Interactions of a Single Ink-Jet Droplet with Textile Printing Surfaces

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Abstract

We are conducting research to better understand ink/textile-media interactions. The interactions of a single ink jet droplet with well-characterized surfaces and with selected textile surfaces are being studied using two experimental setups. Droplet impingement on silicon wafers with well-characterized surface chemistry and roughness, and selected fabrics is being investigated. The initial droplet impingement data obtained lay a foundation for conducting further study on droplet impinge onto textiles, which should lead to a better understanding of the interaction of an individual droplet with textile printing surfaces

Introduction

Ink jet printing is as a critical technology for mass-customization manufacturing of textile products; however, hardware reliability and speed limitations are technical barriers limiting the use of ink jet printing primarily to generation of samples. Existing commercial textile ink jet systems employ multi-phase inks or require specially prepared fabrics; yet almost no information on multi-phase droplet formation or fabric preparation for ink jet printing is available in the literature. The properties (for example, viscosity and surface tension) of ink formulations for ink jet printing are quite different from those used in traditional textile printing systems. We are conducting research to study the interactions of a single ink jet droplet with well-characterized surfaces and with selected textile surfaces. Droplet impingement on silicon wafer with well-characterized surface chemistry and roughness, textile rayon and polyester fabrics are being investigated. The objective is to obtain fundamental data and knowledge for the developing reliable and practical ink jet printing technology for textile printing applications.

The droplet/substrate interaction can be separated into two stages. The first stage is referred to as impact. Over a very short time period, the droplet impacts the substrate, spreads, retracts, in some cases rebounds, and then spreads and comes to rest. We are observing retraction and rebound, and measuring maximum spread and resting diameter ratio.

After the impact period is over and the droplet has come to rest on the substrate, the wicking period begins. Depending on the porosity and surface chemistry of the substrate, the droplet can wick either partially or totally into the substrate. The wicking period is much longer the impact period. This paper addresses the impact, but not wicking phenomenon.

Impact can consider in four stages as shown in Figure 1. Stage (a) is before impact. The droplet impact energy consists of kinetic energy, surface energy, and potential energy; Stage (b) is at maximum spread. This is the point at which the liquid flow changes direction from spreading outwards to recoiling inwards. The surface energy of the droplet is at a maximum while the kinetic energy is zero. Stage (c) is at maximum recoil/rebound. At this moment, the droplet changes its direction of motion from up to down under the influence of gravity. Stage (d) is quasi-equilibrium (constant diameter). The droplet possesses a minimum surface and kinetic energy that is equal to the static surface energy.

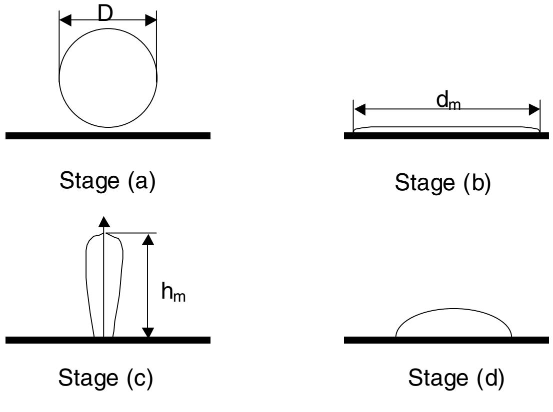

Figure 1. Impact process

The maximum spread is affected by droplet inertia, viscous forces within the spreading fluid and droplet surface tension. The dimensionless numbers, usually used to characterize phenomena involving these factors are the Reynolds number and the Weber number.

We have set up an experimental apparatus for studying the interactions of a single ink-jet droplet with surfaces and to characterize the ink jet droplet size and velocity. This research on the interaction of single ink droplet with substrates, with attention to the role of surface properties on image formation, is expected to yield better understanding of the fundamentals affecting printing quality. Using the results of parametric studies, we plan to correlate the print quality parameters such as maximum and resting diameter ratios with the dimensionless numbers. The key factors affecting textile printing quality will be determined.

Tests are being conducting with two types of setups. The first uses ink jet droplet diameter and velocity typically produced by DOD ink jet printing engines. The second setup uses larger droplet diameters and lower droplet speeds to allow studying the impact phenomena in more detail. Similarity analysis using the important dimensionless numbers allow us to use larger diameter droplets moving at lower impact velocities if fluid viscosity is changed appropriately. Since the dimensionless numbers are the same, the phenomena for the two setups are expected to be the same, but the time in the second setup is scaled to facilitate making observations.

Experimental

Materials and Methods

The ink jet inks used in the tests are mixtures of distilled water and glycerin (Fisher Scientific). A Brookfield viscometer (model DV-1) is used to measure the viscosity of the fluid. Viscosities of 1, 8, and 100 cP are being used for inks for the scale up-devices, while ink viscosity of 1 cP is being used for the printer. A Bubble Pressure Tensiometer BP2 (Krüss GmbH) is being used for measuring dynamic surface tension. The surface tension is being held fixed for the tests at approximately 72 dyne/cm.

Silicon wafers are being used with three different surface chemistries: polymer coated (1,1,1,3,3,3, Hexamethyl disilazane (HMDS, Aldrich), gold coating, and pure silicon). The polymer coating was applied using a CEE Model 100CB Spinner, and the gold coating was applied by an ISI Sputter-Coater.

Contact angles of the silicon wafers with distilled water were measured using a VCA2500KE Contact Angle Surface Analysis System. The results are given in Table 1.

The pure silicon wafer shows the highest hydrophilicity, while gold coating silicon wafer has the lowest hydrophilicity. The Zisman's approach (reference number) is being used for estimating the surface energy of the three substrates.

Rayon and polyester fabrics are also being be used. To facilitate optical observation, filament fabrics were selected because they have smooth surfaces with almost no protruding fibers. Rayon fabric is hydrophilic while polyester fabric is fairly hydrophobic. The roughness of the fabrics is being determined via Kawabata system for fabric hand evaluation (KES-FB-4, KES Kato Tech Co., Ltd.) and Scanning Electro Microscopy (SEM; Leica Stereoscan 430).

Table 1. Contact angles of silicon wafers with distilled water.

	Gold coating silicon wafer	HMMS coating silicon wafer	Pure silicon wafer
Contact angle (degree)	105	73	33

Procedure

Two experimental setups are being used for the droplet impingement tests. Figure 2 shows the schematic of the experimental setup, the Optica system (VisionJet Ltd.) for studying a single droplet impingement. The droplet is produced using a DOD ink-jet engine (PixelJet 64, Trident, Inc.).

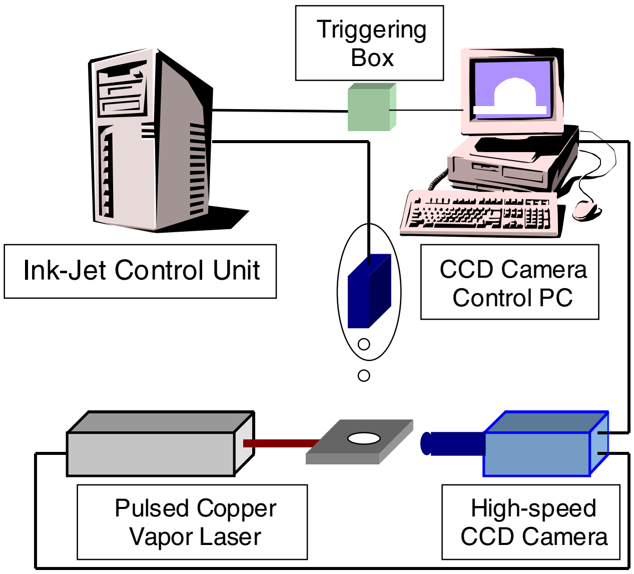

Figure 2. Experimental setup using a drop-on-demand, ink-jet engine

The triggering box sends 5 volt TTL signals to ink-jet engine control unit and to the CCD camera control PC, simultaneously. The ink-jet engine control unit fires a single droplet through DOD inkjet head to the substrate. The high speed CCD camera captures a picture of the droplet impacted on the substrate. By controlling the delay time of the camera, the picture of the droplet can be taken at different points in the impacting process.

Figure 3 shows a schematic of the experimental setup of the single-drop apparatus. A syringe pump (Mode 230; KD Scientific Corp.) connected to a flat-tipped stainless steel needle (28G) is used to generate a single droplet. The liquid volume and flow are set so that a single droplet is formed and falls due to gravity.

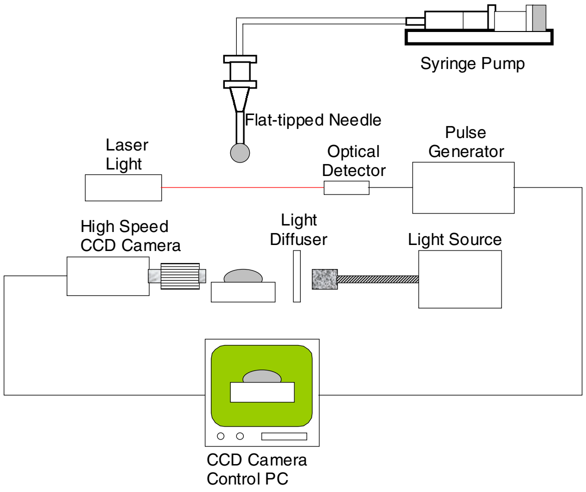

Figure 3. Experimental setup of a single-drop apparatus.

An optical trigger (OPTOLOGIC^{tm} QSA157, Fairchild semiconductor) is used to sense when a single droplet moves between it and a laser light. When this occurs, a 5 volt TTL signal is sent to a pulse generator which sends 5 volt rising or falling edge signals to a high-speed CCD camera, SensiCam (the COOKE Corporation, Auburn Hills, MI) after a preset time delay. The camera captures images of the impingement and loads the digital file in a computer. The series of images are made from single images of many droplets with different delay times. The high-speed CCD camera was also used to determine drop diameter and droplet speed using superimposed images in on a frame.

Results and Discussion

The single-drop apparatus has been used to observe droplets impacting silicon wafers with three different surface chemistries. Figure 4 shows the impact sequence of a distilled-water droplet on a gold coating, an HMDS coating, and a pure silicon wafer. The camera was setup a little above the horizontal for obtaining clear images of the droplet spread upon impact. The impact velocity of a 2.3 mm-diameter drop was about 1 m/s, and the corresponding Reynolds number ($Re = \rho uD/\mu$) and Weber number ($Re = \rho u^2D/\gamma$) was 2300 and 32, respectively.

The photographs taken at t = 0.0 ms show the spherically shaped droplets just before impact (see Figure 4). At t = 4.0 ms, the droplets on the gold and polymer coated surfaces are approximately at the maximum spreading ratio (d_m/D). However, the droplet on the pure silicon wafer does not reach its maximum ratio until t = 15.0 ms (see Table 2). The maximum spreading ratio for the silicon wafer is only about 10-20 % greater than for the other two surfaces. The surface energy of the pure silicon is high, and thus the interaction between the distilled water and the pure silicon wafer is greater than for the other two surfaces. Spreading is driven by kinetic energy and interfacial energy due to the interaction of the liquid with the solid surface. For the Weber and Reynolds numbers for this test, the interfacial energy relative to kinetic energy is sufficiently large so that it has an effect on spreading. However at higher Reynolds and Weber numbers (Re = 7350 and We = 212), the maximum spreading ratios are almost identical for the three surfaces, and it takes almost identical times (about 4.5 ms) to reach this value (see Table 3). Apparently at the higher Reynolds and Weber numbers, spreading is dominated by the kinetic energy of the system. The maximum spreading ratio for the silicon wafer is only about 2-4% greater than for the other two surfaces.

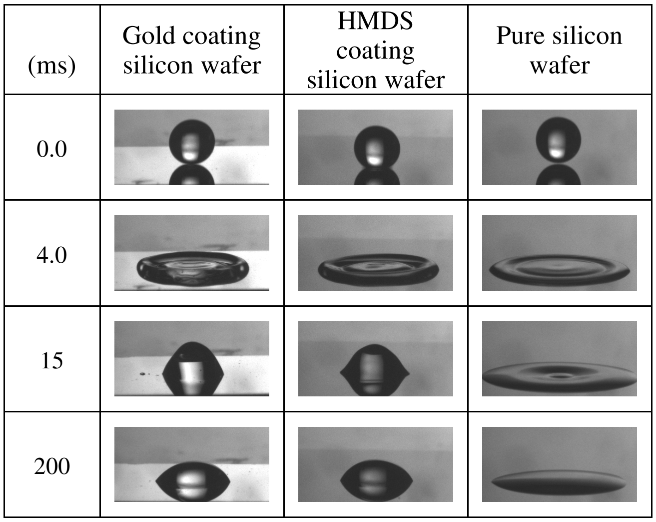

Figure 4. Impact of a 2.3 mm water droplet on the gold coating, HMDS coating, and pure silicon wafer.

At t = 15 ms, recoil stage can be observed for the droplets on the gold and polymer coated surfaces; however, the droplet on the pure silicon surface recoiled very little. At t = 200 ms, constant diameters at quasi-equilibrium can be observed. The resting diameter for the droplet on the pure silicon surface is much larger than for the other two surfaces.

Table 2. Spreading ratio after impacting on the gold coating, HMDS coating, and pure silicon wafer (Re = 2300 and We = 32).

Time (ms)	Spreading ratio (d/D)		
	Gold coating silicon wafer	HMDS coating silicon wafer	Pure silicon wafer
0.0	1.0	1.0	1.0
4.0	2.5	2.7	3.0
15	1.3	1.5	3.5
200	1.7	1.7	3.1

Table 3. Spreading ratio after impacting on the gold coating, HMDS coating, and pure silicon wafer (Re = 7350 and We = 212).

Time (ms)	Spreading ratio (d/D)		
	Gold coating silicon wafer	HMDS coating silicon wafer	Pure silicon wafer
0.0	1.0	1.0	1.0
4.5	5.3	5.4	5.5
30	*	3.7	5.4
800	*	2.0	3.7

*No data available, the droplet divided into two parts.

Conclusion

Research is being conducted to better understand ink/textile-media interactions. The interactions of a single ink jet droplet with well-characterized surfaces and with selected textile surfaces are being studied using two experimental setups. The initial droplet impingement data provides a foundation for conducting further study on droplet impinge onto textiles, which should lead to a better understanding of the interaction of an individual droplet with textile printing surfaces.

Biography

Heungsup Park received his B.S. (1994) and M.S. (1996) in Textile Engineering from Pusan National University in Korea. He has also earned an M.S. in Textile Chemistry from Georgia Institute of Technology in 1999. He is currently pursuing a Ph.D. in Textile Chemistry at Georgia Institute of Technology. Mr. Park's research interests are in surface science, computational fluids and digital printing.