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Wetting states of superhydrophobic surfaces made of polygonal pores or posts

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In this work, a mathematical framework is developed to describe some of the important intermediate wetting states of a superhydrophobic surface between the two extreme states of Cassie and Wenzel. The superhydrophobic surfaces considered here are comprised of sharp-edged polygonal pores or posts. Two different critical pressures are defined in this work, and used to distinguish pinned, partially pinned, and de-pinned air–water interfaces from one another. This information, in particular, is used to develop predictive expressions for the critical pressure and wetted area of the surfaces. Good agreement is observed between the predictions of our expressions and those obtained from numerical calculations or experiment. The work presented here compares the pressure-dependent performances of the superhydrophobic surfaces having different pore or post designs with one another. *Published by AIP Publishing.*
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I. INTRODUCTION

Surfaces promoting a water droplet contact angle of 150° or greater are often referred to as superhydrophobic (SHP) surfaces.[1] Superhydrophobicity can be achieved by adding micro- or nano-scale asperities to a hydrophobic surface.[2,3] When an SHP surface comes into contact with water (e.g., when it is submerged), it may entrap some air in its pores, resulting in the formation of the so-called Cassie state, in which the contact area between the solid material and water is reduced. A surface in the Cassie state may exhibit a reduced skin-friction drag if exposed to a moving body of water.[4,5] However, the Cassie state may become unstable under elevated pressures, causing the surface to transition to the so-called Wenzel (fully wetted) state. The pressure at which such a transition takes place is generally referred to as the critical pressure, and it has been investigated in many previous studies.[6–12] In fact, an SHP surface may experience a series of transition states in between the Cassie and Wenzel states, depending on the hydrostatic/hydrodynamic pressure applied to the surface and its microscale geometry.[13–18] Therefore, the solid–water contact area (and so the skin-friction drag) may depend on the shape and position of the air–water interface (AWI) between the peaks and valleys of the surface at each transition state (see for instance, Refs. 5, 19, and 20). An example of how skin-friction drag over an SHP surface comprised of round asperities may vary with hydrostatic pressure is given in the work of Refs. 21–23. Conducting a similar study for surfaces that have sharp asperities is more challenging, as the AWI tends to pin itself to the sharp corners of these asperities. A pinned AWI often experiences a partial de-pinning process when the hydrostatic pressure is increasing. The de-pinning process can be difficult to predict accurately as it depends strongly on the surface microscale geometry. This, in turn, makes it challenging to predict the solid–water contact area (wetted area) and the skin-friction drag of the surface. The current research is devised to shed some light on the behavior of SHP surfaces that promote partial de-pinning. For the sake of simplicity, the study is limited to SHP surfaces comprised of polygonal posts or pores (sharp asperities with ordered spatial distributions). Similar to many previous studies, a force balance method, as it applies to an AWI in equilibrium, is considered in the present work, but the boundary conditions are modified here to simulate additional critical pressures and AWIs as will be discussed later.[11,18,19,24–26]

As will be discussed later, critical hydrostatic pressure (CHP) and wetted area will be calculated in this paper for SHP surfaces made of polygonal pores or posts, and the results will be discussed with respect to those reported for surfaces comprised of circular posts or pores with comparable geometric properties. The remainder of this paper is organized as follows. Section II presents our force balance formulations for surfaces comprised of polygonal asperities. These equations are then solved for surfaces with different pore (Section III A) and post (Section III B) shapes to produce predictive correlations for the surface critical pressures and wetted area. Detailed comparison between the predictions of the above correlations and previously reported data from literature and our capillary rise experiment is given in Section IV. This is followed by our conclusions in Section V.

II. FORMULATIONS

As previously stated, critical pressure is generally assumed to be the pressure at which an SHP surface starts transitioning from the Cassie state to the fully wetted state. However, depending on the hydrostatic pressure and surface geometry, an SHP surface may experience a series of

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