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Short communication

Lamellar orientation control of Ti–47Al–0.5W–0.5Si by directional solidification using β seeding technique

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ABSTRACT

In this paper, we report a β seeding technique for the lamellar orientation controlling in TiAl alloy, which is a novelty and effective method for aligning the lamellar orientation of Ti–47Al–0.5W–0.5Si with primary α phase. The shorter composition transition zone and simpler process procedure can improve the deficiency of α seeding technique. The proper temperature gradient and normal growth rate are necessary for aligning the lamellar orientation in TiAl alloy with primary α phase using β seeding technique.

1. Introduction

Gamma titanium aluminides (TiAl) with fully lamellar ($\alpha_2 + \gamma$) microstructure have gained great interest for research on high-temperature applications because of their weight saving in combination with excellent high temperature properties such as creep and oxidation resistance [1,2]. The mechanical properties of TiAl-based alloys are extremely anisotropic with respect to the lamellar orientation. A balance combination of room-temperature ductility and strength can be achieved when the lamellar orientation is aligned parallel to the tensile stress direction [3,4]. Lamellar orientation can be aligned by directional solidification with or without seeding technique [5]. For seeding technique, the Ti–43Al–3Si (at.%) has been used as α seeding firstly since the primary phase of Ti–43Al–3Si alloy is α phase and the lamellar microstructure can be restored after heating and cooling from the single α region [6]. However, a large composition transition region is formed at the initial stage of the directional solidification, and the high content of Si in the seed causes the formation of Ti_5Si_3 phase in the master alloy, which leading to reduce the mechanical properties of the alloy. Therefore, it is difficult to use Ti–43Al–3Si alloy to control the lamellar orientation of TiAl alloys of commercial interest.

To further develop seeding technique, the double Bridgman directional solidification (DS) technique is proposed by Ding et al. [7,8]. The DS experiment is performed on the alloys twice, with the sample is inverted when the DS is repeated. A well aligned lamellar microstructure can be easily achieved for specific composition alloys by double Bridgman DS technique [9]. However, the double DS technique is a relatively complicate procedure in engineering application. Then self-seeding directional technology (SST) is developed to control the lamellar orientation of TiAl alloys solidifying through the primary α phase [10]. The benefit of the SST is that the growth rate during the solidification is higher than the common seeding technology of TiAl alloys. The composition transition region between the seeding material and master ingot also can be eliminated, which can increase the efficiency of the lamellar orientation control by SST. However, The stability of the original lamellar orientation after heating and cooling from the high temperature is still under verify in self-seeding directional technology.

In this work, a new seeding directional solidification technique of TiAl alloys, which is based on the seeding material with primary β phase, is tried to put forward. The β seeding technique is using the seeding material with primary β phase to align the structure of TiAl alloy with primary α phase, since the aligned structure can be easily obtained when β phase is primary phase. To form β phase between seeding and directionally solidified TiAl alloys, pure Ti had tried to

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use as seeding material to assure the lower concentration of Al element in transitional interface, which is helpful to the form of β phase. Compared with the traditional seeding technique, the β seeding technique has advantages of reducing composition transition zone and simplifying process procedure. The present work is also to investigate the possibility of the lamellar orientation controlling in the primary α phase TiAl alloys by using a β seeding, which is a novel seeding directional solidification technique for TiAl alloys.

2. Experiments

Master ingot of Ti–47Al–0.5W–0.5Si was prepared by induction skull melting (ISM) and pure Ti as seeding ingot was fabricated by arc melting in purified argon at 1 atm. The size of seed crystal was 6 mm in diameter and 25 mm in length cut from pure Ti ingot, placed on the bottom of the crucible. The directionally solidified bar which was 6 mm in diameter and 90 mm in length cut from the master ingot. The combined bar was placed into an alumina crucible with an yttria mold isolating the alloy from crucible. The directional solidification experiments were conducted in the Bridgman type furnace under the protection of the high-purity argon to prevent the evaporation of aluminum. The specimen was heated to 1873 K during 4 h and thermal stabilization treatment for 30 min, and then was directionally solidified at a temperature gradient of $G_L = 18 \times 10^3$ K m^{-1} at the growth rate of 20 μm s^{-1}. After growth about 40 mm the sample was quenched into the liquid Ga–In–Sn alloy to preserve the solid–liquid surface. The directionally solidified bar was sectioned longitudinally, polished and etched with a solution of 10 ml HF + 10 ml HON_3 + 180 ml H_2O. Microstructure details were examined by scanning electron microscope (SEM) in backscattered electron (BSE) mode and energy dispersive spectrometer (EDS) was used for qualitative analysis of the composition.

3. Results and discussion

Fig. 1 shows the image of the sample after directional solidification and macrostructure of the interface between seeding and directionally solidified ingot. The directionally solidified bar is divided into three zones along the growth direction, which are the seeding zone, the directional solidification zone, the quenched zone. Because the heated temperature is about 1873 K, which is not high enough to melt the seeding material (pure Ti), the melting point of pure Ti is about 1950 K. Then there is an interface between seeding and directional solidified zone obviously, as shown Fig. 1(b). The interface can be welded through the diffusion between superheat melt of Ti–47Al–0.5W–0.5Si alloy and solid of pure Ti during heating and thermal stabilization treatment.

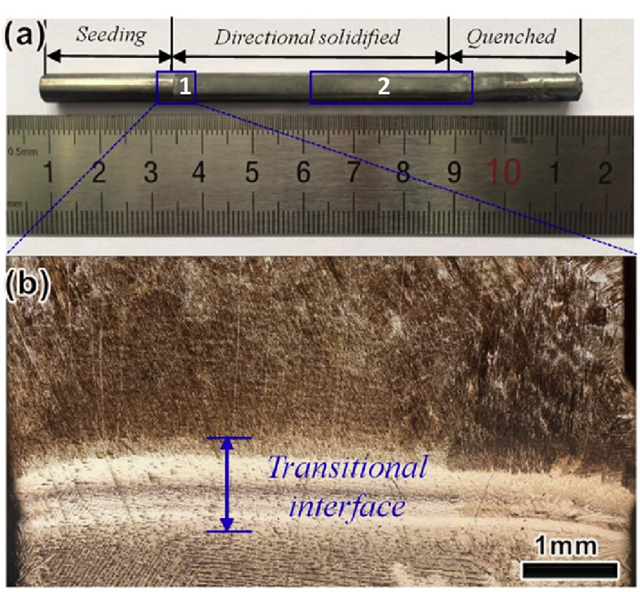

Fig. 1. Directional solidified ingot with indication of positions where composition transition zone and directional solidification zone (a), macrostructures of the transitional interface between seeding material and directionally solidified alloy (b).

Fig. 2 presents high magnification micrographs of the locations labeled with 1 in Fig. 1. The interface is about 1.5 mm in length, as shown in Fig. 2(a), and the interface can be thought of as composition transition zone between the seeding and directionally solidified bar at the initial stage of the directional solidification. The shorter composition transition region makes the seeding process relatively easier than the large composition transition region in traditional Ti–43Al–3Si seeding. Fig. 2(b) shows the change of the composition in the transition zone, and the composition change displacement is about 1.5 mm, then the composition of directionally solidified bar gets close to Ti–47Al–0.5W–0.5Si. The composition of Al element is from 0 to 47 (at. %) in the transition zone gradually, and Ti gradually transition from 100 to 52 (at. %). When the pull system start, the initial interface of directional solidification lands in transition zone. According to the phase diagram, β phase is the primary phase for binary TiAl alloys containing 45–49 at. % Al, as a result, the β phase is nucleated firstly during the initial solidification and growth with dendrite along the temperature gradient direction. The more close to the position of the seed crystal interface, the higher content of the beta phase, as illustrated in Fig. 2(c). Upon the Blackburn solid-state transformation relationship, the last lamellar orientation is inclined at an angle of 0° or 45° to the growth direction because the preferential growth direction of the bcc β phase is the ⟨001⟩direction [11]. Therefore, the initial stage of the lamellar is inclined with an angle about 45° to the growth direction, as illustrated in Fig. 2(d), although there is a little deviation for the probability that the ⟨001⟩direction of β phase grows with an low-angle to the growth direction.

Fig. 3 shows the microstructures of the directional solidified zone marked in Fig. 1 with the bigger blue rectangle labeled with 2, the microstructures consisted of α_2 (Ti_3Al)/γ (TiAl) lamellar structures and ξ-Ti_5Si_3 phase. The lamellar orientation in this region has the accordant direction with the initial composition transition zone, as shown in Fig. 3(c) and (d). This clearly indicates the lamellar orientation of the directional solidification ingot well inherits the lamellar orientation of composition transition zone. Fig. 3(b) shows morphologies of the solid–liquid interfaces of DS specimens, the primary solidification phase is α phase with hexagonal crystal structure by examining the angle between the secondary dendritic arms and primary dendritic spines [12]. Therefore, it is found that the primary β phase at the beginning of directional solidification has transformed to α phase while solidification process is in steady-state growth region. The reason for that is the primary phase of Ti–47Al–0.5W–0.5Si is α phase, as demonstrated in Ref. [13]. The other reason is Al gradually concentrates in the solid–liquid interfaces. If the alloy with the primary β phase is directionally solidified, the lamellar orientation of columnar grains with parallel and inclined at an angle of 45° to the growth direction are supposed to form with the ratio of 1:2 potentially, the experimental studies show that the β phase with an angle of 45° to the growth direction would grow stably under the higher temperature gradient [14].

This work proposed the β seeding technique for TiAl alloys can overcome the unstability of α seeding technique and change the