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Laser polishing of additive manufactured Ti alloys

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ABSTRACT

Laser-based additive manufacturing has attracted much attention as a promising 3D printing method for metallic components in recent years. However, surface roughness of additive manufactured components has been considered as a challenge to achieve high performance. In this work, we demonstrate the capability of fiber laser in polishing rough surface of additive manufactured Ti-based alloys as Ti-6Al-4V and TC11. Both as-received surface and laser-polished surfaces as well as cross-section subsurfaces were analyzed carefully by White-Light Interference, Confocal Microscope, Focus Ion Beam, Scanning Electron Microscopy, Energy Dispersive Spectrometer, and X-ray Diffraction. Results revealed that as-received Ti-based alloys with surface roughness more than 5 µm could be reduce to less than 1 µm through laser polishing process. Moreover, microstructure, microhardness and wear resistance of laser-polished zone was investigated in order to examine the thermal effect of laser polishing processing on the substrate of additive manufactured Ti alloys. This proof-of-concept process has the potential to effectively improve the surface roughness of additive manufactured metallic alloy by local polishing method without damage to the substrate.

1. Introduction

Titanium (Ti) alloys have wide applications in aerospace and biomedical fields due to high specific strength and excellent corrosion resistance [1–3]. Conventional machinery manufacturing of titanium alloy components is very difficult caused by low thermal conductivity and high chemical reactivity with cutting tool materials [4,5]. Laser additive manufacturing (LAM) has attract much attention as a promising technology for producing titanium alloy parts using layer-by-layer manufacturing method [6–9]. LAM has been commonly used for fabricating or repairing large complex components including steam turbine blade, turbo-engine blade and turbo-engine case [10–12]. Surface roughness of LAM is usually higher than 10 µm due to waviness of the scan tracks and layered structure [13,14].

Laser polishing has been considered as a potential method to reduce surface roughness of additive manufactured metals. It is mainly based on melting caused by thermal input of laser irradiation. When a laser beam of sufficient energy density impinges on material surface, morphological apexes reach the melting temperature and melt quickly. After molten pool is formed, liquid material tends to redistribute to the same horizontal level due to surface tension and gravity. When laser beam left, surface temperature of laser irradiated area will drop quickly, leading to molten pool solidified and surface roughness reduced correspondingly [15–17]. Compared with conventional mechanical polishing methods, laser polishing changes surface morphology by re-melting without altering or affecting bulk properties with high automation in environmental friendly way. In recent 20 years, laser polishing process has been developed for metallic materials, especially for difficult machining metals. For micro polishing with pulsed lasers, Chang et al. carried out surface polishing process of SKD61 tool steel using a microsecond fiber laser system, and reduced the surface roughness from 0.28 to 0.13 µm [18]. Guo et al. investigated polishing result of originally milled DF2 tool steel using microsecond Nd:YAG laser, which showed a decline of roughness value from 0.4 to 0.12 µm [19]. Giorleo et al. studied the a polishing process executed with a Nd:YVO4 laser radiation on Titanium sheet, and the surface was polished from 0.58 to 0.42 µm [20]. Different from micro polishing with pulsed lasers, laser macro polishing with high-power laser has also been developed to adapt much more complex surface. Bordatchev et al. contrasted the polishing effect of CW and pulsed lasers on Ni alloy, and reduced the surface roughness from 10 µm to 2 µm [21]. With the rise of LAM technology, laser polishing has been used to finish LAM parts surface. Lamikiz et al. investigated the polishing effect of high-power CW CO_2 laser on selective laser sintering (SLS) bronze alloy with roughness of 7.5 µm, and presented final surface roughness below 1.49 µm [22]. However, little literature is available in the public

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Table 1
Actual chemical compositions of titanium alloys.

Material	Al	V	Mo	Si	Zr	Fe	Ti
TC4	5.5–6.8	3.5–4.5	–	–	–	< 0.30	Balance
TC11	5.8–7.0	–	2.8–3.8	0.20–0.35	0.8–2.0	< 0.25	Balance

domain on laser polishing of additive manufactured Ti alloy components, especially for laser-based additive manufacturing method.

In this paper, we carry out laser polishing of two typical laser additive manufactured Ti alloys as TC4 and TC11 surfaces by nanosecond pulse laser. The aim of this study is to understand the effects of laser polishing on laser additive manufactured TC4 and TC11. By using scanning electron microscopy (SEM) and laser scanning confocal microscope (LSCM), we discuss how effective the laser treatment affects surface morphology and roughness of the titanium alloys, Vickers is used to investigate surface hardness, and a ball-on-flat wear tester is used to test wear resistance.

2. Experimental procedures

2.1. Materials

Ti-6Al-4V (TC4) and Ti-6.5Al-3.5Mo-1.5Zr-0.3Si (TC11/BT9) titanium alloy blocks with a nominal composition were chosen, the alloy blocks was produced by laser additive manufacturing. Nominal composition of TC4 and TC11 titanium alloy are given in Table 1. Specimens were cut to thickness of 10 mm for experiments by wire-electrode cutting.

2.2. Laser processing

A nanosecond pulsed fiber laser (wavelength 1060 nm, pulse duration 220 ns, repetition rate 500 kHz, spot size 44 μm) was used in this study to polish wire-electrode cutting surface of LAM Ti alloys. The optimized power density was 1.20×10^7 W/cm^2, and the optimized scanning speed was 200 mm/s. The irradiated area was 100×100 mm^2 in square using hatched scanning mode with 50% overlapping in the program. When laser was turned on, the specimen was placed under Ar gas protection.

2.3. Surface characterization

Morphology was observed by FEI Quanta 450 FEG SEM with energy dispersive spectrometer (EDS) and Keyence VK-X series LSCM. Surface hardness was measured by FUTURE-TECH FM-800 Vickers, the loading force was chosen as 0.98 N, and five indentation measurements were averaged for each microhardness. Holding time was 10 s. Dry sliding friction tests were conducted using MFT-4000 multifunctional material surface performance tester. Al_2O_3 balls with a diameter of 5 mm were used as the counterpart. The applied load was 50 N with a linear velocity of 200 mm/min and last for 30 min. The wear tracks were measured by the Keyence LSCM.

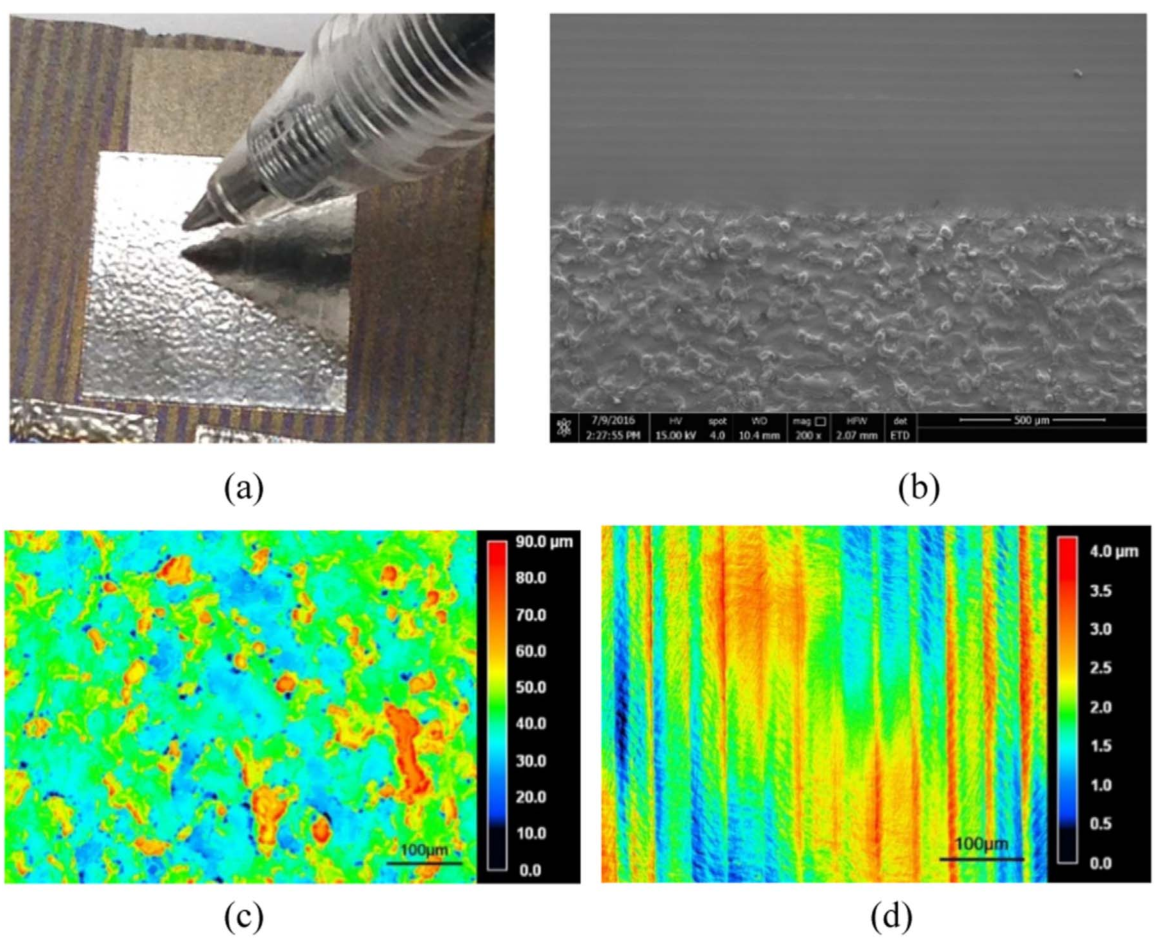

Fig. 1. Effects of laser polishing on TC4 Ti alloy: (a) laser-polished region at the LAM surface; (b) SEM micrograph of the boundary between laser-polished region and as-received region; (c) Topographic image from LSCM of as-received surface; (d) Topographic image from LSCM of laser polished surface.