Surface & Coatings Technology 205 (2011) 5387–5393

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

Functional silica film on stainless steel mesh with tunable wettability

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ARTICLE INFO

Article history:
Received 5 January 2011
Accepted in revised form 31 May 2011
Available online 12 June 2011

Keywords:
Superhydrophobicity
Superoleophilicity
Superamphiphilicity
Amphiphobicity
Sol–gel process
Oil/water separation

ABSTRACT

A series of functional silica films on stainless steel meshes are fabricated by simple sol–gel process using tetraethyl orthosilicate (TEOS) and methyltriethoxysilane (MTES) as precursors and post-thermal treatment or hydrophobization. The wettabilities of these meshes can range from superhydrophobicity and superoleophilicity to superamphiphilicity or amphiphobicity. The tunable wetting states are controlled by changing surface chemistry or morphology. Firstly, methyl-endcapped silica film with superhydrophobic and superoleophilic property is formed using a dip-coating method; then, the methyl groups are removed by adequate annealing, and the mesh exhibits superamphiphilic property; finally, after surface modification by perfluorooctyltriethoxysilane, the amphiphobic mesh is obtained. These stainless steel meshes with different wettabilities may act as "smart" switches, which can allow oil or water pass through the mesh or not selectively, and this is potential to be used in intelligent oil/water separating device.

1. Introduction

In recent years, the wettability of solid surface has attracted great interests both in academic research [1–4] and practical applications [5–8], particularly for the special wetting behaviors, such as superhydrophobicity [9–11], superhydrophilicity [12–14], superoleophobicity [15–17] and superoleophilicity [18,19]. Materials combining any two different wetting behaviors of solid surface have many potential applications for their functional properties. For example, superhydrophobic and superoleophobic surfaces (also called superamphiphobic surfaces) of textiles have self-cleaning properties by means of repelling oils and water [20,21]; superhydrophilic and superoleophilic surfaces (also called superamphiphilic surfaces) of windshield glasses can keep transparent and clean when liquids contact on the windshield [22,23]. And superhydrophobic and superoleophilic (abbreviated as Shy-Sol) surfaces of filters can separate water from oil (or oil from water) easily and efficiently due to the interfacial phenomena [24–26].

Furthermore, different wetting states can be switched from each other, which were proved to be feasible and potentially useful in industrial, environmental, and biological applications, such as microfluidics, drug-delivery, biosensor and protein enrichment [27–30]. The tunable wettability of surface can be realized by various methods, including light-irradiation [31,32], use of an electric field [33,34], thermal treatment [35,36] and treatment with solvents [37,38]. For instance, surfaces with harshly rough nanostructures modified with fluorinated monolayer or long chain of fatty acids can be turned from superhydrophobicity to superhydrophilicity by exposing to ultraviolet light [39,40]. Thermoresponsive amphiphilic copolymers surfaces with roughness can be swithed from superhydrophilicity to superhydrophobicity with increasing temperature due to the hydrogen bonds variation [41,42]. This inspires the possibilities of transitions among superamphiphobicity, superamphiphilicity and superhydrophobicity and superoleophilicity.

In this paper, tunable wettabilities of stainless steel meshes were obtained as follows: firstly, a Shy-Sol silica film was fabricated on stainless steel mesh using sol–gel process, and the mesh can separate water from oil easily. The efficiency for oil/water separation can be found in Supplementary Data. Secondly, the mesh was treated with elevated temperature and the wettability of the mesh was switched from superhydrophobicity to superhydrophilicity while maintaining superoleophilicity. It allowed both oil and water pass through the mesh. At last, self-assembled monolayer of perfluorooctyltriethoxysilane was coated on the thermal treated mesh, the obtained mesh exhibited amphiphobic property, and oil and water were prevented to pass through the mesh. Schematic illustration of different oil/water separating states of stainless steel meshes with different wetting properties can be seen in Fig. 1. The tunable wetting meshes can thus be used as switches to control oil or water penetrating the mesh and may have potential application in smart oil/water separating device.

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doi:10.1016/j.surfcoat.2011.05.049

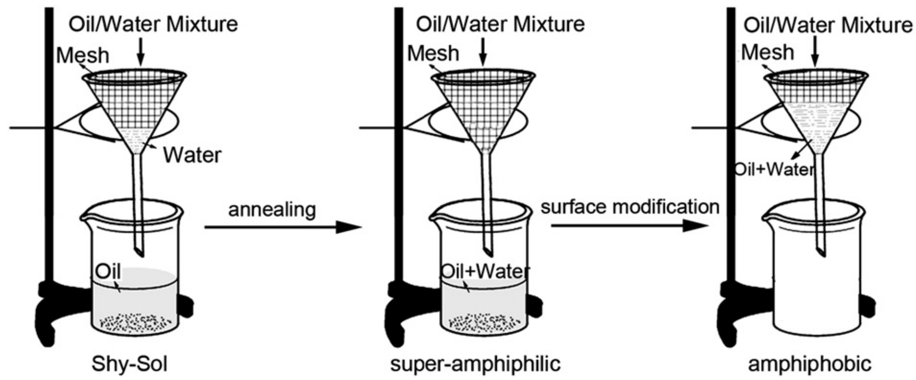

Fig. 1. Schematic illustration of different oil/water separating states on stainless steel meshes with different wetting properties.

2. Material and methods

2.1. Preparation of silica sol

The preparation of hydrophobic silica sol was carried out using a method described in our previous work [43]. Briefly, 7 mL (0.03 mol) tetraethyl orthosilicate (TEOS, 98%, analytical reagent, abbreviated as A. R.) was added to 5 mL (0.13 mol) ammonia (NH_3, 25% in water, A.R.), 9 mL (0.5 mol) deionized water (H_2O) and 100 mL (1.74 mol) absolute ethanol (EtOH, 99.5%, A.R.) under rapid stirring using a mechanical agitator. The mixture was allowed to react at 60 °C for 90 min. Then, 3.9 mL (0.02 mol) methyltriethoxysilane (MTES, 98%, A.R.) was added dropwise to the mixture and stirred for 19 h to avoid gel formation. As a result, the silica sol cannot turn to gel within one week, which can prolong the service life of the sol solution. The obtained silica sol was composed of about 220 nm spheric silica nanoparticles, and the polydispersity index of the nanoparticles was 0.028, which indicated that the silica sol was monodisperse and stable (see Fig. S1).

2.2. Preparation of samples

The procedure for preparing different wetting properties of stainless steel meshes is outlined in Fig. 2. Shy-Sol silica film on stainless steel mesh was prepared based on a dip-coating method described earlier [43]. In detail, fresh silica sol solutions were aged for 3 days at ambient temperature and pressure, and then stainless steel mesh was dipped into the sol solutions for about 5 min, and dried at 110 °C for 30 min. This procedure was recycled 4 times to get enough roughness of the silica film. Shy-Sol mesh was acquired at 400 °C for 2 h. After that, the mesh was annealed at 600 °C for another 2 h to gain superamphiphilic property. Lastly, amphiphobic mesh was obtained by further surface modification using perfluorooctyltriethoxysilane.

Surface modification of the stainless steel mesh was conducted as follows: the mesh was put into the mixtures of perfluorooctyltriethoxysilane (Dynasylan F8261, Degussa), EtOH, H_2O and 0.1 M hydrochloric acid in 0.5/88/10/1.5 weight percentage for 30 min and was dried at 120 °C for 2 h. The resultant mesh was washed in ethanol under ultrasonication to remove surplus silica and dried prior to analysis.

2.3. Characterization

The surface morphology of the silica film was measured by field-emission scanning electron microscopy (FESEM, LEO 1530 VP, Germany). The surface roughness of the film was characterized by atomic force microscope (AFM, CSPM5000, Benyuan, China). Scanning scope is 25 × 25 μm. The surface chemical composition of the film was

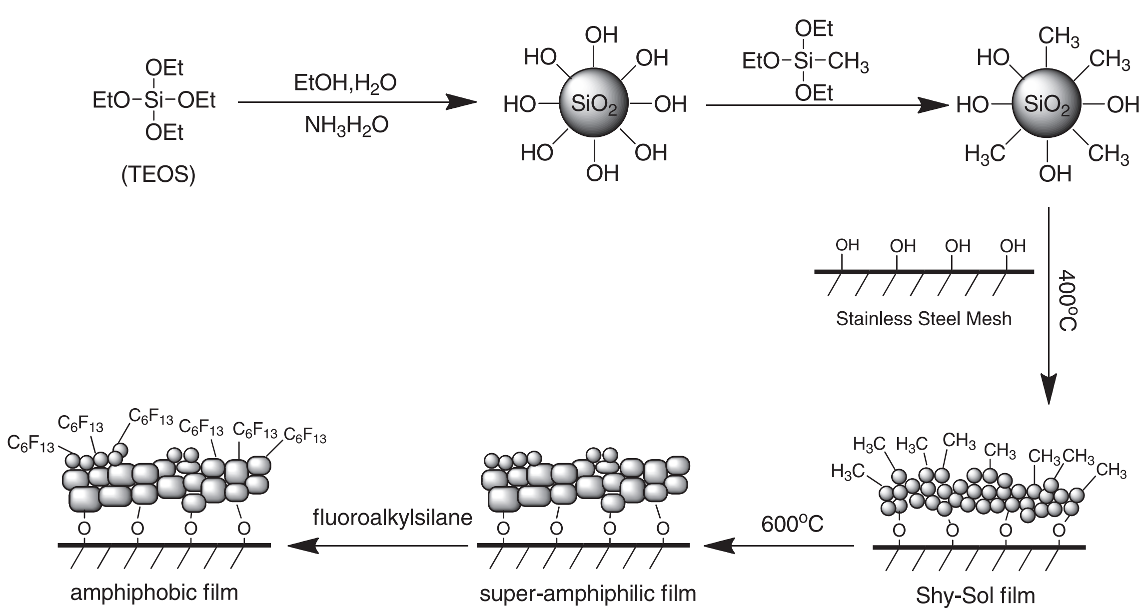

Fig. 2. Schematic diagram of procedure to fabricate Sho-Sol, superamphiphilic and amphiphobic silica films on stainless steel meshes.