Simulating Droplet Adhesion on Superhydrophobic Surfaces

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Understanding and quantifying the topography of superhydrophobic surfaces is essential for optimising their performance in a wide range of applications including drag reduction and de-icing. Whilst contact angle goniometry remains the standard characterisation method, direct force measurements offer superior sensitivity for surfaces with complex microscale structures. However, existing approaches lack a quantitative framework linking measured adhesion forces to surface topography.

We present a novel energy minimisation approach using Surface Evolver [1] to simulate droplet adhesion on pillared superhydrophobic surfaces, replicating force probe microscopy experiments. Our numerical model captures the movement of the contact line as it advances and then recedes over the surface. We use the model to demonstrate that adhesion forces are governed by microscale deformations near the contact line. When the drop is receding, the contact line exhibits characteristic stick-slip motion with periodic jumps, generating distinctive sawtooth-pattern force signatures that reflect the underlying surface structure. Energy dissipation during contact line jumps is anisotropic, depending on surface orientation. We establish that the average tensile force during droplet recession is a better measure of surface structure than the maximum adhesion force. Direct force measurements using a commercial tensiometer on pillared silica surfaces demonstrate excellent agreement with numerical predictions across a range of pillar area fractions.

This work establishes a quantitative link between microscale surface topography and macroscopic force measurements, enabling characterisation of superhydrophobic surfaces using droplet adhesion, providing design guidance for engineering surfaces with tailored wetting properties, and advancing understanding of microscale physics governing contact line dynamics on textured surfaces. The numerical framework is freely available [2-3] and extensible to arbitrary surface chemistries and geometries.

Keywords:
Wetting, Superhydrophobicity, Droplet adhesion, Contact line dynamics

References:

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