Generic Behaviour of Model UV Cure Ink-Media Interactions

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Abstract

In this work we present a study of the characteristics of UV cure ink droplets on different media (model homogeneous and heterogeneous surfaces, PET, treated PET, etc.). By varying the magnitude of chemical heterogeneities on model surfaces, we are able to highlight the parameters that affect droplet shape. Using Lattice Boltzmann simulations of droplet spreading, we show that the location of the impact point of a droplet on patterned substrate with micron size chemical heterogeneity is an important criterion to consider with respect to the equilibrium shape of a droplet. This allows a complete understanding of the effect of chemical heterogeneity on droplet shape, and therefore on printing quality. We also report an experimental study of the internal morphology of ink droplets adsorbed on chemically defined substrates. This morphology appears to be related with the surface properties of the media considered.

Introduction

The study of wettability has been a matter of interest for many years. Indeed, understanding the multiple parameters governing the spreading and the wetting of a droplet on a surface is of crucial importance for applications such as inkjet printing, as well as from a fundamental and experimental point of view.[1] In the case of ideal surfaces and pure fluids, Young established a relationship between equilibrium contact angle, θ_e, surface energy of the substrate, γ_{sv}, interfacial tension between solid and fluid, γ_{sl} and the surface tension of the fluid, γ. However, for real (non-ideal) surfaces, the equilibrium state of a system may be different, mainly due to surface impurities. Cassie developed a relationship for θ_e taking into account the surface fraction of two different chemical species on the surface. In the case of very small heterogeneities as compared to the size of the droplet, this model has been verified experimentally.[2] However, for chemical heterogeneities close to the size of a spreading droplet, some deviations of the expected shape are observed.[3-5] When the size of the chemical heterogeneities are of the same order as the size of the droplet, the above models are not sufficient to explain the profiles obtained.[6,7] With the exception of a few reports,[8] there is a lack of systematic study on this subject and from a practical point of view (UV cured inkjet printing for example), it is important to understand these phenomena. Indeed, taking into account the complexity of real substrates, and the small droplets considered in inkjet printing, the magnitude of chemical heterogeneity is expected to have a major influence on print quality.

In this paper we describe the initial work within the IMAGE-IN project[9] to study the effects of chemical surface heterogeneities on the spreading of UV cure ink droplets with non-zero initial impact velocity. We consider spreading dynamics and equilibrium shapes of droplets on model surfaces, and show that our results are able to explain some printing defects. Modelling of the phenomena observed experimentally is proposed by means of lattice Boltzmann simulations. Lattice Boltzmann models are a class of numerical techniques ideally suited to probing the behaviour of fluids on mesoscopic length scales.[10] They solve the Navier-Stokes equations of fluid flow but also input thermodynamic information, typically either as a free energy or as effective microscopic interactions. Here we show that it is possible to use a lattice Boltzmann approach to model the spreading of mesoscale droplets,[11] and in particular, to illustrate how a droplet spreads on a substrate comprising of hydrophilic and hydrophobic stripes.

Results

The inks used in this study are model UV cure inks supplied by SunJet (UK), and printed at Agfa-Gavaert (Belgium) using a test-bed ink-jet printer operating a Spectra print head. Figure 1*a* shows a scanning electron microscope (SEM) image of a set of inkjet droplets that were jetted onto a model surface that has been chemically patterned. The dark and light vertical stripes are hydrophilic and the hydrophobic regions, respectively, which have been patterned onto a topographically flat gold coated silicon wafer using standard microcontact printing techniques. The droplets adopt various equilibrium shapes, and for this combination of stripe widths two general equilibrium shapes can be distinguished. A magnified droplet circled in Figure 1*a* is shown in Figure 1*b*, together with a numerical simulation obtained from Lattice Boltzmann modeling as shown in Figure 1*c*. In the latter, the thick line is the equilibrium shape of the droplet. The thin lines are droplet shape at intermediate time steps and reveal the dynamic processes of the droplet shape formation. It can be seen that the lateral wetting on the hydrophilic areas (dark vertical stripes) extends further than the equilibrium position, indicating that slight dewetting occurs. The impact point (indicated by an arrow in Figure 1*c*) has an important influence on the final droplet shape. Indeed, by varying the impact point on the stripes with the lattice Boltzmann model, we are able to generate all the shapes shown in Figure 1*a*. Due to the similarity between the model and the measured droplets the relative impact point is clearly an important parameter in determining the deviation of a droplet from a perfect spherical shape. The impact point is only important if the size of the heterogeneity is similar to the initial diameter of the droplet. It is useful, from a practical point of view, to be able to predict when this type of deviation can occur and we are now in a position to describe the evolution of droplet shape as a function of micron to millimeter size heterogeneities.

Although the most obvious measurement to make is the equilibrium droplet shape, this does not address the issues related to the chemical interaction between the media and the multi-component UV jet inks. To tackle this issue we are also studying the internal chemical and morphological nature of droplets as a function of surface heterogeneities. This is being addressed by use of laterally resolved secondary ion mass spectroscopy, AFM and SEM techniques as our primary tools, coupled with lattice Boltzmann modeling.

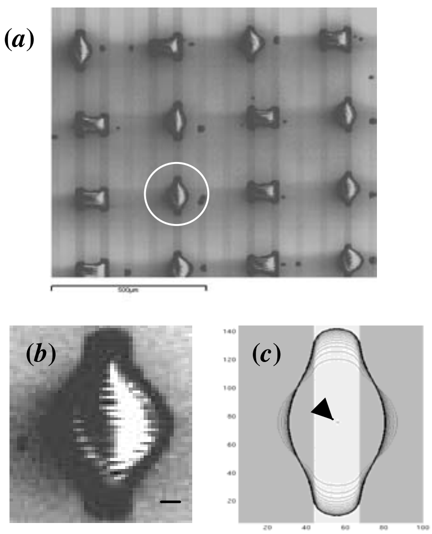

*Figure 1(**a**): SEM image of a set of ink-jetted droplets on a chemically patterned substrate. The scale bar is 500 μm. (b) Magnified image of the droplet circles in (a). Scale bar is 10 μm. (c) Lattice Boltzmann simulation of droplet spreading, where the hydrophilic areas now shown by light grey. The point of impact of the droplet is indicated by an arrow.*

Conclusion

The evolution of droplet shape as a function of the size of surface chemical heterogeneity has been studied. It has been proved that the Lattice Boltzmann model is a power method for studying the evolution of droplet spreading on heterogeneous surfaces. For small heterogeneities, the shape of the droplet can be approximated by a spherical cap. For intermediate sizes of chemical heterogeneities that are close to the initial droplet diameter, the droplets show distinctive equilibrium shapes. In this case, the location of the impact point relative to the chemical patterning determines the final equilibrium shape. For surfaces heterogeneities much larger than the initial droplet diameter, the final shape depends mainly on the equilibrium contact angle, through Young's equation.

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Biography

David Bucknall gained his PhD in polymer physics in 1991. Since this time he has specialised in studies of surfaces and interfaces, in both government research and academic institutes. He is currently a lecturer at Oxford University studying aspects of polymers and biomaterials. He is also co-ordinator of the multinational European funded IMAGE-IN research project to study and develop a better understanding of ink-media interactions for improved industrial ink-jet printing.