Development of an On-machine Polishing CAM System Based on Five-axis Control - Application Result to Convex Surface -

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Abstract. Polishing requires skill and time to obtain a smooth finished surface of a die or mold. To reduce the polishing time, often, an automated system, such as a robot or an exclusive machine tool, is necessary. Therefore, this work aims at developing an on-machine polishing CAM system based on the five-axis control of a ceramic fiber abrasive brush, a rubber polishing tool and a PCD tool. Previously, a ceramic fiber abrasive brush has been used in the automated deburring and polishing of a flat surface; however, the brush was not suitable for the polishing of a sculptured surface. Here, a ceramic fiber abrasive brush is controlled to fit the normal vector of a sculptured surface, thus, enabling the polishing of the surface through the five-axis control of the machine tool and the path generation by CAM. We performed polishing experiments on a convex spherical surface to verify the effectiveness of the proposed method, and the results demonstrated the suitability of our method. The tool paths to polish the surface; the contour tool path and the scanline tool path, and the polishing conditions were compared by the roughness of the polished surface.

Introduction

Cutter marks and cusps are generated on a machined surface when cutting is performed using an end mill. Currently, to smoothen the machined surface, a manual polishing process is performed [1]. However, manual polishing requires skilled labor and consumes 30–40 % of the total manufacturing time [2, 3]. Recently, on-machine ceramic fiber brushes for deburring have been introduced and have been used for the polishing of flat surfaces. However, it is difficult to polish a curved surface because the ceramic fiber brush itself has a flat polishing surface.

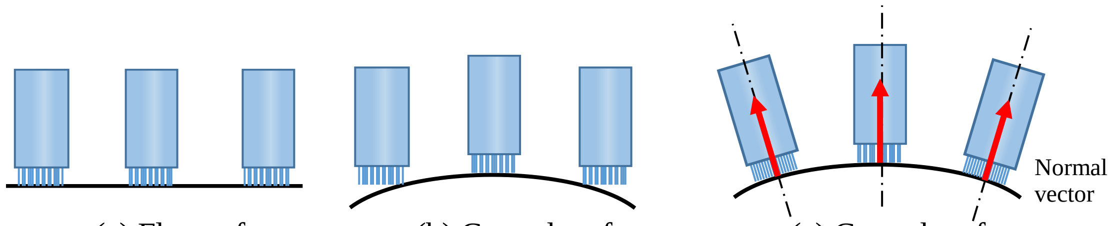
Therefore, the purpose of this work is to develop an on-machine polishing computer-aided manufacturing (CAM) system that automatically polishes various curved surfaces through the five-axis control of a ceramic fiber brush. Specifically, a method to control the ceramic fiber brush that moves perpendicular to the curved surface has been developed. The experiments on a convex spherical surface was designed to identify any difference in performance of two tool paths and two polishing parameters.

Proposed Method to Polish a Convex Surface by Five-Axis Control

As Fig. 1(a) shows, the ceramic fiber brush used in this experiment comprises of abrasive ceramic fiber material instead of an abrasive grain. As Fig. 1(b) shows, the bristles are collected in bundles with a diameter of 3 mm and are arranged along the outer periphery of the brush sleeve so that the central region of the brush forms a cavity. The outer diameter of the fiber brush varies from 5 to 25 mm. Four different fiber brushes were used, depending on the material that required polishing, such as resin, general steel, and a hard-to-cut material. In addition, the fiber brush can be attached directly to the main spindle of a machine tool and handled in the same manner as a regular tool. Fig. 2(a) shows that it is possible to polish a planar surface by using the ceramic fiber brush. However, it is difficult to polish a curved surface because the contact to the fiber brush is not uniform and the brush has three-axis control only, as Fig. 2(b) shows. This study proposes an on-machine polishing CAM system that can polish not only a flat surface, but can also polish a curved surface by tilting the fiber brush in the direction of the normal vector of the polished surface, as Fig. 2(c) shows.

(a) Some examples of ceramic fiber brush (b) Ceramic fiber brush and sleeve

Figure 1. Ceramic fiber brush used in this experiment (XEBEC Technology Co., LTD)

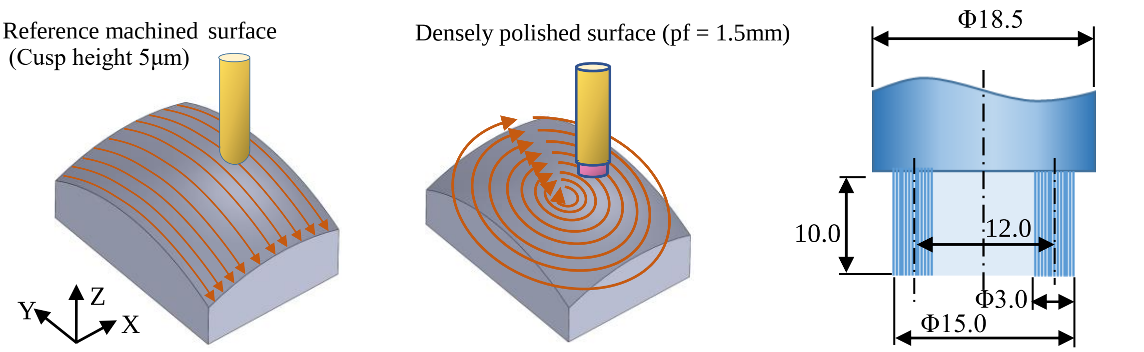


(a) Flat surface (b) Curved surface by three-axis control (c) Curved surface by five-axis control

Figure 2. Proposed method to brushing curved surface with five-axis control

Result of Polishing on a Contour Tool Path

In a previous study, it was shown that, compared to three-axis control, five-axis control could reduce shape deterioration and improve precise polishing [4]. Therefore, the spindle rotation speed, the number of polishing cycles, and the depth of cut were varied and the surface roughness was compared using the contour tool path. As Fig. 3(a) shows, an aluminum block was machined into a spherical surface with radius 120 mm, and with a cusp height of 5 μm in the Y direction, and was used as the reference machined surface. The entire spherical surface of the reference machined surface was polished by dense polishing with a contour line path by using a pick feed of 1.5 mm. Fig. 3(b) shows the contour tool path and Fig. 3(c) shows the fiber brush. These experiments were performed at polishing depths on the spherical surface of 0.2, 0.5, and 1.0 mm, the spindle rotation number was either 2400 or 4800 rpm, and the number of polishing cycles was 10, 30, or 50. The polishing feed rate was set at 1200 mm/min, and the fiber brush was controlled perpendicular to the spherical surface by using five-axis control. The polishing time of 10 cycles took 3 hours 6 minutes, 30 cycles took 8 hours 46 minutes and 50 cycles took 15 hours 4 minutes. A surface roughness meter was used to measure the surface roughness, and the arithmetic average roughness, Ra, over a measurement length of 2.5 mm was measured in the Y direction and X direction in which the height of the capsule at the reference surface remained constant. Fig. 4(a) shows the surface roughness in the X direction after polishing with five-axis control, and Fig. 4(b) shows the surface roughness in the Y direction. It can be seen from the figure that variations are observed, but when the depth of the cut is increased, the value of the surface roughness is improved. Surface roughness was reduced by increasing the number of polishing cycles. However, it turned out that the surface roughness also improved when the spindle rotation speed was lowered, contrary to the manufacturer's guidelines. In general, it is described in the guidelines that if the feed rate is low, the spindle speed is high and the polishing cycle is increased, then the surface can be satisfactorily polished.

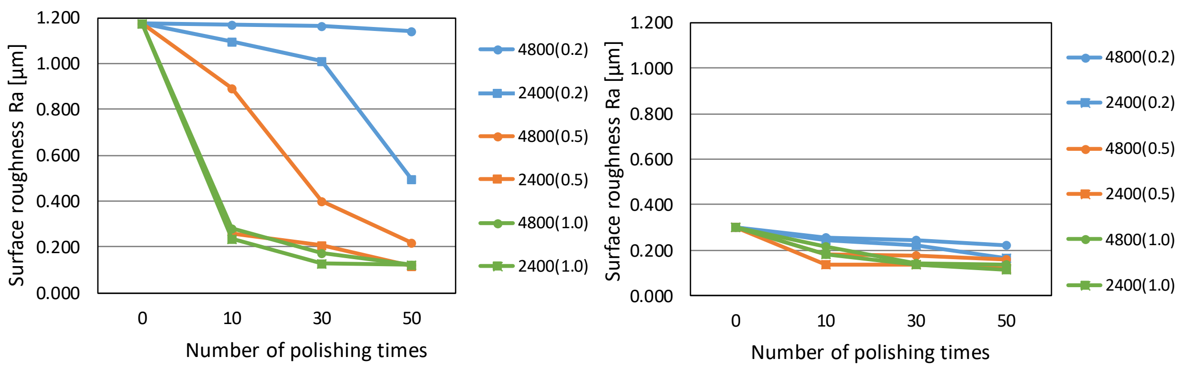


(a) Tool path to make 5μm cusp

(b) Polishing areas and contour tool path

(c) Used ceramic fiber brush

Figure 3. Process of polishing using contour tool path to a spherical surface and used ceramic fiber brush



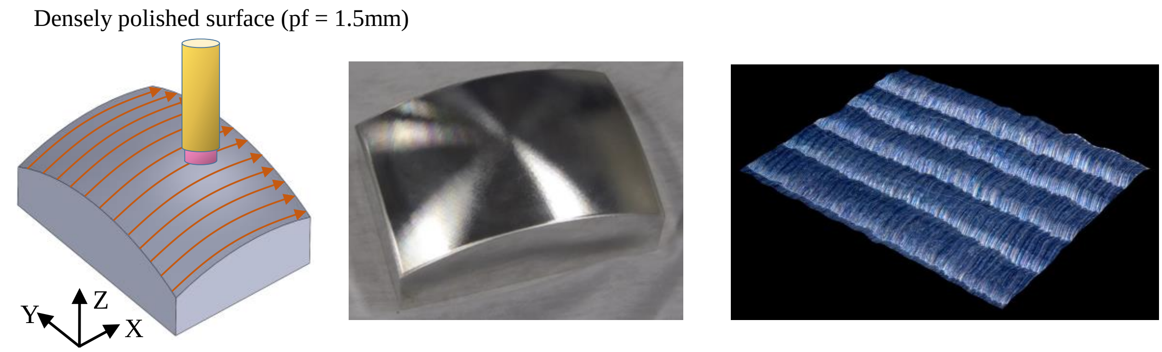
(a) Result of roughness along to the X direction

(b) Result of roughness along to the Y direction

Figure 4. Measured surface roughness of spherical surface using contour tool path

Effect of Contour and Scanline Tool Path on the Polishing Performance

For the same reference spherical surface machined by the contour tool path shown in Fig.3(a), a polishing experiment is carried out with a scanline tool path by using the pick feed of 1.5[mm] as shown in Fig.5(a). Fig. 5(b) shows a photograph of the reference surface and Fig. 5(c) is a three-dimensional photomicrograph of the reference surface. As shown in this figure, there is cusp height with 5 [μm] on the reference surface. Polishing experiments are executed for the polishing depths of the spherical surface of 0.5 and 1.0[mm], the spindle rotation number is 2400[rpm], and the number of polishing times is either 10, 30, or 50. The polishing feed rate is set at 1200[mm/min]. At this time, the polishing time of 10 times takes 3 hours 26 minutes, 30 times takes 10 hours 21 minutes and 50 times takes 18 hours 4 minutes. Figure 6 shows the polished surface by using contour and scanline tool path. Figure 7(a) indicates the roughness of polished surface in the X direction, and Fig. 7(b) shows roughness in the Y direction. From this graph, it is found that the steaks made by brush move remain on the surface, but there is no large difference in the surface roughness.

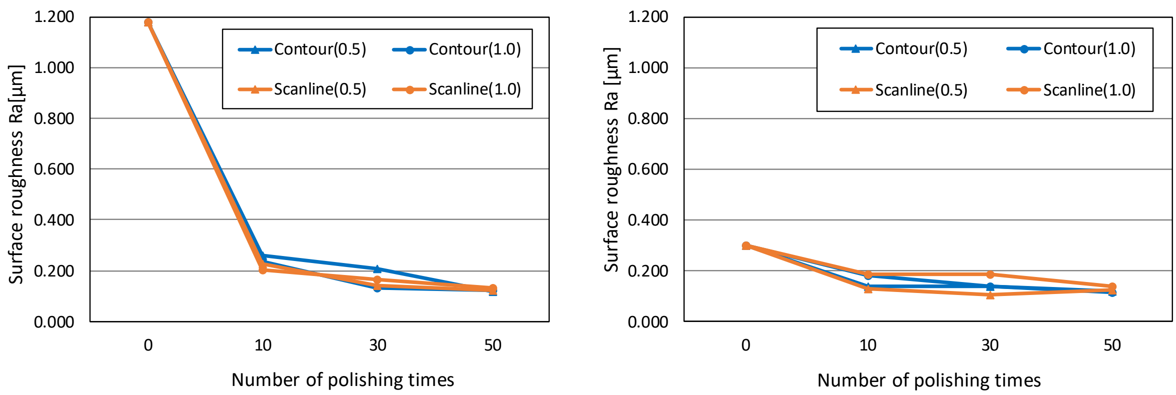


(a) Polishing areas and scanline 5μm cusp (b) Reference surface (c) Photomicrograph of reference surface

Figure 5. Process of polishing using scanline tool path and reference surface

(a) Surface used by contour tool path (b) Surface used by scanline tool path

Figure 6. Polished surface by using contour and scanline tool path



(a) Result of roughness along to the x direction (b) Result of roughness along to the y direction

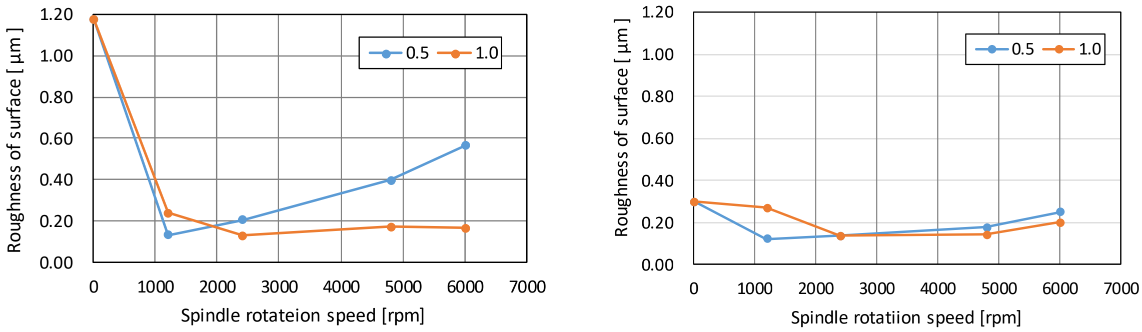
Figure 7. Measured surface roughness comparison with contour and scanline tool path

Effect of Changing the Spindle Rotation Speed and Feed Rate on the Polishing Performance

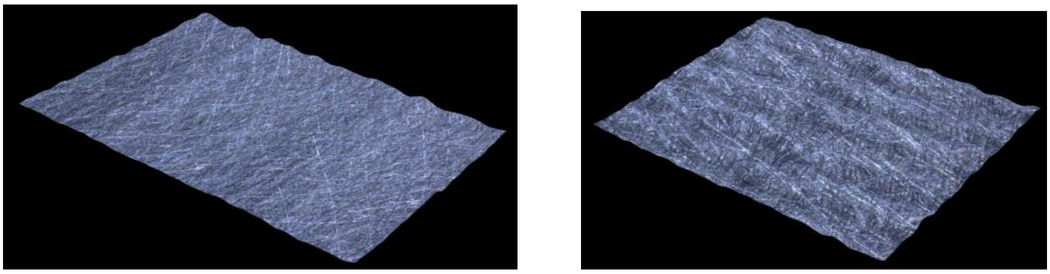
In the proposed polishing method, it was revealed that contour line and scanning line tool paths do not greatly affect the polishing result. Therefore, by using the reference spherical surface generated by the tool, shown in Fig. 3(a), the difference in surface roughness was measured upon changing the spindle rotation speed and the feed rate, using the contour tool path method, as shown in Fig. 3(b). The polishing experiments were executed at a polishing depth on the spherical surface of 0.5 and 1.0 mm, and the number of polishing cycles was 30.

Effect of changing Spindle Rotation Speed. Fig. 8 shows the surface roughness in the X and Y directions after polishing with spindle rotation speeds of 1200, 2400, 4800 and 6000 rpm.

Here, the rotational speed of zero indicates the roughness of the reference surface. Fig. 9 compares the three-dimensional photomicrographs of the surfaces at spindle rotation speeds of 1200 and 6000 rpm, at a depth of 0.5 mm. It is understood that, compared to Fig. 5(c), the height of the capsule on the reference surface is polished. The manufacturer of the fiber brush states that polishing increases as the spindle rotation speed is increased; however, our experimental result shows that the surface is more polished at low rotation speeds. In the case of a convex spherical curved surface, since the contact area of the brush decreases due to centrifugal force, it is clear that the roughness of the polished surface is worse as the spindle rotation speed increases. However, when the depth of the cut is as large as 1.0 mm, the polishing amount is increased, although it is small in proportion to the spindle rotational speed.



(a) Result of roughness along to the x direction (b) Result of roughness along to the y direction
Figure 8. Measured surface roughness comparison with contour and scanline tool path



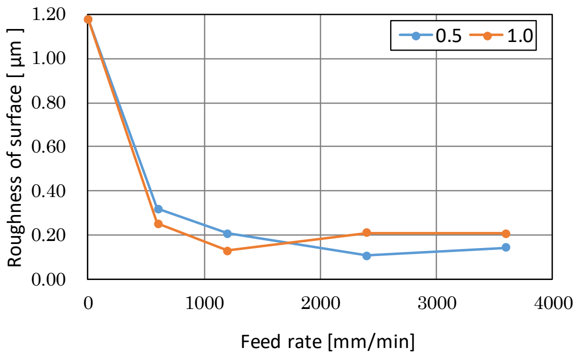
(a) Spindle rotation speed 1200 [rpm] (b) Spindle rotation speed 6000 [rpm]
Figure 9. Photomicrograph of polished surface when the spindle rotation is changed

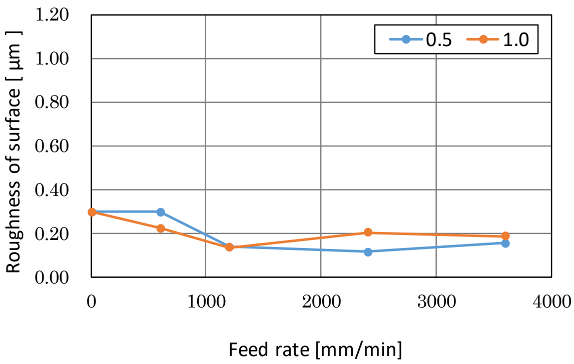
Effect of changing Feed Rate. Fig. 10 shows the surface roughness in the X and Y directions after the polishing process at feed rates of 600, 1200, 2400, and 3600 mm / min. It can be seen that the polishing amount slightly increases in proportion to the feeding speed. Fig. 11 shows the three-dimensional photomicrographs of the surface at feeding speeds of 600 and 3600 mm / min at a depth of 0.5 mm. It can be seen that at the feeding speed of 3600 mm / min the surface is polished more smoothly. In addition, it became clear that there is no difference between the cutting amount and the feed rate.

Conclusions

In this research, a CAM system for the on-machine polishing of curved surfaces by using the five-axis control of a ceramic fiber brush was investigated. It was verified by the polishing experiments, that the proposed method can be performed by controlling the five axes of a fiber brush perpendicular to a convex spherical surface. The polishing process was performed on the spherical surface by five-axis control using both contour and scanline tool paths. Consequently, it is clear that there is no significant difference in the surface roughness of the convex spherical surface polished by these two tool paths. Furthermore, experiments were carried out to ascertain how the spindle rotation speed and the feed rate affected the surface roughness. When the spindle rotation speed was increased, it became clear that the surface could not be polished sufficiently at the high spindle rotation speed. In addition, it became obvious that the roughness of the polished surface does not depend heavily on the feed rate. In each case, it is possible to polish the surface to a roughness of 0.2 μm or less which was the target of this research, and the effectiveness of the proposed method was therefore confirmed.

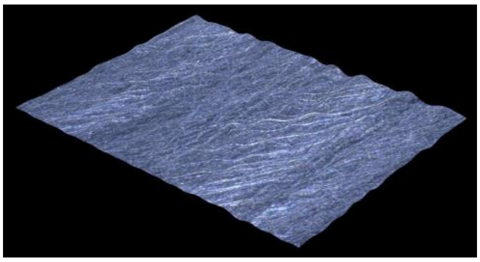
For future work, we will consider the optimum polishing conditions and tool paths, deal with concave shapes and more complex curved surfaces. In addition, it is necessary to develop the CAM function to generate an optimum tool path.

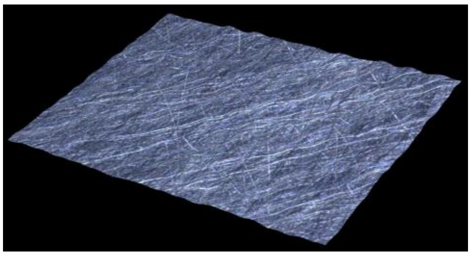




(a) Result of roughness along to the x direction (b) Result of roughness along to the y direction

Figure 10. Measured surface roughness comparison with contour and scanline tool path





(a) Feed rate 600 [mm/min] (b) Feed rate 3600 [mm/min]

Figure 11. Photomicrograph of polished surface when the feed rate is changed

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