Materials Science and Engineering B 214 (2016) 1–10

Contents lists available at ScienceDirect

Materials Science and Engineering B

journal homepage: www.elsevier.com/locate/mseb

Studies on soy protein isolate/polyvinyl alcohol hybrid nanofiber membranes as multi-functional eco-friendly filtration materials

Qun Fang, Ming Zhu, Siruo Yu, Gang Sui *, Xiaoping Yang

State Key Laboratory of Organic-Inorganic Composites, Beijing University of Chemical Technology, Beijing 100029, China

ARTICLE INFO

Article history:
Received 21 April 2016
Received in revised form 7 August 2016
Accepted 14 August 2016

Keywords:
Air filtration
Soy protein isolate
Polyvinyl alcohol
Biodegradable
Nanofiber

ABSTRACT

A biodegradable and multifunctional air filtration membrane was prepared by electrospinning of soy protein isolate (SPI)/polyvinyl alcohol (PVA) system in this paper. The optimized SPI/PVA proportion in the spinning solution was determined according to the analyses of microstructure, surface chemical characteristic and mechanical property of the hybrid nanofiber membranes. Under the preferred preparation condition, two kinds of polymer materials displayed a good compatibility in the hybrid nanofibers, and a large number of polar groups existed in the membrane surface. The loading filtration efficiency of the nanofiber membrane with optimal material ratio and areal density can reach 99.99% after test of 30 min for fine particles smaller than 2.5 μm in the case of small pressure drop. Besides, this kind of filtration membrane showed an antimicrobial activity to *Escherichia coli* in the study. The SPI/PVA hybrid nanofiber membrane with proper material composition and microstructure can be used as a new type of high performance eco-friendly filtration materials.

1. Introduction

Nowadays, air pollution is becoming a serious problem that severely threatens more and more people's health worldwide. There are more than 100 known pollutants in air, which exist in the form of fine particle, aerosol and gas state. "PM 2.5", defined as fine particles with aerodynamic diameters equivalent to or less than 2.5 μm, is one of the most serious sources of air pollution, which can cause adverse effects on human health, climate change, and air visibility [1]. It has large specific surface area, high activity and capability of carrying toxic substances and bacteria, and turns out to be a major cause of adverse health effects ranging from human respiratory tract to extrapulmonary organs [2].

Professional dust mask and indoor air filtration are needed for health. So far the most widely used air filter is conventional nonwoven fiber filter, made from glass fibers, melt-blown fibers, etc. But it is unsuitable for the capture of fine particles, such as PM 2.5, due to the micron-size diameter of fibers [3,4]. Submicrofiber is well-documented to have better filtration performance and less resistance against air flow, which has proved to possess longer service life and more contaminant holding capacity in the test [5,6]. Many approaches such as template synthesis, phase separation, melt-blown method, and plasma treatment have been developed to fabricate sub-microfibers [7–11]. In recent years, electrospinning technique is considered to be an efficient, cost-effective way to prepare nanofibers, which can be standardized and industrialized, and has emerged as a promising technology in air filtration and water purification devices mainly owing to the advantageous features of controllable fiber diameter, high porosity, remarkable specific surface area, and interconnected porous structure [12–16]. Hierarchically structured polysulfone/titania and polyetherimide/silica fibrous membranes were prepared for air filtration with filtration efficiency higher than 99.9%, and the addition of titania and silica endowed pristine fiber with promising superhydrophobicity and self-cleaning performance, respectively [17,18]. The electrospun flexible self-standing g-alumina fibrous membranes as high-efficiency fine particle filtration media were prepared by Wang et al., and displayed a filtration efficiency of 99.848% [19]. Water-soluble ultra-thin polyvinyl pirrolidone nanofibers were designed as the filtration material for sub-micron and nanoaerosol particles by attaching to a household vacuum cleaner [20]. Some electrospun nanofibers of common polymers such as Polyacrylonitrile (PAN), Poly(vinyl alcohol) (PVA), Polyvinylpyrrolidone (PVP) and Poly(styrene) (PS) were also used as air filters for indoor air protection, and the surface chemistry and microstructure of the air filters were proved to be key factors affecting capture possibilities [21].

As we all know, the air filtration membranes must be replaced frequently, and the discarded filtration materials are of great burden on the ecological environment protection and environmentally

* Corresponding author.
E-mail address: suigang@mail.buct.edu.cn (G. Sui).

http://dx.doi.org/10.1016/j.mseb.2016.08.004
0921-5107/

friendly material source is urgently needed. Up to now, the electrospinning of some biopolymers have been reported, such as cellulose acetate, chitin, chitosan, protein, and their composites with other polymers. For example, the optimal electrospinning process parameters of chitosan have been investigated [22]. The electrospinning of proteins including collagen and gelatin with complicated structure were also extensively researched [23]. Soy protein isolate (SPI) is known as renewable resource, intrinsically exhibiting biocompatibility, biodegradability and even antibacterial activity after acid treatment. SPI is formed by strong covalent peptide bonds and the folded conformation of the globular protein, which contains a lot of polar groups such as OH, COOH, and NH_2 [24,25]. There exist strong hydrogen bonds and electrostatic interactions between molecular chains. All these are favorable for the adsorption of harmful substances (including fine particles, toxic gases, even bacteria and viruses) [26]. But pure SPI cannot be electrospun till now. Apart from this, the mechanical property of SPI, like most of the bio-based polymer, is not strong enough even it is spun into fiber. However, it can be blended with some other polymers to prepare hybrid nanofibers [27].

Polyvinyl alcohol is a biocompatible and degradable polymer, and widely used in biological medicine and food industry. In this study, SPI was mixed with PVA to prepare a kind of biodegradable hybrid nanofiber membrane. The relationship between the material collocation and microstructure, as well as filtration properties of the nanofiber membranes were studied in detail. In addition, the filtration efficiency of the SPI/PVA nanofiber membranes was compared to that of PAN sample which was identified as a kind of high efficient filtration material in the relevant research report [21]. The results showed the SPI/PVA hybrid nanofiber membranes with proper material composition can act as a high performance and multi-functional material in air filtration.

2. Experimental

2.1. Materials

The commercial SPI powder (glutamic acid content, 19.2%; aspartic acid content, 11.5%; protein content, >90%; fat content, <1%; ash content, <6%, Chengwang chemical products Co., China), PVA (average molecular weight of 75,000 g mol^{-1} and a hydrolyzing degree up to 88%, Kuraray Co., Japan), PAN (average molecular weight of 10^5 g mol^{-1}, Jilin Petrochemical Co., China), glacial acetic acid (99%, Beijing Chemicals Co., China) and N,N-dimethylformamide (DMF, analytical reagents, Beijing Chemicals Co., China) were used to prepare the SPI/PVA and PAN spinning solutions, respectively.

2.2. Sample preparation

The spinning solutions in the current study were prepared by controlling the weight ratio of SPI to PVA. Firstly, the required amount of SPI powder was dissolved in a solvent system 80:20

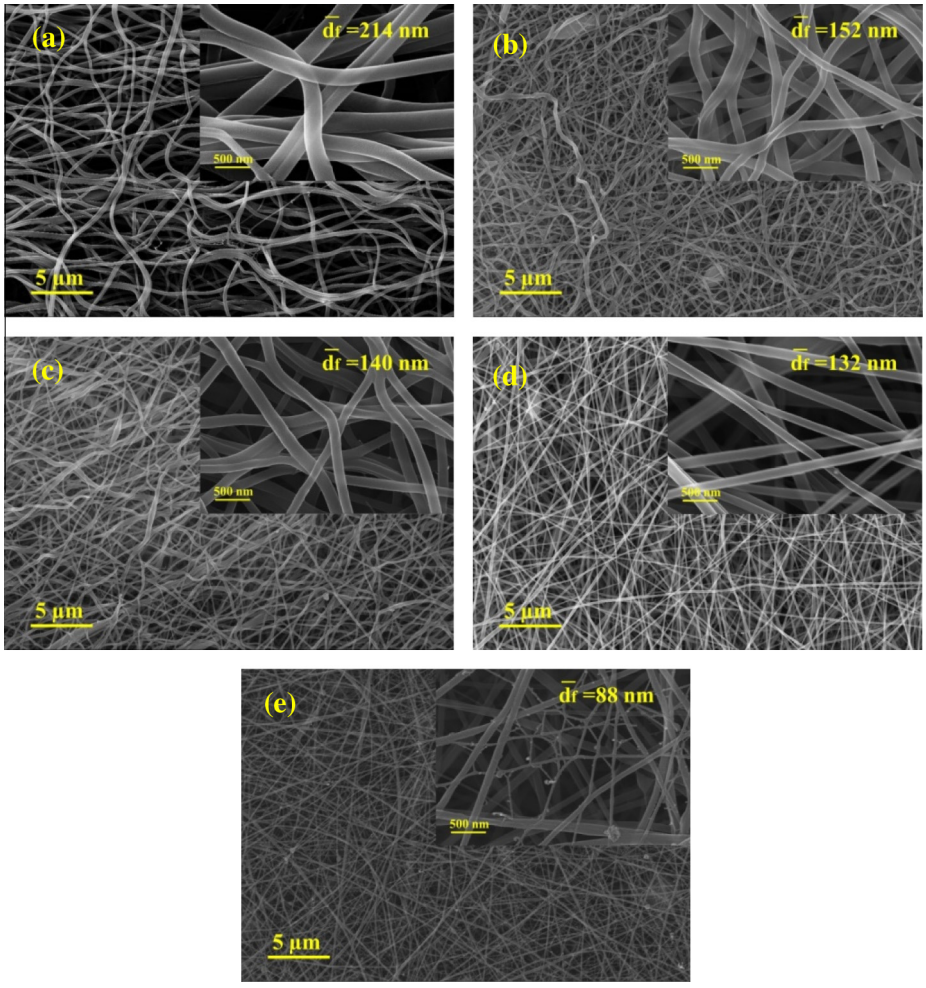

Fig. 1. SEM images of SPI/PVA nanofiber membranes with different material compositions: (a) SPI/PVA(0:1); (b) SPI/PVA(1:1); (c) SPI/PVA(1.5:1); (d) SPI/PVA(2:1) and (e) SPI/PVA(3:1).