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Control of a fine-grained microstructure for cast high-Cr TiAl alloys

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Abstract

In order to refine the cast microstructure and improve the mechanical property of TiAl alloy, the element of Cr was chosen for alloying. Experimental results show that the refinement was achieved and the cast microstructure was controlled to be fine by inducing β solidification due to the addition of a high content of Cr. Furthermore, the cast microstructure was optimized to be a fine fully lamellar (FL) one by one-step heat treatment. And with the microstructure refinement and optimization, the tensile strengths of the present cast alloys both at room and high temperatures were improved to exceed the strength level for traditional cast TiAl alloys, and reached that for wrought TiAl alloys.

Keywords: TiAl alloy; Cast; Microstructure refinement; Tensile strength

1. Introduction

It is well established that the mechanical properties of TiAl alloys are very sensitive to their microstructures, near γ or duplex or fully lamellar (FL) [1,2]. Those alloys with a fine-grained FL structure (FFLS) were found to have good balanced mechanical properties, namely, high tensile strength, decent tensile ductility and good creep resistance. To obtain the FFLS, two kinds of methods were utilized. The first one is thermomechanical treatment. That is, the alloy was first forged or extruded at a temperature T lower than the α transus temperature T_α to have a fine near γ structure and then heat treated at $T \geq T_\alpha$ to have a FFLS. Alternatively, the alloy was directly extruded at $T \geq T_\alpha$, and a FFLS was also obtained. For example, the so-called thermomechanically processed lamellar structure with a grain size of ~90 μm was obtained after the alloy with a composition of Ti–46.5Al–2Cr–3Nb–0.2W (at.%) was extruded at or above the T_α of this alloy (~1320 °C) [3,4]. To simplify the processing route mentioned above, a second method was investigated in recent years, which involved conversion of a coarse-grained FL structure in alloys with compositions of Ti–48Al–2Cr and Ti–46Al–2Cr–2Nb (at.%) to a FFLS merely by heat treatment [5–7]. There is evidence that both the tensile strength and ductility could be improved with the grain refinement [5]. The microstructure needed to be refined in previous studies because it consisted of coarse grains that originated from α solidification. In this study, it is shown that the cast microstructure can be controlled to be fine by inducing β solidification, and this may be achieved by the addition of a high content of Cr.

2. Experimental

The nominal compositions of the TiAl alloys used in this study are listed in Table 1. Compared with alloy A, alloys B and C contained a higher amount of Cr and additional elements of W and B. The addition of W is to improve the creep resistance, and its amount of 0.5% is so minor that it can not influence the solidification path of the alloys. The low amount of B (0.15%) was added to slow down grain growth during heat treatment. It is not for grain refinement during solidification because a large amount of B (generally >0.5%) is needed for refining the cast microstructure [8,9].

The alloys were prepared by arc-melting with a non-consumable electrode in an argon atmosphere and drop

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Table 1
The nominal compositions of the present TiAl alloys

Alloy no.	Nominal composition (at.%)
A	Ti–46Al–2Cr–2Nb
B	Ti–46Al–6Cr–2Nb–0.5W–0.15B
C	Ti–44Al–6Cr–2Nb–0.5W–0.15B

casting in a steel mould. Specimens for heat treatment with a dimension of 10 mm × 10 mm × 10 mm were cut from the ingot using electrical discharge machine (EDM). The microstructures after treatment were studied under optical microscope and transmission electron microscopy (TEM).

For tensile test the ingot of alloy C was further hot isostatically pressed (HIP) at 1200 °C and 175 MPa for 3 h to eliminate the casting flaws. The tensile property was tested at room temperature and at a strain rate of $5 \times 10^{-4}\,s^{-1}$ using cylindrical samples with a gauge dimension f Ø 3 mm× 10 mm, and at 800 and 900 °C flat samples with a gauge dimension of 8 mm × 4 mm × 1.4 mm were tested.

3. Results

Fig. 1a shows the cast microstructure of alloy A. It can be seen that the microstructure is composed of coarse columnar prior α grains with a width of ∼300 μm and a length of ∼1 mm. Within every grain, the alternate α_2 and γ plates constitute a lamellar structure. And the orientation of the lamellae is roughly perpendicular to the extension of the columnar grain.

By alloying with a high amount of Cr, the microstructure appeared different. It changed from a columnar structure to a typical fine-grained lamellar structure with a grain size of ∼30 μm (Fig. 1b), and the microstructures in alloys B and C are similar. In such alloys, additional phases were observed both within the lamellar grains and at their boundaries. TEM examination (Fig. 2) revealed that these phases were α, γ and β phases. Generally β (phase 1 in Fig. 2a) and γ phases (phase 2 in Fig. 2a) distributed irregularly in the lamellar structures. But in some areas the γ phase (phase 1 in Fig. 3a) was included within a thin layer of α phase (phase 2 in Fig. 3a).

Fig. 4 shows the microstructure after the sample of alloy C was heat treated at 1280 °C for 24 h and then cooled in air. It is clear that after treatment the cast microstructure transformed to a FFLS with a grain size of ∼50 μm. Fig. 5 illustrates the changes with the α, γ and β phases that were originally included in lamellar grains or at their boundaries (Figs. 2 and 3) after heat treatment. As can be seen, new plates of γ and α precipitated, and their orientations were different from those of the matrix lamellae.

Fig. 6 presents the comparison of the ultimate strength σ_b for the present cast high-Cr TiAl alloy with those for the previous cast (Fig. 6a) and wrought TiAl alloys (Fig. 6b). Although the tensile elongation was low (<1%) at room temperature, the σ_b was improved from $\lesssim$ 550 MPa for previous cast TiAl alloys to a higher level of 710 MPa for the present cast alloy. And the improvement in σ_b persisted to high temperatures. The σ_b for the present cast alloy is comparable with those for previous wrought alloys.

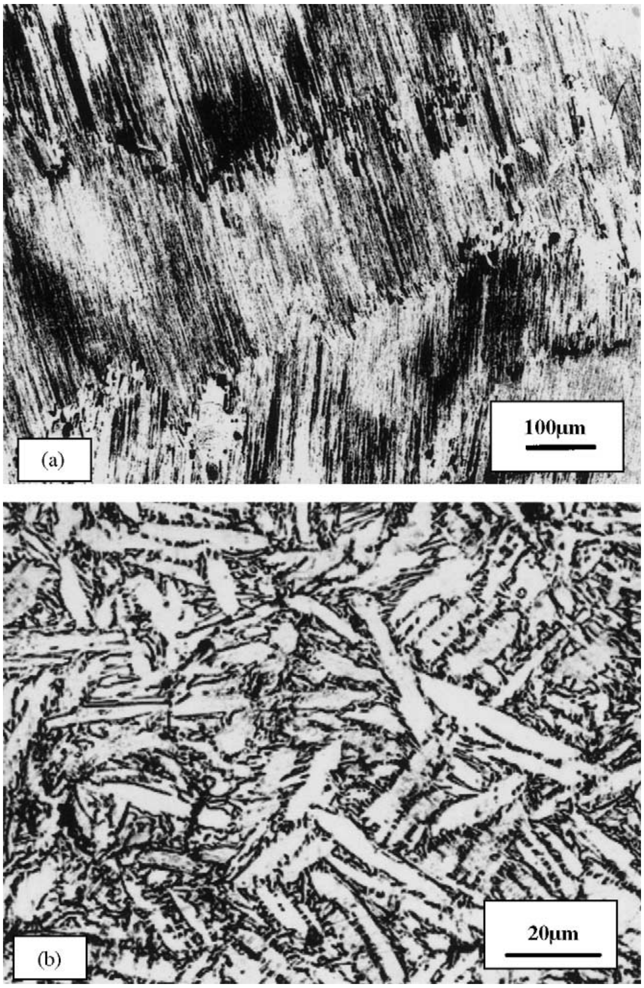

Fig. 1. The cast microstructures of the present alloys A (a) and C (b).

4. Discussion

It is well known that the solidification route of TiAl alloys is influenced by the content of Al, and it will shift from α to β solidification when the content of Al decreases to a certain level. But in addition to the factor of Al, the addition of alloying element is also an important factor having a great influence on the solidification route and thus the cast microstructure.

From the present experimental results, it is apparent that the solidification for alloy A followed the α route, which resulted in a coarse columnar structure. But with the addition of Cr the solidification was modified and might follow the β route. As a result, a fine cast microstructure developed (alloy