Study of the Microstructure and Mechanical Properties of Novel As-Cast Titanium Alloys Containing Ta

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Abstract: The effect of Ta content on the microstructures, precipitated phases and mechanical properties of novel as-cast titanium alloy Ti-6.5Al-4Sn-5.5Zr-2.7Mo-1.7Nb-3.5W-0.4Si-0.1Y-xTa (x = 0, 1.0, 2.0 wt.%) was systematically studied. The results showed that the microstructure of the as-cast alloys is basket-weave microstructure, mainly composed of α-Ti, β-Ti, Y2O3 and silicides, belonging to α+β type titanium alloy. The addition of Ta element can inhibit the precipitation of Y2O3 at the grain boundary and promote the precipitation of silicides. The orientation relationship between the S1-type silicide and α-Ti matrix of 2.0 wt.% Ta alloy can be identified as $(01\bar{1}0)$S1 // $(01\bar{1}\bar{1})$α and $[\bar{2}11\bar{6}]$S1 // $[2\bar{1}\bar{1}0]$α; the orientation relationship between the S1-type silicide and β-Ti matrix can be identified as $(01\bar{1}0)$S1 // $(01\bar{1})$β and $[1\bar{2}1\bar{3}]$S1 // [100]β; $(01\bar{1}0)$S1 // $(01\bar{1})$β, $(2\bar{1}\bar{1}\bar{1})$S1 // (200)β and $[\bar{2}11\bar{6}]$S1 // $[0\bar{1}\bar{1}]$β. The tensile strength of the as-cast alloys increases with the increase of Ta content, whereas the elongation change is not significant, which is due to the solid solution strengthening of Ta atom and the second phase strengthening of silicides.

Keywords: high-temperature titanium alloy; Ta element; precipitate phases; microstructure; mechanical property

1 Introduction

Titanium and titanium alloys are widely used in aerospace, military, petrochemical and other fields due to their low density, high specific strength and excellent corrosion resistance [1, 2]. In order to adapt to the rapid development of modern aerospace industry, the development of new high-temperature and high-strength titanium alloys has attracted much attention. In this present work, the effects of Ta content (0, 1.0, 2.0 wt.%) on the microstructure precipitation behavior, mechanical properties of the self-designed short-term cast high-temperature titanium alloys (Ti-6.5Al-4Sn-5.5Zr-2.7Mo-1.7Nb-3.5W-0.4Si-0.1Y) were studied. In addition, the corresponding room and high-temperature fracture mechanisms were also discussed.

2 Experimental procedure

Ti-6.5Al-4Sn-5.5Zr-2.7Mo-1.7Nb-3.5W-0.4Si-0.1Y-xTa (*x* = 0, 1.0, 2.0 wt.%) alloys were prepared by the vacuum levitation melting furnace equipped with the water-cooled copper crucible of 5 kg capacity by cooling with the furnace. The microstructures and precipitated phases were characterized by XRD, SEM and TEM. Mechanical properties were studied by tensile test at room-temperature and high-temperature of 700 ℃ and 750 ℃.

3 Result and discussion

1. Phase identification and microstructure

Fig. 1 shows the phase composition of Ti-6.5Al-4Sn-5.5Zr-2.7Mo-1.7Nb-3.5W-0.4Si-0.1Y-xTa (x = 0, 1.0, 2.0 wt.%) analyzed by XRD. The XRD diffraction peak of the alloy indicated that the designed alloys were all composed of α+β phases composition, with Ta element completely dissolved in the matrix.

Fig. 2 shows the OM and SEM microstructures of the titanium alloys with different Ta contents. It can be seen that there was a staggered arrangement between α-Ti phase and β-Ti phase which belongs to the basket-weave structure. With the increased of Ta content, the width of α lamella in the alloy decreased; the content of the α-Ti phase decreased while the β-Ti phase increased in the alloy. This was due to the fact that Ta element as the high-melting point β-Ti phase stabilizing element, promoted the formation of β-Ti phase. It also found that the bright white precipitated phase at local β grain boundary was Y_2O_3 phase by the following TEM analysis.

An ellipsoidal precipitated phase was present in the β-Ti phase with a size of about 130 nm in Fig. 3(a). In order to determine the precipitate phase, the precipitate phase was analyzed by SAED from three different directions, as shown in Fig. 3(b), (c) and (d). The results showed that the precipitated phase on the β-Ti phase of 2.0 wt.% Ta alloy was $(TiZr)_5Si_3$, (S1-type silicide), and the S1-type silicide had the specific orientation relationship with α-Ti and β-Ti phase: $(01\bar{1}0)_{S1}$ // $(01\bar{1}\bar{1})_{\alpha}$ and $[\bar{2}11\bar{6}]_{S1}$ // $[2\bar{1}\bar{1}0]_{\alpha}$; $(10\bar{1}0)_{S1}$ // $(01\bar{1})_{\beta}$ and $[1\bar{2}1\bar{3}]_{S1}$ // $[100]_{\beta}$; $(01\bar{1}0)_{S1}$ // $(01\bar{1})_{\beta}$, $(2\bar{1}\bar{1}\bar{1})_{S1}$ // $(200)_{\beta}$ and $[\bar{2}11\bar{6}]_{S1}$ // $[0\bar{1}\bar{1}]_{\beta}$.

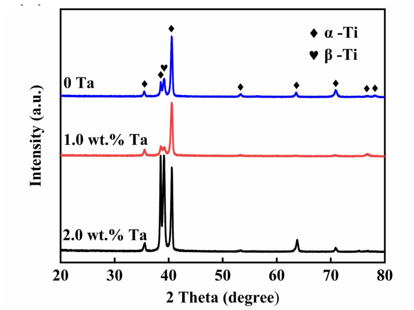

Fig. 1: XRD spectra of alloys with different Ta contents

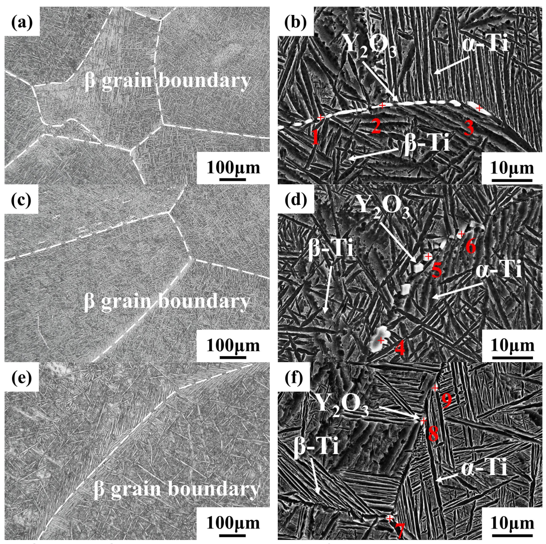

Fig. 2: OM and SEM microstructures of the alloys (a, b) 0 Ta alloy; (c, d) 1.0 wt.% Ta alloy;(e, f) 2.0 wt.% Ta alloy

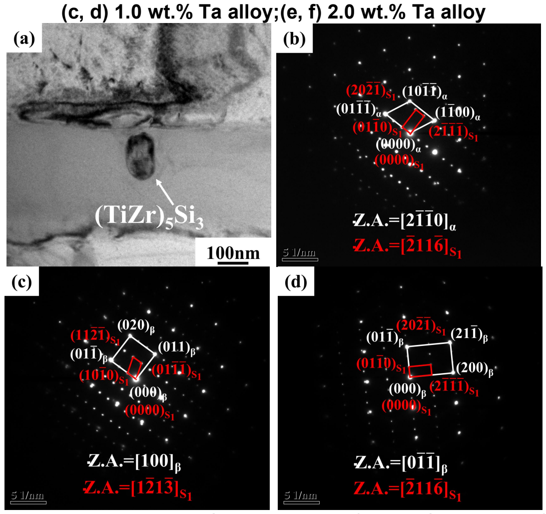

Fig. 3: (a) TEM image and SAED pattern of $(TiZr)_5Si_3$ in 2.0 wt.% Ta alloy;(b, c, d) The complex SAED pattern of $(TiZr)_5Si_3$ in three different directions in (a)

2. Mechanical properties

Table 1 shows the UTS and EL of the alloy at room-temperature and high-temperature. The results showed that the UTS of the three alloys at room temperature and high temperature increased as the Ta content increased, but the EL of the three alloys at the same temperature was not much different. It also can be seen that the tensile properties of the alloy at the same temperature increase with the increase of Ta content. This was due to the different atomic radius of Ta atoms (0.148 nm) and Ti atoms (0.145 nm). When Ta atoms were dissolved in the alloy, the lattice distortion of the matrix alloy occurred, which hindered the movement of dislocations and strengthened the matrix alloy.

Table 1: Mechanical properties of the as-cast alloys

Temperature	Alloy	UTS/MPa	EL/%
25 ℃	0 Ta	1125	0.6
	1.0 Ta	1157	0.5
	2.0 Ta	1175	1.0
700 ℃	0 Ta	707	1.6
	1.0 Ta	708	1.8
	2.0 Ta	874	2.4
750 ℃	0 Ta	606	4.3
	1.0 Ta	612	5.3
	2.0 Ta	749	3.8

4 Conclusion

(1) The as-cast alloys are mainly composed of α-Ti, β-Ti, Y_2O_3 and silicides, belonging to α+β type titanium alloy.

(2) The orientation relationship between the S1-type silicide and α-Ti matrix of 2.0 wt.% Ta alloy can be identified as $(01\bar{1}0)_{S1}$ // $(01\bar{1}\bar{1})_{\alpha}$ and $[\bar{2}11\bar{6}]_{S1}$ // $[2\bar{1}\bar{1}0]_{\alpha}$; the orientation relationship between the S1-type silicide and β-Ti matrix can be identified as $(01\bar{1}0)_{S1}$ // $(01\bar{1})_{\beta}$ and $[1\bar{2}1\bar{3}]_{S1}$ // $[100]_{\beta}$; $(01\bar{1}0)_{S1}$ // $(01\bar{1})_{\beta}$, $(2\bar{1}\bar{1}\bar{1})_{S1}$ // $(200)_{\beta}$ and $[\bar{2}11\bar{6}]_{S1}$ // $[0\bar{1}\bar{1}]_{\beta}$.

(3) The UTS of the as-cast alloys increase with the increase of Ta content, whereas the elongation change is not significant.

5 Acknowledgments

This research was funded by the S&T Program of Tianjin under Grant No. 22YDTPJC00150.

References

[1] Y. N. Sun, H. C. Gong, J. Y. Ying, S. Xu, L. Yang, J. J. Zhang, Q.B. Fan, Quantitative relationship between impact toughness and quasi-static tensile properties of Ti-652 titanium alloy, J. Alloys. Compd. 971 (2024) 172678.

[2] M. D. Hayat, H. Singh, Z. He, P. Cao, Titanium metal matrix composites: An overview, Compos. Part. A. Appl. Sci. Manuf. 121 (2019) 418-438.