained by adding 0.1 g polyethylene fiber.

Keywords: sound absorption, porous materials, polymeric composites, open-cell foams, microstructure.

1. INTRODUCTION

The gradual increase in the undesirable and hazardous noise level has perplexed our living and working environment. Therefore, noise pollution is always one of the major environmental issues [1]. A large part of the noise comes from the increase in car ownership. Meanwhile, the interior noise has become one of the signatures of passenger vehicles, and automotive manufactures have put tremendous efforts to reduce the overall noise and vibration of vehicles, for it is desirable for vehicle occupants to experience low noise levels.

Many materials have been applied to sound absorption and sound insulation. Ganesan et al. [2] put forward to try the sound absorption property of natural fibres and their blends by needle-punched nonwoven techniques. Results showed sound reduction increased with increase in blend proportion of kapok and milkweed fibres. Asdrubali et al. [3] determined the thermal and acoustic performance of corrugated cardboard panels usually applied in the packaging industry.

The vehicle acoustic packages, such as sound absorbing materials, are used throughout a vehicle to reduce interior noise level and meet the expectation of customer. Porous materials have been used in the field of acoustic control [4 – 6]. Polymer foams were comprised of gas pore surrounded by a continuous solid phase so that the sound waves could be absorbed. Currently, sundry acoustic porous foams are fabricated for noise protection, such as polyolefin foams [7], polymethylmethacrylate foams [8], polyvinyl formal foams [9], etc. Lightweight porous materials such as polyurethane (PU) foams are extensively used as noise control materials in the automotive industry.

It is well known that the acoustic absorption capacity depends on the acoustic porosity content. PU foams with open-cell morphology are widely used in automobiles to improve the noise, vibration, and harshness comfort [10 – 12]. The sound absorption characteristic of PU foams can be controlled by varying raw materials such as polyol, isocyanate, crosslinking agent, blowing agent, surfactant, catalysts, and any other additives. The filler of polyurethane composites involves nanomaterials [1], powders [13], fibers [14], and so on. PU/nanosilica nanocomposite foams were prepared by Lee et al. [1] to improve the sound absorption ability of PU foams by adding nanosilica to PU foam. Gwon et al. [15] analyzed the development of cell morphologies in manufacturing flexible polyurethane urea foams as sound absorption materials. Moreover, the result turned that uniformly distributed cavities and pores show better efficiency than the non-uniform cases, in the sound absorption characteristics. Celebi et al. [16] found that adding different contents or sizes of natural fibers to PU foams resulted in significant impacts on the sound absorption performances. Most fundamental studies of acoustic behavior have been performed on open-cell PU foams, because these are the more widely used materials for acoustic absorption.

Polyethylene fiber is the most commonly used plastic polymer in the world, it can be used as a filler to make polyurethane composites. However, study on composite polyurethane foams mostly stays in its mechanical properties, and, as far as we know, detailed analysis of the acoustic absorption of these materials has not yet been carried out. So, the main aim of this work is to compare the acoustic response of PU foams with polyethylene fiber with those of conventional open-cell PU foams.

2. EXPERIMENTAL

2.1. Materials

PU foams were synthesized using isocyanate and polyether polyols or isocyanate and polyester polyols. The

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foams are blends of 29 % polyether polyols 3630 (OH-value: 33 – 37 mg KOH/g), 43 % polyether polyols 330 N (OH-value: 33 – 36 mg KOH/g) and 22 % modified isocyanate (MDI). A1, A33 and triethanolamine were used as catalysts, water was used for blowing agents. Silicone was selected as the foam stabilizer and surfactant in this study. The materials for preparing the PU foams were supplied by Guangzhou Yiju Chemical Company, China. Table 1 shows main components and properties of the foam.

The polyethylene fiber content of each PU foam is from 0.1 g to 0.6 g. Table 2 shows the parameter of polyethylene fiber used in this paper.

Table 1. Foam formulation and design

Main component	Content, g
3630	40
330N	60
MDI	30
Catalyst A1	0.05
Catalyst A33	1
Catalyst TEA	3
Silicone oil	1.8
deionized water	3
polyethylene fiber	0.1 – 0.6

Fig. 1. Sample foam used for testing

The materials, except for polyethylene fiber and MDI, were gradually weighed, added in a plastic cup, and then mixed and stirred uniformly using a mechanically driven mixer at a rotational velocity of 1200 rpm for 60 s.

Table 2. Parameter of polyethylene fiber

Fiber density	1.80 – 2.40 dtex
Length	6 mm
Monofilament diameter	5 – 20 μm
Elastic modulus	32 – 40 GPa
Tensile strength	1200 – 1500 MPa
Elongation at break	5 – 15 %

Then, polyethylene fiber was added and the mixture was stirred for 60 s. Finally, MDI was added and stirred for an additional 7 to 8 s. The mixture was poured rapidly into a rectangular mold. After curing at 50 °C for 2 hours, the foam was removed and aged for 24 h at room temperature. Fig. 1 shows the sample foams used for testing. Fig. 2 shows the process for preparing the PU foams.

2.2. Techniques

The airflow resistivity σ is determined from the flow measurements. A flow resistance apparatus is devised according to the American National Standards ASTM C522-03[17]. The sample is placed in a tube, and the pressure difference (ΔP) between two sides of the sample is formed by pumping or compressing, when a steady flow of air is established. The airflow (v) through the sample is measured and the differential pressure (ΔP) is obtained by the pressure measurement. The flow resistance is calculated by the following equation:

$$\sigma = \Delta P / v. \quad (1)$$

The samples were cylindrical discs with a diameter of 100 mm and thickness of 35 mm. Each sample was measured three times.

The porosity Φ is related to the amount of air in the porous material [18, 19]. The uniformity of pore distribution can affect the sound absorption property of the material. The porosity Φ was measured by the simple measurement device consisting of two 60 mL chambers and a U-tube (5 mm diameter) water manometer connecting them. Samples, with a diameter of 100 mm and thickness of 35 mm, were used and measured five times.

The mean cell size in each foam direction was estimated with the intersection method by SEM (ZEISS EVO18) micrographs [20]. The prepared PU foams were incised into samples and treated with a gold film sputter.

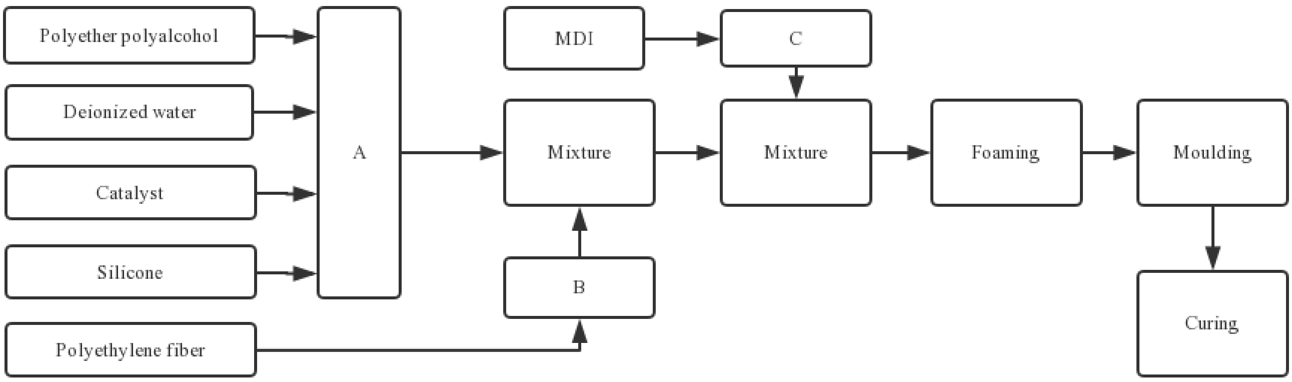


Fig. 2. Process for preparing the PU foams

The average cell size was computed as the mean value of the cell sizes in the three different directions. All foams were isotropic. The samples were slices of 50 mm^2.

The experimental methods according to ASTM E-1050 were used to determine the normal sound absorption performance. The standard test for impedance and absorption of acoustical materials of ASTM E-1050 is based on the standard ISO 10534-2:1998(E). This test method was applied to measure the sound absorption coefficients of absorptive materials at normal incidence. The sound absorption coefficient test was performed using a two-microphone impedance tube, also called the "transfer function method." The test was performed at room temperature (20 °C) under a relative humidity of 65 %. The sample diameter was 100 mm.

3. RESULTS AND DISCUSSION

3.1. Pore morphologies and characteristics

Fig. 3 shows the cellular structure of the standard PU foam and the PU foam with 0.1 g, 0.3 g and 0.5 g polyethylene fiber under magnification 50. The acoustic absorption properties of PU foams are related to the pore characteristics such as pore sizes and pore interconnections. So, morphological analysis for the cells is the first concern to understand sound absorption properties of the PU foam composites.

Generally speaking, the movement of sound waves into foam cell can cause the vibration of cell wall and cell interior air, and the sound energy can be converted to heat through the vibration attenuation of cell wall and air [21]. Larger cell sizes of PU foams can be obtained with addition of fillers, and the addition of fillers can cause the cell deformation and the transformation of sound energy [22]. As seen in Fig. 3, all PU foams shows edges, and most of the cell walls contain holes, which can be large or very small. When the polyethylene fiber was added to the polyurethane foam, the hole became larger. Moreover, the distribution of cells in pure PU foams are relatively uniform compared with that of PU foam with different content of polyethylene fiber. Polythene fibers do not participate in chemical reaction during foaming process of PU foams. The existence of polythene fibers causes the deformation of the cell structure. Therefore, the changes appeared in the microstructure of the PU foams.

3.2. Porosity and airflow resistivity

From Fig. 4, the addition of polyethylene fiber changed the porosity of PU foams. Generally, the sound absorption coefficient of the system improved with the increase of open porosity over the entire frequency range of 125 – 4000 Hz [21]. The porosity of pure PU foam is largest among the specimens. With the content of polyethylene fiber increasing, the porosity of PU foam composites tends to increase roughly. When 0.5 g polyethylene fiber was added, the porosity of PU foam composite is closest to pure PU foam.

In accordance with Fig. 3, the distribution of cells in pure PU foam is the most uniform, so it has larger porosity. PU foam with 0.5 g polyethylene fiber has larger holes in the microstructure than the others. Therefore, its porosity is closest to pure PU foam.

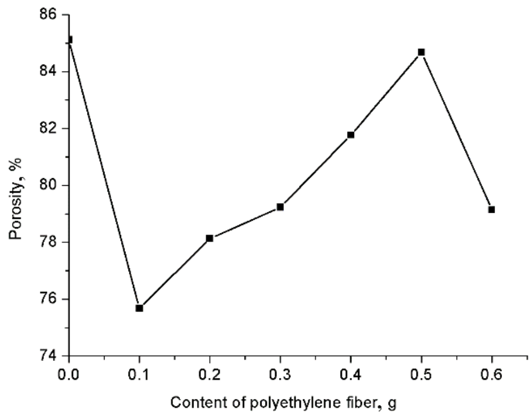
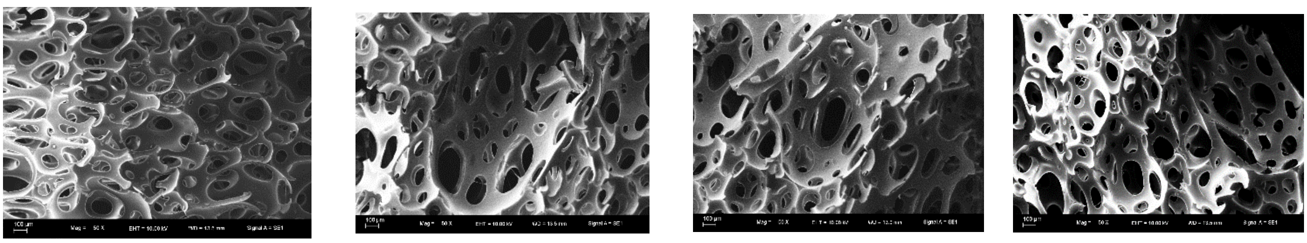


Fig. 4. Porosity of PU foams

Airflow resistivity is an important parameter that affects sound absorption characteristics. Appropriate airflow resistivity value leads to the best sound absorption performance. Generally, increasing the airflow resistivity can improve the sound absorption performance in the low frequency band [23].

Low airflow resistivity gets low sound absorption capacity in the low frequency. We can find the results of airflow resistivity of different fiber content specimens in Fig. 5. The addition of polyethylene fiber changed the airflow resistivity of polyurethane foams. The airflow resistivity of pure PU foam is lowest among the specimens while polyurethane foam with 0.2 g polyethylene fiber is highest. With the content of polyethylene fiber increasing, the airflow resistivity of PU foam composites tends to decrease roughly. When 0.6 g polyethylene fiber was added, the airflow resistivity of polyurethane foam composite is closest to pure PU foam.



a b c d

Fig. 3. a – microstructure of pure PU foam; b, c, d – PU foam with polyethylene fiber

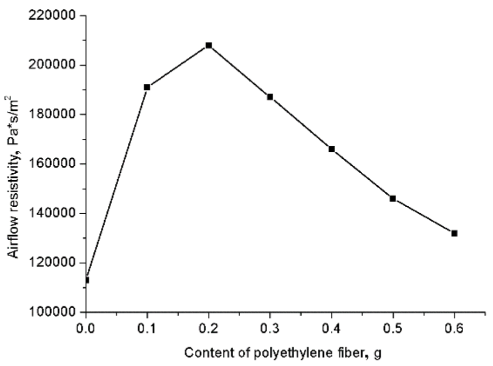


Fig. 5. Airflow resistivity of PU foams

3.3. Sound absorption properties

The pure PU foams were produced to make a comparison with PU foam composites. Fig. 6 shows the sound absorption coefficient curves for the PU foams with varying polyethylene fiber contents. Generally, the sound absorption property of porous materials is related to the interior pore sizes and pore interconnections. The sound waves lead to the vibration of the cell walls and air inside pores. Then, the sound energy dissipates or converts to the heat through vibration damping of the cell walls and viscidity damping of the air. Obviously, adding polyethylene fiber can affect sound absorption properties of PU foams.

The specimens show similar trends in Fig. 6. The main absorptions have values of approximately 0.1 – 0.6 around 100 – 800 Hz, 0.5 – 0.8 around 1250 – 3150 Hz. For higher frequencies (5000 – 6300 Hz) the absorption coefficient remains around 0.65 – 0.9.

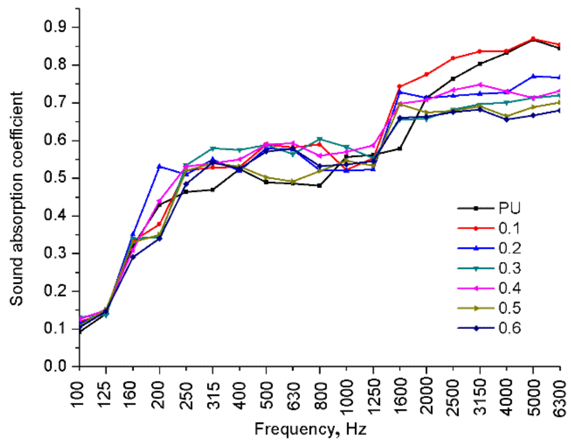


Fig. 6. Curves of sound absorption character of the PU foams

From Fig. 6 we can see that with increasing polyethylene fiber content, obvious increase in the absorption coefficient was observed in the low frequency range (100 to 800 Hz). However, the absorption coefficient gradually decreased in the high frequency region 2000 – 6300 Hz. When 0.2 g polyethylene fiber was added into the PU foam composite, the sound absorption coefficient is best especially around 125 – 315 Hz. The acoustic absorption coefficient of the foam with 0.1 g polyethylene fiber is obviously higher than that of the rest of the composites in the higher frequency range, particularly in the range 2000 – 6300 Hz.

4. CONCLUSIONS

In this study, flexible PU foams with varying polyethylene fiber contents (0.1 g to 0.6 g) were synthesized to improve sound damping and absorption. To investigate the effect of the additive components on the sound absorption of the foams, the correlations between the contents of additive components and absorption coefficients were studied. The two-microphone impedance tube was applied to measure the sound absorption. Adding polyethylene fiber as fillers into PU foams can achieve a noticeable improvement of sound absorption properties, especially in low-frequency region (100 – 630 Hz). It has been found that the PU foam composites with 0.1 g polyethylene fiber possess an optimal sound absorption ability. It has a higher sound absorption coefficient than pure PU foam. It should be noted that it is difficult to enhance the sound absorption property in low frequency region without increasing the thickness of the material. It suggests that adding polyethylene fiber can improve the sound absorption properties of PU foams especially in the low frequency region. And less additive components give better sound absorption within the specified polyethylene fiber contents range. Addition of polyethylene fiber may create more paths for passing sound waves into foams and further increase the transformation of sound energy into heat. Further study is needed for further explanation of sound attenuation behavior in low frequency region. The results can provide guidance for future design of low frequency acoustic materials.

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