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Effect of nitrogen addition on microstructures and mechanical propeties of TiAl based alloys①

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Abstract: Through adding 0% ~ 3% (mole fraction) nitrogen in cast TiAl based alloys, it was found that colony size in cast condition decreased from 600 μm to 58 μm with nitrogen content increasing from zero to 1% and then decreased slowly with further increase of nitrogen content, tensile strength increased with nitrogen content; but comparing to the value of the mother alloy, tensile elongation at room temperature decreased in the alloy with 0.5% nitrogen, then recovered in the alloy with 1% nitrogen.

Key words: TiAl based alloys; microstructure; nitrogen addition; grain refinement **Document code**: A

1 INTRODUCTION

The TiAl based alloy has been known to be one of the most promising candidates for high-temperature structural applications[1]. The properties of the alloys strongly depended on their microstructures[2]. It has been thought that the fine fully lamellar microstructure had the best combination of mechanical properties[3]. In order to refine the coarse fully lamellar microstructure in cast condition, thermomechanical treatments (TMTs), including hot extruding, hot rolling and isothermal forging, have been used; but because of their high cost and complicated technological processes, it was difficult to use TMTs widely[4,5]. In order to improve the combination of mechanical properties, recent researches with additions of substitutional elements such as Cr, Nb and Mo[6,7] and interstitial elements such as B, W and C[8,9,10] have been carried out successfully. The addition of interstitial elements was expected to improve room-temperature ductility by grain refinement and to enhance high-temperature strength and creep resistance. In the present study, the effect of nitrogen addition on the microstructures and mechanical properties of the TiAl based alloys were studied.

2 EXPERIMENTAL

The alloys used in this study were made by consumable electrode arc melting under argon atmosphere and remelted for two times. The starting materials were 99.99% Ti, 99.9% Al and 99.9% TiN powders (mass fraction, %). The ingots for room-temperature tensile tests were homogenized at 1 340 ℃ for 4 h followed by furnace cooling or hot isostatic pressing (HIPing) treatment at 1 250 ℃ for 4 h under argon pressure of 150 MPa. Table 1 listed the alloys compositions and heat-treatment processes of the alloys. Nephot-Ⅱ optical microscope was used to observe the microstructures. The etchant used was 1.5% HF and 2.5% (volume fraction) HNO_3 in distilled water. The phases in the alloys were determined by X-ray diffraction analysis. Room-temperature tensile tests were carried out using an INSTRON testing machine at a strain rate of 1×10^{-4} s^{-1}. Tensile specimens were manufactured as round-shaped with dimensions of 5 mm in diameter and 25 mm in gauge length. The value of room-temperature tensile

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strength or elongation of each alloy was the average value of four specimens.

Table 1 Compositions, heat treatments and tensile properties of the TiAl based alloys

Alloys	Ti-48Al		Ti-48Al-0.5N		Ti-Al-1.0N		Ti-48Al-3.0N	
	T1	T2	T1	T2	T1	T2	T1	T2
σ_b/MPa	269	288	305	318	461	482	508	521
δ/%	0.48	0.52	0.32	0.34	0.77	0.94	0.50	0.58

* T1—Homogenization treatment; T2—HIPing treatment

3 RESULTS AND DISCUSSION

3.1 Effect of nitrogen addition on microstructure

Fig. 1 shows the microstructure of the as-cast TiAl alloys with different nitrogen contents. As can be seen in the figure, colony size decreased with nitrogen content increasing from zero to 3% (mole fraction, the same below). Colony size of the mother alloy is 600. When nitrogen content increased from 0.5% to 1%, colony size decreased from about 380 μm to 58 μm; but from 1% to 3%, the increase was very slow. Colony size of the 3% (mole fraction) N alloy is 46 μm.

From Fig. 1, it is also found that nitrogen addition changes the morphology of the microstructure of the alloys. In the mother alloy, fully lamellar microstructure was formed. However, in nitrogen containing alloys, there are two types of precipitates dispersed in the lamellar microstructure. One is fine point precipitate, the other is coarse round precipitate. In the 0.5% (mole fraction, the same below) N alloy, there are a few fine point precipitates. In the 1.0% N alloy, major part of the precipitates are point-like and in the 3.0% N alloy, round-like. Fig. 2 exhibits profiles of X-ray diffraction of the 1.0% N alloy. As seen in the figure, the alloy contains γ-TiAl, α_2-Ti_3Al and Ti_2AlN.

It could be found from the Ti-Al-N ternary phase diagram that the solubility limit of nitrogen is about 0.3% when the temperature is over 1 000 ℃, and that TiN phase exists at the highest temperature in the system[11]. Therefore, it might be suggested that the TiN dispersoids were formed as a primary solid phase when the

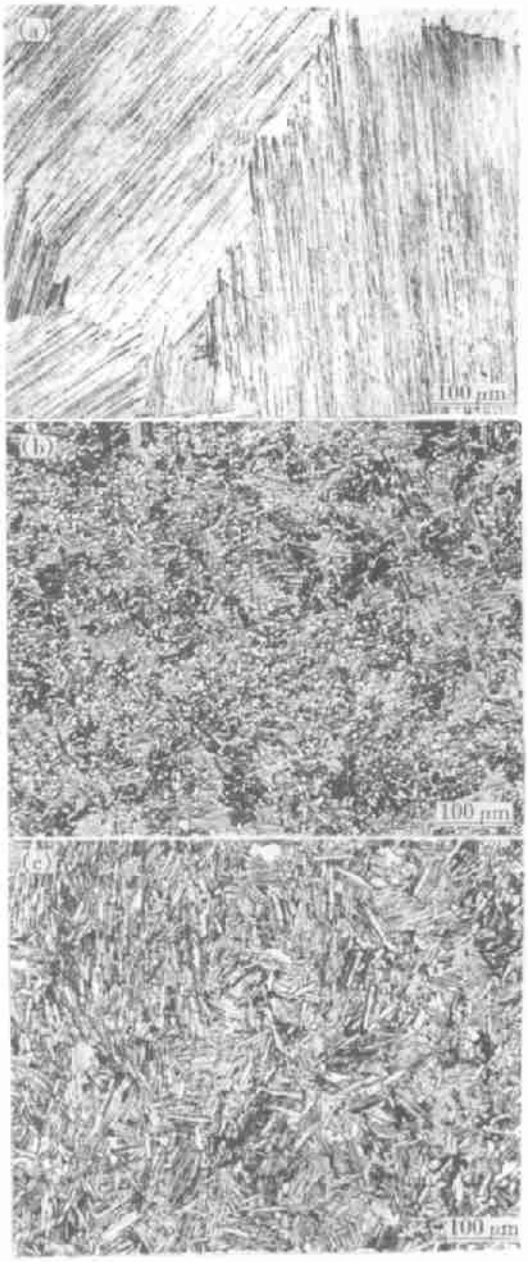

Fig. 1 Optical microstructures of cast Ti-48Al alloys
(a)—With to N; (b)—Ti-48Al with 1% N; (c)—Ti-48Al with 3% N

alloys with nitrogen addition began to solidify. In these alloys, TiN dispersoids were able to act as the nucleation cites during solidification, this

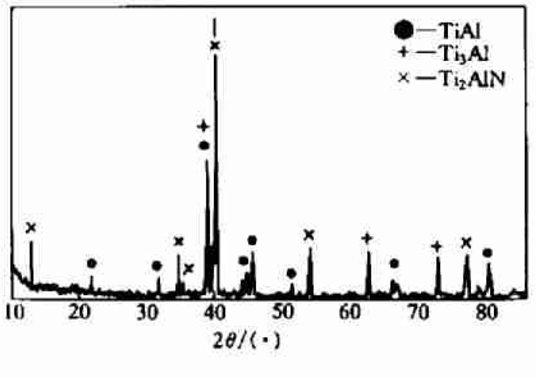

Fig.2 Profiles of X-ray diffractions of Ti-48Al with 1%N

may be the reason that nitrogen addition refines grain size of the alloys. In 0.5%N alloy, nitrogen exists as solid solution, so colony size refines to a small extent. In the 1.0%N alloy, there are enough TiN dispersoids to act as the nucleation sites, so colony size refines remarkably. When nitrogen content increased to 3.0%, the number of TiN dispersoids increased to a small extent, but the volume of each TiN dispersoid increased obviously, therefore it is difficult to refine grain size further. In addition, according to the ternary phase diagram, the TiN phase is transformed to Ti_2AlN phase during solidification, therefore, the Ti_2AlN precipitates observed in the alloys are supposed to be formed by such a way.

After homogenization at 1340 ℃ for 4 h followed by furnace cooling, Ti_2AlN dispersoids were basically dissolved (Fig. 3(a)). There are black block in the alloy and the lamellar microstructure precipitates on the grain boundaries. Kim[3] has suggested that fully lamellar microstructure could be formed in the TiAl alloy when it was furnace cooled from α phase field. So it was supposed that nitrogen has acted as the α phase stabilization element by slowing down the kinetics of the formation of lamellar microstructure. Fig. 3(b) shows the optical microstructure of the alloy after HIPing, as seen in the figure, lamellar microstructure formed completely. From Fig. 3, it can also be found that colony size does not change obviously after the alloys were annealed or treated. It is thought that nitride precipitates could play a role in suppressing the grain boundary migration.

3.2 Effect of nitrogen addition on room-temperature tensile properties

Room-temperature tensile strength and elongation of the TiAl alloys with different nitrogen content after homogenization or HIPing are listed in Table 1. The room-temperature tensile strength of the alloys increased with nitrogen content increasing from zero to 3.0%, room-temperature tensile elongation decreased remarkably in the 0.5%N alloy, then recovered

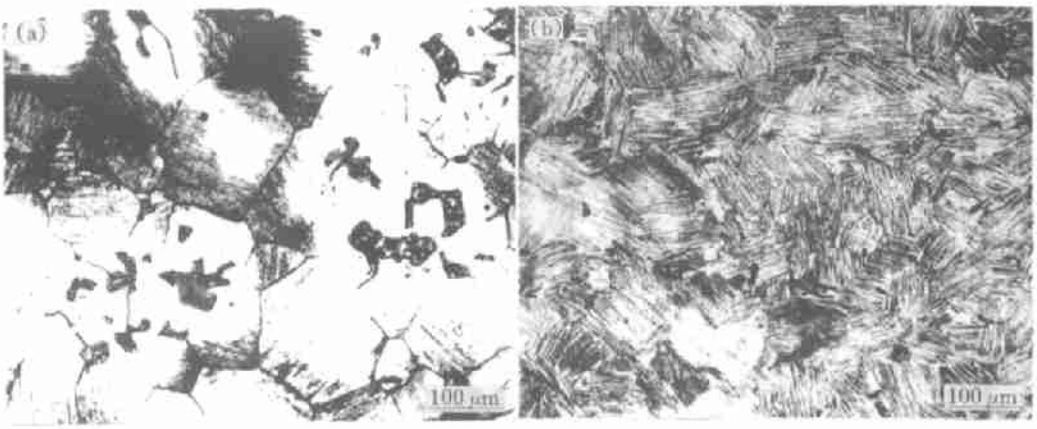

Fig.3 Optical microstructures of Ti-48Al adding with 1%N
(a)—After homogenization; (b)—After HIP treatment

in the alloy with 1.0% nitrogen, compared with the mother alloy, however, tensile elongation decreased obviously when nitrogen content increased from 1.0% to 3.0%. From Table 1, it can also be seen that tensile elongation and strength of the HIP alloys are better than that of the alloys only treated by homogenization in all alloy compositions.

It seems that there are three mechanisms that contribute to improve room-temperature tensile strength. Firstly, nitrogen addition refines grain size. Mercer[12] has suggested the tensile strength is related to grain size via the Hall-Petch equation. The finer the lamellar grain, the higher the tensile strength becomes. Secondly, the Ti_2AlN precipitates are dispersed in the alloys producing an appreciable strengthening effect. Thirdly, nitrogen that is solid dissolved in the alloys can also improve tensile strength. Therefore, the more nitrogen is added, the higher the tensile strength will be.

It seems that there are two conflicting effects that affect room-temperature tensile elongation. When only the effect of grain refinement on room-temperature tensile elongation is considered, the finer the grains, the higher the tensile elongation becomes. It was suggested that the tensile elongation of a TiAl alloy relates to grain size by an inverse square root dependence[12]. However, the alloys containing nitrogen grow harder due to a precipitation hardening mechanism. The 0.5%N alloy shows poor tensile elongation because of the relatively less effect of the grain refinement effect compared to the precipitation hardening effect. In the 1.0%N alloy, tensile elongation could be recovered because the grain refinement effect is more prominent than the precipitation hardening effect. When nitrogen content increases from 1.0% to 3.0%, grain size decreases lightly, but the volume of Ti_2AlN precipitates increases markedly. Therefore, room-temperature tensile elongation decreases obviously.

The difference of the tensile properties between the homogenization alloys and the HIP alloys may result from their difference of the microstructure morphology. It is suggested that the formation of the lamellar microstructure in a TiAl alloy could improve room-temperature tensile strength and elongation, so the tensile strength and elongation of the HIP alloys are better than that of the homogenization alloys for all the alloy compositions.

4 CONCLUSIONS

(1) Colony size of the lamellar microstructure in cast condition decreases markedly with nitrogen content increasing from zero to 1.0%, and colony size decreases slowly when nitrogen content increases further .

(2) Tensile strength increases with increasing nitrogen content.

(3) Tensile elongation decrease remarkably in the alloy with 0.5% nitrogen, but recovers in the alloy with 1.0% nitrogen compared with the value of the mother alloy.

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