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Application research of centrifugal investment cast TiAl component used for advanced aircraft engine ①

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[Abstract] A more complex structural component with small size and very thin walls and blades used for advanced aircraft engine was fabricated well by induction skull melting and centrifugal investment casting with a proper ceramic mold. The tensile elongation and ultimate strength of the hot isostatically pressed (HIPped) Ti-46.5Al-2.5V-1Cr (mole fraction, %) casting alloys are up to 2.5% and 645 MPa at room temperature, and 31% and 593 MPa at 800 ℃. The fracture roughness at room temperature is up to 28 MPa·$m^{1/2}$. The endurance tensile strength at 800 ℃ for 150 h, is higher than 200 MPa. The high cycle rotary bending fatigue strengths for 1×10^7 cycles at room temperature and 800 ℃ are 412 MPa and 270 MPa, respectively.

[Key words] TiAl alloy; mechanical properties; microstructure; investment cast; components
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1 INTRODUCTION

TiAl alloys exhibit numerous attractive properties for high temperature structural applications in aerospace and automotive industries. These include high elastic modulus, low density, good oxidation and burn resistance, good creep properties and specific strength at elevated temperatures[1~3]. Research and development in TiAl alloys has progressed significantly within the last decade. TiAl alloys may be produced via either cast or wrought processing. However, casting processes are of greater interest for fabricating components such as the turbine blades of aircraft engine, automobile turbocharger rotators and exhaust valves etc[4]. In cast condition, the typical microstructure of TiAl alloys commonly is fully-lamellar (FL) microstructure. FL microstructure with coarse grain size exhibits adequate fracture toughness but usually poor tensile ductility at room temperature (RT). The specific heat treatment has been used to obtain the fine fully lamellar (FFL) microstructure by reducing the lamellar colony sizes to improve RT properties of TiAl alloys[5].

Product development efforts at Central Iron & Steel Research Institute (CISRI) for gamma TiAl castings have been focusing on improvement of mechanical properties and manufacturing techniques. A castable TiAl alloy, Ti-46.5Al-2.5V-1.0Cr (mole fraction, %), developed in CISRI, has good mechanical properties at both room and elevated temperatures, as a result of proper control of chemical composition and microstructure[6]. Recent testing results indicated that the cast alloy with nearly lamellar (NL) microstructure obtained just after HIPping exhibits a good combination of RT tensile ductility and high temperature tensile strength.

Several TiAl castings, such as the turbocharger rotators and automotive valves, have been manufactured successfully using investment casting technology. A more complex structural component with small size and very thin walls and blades used for aircraft engine has been fabricated well by centrifugal investment casting with a ceramic mold. The component was successfully subjected a simulated aircraft engine running test on the ground. This paper describes the details associated with the microstructures, fracture features and the manufacturing technology of the TiAl components.

2 EXPERIMENTAL

The alloy Ti-46.5Al-2.5V-1Cr was melted with the induction skull melting (ISM) furnace to obtain ingots of 40mm in diameter and about 150 mm in length. The ingots were hot isostatically pressed (HIPped) in argon atmosphere under 150 MPa at 1 290 ℃ for 2.5 h. Current oxygen and nitrogen contents in the TiAl ingots and castings are around 5×10^{-4} and 5×10^{-5}, respectively. The tensile specimens had a gauge size of 25 mm in length and 5 mm in diameter and the endurance tensile specimens had a gauge size of 25 mm in length and 5 mm in diameter. Three point bending specimens with a size of 6.4 mm × 12.8 mm × 60 mm were used for measuring the fracture toughness of the alloy. The high cycle rotary bending fatigue specimens with 4 mm in diameter were used to measure the high cycle rotary bending

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fatigue strengths at RT and 800 ℃. Microstructures and fractographic features of the specimens were examined by an optical microscopy and SEM.

3 RESULTS AND DISCUSSION

The microstructure of as-cast Ti-46.5Al-2.5V-1.0Cr alloy is FL microstructure, and after HIPping, it becomes NL microstructure which consists of coarse lamellar and fine colony boundary γ grains, as shown in Fig. 1.

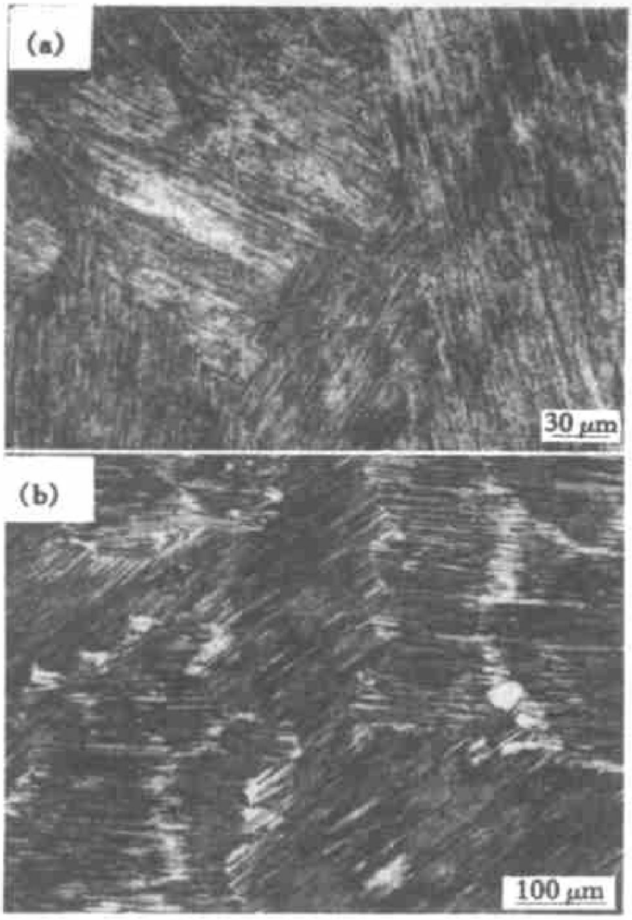

Fig. 1 Microstructures of Ti-46.5Al-2.5V-1.0Cr alloys
(a) —As-cast; (b) —After HIPping

The tensile properties of Ti-46.5Al-2.5V-1.0Cr cast alloy with NL microstructure are summarized in Table 1. The elongation (δ) and ultimate tensile strength of the cast alloy just after HIPping are up to 2.5 % and 645 MPa at room temperature, and 31% and 593 MPa at 800 ℃ respectively. The ultimate

Table 1 Tensile properties of Ti-46.5Al-2.5V-1Cr alloy

Temperature / ℃	σ_b/ MPa	$\sigma_{0.2}$/ MPa	δ/ %	K_{IC} / (MPa·m$^{1/2}$)
RT	645	530	2.50	28
700	645	465	3.83	
800	593	464	31.0	

RT —Room temperature

tensile strength and yield strength ($\sigma_{0.2}$) do not significantly decrease until 800 ℃.

Fractographs of the tensile fracture surfaces of Ti-46.5Al-2.5V-1Cr cast alloy tested at RT and 800 ℃ are shown in Fig. 2. It was noted that during the tensile fracture at RT, a mixture fracture mode occurred, consisting of very less cleavage facets of the colony boundary γ grains and a large number of transgranular fracture of the lamellar microstructure (as shown in Fig. 2(a)). This fracture mode is quite similar to that observed on the tensile fracture surface of the duplex(DP) microstructure. In addition, more ductile tear ridges occurred accompanied with the transgranular lamellar cracking, as shown in Fig. 2 (b). Ductile tabular like and ductile dimple fractures were frequently observed on the tensile fracture surface fractured at 800 ℃ (as shown in Fig. 2(c) and (d)). In general, comparing to DP microstructure, the NL microstructure with relatively large lamellar colonies appears to be more benefit to the fracture toughness, high temperature strength and endurance tensile strength. Therefore, the good combination of the mechanical properties of the present alloy may be related to the NL microstructure, consisting of coarse lamellar with fine and less colony boundary γ grains.

The fracture toughness of Ti-46.5Al-2.5V-1Cr cast alloy with NL microstructure is up to 28 MPa·m$^{1/2}$ at RT. This fracture toughness value is much higher than that of DP microstructure[2] and close to that of FL microstructure[2]. The endurance tensile strength of Ti-46.5Al-2.5V-1Cr cast alloy with NL microstructure at 800 ℃ in air, is over than 200 MPa (unfractured).

The high cycle rotary bending fatigue strengths of Ti-46.5Al-2.5V-1.0Cr cast alloys are 412 MPa at RT and 270 MPa at 800 ℃at 10^7 cycles. The fatigue crack morphology changed very little at RT and 800 ℃, but a blue color film covered on the fracture surfaces of the specimens tested at 800 ℃. Fractographs of the high cycle rotary bending fatigue fracture surfaces of Ti-46.5Al-2.5V-1Cr cast alloy tested at RT are shown in Fig. 3. On a macro-scale, rough fracture surfaces were observed for the fatigue tests both at RT and at 800 ℃, which is consistent with the enhanced crack growth resistance of the NL microstructure of the alloy. However, very small ratio of the fatigue region observed on fracture surfaces implied that the fraction of the total fatigue life of the alloy resulted from crack propagation is still small.

These results show that Ti-46.5Al-2.5V-1.0Cr cast alloy with NL microstructure have a good combination of RT tensile ductility, fracture toughness, high cycle rotary bending fatigue strength, high temperature tensile strength and endurance tensile strength. It is also noted that the values of high temperature tensile strengths, endurance tensile strength

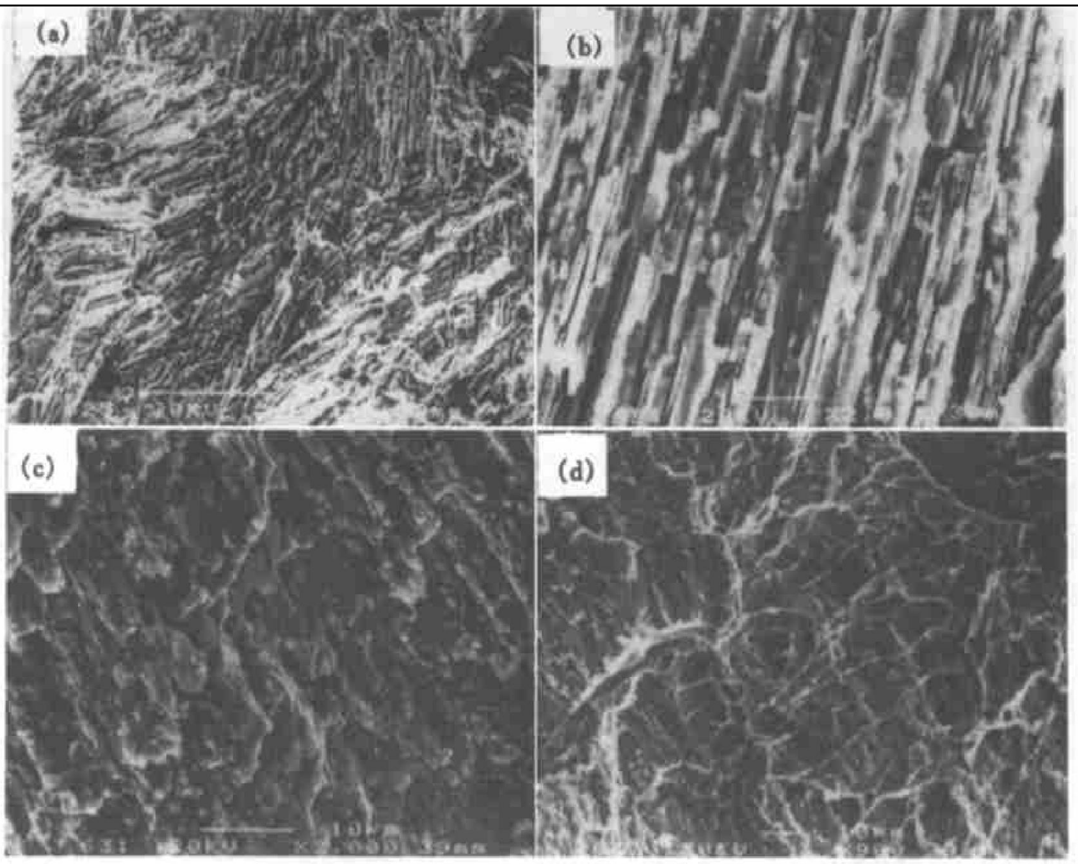

Fig. 2 Fractographs of tensile specimen of Ti-46.5Al-2.5V-1Cr alloy
(a), (b) —At RT; (c), (d) —At 800 ℃

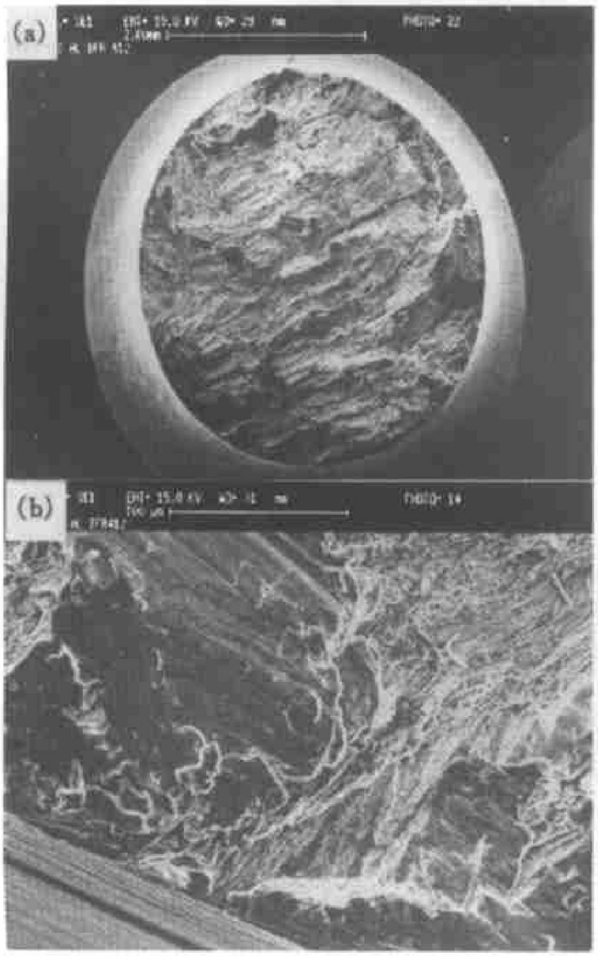

Fig. 3 Fractographs of Ti-46.5Al-2.5V-1Cr cast alloy

and fracture toughness of NL microstructure of this cast alloy are similar to those of the FL microstructure. In addition, the room temperature ductility of NL microstructure of the cast alloy is higher than that of the FL microstructure.

4 CENTRIFUGAL INVESTMENT CASTING OF COMPONENTS

The TiAl alloys were prepared by centrifugal investment casting. The master alloy was prepared with an induction skull melting (ISM) furnace. The investment casting ceramic molds were coated with one kind of specific oxide refractories to decrease the interaction between alloy melts and the mold surfaces, and to further improve the transparent to gas of the mold. Before centrifugal casting, the ceramic mold was preheated at temperatures from 500 r/mm to 1 000 ℃. The rotation speeds of the centrifugal molds were preset from 500 r/min to 1 100 r/min. After casting, the components were HIPped at 1290 ℃, 150 MPa for 2.5 h to close cast porosities.

The precision casting tests of components showed that the preheated temperature of ceramic molds and the rotation speed must be properly preset in order to obtain the integrated components because the structure of the component in the present is more complex, which is with small size and very thin walls and blades, as shown in Fig. 4. When the preheated

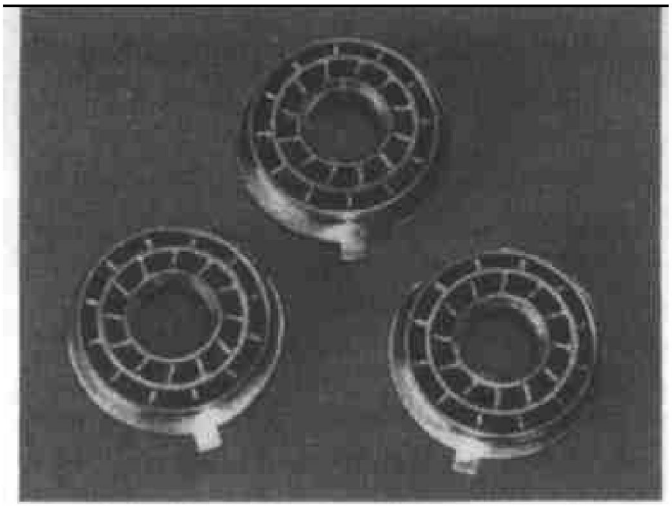

Fig. 4 Examples of cast TiAl components

temperature is too lower, the melted alloy will solidify earlier and can not fill up the mold. When the preheated temperature is too higher, the melted alloy will interact strongly with the mold faces. Neither the faster rotation speed nor the slower rotation speed is beneficial for obtaining the integrated components. The hot isostatically pressing (HIPping) of the castings can effectively close cast porosities.

5 CONCLUSIONS

1) The cast and HIPped Ti-46.5Al-2.5V-1.0Cr alloy has a NL microstructure, consisting of relatively large lamellar colonies structure with less and small sizes of γ grains distributed on the lamellar colony boundaries.

2) The NL microstructure of the cast alloy has a good combination of RT tensile ductility, fracture toughness, high cycle rotary bending fatigue strength, high temperature tensile strength and endurance tensile strength.

3) In order to cast the complex components with a good quality, the mold material and preparation technique, the preheated temperature of ceramic molds and the centrifugal speed applied must be properly preset.

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