Manufacture of mold inserts with micrometer sized features using ultra precision machining (UPM)

F. Böhmermann[1], K. Liu[1], O. Riemer[2]
[1] *SIMTech - Singapore Institute of Manufacturing Technology, Singapore*
[2] *LFM - Laboratory for Precision Machining, University of Bremen, Germany*
florianb@SIMTech.a-star.edu.sg

Abstract

In recent years microfluidic devices became of great interest, as they offer a wide range of bio-analytical and fluid processing applications through the utilization of size effects. Especially a mass manufacture of disposable polymeric microfluidic devices by hot embossing or injection molding is expected to have high economic potential [1]. It is known that channels and areas showing a localized change in wettability can considerably improve fluid processing tasks like mixing or droplet generation. Chemical approaches, like the polymerization of lauryl acrylate, were successfully shown to achieve hydrophobic coatings for micro channels but are not suitable for a mass manufacture [2]. Since microstructures are known to provide water repellent properties of surfaces, this work focuses on the microstructuring of mold inserts, leading to localized hydrophobic properties of molded parts. Diamond machining can be applied to this task, as it can generate the small size of the effective features.

1 Introduction

The wetting state of a droplet on a smooth and flat surface is given by the balance between the three relevant interfacial tensions (solid-liquid-vapor) and results in an equilibrium contact angle Θ_e, the tangent angle of the liquid-vapor interface. This idealized view is described by Young's equation. The roughness of a surface can amplify the hydrophobicity, which was first described by Wenzel [3] as well as Cassie and Baxter [4]. Wenzel assumed a remaining contact of the droplet with the entire rough surface, increasing the interfacial contact area, while Cassie and Baxter defined the composite state. Here the drop rests on the top of the rough surfaces peaks, leaving air trapped under it. A very impressive implication can be found in nature in the water repellent behavior of the lotus leaf. Structures in a height of 15µm (aspect ratio 1.5) and a spacing of 10µm superimposed with sub-micrometer sized wax crystals generate distinctive hydrophobic properties, leading water droplets to roll off the leaf's surface [5]. To utilize those kind of structures for technical applications, an abstraction is necessary, to enable a manufacture e.g. through diamond machining.

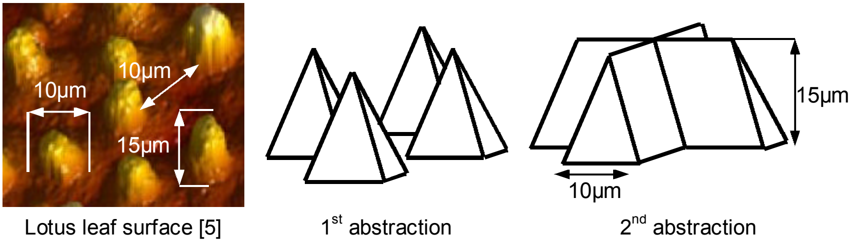

Fig. 1: Abstraction of lotus leaf surface structures

Fig. 1 shows the abstraction chosen for this approach, derived from the natural model of the lotus leaf. The negative of these structures can be cut by a "diamond grooving" process with V-shaped tools to precisely achieve pre-defined dimensions and aspect ratios. The resulting surface structures of the molded part therefore are expected to act in a similar way as the structures of the lotus leaf, i.e. they mimic structures given by nature adopted for technical purposes.

2 Experimental setup for microstructuring

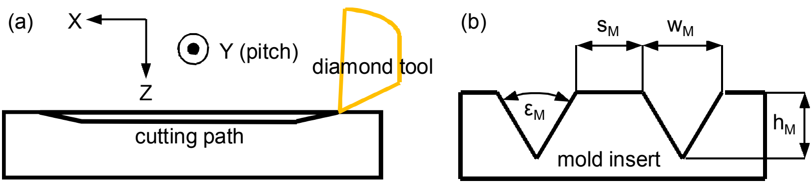

Fig. 2 Cutting kinematics (a) and resulting feature dimensions on mold insert (b)

Cutting experiments are conducted on a Precitech Optimum Series 4200 ultra precision machine tool. Diamond turned brass samples (CuZn37, d = 60mm, t = 15mm, R_a < 20nm) are used as base material for mold inserts. The cutting kinematics for diamond grooving are provided by the linear stages, cutting motion by X-axis, cutting depth by Z-axis and the groove pitch by Y-axis (Fig. 2(a)). Areas of 6 x 6mm^2, each with different structure geometry, are cut into the mold insert, applying V-shaped diamond tools with different including angles ε. The diamond tool geometry is directly copied into the workpiece (tool including angle ε equivalent to groove opening angle ε_M), leading to a variation in features aspect ratios. Cutting is performed in two directions, 0° and 90° resulting in a cross pattern. The parameters depth of cut h and spacing s are determined by the natural model of the lotus leaf. The feature ground width w_M on mold inserts is resulting from tool opening angle and cutting depth (Fig. 2(b)). An overview of the cutting parameters is given in Table 1.

Table 1: Cutting parameters for micro grooving

tool including angle	aspect ratio	depth of cut	spacing
ε	h:w	h	s
90° / 45° / 18°	0.5 / 1.2 / 3.2	6 / 10 / 16µm	10 / 20 / 30µm

3 Molding and functional testing

Molding is carried out using a two component silicone filler (Struers RepliSet, resolution 0.1µm). The molding material is attached to a supporting plate, enabling an even replication as well as easy demolding. The successful replication of features is proven by confocal microscopy (SENSOFAR Plu 2300). The performance of replicated hydrophobic surfaces and unstructured references is evaluated by video droplet contact angle measurements (AST VCA 3000S) with water and ethylene glycol. Examples for a droplet formation on an unstructured surface and a surface with microstructures are given in Fig. 3.

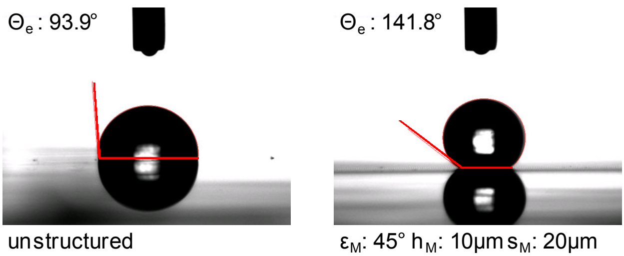

Fig. 3: Water droplet contact angle measurement

4 Results and discussion

The microstructured areas generally show an increased hydrophobicity. Compared to an average water droplet contact angle of 95° (ethylene glycol 89°), replicated structures cut with a 90° including angle tool show an average water droplet contact angle of 117°, 135° for those cut with a 45° including angle tool and 130° for the 18° tool. The measured contact angles for ethylene glycol are 110°, 135° and 127° respectively. Best results are achieved with those structures replicated form molds cut with a 45° including angle tool (Fig. 4). The aspect ratio of the structures (height:width) is given with 1.2 and therefore comparable to those of the lotus leaf (1.5). A stable droplet formation in a Cassie-Baxter state is observed showing air traps under the droplets.

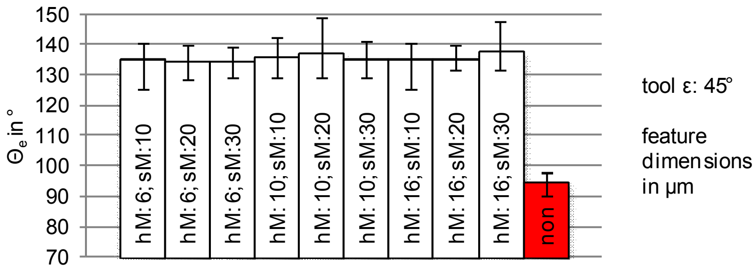

Fig. 4: Water droplet contact angle measurement results

4 Conclusion and outlook

The technical adoption of the natural lotus leaf is successfully demonstrated by replicated parts showing a distinctive increase of hydrophobicity. This effect can help improving the performance of microfluidic devices. Following work includes the manufacture of mold inserts with micro structured protruisons and areas for a hot embossing of microfluidic chips. Replicated parts are to be bonded forming a microfluidic device. Functional tests are to be conducted.

References

[1] Fiorini, G.S.; Chiu, D.T.: Disposable microfluidic devices: fabrication, function, and application; BioTechniques (38), 2005, pp. 429-446

[2] Öztürk, E.; Turan, E.; Caykara, T.: Fabrication of ultrahydrophobic poly(lauryl acrylate) brushes on silicon wafer via surface-initiated atom transfer radical polymerization; Applied Surface Science (257), 2010, pp. 1015-1020

[3] Wenzel, R.N.: Resistance of solid surfaces to wetting by water; Industrial & Engineering Chemistry (28), 1936, pp. 988-994

[4] Cassie, A.B.D.; Baxter, S.: Wettability of porous surfaces; Transactions of the Faraday Society (40), 1944, pp. 546-551

[5] Wang, J.; Chen, H.; Sui, T.; Li, A.; Chen, D.: Investigation on hydrophobicity of lotus leaf: Experiment and theory; Plant Science (176), 2009, pp. 687-695