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Effects of processing parameters on microstructure and mechanical property of selective laser melted Ti6Al4V

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ABSTRACT

Selective laser melting, as a facile method, was successfully used in this paper to manufacture perfect Ti6Al4V parts. Based on a series of single tracks, the processing windows were firstly proposed, corresponding to different melting mechanisms. And selective laser melted Ti6Al4V parts using various parameters within the processing map were investigated in terms of microstructure, roughness, densification and microhardness. It was found that the microstructure, roughness, densification and microhardness of Ti6Al4V parts were a strong function of processing parameters. An excellent Ti6Al4V part with the high microhardness and the smooth surface can be manufactured by selective laser melting using preferable laser power 110 W and scanning speed 0.4 m/s, corresponding to continuous melting mechanism. The density is so high that it can be comparable to that of bulk Ti6Al4V alloy.

1. Introduction

Titanium alloys have been widely applied for load-bearing orthopedic implants in the physiological environment due to their attractive properties, such as high corrosion resistance and excellently soft and hard tissue biocompatibility [1–4]. Among titanium alloys, Ti6Al4V is the most favorable since its first introduction in the early 1950s. However, due to the intrinsic property of pre-alloyed Ti6Al4V, it is difficult to elaborate parts using Ti6Al4V feedstock.

The existing studies on manufacturing technology for Ti6Al4V focused on the traditional processing method, casting. This process not only needs to prepare a complex mold but also has the oxidation problem of Ti6Al4V, phase transitions, decomposition and grain growth, due to the high-temperature holding for a long time.

Selective laser melting (SLM), as one of the rapid prototyping techniques, was proposed in the present paper to manufacture Ti6Al4V parts. SLM represents an evolution of selective laser sintering (SLS) process when the complete melting of powder occurs rather than sintering or partial melting [5]. After noticeable improvements in recent years, this processing technique appears which can transform metallic and alloy powders directly into dense parts, in contrast to selective laser sintering (SLS) where post-processing is needed to obtain fully dense parts [6]. During the SLM process, once a powder layer has been scanned, the building platform moves down one step (typically between 30 and 100 μm), and the next powder layer is placed upon the previous one by means of a powder feeder. After all layers have been deposited, the rest powder which was not scanned can be removed and the produced part can be taken out of the machine [7,8]. These advantages promote its potential for material processing and rapid manufacturing applications. Recent research efforts have also demonstrated that SLM, due to its flexibility in feedstock and shapes, has a promising potential for the net-shape production of complex-shaped, high-performance composites parts. SLM processes of Al–Si–Mg/SiC, stainless steel/hydroxyapatite, 663 copper alloy, Fe–Ni–Cr and TiC/Ti5Si3 powder have been reported [9–13]. Thus, SLM, as a facile method, was tentatively used to melt Ti6Al4V powder.

In this paper, the importance of the processing parameters in striving to obtain fully dense Ti6Al4V parts by selective laser melting has been demonstrated. The effects of processing parameters on the microstructure, roughness, densification and microhardness were carried out.

2. Experimental procedure

2.1. Powder used

The Ti6Al4V powder used as feedstock was prepared in the laboratory by gas atomization and thus has a spherical shape. The distribution size is homogeneous as shown in Fig. 1a. Spherical or near-spherical particles generally result in close packing, thereby leading to a more efficient densification during SLM process. Fig. 1b shows an essential lognormal distribution with a particle size of 10.62 μm (d10), 18.35 μm (d50) and 31.46 μm (d90).

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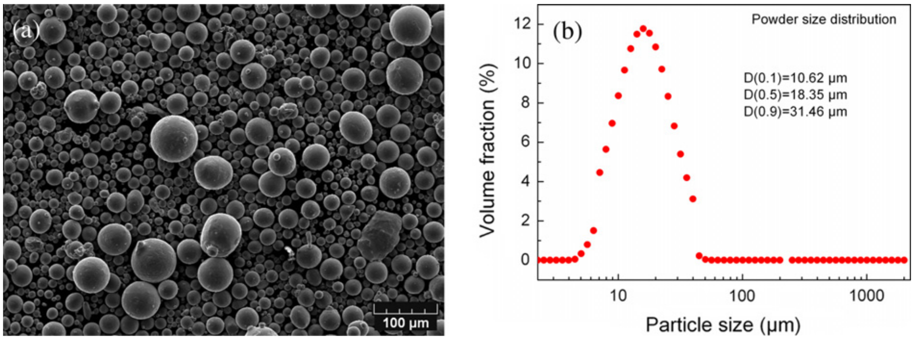

Fig. 1. (a) SEM morphology and (b) size distribution of Ti6Al4V powder.

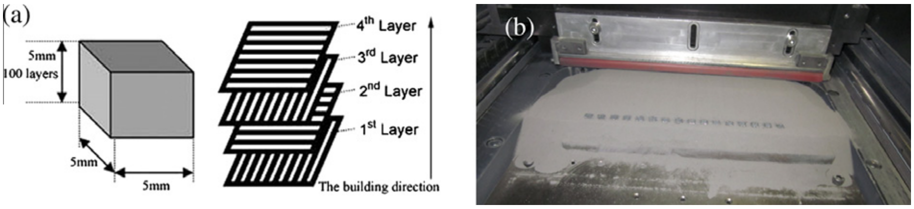

Fig. 2. (a) Layer cross-hatching technique and (b) photographs showing real-time selective laser melting process.

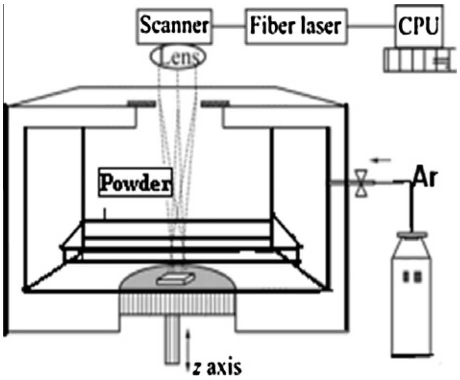

Fig. 3. Schematic diagram of selective laser melting machine.

2.2. Selective laser melting process

Stainless steel plates of 25 mm × 10 mm × 5 mm dimensions were used as stacking platform. Before being installed, this platform was grit-blasted with alumina. In order to identify a range of suitable parameters for manufacturing Ti6Al4V alloy, a series of single tracks with length 10 mm were firstly melted. And then a set of 5 mm long, 5 mm wide and 5 mm thick specimens were produced using various parameters as illustrated in Fig. 2.

The laser source of the SLM machine used is a YLR-100-SM single mode CW Ytterbium fiber laser (1064–1100 nm). The diameter of laser beam is adjustable between 34 μm and 75 μm and the maximum power is 120 W. The maximum laser scanning speed is $v = 3$ m/s. The working chamber provides a closed environment which is filled with Argon as a protective gas to maintain the pressure of oxygen below (0.8%), where the temperature of stacking platform can be adjusted and fixed at 100 °C. SLM was performed in the following ranges: laser beam 34 μm, laser power from 70 and 120 W, laser scanning speed 0.05–1.6 m/s, scan line spacing 40 μm and powder layer thickness 50 μm. The SLM machine was schematically shown in Fig. 3.

2.3. Characterization

The top-surface microstructure of melted Ti6Al4V parts was characterized using a scanning electron microscope. The cross-sectional microstructure of Ti6Al4V parts was examined by optical microscope (OM). The density was estimated using Archimedean method. The Vickers hardness of polished parts was measured under 300 g load with load time 15 s. Each mean hardness value is obtained from 20 measurements. The surface roughness of Ti6Al4V parts was obtained with a Taylor–Hobson Surtronic 3P profilometer.

3. Results and discussion

3.1. Mechanisms of powder melting

As well known, the densification level and the attendant microstructure of selective laser melted Ti6Al4V parts depend strongly on

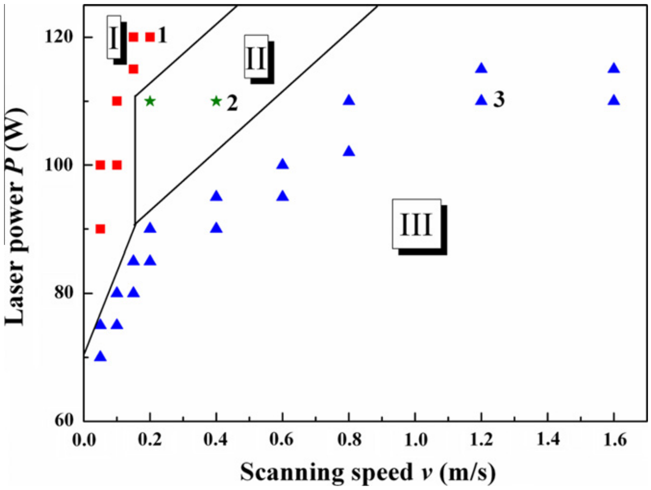

Fig. 4. Mechanisms of single tracks for selective laser melted Ti6Al4V (zone I-melting with cracks, zone II-continuous melting, zone III-partial melting) versus laser power and scanning speed.