1. Introduction

The rapid development of urbanization and industrialization is accompanied by inevitable noise pollution problems [1–2]. According to a report of the World Health Organization (WHO), noise pollution not only affects human auditory system, but also leads to abnormal fluctuations of physiological indicators, which can even cause memory decay, nervous tension, hypertension, heart disease and so on [3–4]. Thus, it is necessary to take some effective measures to reduce the noise pollution [5].

One of the most effective measures to prevent and control noise pollution is to use sound-absorbing materials, and the materials with a high sound-absorbing ratio are usually porous [6]. The micro pores in the internal structure of sound-absorbing materials interconnect with one another and connect with the surface of materials. When noise wave propagates to the material’s surface, one part of the sound wave passes through the micro pores on the material’s surface and then transmits between micro pores and gaps, whereas the other part is reflected on material’s surface. The gas vibration caused by noise

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can generate frictional resistance and viscous resistance in the pore walls of the porous material, which can reduce the sound energy, and then achieve the purpose of reducing noise [7‒11]. Ultimately, sound energy is converted into mechanical energy and heat energy, and a sound-absorbing effect of the materials is achieved.

Porous sound-absorbing materials can be classified as cellular, granular and fibrous materials based on the micro structure. Aerogel is a commercial material based on silica with extremely small pores. It could serve as a good sound-protection material due to its nanoporous structure [12]. Unfortunately, the application of aerogel is expensive due to the complicated production process. Commercial polyethylene terephthalate (PET) nonwovens are widely used as acoustic materials due to their low cost, light weight and good sound-absorbing effect [13‒14]. However, PET nonwovens have a defect of sound absorption coefficient in low frequency region due to the thick diameter of the fiber [15].

A research had showed that nanofibers exhibit better sound-absorbing property than commercial PET nonwovens fibers due to their large specific surface area and porosity [16]. Electrospinning technology is a simple and low-cost method for preparing nanofibers [17]. The polystyrene (PS) porous fibers prepared by electrospinning have great potential application in sound absorption [18‒22], which mainly utilize the friction between sound wave and micro pores in membranes, the interaction between fibers and resonance with membranes to absorb noises [23‒24]. Moreover, the surface morphology of the PS nanofibers can be adjusted by varying the volume ratio of the solvent [25]. However, the PS fibrous membranes in sound absorption applications require a substrate. Thus, composite materials with low cost, usability, high sound-absorbing efficiency and excellent usability need to be developed.

This work aims to prepare the composite sound-absorbing materials using PS fibrous membranes as functional sound-absorbing materials and needle-punched PET non-woven fabrics used as the core fabrics by using advanced electrospinning technology. The scanning electron microscopy (SEM) was used to characterize the micro morphology and the diameter of the composite sound-absorbing materials. The pore size and porosity were calculated to analyze the sound-absorbing mechanism. In addition, the sound-absorbing property of the composite materials was tested by the transfer-function method.

2. Experimental

2.1 Materials

Polystyrene (PS, Mw=2.5×10^5, Mn=1.1×10^5, Mw/Mn=2.27) was purchased from Guoheng Chemical Co. Ltd. (Zhenjiang, China). N, N-dimethyl formamide (DMF) and tetrahydrofuran (THF) were purchased from Komeo Chemical Reagent Co. Ltd. (Tianjin, China). The sound-absorbing PET nonwovens were purchased from Xingyuan Environmental Material Co. Ltd. (Jilin, China), which were fabricated by needle-punching and then thermal calendaring of carded PET staple fibers’ web. The fibers length of the needle-punched PET non-woven fabrics is 47 mm-60 mm, and the fiber diameter of the needle-punched PET non-woven fabrics is 45 µm-60 µm. All agents were used without further purification or processing.

2.2 Electrospinning

PS solution (20 wt%) with THF and DMF (v/v: 100/0, 95/5, 85/15, 75/25, 50/50, 0/100) as solvent was prepared and stirred magnetically at room temperature for 12 hours. The solution was then placed in a 5 ml syringe with a metal needle (inner diameter of 0.5 mm), which was connected to a high-voltage (20 kV) direct-current power supply (JDF-1, China). A pump (789100C, Cole-Parmer, USA) was utilized to control the flow rate of solution at 1 ml/h. The receiving plate was grounded and the distance from the tip of nozzle was fixed at 15 cm. The above experiments were carried out at 25 °C with controllable relative humidity (25%‒55%). The electrospun fibers were collected and then dried in vacuum overnight, so that the solvent in fibers could be fully volatilized. Low-melting PET fibers are important materials for the production of non-woven fabrics due to the excellent thermal bonding property and stable processability. The low-melting PET fibers can be melted at a relatively low temperature (100–150 °C) and then bonded with other fibers. In this work, the low-melting PET fibers were placed between electrospun PS fibrous membranes and needle-punched PET non-woven fabrics, and then put the materials into an oven (130 °C). The needle-punched PET non-woven fabrics combined with the electrospun PS membranes through thermal bonding.

2.3 Morphological Characterization of Fibers

The morphology of the electrospun fibers were

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observed by scanning electron microscopy (SEM, JSM-7800 F, JEOL Ltd. Tokyo Japan) at 15 kV. Samples were sputter-coated with gold for 60 s before examination. At least 60 fibers were measured by Image J software, and further analyzed through Origin software.

2.4 Pore size and porosity

The pore sizes of as-spun fibrous membranes, needle-punched PET nonwovens and their hybrids were measured by capillary flow porometer (CFP-1100-AI, PMI Porous Materials Int., USA). Each sample was randomly selected to test three times in order to ensure repeatability. The porosity evaluated by the following equation [26]:

\[ n_1 = \left(1 - \frac{m}{\rho - \delta}\right) \times 100\% \]  

Where \( n_1 \) is porosity (%), \( m \) is surface density (g/m\(^2\)) of sample, \( \rho \) is density of materials (g/m\(^3\)), \( \delta \) is the thickness (m) of the sample.

The porosity of the hybrid could be calculated by the thickness ratio of two materials and porosity of single component materials [27].

\[ n_3 = \frac{n_1 \cdot L_1 + n_2 \cdot L_2}{L_1 + L_2} \times 100\% \]  

Where \( n_1 \), \( n_2 \) and \( n_3 \) were the porosities (%) of the electrospun membrane, needle-punched nonwoven and their hybrid respectively. \( L_1 \) and \( L_2 \) were the thicknesses of electrospun membranes and needle-punched nonwoven respectively.

2.5 Sound absorption test

The sound-absorbing performance of samples were tested with transfer-function method basing on ISO 10534-2. The instruments about this testing were SW477 and SW422 impedance tube (BSWA Technique Company, Beijing, China) under ambient temperature 20±1°C, relative humidity 65±2%. There was a power amplifier that provides a signal to a speaker, and the speaker released a sound toward the test sample. Two microphones placed at a fixed distance between the speaker and the sample, which consisted of a long (99.8-mm-diameter impedance tube) and a short tube (30.4-mm-diameter impedance tube). The impedance tubes were used to measure the acoustic absorption 5 times for each sample in the range of 80-6300 Hz. The average sound absorption coefficients were calculated from the sound-absorbing coefficient at 125, 250, 500, 1000, 2000 and 4000 Hz.

3. Results and discussions

3.1 Morphology of electrospun PS fibers membranes

3.1.1 Effect of solution concentration on morphology

The concentration of polymer solution is the main factor affecting the morphology of electrospun fibers [28]. Fig. 1 shows the SEM images of PS (\( V_{THF}/V_{DMF} = 0/100 \)) fibers under different PS concentration. When the solution had low concentration and viscosity, there was no or insufficient entanglement among molecular chains to support the extension of the jet, so the polymer tended to shrink and solidify to form beads due to the viscoelastic effect of molecular chains, as shown in Fig. 1 (a)-(b). With the further increase of solution concentration and viscosity, a string of beads was gradually formed in the structure of fibers because of increased entanglement among molecular chains [29]. When the concentration of the solution continued to increase, there was sufficient entanglement among the molecular chains. The motion of spinning jet changed from one-dimensional linear motion to three-dimensional helical motion and the electric force acting on the jets became more uniform, eventually the jets solidified to form uniform fibers. It was found that the obtained fibers were bead-free and uniform at the solution concentration of 20% and 25 % w/v.

![Fig. 1 The SEM images (\( V_{THF}/V_{DMF} = 0/100 \)) of fibers with different PS concentration (PS (w/v) a, a'-10%; b, b'-15%; c, c'-20%; d, d'-25%)](image-url)
different mixing ratios of THF/DMF. The viscosity, surface tension and conductivity increased and the diameter of fibers decreased with the increase of DMF. As Fig. 2 shows, the electrospun fibers with THF as the only solvent had a beaded structure at relative humidity of 25%. When the mixing ratio of THF/DMF was 50/50, the grooved structure began to appear on the surface of uniform fibers. Moreover, the grooved structure became more obvious with the single solvent of DMF. Therefore, the morphology and structure of electrospun fibers are related to the evaporation of the solvent, conductivity and the variation of the viscosity. The volatility of solvent affected the stability and continuity during the electrospinning process. Because of the rapid evaporation of solvent, the Taylor cone formed at the tip solidified quickly, which can cause the blockage at the tip. However, reducing the volatility of the solvent was beneficial to maintain the fluidity of jet to form fibers with uniform structure in the electric field [30]. Therefore, the structure of the fibers can be controlled by changing the ratio of mixed solvent.

Moreover, the surface tension and viscosity of the solution also affect the spinnability and the resultant morphology of fibers. During electrospinning, high voltage chargers were applied on the polymer solution to overcome the surface tension, which has been attributed to the formation of beads on electrospun fibers. Therefore, the decrease of surface tension will lead to more smooth fibers. Meanwhile, the increase of viscosity means higher amount of chain entanglement in the solution, and thus leads to the increase of fiber diameters [31]. In our study, the viscosity decreased while the surface tension increased with the addition of DMF, as shown in Table 2. From the morphology of the resultant fibers, the applied voltage was not high enough to stretch the solution with THF alone as solvent, and lead to the formation of string beads in the resultant fibers. When incorporating of DMF in the solvent, the viscosity decreased which means better fluidity of the solution and the resultant fibers became smoother. The conductivity of polymer solution influenced the fibers morphology directly, which was concerned with the ability to carry electric charge. The charged density on the surface of jet increased gradually with the increase of solution conductivity, then the effect of electric field on the jet also increased, consequently the fibers changed from beaded to linear. The conductivity of the solution could be controlled by regulating the ratio of solvent. Owing to higher conductivity of DMF, with the increase of its content, the conductivity of the solution increased concurrently and then the electrospun fibers became

![Table 1](attachment:image1.png)

**Table 1** The property of 20% PS (w/v) solutions (25°C).

| V<sub>THF</sub>/V<sub>DMF</sub> | Viscosity (mPa·s) | Surface tension (mN·m<sup>-1</sup>) | Conductivity (µs·cm<sup>-1</sup>) |
|-----------------------------|-------------------|-------------------------------|-------------------------------|
| 100/0                      | 362.00±0.82       | 29.13±0.33                    | 0.001±0.03                    |
| 50/50                      | 342.67±0.67       | 32.27±0.21                    | 0.447±0.02                    |
| 0/100                      | 301.00±0.82       | 37.87±0.21                    | 0.639±0.03                    |

![Fig. 2](attachment:image2.png)

**Fig. 2** The SEM images and size distribution of 20% (w/v) PS fibers with different solvent (a, a’ and a’’- V<sub>THF</sub>/V<sub>DMF</sub>= 100/0; b, b’ and b’’- 50/50; c, c’ and c’’- 0/100)
uniform, thinner and un-beads. The average diameter of PS fibers using THF/DMF 50/50 as solvent was 2.55 micron, while the average diameter of PS fibers using DMF was 1.1 micron, as shown in Fig. 2. Thus, the increase of DMF content could lead to the increase in the conductivity. Moreover, the increase of conductivity can enhance the draft force and promote uniform fibers.

3.1.3 Effect of environmental relative humidity on morphology

The apparent structure of fibers could be changed by the environmental relative humidity [32]. The experiment was generally carried out in the air environment, in which abundant vapor evenly distributed in the form of mist-like nanoscale droplets. The environmental humidity reflected the content of water vapor in air and therefore the bulk density of micro-droplets increased in high humidity.

To investigate the environmental relative humidity on the morphology, THF was chosen as the only solvent and the electrospun process was conducted under different relative humidities. As shown in Fig. 3, the surface of fibers was smooth; and then the fibers began to appear micro-pits on the surface with the increasing of humidity. And the depression part transformed into deep pores which were evenly distributed on the surface of fibers with the humidity increasing to 45%, meanwhile the diameter and depth of the pores also increased, ultimately some circular pores developed into irregular elliptical pores that took up more space, and the porous structure distribution on the fibers surface became less uniform. Comparing with the morphology of fibers under different humidity, it was found that the optimal humidity for forming porous fibers was 45% because the pores on the fibers surface were round and the overall distribution was relatively uniform in this condition.

The formation of pores on the fibers requires appropriate environmental humidity and high volatile solvent. The main mechanisms of pores formation can be attributed to the breath figures and vapor induced phase separation. When the jet of solution from the nozzle travels towards to the collector, the water from the environment condenses on the surface of the fiber and further leave an imprint. Moreover, water in the air, as the nonsolvent will induce the phase separation of the mixture of PS and THF. With the evaporation of THF, pores formed on the surface of fibers.

3.1.4 Optimum parameters to produce porous microfibrous membrane

The porous surface structure can be obtained under the relative humidity of 45% with THF as solvent, however, the nozzle was easy to be blocked due to the high volatility of THF, and thus to influence the continuity. Therefore, DMF was added to reduce the volatility of the solvent and improve its conductivity. The effect of DMF content in the mixed solvent on porous structure was investigated at relative humidity of 45%. It was found in Fig. 4 (a) that the flat and ribbon-like fibers were formed; meanwhile the surface was covered with dense pores of small diameter when the ratio of THF/DMF solvent was 95/5. When the ratio of THF/DMF solvent was 85/15, the fibers changed from the ribbon-like to the cylinder-like shape. The larger pores evolved from the
circle-like to the ellipsoidal shape, and were evenly distributed. Furthermore, when the mixing ration of THF and DMF was 75/25, the fibers had obvious folds without porous structure that the surface formed huge gullies looking like barks. In conclusion, the optimum experimental condition of electrospun polystyrene fibers with porous surface was the humidity 45%, and the ratio of THF/DMF was 85/15.

3.2 Pore size and porosity Analysis

The pore size and porosity of the electrospun PS (20% w/v, V<sub>THF</sub>/V<sub>DMF</sub>=85/15) fibrous membranes, needle-punched PET nonwovens, and their hybrids were also analyzed and summarized in Table 2. From the pore size test, the average pore size of electrospun PS fibrous membranes was 4.45 μm with range of 0.48-9.05 μm. Meanwhile, high porosity of 93.8% leads to superior porous structure, and thus had good prospects for application in the field of sound absorption [33]. The fibers interconnected to form porous structure that can increase the consumption of sound energy during the sound wave transmission, and thus it can be beneficial for enhancing the sound-absorbing performance. Compared with the electrospun PS fibrous membrane, the average pore size of commercial needle-punched nonwovens was larger, which was 28.26 μm and the pore size ranged from 2.01 to 95.27 μm. However, when the electrospun PS fibrous combined with the needle-punched nonwovens and formed the hybrid, the average pore size became closer to that of electrospun PS layer, which was 3.68 μm and the pore size ranged from 0.46 to 6.77 μm. Meanwhile, the bubble point, which refers to the largest pore, was smaller than that of electrospun PS membrane. The pore size of electrospun PS layer focused in the range of 0.48-2 μm, while that of needle-punched PET nonwovens focused in the range of 2-15 μm. It’s interesting to find that the pore size of the hybrid focused in the range of 0.46-2 μm. Therefore, the pore size and distribution of the hybrid were closer to those of electrospun PS layer, while the porosity of the hybrid was similar to that of the needle-punched nonwovens.

The mechanism of the enhanced sound absorption is related to the fact that in the process of transmission, sound waves were blocked by membranes materials with dense porous structure before it passed through the substrate. Some of waves were directly reflected by electrospun membranes within superfine pore size, and others would be dissipated. The sound-absorbing performance of the substrate itself could be improved, because the electrospun high porosity fibers greatly depleted the kinetic energy of air molecules moving along with the sound waves.

3.3 Sound-absorbing performance

Sound-absorbing coefficient is a quantity describing the sound absorption ability of sound-absorbing materials, which can be expressed as a percentage ratio of the absorbed sound wave and the incident sound wave. Sound waves can cause the vibration of resonant microfibers. Some of the acoustic energy is converted into kinetic energy to vibrate the membrane, and the other ultimately dissipated in the form of thermal energy because the acoustic wave is suppressed by the blocking effect of the membranes in the process of transmission in the impedance tube.

3.3.1 The influence of film’s thickness on sound-absorbing performance

In order to explore the electrospun fibrous membranes in sound absorption, commercial PET sound-absorbing nonwoven with thickness of 10 mm, which was manufactured by needle-punching and selected as the base material. The PS fibrous membranes were evenly superimposed (thickness gradient was 0.4 mm), then exploring the influence of electrospun PS layers’ thickness on sound-absorbing properties of substrates was studied. Fig. 5 (a) shows the photo of the hybrid and Fig. 5 (b) presents the sound absorption coefficients of the hybrids varying with the thickness of electrospun PS membranes. Table 3 summarizes the average values of the sound-absorbing coefficient of different hybrids with different thickness. As the Fig. 5 (b) shows, the trend of sound-absorbing coefficient of base material, i.e. needle-punched PET nonwovens increases gradually from the low frequency to the high frequency. However, the average sound-absorbing coefficient is

| Sample type                        | Average pore size/μm | Range of pore size/μm | Porosity (%) |
|------------------------------------|----------------------|-----------------------|--------------|
| PS membrane                        | 4.450                | 0.48-9.05             | 93.8         |
| Needle-punched PET SAN             | 28.26                | 2.01-95.27            | 81.7         |
| PS(0.8 mm) + Needle-punched PET SAN| 3.68                 | 0.46-6.77             | 82.8         |
just 0.188, thus showing poor sound-absorbing property. As Fig. 5 (b) shows, the sound-absorbing performance of the hybrid was improved especially in high frequencies when the thickness of as-spun PS layer on the needle-punched was 0.4 mm. The resonance absorption peak of hybrid reached up to 0.97 at the frequency of 3150 Hz. The vibration of air molecules in porous materials was driven by sound waves propagating in medium. Energy transfer in nature followed the law of energy conservation. Furthermore, during the process of diffusion, sound energy was converted into kinetic energy of porous materials with the vibration of air, and finally consumed along with viscous friction and heat conduction. At low frequencies, these energy losses were isothermal and limited (resulting in low sound absorption at low frequencies), while at high frequencies, they were adiabatic and generally more important [34]. Therefore, electrospun membranes showed excellent property of sound absorption at medium and high frequency. Meanwhile, the average sound-absorbing coefficient of hybrid was 0.335, which could achieve high performance in sound absorption.

Subsequently, the thickness of the electrospun fibrous membranes was further increased. It could be found that the absorption peak shifted gradually from high frequency to low and intermediate frequency which increased sharply but keeping almost invariable peak value, as shown in Fig. 5 (b). The sound-absorbing coefficient of the hybrid increased to 0.43, which was 2.3 times of the base material, when the thickness of electrospun membranes was 2.0 mm. Sound absorption curve of hybrid materials showed that the general trend of sound-absorbing coefficient increased with the increase of frequency, changed gradually from low frequency to high frequency and appeared resonance absorption peaks and fluctuations in intermediate frequency [35]. Electrospun PS fibers belonged to ultrafine fibers due to the diameters in micron. So incident sound waves can pass through electrospun layers because of high porosity. Lower diameter of fibers caused more friction between surface of electrospun fibers and sound waves. The narrower width of the channels between fibers was the more loss of sound energy in viscous and thermal boundary layers. Within the certain scope, the sound-absorbing coefficient of the multilayer electrospinning microfibers network was higher than that of the regular fibers under the same weight. With the increase of specific surface area, the probability of interaction between sound absorbing materials and sound wave increased. More chances for contact meant more loss of sound energy by the friction and vibration of the internal fibers. Therefore, the microfibrous membranes had high sound-absorbing properties, because of the high specific surface area, viscous friction in micro pore and vibration of microlayer.

On the other side, from the above study of pore size, the hybrid's pore size was much smaller than that of needle-punched nonwovens, then the air flow resistance of the hybrid increased, the permeability decreased accordingly and acoustic energy attenuated substantially in the process of transmission. Therefore, the sound-absorbing performance had been significantly improved after composing the base materials and electrospun membranes. Moreover, increasing the thickness of

![Fig. 5](image)

**Fig. 5** Photo (a) and sound absorption coefficient (b) of the composite sound-absorbing materials

| Thickness of PS membranes | 0 mm | 0.4 mm | 0.8 mm | 1.2 mm | 2.0 mm |
|---------------------------|------|--------|--------|--------|--------|
| Average sound-absorbing coefficient | 0.188 | 0.335 | 0.343 | 0.395 | 0.430 |

**Table 3** The average sound-absorbing coefficient of basement after combining with different thickness PS membranes.

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Electrospun membranes could increase the acoustic resistance of materials [36‒37]. With the increase number of electrospun membranes layers, the number of perfoliate pores decreased, which caused the impedance of sound wave increased in the process of transmission. Acoustic energy dissipated in the form of internal energy with the vibration of microfibers, so that the residual acoustic energy decreased. Therefore, compound commercial sound-absorbing needle-punched PET and microfibrous membranes, the sound-absorbing properties of the hybrids will be significantly improved with the increase of layers or surface density of microfibers. Abdelfattah et al [38] showed that the sound-absorbing coefficient of materials was in direct response to the gram square meter. The tiny gram square meter was determined by highly porous structure of electrospun membranes. With the thickness of electrospun PS membranes in hybrid increasing, the sound-absorbing performance of hybrid had been significantly improved, while the gram square meter of hybrid increased insignificantly.

### 3.3.2 The influence of porous structure on sound-absorbing performance

Fig. 6 showes that the different ratio of solvent caused the change of hybrids about sound-absorbing performance. It was because that the fibrous structure of hybrids could be controlled by changing the ratio of THF and DMF at 45% relative humidity. With the increasing ratio of THF, it was obvious that the absorption peak shifted left from 2000 Hz to 1250 Hz and the sound-absorbing coefficient of hybrids remained steady at high frequency. This was mainly because the surface roughness of fibers increased gradually with the ratio of THF increasing. In other words, the fibers surface changed from slight fold (Fig. 2 (c)) to obvious fold (Fig. 2 (b)) and then to dense hole (Fig. 4 (b)) morphology. It was beneficial to improve fibers original sound-absorbing performance by increasing the specific surface area of the fibers. Table 4 compares the average sound-absorbing coefficient about three kinds of hybrids with the membranes thickness of 1 mm or 2 mm using different reagents. The largest average coefficient of sound-absorbing was acquired by stacking the porous fibrous membranes ($V_{THF}/V_{DMF}$=85/15, 45% RH) and substrate. The average sound-absorbing coefficient of hybrid including 1 mm porous fibrous membranes was 0.438, which was 24% higher than for the hybrid of the same thickness including electrospun membranes made by the solvent of DMF solvent. Similarly, when the thickness of membranes was 2 mm, the average sound-absorbing coefficient of the hybrid including porous fibrous membranes was 0.468, which was 13% more than when smooth membranes were used ($V_{THF}/V_{DMF}$=0/100, 45% RH). The analysis above suggests that the average sound-absorbing coefficient increased with the rise of THF ratio increasing within an appropriate range, when the hybrids were under the same thickness.

The evidence from this study suggested that it had a significant positive effect on improving the sound-absorbing performance by controlling the porous structure of the fibers. The porosity and the specific surface area were increased due to the porous structure, accordingly the opportunity for sound waves contacting with materials was increased. For this reason, sound energy was more easily dissipated with the vibration of sound waves passing through the pores. Consequently, the sound-absorbing performance of the porous fibers was better compared to the fibers without pores.

### 4. Conclusion

Electrospun fibrous membranes with the characteristics of high specific surface areas and porosity, small diameter and pore size have tantalizing application prospect in sound absorption. The electrospun PS membranes can enhance the sound absorption of commercial needle-punched PET.
nonwovens. The sound-absorbing performances in the medium and high frequency range were improved when the thickness was less than 0.8 mm. With the further increase of thickness, the sound-absorbing capacity was enhanced at low-medium frequency. To sum up, the main reason could be thinner fibers’ diameter resulting in large surface area, smaller pore size leading to the increase of airflow resistance, as well as the more thickness increasing the acoustic resistance. Therefore, combining the electrospun PS with commercial sound-absorbing nonwovens was an effective way to improve the sound-absorbing property, especially in the low and medium frequency range.

In addition, porous fibers can be prepared by controlling the humidity and mixed solvent to change its morphology and microstructure. The porous fibers could further improve the sound-absorbing performance of the fibrous membranes because of their high specific surface area. The materials composed by the electrospun membranes have great application prospects in transportation, aeronautics and astronautics, because the improved sound-absorbing performance was achieved while minimizing the materials’ weight due to the very high porosity. Our method is very simple and effective to improve the sound-absorbing performance of substrate by combining the sound absorbing substrate with electrospun membranes and it has excellent application prospects in sound absorption.

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