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Investigation of magnetic polishing characteristics of additive manufactured Ti-alloy

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Abstract
In recent years, an attention degree of a metal additive manufacturing has been increased. Accordingly, it is expected that the fabrication of artificial replacement products made of titanium alloy with the metal additive manufacturing. In addition, a novel machine tool that combined additive manufacturing system and machining centre has been developed. By using this machine tool, it is considered that the fabrication efficiency of these products will increase. Therefore, in this study, the magnetic polishing method that can mirror polish on the machining centre is developed. This polishing method use an end-mill shaped permanent magnet tool. This tool is attached to spindle on machining centre, and is adhered a magnetic polishing paste that is composed of magnetic fluid and abrasive. Then, this tool rotates and moves on the workpiece. From the above, the workpiece is polished. This proposed method obtained a good polishing effect to the typical Ti-alloy (Ti-6Al-4V) in the past report. However, it was reported that the additive manufactured Ti-alloy has different mechanical characteristics compared with the typical Ti-alloy. For example, a toughness is smaller and a hardness is larger. Consequently, in this report, additive manufactured Ti-alloy and typical Ti-alloy that are having a flat shape are magnetically polished. Furthermore, the comparison of magnetic polishing properties such as surface roughness or polishing efficiency is carried out.

magnetic polishing, additive manufacturing, titanium alloy, machining centre

1. Introduction

It is expected that a hybrid additive manufacturing (AM) machine that include function of machining centre is effective to automated manufacture the products such as mould or artificial replacement product [1]. Several reports have been presented an additive manufacturing or cutting characteristics of maraging steel. On the other hand, these characteristics of Ti-alloy has not been almost reported. Therefore, in this study, the machining method that can obtain the additive manufactured Ti-alloy having high surface quality on the hybrid AM machine is developed. First, the surface quality of additive manufactured Ti-alloy is evaluated. Second, the ball end-milling characteristics is compared with a conventional Ti-alloy. Finally, in order to obtain high quality surface that corresponds to surface roughness of artificial replacement product, the additive manufactured Ti-alloy is polished with proposed method that has been developed in the past report [2]. Then, it is examined whether the hybrid AM machine can attain perfect process integration.

2. Experiment method, Magnetic polishing method

In this study, the hybrid metal additive manufacturing machine LUMEX Avance-25 (Matsuura Machinery Corp.) was used, and fabricated the workpiece made of Ti-6Al-4V. In this report, the plate shaped Ti-alloy (30×30×t5 mm) was fabricated and. The additive manufacturing conditions are below: Yb fibre laser (1070 nm), Laser power is 120W, Beam diameter is 0.2 mm, Layer thickness is 50 μm, Maximum powder size is 45 μm, Material of base plate is pure titanium, Assist gas is Ar (99.999%). Fabricated Ti-alloy was ball end-milled to flat shape with zig-zag tool path. In this study, since the workpiece is magnetically polished as the finish machining, an anisotropy of surface roughness should be small. Therefore, a feed rate per cutting tooth and radial depth of cut were made equal. The ball end-milling conditions are below: Tool radius is 2 mm, Cutting speed is 100 m/min, Feed rate per tooth and radial depth of cut are 0.06 mm, Axial depth of cut is 0.2 mm, Number of cutting edge is 2, Coating type is TiAlN, Coolant is an emulsion type. The ball end-milled Ti-alloy was magnetically polished with our proposed method as shown in Figure 1. As the polishing tool, a ball end-mill shaped permanent magnet is used, and is attached a magnetic paste that was combined magnetic fluid, WA abrasives (Mean diameter: 3 μm), Fe particles (Mean diameter: 100 μm), kerosene and α-cellulose. The polishing tool path was applied the single circular path that can mirror-polish with high efficiency [3]. The polishing conditions are below: Tool radias is 5mm, Tool rotational speed V are 4types (5, 15, 25 and 40 m/min), Feed speed: 5 mm/min, Amount of paste is 0.4 g. There is a gap between tool tip and workpiece to intervene the paste. In this report, the gap g was changed between from 0.3 to 1.0 mm. This polishing experiment carried out on a general vertical 3axis machining centre MD-46VA (Okuma) to measure a pressing force by tool with a dynamometer 9257B (Kistler). After polishing, a surface roughness and removal amount were measured with non-contact type 3D Measuring Instrument NH-3N (Mitaka Kohki Co., Ltd.) and precision electronic balance.

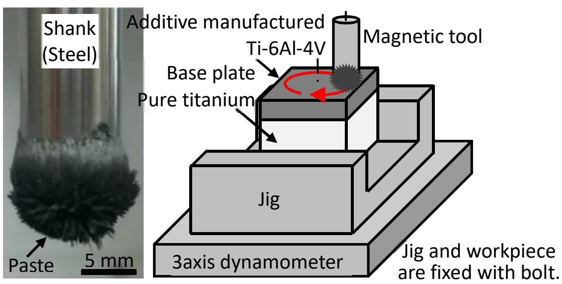

Figure 1. Overview of magnetic polishing tool (paste) and experiment.

3. Experimental result

Figure 2 (a) shows the overview of additive manufactured Ti-alloy. In the metal AM, since the linear expansion coefficient of formed object and base plate should be equal that to avoid an occurrence of bend, the pure titanium was used. Moreover, in order to contain an accumulation of heat on fabricated Ti-alloy, the laser beam was randomly scanned. However, a delamination (crack) was occurred. Figure 2 (b) shows the microscopic image of additive manufactured Ti-alloy after ball end-milling. The pores having variety of sizes were occurred. It is considered that these pores were generated with the effect of residual gas or unmelted powder. Therefore, it was found that the changing additive manufacturing condition is needed. For example, the decrease of laser scanning speed or applying duplex laser irradiation. As the surface roughness after ball end-milling, 2.5 µm*Rz* (Tool feed direction) and 2.7 µm*Rz* (Tool pick direction) were obtained. Where, the large pores were excluded from the measuring area. When the general Ti-alloy was ball end-milled under same cutting condition, 1.6 µm*Rz* (Tool feed direction) and 2.1 µm*Rz* (Tool pick direction) were obtained. The surface roughness of additive manufactured Ti-alloy is larger than the general Ti-alloy, by the influence of fine pores as shown in Figure 2 (b). However, the definite difference of surface roughness between the two did not be seen.

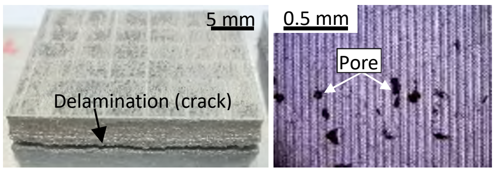

Figure 2. Appearance of additive manufacutured Ti-alloy.

The ball end-milled additive manufactured Ti-alloy was magnetically polished on the machining centre. Figure 3 shows the relationship between gap and removal amount. In this experiment, the tool rotational speed was 25 m/min. First, the removal amount of AM Ti-alloy is larger than the general Ti-alloy. In the past study, it has been found that the removal amount decreases in proportion to increase of coefficient of extension of workpiece [2]. Thus, it is considered that the decrease of coefficient of extension of AM Ti-alloy was occurred. Second, when comparing *g*=0.3, 0.5 mm, the removal amount of *g*=0.5 mm was larger than *g*=0.3 mm. It is known that the removal amount increase in accordance with the increase of pressing force. In this polishing method, since the magnetic flux density becomes large when the gap is small, this result is contrary to a theoretical result. As this reason, it is considered that the decrease of pressing force in accordance with the extension of magnetic paste by a centrifugal force. This is clear from Figure 4 as stated below. Next, the relationship between tool rotational speed and removal amount is shown in Figure 4. The gap=0.5 mm was applied. In the case of the tool rotational speed is small, the removal amount was large. In the general polishing method, when the rotational speed is large, the removal amount also becomes large. Thus, since this result is contrary to the theory as before, it is considered that the influence of centrifugal force is great. Next, in order to clarify the influence of centrifugal force, the relationship between pressing force and tool rotational speed is shown in Figure 4. The pressing force becomes large in accordance with the decrease of tool rotational speed. Therefore, the amount of magnetic paste which intervenes between tool and workpiece decreases by the centrifugal force. When *V*=5, 15 m/min were applied, there is a difference of pressing force; nevertheless the polishing amounts are same level. Namely, if the tool rotational speed is small, the effect by the pressing of abrasive (=burnishing) becomes dominant. On the other hand, when the tool speed is large, the workpiece is cut by the rolling of abrasive (=polishing) on the workpiece. Therefore, the tool rotational speed of 15 m/min that can maintain pressing force and rolling of abrasive is the optimum condition. From the above, the optimum polishing conditions of additive manufactured Ti-alloy are *g*=0.5 mm and *V*=15 m/min.

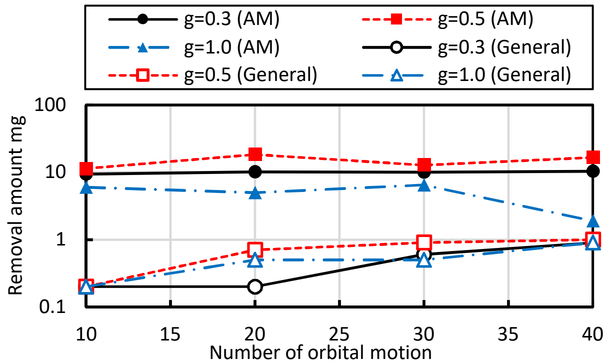

Figure 3. Relationship between gap and removal amount.

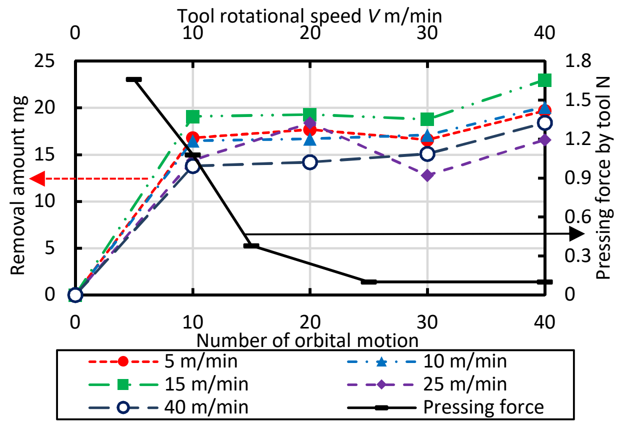

Figure 4. Relation between tool rotational speed and removal amount.

4. Conclusion

In this report, in order to establish the fabrication method of artificial joint that uses metal AM, Ti-6Al-4V was additive manufactured. Moreover, it was ball end-milled and magnetically polished. Thus, the following results were obtained.

- The additive manufactured Ti-alloy has the pores. Since the pores cause fatigue strength degradation of product, it is necessary to change the AM conditions.
- In the finish magnetically polishing, the pressing force changed in accordance with the tool rotational speed. The optimum gap and tool rotational speed that can obtaine additive manufactured Ti-alloy having mirror surface with high efficiency are 0.5 mm and 15 m/min.

Here after, a prediction model that can obtain mirror surface on all face of additive manufactured product will be constructed.

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