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High-performance, recyclable and superhydrophobic oil absorbents consisting of cotton with a polydimethylsiloxane shell

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ABSTRACT

This study presents the results related to the preparation and characterization of cotton-based oil absorbents dry-coated with polydimethylsiloxane (PDMS) that can absorb 30–65 times their weight in oil. PDMS is coated onto these absorbents using chemical vapour deposition without the use of chemicals other than PDMS. The absorbed oils can be separated from the absorbents by centrifugal force indicating that the absorbents are recyclable. The absorbents are also hydrophobic and have a water contact angle exceeding 150°. This hydrophobicity allows perfectly selective removal of oil from an oil/water mixture. We also suggest a funnel structure for effective filtering of oil.

Introduction

Selective removal of oil from water is a key issue in environmental protection technology because oil spills occurring in the ocean, rivers, or wastewater can be harmful to ecosystems [1]. There are various methods for removing oil from water. These methods include the physical separation of liquid oil from water using mechanical pumps [2], solidifying the oil by using chemical and physical gelling agents [3,4], spreading out the oil using an oil dispersant [5,6], and physically separating oil from water using oil-absorbents [7–15]. Perfect separation of oil from water using a physical method is challenging, particularly when the amount of oil in the oil/water mixture is low [16–18]. Furthermore, oil gelling agents can be harmful to the environment. Finally, the use of oil dispersant does not isolate oil from water, and therefore this method can cause a secondary contamination problem.

Oil can safely be separated from water when oil absorbent is used, and recycling of the absorbent is even possible by extracting oil from the absorbent [7–10,19–23]. High-performing oil absorbents have high porosity resulting in superior oil absorption capacity, and they are superhydrophobic allowing them to repel water from the absorbent interface [24,25]. Hydrophobic surface groups and surfaces having dual-roughness are required for superhydrophobicity because water droplets on such dual-roughness surfaces can be repelled by air pockets trapped at the water/solid interface according to the Lotus effect [26–29].

Previous studies reported various structures that have high oil absorption capacities and hydrophobic properties; in particular, group of A. Li and C.Y. Wang recently suggested interesting materials such as surface-modified cotton, sponge, and mesh with superhydrophobicity as oil absorbents [8–11]. Hydrophobic modifications of substrate surfaces in previous studies are generally based on wet-chemical processes with complicated procedures and numerous kinds of chemicals. Although some of these are commercially available [16,30,31], development of a simpler and more environmental-friendly process (for example, no use of solvent in the fabrication process) for the preparation of superhydrophobic materials is required. In addition, the performance of the commercialized oil absorbents still needs to be improved because these absorbents do not perfectly repel water. Therefore, oil absorption capacity is limited when they are immersed in water.

In the present work, we used commercially available cotton and PDMS, both of which are inexpensive. We made the cotton superhydrophobic by coating it with PDMS using chemical vapour deposition (CVD). Furthermore, we demonstrated that the resulting superhydrophobic cotton can be utilized as an oil absorbent, and it showed recyclability and an extraordinarily high oil absorption capacity. This oil absorbent can be commercially useful

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in the applications of the treatment of sea-water contaminated by marine oil spill. In addition, it is possible to be commercially used as oil absorbent pad, roll, wipe, and towel in everyday life.

Experimental

Preparation of the sample

Fabrication of the PDMS-coated samples was performed using CVD. Absorbent cotton (Hanil cotton, Hanil Corporation) was cut into 3 cm × 3 cm pieces, and these were placed on silica wool above a stainless steel mesh. Fluidic PDMS (PMX-200 SILICONE FLUID 1000 CS, Dow Corning) was placed under the stainless steel mesh such that it was physically separated from the absorbent cotton. The chamber was then heated to 300 °C and was held for 1 h. During the CVD process, fluidic PDMS was evaporated and subsequently deposited on the absorbent cotton, resulting in the formation of a hydrophobic thin film on the surface of the cotton.

Characterization of the sample

Water contact angle measurements were conducted using a Theta Optical Tensiometer (KSV Instruments, Ltd.). A digital camera connected to a computer was used to take images water droplets (3 μL) on the surface of the cotton. KSV bundle software (Attention Theta) was used to get the images, and Young-Laplace curves were employed to fit the data. Each water contact angle measurement was repeated 3 times to obtain an average. Fourier transform infrared (FT-IR, Optics/vertex 70, BRUKER) analysis was performed in the range of 600–4000 cm^{-1}. Each spectrum was collected for 32 scans with a resolution of 4 cm^{-1} and was corrected for atmospheric H_2O and CO_2 peaks. Surface morphological and topographical images of the sample were obtained by using scanning electron microscopy (SEM, JSM-7100F, JEOL) and atomic force microscopy (AFM, Park NX10, Park Systems), respectively.

Oil absorption test

In order to investigate the oil absorption capacity of each sample, the weight gains (defined by the maximum weight of absorbed oil divided by the initial weight of the sample) were measured. The sample was immersed in oil, and the oil/absorbent mixture was subsequently stirred for 1 min. After stirring, the oil-containing sample was placed on top of the stainless steel mesh, and we waited for 10 min until no additional oil droplets fell down from the absorbent. Then, the weight of the oil/absorbent mixture was measured. The weight gain measurements of the sample for all of types of oil were repeated 3 times to obtain an average value of weight gain.

Table 1 shows the viscosity and density of various oils such as pump oil (Pochem Korea Co., Ltd.), motor oil (SK Lubricants), diesel (SK Innovation), gasoline (SK Innovation), sesame oil (Ottogi), silicone oil (Shin-Etsu Chemical Co., Ltd.). The viscosity of the studied oils was measured using a viscometer (SV-10, A&D company Ltd.) at room temperature. The density of studied oils was cited from oil-data sheets which were made by each manufacturing companies.

Table 1
Characteristics of the studied oils at room temperature.

Type of oil	Viscosity (mPa s)	Density (g/cm^3)
Pump oil	93.1	0.867
Motor oil	105.0	0.852
Diesel	2.0	0.825
Gasoline	0.4	0.704
Sesame oil	47.4	0.918
Silicone oil	2600	0.970

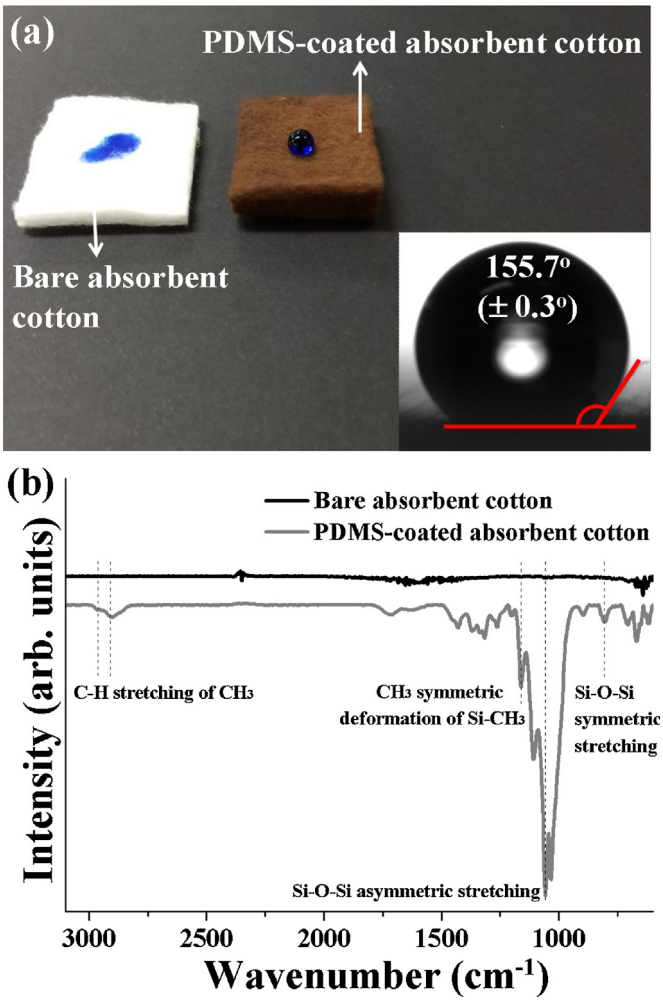

Fig. 1. (a) Photographs of water droplets (dyed with methylene blue) on the bare and PDMS-coated absorbent cotton surface; the bare absorbent cotton instantly absorbed water droplet in measurement of water contact angle, while the contact angle on the PDMS-coated absorbent cotton was determined to be 155.7° (±0.3°). (b) FT-IR spectra of the bare and PDMS-coated absorbent cotton.

To construct the oil–water separation system, mesoporous SiO_2 (purity 99%, mean particle size = 150–250 μm, Sigma–Aldrich) was placed in the funnel. Donut-shaped stainless steel mesh containing PDMS-coated cotton was placed on top of the SiO_2 layer. Oil/water mixtures were poured from the top of the filtering apparatus. The subsequent flow of the water through the filter and selective absorption of oil (dyed red) by the PDMS-coated cotton were recorded using a digital camera.

The PDMS-coated sample that had been immersed in oil was then placed on a stainless steel mesh inside a centrifuge tube. The tube was then centrifuged at 4000 rpm for 5 min. During this process, oil moved through the metal mesh leaving behind a dried absorbent. The weight gain of the recycled sample was then

Table 2
Comparison in the water content of absorbent cotton before and after PDMS-coating.

Absorbent fibre	Water content (g_a/g_b)
Bare absorbent cotton	28.06
PDMS-coated absorbent cotton	0.15

g_a: weight of absorbed water; g_b: weight of sample.