Machining hydrophobic structures with ultra-small micro end mills

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Abstract

Within the scope of our research, hydrophobic structures have been machined in polymethyl methacrylate (PMMA) using micro end milling with tool diameters $\leq$ 50 µm. In experiments, the water contact angle (Θ) on the manufactured structures is measured and significant differences are obtained. The advantages of the micro milling process in prototyping hydrophobic structures are shown and the resulting hydrophobic properties discussed.

1. Introduction

The wetting properties of a surface play an important role in many different disciplines. For instance they may be exploited in order to intensify the performance of heat exchangers [1]. Furthermore, areas showing hydrophobic properties can improve micro fluidic processing tasks like droplet generation and mixing [2]. So specialized knowledge of both, the mode of operation and the manufacturing processes are crucial. Modelling and simulation as well as the validation via experiments on test structures are complementing each other. Thus, suitable manufacturing processes are needed. Micro end milling is a flexible manufacturing process, characterized by high material removal rate and great diversity of workpiece materials and structure geometries.

The research presented in this paper shows micro machined surfaces that are inspired by Molecular Dynamics simulations (MD) and the wettability of those.

2. Molecular dynamics simulation and experimental set-up

MD was carried out with conserved number of particles (N), Volume (V) and Temperature (T). The contact angle of a model fluid placed on top of a cylindrical pillar was determined by evaluation of the density profile. Based on the simulation, the influence of roughness and sharp edges on wetting interaction was determined.

The machining was performed using a C-frame 3-axis CNC precision milling machine and ultra-small micro end mills with 20 µm and 50 µm diameter [3]. All structures were milled under dry machining and, after milling, ultrasonic cleaning was applied. Before Θ measurement, the surfaces were cleaned by rinsing with double distilled water.

The Θs were measured with the drop shape analysis system DSA100 by Krüss. Double distilled water was the test liquid. The droplets had a volume of 3 µl, air was the surrounding medium, the temperature was 20 °C. Two droplets were dispensed by a microlitre syringe and the influence of the surface texture was determined by the difference between the Θ on the structured and the unstructured surface. In addition to the Θ analysis a confocal measurement was performed to study the dimension of the structures, and after gold sputtering SEM images of the surface were taken.

3. Results

The MD reveal a strong impact of contact line pinning at sharp edges on the wettability. The increased surface area as a result of the texturing has, if any, only a minor effect on the contact angle. As can be seen in Fig. 1a for the Epitaxial Cassie state, the contact angle equals 90° as long as the drop is smaller than the pedestal. For radii of the drop larger than the pedestal's radii, the angle increases due to pinning only.

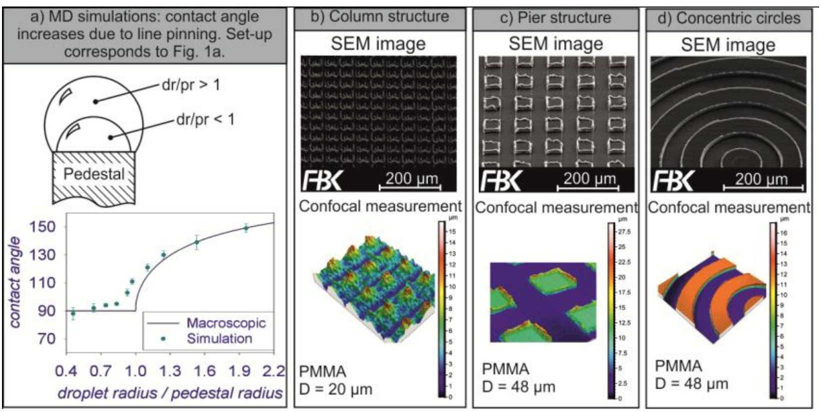
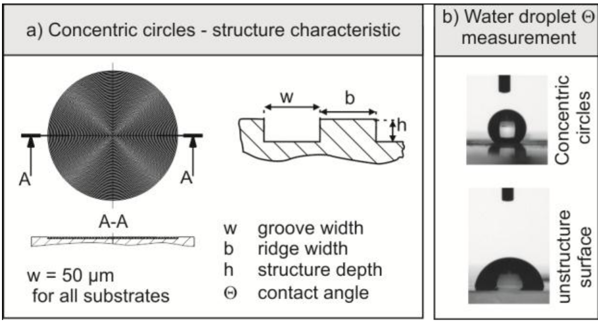


Fig. 1. MD and machining results

Based on the MD simulation results, structures were chosen that promote contact line pinning. Several possible structures were produced by micro milling. Fig. 1bcd indicates the flexibility of milling regarding the geometry of the structure. In all cases, structuring increases the hydrophobicity, the extent of which is different for the distinct topographies. The Θ on the column structure (round section) increases only by 4° compared to a flat surface, on which a Θ of about 80° was measured. The pier structure (rectangular section) shows a strong impact on the Θ with an increase of about 34°. The concentric circular grooves show the largest effect because the contact line can adapt to the structure most favourably. Here an increase of 68° in Θ was observed.

Based on these results and in line with the predictions from the simulation the concentric circular groove type structure was chosen for a more detailed investigation. The structured area was 8x8 mm². In Fig. 2 the structures' characteristics are summarized along with the results.



c) Dimension and corresponding Θ

Sample #	b/w	h/w	Θ
1	1	0.1	130
2	1	0.2	148
3	1	0.4	147
4	2	0.1	100
5	2	0.2	139
6	2	0.4	148
unstructured surface			80

Fig. 2. Characteristic dimensions of the substrate texture and the corresponding Θ.

The ridge width b and the structure depth h were varied. The groove width w was held constant. The Θ is the same within the experimental uncertainty of its determination (which is about +/- 4°) for the samples #2, #3. #5, and #6 (Θ ≈ 144°). Only at very low numbers of the structure depth h (samples #1 and #4, h/w = 0.1) smaller numbers for Θ are observed, indicating a lower hydrophobicity. Upon inflating the drop a stick-slip behaviour of the contact line is observed (Fig. 3). From the present data, it is difficult to assess the influence of the ridge width b. The preliminary results presented here show that fast prototyping via milling is suitable and that a complex and time-consuming structuring is not proportional to the hydrophobic behaviour of the structure.

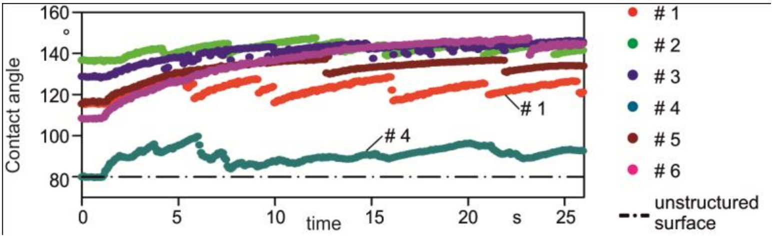


Fig. 3. Time-Θ diagram upon inflation of the droplet on different surface textures.

4. Conclusion and Outlook

MD reveal that compared to the texture of a surface, sharp edges have a strong impact on the hydrophobicity. In experiments, the water contact angle (Θ) on the manufactured structures is measured and significant differences obtained. Concentric grooves turn out to be most efficient for inducing hydrophobic behaviour showing an increase in Θ of 80 %. Micro milling is attractive for manufacturing prototypes for studying the influence of surface structure on wetting, helping to design a component as a function of its requirements.

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