SYNTHESIS OF Ti-47Al-2Cr-2Nb ALLOY THROUGH ELEMENTAL POWDER METALLURGY①

Liu Yong, Huang Baiyun and He Yuehui
Powder Metallurgy Research Institute, Central South University of Technology, Changsha 410083, P. R. China

ABSTRACT Under the protection of Ar, TiAl-base alloy of high density has been prepared through hot pressing elemental Ti, Al, Cr and Nb powders at elevated temperatures. The microstructure, phase constitution and composition were analyzed through optical microscopy, SEM, EDAX, and XRD techniques. Results show that TiAl-base alloy with near fully lamellar microstructure and a mean colony size of 60 μm, can be obtained after hot pressing at 1 300 ℃ for 1 h; however, incomplete diffusion of Nb element exists in the microstructure. Through subsequent isostatic hot pressing (HIP), the material density can increase and the homogeneity of alloy elements can be improved simultaneously. Furthermore, it has been found that the initial microstructure of the alloy has great influence on its microstructure after HIPping in ($\alpha+\gamma$) field.

Key words elemental powder metallurgy TiAl-base alloys synthesis

1 INTRODUCTION

TiAl-base alloys have attracted more and more attention by their high specific strength, specific rigidity and excellent properties at elevated temperature. However, their brittleness and insufficient oxidation resistance above 900 ℃ have restricted their applications[1]. Addition of alloy elements has been proved to be an effective way to improve properties. It has been shown that addition of Cr can improve ductility of TiAl-base alloys[2, 3], while addition of refractory alloy element Nb can improve their strength and oxidation resistance at elevated temperatures[4, 5]. Therefore, Ti-47Al-2Cr-2Nb alloy has been a representative of the second generation TiAl-base alloys, and has received extensive investigations[6-8]. Powder metallurgy is a widely useful method in the preparation of TiAl-base alloys, because it has advantages in producing materials with fine, homogeneous microstructures and avoiding compositional segregation and other cast defects. However, owing to difficulties and high cost in preparation of TiAl-base prealloyed powders, elemental powder metallurgy has been an cost effective alternative. Currently, preparation of TiAl-base alloys through elemental powder metallurgy mainly concentrates on mechanical alloying, hot extrusion and/or HIPping[9-13]. In this work, preparation of Ti-47Al-2Cr-2Nb alloy through hot pressing elemental powders at elevated temperatures and the related microstructures were investigated, and the feasibility of this method was also discussed.

2 EXPERIMENTAL

Ti, Al, Cr elemental powders (particle size < 45 μm) and Nb powders (particle size < 100 μm) were mixed according to nominal composition of Ti-47Al-2Cr-2Nb (mole fraction, %) for 4 h at a rotary rate of 120 r/min. The mixed powders were then cold pressed into d 18 mm × 30 mm compacts at a pressure of 600 MPa. The density of those compacts was approx 80% of the theoretical density. The compacts were put into graphite die for hot pressing in Ar atmo-

① Project 715-005-0040 supported by the National Advanced Materials Committee of China
Received Mar. 25, 1998; accpeted Jun. 19, 1998

sphere (flow rate: 2 L/min); the heating rate was 100 K/min, and the hot pressing temperatures were 1 200 ℃ and 1 300 ℃ respectively. All samples stayed at 800 ℃ for 0.5 h at first to avoid liquid Al to flow out, then pressed at a pressure of 40 MPa. Melting point of Al is 667 ℃, a stay at 800 ℃ causes reaction between liquid Al and solid Ti powders. Because the reaction is very fast, liquid Al is consumed before pressing. The hot pressed samples were then HIPped at 1 250 ℃ and a pressure of 160 MPa for 4 h. The final densities of those samples were measured through Alchemiic method. Optical microscopy, SEM, EDAX, XRD techniques were adopted to analyze microstructures and phase compositions of the prepared materials.

3 RESULTS AND DISCUSSION

The porosity distributions of polished samples after hot pressing at various temperatures are shown in Fig. 1. It indicates that high densities have been obtained through hot pressing at elevated temperatures. The remained pores are all closed with diameter of approx. 10 μm. Through Alchemiic method, the densities of Ti-47Al-2Cr-2Nb samples were: 3.98 g/cm^3 after hot pressing at 1 200 ℃, 4.00 g/cm^3 at 1 300 ℃; and the densities of all samples were 4.01 g/cm^3 after HIPping.

The microstructures of TiAl-base alloy after hot pressing at various temperatures are shown in Fig. 2. After hot pressing at 1 200 ℃, the microstructure of TiAl-base alloy mainly consists of island-like α_2 phase, α_2/γ lamellar colonies and fine equiaxial grains, a few incompletely reacted microstructures exist, as shown in Fig. 2(a). After hot pressing at 1 300 ℃, near fully lamellar microstructure has been obtained, and small amount of γ grains and incompletely reacted microstructure remained, as shown in Fig. 2(b). The mean size of lamellar colonies is 60 μm. Inhomogeneous etching in Fig. 2(b) is due to the compositional inhomogeneity in the microstructure. Fig. 3(a) shows the microstructures of TiAl-base alloy under SEM after hot pressing at 1200 ℃. It indicates that through SEM observation, the fine, equaxed grains observed under optical microscopy consist of discontinuous α_2/γ lamellar colonies and γ grains. The formation of the discontinuous α_2/γ colonies is mainly due to the fact that at elevated temperatures compositional transition area formed between α phase and γ phase, where α_2/γ laths nucleated and grew discontinuously during cooling[9, 10]. Fig. 3(b) shows the microstructure of TiAl-base alloy under SEM after hot pressing at 1 300 ℃. EDAX surface analysis shows the homogeneous distribution of Cr and Nb elements in lamellar colonies (Fig. 3(c, d)). The addition of Cr and Nb elements will decrease T_α temperature of TiAl-base alloy, and increase the amount of α phase at elevated temperatures[6]. During cooling, γ lathes precipitate from α (or α_2) phase

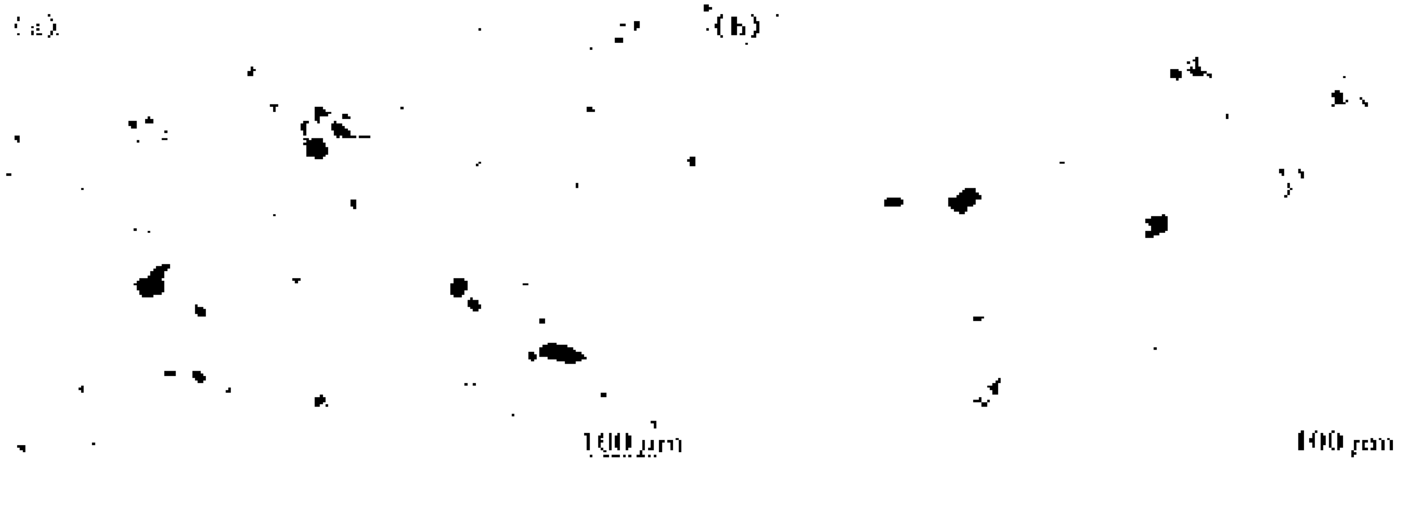

Fig. 1 Porosity distribution of Ti-47Al-2Cr-2Nb alloy after hot pressing at various temperatures
(a) —1 200 ℃, 1 h; (b) —1 300 ℃, 1 h

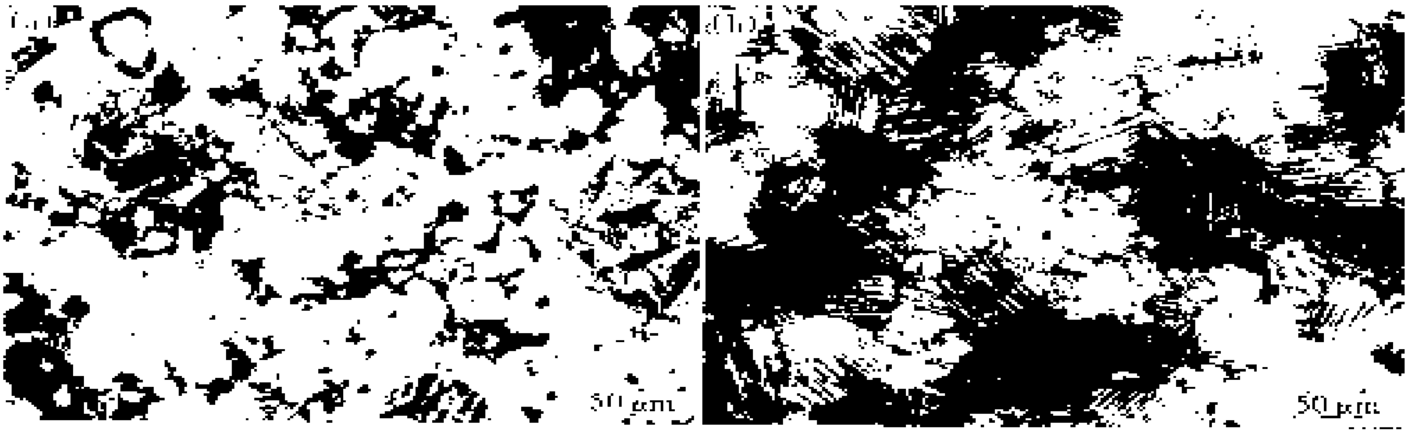

Fig. 2 Microstructures of Ti-47Al-2Cr-2Nb alloy after hot pressing at various temperatures
(a) —1 200 ℃, 1 h; (b) —1 300 ℃, 1 h

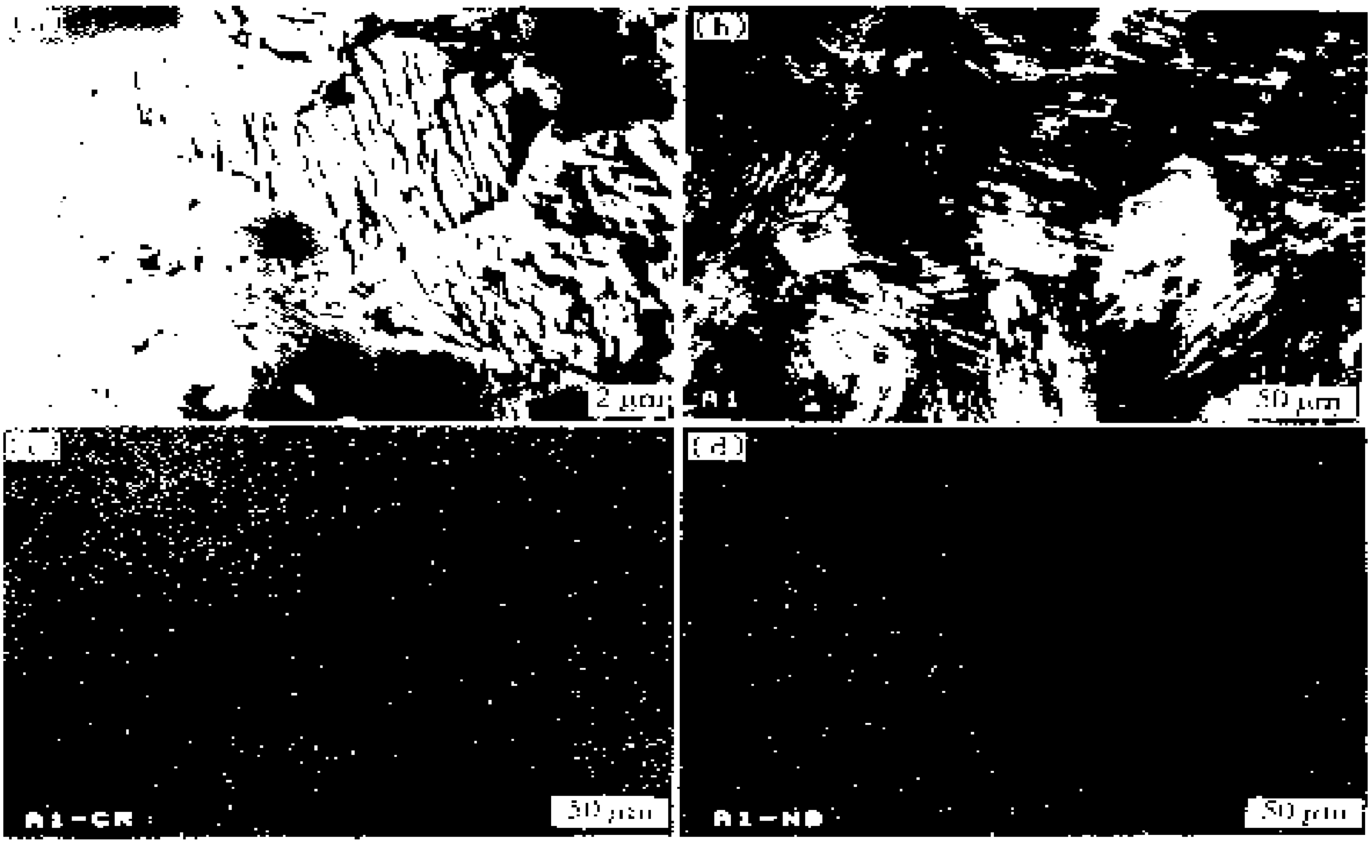

Fig. 3 SEM (BEI) and alloy elements distribution of Ti-47Al-2Cr-2Nb alloy
(a) —1 200 ℃, 1 h; (b) —1 300 ℃, 1 h, NFL;
(c) —Distribution of Cr element; (d) —Distribution of Nb element

according to a strict orientation relationship: $\langle 110\rangle_\gamma//[11\bar{2}0]_\alpha \,||\, \{111\}_\gamma//(0001)_\alpha$, hence, TiAl-base alloy with near fully lamellar microstructure can be obtained after hot pressing at 1 300 ℃. However, incomplete diffusion of Nb element in local area can be seen in Fig. 4(a). Dendritic phases disperse around the former Nb particle. In the center of the former Nb particle, the content of Nb is 74% (mole fraction, %); the content of Nb in the dendrites is 27%, while that of the area between the center and the dendrites is 10%, as shown in Fig. 4(b~ d). It indicates that Nb element diffuses to surrounding area at elevated temperatures, but because of large Nb particle and slow rate of solid phase diffusion, it is very difficult for initial Nb particle to diffuse completely into base alloy. In Nb-rich area form Ti-Al-Nb precipitates. Furthermore, it is found that the content of Al element is higher than that of Ti element inside the remaining Nb particle, but is lower outside. This is due to the fact that the diffusion rate of Al element is higher than that of Ti element.

The microstructures of Ti-47Al-2Cr-2Nb alloy after HIPping are shown in Fig. 5. The amount of incompletely reacted phases has decreased, and they only remain in the area where the initial Nb particle is too large. Although the microstructure of the material hot pressed at 1200 ℃ has not changed too much after HIPping, the volume content of γ lamellar colonies has increased largely.

After HIPping, elements distribution of the material hot pressed at 1300 ℃ became more homogeneous after HIPping, this can be seen in the condition of the erosion. On the other hand, lamellar colonies have grown and their mean size is 80 μm. Because lamellar colonies have high thermal stability, when they are heat treated in ($\alpha+\gamma$) field for a short term, only growth and coarsening of lamellar colonies occur[14]. Therefore, the initial microstructure has hereditary effect on the microstructure after HIPping.

Phase constitution of Ti-47Al-2Cr-2Nb before and after HIPping are shown in Fig. 6. It indicates that both samples consist of Ti_3Al and TiAl phase. But there is a small peak at $2\theta = 40°$ position which is adjacent to that of (110) peak of B2 in normal Ti-Al-Nb alloys[15]. It also indicates that after HIPping, the amount of α_2 phase

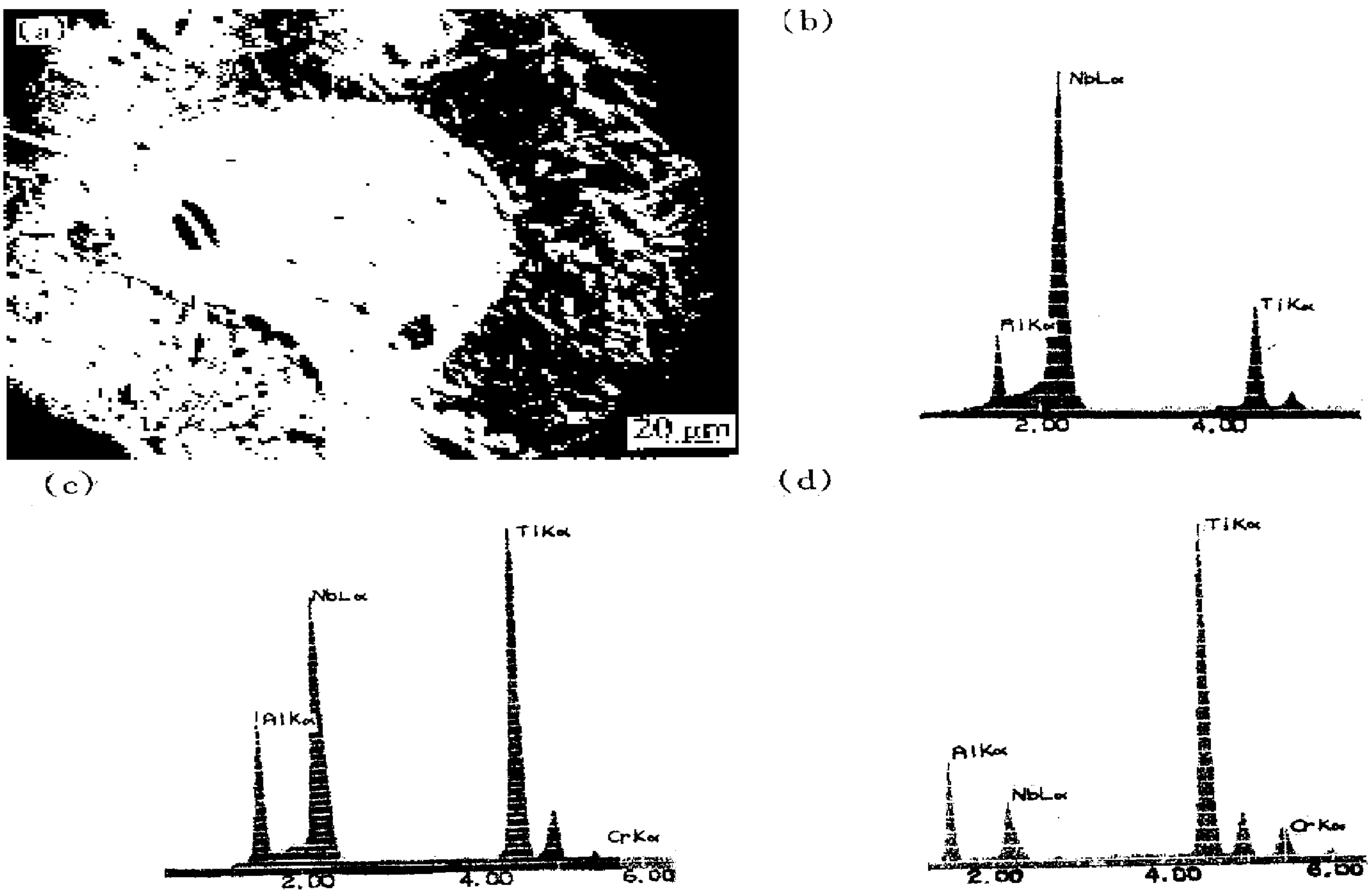

Fig. 4 Incomplete diffusion of Nb in Ti-47Al-2Cr-2Nb alloy
(a) —Incomplete diffusion of Nb particle; (b) —EDAX inside the particle;
(c) —EDAX of the dendrites; (d) —EDAX of area between the dendrites

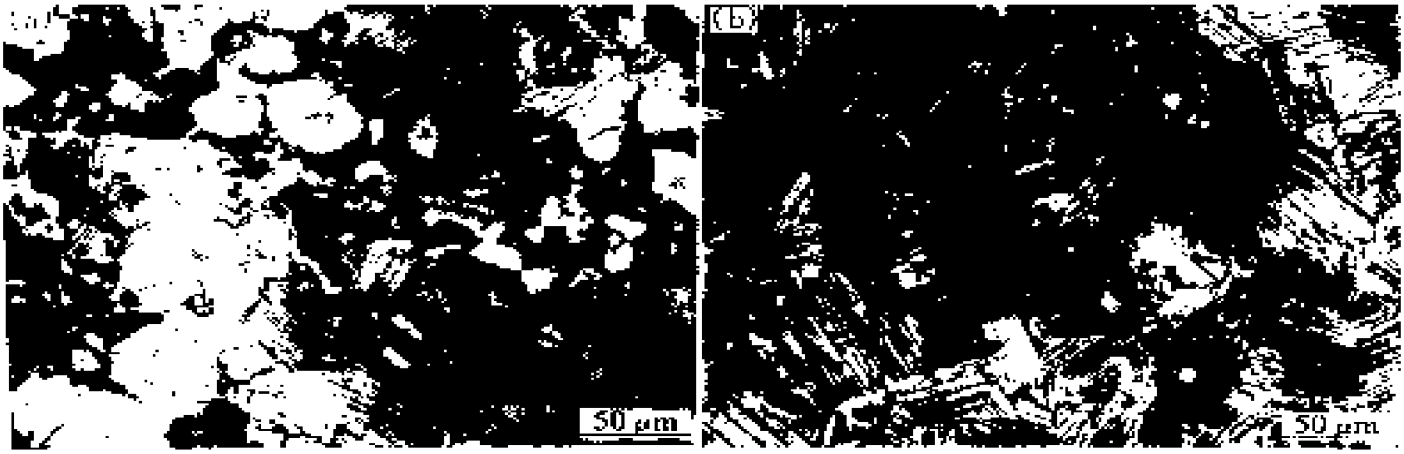

Fig. 5　Microstructure of Ti-47Al-2Cr-2Nb after HIPping
(a) —1 200 ℃ hot pressed sample; (b) —1 300 ℃ hot pressed sample

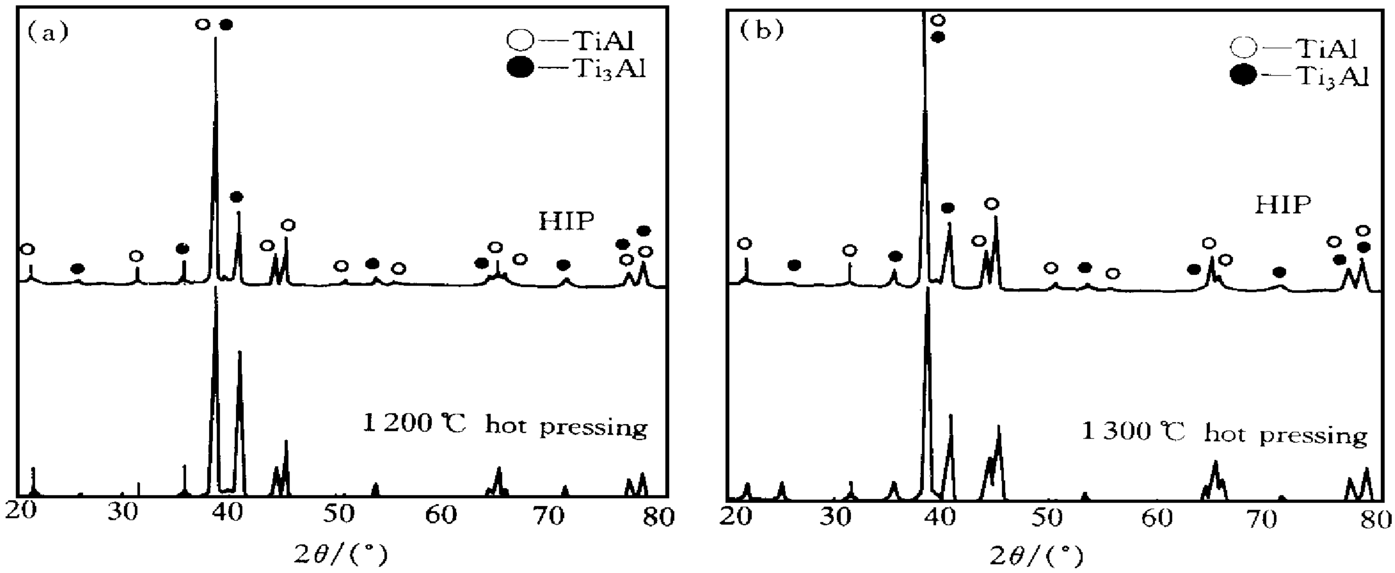

Fig. 6　phase constitution of Ti-47Al-2Cr-2Nb after HIPping
(a) —1 200 ℃ hot pressed sample; (b) —1 300 ℃ hot pressed sample

in two samples has decreased. When hot pressing at 1 200 ℃, diffusion of Al and other alloy elements Cr, Nb to Ti particles was incomplete, the contents of these elements in remained α phase at elevated temperature were very low and ordering transformation from α to α_2 phase occurs after cooling. At the same time because of inhomogeneous element distribution, contents of Al and other alloy elements in some α phase are high, γ phase precipitated when cooling and α_2/γ lamellar colonies formed. So after hot pressing at this temperature, the content of α_2 phase is high. When HIPping for 4 h at 1 250 ℃, the material composition became homogeneous, and contents of Al and other alloy elements in α phase increased, which is beneficial to the precipitation of γ lath during cooling. Therefore, the amount of α_2 phase decreased. The above analyses also can be adopted to TiAl-base alloy hot pressed at 1 300 ℃, except that at 1 300 ℃, the content of Al and other alloy elements were high enough for the precipitation of γ phase during cooling, leading to the formation of large amount of α_2/γ lamellar colonies.

Reaction synthesis of Ti, Al elemental powders is mainly controlled by diffusion. After adding alloy elements Cr, Nb, diffusion process become more complex, and because of such phenomenon as incomplete diffusion, it is difficult to analyze the change of microstructure in hot pressing process by equilibrium phase diagram. Therefore, it is important to gain homogeneous alloy to control microstructure and mechanical properties. From the result of this article, Cr element can diffuse into TiAl alloy completely, there is no Cr-rich area in microstructure. But incomplete diffusion of Nb element can be found because diffusion coefficient of Nb is lower than that of Cr at elevated temperatures and original Nb particles are coarse. In order to gain homogeneous alloy element distribution, one choice is to increase the reaction temperature, but it might cause coarse microstructure. The other choice is to decrease the particle size of alloy elements, for example adopting Nb powders with particle size of several μm. This will be discussed in subsequent work.

4 CONCLUSIONS

(1) Elemental powder metallurgy is an efficient method in synthesis Ti-47Al-2Cr-2Nb alloy with high density. After hot pressed at 1300 ℃, fine and near fully lamellar microstructures have been obtained. The mean size of lamellar colonies is 50~ 60μm. Cr element can diffuse into TiAl alloy completely. Nb powders with fine particle size should be adopted to obtain complete diffusion of Nb.

(2) HIPping can increase the density of the material and improve the homogeneity of elements. The initial microstructure of the alloy has great influence on its microstructure after HIPping in ($\alpha+\gamma$) field.

REFERENCES

1 Kim Y W. JOM, 1995, 47(7): 39- 41.
2 Huang S C and Hall E L. Metall Trans A, 1991, 22A(9): 2619- 2627.
3 Kim Y W. In: Mat Res Soc Symp Proc, MRS, PA, 1991, 213: 777- 794.
4 Yoshihaya M and Miura K. Intermettallics, 1995, 3: 357- 363.
5 Taniguchi S and Shibata T. Intermetallics, 1996, 4: S85- 93.
6 Kim Y W. JOM, 1994, 46(7): 30- 39.
7 Liu C T, Schneibel J H, Maziasz P J *et al*. Intermetalics, 1996, 4: 429- 440.
8 Keller M M, Jones P E, Porter W J *et al*. In: Kim Y W, Wagner R and Yamaguchi M eds, Gamma Titanium Aluminides, TMS, 1995: 441- 450.
9 Wang G X and Dahms M. Scripta Metall et Mater, 1992, 26(5): 717- 722.
10 Yang J B, Teoh K W, Hwang W S. Mater Sci & Tech, 1997, 13(8): 695- 701.
11 Liu Zhijian, Qu Xuanhui, Huang Baiyun. Trans Nonferrous Met Soc China, 1997, 7(1): 96- 100.
12 Wu Nianqiang, Wu Jinming, Li Wu *et al*. Trans Nonferrous Met Soc China, 1997, 7(4): 1- 4.
13 Nie Xian, Tang Rengzhen. The Chinese Journal of Nonferrous Metals, 1994, 3(5): 82- 86.
14 He Yuehui, Huang Beiyun *et al*. Rare Metals, 1997, 21(2): 109- 114.
15 Yuji Muramatsu *et al*. J Japan Soc of Powder & Powder Metall, 1995, 42(5): 611.

(Edited by Zhu Zhongguo)