Experimental Studies on Finishing of Additive Manufacturing Titanium Alloy Parts with Difficult-to-machine Structures Using Abrasive Flow Machining

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Abstract. Additive Manufacturing (AM) is capable of building parts with complex geometries. However, the quality of as-built surfaces of AM metal parts is far inferior to service requirements. Abrasive Flow Machining (AFM) is a finishing technique offering high efficiency for parts with difficult-to-machine structures. The application of AFM to finishing AM titanium alloy parts is taken in this paper, and the effects of number of cycles on surface microtopography and surface roughness of parts are studied. As the number of processing cycles increases, the experimental results show that AFM can rapidly remove the inherent surface defects of AM parts like balling effect, step-stair effect and powder adhesion, and achieve a uniform surface eventually.

Introduction

ASTM has defined Additive Manufacturing (AM) also called 3D printing as a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. In recent years, the types of forming materials are increasing and the structure of manufactured components becomes more and more complicated. Metal AM as one of the most advanced technology of AM, has been widely used in the fields of aviation and aerospace vehicles, medical equipment and so on, and it has great potential for future development [1].

In general, the static mechanical properties of AM metallic materials are comparable to conventionally fabricated metallic components [2]. However, inherent characteristics of powder adhesion and balling effect lead to the poor surface quality of the AM parts, and the surface roughness is no less than Ra 10μm and variable depending on different AM processes, the processing parameters and the parts geometry. The functional surface quality of some high service performance requirements parts made by AM usually cannot satisfy with the requirements, so post-processing is necessary for these parts. Finishing process can effectively improve the surface quality of parts. But some components with complex surfaces and geometries cannot be finished efficiently and economically for traditional finishing processes like grinding, lapping and honing because of their poor machining accessibility and flexibility. Abrasive Flow Machining (AFM) is an alternative to finish difficult-to-access area.

Fig.1 illustrates the principle of AFM. Two opposed cylinders extrude a semi-solid viscoelastic abrasive media back and forth through passages formed by the workpiece and the fixture, and surface roughness is improved by the reciprocated movement of active abrasive grits along the workpiece surface. The abrasion during AFM depends on the extrusion pressure, flow volume and media flow speed determined by the machine setting in relation to media type, passage area, and media formulation which includes media viscosity and abrasive type and size [3].

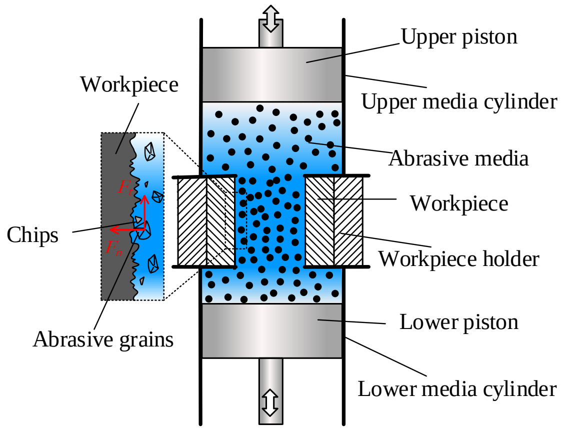
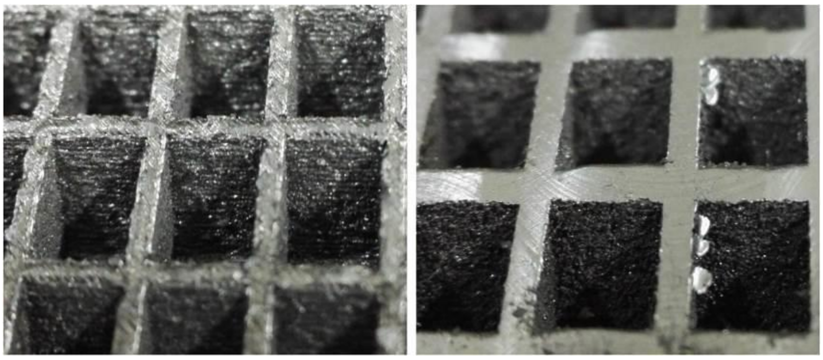


Fig. 1. Schematic depiction for the principle of AFM.

In the previous literature, there are few researchers studying on the finishing process of additive manufacturing parts using AFM. In this paper, AFM process is applied to finish additively manufactured titanium alloy grille parts. The effects of AFM process on both surface micro-topogragh and surface roughness are studied.

Experimental Methodology

As shown in Fig.2, the titanium grille is built up by Ti6Al4V powder through Selective Laser Melting (SLM), where inclined rectangle holes with the dimension of 4mm wide and 5mm long are distributed in equal distance. As shown in Fig.2 (a) and Fig.2 (b), there are obviously titanium alloy balls from the SLM process and alloy powders adhered on the grille surface, which results in the poor surface quality. Meanwhile, the front surface show clearly stair-step profile specially. Fig. 3 shows the relative position between workpiece and holder, where grille part is fixed on the tilt making inclined rectangle holes along the vertical direction.


(a)Front surface (b)Back surface
Fig. 2. The initial surface of grille parts

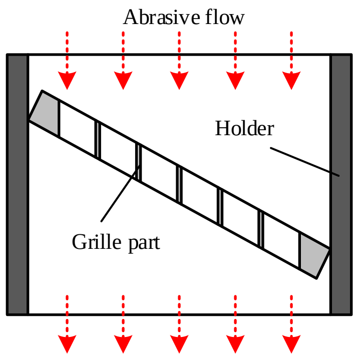


Fig. 3. Workpiece holder

Experimental Conditions. In the AFM process, abrasive media, which is a mixture of abrasive grits and polymer with viscoelasticity, is extruded across the inclined rectangle holes, and the material removal occur during this process. Process parameters in the AFM finishing are listed in Table 1. The abrasive media FC080070H is used, which abrasive grains is silicon carbide with mesh size 80 and abrasive concentration by weight is 70%. The effects of the number of cycles (25–300) on surface finishing have been investigated. Other parameters such as the type of abrasive, abrasive weight concentration, and extrusion pressure are kept constant during the process. A grille part was finished with grits mesh size 80 by 25, 50, 75, 100, 125, 150, 175, 200, 250 and 300 cycles successively. The surface roughness value and surface micro-topography of the part are measured using Keyence confocal microscope (VK-X1000).

Table 1. Experimental conditions.

Parameters	Description
Abrasive media	FC080070H
Extrude pressure	3.5MPa
Number of cycles	25, 50, 75, 100, 125, 150, 175, 200, 250, 300

Results and Analysis

Surface Micro-topography. Fig. 4 and Fig. 5 show the variation of surface micro-topography with number of cycles. It can be seen that both the initial front surface and back surface have lots of alloy balls and adhered metal powders from SLM process. After 25 cycles of AFM process, the defects are all removed, but front surface shows new transverse stripes and back surface has lots of new irregular bumps and hollows. This results would be due to the fact that the grille near surface layer with the alloy balls adhered on is loose and easy to fall off and AFM can easily remove the alloy balls by few cycles. It can be considered that the surface after 25 cycles is the real surface of the grille part. Furthermore, it can be found that the peaks are removed gradually with the increase of number of cycles and the grille surface becomes flat with few valleys after 300 AFM process cycles.

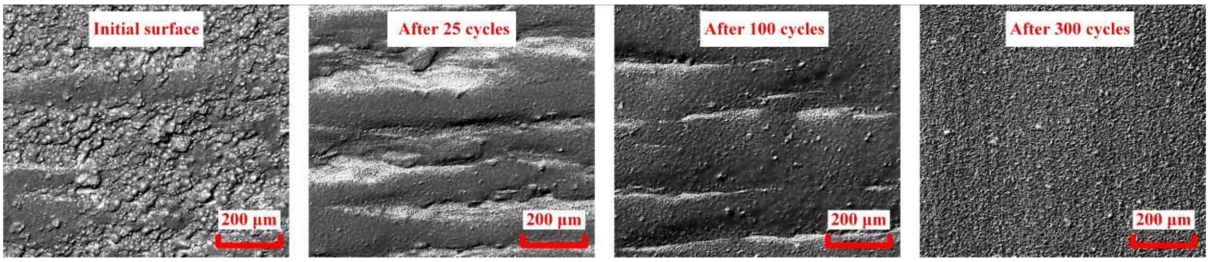


Fig. 4 Variation of surface microtopography for front surface

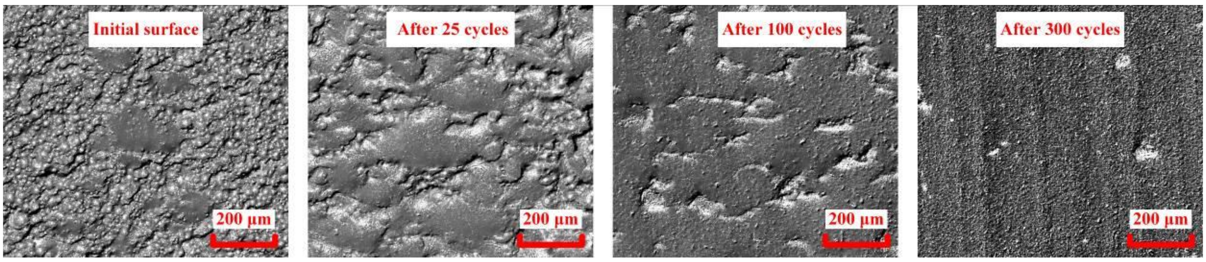
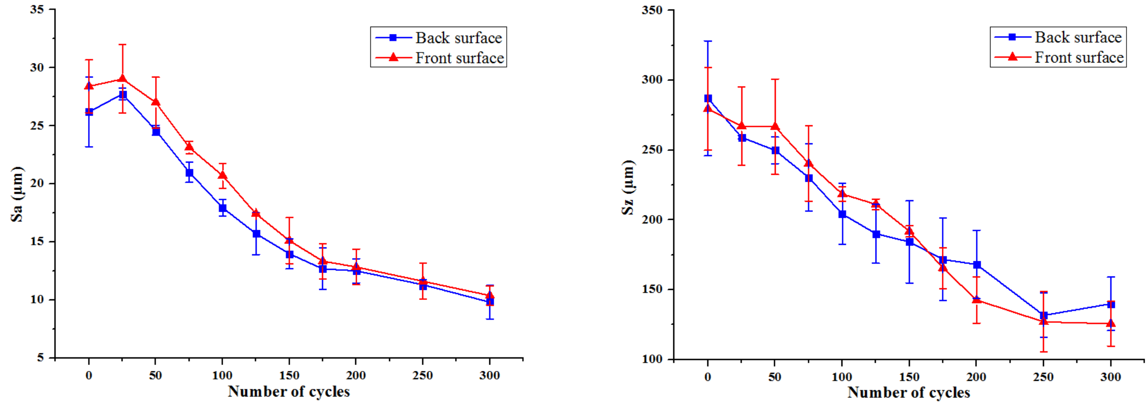


Fig. 5 Variation of surface microtopography for back surface

Surface Roughness. Variation of the surface roughness Sa and Sz with the number of cycles is shown in Fig. 6. It can be seen that the surface roughness Ra of front surface and that of back surface increase lightly after 25 cycles. This is because the loose layer is removed and the real surface is rougher than the initial surface. After 300 cycles, surface roughness Sa of back surface decreases form 26.2μm to 9.8μm and Sz decreases form 287μm to 140μm. Surface roughness Sa of front surface decreases form 28.4μm to 10.4μm and Sz decreases form 279.4μm to 125.6μm. We can also find that as the number of cycles increases both Sa and Sz decrease rapidly in the early stage of finishing process and then tend to a stable value. This can be explained as follows. The surface after 25 finishing cycles has a lot of sharp peaks. When abrasive grits act on these peaks, the peaks get removed and become flatter than before. In the following cycles, it will result in lower material removal rate.



(a) (b)

Fig. 6. Variation of the surface roughness with the number of cycles : (a) Sa, (b) Sz

Summary

In this paper, AM titanium alloy grille parts are finished using AFM process in this paper, and the effects of number of cycles on surface micro-topography and surface roughness of parts are studied. The following conclusions have been derived from the experimental results and analysis. Firstly, surface roughness of inclined rectangle holes of grille parts decreases with number of cycles increasing, and the roughness values reduce to less than 50% of the initial roughness value finally. Meanwhile, AFM process can rapidly remove the inherent surface defects of AM parts like balling effect, step-stair effect and powder adhesion, and achieve a uniform surface eventually.

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