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Superhydrophobic Materials for Biomedical Applications

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Abstract

Superhydrophobic surfaces are actively studied across a wide range of applications and industries, and are now finding increased use in the biomedical arena as substrates to control protein adsorption, cellular interaction, and bacterial growth, as well as platforms for drug delivery devices and for diagnostic tools. The commonality in the design of these materials is to create a stable or metastable air state at the material surface, which lends itself to a number of unique properties. These activities are catalyzing the development of new materials, applications, and fabrication techniques, as well as collaborations across material science, chemistry, engineering, and medicine given the interdisciplinary nature of this work. The review begins with a discussion of superhydrophobicity, and then explores biomedical applications that are utilizing superhydrophobicity in depth including material selection characteristics, *in vitro* performance, and *in vivo* performance. General trends are offered for each application in addition to discussion of conflicting data in the literature, and the review concludes with the authors' future perspectives on the utility of superhydrophobic surfaces for biomedical applications.

Keywords

Superhydrophobic, Biomaterials, Polymers, Drug Delivery, Tissue Engineering, Diagnostics, High Throughput Assays

1. Introduction

Superhydrophobic materials maintain air at the solid-liquid interface when in contact with water. These surfaces possess high apparent contact angles, by definition exceeding 150°, as a result of the composite solid-air surface formed under a water droplet (**Figure 1a**). An additional stipulation sometimes included in the superhydrophobic definition, depending on the application, is a low roll-off angle [1]. Cassie and Baxter are credited with first reporting the basis of superhydrophobicity in 1944 [2], expanding on the work by Wenzel in 1936 [3]. They demonstrated that porous hydrophobic surfaces exhibit high apparent contact angles compared to chemically equivalent flat substrates because of the maintenance of air at this interface. The very rough, hydrophobic substrate affords a partially wetted initial state, with a large air-water surface area, which serves as an energetic barrier that stabilizes the air. Cassie and Baxter specifically studied this effect in order to understand the water repellency of natural and synthetic clothing, and showed that porous, wax-covered textiles exhibit high apparent contact angles. They went on to discuss the roughness of feathers and fur and the resultant water repellent properties. Superhydrophobicity is a property of many naturally occurring substrates including plant leaves [4–8], many insect features including wings, legs, and eyes [9–16], feathers [17,18], fur [19], and beetle shells [20] (**Figure 1b**). Superhydrophobicity on these natural surfaces leads to improved function by providing water repellency or alternatively providing a self-cleaning surface where debris and pathogens are removed as water contacts and subsequently rolls off the surface. For example, dragonflies in the order *Odonata* possess a rough, fractal structure on their wings that aids in cleaning and preventing water adherence which inhibits flight [21]. A significant body of research now exists documenting that

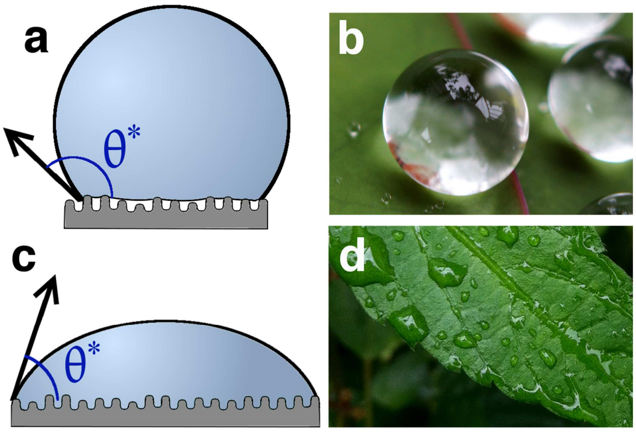

Figure 1. Diagram of wetting states on rough materials and examples in nature. **a)** The Cassie-Baxter (CB) partially wetted state and **c)** the Wenzel complete wetting state. Examples of natural materials are **b)** lotus leaves, which are the canonical example of a natural superhydrophobic material, and **d)** the hydrophilic leaves of petunias in genus *Ruellia*. Photos are courtesy of Takashi Matsuzawa and Mark Swanson.