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Microstructure of TB6 Titanium Alloy Fabricated by Laser Deposition Manufacturing

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Abstract. Titanium alloy is a kind of difficult-to-machine material, which needs to seek an efficient processing method. In this paper, the deposition samples of TB6 titanium alloy were prepared by laser deposition manufacturing. The internal microstructure of the as-deposited was analyzed by Optical Microscope(OM) and Scanning Electron Microscope(SEM). The formation mechanism of interlaminar bands and the variation law of microhardness were studied. The microstructure of TB6 titanium alloy prepared by laser deposition is composed of most equiaxed and a small part of original β grains elongated along the deposition direction and approximately ellipsoidal. The original β grains are mainly composed of primary α phase(α_p), grain boundary α phase(α_{GB}) and matrix β phase. The temperature fluctuation between the deposition layers in the laser deposition process leads to the change of α_p phase size, which forms the layer band distribution with different contrasts.

Keywords. Laser deposition manufacturing, TB6 titanium alloy, microstructure, band distribution.

1. Introduction

TB6 titanium alloy is a near beta titanium alloy with nominal composition Ti-10V-2Fe-3Al. Its excellent comprehensive mechanical properties match the material requirements of aerospace and other defense fields[1]. However, due to the poor processing performance of titanium alloy for traditional material reduction manufacturing. It is easy to bring high cost and high difficulty[2]. In view of these practical problems, many researchers use laser deposition manufacturing (LDM) to realize the manufacturing of difficult-to-machine materials. Professor Huang Weidong's team of Northwest University of Technology has carried out the basic research on laser additive manufacturing technology for titanium alloys, superalloys and other materials, and found that the alloy microstructure with good metallurgical bonding can be obtained by accurately controlling the main laser process parameters[3]. Lore Thijs et al. studied the

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microstructure development of Ti-6Al-4V alloy fabricated by selective laser sintering. These were found that martensite phase appeared in the microstructure and the grains grew epitaxially. The grain direction and size were directly related to the process parameters[4]. Jinoop A. N. et al. studied Inconel 718 alloy by directional energy deposition manufacturing technology and analyzed the influence of process parameters on forming quality[5].

Laser deposition manufacturing can not only avoid the traditional processing difficulties. But also reduce production costs, improve material utilization, and prepare parts with higher structural complexity. In this paper, TB6 titanium alloy test pieces were prepared by laser deposition manufacturing technology. Combined with various types of microscopes, the microstructure morphology of TB6 titanium alloy fabricated by laser deposition was observed and analyzed. Then, the precipitation mechanism of microstructure during laser deposition was explored, which provided a theoretical basis for the laser deposition manufacturing of TB6 titanium alloy.

2. Experimental

The LDM experiments were carried out in a LDM800 laser deposition manufacturing system, developed by Shenyang Aerospace University. Oxygen content in forming chamber atmosphere was less than 100 ppm. Melt powders with a particle size ranging from approximately 50 μm to 150 μm produced by the plasma rotating electrode process (PREP) were used as the raw material. its chemical composition was shown in table 1.

Table 1. Chemical composition of TB6 titanium alloy powders (wt%)

Elements	Al	V	Fe	C	N	H	O	Ti
TB6	2.6~3.4	9.0~11.0	1.6~2.2	0.05	0.05	0.0125	0.13	Bal

In order to prevent from absorbing water vapor, the powder was dried before the experiments for 12h at 100°C in a vacuum drying oven. A Ti-6Al-4V thick plate was used as substrate with size of 135x60x40 mm. The surface layer of substate was treated by sanding and scrubbing. The LDM process parameters were followed, laser power in 2000 W, beam scanning speed in 10 mm/s, powder feeding speed by 0.8 r/min, scanning gap of 2.1 mm, and layer height in 0.6 mm. A LDM block in 70x28x75 mm was prepared and metallographic observation samples were performed. Then, the metallographic sample was etched by Kroll corrosion solution ($V_{HF} : V_{HNO_3} : V_{H_2O} = 3 : 6 : 200$). Microstructure observation was performed with an OLYMPUS-GX51 optical microscope and a TESCAN scanning electron microscope. Detail information of α_p was measured with an Image J software.

3. Results and Discussion

Figure 1 shows the sample block of TB6 titanium alloy fabricated by laser deposition. It is observed that the sample block has good formability, strong stereoscopic feeling, slight oxidation on the surface, uniform thickness of each deposition layer, and parallel to each other. The sample block has no obvious collapse, and the top surface is low in the middle and high on both sides. The formation of the top concave surface is directly related to the characteristics of laser deposition manufacturing[6]. The short side unidirectional reciprocating scanning makes the motion process accelerate-uniform-reduce to zeroreverse acceleration cycle. The edge position will inevitably be accompanied by the acceleration and deceleration process. This position will fix more powder, resulting in the growth rate of the edge position is greater than the middle position, and finally makes the top concave of the laser deposition part.

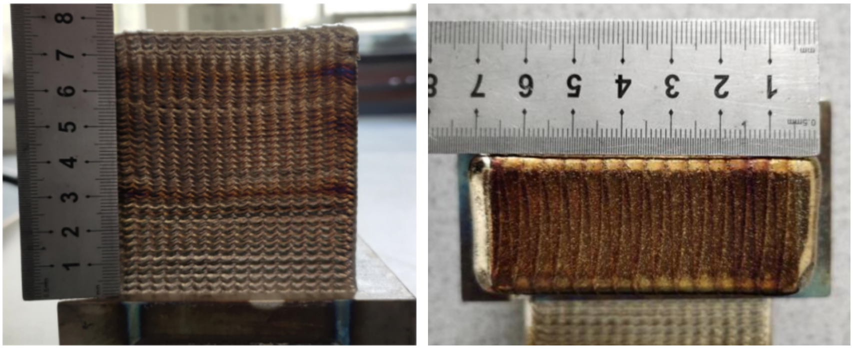

Figure 1. Deposition of sample blocks by laser deposition

Figure 2 shows the OM microstructure morphology of TB6 titanium alloy sample block fabricated by laser deposition. Figure 2(a) and 2(b) are the microstructures in the deposition direction and vertical deposition direction, respectively. It is found that most of the deposited microstructure is equiaxed, and a small part of the original β grains are elongated along the deposition direction and are approximately ellipsoidal. The ratio of long axis to short axis is generally not greater than 2. The original β grains are approximately equiaxed in YOZ, and the average grain diameter is 300 ~ 500 μm. The original β grains in XOY direction elongated along the deposition direction, and the overall shape was ellipsoid. The ratio of long axis to short axis was close to 2. The short axis size was equivalent to the grain diameter in YOZ direction.

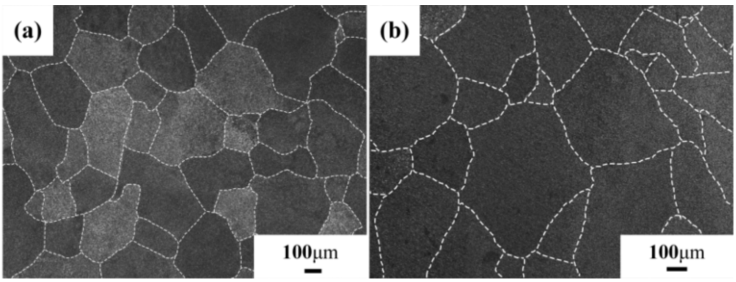

Figure 2. Microstructure of laser deposition samples (a) XOY (b) YOZ

Metal additive manufacturing components generally consist of columnar crystals. The formation of columnar crystals is closely related to the different thermal gradients in different directions during the deposition process. Mangesh V. Pantawane et al. monitored the thermal gradient vector components in the laser forming process. It was found that the thermal gradient values in the scanning direction and the lap direction are far less than those in the deposition direction[7]. According to the grain competition growth theory, the grain preferentially grows along the direction of high temperature gradient[8]. The heat radiation velocity in the outward direction is less than that in the internal heat conduction velocity of the specimen. Therefore, there will be a greater temperature gradient in the deposition direction. So the original β grain will tend to grow along the deposition direction. Finally, the original β grains are larger in the deposition direction. In the vertical deposition direction, the thermal gradient is not much different. The relative performance is more uniform. In the nickel-based superalloy, α + β titanium alloy (such as Ti-6Al-4V) and near α titanium alloy (such as TA15) with higher content of α stable elements. Under the condition of laser coaxial powder feeding and additive manufacturing, most of them show obvious coarse columnar crystal structure.

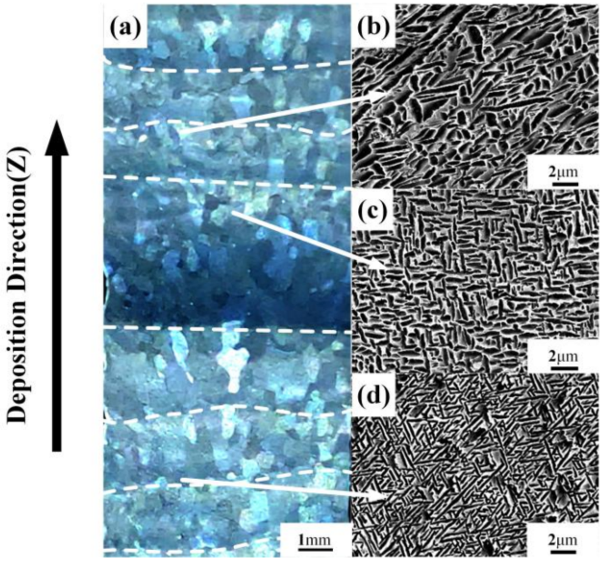

Figure 3. Strip distribution of laser deposition samples

Figure 3 is the schematic diagram of TB6 titanium alloy as-deposited prepared by laser deposition. From the macroscopic morphology observation of figure 3(a), it was found that there was obvious band distribution in different contrast areas. The microstructure of different contrast areas was observed by scanning electron microscopy. It was found that the microstructure in the deposition area was mainly composed of primary α phase (α_p), grain boundary α phase (α_{GB}) and β phase. The size and morphology of α_p phase in different contrast areas were significantly different (as shown in figure 3(b), 3(c), 3(d)). In the dark band region, α_p phase is needle-like. The average length of α_p phase is about 2.2 μm, the average width is 0.17 μm, and an average aspect ratio is 13.5; In the transition region of the bright and dark contrast band, the morphology of α_p phase gradually changes. Compared with the dark band region, α_p phase has obvious coarsening and growth. The aspect ratio is about 5.8. The α_p phase gradually coarsens from the slender needle shape to the lamellar feature. At the bright band position, the lamellar α_p phase further coarsens and grows. The average length of α_p phase is about 1.9 μm, which is 13.6 % lower than that of the dark band. The average width is 0.43 μm, much larger than that of the dark band. However, the average aspect ratio decreases significantly. Some lamellar α_p phase coarsens and grows in an equiaxed shape. From the above analysis, it can be seen that the difference of light and dark contrast is caused by the size difference of α_p phase in the alloy structure. The relatively coarse lamellar α_p phase distribution forms a 'bright area'; The elongated acicular α distribution corresponds to the 'dark area'. The formation of different α layer sizes is closely related to the laser deposition manufacturing process.

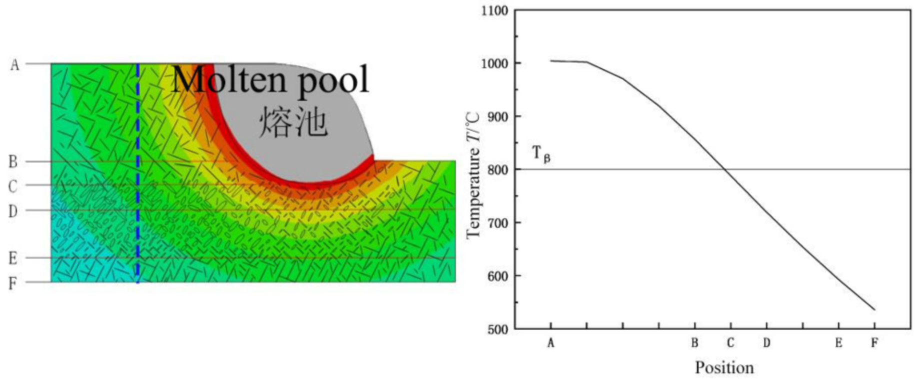

Figure 4. Formation mechanism and temperature curve of strip

According to the results of microstructure analysis in figure 3, the light and dark contrast in TB6 metallographic structure is the reaction of fine α lamellar structure with different sizes. Since TB6 titanium alloy belongs to the near-β type titanium alloy, the phase transformation temperature is low, and the microstructure is relatively sensitive to the change of ambient temperature, which will affect its final mechanical properties. Therefore, it is essential to explore the causes of different lining bands between layers. Formation mechanism of strip and temperature curve are shown in figure 4. When the new deposition layer (AC) is melted on the previous deposition layer (BF), the top area of the previous layer will be remelted (BC) to form a molten pool. In this area, due to direct laser irradiation, the temperature increases rapidly and is much larger than T_β. Since laser deposition has the characteristics of rapid solidification, the α_p phase precipitated in the original β grain during the solidification process of molten pool cannot grow up, showing a slender needle shape and evenly distributed on the β matrix. The macro performance of this region is a dark band. From the lower position of the remelted zone to the bottom area (CF) of the upper sedimentary layer, the temperature in this area is lower than T_β. With the continuous deposition process, the temperature in the area changes with oscillation attenuation and finally tends to be stable[9]. For the slender needle-like α_p phase formed by the previous rapid cooling, after enough thermal cycles, it is equivalent to a period of heat treatment. The needle-like α_p phase gradually coarsens and grows, and the aspect ratio tends to decrease. In the CF region, the thermal conductivity of titanium alloy is lower than that of other alloys. In the region near the molten pool (CD), the temperature in this region is relatively high and close to the molten pool, which is equivalent to solid solution and aging treatment. The needle-like α_p phase grew up and coarsened obviously, and the macroscopic appearance was bright band. In the DE region, the temperature is relatively low, which is equivalent to stress relief annealing. With the increase of the distance from the relative molten pool, the influence of the molten pool is reduced, and the degree of thermal coarsening of needle-like α_p is gradually reduced. The strip shows obvious transition characteristics (DE). The bottom position (EF) is relatively far from the molten pool, and the temperature increase is not obvious. The coarsening effect is not obvious, and the macroscopic still shows dark bands. With the continuous process of laser deposition, the new and old sedimentary layers are accumulated layer by layer, and then the alternating distribution of different contrast bands between layers occurs.

4. Conclusion

The TB6 titanium alloy sample prepared by laser deposition manufacturing has good formability and strong three-dimensionality. The as-deposited microstructure consists of mostly equiaxed primary β grains elongated along the deposition direction and approximately ellipsoidal. The temperature cycle fluctuation between the deposition layers during laser deposition leads to the change of the size of α_p phase in a single deposition layer. Therefore, the deposition samples show the distribution of different contrast layers. Along the growth direction of deposition height, the bands show a gradual change from dark to bright. The darker position is the slender needle-like α_p phase, and the brighter position is the flake α_p phase.

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