Wettability modification with controlled cutting conditions and application to patterned self-assembly of fine particles

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Abstract

Cutting process leaves periodical structures or texture on the finished surface. Spreading of liquid over such surface is strongly affected by the cross-sectional profile. On the other hand, drawing up a substrate from suspension in which fine particles are dispersed, packed structure of particles are self-assembled. Changing the wettability with texture and spreading of the suspension, assembly can be patterned or aligned along the texture. This paper introduces the wettability modification of surface with controlled cutting conditions and the application to patterned self-assembly of particles. Substrate was finished by five-axis milling machine, contact angles of water droplet were measured, and then both of the relationship between machining conditions and wettability and its controllability were made clear on a flat surface. Then, parabolic surface was machined with texture and silica particles of 1 micron diameter were successfully self-assembled on it.

1. Introduction

In biochemical sensing, fluorescent detection is often used in which detecting surface is modified with specific proteins. Fine particle assembly is often used as carrier to improve sensitivity utilizing its wide specific surface area. Further sensitivity improvement is possible if the particles are placed on an optical element such as parabolic mirror and the fluorescent beams are focused or intensified.

Self-assembly of fine particles is one of the attractive processes to produce monolayer packed-structure of particles because the process is just dip-in and drawing-up from suspension in which particles are dispersed [1] as shown in Fig. 1(left). The principle of the assembly is meniscus attraction between the particles, thus uniform spreading of the suspension over the surface is necessary. However, the suspension slips down

quickly steep slope, and it becomes difficult to apply to three-dimensional surface in spite of theoretical analysis [2]. Surface texture left on machined surface can change the wettability to hold the suspension. In other words, liquid film is pinned at the point where physical and/or chemical property changes and the assembly can be localized as shown in Fig. 1(right). The effect of the texture profile on wettability and the assembly is difficult to estimate. This paper aims to make clear the effect of cutting conditions on wettability modification and final assembly. The final objective is to assemble fine particles uniformly on three-dimensional structure.

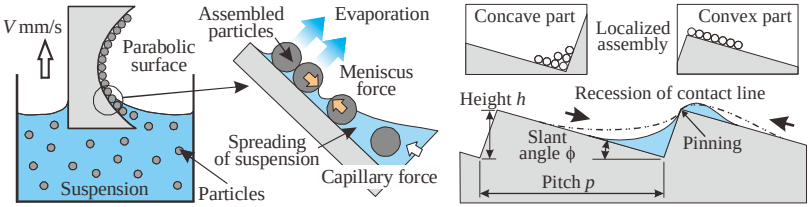


Figure 1: Self-assembly of particles on an optical element (left) and spreading of suspension on a structured surface and localized assembly (right)

2. Modification of wettability with texture

Figure 2 shows the setup for the preparation of the samples. Textured sample was produced with 5-axis milling machine. Square end mill of 4 mm in diameter was used as a cutting tool and its path and inclination were set using CAM software. It is expected that the assembly align or patterned with the tool path along optical element surface. The workpiece material was a wax for modelling because of the easiness to machine. The profiles were replicated to silicone resin for the convenience to change the wettability with plasma treatment.

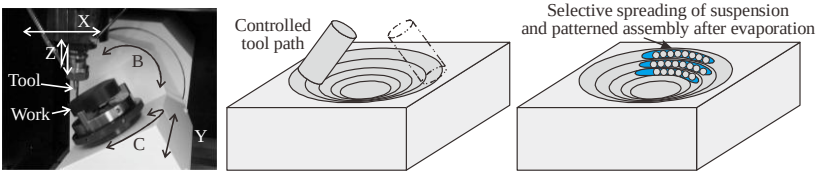
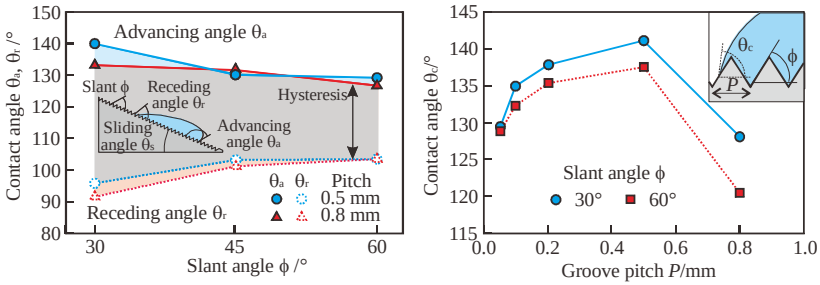


Figure 2: five-axes milling (left), tool path (middle), and patterned assembly (right)

Figure 3 shows the results of wettability modification on a flat substrate. The slant angle ϕ of the texture was changed with the tool inclination. Both of advancing and receding contact angles of a water droplet were measured. The difference between advancing angle and receding contact angle is referred as hysteresis. Liquid can be well held on a surface which has larger hysteresis. It is found from the left figure that hysteresis becomes larger with the decrease in angle ϕ and larger advancing angle corresponds to larger hysteresis. It was also found from other experiments that large pitch *p* makes the assembly discontinuous and finer pitch is appropriate from the standpoint of the assembly. Pitch 0.1 mm and ϕ 30 degrees are considered appropriate.



(a) Effect of the slant angle (b) Effect of groove pitch

Figure 3: Modification of wettability with texturing conditions

3. Patterned self-assembly along the texture

Table 1 shows the conditions for texturing and self-assembly. Silica particles were chosen referring the previous studies [3]. Figure 4 shows the SEM photos of the assembly results on a parabolic surface without texture. The profile of the parabolic substrate is 20 mm in diameter and 5 mm in depth respectively. It was confirmed that suspension cannot be held uniformly on the smooth surface and the assembly has become scattered or island-like though dense assembly can be observed partially.

Table1: Texturing and assembly conditions

Texturing conditions	Pitch *p* 0.1 mm, slant angle ϕ 30 degrees
Suspension	Pure water + SiO_2 particles, ϕ1μm, 5wt%
Assembly process	12.5 mm/s, 90 degrees , four-times iteration

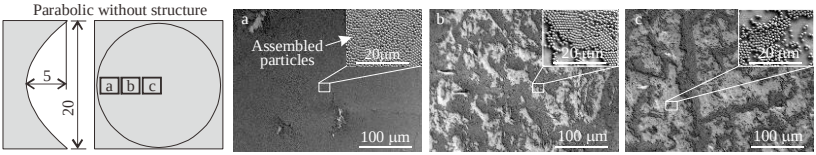


Figure 4: Assembly result on smooth parabolic profile

Figure 5 shows the assembly results on the textured surface. The parabolic profile is same with Fig. 4, but it has the texture of pitch 0.1 mm and slant angle 30 degrees. The ridge profile of the texture can be observed and assembled particles are also uniformly observed along the concentric texture pattern. It is confirmed that the top layer has uniform and packed structure though the number of assembly layers is difficult to identify.

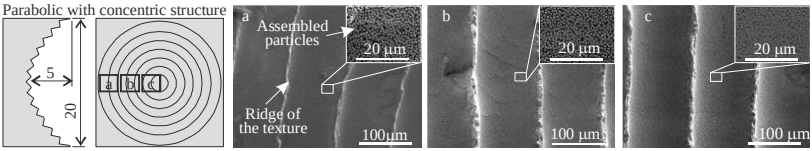


Figure 5: Assembly result on textured parabolic profile

4. Conclusion

The wettability modification with texture machining was investigated and applied to patterned-self-assembly of particles. The results as summarized as follows:

- The relationship between cross-sectional profile of the texture and contact angles was made clear.
- Silica particles of 1 μm in diameter were assembled uniformly along the texture on a parabolic surface.

References:

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