Mechanical Engineering Doctoral Defense

Tuning Surface Wettability Through Volumetric Engineering: Healthcare, Defense, and Energy Applications of Liquid Shedding Materials

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abstract

Many defense, healthcare, and energy applications can benefit from the development of surfaces that easily shed droplets of liquids of interest. Desired wetting properties are typically achieved via altering the surface chemistry or topography or both through surface engineering. Despite many recent advancements, materials modified only on their exterior are still prone to physical degradation and lack durability. In contrast to surface engineering, this work focuses on altering the bulk composition and the interior of a material to tune how an exterior surface would interact with liquids. Fundamental and applied aspects of engineering of two material systems with low contact angle hysteresis (i.e. ability to easily shed droplets) are explained. First, water-shedding metal matrix hydrophobic nanoparticle composites with high thermal conductivity for steam condensation rate enhancement are discussed. Despite having static contact angle $<90°$ (not hydrophobic), sustained dropwise steam condensation can be achieved at the exterior surface of the composite due to low contact angle hysteresis (CAH). In order to explain this observation, the effect of varying the length scale of surface wetting heterogeneity over three orders of magnitude on the value of CAH was experimentally investigated. This study revealed that the CAH value is primarily governed by the droplet shape which in turn depends on length scale of wetting heterogeneity. Modifying the heterogeneity size ultimately leads to near isotropic wettability for surfaces with highly anisotropic nanoscale chemical heterogeneities. Next, development of lubricant-swollen polymeric omniphobic protective gear for defense and healthcare applications is described. Specifically, it is shown that the robust and durable protective gear can be made from polymeric material fully saturated with lubricant that can shed all liquids irrespective of their surface tensions even after multiple contact incidences with the foreign objects. Further, a couple of schemes are proposed to improve the rate of lubrication and replenishment of lubricant as well as reduce the total amount of lubricant required in making the polymeric protective gear omniphobic. Overall, this research aims to understand the underlying physics of dynamic surface-liquid interaction and provides simple scalable route to fabricate better materials for condensers and omniphobic protective gear.

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