Journal of Colloid and Interface Science 395 (2013) 315–321

Contents lists available at SciVerse ScienceDirect

Journal of Colloid and Interface Science

www.elsevier.com/locate/jcis

Novel method to characterize superhydrophobic coatings

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

Department of Mechanical & Nuclear Engineering, Virginia Commonwealth University, Richmond, VA 23284-3015, USA

ARTICLE INFO

Article history:
Received 17 November 2012
Accepted 25 December 2012
Available online 10 January 2013

Keywords:
Superhydrophobic coatings
Fibers
Aerogel
Buoyancy force
Effective thickness
Gas volume fraction
Coating's thickness

ABSTRACT

Superhydrophobic coatings possess a strong water-repellent characteristic, which, among several other potential applications, enhances the mobility of water droplets over the surface. The coating traps air within its micropores, such that a submerged moving body experiences shear-free and no-slip regions over, respectively, the air pockets and the solid surface. This, in turn, may lead to significant skin-friction reduction. The coating maintains its superhydrophobicity as long as the air remains entrapped. It is therefore of great interest to precisely measure the amount of trapped air, which is particularly difficult to estimate for coatings with disordered microstructures. A novel method to measure the *effective* thickness and gas volume fraction of superhydrophobic coatings with either ordered or random microroughness is advanced. The technique is applied to both aerogel and electrospun fibrous coatings. The experiments utilize a sensitive weighing scale (down to 10^{-4} gm) and height gauge (down to 10 μm) to determine the buoyancy force on an immersed, coated glass-slide substrate. The measured force is used to calculate the volume fraction of entrapped air. The coating's effective thickness also follows from the same calculations. The sensitivity of our particular scale enables the measuring of thicknesses down to 3 μm, which is not readily possible with conventional thickness gauges. Smaller thicknesses could be measured using more sensitive scales.

1. Introduction

1.1. Superhydrophobicity

Superhydrophobicity could be achieved by a combination of low surface energy (chemical hydrophobicity) and micro- or nanoscale surface roughness. Chemical hydrophobicity is a material property of repelling water, which is achieved when the chemical structure of the surface is sufficiently different from that of water. This leads to strongly reducing the ability of the surface to interact with water. The superhydrophobic phenomenon is primarily manifested by water droplets beading on the solid surface with contact angles exceeding 150°, and the droplets readily roll off when the surface is tilted at a small angle. In nature, superhydrophobic surfaces are exemplified by the lotus leaves, which enhance the mobility of rain drops on them, carrying dirt away, and creating a self-cleansing effect (so-called lotus effect). Neinhuis and Barthlott [1] obtained scanning electron microscopy (SEM) images for several water-repellent plants and reported the micromorphological characteristics of 200 species. They demonstrated that the epidermal (i.e., outermost) cells of the lotus leaf form papillae, which act as microstructure roughness. The papillae are topped off by a very dense layer of epicuticular waxes (hydrophobic wax crystals), also referred to as hair-like structures [2] or nanostructure roughness [3]. Over the past two decades, biomimetic research of the lotus effect evoked several studies on manufacturing, characterizing, and applying superhydrophobic surfaces [1–9].

A superhydrophobic surface entraps air in its pores, and when a coated body is fully submersed in water, alternating water–solid and water–air interfaces are formed. The entrapped air is separated from water with a thin interface anchored on the solid walls and stretched due to surface tension forces. It has been observed that a moving body of water "slips" over the air–water interfaces, whereas the water "sticks" to the solid portions of the surface [7]. Therefore, if the percentage of the surface covered by air pockets is sufficiently high, a superhydrophobic surface can cause the so-called "slip effect," resulting in a reduction in the skin-friction drag exerted on the surface [7]. As long as the air pockets exist, the surface remains superhydrophobic. In other words, the degree of hydrophobicity and the beneficial effects are diminished by the reduction of the amount of entrapped air [10–12]. The longevity of a superhydrophobic surface—how long the surface can maintain the air pockets—is critical, especially in underwater applications. An elegant experiment carried out by Sakai et al. [13] demonstrates the effect of surface microstructure on air-layer sustainability.

1.2. Fabrication

Early manmade superhydrophobic surfaces were produced using the same microfabrication techniques developed for the computer industry. The coatings typically consisted of a regular ar-

* Corresponding author.
E-mail address: gadelhak@vcu.edu (M. Gad-el-Hak).

0021-9797/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jcis.2012.12.066