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Fundamental study of magnetic polishing for Ti-alloy by use of machining centre

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Abstract

Products for regenerative medicine such as artificial joint or artificial bone has been recently used. These products are typically fabricated by cutting, grinding and polishing. However, these traditional processes are characterized by long machining times. On the other hand, because it became possible to fabricate the product made of metal such as Ti-6Al-4V or stainless steel additive manufacturing, it is expected to shorten the overall production time. However, since the surface roughness of these additive manufactured products are large (approximately 10 µm *Ra*), it is impossible to use in regenerative medicine product. Thus, additional operations such as cutting or polishing are needed. Therefore, in this study, a magnetic polishing method that uses a machining centre is developed to obtain the additive manufactured product made of Ti-6Al-4V is having the required surface quality. In this proposed method, a magnetic paste that composed by a magnetic fluid and an abrasive is adhered onto end-mill shaped permanent magnetic tool. The tool is controlled by the machining centre based on CAD data that was used in the additive manufacturing as well. In this research, the Ti-6Al-4V material is polished using the proposed method, and the polishing performance is investigated.

magnetic polishing, Ti-6Al-4V, machining centre, additive manufactured products

1. Introduction

An additive manufacturing for metal material has been selected to fabricate a medical product such as artificial joint or artificial bone with high efficiency. However, since these fabricated products have poor surface roughness, these are machined with milling and polishing. Because it is possible that the inferior surface quality will have a negative influence on a healthy region of the body. However, the efficiency of the conventional fabrication methods as described above is low, due to the fact that several machine tools and long setup times are required. On the other hand, a hybrid machine that combines a metal 3D printer and machining centre has been developed [1]. Therefore, it is expected to be possible to realize a complete process integration by carrying out the polishing on the hybrid machine. Therefore, in this study, a magnetic polishing method that uses ball end-mill type tool made of permanent magnet on a machining centre is proposed [2]. In this paper, the effect of the polishing condition on surface quality is investigated by polishing a flat-shaped component made of a Ti-alloy.

2. Proposed Magnetic Polishing Method

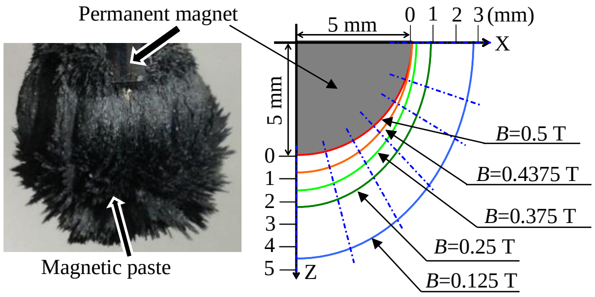
A permanent magnetic tool that absorbed a magnetic paste is shown in Figure 1 (a). This tool is having a ball shape of R5 mm on tool tip. A distribution of magnetic flux density is shown in Figure 1 (b). The magnetic flux density becomes small along with the increase of a distance from magnetic tool. The magnetic paste is composed of magnetic fluid (Oil based), carbonyl iron powder (mean diameter =100 µm), white kerosene, small diameter fibre and WA abrasives (semi-final polishing: mean diameter = 1 µm, final polishing: mean diameter = 0.3 µm). The tool is attached to spindle of machining centre. By controlling this tool along a machining path on the workpiece, the polishing operation is achieved.

3. Experimental Set-up and Conditions

In this experiment, a flat-shaped Ti-6Al-4V (Size: W30 x L30 x T9 mm) component was polished. As machining centre, a vertical 3-axis machining centre VD-46VA (OKUMA Corp.) was used. As measuring equipment, a point autofocusses probe 3D measuring instrument NH-3N (Mitaka Kohki Co., Ltd.) was used. Before the polishing experiment, the workpiece was ball end-milled. In order to reduce the anisotropy of surface roughness, a milling condition was determined by Eq. 1 that considered a tool run-out. Where, Δx_b is pickfeed, f'_b is feed rate per revolution and *Rzth* is theoretical surface roughness (1 µm *Rz*).

$$\Delta x_b = f'_b = \sqrt{\frac{8R \cdot Rzth}{2}} \tag{1}$$

Ball end-milling condition are as follows: tool radius = 1 mm, number of cutting edge = 2, rotational speed = 15000 min^{-1}, feed speed = 900 mm/min, axial depth of cut = 0.2 mm, pickfeed = 0.06 mm and coolant is emulsion type. The surface roughness that was obtained by above condition was 0.2 µm *Ra*/2.2 µm *Rz*.



(a) Ball end-mill type tool (b) Distribution of magnetic flux density

Figure 1. Images of magnetic polishing tool and polishing paste.

Figure 2 shows the illustration of polishing experiment. In order to clarify the effect by a difference between tool rotation direction and workpiece scanning direction, the tool move in one direction. In addition, there is a gap between tool tip and workpiece. This gap is called "Polishing gap". The polishing condition was determined based on a previous research [3] as follows: tool rotational speed = 750 min^{-1}, feed speed = 5 mm/min, polishing gap = 0.3 mm, polishing length = 10 mm, polishing time = 12 min, amount of polishing paste = 1.2 g.

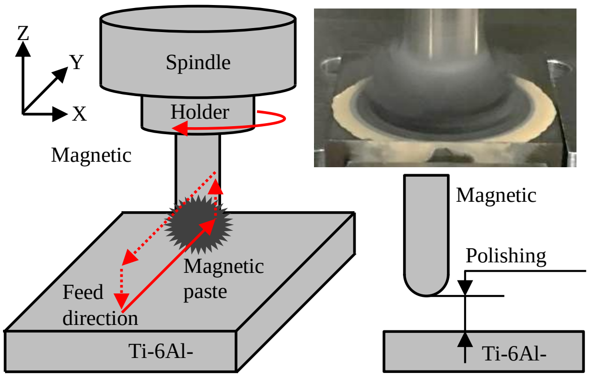


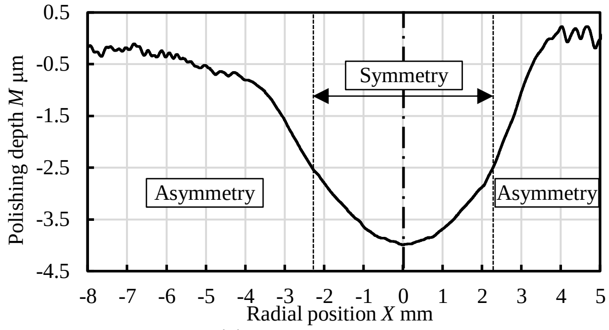
Figure 2. Schematic illustration of magnetic polishing experiment.

4. Experimental Result and Discussion

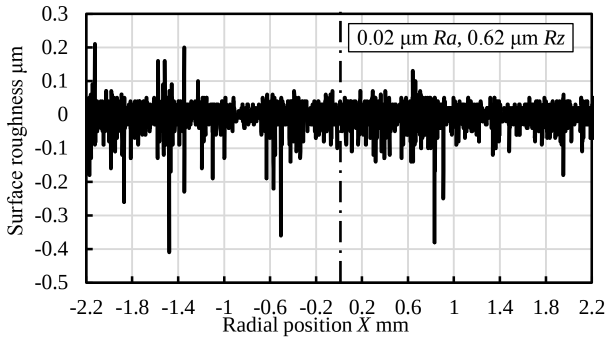
Figure 3 shows the relationship between the polishing depth *M* and tool radial position *X*. The polishing paste for semi-final polishing was used. Since the maximum height roughness before polishing was 2.2 µm, it is found that the effective radius that can obtain a mirror surface is ±2.5 mm. On the other hand, on the region outer than *X* = ±2.2 mm, since the removal pattern is asymmetric, it was found that an effect due to the difference between rotational direction and scanning direction occurs. Therefore, if the pitch between each tool path is larger than 4.4 mm, it is considered that the workpiece cannot be machined to the mirror surface finish, as a surface waviness occurs. Figure 3 shows the surface roughness profile from tool centre to *X* = ±2.2 mm. *Ra* was improved by 90%, to 0.02 µm *Ra*. *Rz* was improved by 72%, to 0.62 µm *Rz*. The photograph of region that was polished with tool centre is shown in Figure 4 (b). The cutter mark (Figure 4 (a)) that was produced by ball end-milling was removed, but it is seen that a scratch which occurred with abrasives is produced. Subsequently, this semi-final polished workpiece was finally polished. The polishing condition was modified by only changing the diameter of WA abrasives. Figure 5 shows the surface roughness profile of final polished workpiece. The surface roughness obtained is 0.01 µm *Ra*/0.29 µm *Rz*. In comparison with the semi-final polished surface, *Ra* improved by 50%, and *Rz* improved by 53%. Figure 4 (c) shows the image of final polished surface that was polished with tool centre. It is seen that the scratches are present as with the semi-final polishing. On the other hand, the workpiece that was polished with polishing position that is approximately 4 mm away from the tool centre is shown in Figure 4 (d). In this area, the scratch was not present. The resulting surface roughness was of 0.01 µm *Ra*/0.21 µm *Rz* as in the centre region.

5. Conclusion

As result of magnetic polishing of Ti-alloy on the machining centre, a high finish surface was obtained (10 nm *Ra*/0.21 µm *Rz*). However, it is found that scratches are present on the centre region where high pressure is applied. Therefore, the use of abrasive type having removal efficiency as high as diamond, and higher polishing gap are required.

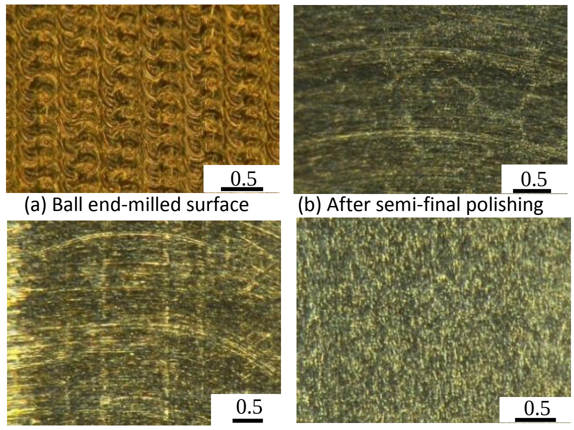


(a) Polishing amount



(b) Surface roughness profile

Figure 3. Measuring results of surface quality after semi-final polishing.



(a) Ball end-milled surface (b) After semi-final polishing

(c) After final polishing (Centre) (d) After final polishing (Outer)

Figure 4. Comparison of machined surface.

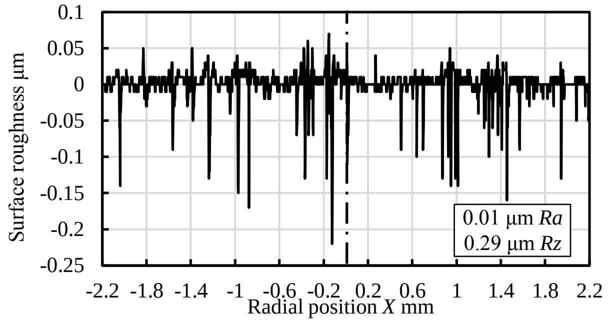


Figure 5. Surface roughness profile after final polishing.

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