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Estimation of magnetic polishing rate on additive manufactured Ti-6Al-4V

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Abstract

An additive manufactured (AM) Ti-6Al-4V has been expected to apply in medical field like an artificial replacement component. This component requires high surface quality. Since the surface of component made by AM is poor quality, the additional machining such as cutting and polishing. The cutting process can be carried on with typical machine tool. However, the polishing process has been done by the craftsman. There are following problems that this study must resolve: The polishing efficiency is low. The quality of polished component is uneven. This study has been proposed the magnetic polishing method that uses ball end-mill shaped permanent magnet tool on the typical machining centre and investigated the optimum magnetic polishing paste for the additive manufactured Ti-6Al-4V. On the other hand, there are still some tasks to polish the various shaped components with high efficiency. In this report, the component specifications of magnetic polishing paste such as abrasive size and amount or α-cellulose amount were changed to improve the polishing efficiency. Consequently, the Preston constant was investigated to support the decision of polishing path. The estimated polishing amount that used calculated Preston constant corresponded reasonably well the actual polishing amount.

3D printing, Estimating, Magnetic polishing, Machining

1. Introduction

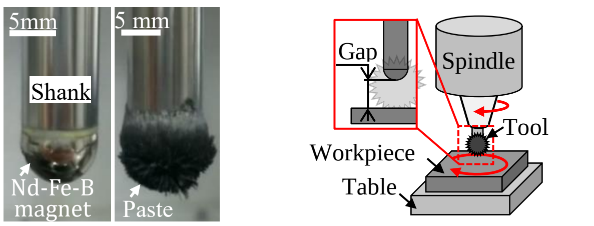
A hybrid additive manufacturing machine having a function of machining centre that can integrate the machining processes (from shape generation to semi-final milling) is expected to carry out the high efficiency fabrication of tailor-made medical component like an artificial joint [1]. On the other hand, a final polishing process has been depended on a craft-man yet. This study proposed the magnetic polishing method using the machining centre for automatically polishing of Ti-6Al-4V [2]. In this report, the optimum polishing paste that can obtain the required surface roughness for artificial coxa and estimation method of polishing amount were investigated.

2. Magnetic polishing method

A tool having the permanent magnet of *R*5 mm is attached on the machining centre and is adhered the magnetic polishing paste that combined magnetic fluid, iron powder, diamond abrasive, solvent oil and α-cellrose fibre (Mean diameter: 30 µm) as shown in the Fig. 1. There is a clearance (called gap) between tool and workpiece and the optimum gap was investigated as 0.5 mm in the past report [2]. The tool rotates and moves on the workpiece along with the circular shaped tool path.

3. Experimental method and conditions

As the workpiece, the additive manufactured Ti-6Al-4V that was fabricated with the hybrid AM machine LUMEX AVANCE-25 (Matsuura machinery Corp.). The fabrication condition was recommended condition as below; Yb fibre laser was used, laser power: 120W, beam spot diameter: 0.2 mm, thickness of layer: 50 µm, maximum powder size: 45 µm and argon gas was used as atmosphere gas. The workpiece size was 30 x 30 x *t*5 mm. A ball end-milling was done as pre-finish machining, the workpiece was generated into flat shape. As the surface roughness after milling, 2.9 µm*Rz* in X direction and 2.8 µm*Rz* in Y direction. The hardness was 519HV. In this report, the two types solvent of magnetic fluid (water and oil) were used. Moreover, diamond abrasive diameter (Mean diameter: 1, 6 and 12 µm) and iron powder diameter (Mean diameter: 2 and 75 µm) were changed. These components were controlled with a mass. The optimum polishing condition (Rotational speed: 15 m/min, feed speed: 5 mm/min, gap: 0.5 mm and rotational radius: 5 mm) that was obtained in past report was used [2]. As the machine tool, the three-axis machining centre was used. The surface roughness and polished shape were measured with a point autofocus probe 3D measuring instrument NH-3N (Mitaka Kohki Co., Ltd.).



(a) Magnetic polishing tool (b) Magnetic polishing on machine tool

Figure 1. Magnetic polishing method on machining centre.

4. Results and Consideration

4.1.Effect of component specification on polishing capacity

First, the influence of solvent type of magnetic fluid on the surface roughness as shown in Fig. 2. In the case of using the water-based fluid, the surface roughness was increased than initial roughness. Because the polishing paste stiffened by a vaporization of water. In addition, the polished surface of that workpiece occurred an oxide film. Thus, it is considered that the workpiece temperature became large by increase of polishing pressure and frictional force. On the other hand, the surface roughness was improved by using the oil-based fluid. Then, the optimum solvent type is oil-based solvent.

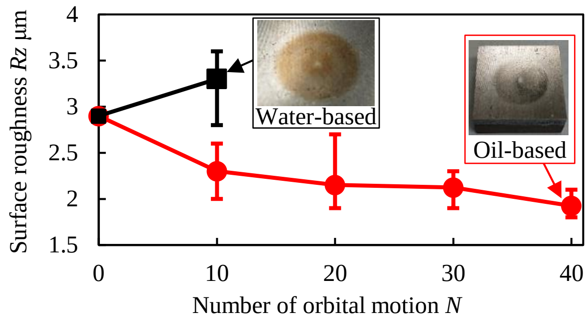


Figure 2. Influence of solvent type on surface roughness.

Next, the influence of abrasive diameter is shown in Fig. 3. In the case of using abrasive diameter of 1 μm and 6 μm, the surface roughness was improved early. In this experiment, since the mass of abrasive were constant in any condition, the effective abrasive number will decrease in accordance with the increase of abrasive diameter. Thus, the surface roughness didn't be improved with abrasive diameter of 12 μm.

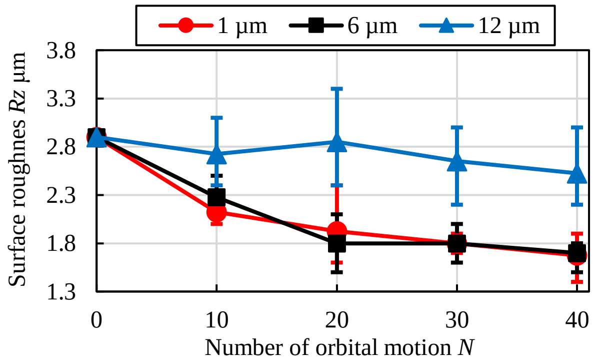


Figure 3. Influence of abrasive diameter on surface roughness.

Finally, the influence of iron powder diameter is shown in Fig. 4. In the case of using iron powder of 75 μm, the surface roughness that was obtained by the abrasive of 1 μm was improved. However, in the case of using abrasive of 6 μm, the surface roughness improved slightly. This different occurred by the difference of effective abrasive number. On the other hand, the surface roughness that was obtained by using the iron powder of 2 μm were also improved slightly. However, these are inferior to iron powder of 75 μm and abrasive of 1 μm. The paste that included the small iron powder doesn't generate the magnetic cluster. Therefore, because the paste using large iron powder that generates the magnetic cluster can obtain large polishing pressure, it is considered that the polishing amount became large. Then, since the cutter-marks of end-milling was removed, the surface roughness became small.

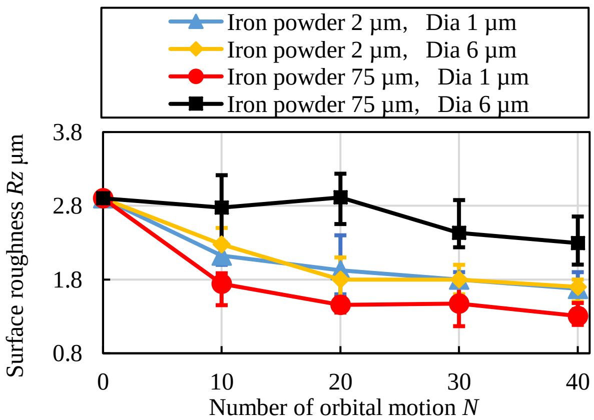


Figure 4. Influence of carbonyl powder and diamond abrasive diameter.

4.2. Estimation of magnetic polishing amount

From the above, the optimum paste components are below; solvent of magnetic fluid is oil-based, abrasive diameter is 1 μm and diameter of iron powder is 75 μm. In order to generate the tool path easily, the prediction model of polishing amount distribution is required. In this report, the prediction model based on Preston's law (Polishing amount = Preston constant x polishing pressure x polishing speed x polishing time) that was proposed in past report [3] was used. However, as the original work of this study, the polishing pressure model was established by use of Hertz contact stress that is defined by Eq. 1. Where, P_0 is maximum polishing pressure that was measured with dynamometer, r_2 is maximum contact radius, r is any polishing point. The calculated pressure distribution is shown in Fig. 5. The average Preston constant when using the optimum paste was 0.2x10^{-7} mm^2/N (standard deviation: 0.05). The comparison between the predicted polishing depth distribution and the actual polished depth is shown in Fig. 5. It is found that these shapes are almost same. The surface roughness after polishing was 50 nm*Ra* as shown in Fig. 6. This value satisfies the requirement of artificial coxa (ISO7206-2).

$$P(r) = (P_0/r_2)\sqrt{{r_2}^2 - r^2} \quad (1)$$

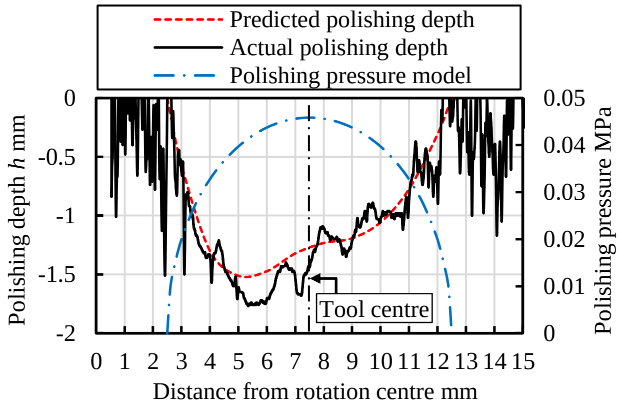
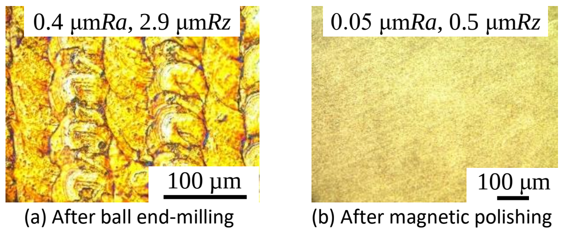


Figure 5. Predicted polishing pressure and comparison between prediction shape and polished depth.



(a) After ball end-milling (b) After magnetic polishing

Figure 6. Comparison of workpiece surface.

5. Conclusion

In this report, the optimum paste components were investigated. Moreover, the prediction model of polishing depth was established. It was found that Investigated paste and prediction model are useful to polish the additive manufactured Ti-6Al-4V product that requires the precise smooth surface.

References

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