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Droplet Mobility on Hydrophobic Fibrous Coatings Comprising Orthogonal Fibers

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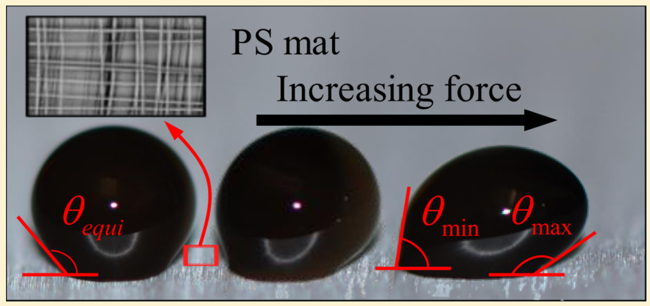
Supporting Information

ABSTRACT: Water droplet mobility on a hydrophobic surface cannot be guaranteed even when the droplet exhibits a high contact angle (CA) with the surface. In fact, droplet mobility on a surface, especially a fibrous surface, has remained an unsolved empirical problem. This paper is a combined experimental−computational study focused on droplet mobility on a fibrous surface. Electrospun polystyrene (PS) coatings were used in this work for their ability to exhibit high CAs simultaneously with low droplet mobility. To simplify this otherwise complicated problem and better isolate droplet−fiber interactions, the orientation of the fibers in the coatings was limited to the *x* and *y* directions. As the earth gravity was not strong enough to mobilize small droplets on PS coatings, experiments were conducted using ferrofluid droplets, and a magnet was used to make them move on the surface. Experimentally validated numerical simulations were used to enhance our understanding of the forces acting on a droplet before moving on the surface. Effects of Young−Laplace CA and fiber−fiber spacing on droplet mobility were investigated. In particular, it was found that droplet mobility depends strongly on the balance of forces exerted on the droplet by the fibers on the receding and advancing sides.



INTRODUCTION

Hydrophobicity is proven to be the required attribute for a surface used in applications involving anti-icing (e.g., refs[1−3]), water-droplet separation (e.g., refs 4 and 5), drag reduction (e.g., refs[6−8]), fog harvesting (e.g., refs 9 and 10), and self-cleaning (e.g., refs[11,15]), among others. Self-cleaning is a desirable property that allows a surface to remain clean for a longer period of time.[11−15] There are two main requirements for such a surface. The first requirement is to allow the liquid to bead up on the surface, and the second is to allow the droplet to move on the surface.[11−15] Although there has been tremendous progress in creating a surface on which a droplet beads up, there has not been much progress in guaranteeing that this surface also promotes droplet mobility, especially if it is made of fibers.[16−26] The focus of the work presented here is therefore to study droplet mobility on hydrophobic fibrous surfaces with low droplet mobility, the so-called rose petal effect.[27−31] Fibrous coatings are usually made by depositing fibers on top of one another. Although a droplet can exhibit high apparent contact angles (ACAs) on such surfaces, its adhesion to the surface may be very unpredictable.[22−31] The root cause of this problem is the empirical nature of the current surface manufacturing procedures in which a fibrous surface is first manufactured and then it is tested for droplet mobility. An ambitious but yet logical alternative to the traditional manufacturing approach would be to first design and test the surface virtually and then manufacture it if the performance was acceptable. This futuristic approach obviously requires detailed information about the impact of the surface micro-scale morphology on the forces acting on a droplet. The study presented in this paper is therefore aimed at providing additional insight into the physics of droplet−fiber interactions specific to fibrous hydrophobic coatings.

The remainder of this paper is organized as follows. We first discuss the challenges involved in determining droplet mobility on a fibrous surface and the approaches considered in prior studies. We then present a quick overview of our experimental and computational methods, which also includes a validation study custom-designed to examine the accuracy of the computational and experimental results against one another. At the end, we discuss the contribution of each individual fiber in contact with a droplet in the total force resisting against droplet mobility.

ADVANCING AND RECEDING CAs ON A FIBROUS SURFACE

Predicting droplet mobility on a rough surface, that is, the tendency of the droplet to move on the surface in response to

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