Journal of Alloys and Compounds 748 (2018) 236–244

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

EBSD study of beam speed effects on Ti-6Al-4V alloy by powder bed electron beam additive manufacturing

Xiaoqing Wang*, Kevin Chou

Department of Mechanical Engineering, The University of Alabama, Tuscaloosa, AL 35487, USA

A R T I C L E I N F O

Article history:
Received 29 July 2017
Received in revised form
12 March 2018
Accepted 13 March 2018
Available online 14 March 2018

Keywords:
Powder bed fusion
Electron beam melting
Ti-6Al-4V
Microstructure
Texture
Electron backscatter diffraction

A B S T R A C T

Electron Beam Additive Manufacturing (EBAM) has a lot of advantages and has become an attractive manufacturing method to produce the Ti-6Al-4V alloy. In this study, four Ti-6Al-4V rectangular blocks were manufactured by the EBAM process with four different beam scanning speeds (Speed Function *x*-SF20, SF36, SF50, and SF65). Based on the experimental results, the beam scanning speed did show notable effects on the preferred orientation of the α phase in the Z-plane which presents a relatively strong $<2\,\bar{1}\,\bar{1}\,4>$ and $<1\,0\,\bar{1}\,0>$ texture. However, with the increase of the beam speed, the intensity of the texture in the Z-plane decreases first and then increases. For the Y-plane, the preferred orientation direction of α changes from $<2\,\bar{1}\,\bar{1}\,1>$ (SF20), $<0\,0\,0\,1>$ (SF36, SF50) to $<1\,0\,\bar{1}\,2>$ (SF65) with their maximum intensity decreased from 13.58 to 8.85 times of the random intensity. Generally, the parts did not show outstanding anisotropic characteristics in hardness and elastic modulus. The SF50 sample presents the highest properties (Vickers hardness and elastic modulus) between the four parts, which results from its finest microstructure and the weakest texture.

1. Introduction

Metal Additive Manufacturing is a method of manufacturing that forms parts from a wide range of materials in a layer-by-layer process [1]. Of the various commercially available technologies [2,3], powder bed fusion additive manufacturing (PBF-AM) [4] has the ability to produce near-full density metal functional components [5,6]. As one of the PBF-AM processes, electron beam additive manufacturing (EBAM), also named as electron beam melting (EBM) [7], has several unique advantages over others [8,9], such as high energy efficiency and rapid scan speed [10,11]. It is growing fast in industrial applications for the production of custom design, complex, and near net shape superalloy components, such as stainless steel [12], cobalt chrome alloy [13] and titanium alloy [14]. As one typical titanium alloy, Ti-6Al-4V has been utilized in numerous applications, such as turbine engines and orthopedic implants [15], which attribute to its excellent strength, high strength-to-density ratio, excellent corrosion resistance, and good biocompatibility compared to its counterparts [16–19].

Ti-6Al-4V has been studied in a wide scope ranging from raw metal powder [20], materials characterization [21], residual stress [22], porosity [23] to heat treatment [24]. Generally, finer grains were found in as-fabricated Ti–6Al–4V with a mix of α platelets and rod-like β phase, and α'-martensitic platelets [7]. In addition, the manufacturing parameters have critical effects on the microstructure and properties of the final parts [25]. Murr et al. [26] found that variations in melt scan, beam current, and scan speed affected the parts defects and might lead to microstructure-property variations in the final product. The volume fraction of spherical porosity was observed to decrease with decreasing speed function [23], and the porosity could be improved by hot isostatic pressing (HIP) which also could homogenize the microstructure and make the tensile properties along the rod axis highly consistent [27]. Riedlbauer et al. [28] studied the lifetime, width and depth of the molten pools for different line energies and revealed that the lifetime of the melt pool increased linearly with the line energy, in which the melt pool dimensions showed a nonlinear relationship with the line energy. The effect of melt strategies on the presence of porosity in EBAM Ti–6Al–4V components was also studied [14]. In addition, the density and surface roughness were more significantly affected by the offset focus than by the beam current and the beam speed [5]. Sun et al. [29] investigated the effects of as-built surface conditions on the tensile properties of Ti-6Al-4V alloy and reported that modification of the surfaces of as-fabricated parts

* Corresponding author.
E-mail address: xwang127@crimson.ua.edu (X. Wang).

https://doi.org/10.1016/j.jallcom.2018.03.173
0925-8388/

is necessary for structural applications. Tang et al. also [30] studied the effect of powder reuse times on the characteristics of the Ti-6Al-4V raw powder. In summary, the microstructures of EBAM Ti-6Al-4V vary with the processing conditions.

There are also some studies of the texture evolution in the EBAM process [31]. Formanoir et al. [32] reported that the reconstructed prior β phase showed a strong ⟨0 0 1⟩ texture in the growth direction and that the phase transformation induced in random texture led to a slightly anisotropic mechanical behavior. Moreover, the allotropic transformation of the bcc β-phase obeyed the typical Burgers orientation relationship and the cooling rate during a formation of the hcp α-phase was the most important parameter controlling the final microstructure [25,32]. Texture also has a strong effect on the mechanical behavior of α/β titanium alloys. The columnar prior β grains in the EBAM components showed a strong fiber texture of ⟨0 0 1⟩ type [33], which formed normal to the deposited powder layers. A pronounced anisotropy was more related to the α-phase texture than to the β-phase texture.

In order to further understand the scanning speed effects on the microstructural variations and orientation, in terms of the formed phases and texture for the Ti-6Al-4V alloy, we performed experiments on a commercial EBAM system and investigated the relationship between the scanning speed, texture and the properties of the EBAM parts [34].

2. Experiments

To study the beam speed effects on the final build parts, 4 rectangular blocks were fabricated at four different speed functions (SF*x*) (SF20, SF36, SF50 and SF65) [35] during the same build cycles by an Arcam S12 EBAM machine located at NASA's Marshall Space Flight Center (Huntsville, AL). Fine gas atomized (GA) Ti-6Al-4V powder was used as the raw material. The four blocks had identical dimensions of 60 mm length, 5.5 mm width, and 25 mm height, and they were built layer by layer with a layer thickness of 70 μm. The details of the manufacturing process can be found in the former studies [36]. The final finishing part fabricated with SF50 is shown in Fig. 1a, in which both the side surface (Y-plane) and the scanning surface (Z-plane) were studied to examine the anisotropic conditions in the microstructure, as indicated by specimen 1 and specimen 2 in Fig. 1a, respectively. To identify the phases in the final finishing parts, X-ray diffraction (XRD) characterization was carried out with an XPERT Pro-type diffractometer using Cu as anode.

The samples were prepared using standard metallographic procedures. To reveal the microstructure, the final polished specimens were etched using a hydrofluoric acid-based solution, which contained 1 ml hydrofluoric acid (50 wt %) and 3 ml (68 wt %) nitric acid and 20 mL distilled water. The etched metallographic samples were examined using a Keyence VHX-5000 digital microscope, and a JEOL 7000 FE scanning electron microscope (SEM). To characterize the texture of the samples, electron backscatter diffraction (EBSD) measurements were performed using a JEOL 7000 FE SEM system equipped with a detector for EBSD. The AZTEC data acquisition software (Oxford Instruments plc) was used in the study. The texture analysis was conducted at a beam voltage of 20 kV with a scanning area of 500 μm by 500 μm in 0.75 μm steps. Post-processing of the data was done using orientation imaging microscopy (OIM) software from EDAX.

3. Results and discussion

3.1. Characterization of microstructure

Fig. 2 presents a typical microstructure of the as-fabricated EBAM Ti-6Al-4V. The Y-plane showed columnar solidification structures along the Z-axis which length might go through multiple

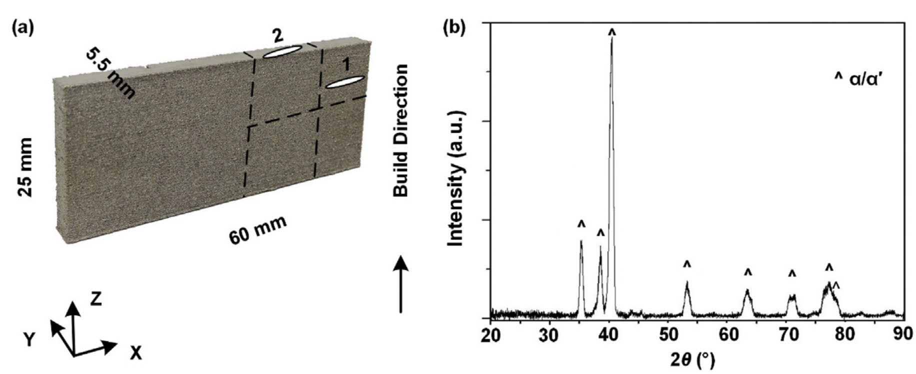

Fig. 1. Ti-6Al-4V: (a) As-fabricated EBAM block built with SF50, and (b) XRD patterns obtained from the as-fabricated bulk part [37].

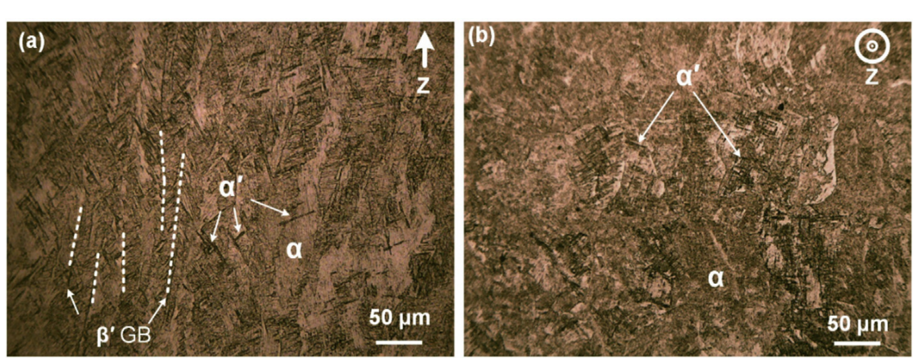

Fig. 2. The optical microstructure of as-manufactured Ti-6Al-4V samples by EBAM revealing the columnar and equiaxed microstructures in (a) Y-plane and (b) Z-plane, respectively.