PHASE EQUILIBRIA OF $\alpha_2(\alpha)/\gamma$ IN Ti-Al-Nb TERNARY SYSTEM①

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ABSTRACT The phase equilibrium relationships and compositions of $\alpha_2(\alpha)/\gamma$ in the Ti-Al-Nb ternary system between 1 000~ 1 300 ℃ have been measured using diffusion couple and EPMA method. The partial isothermal sections of the Ti-Al-Nb ternary system with Nb content less than 10.0% (mole fraction) and partial vertical diagram of the Ti-Al binary system have been drawn. The results confirmed the change rule of $\alpha_2(\alpha)+\gamma$ dual-phase field with temperature, Nb content and the distribution ratio of Nb element in $\alpha_2(\alpha)$ and γ phases.

Key words Ti-Al-Nb ternary system diffusion couple $\alpha_2(\alpha)/\gamma$ phase equilibria

1 INTRODUCTION

Alloying element addition is an efficient method for the improvement of ductility at room temperature of γ-TiAl intermetallics and Nb is one of the very important alloying elements[1, 2]. The phase diagrams associated with the Ti-Al-Nb ternary system have been reported for a long time. In 1962, Popov *et al* studied the phase equilibrium relationship at Nb-richer corner of the isothermal sections at 1200, 20 ℃[3]. In 1980', Troitskii *et al* further studied the phase equilibrium relationship at Nb-richer and Ti-richer corners of three isothermal sections between 600~ 1200 ℃[4, 5]. Recently, Perepezko *et al* determined the isothermal section at 1 200 ℃[6, 7]. Chen and Hao systematically studied the isothermal sections at 1 000, 1 150 and 1 400 ℃[8, 9]. But the above researches focused on the phase equilibria with γ_1, T_1 and T_2 phases. $\alpha_2(\alpha)/\gamma$ phase equilibria which are directly related to the development of γ-TiAl have not been systematically studied and have not reach the level to direct the alloying. The temperature range between 1 000~ 1 300 ℃ is for hot working and heat treatment of γ-TiAl. So, this study has taken systematic measurement on the phase equilibria of $\alpha_2(\alpha)/\gamma$ in the Ti-Al-Nb ternary system between 1 000~ 1 300 ℃ using diffusion couple and EPMA, in order to supply more precise data for alloying and thermo-calculation on phase equilibria of γ-TiAl.

2 EXPERIMENTAL

Six single-phase alloys were designed for this experiment. The alloy compositions are shown in Table 1 in which the numbers refer to mole fraction. The alloy ingots with iodide titanium (99.95%), high-purity aluminium (99.99%) and high-purity niobium (99.99%) were melted five times in an arc furnace under argon with a non-consumable tungsten electrode and magnetically confined mixing conditions. Because no mass loss exceeded 0.2%, compositions were taken as nominal.

The specimens of 3 mm × 3 mm × 10 mm were cut from the alloy ingots, and then used solid diffusion welding for preparing two kinds of diffusion couples: one kind is couple of $\alpha_2(\alpha)$ Ti-Al binary alloy and γ-TiAl ternary alloy con-

① Supported by the National Natural Science Foundation of China (No. 59371025)
Received Dec. 30, 1996; accepted May 9, 1997

taining Nb, *e. g.* Ti70Al30/Ti39Al51Nb10/Ti47Al53 couple; another kind is couple of γ-TiAl binary alloy and $\alpha_2(\alpha)$ ternary alloy containing Nb, *e. g.* Ti47Al53/Ti60Al30Nb10/Ti70Al30 couple. To do so, the diffusion couple can obtain more phase equilibrium lines and the two kind of couples can give more supplement and confirmation each other. The diffusion couples were wrapped with Mo foils. Below 1 200 ℃, the diffusion couples were encapsulated in single layer quartz tube with a little high-purity argon backfilled. Above 1 200 ℃, the diffusion couples were encapsulated in double-layer quartz tube with a pressure of about 0.1 Pa in internal layer and 1 Pa in outside layer. The equilibrium heat treatments are shown in Table 2.

Table 1 Alloy compositions used for experiment

Alloy	Alloy compositions (mass fraction) / %			Expected phase*
	Ti	Al	Nb	
Ti70Al30	80.52	19.48	0.00	α_2
Ti60Al40	72.66	27.34	0.00	α
Ti47Al53	61.15	38.85	0.00	γ
Ti60Al30Nb10	62.26	17.57	20.17	α_2
Ti52Al38Nb10	55.98	23.09	20.93	α
Ti37Al53Nb10	42.85	34.64	22.51	γ

* Phases expected at treated temperatures

At the end of heat treatment, the couples were rapidly pulled out and quenched in water to maintain the equilibrium compositions at the treated temperature. The diffusion couples were cut along with the diffusion direction and prepared for optical analysis on a Versamet-2 reflection light microscope (RLM) and EPMA on a CAMEBAX-MICRO. Voltage for the EPMA was 15 kV, and the probe angle was 40°. Every phase composition was measured with steps of 3 ~ 5 μm along with the diffusion direction. The X-ray intensity of each element was modified using ZAF theory (Z—"Z" number correction, A—absorption correction, F—fluorescence correction) and exchanged into mole fraction. The composition profile data were modified by computer and the equilibrium concentrations were taken at the phase boundary by extrapolating the composition profiles to the phase boundary.

3 RESULTS AND DISCUSSIONS

3.1 Optical microstructure of the diffusion couple

Fig. 1(a) is optical microstructure of one Ti-Al-Nb couple treated at 1 000 ℃ with clear phase boundary of $\alpha_2(\alpha)$. Fig. 1(b) is the composition profile across the phase boundary with clear composition jump. This inplies that they are different phases across the phase boundary.

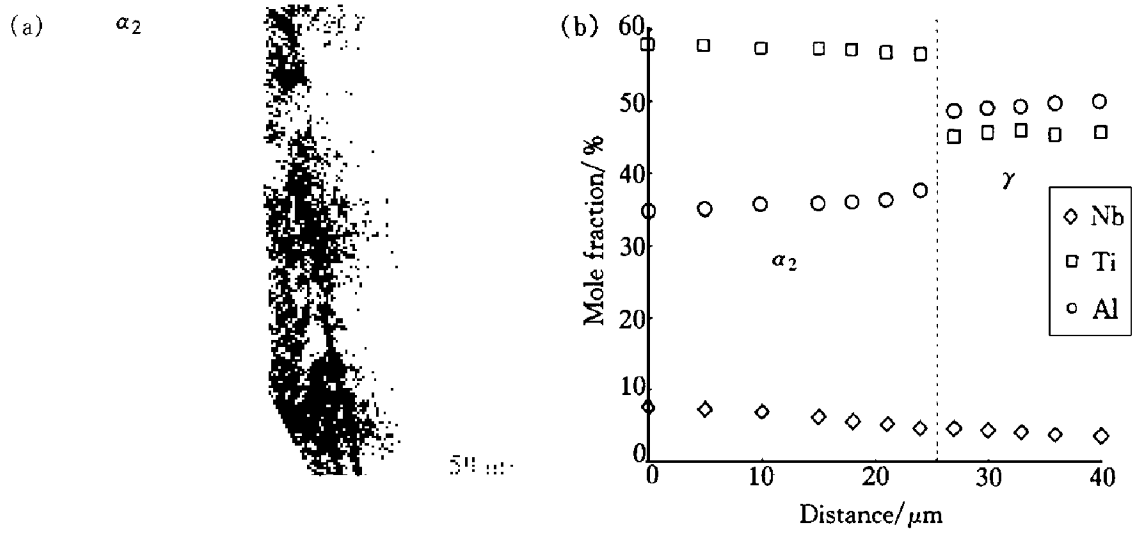

Fig. 1 Optical microstructure (a) and composition profile (b) of Ti47Al53/Ti37Al53Nb10/Ti70Al30 diffusion couple treated at 1000 ℃

Table 2 Standard of equilibrium heat treatment of the diffusion couples

T/ ℃	1 000	1 050	1 100	1 150
Time/ h	200	100	50	40
T/ ℃	1 200	1 250	1 300	
Time/ h	25	25	20	

The equilibrium composition was obtained by extrapolating the profile to the phase boundary, that is equilibrium line.

3.2 $\alpha_2(\alpha)/\gamma$ phase equilibrium relationships and compositions in the Ti-Al-Nb ternary system

Fig. 2 is the partial isothermal sections of the Ti-Al-Nb ternary system between 1000~ 1300 ℃ according to this experimental data.

At all treated temperatures, the increase of Nb content resulted in the intention of $\alpha_2(\alpha)+\gamma$ dual-phase field and the distribution ratio of Nb in $\alpha_2(\alpha)$ and γ is close to 1.0. The width of $\alpha_2(\alpha)+\gamma$ dual-phase field is mainly affected by the decreasing of Al concentration in $\alpha_2(\alpha)$ phase but the decreasing of Al content in γ phase is small. With the temperature change, $\alpha_2(\alpha)+\gamma$ dual-phase field clearly moves to Al-richer direction and the dual-phase field becomes thinner. α_2/γ phase relationship is at 1000~ 1100 ℃ and α/γ relationship at 1150~ 1300 ℃.

These experimental results agree with Wang's report[9]. Wang reported that Nb prefers to occupy Ti site in γ phase. Because Nb slightly reduces Al-concentration in γ phase, so these experimental results supported the viewpoint that Nb mainly occupied Ti site in γ phase[1, 2, 8, 9] and Kim's viewpoint that Nb fully occupied Ti site is not accurate[1, 2].

As the comparison of the Ti-Al-Cr ternary system, one clear character of the Ti-Al-Nb ternary system is that Nb has higher solution degree in α_2, α and γ. At 1 000 ℃, Nb has higher solution degree up to 10.0% (mole fraction) in α_2 and γ, but Cr has 2.0% in α_2 and 4.0% in γ.

3.3 Partial vertical diagram of the Ti-Al binary system

Fig. 3 showed the partial vertical diagram of the Ti-Al binary system according to the partial isothermal sections of the Ti-Al-Nb ternary system. The addition of Nb leads $\alpha_2(\alpha)$ phase boundary move to lower Al content and has slightly effect on γ boundary.

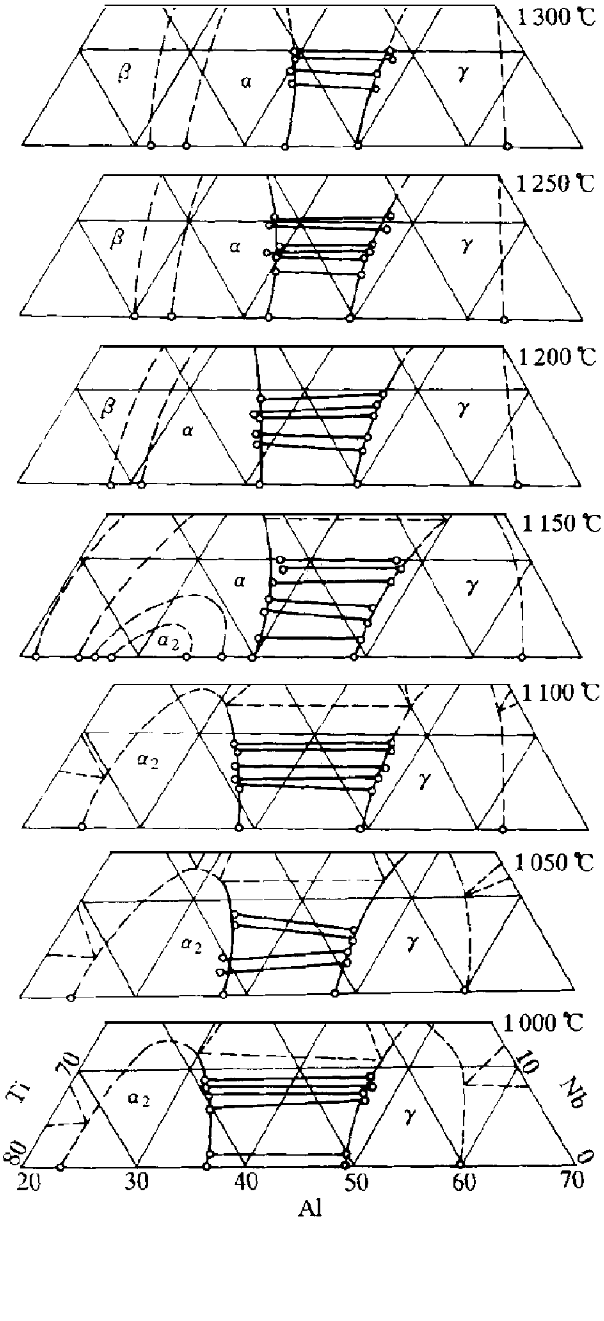

Fig. 2 Partial isothermal sections of the Ti-Al-Nb ternary system at 1 000~ 1 300 ℃

4 CONCLUSIONS

(1) The $\alpha_2(\alpha)/\gamma$ phase equilibrium relationship and composition in the Ti-Al-Nb ternary system with Nb addition lower than 10.0%

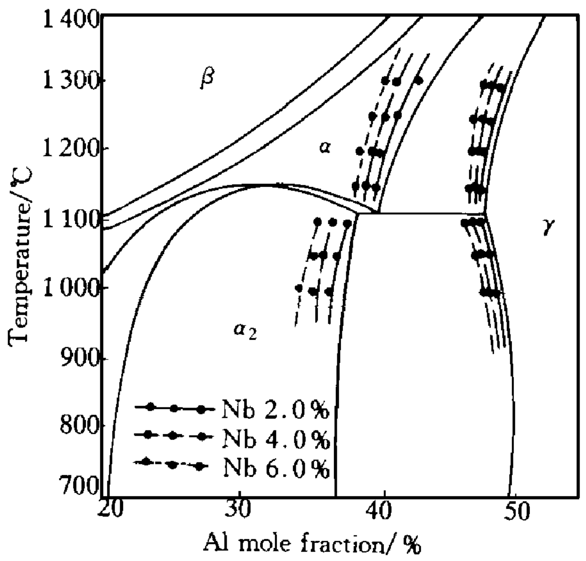

Fig. 3 Partial vertical diagram of Ti-Al binary system

(mole fraction) at 1000~ 1300 ℃ have been determined using diffusion couple and EPMA method. Phase equilibrium relationship is α_2/γ at 1 000 ~ 1 100 ℃, and is α/γ at 1 150 ~ 1 300 ℃. The partial isothermal sections of the Ti-Al-Nb ternary system and the partial vertical diagram of the Ti-Al binary system have been drawn.

(2) The distribution ratio of Nb in $\alpha_2/(\alpha)$ and γ phases is near 1.0. Nb slightly reduced Al concentration in γ phase. This result supports the viewpoint that Nb mainly occupied Ti site in γ-TiAl.

REFERENCES

1 Kim Y W. JOM, 1989, 41(7): 24.
2 Kim Y W. JOM, 1994, 46(7): 30.
3 Popov I A, Rabezova V I. Titan Iego Splavy, Akad Nauk USSR, 1962, 7: 105, 436.
4 Troitskii B S, Zhakarov A M, Karsanov G V *et al*. Izv Vuz Tsvetn Metall, Moscow, 1983: 77.
5 Zhakarov A M, Karsanov G V, Troitskii B S *et al*. Russian Metall, 1984, 1: 199.
6 Jewett T J, Lin J C, Bonda N R *et al*. Mat Res Soc Symp Proc, 1989, 133: 69.
7 Perepezko J H, Jewett T J, Das S *et al*. In: Proceedings of the 3rd International SAMPE Metals and Metals Processing Conference, Toronto, Canada. SAMPE, Covina, VA, 1992: 357.
8 Chen G L, Wang X T, Ni K Q *et al*. Intermetallics, 1996, 4: 13.
9 Wang X T. PhD thesis. (in Chinese). University of Science and Technology Beijing, 1995.

(Edited by Yan Saiqian)