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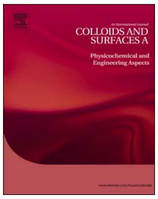

Droplet dynamics on a hydrophobic surface coated with N-octadecane phase change material

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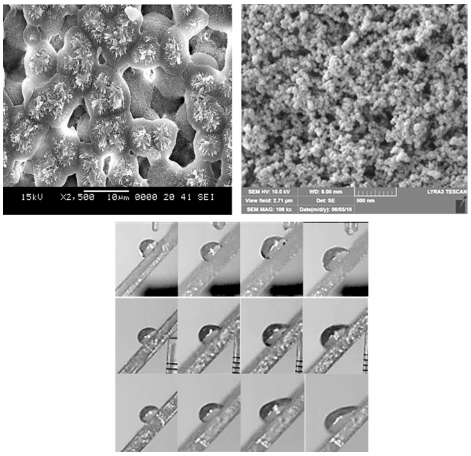
GRAPHICAL ABSTRACT

SEM micrographs of solution crystallized polycarbonate surface prior to and after functionalized silica particles deposition and droplet images on inclined surface.



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ABSTRACT

Water droplet mobility on the inclined hydrophobic surface coated with n-octadecane phase change material is examined. Polycarbonate surface is initially crystallized and later nano-size functionalized silica particles are deposited on the crystallized surface to increase the water droplet contact angle and reduce the contact angle hysteresis. Reversible exchange of wetting state is achieved via introducing a thin film of n-octadecane phase change material with 1.5 μm thickness on the functionalized silica particles deposited surface. The resulting surface remains hydrophobic if n-octadecane is in the solid phase while it becomes hydrophilic if thin film remains in the liquid phase. The surface wetting state reversibly exchanges during melting and re-solidification of n-octadecane film. Water droplet undergoes rolling and sliding on the inclined hydrophobic surface if n-octadecane is in solid phase. In this case, the solid n-octadecane flakes are formed on the surface and the functionalized silica particles deposited surface exposes to the free surface from the close regions of the flakes. This gives rise to a hydrophobic characteristic on the surface with droplet contact angle 140° and contact angle hysteresis 8°. Droplet rolling and sliding are influenced by the solid flake distribution on the n-octadecane coated

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surface. The closely spaced solid flakes results in hydrophilic surface while contributing to the droplet sliding on the inclined surface, which is more pronounced for large volume droplets.

1. Introduction

Recent changes in climate gives rise to sand storms, predominantly, in the Middle East. Settlement of dust particles on surfaces has adverse effect on the performance of the devices, particularly for those associated with the solar energy harvesting [1]. Effect of environmental dust particles on surfaces magnifies in humid air ambient because of dissolution of dust compounds in condensate water while forming chemically active fluid on surfaces [2]. The liquid solution causes not only performance degradation, but permanent surface damage via corrosion attack. Removal of dust particles from surfaces requires additional external efforts. Several methods are introduced implementing the surface cleaning process. Some of these processes are expensive and requires clean water, which remain critical due to scarcity of clean water. One of the cost effective cleaning method of surfaces is the self-cleaning via using water droplets. The water droplet mobility on surfaces plays a vital role for an effective self-cleaning process. Droplet motion consisting of rolling and sliding are required to remove dust particles from surfaces. In general, such dynamic motion of droplet depends on the characteristics of the solid surface and surface tension of the droplet liquid. Mimicking the nature towards generating Lotus effect becomes necessary for lowering adhesion between water droplet and the solid surface. In this case, surface hydrophobicity and pinning of droplet, which is created by large contact angle hysteresis, become important. In general, droplet slides on the inclined surface if the wetting state is hydrophilic. This enables to characterize the surface and the fluid in various applications [3,4]. On the other hand, reversible exchange of wetting state of surfaces can modify the properties of the substrate, such as graphene [5], finds applications in advanced multi-functional systems [6] and becomes important for extraction, separation, surface chemistry, life science, and organic solvents [7]. A method to achieve reversible exchange of wetting state consists of depositing a thin coating layer of phase change material on a hydrophobic surface [8]. The surface remains hydrophobic in the solid phase of the phase change material while it becomes hydrophilic in liquid phase of the phase change material [8]. The wettability in terms of spreading rate (S) of the phase change material in a liquid phase plays a crucial role to secure the formation of continuous film on the hydrophobic surface. Since the surface remains hydrophilic in the liquid phase of phase change material, the interfacial and surface tension of the liquid phase and the solid surface should satisfy the condition for the spreading rate $S > 0$. Therefore, the selection of phase material becomes important to give rise to a positive spreading rate on the hydrophobic surface in the liquid phase. In general, pure materials, such as pure metals, have a single melting temperature; however, materials with compounds, such as metallic alloys or polymeric materials, have different phase change temperatures for complete melting. The liquidus temperature is the lowest temperature at which the material is completely liquid and the solidus temperature is the highest temperature at which the material is completely solid. In the case if the material temperature is in between the solidus and liquidus temperatures, solid and liquid phases are copresent under the thermodynamic equilibrium, which is named as the mushy zone. One of the candidates of the phase change material fulfilling the requirements of positive spreading rate is n-octadecane, which has low solidus and liquidus temperatures and positive spreading rate for most of hydrophobic surfaces in the liquid phase. Consequently, investigation of water droplet mobility on the hydrophobic surface with reversible exchange of wetting state becomes essential.

Several methods are adapted to form and develop hydrophobic characteristics on the solid surface [9–14]. In general, some of these methods require multi-step processing in harsh conditions while using costly specialized reagents. Some of the current methods towards achieving surface hydrophobicity include phase separation [9], electrochemical deposition [10], plasma treatment [11], sol-gel processing [12], electrospinning [13], and laser texturing [14]. These methods use the processes, which give rise to low surface energy, via altering chemical composition of the surface, and surface texture composing of micro/nano pillars. In the texturing process, generation of hierarchical structures on the surface becomes essential for achieving the hydrophobic state at the surface. A solution immersion for creation of the hydrophobic surface is one of the one-step texturing techniques. A typical application of the solution immersion technique is the solution crystallization of polycarbonate surface [15]. This process is favorable because of its simplicity, short process duration, and cost-effective processing. The crystallized polycarbonate surface possesses hierarchically distributed micro/nano size spherules and fibrils [15]. Although the crystallized surface has hydrophobic characteristics, minimizing the droplet pinning on the textured surface becomes a challenge because of high contact angle hysteresis. However, further treatment of such surfaces overcome this problem; in which case, deposition of functionalized silica particles solves the issues related to the droplet pinning [16]. Moreover, the droplet mobility on the hydrophobic surface plays an essential role for removal of particles from the surface. Considerable research studies were carried out to examine droplet adhesion and mobility on the hydrophobic surfaces. The adhesion energy of liquid droplets on a hydrophobic flat surface incorporating the wetted area was investigated by Kim et al. [17]. They claimed that the current adhesion force models had not been successful for predicting the sliding angle due to omission of the wetted area and consideration of the length of the three-phase contact line. They suggested a new method predicting the adhesion energy of a droplet on a flat solid surface, which based on the relationship between the solid and liquid contact area. They indicated that the definition of adhesion energy per unit area was more appropriate than three phase contact line analogy for describing the movement of a liquid droplet on a hydrophobic solid surface. A study for the correlation between shape, evaporation mode, and mobility of small water droplets on the surface of nano-rough fibers was carried out by Funk et al. [18]. They showed that the mobility of water droplets could be correlated with the droplet–fiber interfacial properties during the droplet conformation. They also indicated that the smaller were the contact angles between water droplets and fibers and the better was the mobility of the droplets on the fiber surface. The reversible conversion of the mobility of the water droplet from rollable to pinned on a superhydrophobic film was studied by Yang et al. [19]. They demonstrated that using functionalized carbon nanotubes enabled to create the transition between the wettability states of the surface while changing the water-droplet mobility on the surface. The dynamic behavior of a liquid droplet on a hydrophobic surface in a gas flowing channel was investigated by Hao and Cheng [20]. The findings revealed that water droplet removal was facilitated by a high gas flow velocity on a hydrophobic surface, which was capable of lifting the water droplet from the surface while resulting in increased surface area available for gas reactant transport. The directional droplet motion on the asymmetric surfaces was examined Chamakos et al. [21]. They showed that a sliding droplet on the asymmetrically structured surface exhibited different migration velocities depending on the direction of the structures with respect to the motion, which only occurred if the capillary forces were predominant against the effect of inertia. In addition, the anisotropic wetting properties, due to the structure asymmetry, could be exploited in order to passively transfer a droplet by