Surface Micromachining by Micro Slurry-jet

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Abstract: The surfaces of a lotus leaf and moth eye have fine structures that produce a water-repellent effect or reflection suppression. The purpose of this study was to explore the use of surface micromachining to create a bio-inspired surface on artificial materials. A micro slurry-jet was proposed as a removal process for a Co-28Cr-Mo alloy, an acrylic resin and a glass surface. The micro slurry-jet is a wet blasting technique that uses alumina particles as an abrasive medium along with compressed air and water to create fine structures. Although the micro slurry-jet has ultraprecision machining ability in the order of nanometers in the orthogonal direction on a material surface, only sub-millimetric machining accuracy in the parallel direction was realized because of the size limitation of the slurry-jet injection nozzle. A mask operation using microelectromechanical technology, which prevents the removal process by the micro slurry-jet, was also adopted to increase the machining accuracy of a material surface. These methods provided few restrictions on the kind of materials that could be created on a bio-inspired surface, and reduced the pre- and post-treatments of the material surfaces.

Key Words: Micromachining, Micro slurry-jet, Bio-inspired surface, Removal process, Wettability

1. Introduction

The biomechanisms of a lotus leaf and a moth eye have been explored. In particular, the relationship between their structures and the water-repellent effect or reflection suppression has been elucidated. These results contribute to the proposal of innovative industrial products1-7). The microscopic structure seen on a natural surface is generally created by a nanoimprint method based on semiconductor manufacturing technology. Therefore, some limitations must be considered in terms of the product size, shape, and material.

This study aims to explore surface micromachining, a mechanical material removal process, as an alternative to a nanoimprint, in creating a bio-inspired surface on artificial materials.

2. Surface micromachining

2.1 Micro slurry-jet

Figures 1 and 2 show the micro slurry-jet8-10) adopted for surface micromachining by a mechanical removal process (MSE-T102K-5050, Palmeso Co., Ltd, Japan). The micro slurry-jet is a type of wet blasting where the slurry (water with alumina particles) is injected through a nozzle using compressed air.

The injection nozzle and table can be moved parallel to the material surface by mechatronics control. The surface profile

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Figure 1. Schematic illustration of micro slurry-jet for surface micromachining.

Figure 2. Image of micro slurry-jet. Table can be moved by mechatronics control.
is determined by the feed speed and feed pitch of the nozzle (Figure 3). The injection time at the same position and the injection pressure are parameters for determination of the profile. The materials processed by the micro slurry-jet were a Co-28Cr-Mo alloy, an acrylic resin and glass. The surface profile obtained by the micro slurry-jet was analysed using a three-dimensional optical surface profiler (New View 7000, Zygo Corp., USA).

2.2 Mask operation

A mask operation using a microelectromechanical technology to prevent the removal process of the micro slurry-jet was adopted to increase machining accuracy (Figure 4). The processed material was glass. A photoresist (SU-8, epoxy resin base) was coated on a glass surface and ultraviolet-irradiated through a photomask; the resist pattern irradiated by ultraviolet rays remained. In the micro slurry-jet mechanical removal process, the resist pattern and glass exposed to the atmosphere were simultaneously removed by the micro slurry-jet. The resist pattern and processed surface of the glass were analysed using a three-dimensional laser measuring microscope (OLS4000, OLYMPUS, Corp., Japan).

3. Results and discussion

3.1 Influence of injection time on removal process

The processed surface profile of the Co-Cr-Mo alloy is shown in Figure 5. It is clear that a longer injection time at the same position created deeper dimples. The dimple diameter was approximately 1 mm, which was equal to the size of the slurry injection nozzle.

3.2 Influences of feed speed and injection pressure on removal process

Figure 6 shows the surface profile of the Co-Cr-Mo alloy, where the feed speed of the nozzle and the injection pressure of slurry were changed. We concluded that a lower feed speed showed a higher removal rate. The injection pressure was also thought to control the depth of the processed area; however, the effect was not obvious in the range of the pressure adopted in these tests (Figure 7).

3.3 Influences of feed pitch on removal process

Figures 8 – 10 show the surface profile of the Co-Cr-Mo alloy with a variety of feed pitches and feed speeds. As the feed pitch was decreased, the flat area not processed by the micro slurry-jet was reduced. The flat area was not observed and a hill-valley structure was created when the feed pitch was less than 1.0 mm. The results might be reasonable because of the limitation of the diameter of the slurry stream.
Figure 6. Influences of nozzle feed speed and injection pressure of slurry on surface profile of Co-28Cr-Mo alloy.

Figure 7. Influences of feed speed and injection pressure on micro slurry-jet removal process.

Figure 8. Surface profile of Co-28Cr-Mo alloy. Feed pitch: 3.0 mm. Injection pressure: 0.31 MPa

Figure 9. Surface profile of Co-28Cr-Mo alloy. Feed pitch: 2.0 mm. Injection pressure: 0.31 MPa

Figure 10. Surface profile of Co-28Cr-Mo alloy. Feed pitch: 1.0 mm. Injection pressure: 0.31 MPa
3.4 Influence of surface material on removal rate

As shown in Figure 11, the slurry-jet can be applied to not only a brittle material (glass) but also to a less elastic material (acrylic resin) in comparison to a metallic material (Co-Cr-Mo alloy). As the slurry-jet is a mechanical process and not a chemical process, its applicability can be extended to a wide range of materials. The removal rate by the slurry-jet depends on the properties of the processed material. As accurate control of the table movement is possible by mechatronics control, the nozzle can trace the same processing route previously processed. Processing the same route twice produced a high removal depth (double processing in Figure 11 (C)).

3.5 Limitation to machining accuracy by micro slurry-jet

The results showed that the slurry-jet had ultraprecision machining ability in the order of nanometers in an orthogonal direction to the material surface. However, even if the feed speed, the nozzle processing routes and the processing times at the same processing route (single, double or quadruple processing) had been adjusted, it was concluded that the machining accuracy was up to 0.25 mm in parallel to the material surface (Figures 12 and 13). From another perspective, if a smooth and flat surface is required of the slurry-jet, the feed pitch should be less than 0.25 mm.

3.6 Effect of masking method by using resist pattern

Figures 14 and 15 show the effects of the masking process. Sharp-edged profiles were obtained using the masking process. Although the resist pattern with a diameter of 30 µm and a thick of 30 µm was fabricated on glass, the slurry-jet blown off the pattern. The result showed that improvement of the machining accuracy parallel to the material surface was the machining

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Figure 11. Surface profiles of glass and acrylic resin. Feed speed: 0.5 mm/s. Feed pitch: 1.0 mm. Injection pressure: 0.31 MPa

Figure 12. Influence of feed pitch on surface profiles of glass. Injection pressure: 0.31 MPa

Figure 13. Surface profiles of glass. Feed speed: 2.1 mm/s. Injection pressure: 0.31 MPa.
accuracy was limited. However, the processed surface wettability changed (Figure 16).

4. Conclusion

Surface micromachining using a micro slurry-jet was proposed as a mechanical material removal process. The method can be applied to a variety of materials. This simple process reduces the pre- and post-treatments for material surfaces. It is possible that there is no limitation in terms of the shape and size of products when a 6-degree-of-freedom motion between the nozzle and the surface is achieved.

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Figure 16. Contact angle of water on glass surfaces.

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