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Magnetic abrasive polishing of additively manufactured 316L stainless steel parts

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Abstract
Selective laser melting (SLM), as one of the additive manufacturing (AM) processes, is widely applied to directly fabricate functional structures and complex geometries by selectively melting layers of powder. However, the surface finish of the parts fabricated by this process could not readily meet the requirements of various applications. Therefore, post-processing is needed to further improve the surface quality of the AM-ed parts. Magnetic abrasive finishing (MAF) uses a flexible polishing head to remove material from the workpiece surface at a controllable rate. The high flexibility of MAF makes it a promising method for post-finishing the complex parts prepared by SLM. It is well recognised that the scanning strategy of the SLM process would greatly affect the microstructure of SLM-ed parts and the associated surface textures. In this paper, the polishability of the SLM-ed 316L stainless steel parts is investigated in the magnetic abrasive polishing tests.

Keywords: magnetic abrasive polishing, additive manufacturing, selective laser melting, 316L stainless steel, surface texture

1. Introduction

Selective laser melting (SLM), as one of the additive manufacturing (AM) processes, has shown its enormous potential on generating functional structures and complex geometries through layer by layer fabrication. In practice, post-processing is generally required to improve the surface finish of the AM-ed parts for specific applications. Magnetic field assisted finishing or magnetic abrasive finishing (MAF) is a non-conventional finishing method which could be employed to polish the confined area due to its flexibility [1]. Thus, MAF may find its wide application in post-processing of the AM-ed parts. Yamaguchi *et al.* [2] employed MAF and magnetic field-assisted burnishing (MAB) to post process the SLM-ed SS316L disk. The results showed that surface roughness Rz was improved from 100 to 0.1 µm and compressive residual stress was imparted after MAF and MAB. However, these works [2] did not consider the effects of various surface features or textures due to the changing normal direction of complex AM-ed parts which may not coincide with the laser-scanning plane of the layer-by-layer fabrication. This study will shed light on the polishability of the SLM-ed 316L parts on the laser-scanning plane and another perpendicular surface with distinctive textures in the magnetic abrasive polishing tests.

2. Methodology

The working principle of the magnetic abrasive finishing process involved in this paper is shown in Figure 1(b). The workpiece was placed between two magnets. With this configuration, magnetic abrasives could form a stable polishing brush in the imposed magnetic field. As the magnet holder vibrated, a relative movement between the polishing brush and workpiece facilitated the mechanical material removal process. The magnetic flux density in the operating zone was simulated using the software Finite Element Method Magnetics (FEMM) and the results are shown in Figure 1(a) which is consistent with the distribution of magnetic abrasive particles between the magnet and the workpiece as shown in Figure 1(c).

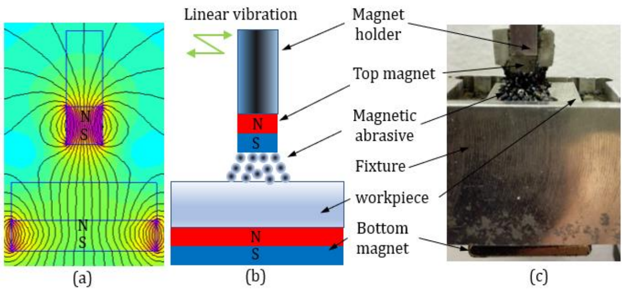

Figure 1. Schematic diagram of the magnetic abrasive finishing tool

2.1. Polishing setup

The vibrating movement of the MAF tool was driven by a linear vibrator. The vibration amplitude used in this experiment is 15mm based on length measurement and vibration frequency is 25 Hz based on spectrum analysis of force data. A magnet holder was mounted at the end of the vibration rod and a Grade N50 Nd-Fe-B magnet with a dimension of 20mm x 5mm x 3mm was fixed on the top face of the magnet holder. To generate a stable polishing brush and prevent the magnetic abrasive particles from escaping during polishing, a 25 x 25 x 3 mm magnet plate was placed below the workpiece. The gap between the polishing brush and the workpiece could be adjusted by a manual Z-stage (Edmund Optics). A dynamometer (Kistler 9256C1) was used to control the constant normal force of 5 N for all the polishing experiments. Since this paper aims to compare the polishability of two typical AM-ed surfaces and develop a rapid surface flattening method rather than an ultra-fine finishing process, only G50 steel grits with an average diameter of 500 µm were employed as the abrasives in the experiments.

2.2. Workpiece preparation and design of experiment

The workpiece was fabricated by an EOS M290 Metal 3D Printer. The laser power used was 195 W with a spot size of 80 µm, the layer thickness was 40 µm, and the scan speed was 1,083 mm/s with a hatching of 0.09 mm. Two building strategies were employed to prepare the two samples with the same dimenson of 20 x 20 x 5 mm (Figure 2). The surface to be polished of sample A was a 20 x 20 mm surface parallel to the building direction, while for sample B it was a 20 x 20 mm surface perpendicular to the building direction. Surface roughness, surface topography, and the mass of both samples were measured and recorded after every 15-minute polishing. The total polishing time was 75 minutes.

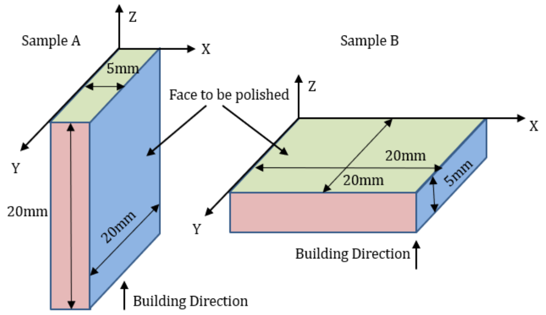

Figure 2. Workpiece dimension and building strategies

3. Results and discussion

The optical images of the unpolished and polished surfaces are shown in Figure 3. The AM-ed surface featured more unmolten particles on sample A than on sample B. This difference can be attributed to the melting of particles in subsequent layers. After a 75-minute polishing, most unmolten particles were removed and the polished surfaces show no significant difference.

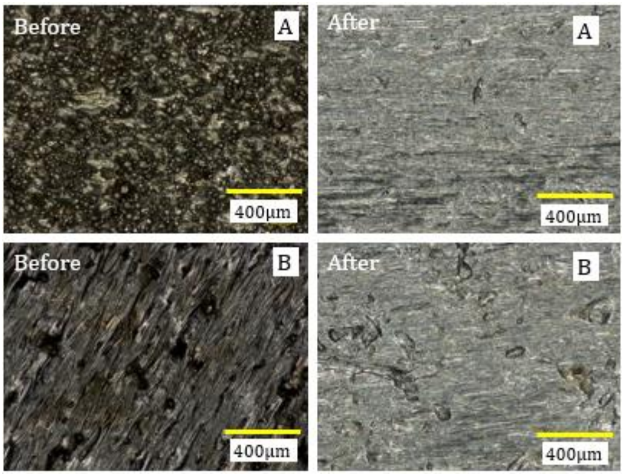

Figure 3. Optical microscope pictures of initial and polished surface

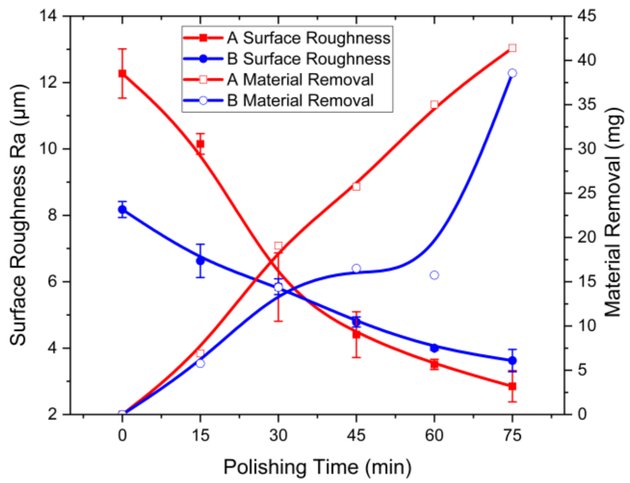

Figure 4. Surface roughness (Ra) and material removal during polishing

Surface roughness (Ra) and material removal during polishing for both samples are presented in Figure 4. It is noted that though sample A had a rougher initial surface than sample B, its surface roughness Ra was improved more rapidly from ~12 to 3 µm (Ra) after a 75-minute polishing. Figures 5 and 6 show surface roughness profile of both samples before and after polishing. It could be seen that the peaks of the intial surface were removed while the valleys were still retained. A 78.5% improvement of surface roughness was achieved for sample A and only 51.4% for sample B. Thus, the experimental results indicated a better polishability for sample A under same polishing condition.

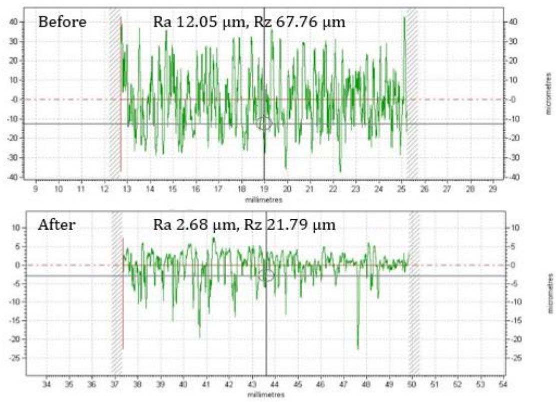

Figure 5. Surface roughness of sample A before and after polishing (Cut off: 2.5 mm; evaluation length: 12.5 mm)

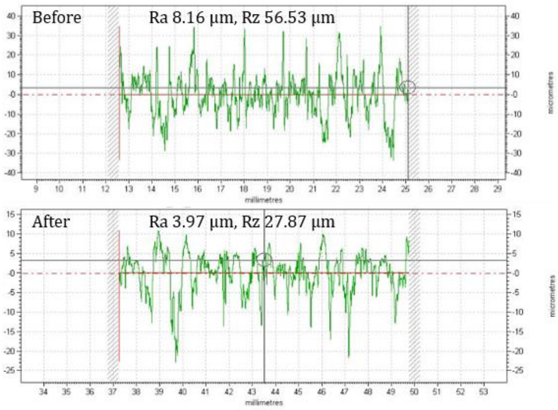

Figure 6. Surface roughness of sample B before and after polishing (Cut off: 2.5 mm; evaluation length: 12.5 mm)

4. Conclusions

This paper studies magnetic abrasive finishing of the SLM-ed 316L surfaces. Two different building strategies were applied. Surface roughness, surface topography, and material removal were characterised. It is concluded that the surface parallel to build direction has higher polishability as compare to transverse surface.

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