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Multi-step heat treatment design for nano-scale lamellar structures of a cast Ti-45Al-8.5Nb-(W, B, Y) alloy

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ABSTRACT

A multi-step heat treatment is proposed to optimize the lamellar structure of as-cast high Nb containing TiAl alloys. The β-segregation is removed effectively after the first two step heat treatment, a short-time holding within β single phase field then annealing in α+β phase field. During the third step heat treatment, a subsequent low-temperature aging, new γ lamellae precipitate by the means of isolated nucleation or twin-related nucleation. After the proposed multi-step heat treatment, the alloy presents nano-scaled lamellar structure with the colony size about 140 μm.

1. Introduction

TiAl-based alloys have been considered for high temperature applications in aerospace and automotive industries [1–3] due to their attractive properties such as low density, high specific yield strength, high specific stiffness, good oxidation resistance, and good creep properties. Over the past decade significant progress has been achieved in the design and processing of TiAl alloys based on γ(TiAl) and α_2(Ti_3Al) [4–6]. Casting is an economical way for the fabrication of TiAl components and the casting blade of Ti-48Al-2Cr-2Nb (all composition are given in at. %) alloy has been used in the last two stages of the low-pressure turbine in the General Electric GEnx-1B engine [7]. However, the application of castings for high Nb containing TiAl alloys is limited, which not only because of their poor castbility and micro-segregation [8–10], the structure homogeneity and the reliability of long service at high temperature oxidation environment are also worthy of attention. As is well known, the service properties of TiAl alloys are quite sensitive to their microstructure and structure stability, and the fully lamellar structure has been identified to possess good balanced mechanical properties. The microstructure features, such as colony size [11–13], lamellar spacing [11–15], lamellar orientation [16,17] and lamellar interface character [15,18] play an important role in their mechanical properties.

The performance of as-cast high Nb containing TiAl alloys is generally improved, if a nanometer scaled lamellar microstructure without β-segregation can be produced. Heat treatments are usually performed to eliminate β-segregation by annealing the alloys within α+γ two phase field or α single phase fields for more than 12 h [19–21], which tend to cause severe coarsening of lamellar structures. A two-step heat treatment has been proposed in our previous work [22,23] to eliminate the micro-segregation and improve the microstructure homogeneity of high Nb containing TiAl alloys. This method greatly improves the efficiency of heat treatment as compare to the traditional methods, but it does not take into account of lamellar spacing. Sun [24] reported an ultrafine, nanometer-scale, fully lamellar microstructure of Ti-45Al-2Cr-2Nb as-cast alloy through quenching and subsequently aging treatment. Cha et al. [25] also obtained well-defined lamellar microstructures with ultrafine widths by annealing a previously quenched Ti-45Al-7.5Nb alloy. This kind of strategy can be used to refine the lamellar structure of high Nb containing TiAl alloys.

In this work, a multi-step heat treatment (HT) is proposed to optimize the lamellar structure of an as-cast high Nb containing TiAl alloy. The first two step heat treatments are conducted within single β phase field and α+β two-phase field in order to eliminate the micro-segregation and obtain a homogeneous

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lamellar colony. The third step heat treatment is designed to manipulate the lamellar spacing and stabilize the microstructure. Correspondingly, the relation between microstructure evolution and phase transformation during the multi-step HT is studied and discussed.

2. Material and methods

The starting material with a nominal composition of Ti-45Al-8.5Nb-0.2W-0.2B-0.02Y was prepared by a plasma cold hearth melting furnace. Specimens with the size of 10 mm × 10 mm × 12 mm were cut from the large ingot. The multi-step HT was applied sequentially at 1480 °C, 1340 °C, 700 °C for different time (marked HT3), as illustrated in Fig. 1. In order to investigate microstructure evolution during each step in detail, another two heat treatments, i.e., HT1 and HT2 were also performed. Subsequently, specimens were grinded and polished for microstructure analysis. The microstructures were characterized by optical microscopy (OM), X-ray diffraction (XRD), scanning electron microscopy (SEM) in back-scattered electron (BSE) mode, selected area diffraction (SAED) and high resolution transmission electron microscopy (HRTEM) performed with an FEI Tecnai G2 F30 transmission electron microscope (TEM). OM was used to investigate the microstructure at lower magnification times and measure the size of the lamellar colonies by an intercept method. X-ray diffraction measurements were carried out for easy quantitative analyzing the volume fraction of different phase, using Cu Kα radiation with an angle range of 20–90° (2θ), and the voltage, current and scanning step is 40kv, 30 mA and 0.03, respectively. The different phases present in the microstructure were discriminated based on their contrast on BSE images. TEM was used to observe the microstructure at higher magnification times, measure the interlamellar space, distinguish the different phases by selected area diffraction patterns (SADPs) and investigate the crystallographic orientations of lamellar interface in the high resolution electron microscopy (HREM) mode. Thin foils for TEM were prepared by means of twin-jet electron-polishing at 27 V and a temperature of −30 °C.

3. Results and discussion

The initial microstructure of the as-cast Ti-45Al-8.5Nb-(W, B, Y) alloy is shown in Fig. 2. It can be seen that this alloy exhibits a near-lamellar microstructure with the average colony size about 100 μm. The β, α and γ phase could be clearly identified as white, grey and dark phases in SEM-BSE images due to different average atomic numbers in composition, respectively. A small number of mixtures of bright residual β/B2 phase and gray γ particles mainly distribute at colony boundaries and triple junctions. The retained β/B2 phase called β-segregation is attributed to solute redistribution of β stabilizing elements Nb and W during β→α transformation, and the volume fraction of β-segregation is about 6.2%.

As shown in Fig. 3(a), the microstructure after HT1 exhibits homogenous lamellar colonies. The β segregation is weakened, but still in the form of network distributes at colony boundaries. To prevent the generation of sharp textures, the cooling rate from β phase field to α+β phase field should be selected as slow as possible

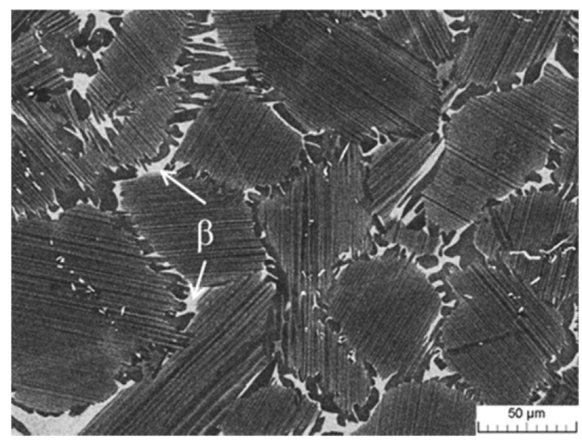

Fig. 2. SEM-BSE image of as-cast Ti-45Al-8.5Nb-(W, B, Y) alloy.

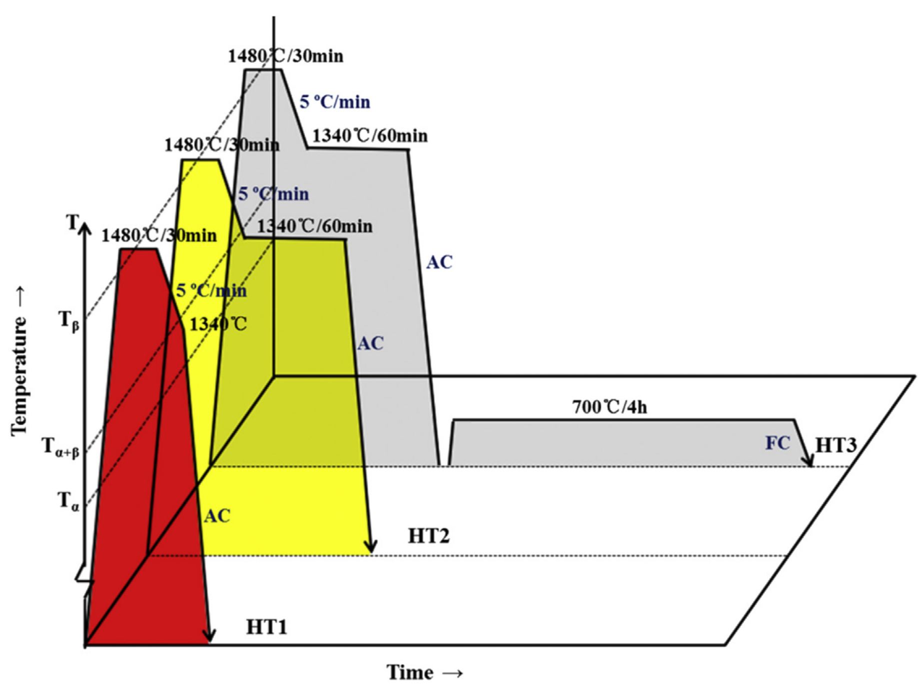

Fig. 1. Schematic overview of the applied heat treatment study starting from the cast microstructure.