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Durably superhydrophobic textile based on fly ash coating for oil/water separation and selective oil removal from water

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ABSTRACT

Fly ash as an industrial solid waste can pose great risks to the environment. In the present study, superhydrophobic cotton textile for oil/water separation was developed based on the formation of fly ash coating and subsequent hydrophobization. The hierarchical fly ash coating immobilized exhibited superhydrophobicity with a water contact angle of 152°. The as-prepared textile can effectively separate a series of oil/water mixtures with high separation efficiency up to 97.3%. Furthermore, the obtained textile can be used under acidic, alkaline, salty, and ultraviolet irradiation conditions. After sixteen cycles of oil/water separation, the textiles still maintained stable superhydrophobicity and high separation efficiency. Owning to good environmental friendliness, low cost, high separation efficiency, and excellent durability and recyclability, the as-prepared textile may be a promising candidate for the separation of oil/water mixtures.

1. Introduction

The wetting capability of a solid surface is governed by its hierarchical surface topography and chemical composition [1,2]. Recently, superhydrophobic surface with a water contact (WCA) larger than 150° has aroused broad attention because of their practical application as water-repellent materials. It is well known that superhydrophobic property can be achieved by combining high surface roughness with low surface energy coating. Up to date, various methods have been utilized to obtain superhydrophobic surface, such as electrospinning deposition method [3], phase separation [4,5], chemical vapor deposition [6], sol–gel process [7,8], and solution-immersion [9], and spray-coating method [10,11]. Despite this, there are still many challenges in fabricating large-scale superhydrophobic surfaces via an inexpensive, simple, eco-friendly, and easy-to-operated technique. Furthermore, more novel and eco-friendly materials are urgently required to prepare superhydrophobic surfaces to satisfy the need of practical applications.

So far, a series of superhydrophobic materials have been used for oil/water separation, such as sponge-based materials [12], carbon-based materials [13], metal foam-based materials [14], natural fiber-based materials [7], and cellulose-based materials [15]. In these studies, oil can be completely separated by these materials while water is completely repelled by the materials. Various materials including inorganic materials, polymers, and metal oxides can be fabricated onto the surface of substrates to form superhydrophobic coating. For instance, the silica coating was fabricated on the surface of kapok fiber, which demonstrates excellent superhydrophobicity and selective oil sorption capability [7]. The TiO_2–SiO_2@PDMS hybrid was coated onto the surface of polyester–cotton fabrics, the obtained fabric can separate oil/water mixture and decolor dye waste water under UV irradiation [16]. Superhydrophobic stainless meshs coated by low-density polyethylene were applied to recover spilled oils [17,18]. Superhydrophobic and superoleophilic copper meshs were fabricated via a simple electrodepositing of $Cu(OH)_2$ nanoneedle arrays or Cu_2O film, which can be used to separate oils from water [19,20]. Besides, the composites derived from inorganic particles and polymers like silica particles/epoxy resin composite and silica particles/polystyrene hybrid were also developed for decorating substrate surface to obtain superhydrophobic coating [21,22]. Even so, to the best of our knowledge, there are few reports about the preparation of superhydrophobic surface using industrial solid wastes as the materials for surface coating.

The textiles with porous structure have been attracting significant attention in oil/water separation due to their low cost and high flexibility. For instance, superhydrophobic filtration fabric was fabricated via coating the surface with poly(dimethyl siloxanes)/silica composite, which can effectively separate oil/water mixture [23]. Durable superhydrophobic textiles for separate

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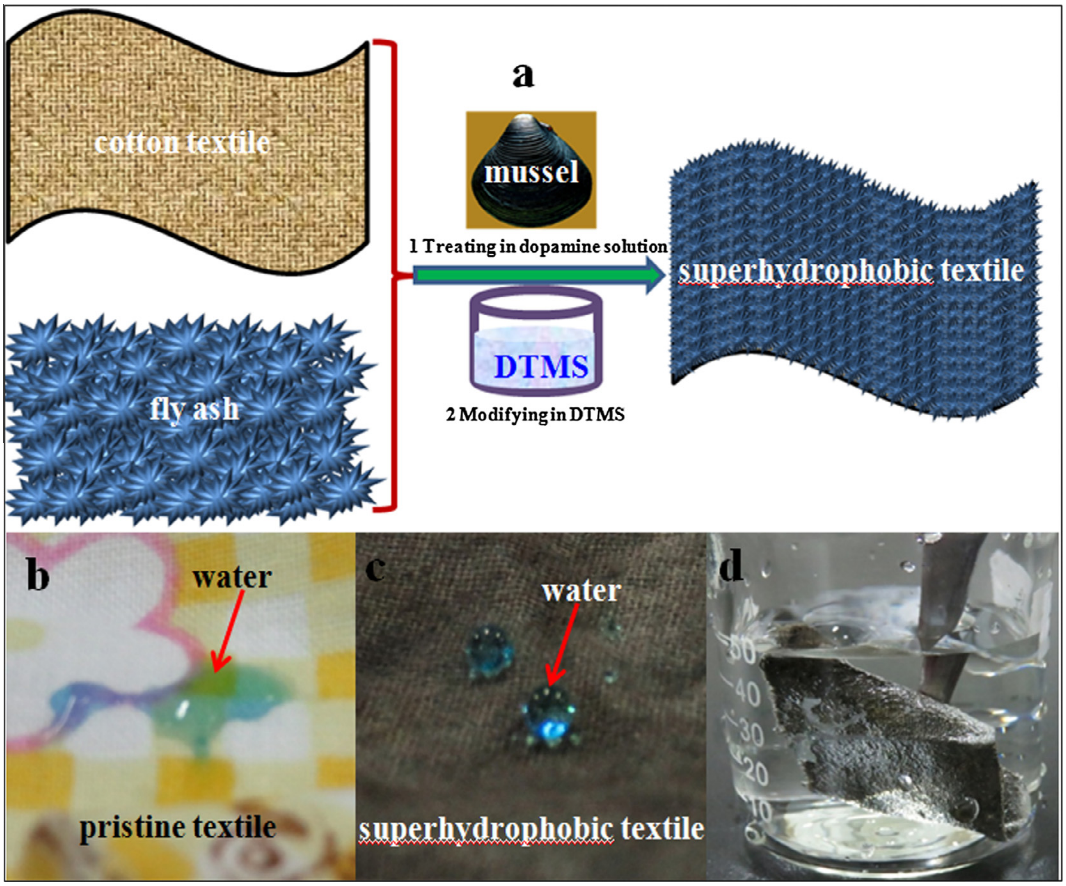

Fig. 1. (a) Fabrication schematic representation of superhydrophobic textile (superhydrophobic textile is obtained via the immobilization of fly ash on cotton textile via polydopamine adhesion and modification in DTMS); (b) the surface of pristine textile was almost entirely wetted by water droplet dyed with methylene blue; (c) the blue-colored water drop displayed a large contact angle on the surface of as-prepared textile; (d) a layer of minute bubble can be found when as-prepared textile was immersed in the water via the external force. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

oil/water mixture were prepared by dip coating in a nanocomposite solution of fluoro-free organosilanes [24]. Superhydrophobic and superoleophilic textiles by a simple sol–gel coating were prepared, which can be used to continuously separate oil from oil/water mixture [25]. These studies pave the way for developing new functionalized textiles for separating oil/water mixture. Fly ash is a kind of solid waste from the burning of fossil fuel, municipal waste, coal, etc. The effective treatment of fly ash has become an attractive environment problem that needs immediate settlement. Despite available technologies, only a small percentage of fly ash has found commercial application, the rest being buried in landfills or stored in holding ponds pending burial [26,27]. Fly ash appears as a relatively fine powder with rounded particle diameters mainly between 1 and 150 μm [28]. The assembly of fine powder with the size ranging from micron to nano can be able to form hierarchical coating. In our previous paper [29,30], superhydrophobic cotton fiber and sponge for oil sorption has been fabricated by immobilizing silica nanoparticles on the substrate surface, and the obtained sorbent showed excellent oil/water selectivity and recyclability. Based on previous studies, in this work, superhydrophobic cotton textile was prepared using fly ash as the material for forming micro- and nano-structural surface under the bioadhesion of polydopamine. The schematic illustration is displayed in Fig. 1a. The resultant fly ash coating with excellent adhesion to the textile surface shows a water contact angle higher than 150°. Importantly, the as-prepared textile can be applied to separate oil/water mixtures effectively and exhibits high separation efficiency, and the coating also shows good durability against harsh conditions and repeated use. Therefore, designing superhydrophobic surface with fly ash may provide a facile, convenient and low cost approach for the fabrication of superhydrophobic materials for separating oils from water.

2. Experimental

2.1. Materials

Cotton textile was purchased from market, Yinchuan, China. Fly ash came from Shenhua Ningxia Coal Industry Group, Yinchuan, China. Toluene, n-hexane and chloroform (analytical grade) were received from Ningxia Yaoyi Chemical Reagent Co. Ltd., China. Dopamine hydrochloride (chemically pure) and Tris(hydroxymethyl)aminomethane (Tris–HCl, chemically pure) were supplied by Nanjin Aoduo Biotechnology Co. Ltd., China. Dodecyltrimethoxysilane (DTMS, chemically pure) was provided by Nanjin Chengong Organosilicon Co. Ltd, China. Gasoline and diesel came from the local market, Yinchuan, China.

2.2. Preparation of superhydrophobic textile

Before use, cotton textile was rinsed with ethanol for several times. In a typical experiment, fly ash and dopamine hydrochloride (0.16 g) were added into Tris–HCl solution (80 mL) to stir for 10 min under ultrasonic. Afterwards, the textile was immersed into the dispersion and stirred for 12 h at room temperature. Finally,