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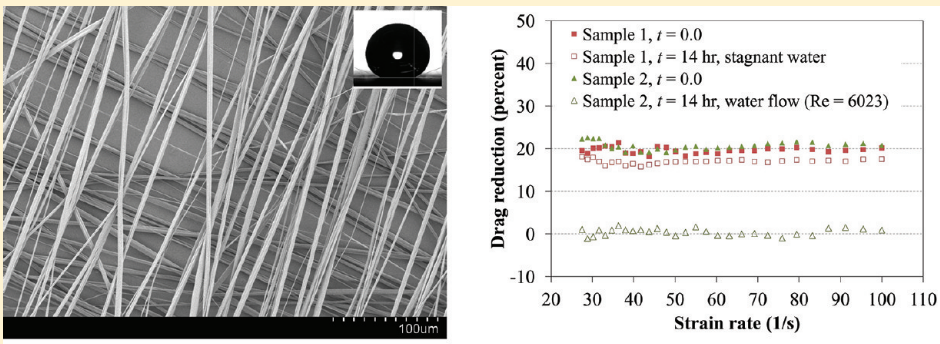
Influence of Flow on Longevity of Superhydrophobic Coatings

Mohamed A. Samaha, Hooman Vahedi Tafreshi, and Mohamed Gad-el-Hak*

Department of Mechanical & Nuclear Engineering, Virginia Commonwealth University, Richmond, Virginia 23284-3015, United States



ABSTRACT: Previous studies have demonstrated the capability of superhydrophobic surfaces to produce slip flow and drag reduction, which properties hold considerable promise for a broad range of applications. However, in order to implement such surfaces for practical utilizations, environmental factors such as water movement over the surface must be observed and understood. In this work, experiments were carried out to present a proof-of-concept study on the impact of flow on longevity of polystyrene fibrous coatings. The time-dependent hydrophobicity of a submerged coating in a pressure vessel was determined while exposing the coating to a rudimentary wall-jet flow. Rheological studies were also performed to determine the effect of the flow on drag reduction. The results show that the longevity of the surface deteriorates by increasing the flow rate. The flow appears to enhance the dissolution of air into water, which leads to a loss of drag reduction.

1. INTRODUCTION

Superhydrophobicity is a surface property that can be achieved by a combination of low surface energy and micro- or nanoscale surface roughness. The phenomenon is primarily manifested by water droplets beading on the solid surface with contact angles exceeding 150°. When submerged, these surfaces can entrap air between their micro- or nanostructures resulting in a surface with alternating air−water and solid−water interfaces. The presence of the air−water interface is responsible for the "slip effect", resulting in a reduction in the skin-friction drag exerted on a moving surface. The reader is referred to the review papers by Rothstein,[1] Shirtcliffe et al.,[2] and Samaha et al.,[3] and references therein. 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.[4] One of the challenges to overcome before field applications are feasible is slowing down the rate of loss of entrapped air to the environment when the coating is exposed to water flow. Longevity—the time until transition from dewetted (Cassie) to wetted (Wenzel) state—is the focus of this paper.

Superhydrophobic surfaces are often produced using the same microfabrication techniques developed for the electronic industry and in many cases consist of a regular array of microposts or microridges.[5−7] Large-scale manufacturing of microfabricated superhydrophobic surfaces is prohibitively expensive. An alternative solution to circumvent the high cost is to produce surfaces made up of random deposition of hydrophobic particles[8−13] or electrospun fibers.[14,15] Electrospinning of superhydrophobic polymers is a simple, low-cost method that can be used to deposit micro- to nanofibrous coatings onto substrates of arbitrary geometry. The resulting superhydrophobic surfaces could be applied in various ways, including self-cleaning, protection from corrosion, and reduction of skin-friction drag in underwater vessels such as submarines. Among several, three recent studies are related to the last application and the particular interest of the present paper. First, Shirtcliffe et al.[16] have developed a technique to cover the inside wall of a small copper tube (radius less than a millimeter) with a superhydrophobic surface and demonstrated drag reduction in laminar pipe flow. Second, McHale et al.[17] demonstrated that the drag reduction could be produced for a sphere coated with a superhydrophobic surface. Third, the same group[18] showed that the drag reduction diminishes as a superhydrophobic surface is subjected to higher flow rates.

In 2006, Liu and Lange[19] provided a theoretical model to predict the so-called "critical pressure" at which a superhydrophobic surface starts departing from the Cassie state. Other numerical and analytical studies to predict the critical

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