Fabrication of Polymer Film with Low Adhesion and High Hydrophobicity Using Locust Wing as a Bio-template

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Abstract: The special wettability and micro/nano-structure of locust wing were investigated by a video-based contact angle (CA) meter and a scanning electron microscope (SEM). The wetting mechanism was discussed from the perspective of biological coupling. Locust wings were used as biomimetic templates to fabricate multi-functional polymer (PDMS, polydimethylsiloxane) films by soft lithography. The natural wing surface exhibits hierarchical micro/nano-structures and high adhesive superhydrophobicity, the water CA is 152°, the water sliding angle (SA) is higher than 180°. The prepared polymer film reproduces faithfully the surface microstructures of the bio-template, and displays a good hydrophobicity and high adhesion (CA 148°, SA>180°). The complex wettability of the natural and artificial locust wing surfaces ascribes to the coupling effect of material element (hydrophobic composition) and structural element (rough micro-morphology). Locust wing can be employed as a biomimetic template for design and fabrication of special functional surface.

Keywords: Hydrophobicity, Adhesion, Fabrication, Biomimetic, Locust.

1. Introduction

The interfacial material with special properties and functions is attracting more and more attention due to valuable theoretical importance and application potential in industrial and domestic fields [1]. In recent years, many researches on superhydrophobic and self-cleaning surfaces have been focused on lotus leaf, on which a droplet displays a special Cassie state called “lotus state” (low adhesive superhydrophobicity) [2]. However, little has been focused on another special contact state of a droplet on hydrophobic surface called “Gecko state” (high adhesive superhydrophobicity). The superhydrophobic material with high adhesion can be used as a “mechanical hand” in no-loss microfluidic transport [3]. After millions of years of evolution, many animals and plants have possessed distinctive body surfaces which are superhydrophobic, self-cleaning, anti-adhesive, anti-corrosive and anti-wearing [4]. Inspired by the complex hierarchical morphologies in biological systems, some biomimetic materials have been prepared by vapor deposition, interference lithography, plasma treatment and sol-gel technique. We have done some work on microstructure and wettability of butterfly wing [5], in this work it was found that the locust wing is of high adhesive superhydrophobicity. The locust wing was used as a template to fabricate biomimetic polymer films by soft lithography. The result may bring interesting insights into the design of micro-controllable superhydrophobic surface and fabrication of novel self-cleaning material.

2. Materials and Methods

2.1 Materials and Reagents

Locust specimens (*Atractomorpha lata*) were collected in Changchun City, Jilin Province of northeast China. The wings were cleaned, desiccated and flattened, then cut into pieces of 8 mm×8 mm from the hind wing. The PVA (polyvinyl alcohol) used in the first soft transfer was purchased from Sinopharm Chemical Reagent Co., Ltd, China. The PDMS (Sylgard 184 Silicone Elastomer Kit) used in the second soft transfer was purchased from Dow Corning, USA.

2.2 Preparation of Biomimetic Polymer Film

In the first soft transfer, the wing piece was affixed to a glass slide with double-sided adhesive tape as the primary template. PVA solution (mass concentration 10%) was dropped homogeneously on the wing. After 24 h under the ambient temperature of (25±1) ℃, the PVA film with the inverse structure of the wing was peeled carefully off the primary template. In the second soft transfer, the prepared PVA film was affixed to a glass slide with double-sided adhesive tape as the secondary template. The prepolymer PDMS and curing agent were mixed in a volume ratio of 10:1. The PDMS mixture was dropped homogeneously on the surface of PVA film, then degassed in a vacuum chamber. Having been baked at 120 ℃ for 1.5 h, the PDMS was solidified and could be peeled off the secondary template with tweezers. The surface structures on the prepared PDMS film were similar to those on the natural locust wing.

2.3 Measurement of Wetting Angles

Using an optical CA measuring system (DataPhysics OCA20, Germany), the water CA of the wing was measured by sessile drop method at room conditions of (25±1) ℃ and relative humidity of approximately 80%. The water droplet was dripped on the sample table in a horizontal position, then the inclination degree of the table was raised 1° each time until the droplet rolled off freely. The inclination degree of the table was recorded as the SA value.

2.4 Characterization of Surface Microstructure

After gold coating (approx. 15 nm) by an ion splash instrument (Hitachi E-1045, Japan), the natural and artificial wing surfaces were observed, photographed and characterized under a SEM (Hitachi SU8010, Japan).

3. Results and Discussion

3.1 Micro-morphology of the Wing Surface

The locust wing surface possesses complicated hierarchical microstructures. The wing veins are very clear as grids, constituting the primary microstructure of wing surface [Fig. 1(a)]. The micrometric pillar gibbosities with uniform size distribute regularly and densely in the vein grids, constituting the secondary microstructure of wing surface [Fig. 1(b)]. The diameter of gibbosity is 5.4~8.6 μm, the height is 4.9~7.2 μm, the spacing is 10.4~13.7 μm. The numerous nano corrugations between pillar gibbosities constitute the tertiary microstructure of wing surface [Fig. 1(c)].

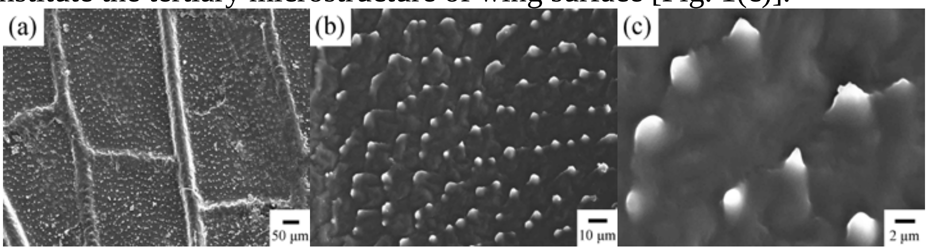

Fig. 1 Hierarchical rough microstructure of the locust wing surface (SEM images)
(a) Primary microstructure (wing veins); (b) Secondary microstructure (pillar gibbosities); (c) Tertiary microstructure (nano corrugations).

3.2 Micro-morphology of the Biomimetic Surface

After the first soft transfer, the prepared PVA film exhibits the inverse structure of the wing surface. The reverse hollow arrays [Fig. 2(a)] and pillar gibbosities [Fig. 2(b), 2(c)] can be found on the PVA film, including macrogrooves and porous microstructures. The width of the macrogrooves is 17.6 μm. The diameter of the porous microstructures is 6.5 μm, the spacing is 10.3 μm.

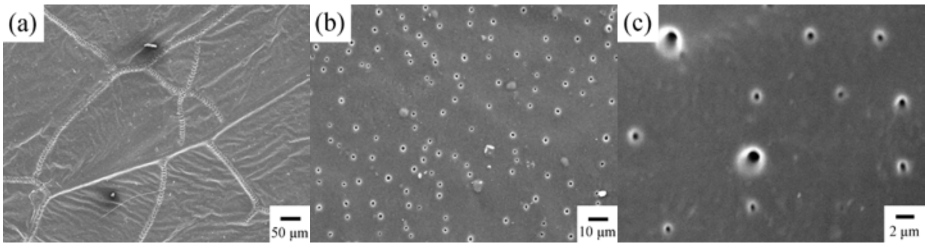

Fig. 2 Micro-morphology of the prepared PVA films (SEM images)
(a) Inverse structure of wing veins; (b), (c) Inverse structures of pillar gibbosities.

After the second soft transfer, the PDMS films were prepared. The macro/micro/nano structures on the natural wing surface are retained on the PDMS film. The wing vein is very clear [Fig. 3(a)]. The length of the rectangular vein grid ranges from 582 nm to 736 nm, the width from 158 nm to 229 nm. The size and distribution of primary and secondary structures are the same as those on the natural locust wing surface [Fig. 3(b)]. The diameter and spacing of the gibbosities are 6.5 μm and 11.6 μm, respectively. Some nanostructures can also be observed [Fig. 3(c)]. The artificial wing surface duplicates the structures on the natural locust wing surface very well.

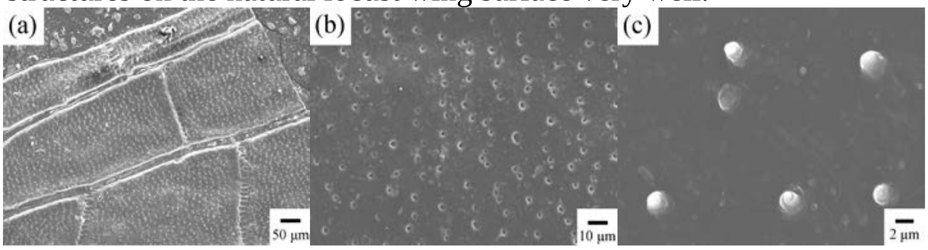

Fig. 3 Micro-morphology of the prepared PDMS films (SEM images)
(a) Artificial wing veins; (b), (c) Artificial pillar gibbosities.

3.3 Complex Wettability of the Natural and Artificial Locust Wing Surfaces

The water droplet stands on locust wing as a sphere. The CA of water droplet on locust wing is 152°, showing that locust wing is a natural bio-surface with superhydrophobicity. The diameter of a water droplet is about 2.1 mm, far outweighing the spacing (10.4~13.7 μm) of pillar gibbosity. The droplet can neither enter totally the grooves between gibbosities, nor contact fully with wing surface. A composite contact occurs. Owing to the chemical composition (waxy layer), the wing surface can achieve hydrophobicity (CA 105°); owing to the multiple-dimensional rough microstructure, locust wing can achieve superhydrophobicity (CA over 150°). The combination of hydrophobic composition and rough hierarchical microstructures contributes to the superhydrophobicity of the wing surface.

Meanwhile, the water droplet displays high adhesion on locust wing, and appears as a “Gecko state”. The droplet does not leave wing surface at any angle of inclination, even verticalized or inverted [Fig. 4(a), (b)]. This property resembles that of peanut leaf and rose petal [2]. Apart from superhydrophobicity, a “Gecko state” droplet exhibits high adhesion and can be pinned on the substrate effectively; whereas a “Lotus state” droplet exhibits low adhesion and extremely small CA hysteresis. The wing surfaces of locust and butterfly (both belonging to Class Insecta) show high adhesive superhydrophobicity and low adhesive superhydrophobicity, respectively, which result from their different surface microstructures. The spacing between micrometric gibbosities on locust wing (averagely 11.85 μm) is 6.8 times of that on butterfly wing (averagely 1.74 μm). The density of micrometric gibbosity on locust wing is far smaller than that on butterfly wing [6]. On a locust wing, the micrometric structures can be partially wetted by water droplets. Relatively less air is trapped and sealed between water droplet and wing surface. As a water droplet is removed from the locust wing, negative pressure is produced due to the exchange of confined air, so high adhesive force is induced. While on a butterfly wing, a water droplet stands on the tips of micrometric gibbosities, much air remains under the droplet. The solid-liquid-gas triple contact lines (TCL) are expected to be contorted and extremely unstable, leading to the low adhesion between the water droplet and the butterfly wing.

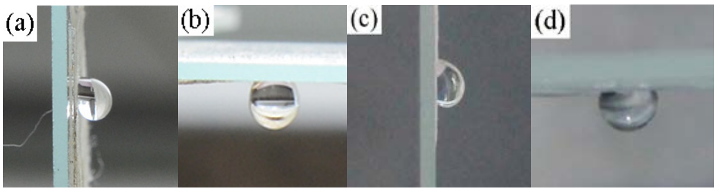

Fig. 4 Contact conditions of a water droplet on the locust wing and PDMS film
(a), (b) On the vertical and inverted locust wing; (c), (d) On the vertical and inverted PDMS film.

The prepared rough PDMS film displays a high hydrophobicity, the water CA on it is 148°. Whereas, the water CA on the smooth PDMS film is just 116°. The artificial PDMS film also has high adhesion [Fig. 4(c), (d)]. The prepared PDMS film does not achieve the superhydrophobicity of the locust wing because of the partial reproduction of nanostructure. It can be concluded that the superhydrophobicity of the locust wing is determined cooperatively by micro/nano-structures. Up to now the reproduction of nanostructure is one of the methodological difficulties in the field of biomimetic materials.

4. Conclusions

Locust wing surface possesses multi-dimensional rough microstructures (primary structure, secondary structure, and tertiary structure) and high adhesive superhydrophobicity (CA 152°, SA>180°). Using locust wing as template, polymer (PDMS) films with multifunction were prepared successfully by a two-step soft imprint method. The prepared PDMS films reproduce faithfully the macro/microstructures of the bio-template and exhibit a good hydrophobicity and a high adhesion (CA 148°, SA>180°). The fabrication method in this paper is simple, efficient and reliable, without the need for costly apparatus and processing. The cooperation of the multi-dimensional surface structures and hydrophobic composition is the origin for the special wettability of locust wing and artificial polymer film. It is believed that locust wing can serve as a biomimetic template for novel multi-functional devices. This work may bring interesting insights for preparation of micro-controllable superhydrophobic surface and no-loss microfluidic transport channels.

Acknowledgments

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