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Full Length Article

# Droplet adhesion to hydrophobic fibrous surfaces

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ABSTRACT

A water droplet can exhibit a high apparent contact angle on a hydrophobic fibrous surface. However, a high contact angle does not guarantee droplet mobility on the surface. The reasons behind droplet adhesion to a hydrophobic fibrous surface has not yet been analyzed or formulated. In this work, the force required to detach a droplet from a hydrophobic fibrous surface is investigated experimentally and computationally. Electrospun Polystyrene mats are considered for this study as they exhibit high contact angles coupled with poor droplet mobility. To better isolate the effects of microstructural properties of the mats and study their effects on droplet detachment, randomness of the fiber orientation is minimized by producing highly oriented fibers in orthogonal layers. As the earth gravity is not strong enough to detach small droplets from such surfaces, aqueous ferrofluid droplets are used in a controllable magnetic field to enhance the effect of gravity. The detachment process is recorded via a high-speed camera and the images are used to detect the moment of detachment and to analyze droplet shape before and during detachment. Numerical simulations are also conducted to provide additional insight into the physics of droplet detachment, and more importantly, to develop an equation for estimating droplet detachment force from a fibrous surface. In this paper, we discuss the effects of fiber properties, e.g., Young-Laplace contact angle or fiber spacing, on the force needed to detach a droplet from a fibrous surface.

## 1. Introduction

Coating a surface with hydrophobic fibers can serve as a cost-effective alternative to micro-fabricating a hydrophobic roughened surface, a surface characterized by high apparent droplet contact angles (ACAs) [1–8]. Fibrous coatings are usually made by depositing layers of randomly orientated fibers on top of one another, and while a droplet can exhibit high ACAs on such surfaces, its adhesion to the surface may still be quite strong and/or unpredictable [1–8]. Nevertheless, one can assume droplet adhesion to a surface to be somehow related to its contact angle(s) on that surface [9–14].

Previous studies have shown that a droplet deposited on a coating with unidirectional fibers may exhibit different ACAs in different directions [15–18]. Therefore, one can potentially improve or control the adhesion force between a droplet and a fibrous coating by controlling the orientation of the fibers. The easiest way to produce a fibrous mat with directional fibers is to deposit parallel fibers in orthogonal layers. This helps to produce coatings with reasonably controlled thickness and porosities [19–24]. As will be seen later in this paper, the strength of droplet adhesion to such a surface depends strongly on the extent of interactions between the orthogonal fibers and the droplet. In this work, we characterize these interactions both computationally, via finite element simulations, and experimentally, using coatings comprised of orthogonal electrospun Polystyrene fibers. We obtain the force needed to detach a droplet from such orthogonal fibrous coatings in a direction normal to the surface (referred to here as droplet detachment force).

The remainder of this paper is organized as follows. Section 2 describes our experimental (Section 2.1) and computational (Section 2.2) methods in detail. Section 2 also includes a one-on-one simulation–experiment comparison for model validation. The results of our study are presented in Section 3, in separate subsections for the experiment and computational results. A force balance analysis is presented in Section 4 to better understand forces resisting droplet detachment from a fibrous surface. Section 4.1 describes forces provided by individual fibers in contact with a droplet whereas Section 4.2 presents equations for the overall capillary forces acting on a droplet. Section 4.2 also presents an approximate equation that can be used to estimate the force required to detach a fiber from a fibrous surface.

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