Applied Surface Science 257 (2011) 7997–8002

Contents lists available at ScienceDirect

Applied Surface Science

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

Improvement of water and oil repellency on wood substrates by using fluorinated silica nanocoating

Chien-Te Hsieh*, Bi-Sheng Chang, Jia-Yi Lin

Department of Chemical Engineering and Materials Science, Yuan Ze Fuel Cell Center, Yuan Ze University, Taoyuan 320, Taiwan

ARTICLE INFO

Article history:
Received 21 March 2011
Received in revised form 17 April 2011
Accepted 17 April 2011
Available online 22 April 2011

Keywords:
Wooden substrate
Superhydrophobic coating
Oil repellency
Sliding angle
Contact angle
Silica nanospheres

ABSTRACT

We have investigated a one-step fabrication of fluoro-containing silica coating on wooden substrates, showing multi-functions including super repellency toward water and sunflower oil, low sliding angles, good durability, and low adsorption capacity of moisture. The repellent slurry, consisting of well-mixing silica nanospheres and perfluoroalkyl methacrylic copolymer, is simply prepared and subsequently sprayed over wooden substrates with good adhesion. It has shown that the decoration of silica nanospheres on microscaled wooden texture acts as a crucial role in improving the repellency toward water and sunflower oil droplets. The maximal contact angles can reach as high as 168.3° and 153.6° for water and sunflower oil drops, respectively. These analyses of wetted fraction and work of adhesion also demonstrate the improved repellency due to the addition of silica. This improvement of the repellencies is ascribed to the fact that the drops partially sit on F-coated silica spheres, leaving a layer of air underneath the droplet (i.e., Cassie state). On the basis of the results, the multi-functional coating on wooden substrates delivers a promising commercial feasibility on a variety of woodworks.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

To date, woodwork is extensively applied in a variety of daily applications such as indoor decoration, woodcarving, wooden bridge, pavilion, pavement, and so forth. Especially, efforts have been devoted to protect the place of historic spots that are made of wood. However, to prolong the lifetime of wooden artistic production is still a challenge. Many environmental factors, such as humidity and acidic rain, are known to strongly affect the durability, causing damage to these wooden products. One ideal solution on improving the durability is to reduce moisture adsorption or oil contamination on the surface of wooden substrate. Accordingly, both features of super repellency and liquid adsorption (or adherence) on the substrates are key factors in determining the woodwork protection. Pioneering studies have devoted to improving water repellency of various wooden surfaces, using multi-layer deposition followed by fluorination treatment [1], mild pyrolysis in inert atmosphere [2], covalent grafting of polymer [3], and silylation treatment [4]. However, a one-step approach that significantly improves water and oil repellency as well as durability is rarely discussed in literature.

Fluorine-containing coatings are frequently used to lower the surface tension of various substrates (e.g., glass or silicone wafer), thus leading to super water repellency on the surfaces [5], that is, with a contact angle (CA) > 150°. This enhancement of water repellency is attributed to extremely low surface tensions with an order: $-CF_3 < -CF_2 < -CH_3 < -CH_2$. For instance, a CF_3-terminated flat surface exhibits essential water repellency, that is, a contact angle of 110–120° [6–8], due to its low surface energy (~6 mN/m). Learning from the lotus effect, pioneer studies have successfully fabricated superhydrophobic surfaces, including carbon nanotubes (CNTs) and microscale carbon fabric (CF) composites [9]; silica sphere and CF composites [10]; silica particles and cotton fibers [11]; CNT array with micro- and nanoscale surface roughness [12]; double-layer freestanding nanotube film [13]; and CNT and polystyrene microsphere composition arrays [14]. These successful examples lead us to achieve the super water repellency using the combination of surface chemistry and roughness on multiple scales [5].

Accordingly, this study aims to develop a facile approach that is able to improve water repellency and to reduce H_2O adsorption capacity of the treated wooden substrates. One repellent solution with an appropriate recipe of silica (SiO_2) nanospheres with an average diameter of 20 nm and fluorine copolymer was uniformly coated on the wooden substrates. Because a wooden substrate generally offers a primary roughness, silica nanoparticles are capable of uniformly decorating both the "valley" and the "hill," offering a secondary roughness. Such dual-roughened surfaces in nano/microscale, similar to the structure of a lotus leaf, are believed to impart the super water repellency [9]. Additionally, to enhance water-proof capability, the approach is capable of coating

* Corresponding author. Tel.: +886 3 4638800x2577; fax: +886 3 4559373.
E-mail address: cthsieh@saturn.yzu.edu.tw (C.-T. Hsieh).

0169-4332/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.apsusc.2011.04.071

the nanosilica gel into porous lignocellulose. The resulting pores thus exhibit the water repellency, mitigating the moisture diffusion and uptake from the high humidity atmosphere. Accordingly, the functions of the fluorinated silica coating are (i) to facilitate water repellency and (ii) to create a thin layer that resists water attachment to wooden substrates. Because the approach can be performed by using a conventional spray apparatus, this study would shed one efficient approach to functionalize wooden substrates with simplicity and convenience, so that the functionalized wooden substrates may display a variety of technological applications (i.e., indoor/outer decoration and historic spot maintenance).

2. Materials and methods

Each piece of pine wood (*Pinus taiwanensis*) was carefully cut into an area of 5 cm × 5 cm. The thickness of the wooden chips was controlled within 3 mm. Prior to any further treatment, the wooden substrates have been dried at 105 °C in oven overnight. In this study, commercial silica nanoparticles with an average size of 20 nm were well mixed with perfluoroalkyl methacrylic copolymer (Zonyl 8740, DuPont Co.) and then magnetically stirred at room temperature for 1 h. The solvent of the slurry solution was distilled water, exhibiting an environmental-friendly process. Generally, the F-containing copolymer acts as two key roles in (i) the adhesion of the interface between silica sphere layers and wooden substrate, and (ii) the hydrophobic/oleophobic agent to lower the surface energy. The weight percentage of the silica/copolymer/water was set at 1:1:98. A spray nozzle was used to coat the F-containing silica nanoparticles onto a piece of pine wooden substrate. After the nanocoating, the treated substrate was oven-dried at 105 °C for 12 h to evaporate the moisture, giving a silica-coated surface on the wooden substrate. Additionally, the F-coated surface on the wooden substrate was also prepared to compare with the F-silica surface in order to show the significance of silica.

To examine both water and oil repellencies, CAs of deionized water (surface tension: 73.2 mN/m) and ethylene glycol (surface tension: 45.1 mN/m) were evaluated as the ability of the resulting wooden plates to repel water and oil. An optical CA meter was adopted to measure the CA of droplets on the prepared surfaces. Each droplet was dropped to the sample surface from a distance of 5 cm by vibrating the syringe. The volume of the droplet was controlled at around 5 μL. The sample plate was vibrated slightly by tapping the sample stand before each measurement to obtain the equilibrium CAs. The adsorption of water vapor on the treated wooden substrates was performed at 40 °C under a relative humidity ∼90% for 24 h, attaining the adsorption equilibrium of moisture. The treated plates were placed into a thermostatic chamber. The long-period adsorption ensures that the maximal adsorption capacity (i.e., a steady state of adsorption) is reached. A thermogravimetric analyzer (TGA, Perkin-Elmer TA7) was used to measure the amount of water adsorption on the treated wooden plate. The TGA and differential thermogravimetry (DTG) analysis was conducted under a high-purity Ar atmosphere with a heating rate of 30 °C/min ramp between 30 °C and 870 °C. The surface morphology of the wooden plates was characterized using a field-emission scanning electron spectroscope (FE-SEM, JEOL JSM-5600).

The durability test of water- and oil-repellent wooden plates was carried out by chemically impregnating the plates in deionized water and ethylene glycol solutions, respectively. In order to clarify the adhesion between nanocoating and wooden substrate, the resulting plates were totally immersed into the two types of solutions at ambient temperature for 10 days. The plates were oven-dried at 105 °C for 0.5 h and then their repellency toward water and ethylene glycol droplets was measured every 24 h. Four combinations of the durability test were carried out as follows: water immersion water repellency (WW), ethylene glycol immersion water repellency (EW), water immersion ethylene glycol repellency (WE), and ethylene glycol immersion ethylene glycol repellency (EE), respectively. The cycling test seems like an accelerating aging test, clarifying long-term water and oil repellencies.

3. Results and discussion

Fig. 1(a) and (b) shows the top- and cross-view FE-SEM images, respectively, of a typical silica film prepared by spray coating. It can be seen that the SiO_2 nanostructure surface consists of a large number of spheres with an average size of 20 nm. The stack of silica particles displays a random arrangement, generating a secondary roughness on the wooden plate, as shown in Fig. 1(b). Because the coating of fluorine species is so thin, the silica stacking layers maintain an essential surface roughness. Electron dispersive X-ray spectrometer (EDS) was applied to examine the surface chemistry of the F-coated silica surface on wooden substrates. The EDS analysis confirms the existence of Si, O, and F elements on the treated wooden plates. It is reasonable that the appearance of Si and F elements originates from the F-containing groups (e.g., fluoromethyl group) over silica spheres. The F/Si atomic ratio is found to be approximately 1:1, favoring the improvement of both water and oil repellencies of wooden substrates. The facile coating technique offers a promising potential to uniformly disperse the F-silica coating on wooden substrates.

To identify the water repellency of the wooden surfaces, five drops of water were placed at different locations horizontal to these surfaces. Five readings of the CAs were then taken. Cross-sectional view images of water droplets on untreated, F-coated, and F-silica-coated wooden plates are illustrated in Fig. 2(a)–(c), respectively. The analysis on the CAs of water displays an obvious difference among these wooden surfaces. The original wooden plate exhibits a superhydrophilic nature (i.e., CA of water: ∼0°), whereas the addition of a fluorine coating significantly improves the water repellency of the wooden plate (i.e., CA of water: > 165°). This improvement of water repellency demonstrates that the low-surface-energy coating, that is, the fluorine coating in this study,

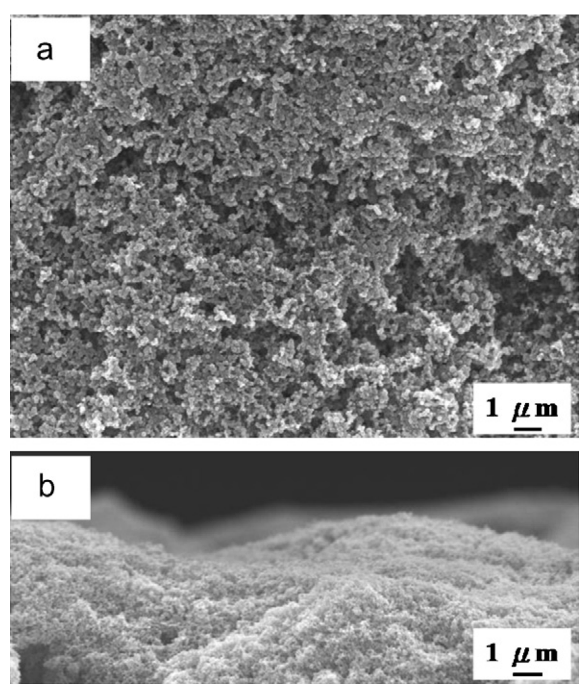

Fig. 1. FE-SEM images for F-coated silica layer onto wooden substrates at (a) top and (b) cross-sectional views.

Download English Version:

https://daneshyari.com/en/article/5363984

Download Persian Version:

https://daneshyari.com/article/5363984

Daneshyari.com