Colloids and Surfaces A: Physicochem. Eng. Aspects 500 (2016) 45–53

Contents lists available at ScienceDirect

Colloids and Surfaces A: Physicochemical and Engineering Aspects

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

Superhydrophobic qualities of an aluminum surface coated with hydrophobic solution NeverWet

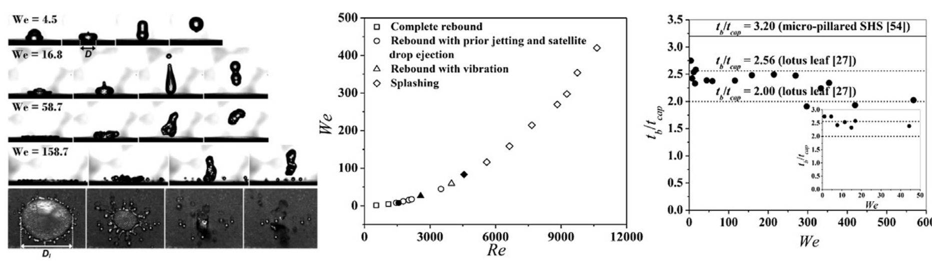
R. Gupta, V. Vaikuntanathan, D. Sivakumar*

Department of Aerospace Engineering, Indian Institute of Science, Bangalore 560012, India

HIGHLIGHTS

- Superhydrophobicity of a spray-coated aluminum surface is evaluated through drop impact.
- Impact outcomes and bounce-off characteristics are similar to that on lotus leaf.
- Maximum drop spread on the coated surface is predicted using the model for drop impact on small target surfaces.
- Power dependence of maximum drop spread on We is affected by fingers at high We.
- Fingers affect the trend of drop contact time with We at high We.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 December 2015
Received in revised form 1 April 2016
Accepted 5 April 2016
Available online 6 April 2016

Keywords:
Superhydrophobic surface
Spray coating
Drop impact test
Maximum spread
Fingers
Contact time

ABSTRACT

Effortless preparation of superhydrophobic surfaces mimicking the wetting characteristics of lotus leaf is of interest to several works. Spray coating methods using hydrophobic solutions are often adopted to realize such superhydrophobic surfaces. The present study investigates the dynamic behavior of impacting water drops on an aluminum surface coated with commercially available hydrophobic solution NeverWet with primary focus to understand the superhydrophobic qualities of the coated surface. The Weber number, We of impacting drop was varied from 1 to 568. The salient features of drop impact dynamics are compared with those of other superhydrophobic surfaces and naturally seen lotus leaf reported in literature. The outcomes as well as the bounce-off characteristics of impacting water drops are comparable to those observed on lotus leaf. The contact time remains almost constant with impact velocity, U_o for $7 < We < 200$. The dynamics of impacting water drops on the coated surface is compared with published works on superhydrophobic surfaces prepared using other fabrication methods. The trend of maximum lamella spread factor with We on the coated surface could be predicted using the analytical relation developed for drop impact on small target surfaces ignoring the effect of viscosity. The power dependence of maximum spread factor on We is higher if fingers at the rim of lamella are accounted for in the maximum spread measurements.

* Corresponding author.
E-mail addresses: dskumar@aero.iisc.ernet.in, deivandren@yahoo.com (D. Sivakumar).

http://dx.doi.org/10.1016/j.colsurfa.2016.04.017

The number of fingers formed at the rim of lamella at its maximum spread for high *We* drop impact increases with *We* which follows the predictions from Rayleigh-Taylor and a modified Savart-Plateau-Rayleigh instability as well as experimental data reported in literature. The findings from the study are useful for works which use NeverWet to develop superhydrophobic qualities on solid surfaces.

1. Introduction

Understanding the creation and characterization of superhydrophobic surfaces (SHS) has received considerable academic interest in recent years due to their use in practical applications involving self-cleaning [1], anti-icing [2,3], reduced adhesion [4,5], and drag reduction [5]. A multi-scale surface roughness and a low energy top surface layer are key requirements to realize SHS exhibiting high contact angle (>150°) and low roll-off angle (<10°) for a water drop. Several methodologies have been proposed over years to prepare SHS for both academic research and commercial purposes [6]. These preparation methods meet the abovementioned requirement and broadly come under one of the following three categories: (i) by micro-texturing solid surface in a particular pattern [7,8], (ii) roughening of surface by creating randomly distributed asperities or pores and subsequent laying of low energy surface layer through wet chemical processes [9,10], and (iii) crowding/foresting of nano-scaled filaments/fibers on surface [11,12]. Coating of target surfaces using hydrophobic chemicals is one of the effective methods to develop durable SHS. For example, SHS were prepared by Saleema et al. [9] by immersing aluminum alloy substrates in a solution containing NaOH and fluoroalkyl-silane (FAS-17) molecules. The desired surface roughness is imparted to the aluminum surface via chemical etching aided by NaOH and the low energy surface layer via the chemical bonding of fluoroalkyl-silane molecules to the surface. Many of these preparation methods require technical support such as specialized laboratory setups, operating skills to manage the level of optimization involved in the preparation process, etc. Alternatively several commercially available products of hydrophobic solutions offer simple methods to prepare SHS without requiring much laboratory-related setups. Even though these simple methods lack clarity on the durability of prepared SHS, several studies have adopted these methods to prepare solid surfaces exhibiting superhydrophobicity.

Superhydrophobic surfaces are evaluated by examining the static and dynamic behavior of water drops interacting with them. The measurements of static contact angle and roll-off angle of a water drop placed gently on the surface are considered as a quick measure to evaluate the quality of SHS [13–15]. The dynamic behavior of impacting water drops on target SHS is one of the key tests done to characterize the stability/durability of their superhydrophobic/liquid-repellent behavior under dynamic flow conditions [16,17]. The review articles by Yarin [18] and Marengo et al. [19] give a quick overview of the complexities involved in drop impact phenomenon. The characteristics of target solid surface influence drop impact dynamics via surface topography parameters such as mean surface roughness, average slope of roughness valleys, etc., and intrinsic contact angle of surface material. A water drop impacting on a superhydrophobic surface exhibits different outcomes depending on its impact Weber number estimated based on the size and velocity of drop before the start of impact process [20–28]. The outcomes, with increasing Weber number, are broadly classified as deposition, bouncing or rebounding, and sticky/fragmentation. The surface features present on SHS can cause the receding drop liquid to get pinned on the surface under certain impact conditions, thereby limiting/delaying the complete rebound of impacting drops [26]. The presence of multi-scale surface roughness (nano scale features distributed over micron scale structures) on a SHS alters the characteristics of spreading for the impact of higher Weber number (>10^2) drops and promotes the fragmentation of impacting drops [24,28].

NeverWet, commercially available from Rust-Oleum, USA, is a hydrophobic spraying solution used to prepare SHS with metallic and non-metallic base surfaces via a two-layer coating process. The nano-particles present in the hydrophobic solution form randomly distributed surface roughness features on the target surface thereby developing superhydrophobicity. Despite the use of NeverWet in several academic research works [29–32], a systematic study on the superhydrophobic capabilities of surfaces coated with NeverWet is still lacking in the current literature. The present study investigates the dynamic behavior of impacting water drops with Weber number in the range 1–568 on an aluminum surface coated with NeverWet to record the superhydrophobic qualities of the coated surface. The salient features on the dynamics of impacting water drops are compared with previously reported works of drop impact dynamics on superhydrophobic target surfaces including lotus leaf. The results obtained from the study are useful to both academic and industrial works which use NeverWet to realize surface superhydrophobicity.

2. Experimental details

The target surface used in the present study, referred to as Al-NW, is prepared as follows. A piece of aluminium alloy (Al-6061) of surface dimension 20 mm × 20 mm is taken. It is cleaned using acetone (99.0%, CAS No. 67-64-1 from S. D. Fine-Chem Ltd.) and excess of water and blow-dried properly. The cleaned surface is exposed to hydrophobic solution NeverWet via two-layer coating process. A layer of base coat containing methyl isobutyl ketone, butyl acetate, and mineral spirits is formed on the surface by spraying uniformly in 2–3 passes over the surface from a distance of around 15 cm from the surface for a period of around 3–4 s per pass. It is left to dry under normal laboratory ambient conditions for about 30 min. Then a layer of top coat containing nanoparticles suspended in acetone is applied over it by spraying as done for the base coating. The coated surface is left to dry for 30 min to get the final surface. The surface is kept for further drying in normal laboratory ambient conditions overnight (~12 h) before conducting studies on it. Fig. 1 shows surface topography details, characterized using optical profilometry (TalySurf CCI-MP from Taylor-Hobson, UK), of Al-NW (Fig. 1(b)). The original surface features of the aluminium surface are completely covered by the hydrophobic coating material resulting in a fresh top surface layer. The clustering/agglomeration of nano particles present in the hydrophobic solution of coating agent results in the formation of micro-bumps with conical top (Fig. 1(b)). Fig. 1(c) shows typical cross-sectional roughness profile traced by the optical profilometer across the surface.

The measurements of equilibrium (θ_e), advancing (θ_a), and receding (θ_r) contact angles for a water drop on Al-NW are obtained through static wetting experiments. Sessile drop method [33] is employed to obtain θ_e. Inclined plane method [34] is employed