Surface & Coatings Technology 277 (2015) 117–127

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Wetting resistance of heterogeneous superhydrophobic coatings with orthogonally layered fibers

T.M. Bucher, M.M. Amrei, H. Vahedi Tafreshi *

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

ARTICLE INFO

Article history:
Received 10 June 2015
Revised 16 July 2015
Accepted in revised form 17 July 2015
Available online 21 July 2015

Keywords:
Fibrous coatings
Superhydrophobicity
Contact angles
Dissimilar fibers
Wettability

ABSTRACT

Superhydrophobic coatings comprised of electrospun nanofibers are a low-cost alternative to micro-fabricated surfaces, and can be applied to substrates of any arbitrary geometry. Such coatings with orthogonally oriented layers have properties that allow their wetting resistance to be predictable for a range of solid volume fractions, fiber diameters, and contact angles. In this paper, we have presented a modeling strategy that solves for the air–water interface shape over several layers of such coatings to predict the resistance of superhydrophobic fiber coatings to hydrostatic pressures and to quantify the relationship between microstructure, meniscus penetration depth, and wetted surface area of the fibers. Slip length predictions are also provided to shed some light on the performance of such coatings in drag reduction applications. It was found that while failure pressure for a coating rises with reducing fiber spacing, there is a tradeoff with wetted fiber surface area relative to a bare substrate. This tradeoff can be offset, however, by using smaller fibers for an intended coating. This results in a higher failure pressure for the same wetted area fraction. The results generated in this work are discussed in relation to those reported in the literature whenever possible.

1. Introduction

A surface is regarded as superhydrophobic (SHP) when it exhibits an apparent contact angle with water greater than 150°. This is often achieved by applying a micro- or nano-scale roughness to a hydrophobic surface [1–4]. Such surfaces can be used for applications ranging from self-cleaning and drag-reduction to corrosion resistance and energy [4–6]. The essential attribute of SHP surfaces is their reduced water–solid contact area (wetted area) which helps decrease the friction between a moving body of water and the surface. This is due to the ability of SHP surfaces to trap air within their microstructure (see e.g., [7–10]). For an SHP surface in contact with water, the solid area in contact with water depends on both the surface morphology and the hydrostatic and/or hydrodynamic conditions of the system. A submerged SHP surface may be found to be in the Wenzel state (fully wetted), the Cassie state (fully dry), or in a series of transition states between the two extremes [9]. When an SHP surface comes into contact with water, the air–water interface (AWI) may penetrate into the pores of the surface depending on the wetting state of the surface. If the AWI penetrates too deeply into the pores, the SHP surface may no longer provide any drag reduction. In fact, it is quite possible that such a surface increases the drag force in certain hydrodynamic conditions [10].

A significant number of studies have been devoted to the manufacture and characterization of micro-fabricated roughness on a surface to impart superhydrophobicity (see e.g., [5]). However, fabricating micro- or nano-roughness remains a costly process, and applying them to geometries with arbitrary curvatures remains difficult. An alternative is to achieve the desired roughness by applying a hydrophobic material to the surface in the form of electrospun nanofibers [11–14] or apply a coating on the surface of a fibrous material [15–17]. The major problem with the conventional electrospinning process (or fibrous materials in general), however, is the lack of control over the orientation and spatial distribution of the fibers, making it difficult to predict the performance of the coating prior to its manufacturing. It has been shown that the conventional electrospinning process can be modified to produce coatings with some additional control over the orientation of the fibers and their spacing (e.g., [18–21]). Producing coatings with fiber layers arranged orthogonally with respect to one another similar to the one shown in Fig. 1 provides a means for engineering superhydrophobic coatings with more predictable performance. The example SEM image shown in this figure is from an electrospun superhydrophobic polystyrene mat with orthogonal fibers having an average fiber diameter of 2.4 μm and a mat solid volume fraction (SVF) of 7.5% [22,23]. Unlike coatings with random fiber orientations, orthogonally layered fiber mats have a degree of order to them that allows one to predict their overall performance based on an analysis conducted on a small portion of their structure, i.e., the spaces between

* Corresponding author at: Department of Mechanical and Nuclear Engineering, Virginia Commonwealth University, United States.
E-mail address: htafreshi@vcu.edu (H. Vahedi Tafreshi).
URL:E-mail address: http://www.people.vcu.edu/~htafreshi/ (H. Vahedi Tafreshi).

http://dx.doi.org/10.1016/j.surfcoat.2015.07.032