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Postprint: Study on Crystallographic Texture Evolution in Electron Beam Melted TC18 Titanium Alloy

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Abstract

TC18 titanium alloy specimens were fabricated via electron beam wire deposition (EBWD), and the growth of columnar grain structures and distribution of crystal orientations were investigated. The results show that the EBWD-fabricated TC18 titanium alloy exhibits a macroscopic metallographic structure of coarse columnar grains growing vertically, which develop from the molten pool bottom through epitaxial growth. Influenced by the unique thermal conditions during deposition, the alloy crystals develop a preferred orientation along specific directions, with both α and β phases showing distinct orientation distribution patterns. Under epitaxial growth conditions, the $\beta \rightarrow \alpha$ transformation exhibits inheritability. Most β grains display a strong <001> fiber texture, and the macroscopic orientation of inter-columnar β phase shows distinct characteristics concentrated in TD, LD, and normal direction ND. The $\beta \rightarrow \alpha$ transformation strictly follows the Burgers orientation relationship; lamellar α/α precipitated within the same parent β grain satisfy the misorientation distribution dictated by the Burgers relationship. The α phase within columnar grains primarily exhibits six orientations, indicating strong variant selection during the $\beta \rightarrow \alpha$ transformation.

Full Text

Study on Crystal Orientation Distribution of TC18 Titanium Alloy Fabricated by Electron Beam Wire Deposition

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Abstract

TC18 titanium alloy specimens were fabricated by electron beam wire deposition (EBWD) to investigate the growth of columnar grain structures and the distribution of crystal orientations. The macrostructure consists of coarse columnar grains growing perpendicular to the workbench plane. These columnar grains form through direct epitaxial growth from the bottom of the melt pool. Influenced by the special heat transfer conditions during the forming process, the TC18 titanium alloy crystals develop a preferred orientation in specific directions, with both α and β phases exhibiting distinct orientation distribution patterns. Under epitaxial growth conditions, the $\beta \rightarrow \alpha$ phase transformation exhibits inherited characteristics. Most β grains display a strong $< 001 >$ fiber texture with orientation differences less than 10°. The macroscopic orientation of β phase between columnar crystals also shows distinct features, concentrating along the transverse direction (TD), longitudinal direction (LD), and normal direction (ND). The $\beta \rightarrow \alpha$ transformation strictly follows the Burgers orientation relationship. The lamellar α/α phases precipitated within the same parent β grain satisfy the orientation difference distribution required by the Burgers relationship. There are six primary α orientations within the columnar grains, indicating strong variant selection during the $\beta \rightarrow \alpha$ transformation process.

Keywords: metallic materials, TC18 titanium alloy, electron beam wire deposition, columnar crystal, epitaxial growth, texture

Introduction

TC18 is a highly alloyed high-strength titanium alloy with a nominal composition of Ti-5Al-5Mo-5V-1Cr-1Fe, originally developed in the former Soviet Union in the late 1960s (designated BT22). This alloy combines the properties of both α and β titanium alloys, featuring high Mo content along with Cr and Fe (approximately 1.0% each). It exhibits heat treatment strengthening effects comparable to Ti-1023 alloy, possesses high hardenability, and demonstrates excellent thermoplasticity, making it particularly suitable for manufacturing load-bearing components such as aircraft fuselage structures and landing gear [?].

Electron beam wire deposition is an additive manufacturing process based on three-dimensional CAD models, where a high-energy electron beam is used as the heat source to melt metal wire fed synchronously in a vacuum environment. The material is deposited layer-by-layer to produce near-net-shape components. Compared with traditional forging methods, EBWD offers shorter production cycles, lower costs, and greater flexibility, making it especially suitable for the integrated manufacturing of large, complex metal structures. Consequently, applying EBWD to TC18 titanium alloy for manufacturing large, complex load-bearing structural components holds promising prospects.

The EBWD process involves multiple energy fields and repeated thermal cycling, with heat dissipation in the vacuum environment occurring primarily through conduction along the normal direction of the deposition plane [?]. Under these special thermo-mechanical field conditions, the crystal orientations within the deposited material exhibit distinct patterns, particularly when coarse columnar grains form in a single direction. Therefore, investigating the microstructural characteristics and crystal orientation distribution under these unique thermo-mechanical conditions is crucial for controlling the mechanical properties of EBWD-fabricated components. This study experimentally investigates the metallographic structure and macro-texture of EBWD TC18 titanium alloy to elucidate the crystal growth and orientation distribution patterns.

Experimental Methods

The experimental material consisted of TC18 titanium alloy fabricated by electron beam wire deposition, followed by hot isostatic pressing at 900°C for 2 hours under $>$ 130 GPa. The surface oxide layer from heat treatment was removed from the test blocks before sample extraction for experimental study.

[Figure 1: see original paper] shows the EBWD TC18 titanium alloy test block. The direction parallel to the deposition direction was defined as the transverse direction (TD), while the direction perpendicular to the deposition plane was defined as the longitudinal direction (LD). Rectangular samples with cross-sections of 22 mm $\times$ 20 mm (22 mm in TD) and square samples of 10 mm $\times$ 10 mm were sectioned from the test block for texture data acquisition and metallographic observation. X-ray diffraction (XRD) and electron backscatter diffraction (EBSD) were employed to characterize the texture of the as-fabricated microstructure.

Texture measurements were conducted using an X-ray diffractometer with Cu $K\alpha$ radiation at 30 kV and 20 mA, scanning in concentric circular steps from 0° to 360° with 5° increments. The scanning range was 20° to 90°, measuring pole figure data for the α-phase $\{0002\}$, $\{10\bar{1}0\}$, and $\{10\bar{1}1\}$ planes to calculate the ODF (orientation distribution function) maps, as well as $\{100\}$ and $\{110\}$ pole figures for the β-phase crystals.

EBSD observations were performed on the longitudinal section (XZ plane) of the fabricated samples using a thermal field emission scanning electron microscope (SEM) equipped with an EBSD detector and Channel 5 orientation analysis software. A scanning step size of 0.2 μm was used to analyze the microstructural characteristics and texture distribution.

Results and Discussion

2.1 Microstructure The macroscopic metallographic structure of the EBWD TC18 titanium alloy test block is shown in [Figure 2: see original paper]. The low-magnification microstructure reveals typical columnar grains oriented in the LD direction. The substrate at the bottom of the columnar grains consists of coarse equiaxed crystals, with grain size decreasing as the distance from the columnar grain bottom increases. The columnar grains grow directly through epitaxial growth from the equiaxed crystals at the substrate top, extending in the normal direction of the deposition plane (LD) and continuing to the top of the fabricated block. The width of the columnar grain structure in the EBWD test block is on the millimeter scale, with maximum widths approaching 3 mm and gradually widening from bottom to top.

As shown in [Figure 3: see original paper], the microstructure within the columnar grains consists of lamellar structures arranged in large, straight colonies that intersect at approximately 90° angles. The colonies exhibit a high aspect ratio. At grain boundaries, numerous fishbone-arranged lamellar structures are observed, which are extremely fine, long, straight, and grow from the grain boundaries into the grain interior.

2.2 Texture X-ray diffraction was used to measure the texture pole figures of the EBWD TC18 titanium alloy α and β phases, with results shown in [Figure 4: see original paper] and [Figure 5: see original paper]. [Figure 4a: see original paper] presents the α-phase basal plane {0002} texture pole figure, revealing that the α-phase basal planes in the EBWD TC18 titanium alloy form a strong texture. The orientations are primarily distributed in four directions: approximately 30°–45° from the normal direction (ND) toward both TD and LD, located along the lines connecting the center point with the TD and LD poles. The maximum intensity occurs at approximately 30° from ND toward TD. The orientation distribution function (ODF) at these positions is shown in [Figure 4b: see original paper], indicating a strong texture at $\phi_1 = 45°$. [Figure 4c: see original paper] and [Figure 4d: see original paper] show the $\{10\bar{1}0\}$ and $\{10\bar{1}1\}$ pole figures, respectively. Compared with the basal plane orientation distribution, other crystal planes do not exhibit strong textures, indicating more dispersed orientations.

[Figure 5: see original paper] shows the measured β-phase texture pole figures. The β-phase {110} pole figure exhibits characteristics similar to the α-phase {0002} pole figure, consistent with the Burgers relationship. That is, the transformation from the body-centered cubic β structure to the hexagonal closepacked α structure follows the relationship $(110)_\beta \parallel (0002)_\alpha$. However, there is a significant difference in texture intensity between the two phases. Under the influence of external thermo-mechanical fields during transformation, variant selection makes the transformed α-phase orientations more concentrated. In the case of epitaxial growth and rapid grain growth, the $\{100\}$ plane orientations of the β-phase concentrate at the LD and TD poles, demonstrating distinct orientation characteristics. Due to sample size limitations and coarse grain effects, the number of grains within the test plane is relatively small, which affects the statistical reliability of β-phase orientation distribution.

[Figure 6: see original paper] through [Figure 9: see original paper] present the texture data obtained from EBSD measurements. [Figure 6a: see original paper] is a contrast image showing that the columnar grains consist of numerous Widmanstätten structures with randomly distributed colony orientations. [Figure 6b: see original paper] shows the two-phase distribution map, where the blue regions represent the β-phase and red regions represent the α-phase. The pattern reveals that the $\beta \rightarrow \alpha$ phase transformation follows the

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