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Spreading of an Inkjet Droplet on a Solid Surface with a Controlled Contact Angle at Low Weber and Reynolds Numbers

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Even though the inkjet technology has been recognized as one of the most promising technologies for electronic and bio industries, the full understanding of the dynamics of an inkjet droplet at its operating conditions is still lacking. In this study, the normal impact of water droplets on solid substrates was investigated experimentally. The size of water droplets studied here was 46 μm and was much smaller than the most of the previous studies on drop impact. The Weber number (We) and Reynolds number (Re) were 0.05−2 and 10−100, respectively, and the Ohnesorge number was fixed at 0.017. The wettability of the solid substrate was varied by adsorbing a self-assembled monolayer of octadecyltrichlorosilane followed by the exposure to UV−ozone plasma. The impact scenarios for low We impacts were found to be qualitatively different from the high to moderate We impacts. Neither the development of a thin film and lamella under the traveling sphere nor the entrapment of small bubbles was observed. The dynamics of droplet impact at the conditions studied here is found to proceed under the combined influences of inertia, surface tension, and viscosity without being dominated by one specific mechanism. The maximum spreading factor (β), the ratio of the diameter of the wetted surface and the drop diameter before impact, was correlated well with the relationship $\ln \beta = 0.090 \ln \mathrm{We}/(f_s - \cos \theta) + 0.151$ for three decades of $\mathrm{We}/(f_s - \cos \theta)$, where θ is the equilibrium contact angle, and f_s is the ratio between the surface areas contacting the air and the solid substrate. The result implies that the final shape of the droplet is determined by the surface phenomenon rather than fluid mechanical effects.

Introduction

During the past decade, the idea of inkjet printing has emerged as a class of technologies essential in many electronic and bio industries. Inkjet printing technology has been applied to three-dimensional shaping,[1−3] flat panel display,[4−9] printed circuit boards (PCBs),[10] semiconductor packaging,[2] and DNA chip and biosensors,[11−16] in addition to conventional printing, and is regarded as one of the most promising future technologies. In this research we will investigate the spreading processes of inkjet drops after the impact of a drop on solid surfaces. The impact of a liquid drop on a solid surface has been studied for almost 100 years since the pioneering work of Worthington[17] because of its relevance to many natural phenomena as well as industrial applications, and significant progress has been made in the understanding of the impact process theoretically, computationally, and experimentally. Recently Yarin[18] reviewed the drop impact dynamics comprehensively and delineated many interesting phenomena such as splashing, spreading, receding, bouncing, crown formation, and so on. Until now, most of the studies on drop impact have been focused on the Newtonian fluids. But there has been a growing interest on the drop impact of rheologically complex fluids reflecting many practical applications, including inkjet printing and spray painting. Zhang and Basaran,[19] Boger and his co-workers,[20−22] Bergeron et al.,[23] and Prunet-Foch and his co-workers[24,25] studied the impacts of surfactant solutions and polymer solutions experimentally and observed the effect of dynamic surface tension, elasticity, and shear thinning.

Schiaffino and Sonin[26] classified the drop impact into four different regimes according to Weber ($\mathrm{We} = \rho D U^2/\sigma$) and Ohnesorge ($\mathrm{Oh} = \eta/\sqrt{D\sigma\rho}$) numbers, where ρ is the density of the liquid, D is the diameter of the drop before impact, U is the impact velocity, σ is surface tension, and η is the viscosity of the liquid. In regime I, where $\mathrm{We} \gg 1$ and $\mathrm{Oh} \ll 1$, kinetic energy dominant motion prevails, and fluid behaves almost like an inviscid fluid; in regime II, where $\mathrm{We} \ll 1$ and $\mathrm{Oh} \ll 1$, capillarity drives the motion of inviscid fluids; in regime III,

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