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Fabrication of durable and regenerable superhydrophobic coatings with excellent self-cleaning and anti-fogging properties for aluminium surfaces

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In this paper, superhydrophobic coatings on aluminium surfaces were prepared by chemical etching process using sodium hydroxide and lauric acid. The surface morphology analysis shows the presence of a rough microstuctures on the treated surfaces and the contact angle measurements confirm the superhydrophobic nature with high static contact angle of 170° and low sliding angle of 5°. Additionally, the effect of etchant concentration and etching time on wettability and morphology is also studied and observed that the contact angle increases with etchant concentration as well as with etching time as roughness enhances. Coating maintains its superhydrophobicity after undergoing 15 cycles of adhesive tape peeling test and under a stream of water jet. Coating remains unaffected on 90° and 180° bending, and repeated folding and de-folding. In addition to the above, coating can withstand after annealing temperature range from 40 to 170 °C and also stable under prolonged UV irradiation. Coating also maintains its superhydrophobicity upto one and four days when immersed in 5% acetic acid and 3% sodium chloride solution, respectively. Although, coating surface is fully damaged after annealing at 300 °C and superhydrophobicility turns into superhydrophilicity, but it regains by simply immersing again in lauric acid solution. Further, coating exhibits the excellent self-cleaning and anti-fogging properties. The aforesaid stable superhydrophobic aluminium surfaces have potential industrial applications.

1. Introduction

Solid surfaces are categorized into three different categories based on their interaction with the water droplet on their surface. These three categories are hydrophilic, hydrophobic and superhydrophobic surface. Hydrophilic surface attracts water and the adhesive force between the surface and water is more than the cohesive force between them. The static contact angle here is always less than 90°. For hydrophobic surface, the static contact angle is more than 90° i.e. it is water repelling in nature, and in this case the adhesive force between the surface and water is less than the cohesive force between them. Superhydrophobic surface shows the extreme water repellent properties with more than 150° static contact angle and the water droplets coming in contact with it form a spherical bead like shape while resting on that surface. This superhydophobic property is bioinspired from nature such as lotus and water strider and it is caused due to the presence of fine and hierarchical structures on their surfaces [1–4]. Recently, superhydrophobic surface has received a lot of research attention due to its great potential in scientific study and industrial applications.

Aluminium is a very important industrial metal due to its high specific strength, excellent heat and electrical conductivities, and low-specific weight. It is widely used in body of areoplanes, part of ships, reactors, and building materials, but its applications are limited due to problem of corrosion, accumulation of icing and scratching. If aforesaid superhydrophobic coatings are prepared on aluminium surface, coatings can slow down the process of corrosion because of self-cleaning and water-repellent properties of coatings. It is, therefore, needed to develop the superhydrophobic coatings on aluminium surface.

The wettability of a solid surface depends on the surface morphology and surface energy. This is explained from Cassie-Baxter state [5]. In this state, air is trapped in the microgrooves of a rough surface and it creates a composite surface comprising air

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and the tops of micro-protrusions. Water droplets rest on this composite surface, air repels the water, and contact angle increases. Suitable combination of surface roughness and low surface energy has been required to construct artificial superhydrophobic surfaces. For fabricating superhydrophobic surfaces, low surface energy substances like fluroalkysilanes, fatty acids and polymers are used [6–8]. Different coating techniques like electrodeposition, sol-gel method, oxygen plasma etching, self-assembly, anodization, layer-by-layer assembly, hydrothermal technique, spray coating, dip coating, wet chemical reaction, and chemical vapor deposition are used for creating biomimicked artificial superhydrophobic surfaces on substrates like polycrystalline metals, silicon wafers, glass substrates, and polymers [1,9–12]. All synthesis techniques have both advantages and disadvantages such as few of them are simple and inexpensive and others involve harsh conditions or require specialized reagents and equipment, which leads to increase the cost of coating. One economical method for fabricating a superhydrophobic surface is chemical etching as it does not require any sophisticated instrument and the process is fast and easy as seen in Fig. 1 (a). Chemical etching also shows more potential to produce superhydrophobic aluminium surface because aluminium has dislocations and selective dislocation etching is possible [13,14].

Some work has been reported on fabrication of superhydrophobic aluminium surfaces using chemical etching technique. For instance, Wang et al. [15] used chemical etching with the HNO_3 and H_2O_2 mixed solution to make rough aluminium surface, then roughed aluminium was immersed in a mixed solution of stearic acid and N, N-dicyclohexylcarbodiimide, and contact angle of 156° was achieved. Guo et al. [16] roughed aluminium surface by immersing it in NaOH solution, then used spin coating with fluorinated silane, and obtained superhydrophobic aluminium surfaces. Saleema et al. [17,18] fabricated superhydrophobic aluminum surfaces by treating with fluoroalkyl-silane (FAS-17) in NaOH solution. Qian et al. [19] carried out synthesis of superhydrophobic surface on three polycrystalline metals aluminum, copper and zinc through chemical etching. For aluminium surface Beck's dislocation etchant, for copper Livingston's dislocation etchant and for zinc hydrochloric acid solution were used as etchant and for lowering the surface energy fluorination was done. It was observed that contact angle increased with increase in etching time. Shi-heng et al. [20] fabricated superhydrophobic surface on aluminium plate substrate by using sodium hydroxide etchant in ultrasonic bath followed by modification with fluorosilane. The maximum contact angle achieved by this was 151.3°. Li et al. [21] fabricated superhydrophobic aluminium surfaces by chemical etching and anodization followed by self-assembly using hydrochloric acid, sulphuric acid and boracic acid, fluoroalkylsilane (FAS). Liao et al. [22] fabricated superhydrophobic aluminium surfaces by chemical etching using hydrochloric acid, hexadecyltrimethoxy silane and $CuCl_2$ solution. Zhang et al. [23] fabricated superhydrophobic aluminium surfaces using hydrochloric acid and myristic acid through chemical etching and immersion and achieved water contact angle of 163°. Xiayi et al. [24] fabricated superhydrophobic aluminium surfaces having water contact angle of 159.7° using nitric acid, copper nitrate and DTS through mechanical roughening, chemical etching and immersion.

Despite having excellent properties like self-cleaning, anticorrosive, and anti-icing, above superhydrophobic surfaces are not widely industry applicable because of lack of mechanical and thermal stability. Aforesaid chemical etching is an inexpensive and facile method to produce artificial superhydrophobic coatings. Recently Xie et al. [25] developed cheaper superhydrophobic aluminium surface by chemical etching process using NaOH as an etchant and lauric acid as a low surface energy material, but they

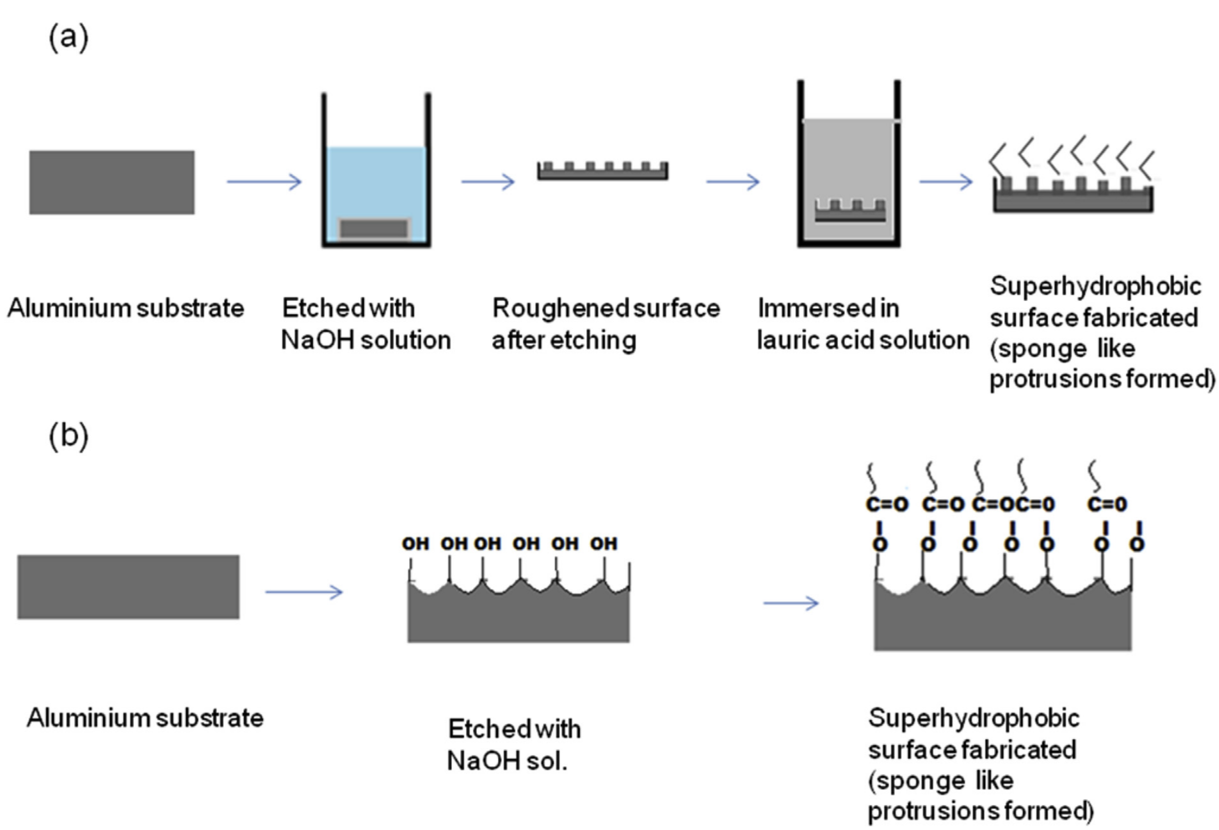

Fig. 1. (a) Schematic diagram for conducting experiment. (b) Schematic diagram for mechanism of synthesizing superhydrophobic aluminium surface.