G Model
JMST-983; No. of Pages 4
ARTICLE IN PRESS
Journal of Materials Science & Technology xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Journal of Materials Science & Technology
journal homepage: www.jmst.org

Variation of crystal orientation during epitaxial growth of dendrites by laser deposition

Guowei Wang [a,b], Jingjing Liang [a], Yizhou Zhou [a,*], Libin Zhao [c], Tao Jin [a], Xiaofeng Sun [a]

[a] Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, China
[b] School of Materials Science and Engineering, University of Science and Technology of China, Hefei 230026, China
[c] Xi'an Aero-engine Control Technology Co. Ltd, Xi'an 710077, China

ARTICLE INFO

Article history:
Received 17 October 2016
Received in revised form 4 January 2017
Accepted 9 January 2017
Available online xxx

Keywords:
Crystal orientation
Epitaxial growth
Laser deposition
Single crystal
Dendrite growth

ABSTRACT

A nickel-based superalloy was deposited onto a single crystal substrate based on epitaxial laser metal forming (E-LMF). The microstructure development in two depositions has been researched. For the first time, the crystal orientation of dendrites varying beyond 20° was found when the dendrites deflected in deposition. In addition, a new grain boundary was found between different orientation dendrites in a grain, and the detected grain boundary angle was 23°. The result shows that flowing field in laser pool is responsible for this phenomenon.

1. Introduction

Previous researches [1,2] indicated that columnar crystals deflected toward incident flow when they grow in their flowing melts. Following this work, different experimental set-ups and different alloys have proved the inclination of dendrites deflecting toward upstream direction (DDUD) [3–7]. Furthermore, according to the results of phase-field simulation [8,9], the mechanism of DDUD was revealed. However, no perceivable modification of dendrite orientation was detected in DDUD in a traditional casting [10], and it is generally believed that dendrites orientation keeps the <001> orientation [3,10].

Laser deposition of single crystal superalloy is a promising method for repairing or even manufacturing of single crystal components in the future [11]. This method is based on the technology of E-LMF, which can achieve the epitaxial growth of columnar dendrites during solidification [12,13]. There are many helpful works to understand this process [14–19]. Whereas, no attempt has yet been made to study the influence of flowing field on the microstructure during deposition.

The aim of this work was to investigate the effects of flowing field on the dendrites growth direction and crystal orientation during deposition. E-LMF was conducted based on two parameters of laser depositions. We observed the remarkable variation of crystal orientation in one of the depositions.

2. Experiments

In the deposition process as Fig. 1, a CO_2 laser (TEM_{01^*} mode) was used as a heat source. For the samples A and B, the laser was set at 600 and 500 W, respectively. And the laser beam was kept 8 mm and 18 mm away from focal point, respectively. The depositing was protected by argon shielding gas fed through the delivery nozzle. Powder feeding rate was about 4.4 g/min, and the powder (75–150 μm) was made from argon atomization. The substrate (22 mm × 11 mm × 6 mm) was cut from a single crystal casting, and it was solution heat treated. During depositing, the substrate was fixed by bench clamp. The contact interface between the substrate and clamp was about 1.5 cm^2 in sample A and 0.3 cm^2 in sample B. The composition (in wt%) of powder and substrate used in this work is: Ni-8Cr-5Co-10W-5.5Al-2.2Ti-3Ta.

The deposition process and tracking method is shown in Fig. 1. In the 1st, 3rd, 5th and more layers of deposition, the cladding strategy worked as Track 1. In the 2nd, 4th, 6th and more layers, the cladding strategy worked as Track 2. The laser was scanned along [100] or

* Corresponding author.
E-mail address: yzzhou@imr.ac.cn (Y. Zhou).

http://dx.doi.org/10.1016/j.jmst.2017.05.002
1005-0302/

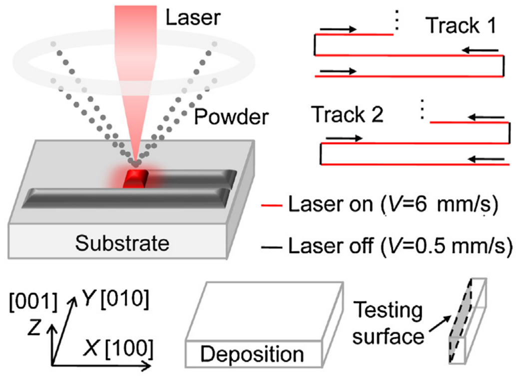

Fig. 1. Schematic diagram showing the laser deposition process.

[$\bar{1}$00] orientation on the surface of (001). The cutting cross section for research was perpendicular to the [100] orientation, and it was about 4 mm away from head face as shown in Fig. 1. The testing surfaces of samples A and B were polished and chemically etched for metallography. And then, they were electrolytically polished for analysis of electron backscatter diffraction (EBSD).

3. Results

The dendrite structures of samples A and B were analyzed by metallographic observation as Fig. 2(a) and (b). The epitaxial growth of dendrites has been achieved from the bottom of substrate to top of deposition. Many dendrites deflected dramatically in sample A as Fig. 2(a). Unlike A, dendrites deflected lightly in sample B as shown Fig. 2(b). The degrees of bending at signed points were measured. Approximately, the dendrites grew along the straight line in the area located at the middle position of pools. The dendrites deflected toward left and right in the left and right area of the pools, respectively. Joint zones were signed with white dotted rectangles and the rest were signed with black dotted rectangles. About 82.5% of dendrites belong to the no joint zone in sample A, and 50% in sample B. The higher magnification of metallography was carried out at the joint zones as shown in Fig. 2(c) and (d), and the zig-zag pattern of dendrites growth was found.

To detect the growth law of dendrites, EBSD investigations were performed, and the results is shown Fig. 3. In the area of white dotted rectangle, the variations of crystal orientation were analyzed in inverse pole figures. As shown in Fig. 3(a), the crystal orientation of dendrites also deflected from the growth direction in sample A. And the angle of variation in crystal orientation was beyond 20°. In Fig. 3(b), the crystal orientation of dendrites deflected slightly from the growth direction in sample B. Moreover, because the orientation deflected, grain boundaries were found between different orientation dendrites. The detected grain boundary angle reached 23° in sample A as shown in Fig. 3(a).

Then, flowing field in laser melted pool was calculated to explain the experimental results. A finite element model (FEM) was developed in an FEM software. In the model, the density of mesh in melted zones was bigger than other areas, and the value of surface tension temperature coefficient $d\gamma/dT = 6.7 \times 10^{-5}$ N/m/K. The $d\gamma/dT$ used in this work is less than actual value, given that surface tension had been reduced because the melting surface was destroyed by feeding powder. In the simulation results, the flowing fields in melting pool are shown in Fig. 4(a) and (b). Fluid currents moved from the heat-source center outward to the fusion line, driven by surface tension and thermal convection.

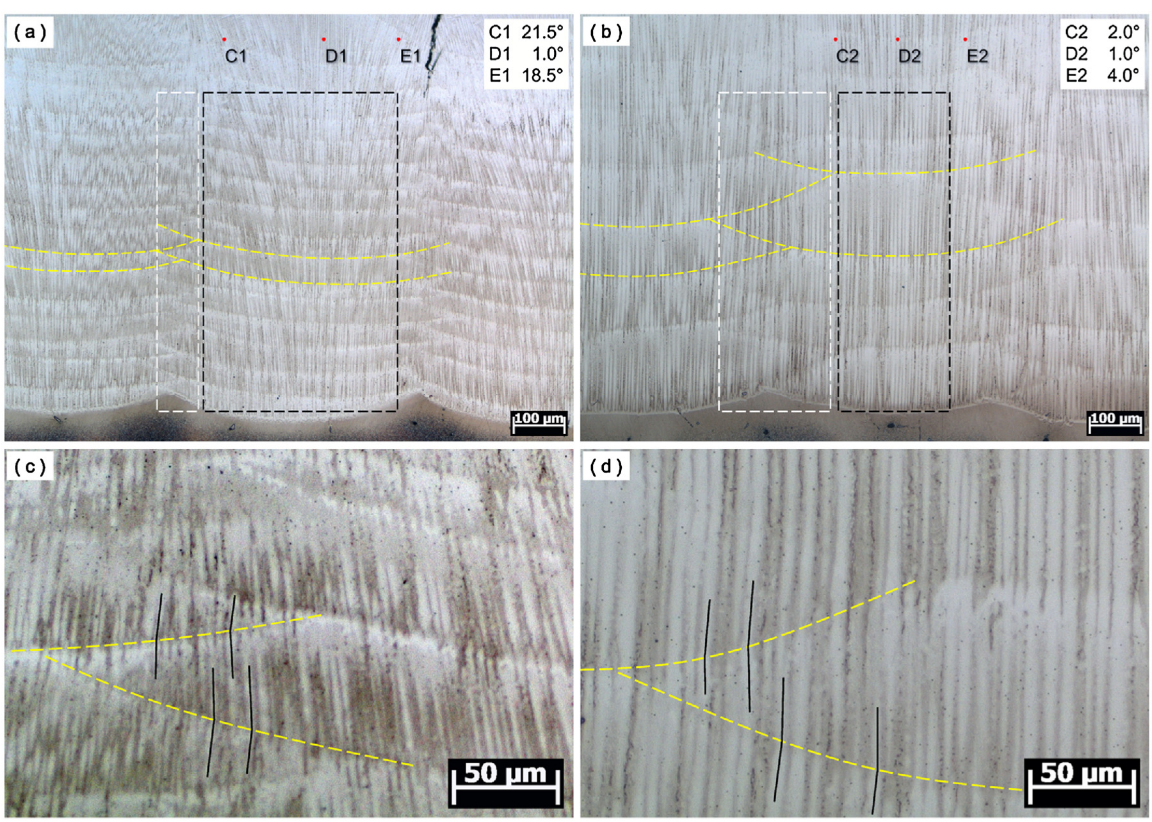

Fig. 2. Optical micrograph of microstructures for (a) sample A and (b) sample B. The yellow dashed curves present the melted traces. The white dotted rectangles are joint zones between right and left melted traces. The deflection angles of dendrite growth direction at red points (C1, D1, E1, C2, D2, E2) were measured. Microstructures of joint zones for (c) sample A and (d) sample B. The deflections of dendrite growth direction at melting traces were signed with black meander-line.