Topographical surface features for self-assembly of microparts using liquid surface tension

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Abstract

In this paper a method to control the spreading of liquid droplets using purely topographical 3D printed micro-structures is presented. Results show the structures ability to effectively pin the droplet, without the need for additional surface modification techniques. Contact angles of up to 150° were achieved when undercut edges were applied to the structures.

1. Introduction

Downsizing of components to sub-millimetre scale introduces the predominance of surface tension effects over gravitational effects. Capillary self-alignment of components using liquid surface tension is an attractive method for assembly and handling tasks in this domain, as it offers high final positional accuracy. One requirement of this technique is the confinement of liquid to a designated area. Several methods have been developed in order to alter the wetting properties of certain regions, with many based on phenomenon occurring in nature. These include hydrophilic/hydrophobic target sites [1, 2], oleophilic/oleophobic for oil-based liquids [3], micropillar arrays to create hydrophobic regions [4], as well as receptor sites with sharp edges to inhibit liquid spreading [5, 6]. This work demonstrates the ability of purely topographical 3D printed microstructures to control liquid spreading.

2. Fabrication

Components were manufactured using projection-micro-stereolithography (PMSL) by successively exposing and solidifying 25µm layers of light-sensitive resin according to data from an STL file. An EnvisionTec Perfactory Mini-Multi lens projection stereolithography machine using EnvisionTec R11 rapid prototyping material was used. Projector brightness was calibrated to 600 mW/dm^2 with exposure time of 6.5 seconds/layer (standard range), at a layer height of 50 micrometres. Resolution was set to 1050 x 1400 pixels (SXGA+), equivalent to a pixel size of 5µm in X.Y-direction. Parts were cleaned post build in an ultrasonic isopropanol bath for 3 minutes, then air dried. Components containing test arrays of Ø1mm and Ø0.5mm topographical circular pads were manufactured in the aforementioned method (see Figure 1).

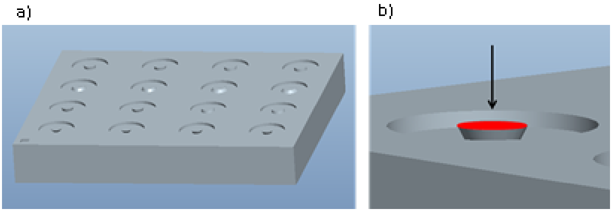

Figure 1: a) CAD model of test component with array of Ø0.5mm circular pads, b) Close-up of structure with 45° undercut with droplet target location indicated in red.

The structures sharp edges were altered to give acute (undercut) angles, and obtuse (chamfer) angles. As seen below in Figure 2.

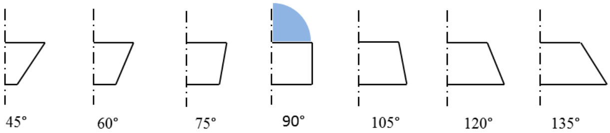

Figure 2: Edge geometries of topographical undercut structures.

3. Experimental setup

Components were mounted on an X-Y precision stage and viewed under an optical microscope with a JVC CCD mounted camera. Data was captured using a Hauppage Win-TV-HVR-1900 interface with post process image analysis conducted using the ImageJ software package. Liquid water droplets were applied to the target sites using a digital timed precision fluid dispenser TS-250 from Adhesive Dispensing Ltd. A 3cc syringe barrel was used in conjunction with a 32 gauge blunt end dispending tip. The liquid used for the experiments was water with surface tension, g=72 mN m^{-1}.

4. Results

Water droplets were applied to a plain polymer sample and contact angle measured using ImageJ software was found to be 70°. The ability of the topographical structures to constrain the spreading of liquid droplets was investigated by incrementally applying liquid to the target site, until the droplet overflowed and collapsed. Undercut angles from 45° - 135° were investigated. Optical microscope images of unconstrained and constrained droplets are shown below in Figure 3.

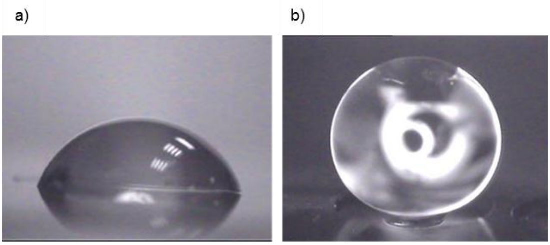

Figure 3: Optical microscope images of droplets; a) Unconstrained droplet on plain substrate, b) Droplet constrained to Ø1mm diameter pad with 60 ° undercut.

It was observed that the contact angle was significantly increased when droplets were applied to the topographical structures, showing their ability to constrain the spreading of liquid by pinning the triple contact line (TCL). Acute edge angles (undercuts) of less than 90° were able to achieve the highest contact angles, compared to obtuse angles (chamfers), as can be seen in Figure 4. Angles less than 90° did not appear to further increase the contact angle of droplets pinned to the Ø1mm pads, unlike the Ø0.5mm pads, where an increase was observed. It was noted that the Ø0.5mm pads were able to achieve higher contact angles than those of the Ø1mm pads. This is thought to be due to the volume of liquid being applied to the pad, with the droplets diameter exceeding the capillary length for the liquid. In the case of water this is approximately 2.5mm. Below this value gravity has a negligible effect on the droplet, but as the diameter of the drop increases the additional forces reduce the robustness of the pads ability to constrain the droplet leading to failure.

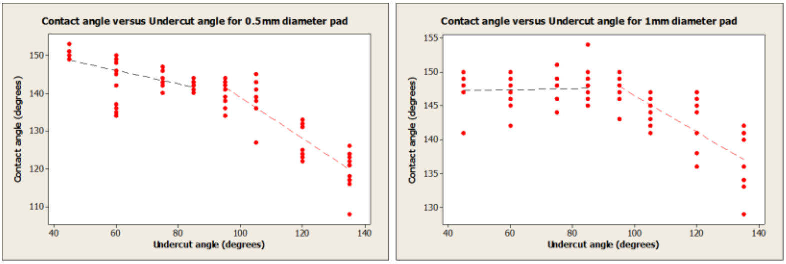

Figure 4: Contact angle of droplet versus undercut angle of structure for 0.5mm and 1mm diameter pads

5. Conclusions

3D printed polymer components have been shown to control liquid spreading using purely topographical structures without the need for additional surface modification techniques. Significant increases in contact angle were observed when liquid water droplets were deposited onto the topographical structures. Highest contact angles were achieved with undercut (acute) angles less than 90°. This technique is attractive as it allows bespoke components to be quickly manufactured using additive manufacturing methods that contain inherent features for capillary self-assembly of components through liquid surface tension.

References:

[1] K. Sato, "Self-alignment of microparts using liquid surface tension-behaviour of micropart and alignment characteristics," *Precision Engineering*, vol. 27, pp. 42-50, 2003.

[2] G. Fantoni, *et al.*, "A new capillary gripper for mini and micro parts," *CIRP Annals - Manufacturing Technology*, vol. 62, pp. 17-20, 2013.

[3] C. Bo, *et al.*, "Capillary-driven self-assembly of microchips on oleophilic/oleophobic patterned surface using adhesive droplet in ambient air," *Applied Physics Letters*, vol. 99, pp. 034104-034104-3, 2011.

[4] J. Yeo, *et al.*, "Robust hydrophobic surfaces with various micropillar arrays," *Journal of Micromechanics and Microengineering*, vol. 20, p. 025028, 2010.

[5] V. Liimatainen, *et al.*, "Controlling Liquid Spreading Using Microfabricated Undercut Edges," *Advanced Materials*, vol. 25, pp. 2275-2278, 2013.

[6] C. G. Tsai, *et al.*, "Self-alignment of microchips using surface tension and solid edge," *Sensors and Actuators A: Physical*, vol. 139, pp. 343-349, 2007.