Surface & Coatings Technology 349 (2018) 503–510

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Laser shock peening of laser additive manufactured Ti6Al4V titanium alloy

Wei Guo[a], Rujian Sun[a], Binwen Song[a,b], Ying Zhu[a], Fei Li[c], Zhigang Che[d], Bo Li[e], Chao Guo[e], Lei Liu[e], Peng Peng[a,f,*]

[a] School of Mechanical Engineering and Automation, Beihang University, Beijing 100191, China
[b] China North Vehicle Research Institute, Beijing 100072, China
[c] Chengdu Aircraft Industrial (Group) Co. Ltd., Chengdu 610073, China
[d] Key Laboratory For High Energy Density Beam Processing Technology, Beijing Aeronautical Manufacturing Technology Research Institute, Beijing 100024, China
[e] AVIC The First Aircraft Institute, Xi'an 710089, China
[f] International Research Institute for Multidisciplinary Science, Beihang University, Beijing 100191, China

ARTICLE INFO

Keywords:
Laser shock peening
Laser additive manufacturing
Titanium alloy
Microstructure
Mechanical properties

ABSTRACT

Laser shock peening is combined with laser additive manufacturing to modify the surface microstructures and mechanical properties of as manufactured Ti6Al4V titanium alloy. Microstructural evolution, microhardness distribution, residual stress distribution and mechanical properties are examined before and after LSP. After peening, the interplanar spacing of lattices of both α and β phases decreases without any new phase formation. Grain refinement is achieved with average grain size of α phase decreasing from 33.6 to 24.3 μm. High density of dislocation lines, tangles, and multi-directional mechanical twins are observed. Residual stress is turned from tensile to compressive state with an affected depth of around 700 μm. The hardening layer reveled by microhardness is around 900 μm in depth. Grain refinement accounts for the yield strength, ultimate tensile strength, and elongation enhancements after peening.

1. Introduction

Laser shock peening (LSP) is an advanced surface treatment technique to modify surface microstructures and enhance mechanical properties of metallic components [1–4]. In a typical LSP process, a high power density (in GW cm^{-2} range), short pulse duration (in nanoseconds) laser is applied onto the surface of metallic components to induce a high-temperature and high-pressure plasma through a rapidly vaporizing of an ablative layer (a black tape or an aluminum foil). The generated plasma immediately forms a shock wave transmitting into the target material and intensively interacts with the surrounding materials. Under this interaction, plastic deformation and residual stress have been introduced in the surface layer, which can effectively enhance mechanical properties of materials, such as microhardness [5], fatigue resistance [6, 7] and corrosion resistance [8]. Comparing with the conventional shot peening, LSP can not only induce residual stresses with a higher value (several hundred MPa) and larger depth (around 1 mm), but it can also generate finer microstructures (even nanocrystallization) in the surface layer [9]. This refinement is mainly due to the dislocation movement and deformation twinning driven by severe plastic deformation during LSP [10], which plays a significant role in enhancing surface-related properties.

Titanium alloy has high specific strength, excellent corrosion resistance, and biocompatibility, which enables its wide application in aerospace engineering, medical device, petrochemical industries and surgical implant material etc. [11–14]. However, the machinability of titanium alloys by traditional cutting methods generally decreases with higher alloy content and hardness. Therefore, laser additive manufacturing (LAM) of titanium alloys has been developed driven by the demand of near net-shaping and cost-effective manufacturing [15]. LAMed Ti6Al4V titanium alloys obtained higher strength than wrought material with slightly lower ductility varying from 5% to 9% at all locations [16]. It is worth noting that the tensile residual stress generated during the additive manufacturing process can also deteriorate the mechanical properties of additive manufactured components and thus hinder their applications [17, 18]. Recently, high-pressure rolling has been utilized to reduce peak residual stress and refine microstructure of AMed materials [19]. However, the reduction of tensile residual stress is still limited. In our previous study, LSP has been employed as a post-treatment process for wire + arc additive manufactured 2319 aluminum alloy to reduce the tensile residual stress, refine microstructure and enhance the tensile properties. Therefore, LSP can serve as an alternative to laser additive manufactured titanium alloy.

In this study, microstructures before and after LSP were examined

* Corresponding author at: School of Mechanical Engineering and Automation, Beihang University, Beijing 100191, China.
E-mail address: ppeng@buaa.edu.cn (P. Peng).

https://doi.org/10.1016/j.surfcoat.2018.06.020
Received 9 February 2018; Received in revised form 31 May 2018; Accepted 13 June 2018
Available online 14 June 2018

Table 1
Parameters for LAM.

LAM parameters	
Laser power	3 kW
Beam diameter	1–2 mm
Scanning speed	800 mm/min
Powder feeding rate	500–1000 g/h

using X-ray diffraction (XRD), optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Residual stress, microhardness, tensile strength and fracture morphology were characterized. This study is aimed to provide a new option to the post-treatment of LAMed titanium or other alloyed components and widen both LSP and AM techniques to satisfy the diversified demand of engineering industries.

2. Experiments

2.1. Materials and LSP procedures

A Ti6Al4V wall was layer-by-layer printed on a Ti6Al4V substrate in an argon purged chamber (oxygen content less than 10 ppm) using a continuous fiber laser with operating parameters given in Table 1. The laser moved a 45° zigzag path with an overlapping rate of 50%, as shown in the left top corner in Fig. 1a. The width of each path was around 6 mm. The as-printed titanium wall is shown in Fig. 1a, with the thickness of every single layer around 110 μm. The wall was then cut and double side milled to 3 mm thin plate. Specimens with a size of 10 mm × 10 mm × 3 mm were cut and one side laser shock peened. Prior to microstructure observation, the specimen was mechanically polished and ultrasonically cleaned. The TEM thin discs were prepared from surface layer before and after LSP. Fig. 1b shows the dimension details of tensile test specimens, and the sampling schematic of these specimens are illustrated in Fig. 1c. Tensile test specimens parallel (Type I) and perpendicular (Type II) to the building direction were cut from the thin plate. They were double side laser shock peened to avoid specimen distortion covering the whole gauge length of 32 mm. The LSP experiments were performed on a Q switched Nd: YAG laser with a wave length of 1064 nm, pulse energy of 15 J (power density was 5.6 GW cm^{-2}), spot size of 4 mm and frequency of 1 Hz. A 0.1 mm thick black tape was used to absorb laser energy and prevent laser ablation. A running water layer about 1–2 mm was applied onto the black tape as the transparent constraint layer to increase the peak pressure of the laser shock wave. The overlapping rate was 50% with a zigzag laser path, as shown in Fig. 1d.

2.2. Material characterizations

Phase transformation was investigated by XRD (D/max 2200PC, Rigaku) with operating current and voltage of 40 mA and 40 kV, respectively. Microstructural evolutions before and after LSP were characterized by OM (ASA1, Carl Zeiss), SEM (JSM-6010LA, JEOL) and TEM (JEM-2100, JEOL).

Microhardness before and after LSP was evaluated by a microhardness tester (FM-800, FUTURE-TECH) with a load of 200 g and dwelling time of 10 s. Surface microhardness was measured in a 15 mm line radially outward from the geometric center with an interval of 1 mm. In-depth microhardness was measured with an interval of 0.2 mm from the peened surface to a depth of 1.6 mm on the cross-section. Prism residual stress measurement system based on the hole-drilling method (STRESSTECH, Finland) was applied to measure the residual stress from the surface to a depth of 1 mm.

Tensile tests were performed on an INSTRON 8801 servo hydraulic

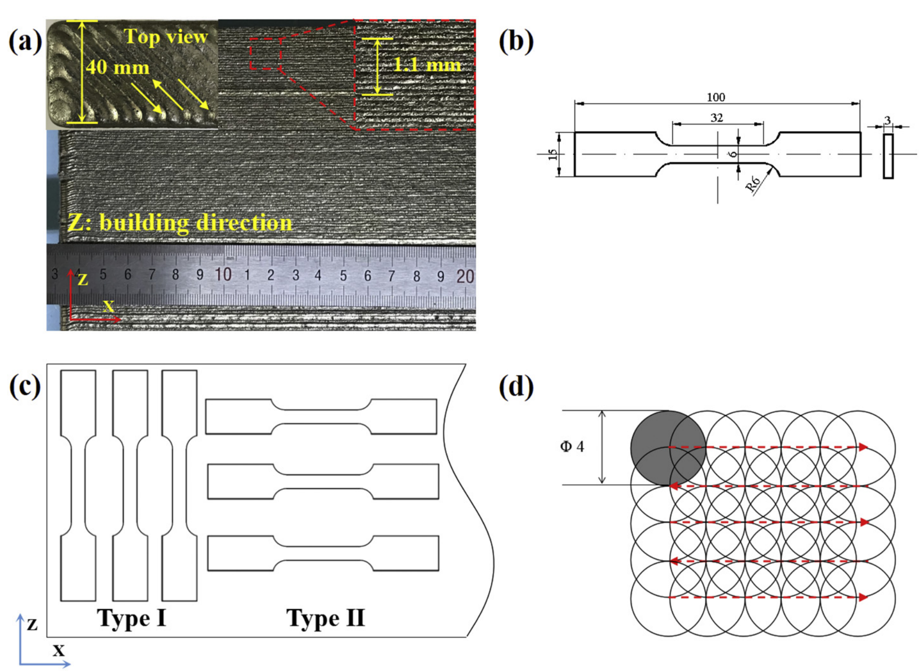

Fig. 1. (a) As-printed Ti6Al4V wall; (b) Dimension details of tensile test specimen; (c) Sampling schematic of tensile test specimen; (d) Schematic diagram overlapping rate.