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Effects of hydrostatic pressure on the drag reduction of submerged aerogel-particle coatings

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ABSTRACT

There are several techniques to fabricate superhydrophobic surfaces. The one used in this paper is closer to natural surfaces found, for example, on lotus leaves. Herein, hydrophobic aerogel particles with different average diameters are randomly deposited onto metallic substrates with a thin adhesive coating to achieve a combination of hydrophobicity and surface roughness. The resulting surfaces show different degrees of superhydrophobicity and are used to study the effects of elevated pressure on the drag reduction and the degree of hydrophobicity (survivability) of such surfaces when used for underwater applications. Several previous studies presented numerical and/or analytical models to evaluate the influence of pressure on the superhydrophobicity. Experimental studies, however, are lacking. In this work, we measure the impact of pressure on the stability of the meniscus (air–water interface). The experiments utilize three instruments: (i) a previously developed optical technique to characterize the time-dependent hydrophobicity in conjunction with a pressure vessel in which the submerged coating is exposed to elevated pressures; (ii) a parallel-plate rheometer where the coating's slip length and drag reduction are measured; and (iii) a goniometer to measure the static contact angle as well as contact-angle hysteresis. We also developed an image-thresholding technique to estimate the gas area fraction of the coating. The results indicate that there exists a new parameter, the terminal pressure, beyond which the surface undergoes a global transition from the Cassie state to the Wenzel state, and therefore can no longer generate drag reduction. This *terminal pressure* differs from the previously identified *critical pressure*. The latter is the pressure above which the surface starts the transition process at some location, but not necessarily at other spots due to the heterogeneity of the surface. For the particle coatings used herein, the terminal pressures are measured to range from 100 to 600 kPa, indicating that such coatings could potentially be used for deep underwater applications.

1. Introduction

Surfaces with static contact angles (CA) greater than 150° and significantly low contact-angle hysteresis are typically classified as superhydrophobic. Superhydrophobicity is exhibited in materials with a combination of low surface free-energy and micro- and/or nanoscale surface roughness. Amongst many others, examples of such surfaces in nature are the self-cleaning lotus leaves [1] and water striders [2]. When submerged, these surfaces can entrap air between their micro- or nanostructures resulting in a surface with both air–water and solid–water interfaces. The presence of the air–water interface is responsible for the slip effect, which could be characterized by the so called "slip length" [3]. This in turn results in a reduction in the skin-friction drag exerted on a moving surface [4,5]. Drag is the force produced by a fluid to resist the relative motion of a submerged solid. That force is the sum of the pressure drag, which mostly results from flow separation, and the skin-friction drag, which results from the no-slip condition. The latter component is reduced when partial flow slip takes place. Superhydrophobic coatings provide a relatively simple, passive drag-reduction method, and may potentially become a viable alternative to the more complex and energy consuming active or reactive flow control techniques such as wall suction/blowing [6]. There are at least three challenges to overcome before field applications are feasible: (1) scaling up the application of superhydrophobic coatings to large submersibles; (2) achieving low-cost fabrication; and (3) preventing the entrapped air from escaping under pressure for reasonably long time, or at least periodically *rejuvenating* the surface.

Superhydrophobic surfaces have often been produced using the same microfabrication techniques developed for the electronic industry, and in many cases consist of a regular array of microposts or microridges [7,8]. Orientation with respect to the flow, spacing, and aspect ratio of the microstructure could be adjusted

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