Colloids and Surfaces A: Physicochem. Eng. Aspects 412 (2012) 108–119

Contents lists available at SciVerse ScienceDirect

Colloids and Surfaces A: Physicochemical and Engineering Aspects

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

Droplet-induced anomalous deformation of a thin micro-plate

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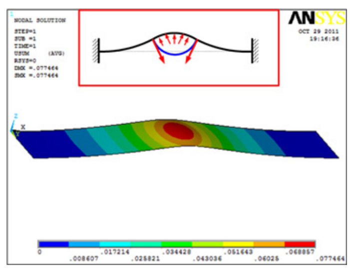
HIGHLIGHTS

- ► Approximate analytical deflection solution of a clamped-clamped plate is presented.
- ► Analytical deflection solution of a clamped circular plate is derived.
- ► The displacement field of a general plate is simulated by FEM (finite element method).
- ► The analytical and numerical results show excellent agreement with each other.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 April 2012
Received in revised form 19 July 2012
Accepted 20 July 2012
Available online 27 July 2012

Keywords:
Surface tension
Laplace pressure difference
Deflection
Analytical solution
Finite element simulation

ABSTRACT

The surface tension of liquid is generally negligible at macroscopic scale but can cause a lot of anomalous deformation of slender structures at small scales. In this study, we presented the analytical deflection solutions of a rectangular plate with two clamped ends and a clamped circular plate based upon the principle of superposition, where a droplet was deposited onto the micro-plate surfaces. In the light of these analytical solutions, the abnormal bending of the plate when the droplet is placed at different positions of the top or bottom surface of the plate was discussed in detail. The FEM (finite element method) simulation was also conducted, and the results show excellent agreement with our analytical solutions. We also put to use the FEM simulation to explore the displacement field of a more general plate with complex boundary conditions and complicated loads originating from the droplet, and the folding of a soft membrane caused by a droplet was also simulated. This investigation is beneficial to understand the physical mechanisms underlying the droplet-induced deformation of slender structures, and is of great interest for the design of new materials and devices by utilizing the effects of surface tension at micro and nano scales.

1. Introduction

Capillary forces or surface tensions of liquids are generally negligible at such macroscopic scales as human buildings, bridges or vehicles, and henceforth they can be ascribed into the terminology of "non-conventional forces". However, novel phenomena associated with capillary forces are ubiquitous at small scales, both in nature and industry. For example, a string of water droplets can be observed on the silks of spider webs in fog or after raining [1]; rain drops do not wet the leaves of lotus, taro and lady's mantle [2,3]; butterflies and cicadas can fly in raining days and their wings are safe to water; water striders, water spiders, mosquitoes, and large groups of ants can easily walk on water surfaces [4–7]; the beetle Stenocara in Namib desert can collect dews by using the special surface microstructures on its carapace [8]; and shorebirds capture the feeding mechanism of surface tension-induced transportation of prey, with its beak in a tweezering motion and ratchet effect [9]. Capillary effects are also of extensive interest in such

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http://dx.doi.org/10.1016/j.colsurfa.2012.07.024