International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 30, No. 4, December 2020, pp. 456–462; https://doi.org/10.17736/ijope.2020.mt28

http://www.isope.org/publications

Manufacture and Characterization of Hot-Embossed Superhydrophobic Surfaces

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Superhydrophobic surfaces have raised a great deal of attention in recent years because of their numerous potential applications. In this work, a method of manufacturing "large" superhydrophobic surfaces using very fine stainless steel mesh to "hot-emboss" hydrophobic polytetrafluoroethylene (PTFE) surfaces is provided. A high static contact angle and low contact angle hysteresis for these "xPTFE" superhydrophobic surfaces were measured as approximately 150° and 15°, respectively. The surfaces' structures were investigated via scanning electron microscopy (SEM). Otherwise, the slip-length was measured using a rheometer as approximately 30 μm, which indicates a great potential drag reduction. This easy and inexpensive method could be a great step to bring superhydrophobic surfaces into real-world use.

INTRODUCTION

Raindrops will stick to glass surfaces but not to the leaves of certain plants such as rice and lotus. This phenomenon is the well-known "lotus effect." Some plant leaves, like lotus and rice leaves, are highly water-repellent: small water drops stand on such surfaces in an almost perfect spherical shape and very easily roll off. Inspired by nature, superhydrophobic surfaces have attracted a great deal of attention in recent decades because of their numerous potential applications, such as self-cleaning surfaces (Cheng and Rodak, 2005; Neinhuis and Barthlott, 1997), surfaces with reduced friction for drag reduction (e.g., for hydrodynamically efficient ship design and drag-reducing pipe flows), and icephobic surfaces (Nosonovsky and Hejazi, 2012) for wind turbine blades. Superhydrophobic surfaces can be characterized by using several wetting properties. The most convenient one is the static contact angle. The contact angle is the angle that is measured through a liquid, where the liquid–vapor interface meets a solid surface. A surface with a contact angle less than 90° is a hydrophilic surface; otherwise, it is a hydrophobic surface. A superhydrophobic surface can be defined simply as a surface that has a very high contact angle (typically greater than 150°) and low contact angle hysteresis (Tian et al., 2016).

The wetting properties (e.g., static contact angle, contact angle hysteresis, etc.) of a surface depend mainly on two factors: (1) the surface free energy, determined by the chemical nature of the surface material, of the interaction between the liquid and the topmost solid molecular layer; and (2) the surface roughness (Feng et al., 2002). Superhydrophobicity arises from a combination of these two factors, and the latter is the dominant factor. Utilizing these two factors, many methods have been developed to manufacture superhydrophobic surfaces, including physical methods, chemical methods, plasma methods, laser methods, and photolithography methods. Currently, a few commercial methods are available and have achieved some success despite their shortcomings, such as lack of resilience, UV sensitivity, and the high cost of manufacturing "large" surfaces. In this work, a cheap and repeatable method of fabricating relatively large superhydrophobic surfaces was achieved.

Besides the water repellence and high static contact angle of the superhydrophobic surfaces, the potential for flow drag reduction is one of the most attractive potential industrial applications. However, it is typically difficult to experimentally measure how easily water will slip past the surface, or how much the drag will be reduced, because the sizes of available superhydrophobic surfaces are small and their resilience to wear is low (Voronov et al., 2008). Drag reduction can occur for a superhydrophobic surface that maintains a Cassie–Baxter state forming the liquid–solid–gas interface. Obviously, the drag between gas and liquid is significantly lower than that between liquid and solid. This phenomenon has potentially enormous economic and technological applications in fluids engineering. Navier (1823) first proposed the concept of "slip-length" to describe the drag provided by a "slip" boundary condition, which is unlike the normal "no-slip" boundary condition. Under this boundary condition, the flow velocity at the boundary is not zero. The slip boundary is defined as an extrapolated distance relative to the wall where the tangential velocity component is equivalent to zero (Lee et al., 2016). Nevertheless, the value of the slip-length is very small for most surfaces and difficult to measure. There are limited slip-length measurements for superhydrophobic surfaces in existing studies. In this work, the slip-length was carefully measured, and the method of measurement is detailed.

MANUFACTURE OF XPTFE SURFACES

Superhydrophobicity can be produced in two ways. One way is to create a rough structure on a hydrophobic surface, which has a water contact angle greater than 90°; the other way is to modify a rough surface with materials with low surface free energy. Polytetrafluoroethylene (PTFE) is a potential material with one of the lowest surface free energies and coefficients of friction against any solid (Dupont, 1996) and with good flexibility to follow any surface curvature for industry applications. (e.g., turbine blades, cylinders, etc.) Several studies, such as Zhang et al. (2004), Yabu and Shimomura (2005), Erbil et al. (2003), and Nilsson et al. (2010), have proved that creating nanoscale or micron-scale features on low surface free energy polymeric surfaces can produce superhydrophobicity. Here we follow a simple method suggested by a collabarator Professor Jonathan Rothstein (2014) from the

Received October 15, 2019; updated and further revised manuscript received by the editors January 11, 2020. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-ninth International Ocean and Polar Engineering Conference (ISOPE-2019), Honolulu, Hawaii, June 16–21, 2019.

KEY WORDS: Superhydrophobic, PTFE, drag reduction, slip-length.