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Microstructure and creep behaviors of a high Nb-TiAl intermetallic compound based alloy

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ABSTRACT

By means of heat treatment, creep properties measurement and microstructure observation, an investigation has been made into the influence of heat treatment on microstructure and creep properties of the high Nb-TiAl alloy. Results show that the microstructure of as-cast high Nb-TiAl alloy consists of lamellar γ/α_2 phases with various orientations. The irregular serrated boundaries with single γ phase are located in between the lamellar γ/α_2 phases with various orientations. After solution and aging treatment, the microstructure of alloy consists of uniform and regular lamellar γ/α_2 phases, and the regular boundaries are located in between the lamellar γ/α_2 phases. Under the applied stress of 200 MPa at 800 °C, the creep lifetime of the as-cast high Nb-TiAl alloy is measured to be 147 h, the one of the alloy after heat treatment is measured to be 297 h. In the ranges of the applied temperatures and stresses, the creep activation energy of alloy after heart treatment is measured to be $Q=432$ kJ/mol. The deformation mechanism of alloy during creep is dislocations slipping in the lamellar γ/α_2 phases, the creep dislocations may be decomposed to form the configuration of the partials plus stacking faults. The deformation of as-cast alloy during creep occurs mainly in the irregular serrated boundary regions with single γ phase. For the heat treated alloy, the primary/secondary slipping systems of dislocations are alternately activated during creep, which results in the bigger plastic deformation of alloy to contort the lamellar α_2/γ phases. In the latter stage of creep, the cracks are firstly initiated along the boundaries parallel to the lamellar γ/α_2 phases, and propagated along the boundaries vertical or at about 45° angles relative to the stress axis up to the occurrence of creep fracture.

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1. Introduction

TiAl alloys have been widely investigated due to their excellent integrated mechanical properties [1–3], such as excellent strength, creep resistance and oxidation resistance at high temperatures [4–6]. Although the TiAl alloys display the poor ductility at room temperature [7–9], adding the elements Nb, W, Cr may improve the ductility of them at room and high temperatures [10,11]. Especially, the TiAl alloys possess a high specific strength, specific elastic module. Moreover, the density of the TiAl alloys is only half of Ni-based superalloys, and some properties of them are similar to those of Ni-based superalloys [12–14]. Therefore, the TiAl alloys are regarded as the better high-temperature structural materials with potential applications prospect for applying in aeronautics and astronautics field [15,16]. They are expected to be used for making the hot parts in aero-engines to replace the high-density metal materials.

When the components made of high Nb-TiAl alloy work for longer time at high temperatures, the creep damage is a common failure model, so that the better creep resistance of alloy at high temperatures is considered to be one of the important using criterions for preparing structure parts. At the same time, the better ductility is needed for avoiding the abrupt failure of the parts in service, which is thought to be the main evaluation criterion of high Nb-TiAl alloy for replacing the nickel-based superalloys as a weight-loss material.

Microstructure of the high Nb-TiAl alloy consists of lamellar phases structure, and the mechanical and creep properties of high Nb-TiAl alloy have close relationships with their microstructure and deformation mechanisms, such as dislocations slipping, twinning and so on [17–19]. And the various microstructures of high Nb-TiAl alloy may be obtained, by different heat-treatment regimes [20,21], for displaying the different creep resistance due to the difference of the deformation mechanisms [22]. Although the

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effects of casting technologies and alloying on microstructure and mechanical properties of high Nb-TiAl alloy had been reported [23–25], the influence of heat treatment on microstructure and creep properties of high Nb-TiAl alloy is still unclear.

In the paper, by means of heat treatment and creep-property measurement, combined with the microstructure observation, the influence of heat treatment on microstructure and creep properties of high Nb-TiAl alloy is investigated to provide the theory basis for promoting the development and application of high Nb-TiAl alloy.

2. Experimental procedure

The high Nb-TiAl alloy was fabricated by a vacuum induction skull melting technique, and then re-melted for three times in an electric slag furnace for making the ingot of 200 mm in diameter. The nominal composition of the alloy is Ti–44Al–8Nb–0.2W–0.2B–0.1Y alloy. The ingot of the alloy is cut into some billets with the sizes of 14 mm × 40 mm × 40 mm, and then some of the billets are heat treated, the heat treated regime of the billets is given as follows: 1320 °C × 20 min for oil cooling, and 1250 °C × 8 h for furnace cooling.

After some billets of as-cast high Nb-TiAl alloy are heat treated, the as-cast and heat treated billets were cut into the specimens with cross-section of 4.5 mm × 2.5 mm and gauge length of 20 mm. And uni-axial tensile creep tests were performed under constant load, in a GWT504-model creep testing machine, for measuring creep curves of the alloy at different conditions. Furthermore, in the ranges of the applied stresses and temperatures, the apparent creep active energy and apparent stress exponent of the alloy are calculated according to the data of creep curves. And the microstructures of as-cast, heat treated and creep ruptured alloys are observed under scanning electron microscopy (SEM) and transmission electron microscope (TEM), for investigating the effect of heat treatment on the microstructure and creep behavior of the alloy.

3. Experimental results and analysis

3.1. Influence of heat treatment on microstructure

The microstructures of the as-cast and heat treated TiAl–Nb alloys are shown in Fig. 1, it is indicated that the microstructure of as-cast alloy consists of lamellar structure which includes the lamellar black and white phases, as shown in Fig. 1(a). The lamellar structure in Fig. 1(a) includes several lamellar congeries with parallel feature, as marked by the letters A, B and C. The lamellar structure with the same orientation in the alloy is defined as one grain, the boundaries consist of irregular serrated γ phase [26], as marked by the arrow in Fig. 1(a), and located in between the lamellar structure with different orientations. After heat treatment, the microstructure of alloy still consists of lamellar structure, as shown in Fig. 1(b), the lamellar phases within one grain are arranged along the same direction, and displaying the wavy-like configuration. The smooth grain boundaries are located in between the lamellar structures with various orientations, compared to the irregular serrated boundaries in Fig. 1(a), the boundaries in Fig. 1(b) display a smooth feature. Moreover, there are some needle-like rod phase precipitated along the boundary, the rod-like precipitate is identified as the TiB phase [27], as marked by the arrow in Fig. 1(b).

XRD spectrums of TiAl–Nb alloy at different states at room temperature are measured, as shown in Fig. 2, indicating that the microstructures of the alloy at different states are mainly composed of γ-TiAl and α_2-Ti_3Al phases, and no rod-like TiB phase is detected in the alloy due to its small amount. But the diffraction peaks of the alloy at different states display the various intensity at special angles, this is attributed to the change of the diffraction intensity for the crystal planes of the phases. It is indicated from the XRD spectrums that the weaker intensity of the diffraction peaks appears in about 39° and 41° of 2θ angle, respectively, which corresponds to the diffraction peaks of the $(111)_\gamma$ and $(201)_{a2}$ planes of γ and α_2 phases in as-cast alloy. And the intensity of those peaks increases obvious after solution and solution + ageing treatment of the alloy. Although the higher intensity of the diffraction peaks appears in the $(311)_\gamma$ and $(222)_{a2}$ planes of γ

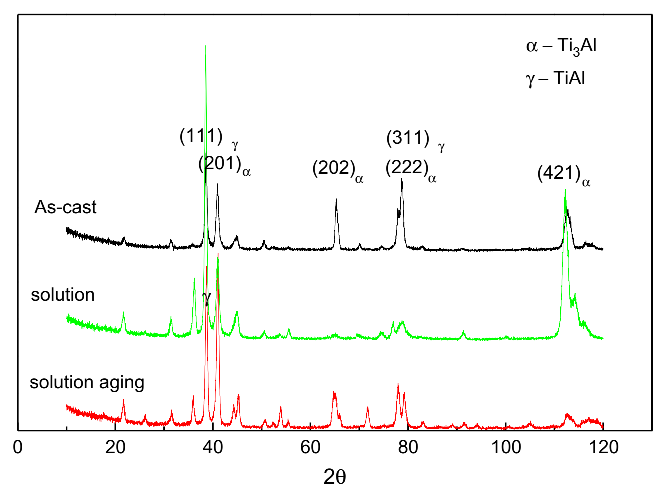

Fig. 2. XRD patterns and phases analysis of as-cast TiAl–Nb alloy after heat treated by different regimes.

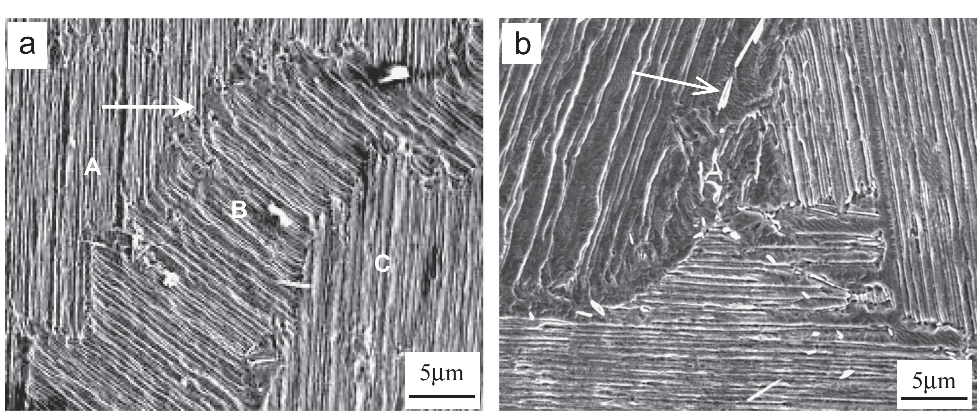

Fig. 1. Microstructures of TiAl–Nb based alloy at different states. (a) As-cast alloy, (b) heat treated alloy.

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