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A novel vibration- and magnetic field-assisted polishing (VMAP) method for microstructured surface finishing

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Abstract
In order to polish microstructured surface without deteriorating the profile of microstructures, a new vibration- and magnetic field-assisted polishing (VMAP) method is proposed. In this method, magnetic force guarantees that the magnetic abrasives can well contact the microstructured surface and access the corners of microstructures while vibration produces a relative movement between microstructures and abrasives. As the vibration direction is parallel to the microstructures, the profile of the microstructures will not deteriorate. The feasibility of this method was experimentally verified and the results show that after polishing a mirror surface finish was obtained while the profile of rectangular microstructures was well maintained.

Keywords: microstructured surface; vibration; magnetic field; polishing; roughness; profile

1. Introduction

Microstructured surfaces, which are increasingly important for optical and microfluidics applications, are typically fabricated by precision machining processes such as precision cutting and milling concerning productivity. However, due to the low surface quality attributed to such as burrs and tool marks around the microstructures, post-polishing process is necessary to improve surface finish [1]. As the feature size of the microstructures is quite small (within a few micrometers to hundreds of micrometers), current tool-based polishing methods such as bonnet polishing, Magnetorheological Finishing (MRF), miniaturized vibrating tool polishing and even conical pin-type and conical wheel-type tools polishing have difficulty accessing the corners of microstructures and remove material uniformly [2-5]. Therefore, improving the surface finish around the microstructures without deteriorating the profile of the microstructures becomes a challenge.

Here, we propose a novel vibration- and magnetic-assisted polishing (MVAP) method to finish the microstructured surface. In this method, magnetic force guarantees that the magnetic abrasives can well contact the microstructured surface and access the corners of microstructures while vibration produces a relative movement between the microstructures and magnetic abrasives. As the vibration direction is parallel to the microstructures, the profile of the microstructures will not deteriorate. This paper addresses the feasibility study of this method and the results show that after polishing a mirror surface finish was obtained while the profile of microstructures was well maintained.

2. Principle of the VMAP method

Fig. 1 shows the schematic illustration of the VMAP method. A magnet is put under the microstructured surface with a small gap so as to provide a magnetic field. From the cross-sectional view, the magnetic abrasives are attracted towards to the magnet and therefore closely contact the microstructured surface by magnetic force. As a result, the abrasive particles can access the corners of microstructures. The source of magnetic field can be from a permanent magnet or electromagnet, and the magnetic pole can be formed into various shapes to fit different microstructures. As the depth of the microstructures is just tens to hundreds of micrometres, the difference of the contact force at top and bottom of the microstructures is negligible. Then, linear vibration is applied to the magnet using a linear actuator. Due to the change of magnetic force caused by the vibration, the magnetic abrasives follow the movement of the magnet, and hence a relative movement is generated between the workpiece and magnet, causing material to be removed. As the vibration direction is parallel to the microstructures, the profile of the microstructures will not deteriorate.

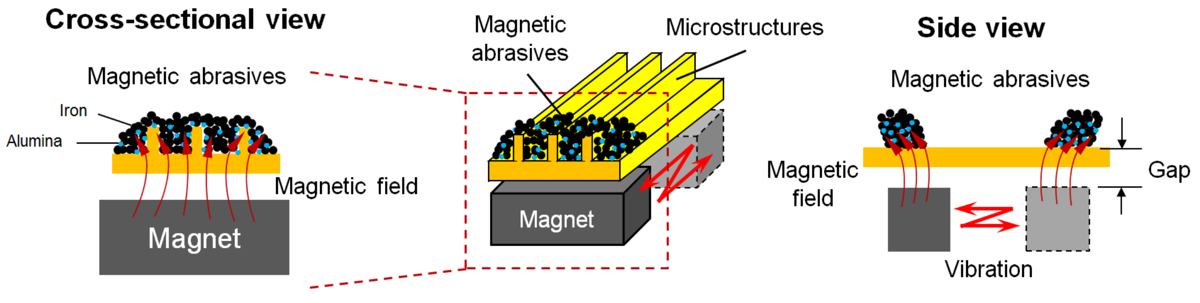

Figure 1. Schematic illustration of the VMAP method

3. Experimental

An experiment was conducted to verify the feasibility of the method. The setup is shown in Fig. 2. A permanent magnet with a cuboid shape (30 mm × 6 mm × 4 mm) was used as a source of magnetic field. It was mounted on a pneumatic actuator that can generate vibration at the frequency of 27 Hz with amplitude of 20 mm at an air pressure of 4 bar. The gap between the magnet and workpiece was set to 3 mm. The magnetic abrasives were composed of iron powder (20 µm mean diameter) and alumina powder (20 µm mean diameter). The workpiece was made of RSP905 [6], which is a fine grain size aluminium alloy having superior mechanical properties such as hardness and Young's modulus than conventional aluminium alloys. The thickness of workpiece was 2.5 mm. The setup was mounted on a 3-axis machine tool with a positioning resolution of 1 µm.

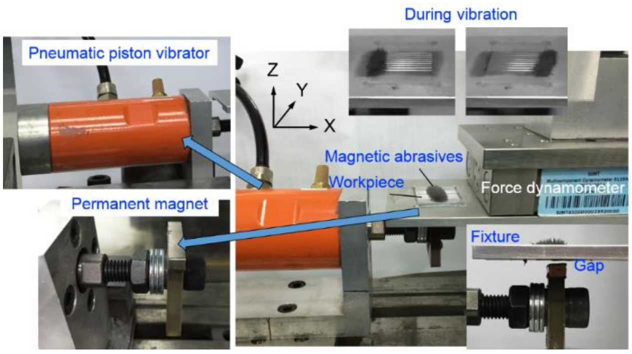

Figure 2. Experimental setup for feasibility study of VMAP method.

4. Results and discussions

Prior to polishing, the workpiece was processed by precision milling to fabricate rectangular microstructures on its surface with geometries as shown in Fig. 3(a). Rectangular microstructures are used to replicate microchannels which are useful in many applications such as microfluidics. Fig. 3(b) shows the feature of microstructured surface before and after polishing. The optical 3D surface topography of rectangular microstructures was measured by Alicona InfiniteFocus. The results show that from top and side views of micostructures (Fig. 4(a) and 4(b)), the burrs and tool marks were clearly removed by the polishing process while the profile of microstructures was well maintained. From Fig. 5, it is found that the surface roughness at tool mark area, which was measured by Form Talysurf PGI 2540, was reduced from 166.9 nm Ra to 25.4 nm Ra.

This technology has the capability to finish microstructures in size of tens or hundreds of micrometres. However, it has two limitations. Firstly, in order to attract magnetic abrasives to the corners of microstructures, workpiece material should be non-magnetic or only slightly magnetic. Secondly, as the magnetic flux density decreases dramatically with an increasing gap, the thickness of workpiece needs to be thin. Otherwise, a strong magnetic field is necessary.

5. Conclusions

In this paper, the VMAP method has been proposed to polish microstructured surface. The principle of the method has been explained, and the feasibility of the method has been verified by experiments. The results show that after polishing, a surface finish of 25.4 nm Ra was obtained while the profile of microstructures was well maintained. Further study will be focused on modelling of the material removal and optimization of process parameters.

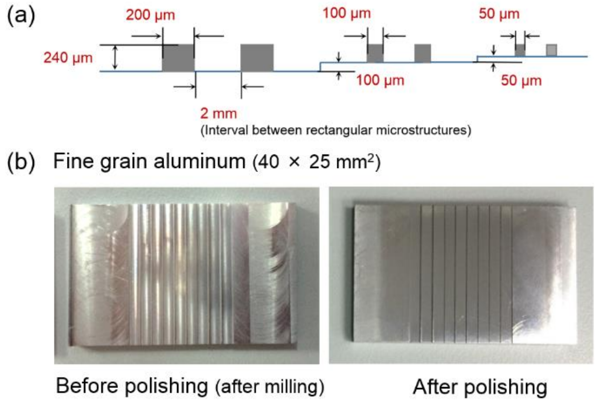

Figure 3. (a) Geometries of the rectangular microstructures, (b) Microstructured surface before and after polishing.

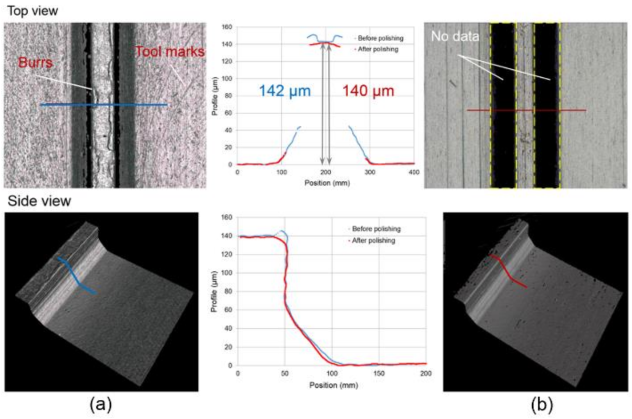

Figure 4. 100 µm width rectangular microstructure (a) before polishing (after milling) and (b) after polishing.

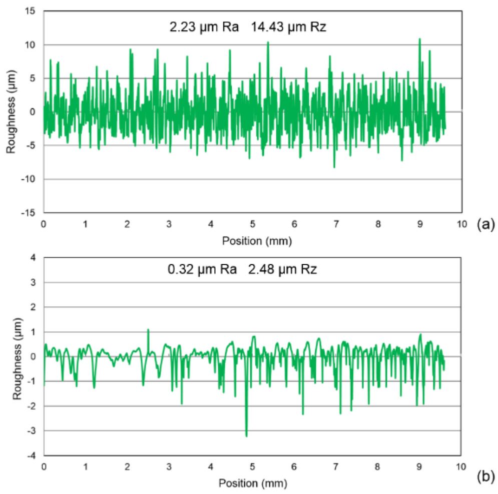

Figure 5. Surface roughness changes (a) before polishing and (b) after polishing.

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