

INFLUENCE OF ALLOYING ELEMENTS ON DEFORMABILITY OF HIGH Nb CONTAINING TiAl ALLOYS

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Abstract

The as-cast microstructures, hot deformation behaviors and as-deformed microstructures of β - γ TiAl alloys containing high niobium and various β stabilizing elements Mn, Cr, Mo and V were investigated. It is found that the increasing addition of Cr and Mo elements contributes to the continuous decrease of flow stress. On the contrary, with increasing the amount of V content, the flow stress enhances. In the Mn content addition range 0.5~2.0at%, the alloy with 1.5%Mn possesses the minimum value of flow stress. The optimum composition for hot working is Ti-44Al-8Nb-1.5Mn-0.2B-0.2Y. The morphology of β phase as well as the amount of β phase plays an important role in controlling the formability of β - γ TiAl alloys containing high niobium.

Introduction

TiAl based alloys are considered for high-temperature applications in aerospace and automotive industries because of their attractive properties, such as low density, good elevated temperature strength, high resistance to oxidation, excellent creep properties [1, 2]. However, the poor ductility and low fracture toughness at room temperature limit their practical applications [2-4]. The novel β - γ TiAl alloys composed of a few β/B_2 phase and dominate γ phase, with the very little amount of α_2 phase, is different from the traditional TiAl alloy that is composed of γ phase and α_2 phase[5]. Resulting from sufficient number of independent slip systems, small deformation resistance, apt to plastic forming of disordered bcc β phase at elevated temperature, the β - γ TiAl alloys exhibited excellent hot-workability [6-7]. In recent years, the investigations of β - γ TiAl alloys have been widely developed [7]. As well known, γ -TiAl alloys containing high niobium are superior to the traditional TiAl alloys. Therefore, it is significant to research the β - γ TiAl alloys containing high niobium. According to the previous work, the addition of β stabilizing elements such as Cr, V, Mo and Mn enlarges the β phase region, as well as stabilizing the β phase. Therefore, the purposes of this study are to present the optimum composition of β - γ TiAl alloys containing high niobium for hot working process by analyzing the deformation behaviors and microstructure of β - γ TiAl alloys containing high niobium.

Experimental

The nominal compositions of the β - γ TiAl alloys containing high niobium used in the present work were presented in Table.1. The as-cast alloys were prepared by a non-consumable electrode arc-melting furnace in argon atmosphere. The buttons were melted five times to ensure the chemical homogeneity. Cylindrical compression specimens with dimensions of $\phi 6\text{mm}\times 8\text{mm}$

were cut from ingot by electric-discharge machining. Compressive tests were conducted on Gleeble 1500 machine at temperature 1200°C with strain rate 0.001s⁻¹ and engineering strain 50%. After compression, specimens were water quenched immediately to preserve the as-deformed microstructures. The as-cast and as-deformed microstructures were characterized using scanning electron microstructure (SEM) in back-scattered electron (BSE) mode. The energy dispersive spectroscopy (EDS) was employed to identify each phases possessing different contrast in the microstructure.

Table.1 The nominal composition of alloys (atomic percent)

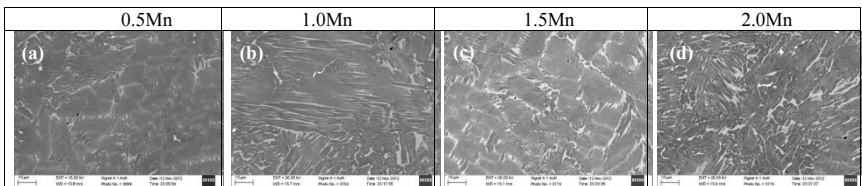
| Number | Ti | Al | Nb | Mn | Cr | Mo | V | B | Y |
|--------|------|----|----|-----|-----|-----|-----|-----|-----|
| 1# | 47.6 | 44 | 8 | 0 | 0 | 0 | 0 | 0.2 | 0.2 |
| 2# | 47.1 | 44 | 8 | 0.5 | 0 | 0 | 0 | 0.2 | 0.2 |
| 3# | 46.6 | 44 | 8 | 1 | 0 | 0 | 0 | 0.2 | 0.2 |
| 4# | 46.1 | 44 | 8 | 1.5 | 0 | 0 | 0 | 0.2 | 0.2 |
| 5# | 45.6 | 44 | 8 | 2 | 0 | 0 | 0 | 0.2 | 0.2 |
| 6# | 47.1 | 44 | 8 | 0 | 0.5 | 0 | 0 | 0.2 | 0.2 |
| 7# | 46.6 | 44 | 8 | 0 | 1 | 0 | 0 | 0.2 | 0.2 |
| 8# | 46.1 | 44 | 8 | 0 | 1.5 | 0 | 0 | 0.2 | 0.2 |
| 9# | 45.6 | 44 | 8 | 0 | 2 | 0 | 0 | 0.2 | 0.2 |
| 11# | 47.1 | 44 | 8 | 0 | 0 | 0.5 | 0 | 0.2 | 0.2 |
| 12# | 46.6 | 44 | 8 | 0 | 0 | 1 | 0 | 0.2 | 0.2 |
| 13# | 46.1 | 44 | 8 | 0 | 0 | 1.5 | 0 | 0.2 | 0.2 |
| 14# | 45.6 | 44 | 8 | 0 | 0 | 2 | 0 | 0.2 | 0.2 |
| 15# | 47.1 | 44 | 8 | 0 | 0 | 0 | 0.5 | 0.2 | 0.2 |
| 16# | 46.6 | 44 | 8 | 0 | 0 | 0 | 1 | 0.2 | 0.2 |
| 17# | 46.1 | 44 | 8 | 0 | 0 | 0 | 1.5 | 0.2 | 0.2 |
| 18# | 45.6 | 44 | 8 | 0 | 0 | 0 | 2 | 0.2 | 0.2 |

Results and discussion

3.1 The Influence of Mn Element on Hot Deformability

3.1.1 The Effect of Mn Element on Microstructure of TiAl Alloys Containing High Niobium

The as-cast microstructures of Ti-44Al-8Nb-0.2B-0.2Y alloy added with Mn element content 0.5-2% (at%) are shown in Fig.1(a)-(d). It is noted that the as-cast microstructures exhibit an equiaxed grains with a dominant lamellar colony, white β (B2) phase and gray γ phase identified by EDS analysis previously. Obviously, with the improvement of the Mn content, the amount of β phase greatly increases and the morphology of β phase converts gradually. When 0.5%Mn, 1.0%Mn and 2.0%Mn are added to the alloys containing high niobium, the morphology of β phase exhibits the lath structure, which mainly disperses inside the lamellar colonies. However, the white network β phase distributed at the boundaries of the lamellar colonies and the triple junction areas is found in alloys containing 1.5%Mn.



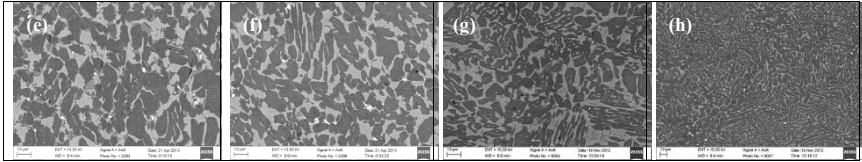


Fig.1 The as-cast ((a) – (d)) and as-deformed ((e) – (h)) microstructures of TiAl alloys containing various Mn content (No.2 to no.5 alloys)

3.1.2 The Effect of Mn Element on Hot Deformation Behaviors of TiAl Alloys Containing High Niobium

The true stress-strain curves of alloys containing 0.5-2.0% Mn content obtained from isothermal compression tests at temperature 1200°C, strain rate 0.001s^{-1} and engineering strain 50% are shown in Fig.2. The shapes of the curves almost present obvious three stages. As the strain increases, flow stress increases continuously to peak stresses at the initial deformation stage, and then decreases gradually and reaches a steady state. These true stress-strain curves exhibit typical work hardening and flow softening features. In the Mn element addition range of 0.5~2.0% (at%), with the content of Mn element enhancing, the flow stress decreases continuously to the peak stress minimum where Mn element content is 1.5%, and then elevates obviously. Therefore, the optimum addition content of Mn element to the current β - γ TiAl alloys containing high niobium (Ti-44Al-8Nb-0.2B-0.2Y) is 1.5%.

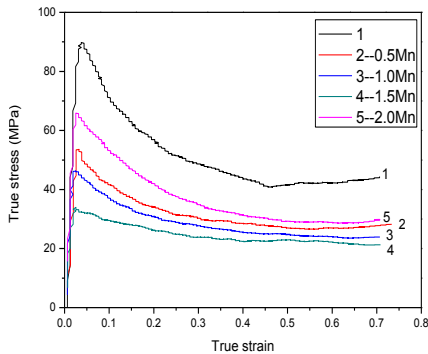


Fig.2 The true stress-strain curves of alloys containing 0.5-2.0% Mn content

The as-deformed microstructures are shown in Fig.1(e)-(h). Dynamic recrystallization plays an important role in high deformation of β - γ TiAl alloys containing high niobium. It is noticed in Fig.1(e)-(h) that compared with the volume fraction of β phase of as-cast microstructure, the amount of β phase after deformation greatly enhances with the increase of Mn element content, which is ascribed to dynamic recrystallization that can break down the lamellar colonies into fine γ phase and β phases during compression deformation. Meanwhile, deformed microstructure reveals bending, elongation, kinking and coarsening of β phase, indicating that the β phase with bcc structure is softer than the α_2 phase and γ phase, resulting from β phase possessing sufficient number of independent slip systems, small deformation resistance and apt to plastic forming. Correspondingly, the soft β phase is preferentially deformed prior to the α_2 phase and γ phase

during the hot deformation process, which conduces to releasing stress concentration and preventing the cracks failure of lamellar colonies.

It is observed in Fig.2 that the enhancement of Mn element content promotes the decline of the flow stress in the addition range from 0.5%Mn to 1.5%Mn, which could be ascribed to the improvement of the β phase content as shown in Fig.1(a)-(c). However, the amount of β phase of the alloy containing 2.0%Mn is more than that of the alloy containing 1.5%Mn, but the former possesses the lower flow stress than the latter, which can be attributed to the influence of the morphology of β phase on hot deformation. Consequently, the feature of β phase, as well as the quantity of β phase has a significant influence on the deformability of TiAl alloy containing high niobium.

3.2 The Influence of Cr Element on Hot Deformability

3.2.1 The Effect of Cr Element on Microstructure of TiAl Alloys Containing High Niobium

The as-cast microstructures of Ti-44Al-8Nb-0.2B-0.2Y alloy added with Cr element content 0.5-2% (at%) are shown in Fig.3(a)-(d). It is observed in Fig.3(a)-(d) that the increase of white lath β phase finely dispersed in the matrix is ascribed to the enlargement of Cr content.

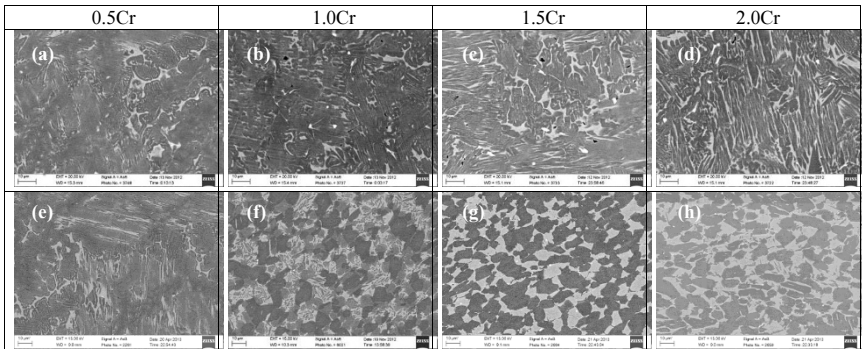


Fig.3 The as-cast ((a) – (d)) and as-deformed ((e) – (h)) microstructures of TiAl alloys containing various Cr content (No.6 to no.9 alloys)

3.2.2 The Effect of Cr Element on Hot Deformation Behaviors of TiAl Alloys Containing High Niobium

The true stress-strain curves of alloys containing 0.5-2.0%Cr content obtained from isothermal compression tests at temperature 1200°C, strain rate $0.001s^{-1}$ and engineering strain 50% are shown in Fig.4. It is shown in Fig.4 that in the Cr content range 0.5-2.0%, the increasing addition of Cr element promotes to the continuous decrease of the flow stress of alloys, which can be attributed to the amount of β phase of the as-cast microstructure in Fig.3(a)-(d). Therefore, the optimum Cr element content added to the current β - γ TiAl alloys containing high niobium (Ti-44Al-8Nb-0.2B-0.2Y) is 2.0%.

The deformed microstructures are shown in Fig.3(e)-(h). Obviously, when the Cr content varies from 0.5% to 1.0%, the deformed microstructure consists of lamellar colonies remained and dynamically recrystallized grains, indicating that the microstructure is partially dynamically recrystallized. The lamellar microstructure of alloys containing the Cr content from 1.5%Cr to 2.0%Cr is full dynamically recrystallized, and the dynamically recrystallized grains areas consist

of dominated γ phase and a few B_2 phases, almost no α phase. So, the volume fraction of β phase of as-deformed microstructure improves with increasing Cr content.

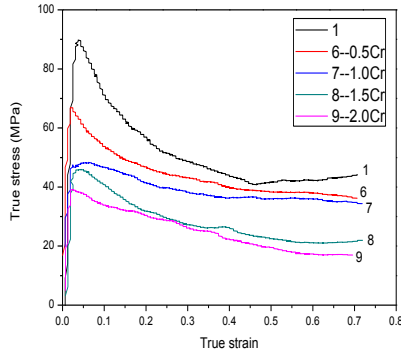


Fig.4 The true stress-strain curves of alloys containing 0.5-2.0% Cr content

3.3 The Influence of Mo Element on Hot Deformability

3.3.1 The Effect of Mo Element on Microstructure of TiAl Alloys Containing High Niobium

The as-cast microstructures of Ti-44Al-8Nb-0.2B-0.2Y alloy added with Mo element content 0.5-2% (at%) are shown in Fig.5(a)-(d). With the amount of Mo element increasing, the change rule of the volume fraction and the morphology of β phase of as-cast microstructures is not much different from that of alloys containing Cr element content from 0.5 to 2.0%.

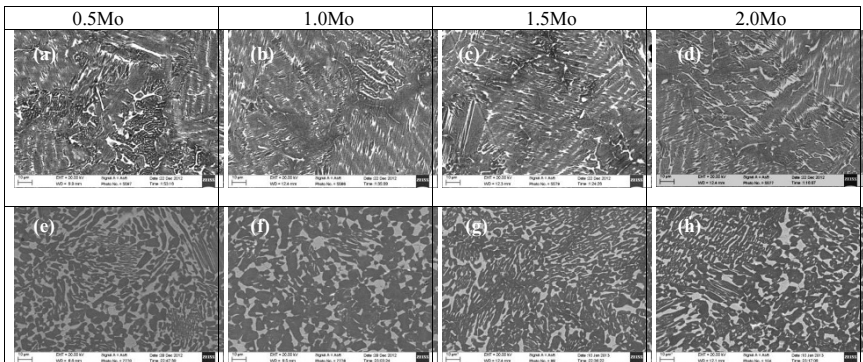


Fig.5 The as-cast ((a) – (d)) and as-deformed ((e) – (h)) microstructures of TiAl alloys containing various Mo content (No.11 to no.14 alloys)

3.3.2 The Effect of Mo Element on Hot Deformation Behaviors of TiAl Alloys Containing High Niobium

Fig.6 shows the true stress-strain curves of alloys containing 0.5-2.0%Mo content compressed at temperature 1200°C, strain rate $0.001s^{-1}$ and engineering strain 50%. It reveals that the increasing addition of Mo element contributes to the continuous decline of flow stress, which

can be illustrated by the BSE images in Fig.5(a)-(d). Therefore, combined the microstructure with the true stress-strain curves, the optimum addition of Mo element to the current β - γ TiAl alloys containing high niobium (Ti-44Al-8Nb-0.2B-0.2Y) is 2.0%.

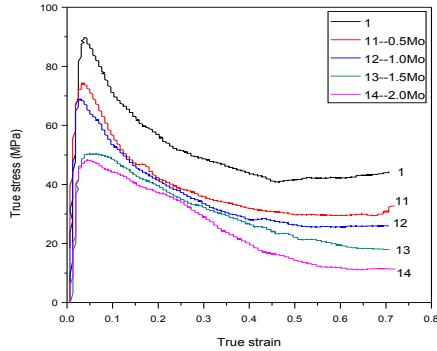


Fig.6 The true stress-strain curves of alloys containing 0.5-2.0% Mo content

The as-deformed microstructures are shown in Fig.5(e)-(h). A few of lamellar colonies are reserved in the deformed microstructures of alloys with Mo element, which can be illustrated by the relatively high peak stress in Fig.6.

3.4 The Influence of V Element on Hot Deformability

3.4.1 The Effect of V Element on Microstructure of TiAl Alloys Containing High Niobium

The as-cast microstructures of Ti-44Al-8Nb-0.2B-0.2Y alloy added with V element content 0.5-2% (at%) are shown in Fig.7(a)-(d). For the as-cast microstructures, when V content varies from 0.5 to 1.0%, the fine lath β phase mainly disperses along the lamellar colonies boundaries, as well as a few β phase grains at the triple junction areas, which leads to harmonize the lamellar colonies deformation. However, in the addition of V element content from 1.5 to 2.0%, it is noteworthy that the coarse bulk β phase grains are found and not finely distributed in the matrix. As a result, the deformation would be concentrated at β phase, which would not contribute to hot deformation and fracture of lamellar colonies.

3.4.2 The Effect of V Element on Hot Deformation Behaviors of TiAl Alloys Containing High Niobium

The true stress-strain curves of alloys containing 0.5-2.0% V content compressed at temperature 1200°C, strain rate 0.001s^{-1} and engineering strain 50% are shown in Fig.8. With the V content varying from 0.5% to 2.0%, the flow stress gradually increases, which is ascribed to the influence of morphology of β phase on hot working. After the comprehensive analyses of the microstructure and the true stress-strain curves, optimum addition of V element to the current alloys is 0.5%.

The deformed microstructures of alloys containing various V content are shown in Fig.7(e)-(h). It is shown in Fig.7(e)-(h) that the alloy containing 2.0%V possesses less β phase than that of the alloy with 0.5%V after deformation, demonstrating that the fine β phase (Fig.7(a)) is more beneficial to deformation than the coarse β phase (Fig.7(d)).

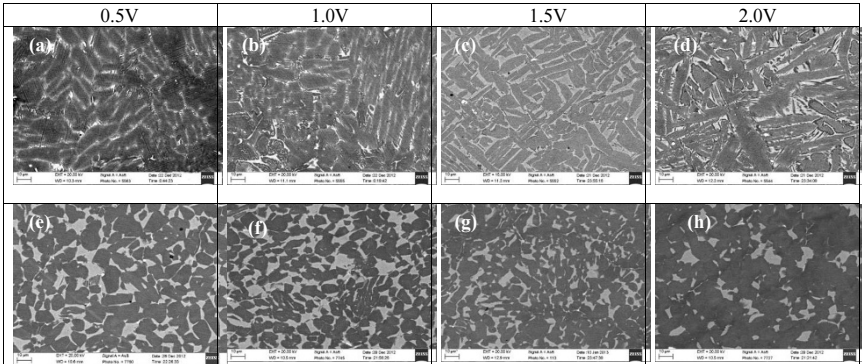


Fig.7 The as-cast ((a) – (d)) and as-deformed ((e) – (h)) microstructures of TiAl alloys containing various V content

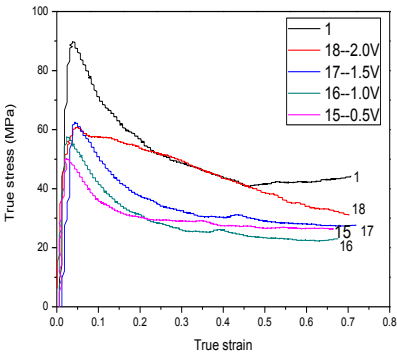


Fig.8 The true stress-strain curves of alloys containing 0.5-2.0% V content

3.5 The Effect of Different β Stabilizing Elements on Hot Deformability

Fig.9(a) and (b) respectively shows the as-cast and deformed microstructures of TiAl alloys containing no β stabilizing elements Mn, Cr, Mo and V. As shown in Fig.9(a), Fig.1 (a)-(d), Fig.3 (a)-(d), Fig.5(a)-(d) and Fig.7(a)-(d), the content of β phase of Ti-44Al-8Nb-0.2B-0.2Y alloy is less than that of alloys with β -stabilizing elements, indicating that the addition of β -stabilizing elements leads to the improvement of hot deformability. As a result, the initial lamellar colonies of the alloy without Mn, Cr, Mo and V elements are partially dynamically recrystallized, with lamellar colonies remained, as shown in Fig.9(b). These retained lamellar colonies with interfaces parallel to compression direction, bend or kink. While those with the interfaces perpendicular to compression direction, are relatively ready. The phenomenon is ascribed to the anisotropic plastic flow features of lamellar colonies.

Inui H. [8] reported that the orientation angle Φ between lamellar boundaries and loading axis plays an important role in the yield stress of lamellar colonies. The lamellar colonies in soft orientation are easier to bend, rotate and break down than those in relatively hard orientation. The dynamically recrystallized areas plus soft β phase can urge soft- orientation areas even softer,

leading to more subsequent deformation in these areas. The addition of β -stabilizing elements results in the enhancement of the β phase content, which conduces to the dynamical recrystallization of lamellar microstructure. Therefore, the larger the volume fraction is, the easier the dynamical recrystallization is.

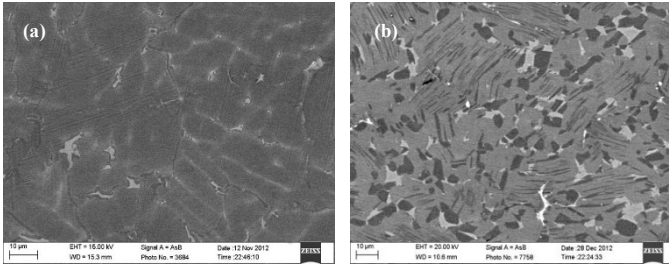


Fig.9 The as-cast (a) and as-deformed (b) microstructures of TiAl alloys containing no β stabilizing elements (No.1 alloy)

The true stress-strain curves of alloys containing 1.5%Mn, 2.0%Cr, 2.0%Mo and 0.5% V are shown in Fig.10. It is noted that the flow stress of alloys containing β -stabilizing elements is greatly lower than that of alloys without Mn, Cr, Mo and V elements, indicating that the larger the β phase amount is, the lower flow stress is. Compared with the true stress-strain curves with the minimum peak stress, the flow stress of the alloy with 1.5%Mn is lower than that of alloys containing 2.0%Cr, 2.0%Mo and 0.5%V, which demonstrates that the addition of 1.5%Mn to Ti-44Al-8Nb-0.2B-0.2Y produces excellent hot deformability.

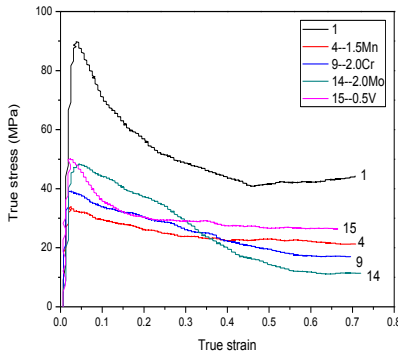


Fig.10 The true stress-strain curves of alloys containing 1.5%Mn, 2.0%Cr, 2.0%Mo and 0.5% V

Conclusions

In this paper, the as-cast and as-deformed microstructures, as well as the hot deformation behaviors of β - γ TiAl alloys containing high niobium and various β stabilizing elements were investigated. The conclusions are drawn as follows.

(1) The true stress-strain curves of β - γ TiAl alloys containing various Mn, Cr, Mo and V content exhibit typical work hardening and flow softening features. The increasing addition of Cr

and Mo elements contributes to the continuous decline of flow stress. On the contrary, with increasing the amount of V content, the flow stress enhances. In the Mn content addition range 0.5~2.0% (at%), the alloy with 1.5%Mn possesses the minimum value of flow stress. Compared with the influence of four elements on flow stress, the optimum composition is found to be Ti-44Al-8Nb-1.5Mn-0.2B-0.2Y.

(2) The addition of β stabilizing elements Mn, Cr, Mo and V leads to not only the generation of β phase, but also the variation of the morphology of β phase. It is demonstrated that the morphology of β phase, as well as the amount of β phase plays an important role in influencing the hot deformability of β - γ TiAl alloys containing high niobium.

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