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A study of magnetic field-assisted mass polishing of additive manufactured surfaces

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Abstract

Additive manufacturing (AM) technology has become a promising method for the production of complex components used in various fields. However, a significant disadvantage arises in the poor surface quality of additively manufactured surfaces, which has become one of the critical factors limiting the development of AM technology. Hence, a study of the magnetic field-assited mass polishing (MAMP) method for the post-process polishing of AM surface is conducted. The MAMP attempts to polish a batch of components simultaneously with nanometric surface roughness. A series of polishing experiments has been conducted on AM 316L stainless steel for flat, convex and concave surfaces. The results show that the MAMP method can significantly superfinishing the AM surfaces, which indicates the effectiveness of MAMP for the post-process polishing of AM surfaces. Moreover, the MAMP method exhibits its potential to become a competitive post-processing method for AM surface, attributing to its high polshing accuracy and relatively low polishig cost.

Additive manufacturing, mass finishing, polishing, magnetic field-assisted, 3D printing, ultra-precision machining

1. Introduction

Additive manufacturing (AM) technology has become a promising production method forf complex components used in various fields, such as optics, aerospace, automotive, electronic, biomedical fields, etc [1-3]. However, a significant disadvantage arises in the poor surface quality of additive manufactured surfaces, which has become one of the critical factors limiting the development of AM technology [4,5]. Even though some AM components made of polymer materials can achieve a good surface texture, further post-process finishing or polishing is still needed for most materials, such as alloys, ceramics, etc. And good surface roughness is critical for many high-value-added products, such as artificial implants, engine turbine blades, reflective mirrors, etc.

Hence, different kinds of polishing methods have been proposed for the post-processing of this kind of surface, such as laser polishing [6], magnetic abrasive finishing [7], shape adaptive grinding [8], etc. However, most of them can only polish one workpiece in one setup which makes the polishing process time-consuming and with high cost. Although several kinds of mass finishing processes were developed to implement mass finishing of freeform surfaces, such as vibratory finishing, centrifugal barrel finishing, rotary barrel finishing, centrifugal disc finishing and spindle finishing [9,10], tens or hundreds of components can be polished simultaneously. Nevertheless, these mass finishing methods can largely degrade the initial surface form , and hardly obtain nanometric surface finish.

Recently, a novel magnetic field assisted mass polishing (MAMP) method was proposed by the authors, which can polish a batch of components simultaneously, with nanometric surface roughness [11]. Nevertheless, it is unknown that if the MAMP method can be adopted for the polishing of AM surfaces. It can further broaden the application of the MAMP method if it can be used for the polishing of AM surface. With this in view, a feasibility study of the MAMP on AM surfaces was carried out to find out if it is suitable for the post-process finishing of AM surfaces.

2. Working principle of MAMP process

In the MAMP, an array of magnetic pole pairs is controlled to rotate along an annular chamber, and the magnetic abrasives inside the chamber generate corresponding magnetic brushes under the effect of the magnetic field. The chamber is fixed during polishing, while the magnetic brushes inside the chamber rotates as driven by the rotation of the magnetic pole pairs. The abrasives inside the brush keep impinging the workpiece to remove material from the surface. Fig. 1 shows at least two pairs of the magnetic pole pairs are used.

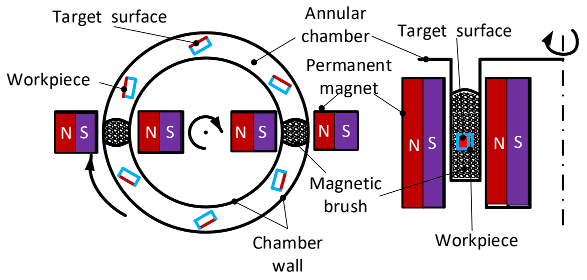


Figure 1. Schematic diagram of the MAMP method

As shown in Fig. 1, six samples can be polished simultaneously. The magnetic brush is composed by bonded magnetic abrasives mixed with lubricant or loose magnetic abrasives mixed with carrier fluid such as water, oil, etc. The bonded magnetic abrasives are fabricated by bonding the magnetic particles with the polishing abrasives, such as alumina, silicon carbide, diamond abrasive, etc. The loose magnetic abrasives and the magnetic particles are mixed with the polishing abrasives in thecarrier fluid.

3. Experiments

As shown in Fig. 2, an experimental prortotype of MAMP system has been built for this study. Four N52 neodymium iron boron (NdFeB) permanent magnets are mounted on a rotatory table to generate two magnetic brushes inside the chamber. A total of six workpieces can be polished at the same time according to the design of fixture in Fig. 2. As shown in Fig. 3, bonded magnetic abrasives made of Iron (i.e. 100-200 μm, 80 wt.%) and alumina abrasive (i.e. ~2 μm in average, 20 wt.%) were used for rough polishing, while carbonyl iron powder (CIP, ~3 μm in average, 76.7 wt.%) mixing with the polishing slurry (i.e. ~150 nm alumina mixed with carrier fluid, 23.3 wt.%, hastilite polynano alumina, Universal Photonics Inc.) was used as the fine polishing media. In this study, a batch of additive manufactured 316L stainless steel using selective laser melting (SLM) technology was used in the experiments. The manufacturing conditions for selective laser melting of the workpiece were shown in Table 1. Three different kinds of AM surfaces were prepared as demonstrated in Fig. 4 which include flat, convex and concave surfaces with their surface definition.

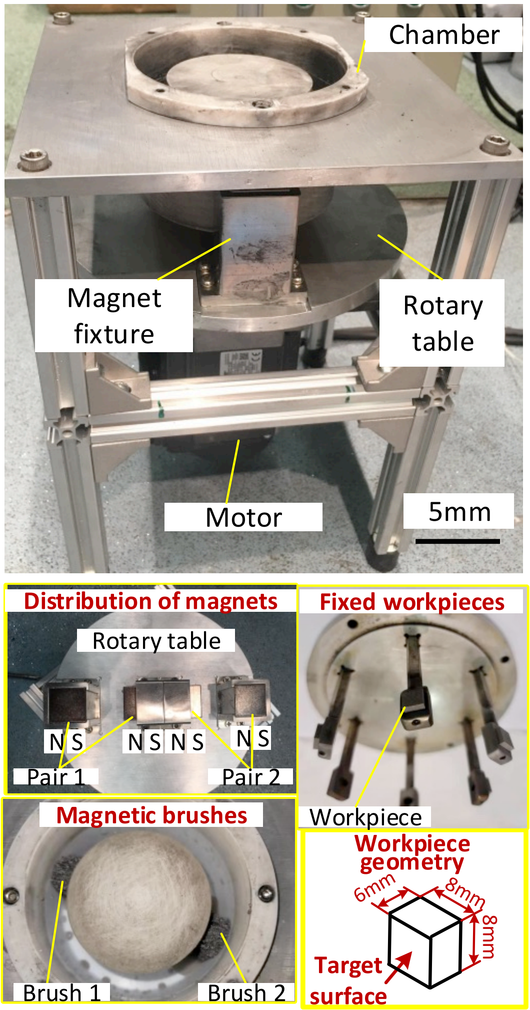
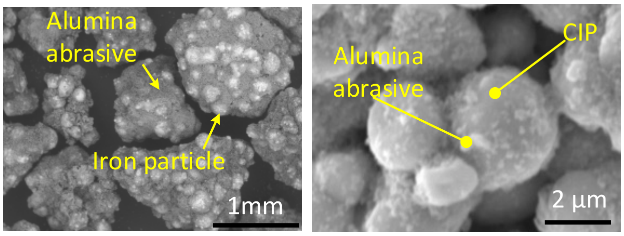


Figure 2. Experimental set-up

The MAMP system was tested through 60 minutes of rough polishing on these kinds of surfaces, followed with 60 minutes of fine polishing. The rotation speed were all controlled at 1500 rpm based on the authors' previous research.[11] The surface roughness was measured by Zygo Nexview optical interferometer. Three workpieces were polished under each condition. Nine points in total were measured on each workpiece surface. The measurement area of each point is about 214 μm×214 μm. The distribution of the measurement points are distributed in three rows and three columns, with the 2mm interval between each row and each column. The surface micro topography was observed by Hitachi Electron Microscope TM3000.



(a) Bonded magnetic abrasive (b) Loose magnetic abrasive

Figure 3. Polishing media for rough and fine polishing

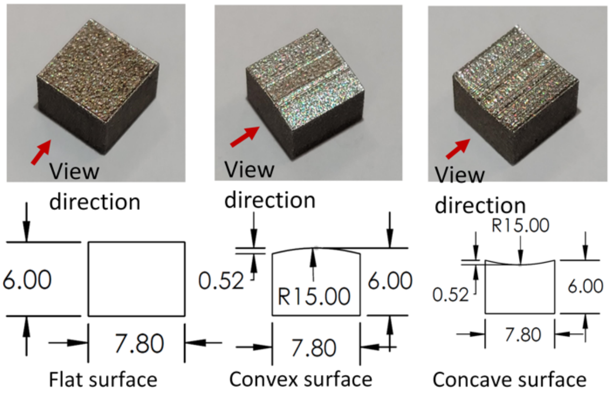


Figure 4. Different kinds of additively manufactured 316L stainless steel workpieces

Table 1 Selective laser melting (SLM) conditions for 316L stainless steel workpiece

Conditions	**Value**
Equipment	HANS M100
Particle size	0-25 μm
Laser spot diameter	25 μm
Laser power	70 W
Scanning speed	700 mm/s
Hatch spacing	0.06 mm
Scan path	Rsater path
Layer thickness	20 μm

4. Results and discussions

4.1. Polishing performance on flat surface

Figure 5 shows the measured surface roughness results in terms of arithmetic mean height (Sa) after rough and fine polishing with different polishing time. The Sa value in Fig. 5 is the average Sa value of nine measured positions. The surface roughness Sa can be reduced from 1.33 μm to 0.51 μm after 10 minutes of rough polishing, and converged to smaller than 200 nm after 60 minutes of rough polishing. Moreover, the rough polished surface can be further improved to surface roughness smaller than 100 nm after 60 minutes of fine polishing as shown in Fig. 5(b).

As shown in Fig. 6, there are obvious laser melting marks on the SLM 316L stainless stell surface. In addition, many unmelted or half melted powders are left on the surface which can be observed from the SEM photographs. After 60 minutes of rough polishing, these laser melting marks were diminished, as well as the unmelted powders. The maximum height (Sz) of the measured area was reduced from 18.715 μm to 3.556 μm. Nevertheless, there are still many pits on the rough polished surface, which maybe due to the abrasion of the large alumina abrasive. After fine polishing, these pits were successfuly removed, and the surface was highly smoothened as compared to the surface before polishing, which indicates the effectiveness of MAMP for the post-processing of the AM surfaces.

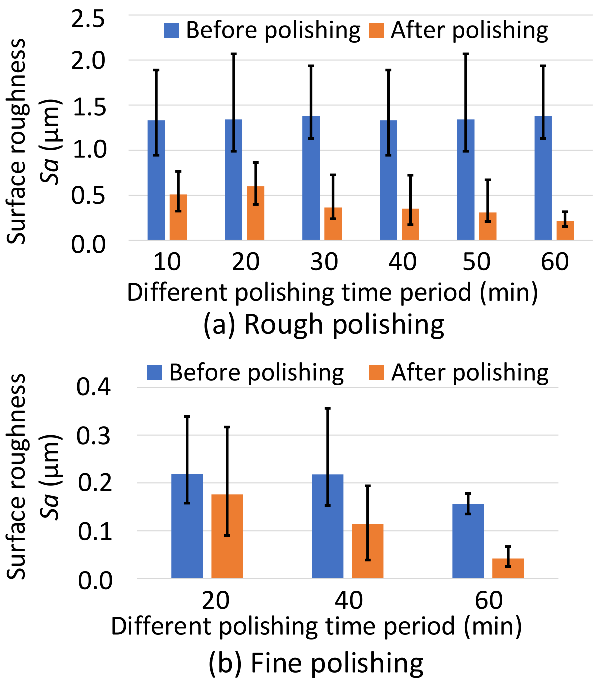


Figure 5. Surface roughness varies with the polishing time

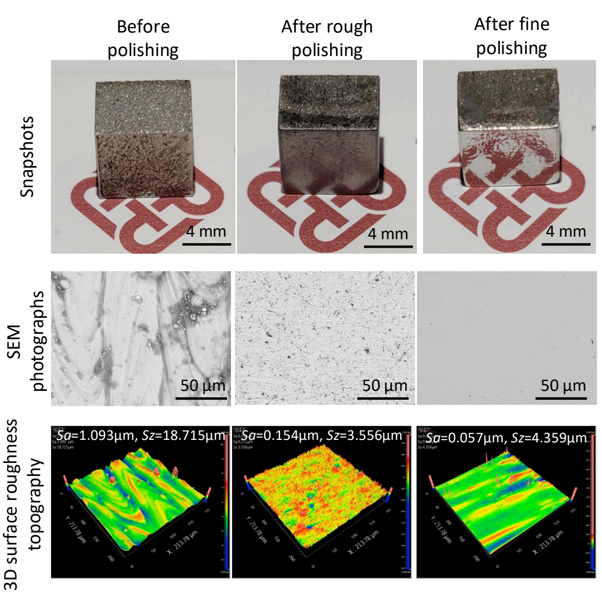


Figure 6. Surface integrity before and after rough and fine polishing

4.2. Polishing performance on curved surface

Except for the flat surface, curved surfaces including the convex and concave surfaces were also sussessfully polished to obtain the surface roughness of about 50 nm in terms of Sa after 60 minutes of rough polishing and 60 minutes of fine polishing. The surface roughness convergency is more than 96% in these two cases as shown in Fig. 7 and Fig. 8.

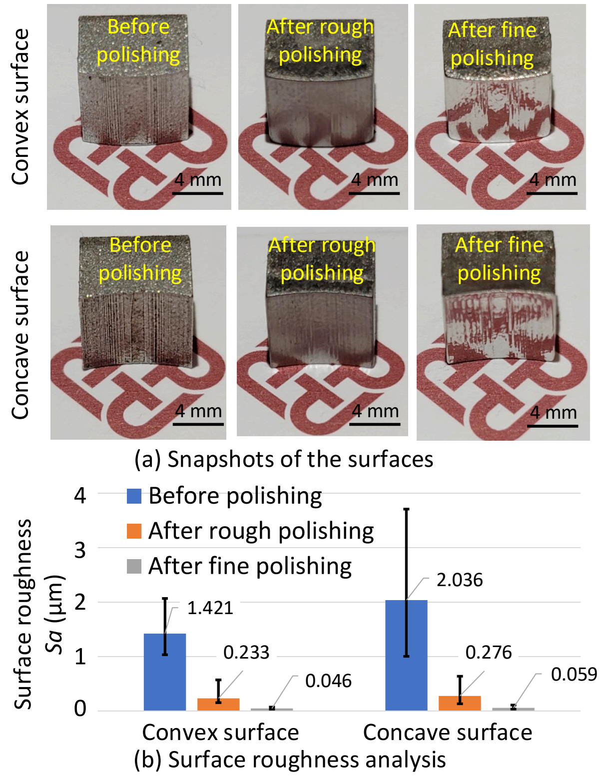


Figure 7. Polishing performance on convex and concave AM 316L stainless steel surfaces.

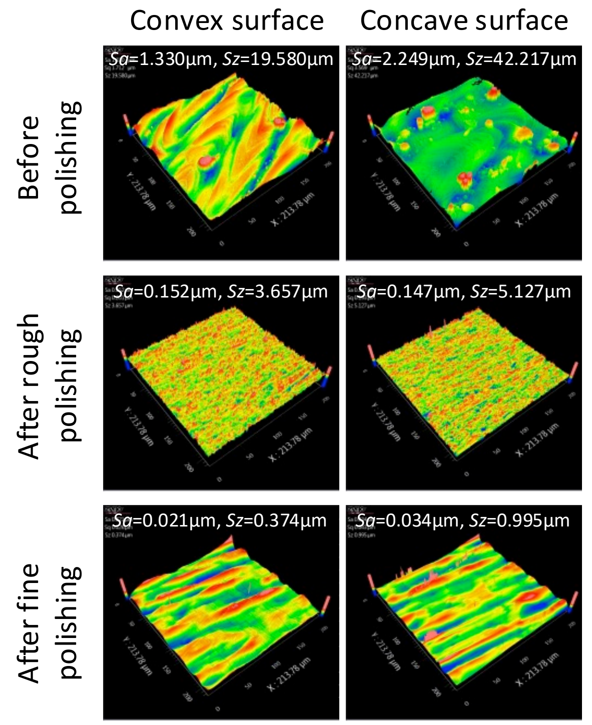


Figure 8. 3D surface roughness topography before and after polishing of convex and concave AM 316L stainless steel surfaces.

However, there still exists milimeter/submilimetre scale waviness form error on both polished flat and curved surfaces as shown in Fig. 6 and Fig. 7. These kinds of errors are in milimetre/submilimetre scale, which is hard to remove by the current magnetic abrasives. In the future, bonded magnetic abrasive with larger size will be purposely desiged and fabricated to further improve the polishing performance on AM surfaces.

5. Conlusions

A pilot study of MAMP on AM surfaces were carried out in this paper. The SLM 316L stainless steel surfaces with surface roughness of about 1.3μm were successfully improved to about 50 nm, on both flat and curved surfaces. The laser metling marks and unmelted powders left on the surface were also thoroughoutly diminished after rough and fine polishing of MAMP. The results indicate that the MAMP process is effective for post-process polishing of the AM surfaces.

However, some milimetre/submilimetre scale waviness error can still be found on the polished surface in this study, limited by the size of current magnetic abrasives. Efforts are still needed to improve the design of the magnetic abrasves to obtain better performance, especially for the applications which are sensitive to the surface form accuracy.

Acknowledgement

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