

Application of electrospun nanocomposites on removal of harmful substances

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Nanomaterials and nanotechnology will undoubtedly become core materials and technologies in advanced materials and technologies. In recent years, nanomaterials and nanotechnology have been widely used in environmental restoration due to their low cost, high efficiency, and other advantages. In this study, the high-performance polyurethane/rare earth (PU/RE) composite nanomaterials were fabricated via electrospinning. The electrospun nanomaterials for adsorption of volatile organic compounds (VOCs) in air was thoroughly investigated. The PU nanofiber containing 50 wt. % RE powder had the smallest fiber diameter of 356 nm; it also showed the highest VOC absorption capacity compared with other composite membranes, having an absorption capacity about three times greater than pure PU nanofibers.

Electrospinning

Nanocomposites

Volatile organic compounds

Polyurethane

1. Introduction

Volatile organic compounds (VOCs) are numerous, varied, and ubiquitous, and they are one of the sources of air pollution. VOCs can be categorized according to their chemical structures: alkanes, aromatic hydrocarbons, esters, aldehydes, alcohols, ethers, and amides ^[1]. There are about 300 different kinds of VOCs; most day-to-day activities lead to the production of VOCs, such as driving, cooking, building, decorating, painting, and even face-painting ^{[2][3][4]}. A high concentration of VOCs can easily lead to acute poisoning, lightheadedness, headache, dizziness, coughing, nausea, vomiting, and liver poisoning, and can even induce a coma. Benzene and formaldehyde are the most common carcinogenic and highly toxic pollutants in VOCs and they can quickly damage the human respiratory system ^[1]. Therefore, it is important to effectively reduce the content of VOCs in the air, and finding a way to control and reduce the content of VOCs in air has attracted attention for a long time.

Electrospinning is a fiber production method that provides a straightforward yet versatile approach for the convenient preparation of continuous fibers ^{[5][6][7][8]}. It has been widely applied to various fields, such as artificial skin, bandages, bulletproof clothing, battery electrolytes, sensors, and hierarchically structured fibrous composites ^{[9][10][11][12]}. Rare earth (RE) materials, 'the Vitamins of Modern Industry', play an important role in industrial development. Smelting and separation of RE raw materials can be accomplished and used for energetic materials, luminescent materials, grinding materials, environmental protection materials, and permanent magnetic materials ^[13].

Therefore, in this study, we investigated the combined characteristics of RE and polyurethane (PU) and their VOC adsorption capacity using the electrospinning technique. The morphology and components and mechanical properties were thoroughly investigated. A certain amount (up to 50 wt. % compared to PU pellets) of RE nanoparticles (NPs) could be loaded on/into PU fibers.

2. Experimental Details

2.1 Materials

Polyurethane (PU) pellets (Estane® Skythane® X595A-11) were purchased from Lubrizol Advanced Materials, Inc., Cleveland, OH, USA, and were used as the polymeric matrix. RE powder were purchased from ZIBO WEIJIE RARE EARTH CO., LTD, Zibo, China. *N,N*-Dimethylformamide (DMF) was purchased from Showa Chemical Co., Ltd., Tokyo, Japan. Extra pure methyl ethyl ketone (MEK, 2-butanone) was purchased from Junsei Chemical Co., Ltd, Tokyo, Japan. In VOCs absorption experiments, five different kinds of gases (styrene, xylene, chloroform, benzene, and toluene) (purity 99.9%, AR grade) were analyzed.

2.2 Fabrication of Composite Nanofibrous Membranes

The fabrication process of PU/RE nanofibrous membranes is given as follows. First, the PU pellets were dried (constant temperature: 80 °C) for about 3 h in a dry oven before dissolving them in the solvent. Second, 10 wt. % PU pellets were dissolved in a DMF/MEK (50:50 by weight) mixing solution, using a magnetic stirrer dissolved for 12 h at room temperature. Then 0, 10, 30, and 50 wt. % (compared to PU pellets) RE powders were added into above the solution as electrospun precursors via ultrasonication for 2 h. The process of electrospinning is shown in Figure 1. The electrospun temperature and relative humidity are constantly controlled at 23 ± 2 °C and 40%–50%, respectively. All PU/RE spinning solutions were electrospun at 15 kV of high-voltage electricity with an 18 cm tip-to-collector distance, the rotating speed of the rotating collector was 650 rpm, and the solution feed rate was 1 mL/h.

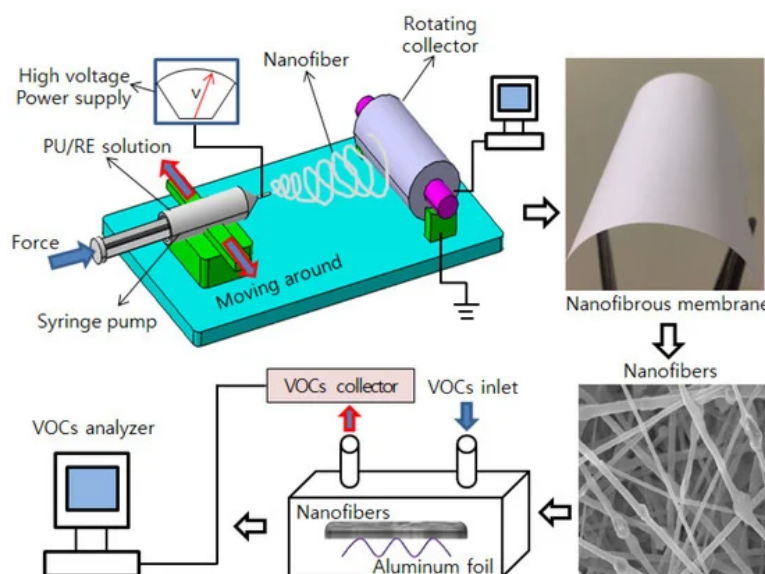


Figure 1. Schematic diagram of the electrospinning setup and volatile organic compounds (VOCs) absorption experiment.

3. Results and Discussion

3.1 Physical Properties of Spinning Solutions and Properties of PU/RE Fiber

The electrospinning effect and VOC adsorption capacity of the PU/RE nanofibrous membranes were determined by the physical properties of the spinning solutions and the properties of the PU/RE composite nanofibers. The specific surface area was measured by the N₂ adsorption-desorption isotherms test via the Brunauer–Emmett–Teller (BET) method. It was found that the viscosity, conductivity and specific surface area increased by increasing the amount of RE powder in the spinning solution. However, the fiber diameter first increased from 489 nm to 524 nm and then decreased from 524 nm to 356 nm when the relative content of the RE powder reached 50 wt. %. The PU nanofiber containing 50 wt. % of the RE powder had the smallest fiber diameter, which was 356 nm.

3.2 Morphological Characteristics of the PU/RE Nanofibrous Membranes

Figure 2 shows the morphology and the fiber diameter distribution of the composite PU/RE nanofibrous membranes. From Fig. 2a–d, it was observed that the changes of the fiber morphology and fiber diameter distribution correlated very closely with the increasing amounts of RE powder in the PU fibers. The pristine PU fibers had smooth surfaces and an average fiber diameter of 489 nm. However, it was found that there were a lot of RE NPs embedded in the PU fibers, and the number of RE NPs increased with an increased concentration of RE powder (Fig. 2b–d). In addition, some particle agglomeration existed in Fig. 2d because higher concentrations of RE powder cannot be completely dispersed into the spinning solution. Fig. 2e–h show the average fiber diameters of the PU, PU/RE-10, PU/RE-30 and PU/RE-50 nanofibrous membranes, which were 489, 513, 524 and 356 nm, respectively. Each of the reported PU/RE nanofibers' diameters represents an average of 50 random fibers. The fiber diameters increased slightly as the amount of RE powder increased from 0 to 30 wt. %, and then showed a marked decrease when the relative amount of RE powder was 50 wt. %. The PU/RE-50 possessed the smallest average diameter of 356 nm.

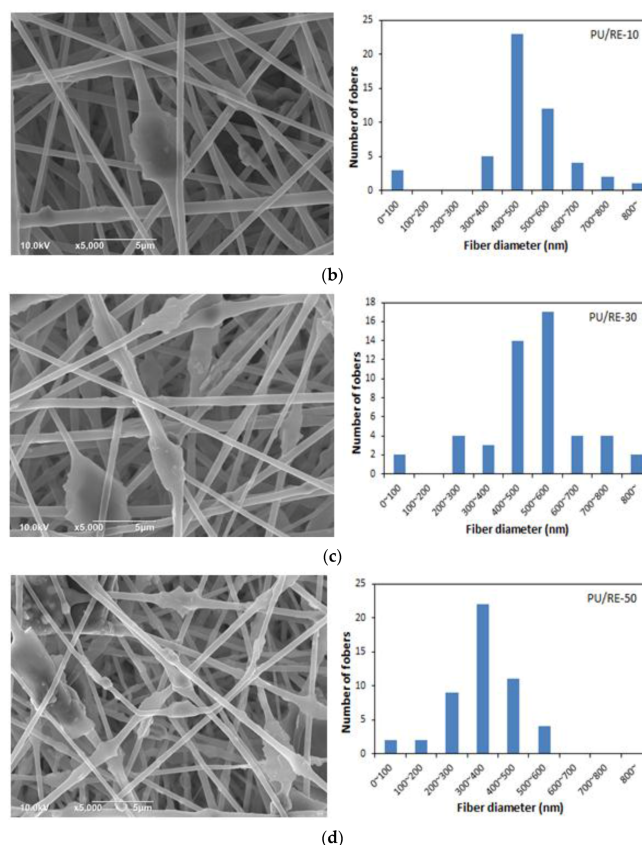


Figure 2. FE-SEM images and diameter distributions of (a) polyurethane (PU); (b) PU/RE-10; (c) PU/RE-30 and (d) PU/RE-50.

3.3 Absorption Characteristics of the Composite PU/RE Nanofibrous Membranes

The VOC absorption characteristics of the PU nanofibers containing different amounts of RE powder (0 wt. %, 10 wt. %, 30 wt. %, 50 wt. %) are shown in Figure 3. As shown in Fig. 3, it can be seen that the pure PU nanofibrous membrane had a weak VOC absorption capacity (about 10%), while the pure RE powder had a better VOC absorption capacity compared with the pure PU nanofibrous membrane. However, the RE powder will limit its usability. To integrate the merit and eliminate the defect of both PU and RE, the RE-incorporated PU fibers were electrospun before the VOC absorption experiment. The VOC absorption capacity of the composite PU/RE nanofibrous membranes increased as the amount of RE powder in the PU fibers increased. The PU nanofiber containing 50 wt. % RE powder had the highest VOC absorption capacity. In addition, the absorption capacity of the PU nanofiber containing 50 wt. % RE powder increased by 320%, 210%, 208% and 187% compared with that of the pure PU nanofibrous membrane during the absorption of styrene, xylene, toluene, benzene and chloroform, respectively. This may be due to the decreasing fiber diameter of the PU/RE composite fibers as the amount of RE powder increased, which subsequently increased the surface area of the composite fiber, producing a high physical absorption capacity. Furthermore, the higher BET surface area of the PU nanofiber containing 50 wt. % RE powder is 1.64 times greater than the pure PU nanofiber.

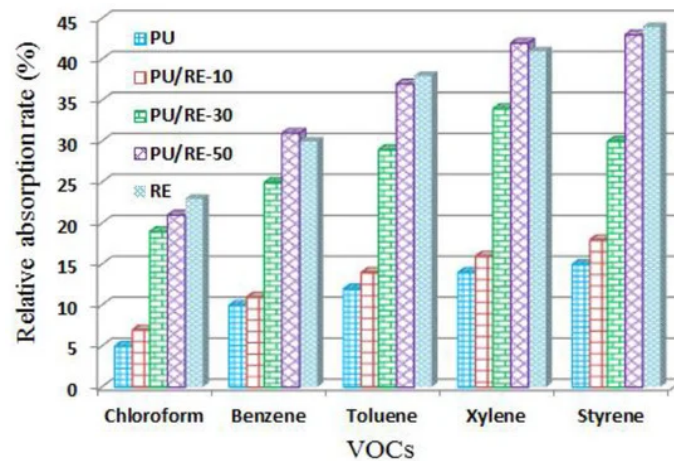


Figure 3. VOC absorption capacity of different nanofibrous mats.

4. Conclusions

In summary, a series of PU nanofibers containing different amounts of RE powder (0 wt. %, 10 wt. %, 30 wt. %, 50 wt. %) with a high VOC absorption capacity can be successfully produced via electrospinning. At RE powder concentrations greater than 50 wt. %, however, the electrospinning nozzle will be seriously blocked. The PU/RE-50 fiber had the smallest fiber diameter, with an average fiber diameter of 356 nm. In addition, this fiber also had outstanding mechanical properties, with an average tensile strength of 8.28 MPa and a percentage strain that was above 700%. Most importantly, it had the highest VOC absorption capacity, more than three times that of the pure PU nanofiber. In addition, the composite PU/RE nanofibrous membranes most easily absorbed styrene, followed by xylene, toluene, benzene and chloroform.

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