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Achieving Super-Hydrophobicity through Mechanical Surface Patterning

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Abstract

Surface roughness plays an important role in determining the hydrophobic properties of materials, with applications in self-cleaning surfaces, anti-corrosion coatings, and drag reduction. Inspired by naturally hydrophobic surfaces, such as lotus leaves, cicada wings, and shark skin, this study investigates the influence of micropillar-shaped surface patterns on surface wettability. The research focuses on the transition between the Cassie-Baxter and Wenzel wetting states, highlighting the importance of geometric features in maintaining stable hydrophobic characteristics.

The study employs a 3D numerical simulation approach to analyze droplet interactions with surfaces containing micropillar arrays of varying shapes and orientations. The methodology is based on the development of a detailed 3D model with distinct pillar geometries, and the application of the Navier-Stokes equations along with the level-set method to simulate droplet behavior. Key surface parameters, such as pillar height, diameter, spacing, and sidewall angles, are varied to assess their impact on hydrophobicity. Simulation results demonstrate that hierarchical pillar textures enhance hydrophobic performance by increasing the energy barrier required for the wetting state to transition from the Cassie-Baxter state to the Wenzel state. This effect is attributed to the enhanced air entrapment within the textured surface, which increases the contact angle and reduces liquid-solid interface. Additionally, the study shows that even surfaces with inherently hydrophilic properties can exhibit hydrophobic behavior when appropriately structured with optimized micropillar geometries. Comparative analysis with previous experimental and numerical studies, such as those by Xu et al. (2022) and Zou et al. (2023), confirms that increasing pillar density and introducing asymmetric geometry significantly improves hydrophobic stability. The proposed inverted trapezoidal pillars and semi-conical structures are identified as particularly effective designs, as they maximize the contact angle while minimizing droplet adhesion.

These findings provide for the design of robust, hydrophobic surfaces through geometric patterning. The work establishes a foundation for the development of cost-effective and environmentally friendly surface treatments applicable to a wide range of fields, including marine coatings, microfluidic devices, biomedical instruments, and self-cleaning materials.