In situ, noninvasive characterization of superhydrophobic coatings

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Light scattering was used to measure the time-dependent loss of air entrapped within a submerged microporous hydrophobic surface subjected to different environmental conditions. The loss of trapped air resulted in a measurable decrease in surface reflectivity and the kinetics of the process was determined in real time and compared to surface properties, such as porosity and morphology. The light-scattering results were compared with measurements of skin-friction drag, static contact angle, and contact-angle hysteresis. The *in situ*, noninvasive optical technique was shown to correlate well with the more conventional methods for quantifying surface hydrophobicity, such as flow slip and contact angle. © *2011 American Institute of Physics*. [doi:10.1063/1.3579498]

I. INTRODUCTION

Superhydrophobicity is a surface property resulting from a combination of material hydrophobicity and micro- or nanoscale surface roughness. The phenomenon is primarily characterized by water droplets beading on the solid surface with contact angles exceeding 150°. As water flows over such surface, "slip effect" is produced resulting in a reduction in the skin-friction drag exerted on the surface.[1] Superhydrophobic coatings can be utilized as a passive method of flow control 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.[2] Most engineered superhydrophobic surfaces are made up of microposts or microridges manufactured via microfabrication techniques. As reviewed by Samaha *et al.*,[3] such surfaces have been extensively studied in the last few years experimentally, analytically, and numerically.[4–10]

A submerged superhydrophobic surface can entrap air between the microposts or microridges resulting in a surface with both air–water and solid–water interfaces. The presence of the air–water interface is responsible for the measurable decrease in shear stress. Cheng *et al.*[11] calculated the influence of the total shear-free area or the air–water interface area (at which slip effect takes place) as well as its dependency on slip length. The stability of the air–water interface (meniscus), i.e., the sustainability of the interface for conversion from nonwetted (Cassie) to wetted (Wenzel) state, against pressure for the staggered microposts was reviewed by Lee *et al.*[12] Samaha *et al.*[3] performed similar studies to numerically calculate both drag reduction and slip length and mathematically estimate the stability limit of the air–water interface for superhydrophobic surfaces with random roughness, e.g., surfaces made via random particle deposition.[13,14] As long as the air is entrapped, the surface remains hydrophobic. In other words, the degree of hydrophobicity and hence the beneficial effects are diminished by the reduction of the amount of air. The longevity of a superhydrophobic surface was studied by Bobji *et al.*[15] They used an optical technique to measure how long the surface can entrap air underwater by measuring the number of shiny spots, each is an indication of an interface between air and water. Similar studies were performed using a laser beam to investigate the effect of the surface structure on longevity.[16]

The objective of the present study is to advance and calibrate a novel optical technique to noninvasively measure the longevity of submerged superhydrophobic coatings subjected to different environmental conditions. We used an optical spectroscopy system to quantify the intensity of reflected light in the visible range scattered from a superhydrophobic surface completely submerged in a controlled water vessel. The time-dependent light-reflection intensity could be measured at a single wavelength or integrated over a range of wavelengths. It is desirable to measure *in situ* the degree of hydrophobicity of coatings fabricated with different techniques and subjected to different environments. Those environments are not possible to reproduce during traditional contact-angle or rheometer measurements and include a broad range of water pressures (i.e., depths), constant or time-dependent pressures, water with different degrees of salinity or dissolved air, still or moving water, etc. However, the novel optical technique developed herein needs to be calibrated against traditional methods for measuring hydrophobicity.

The optical spectroscopy system used herein was previously utilized for different purposes and applications. In geochemistry, e.g., it was used to screen soil and sediment to study the distribution of heavy metals along soil profile.[17] In biology, it was used to detect and classify bacterial pathogens.[18] In chemistry, it was used to study the excitation and reaction of chemical solutions.[19] All of these examples and others prove the precision of this device, which motivated us to use it to measure the time-dependent surface's hydrophobicity.

In order to validate this novel technique, the results were compared with drag-reduction data using a rheometer, as well as static contact angle and contact-angle hysteresis using a

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