Characteristics of α Precipitated Phase and Tensile Properties of Cast Ti5553 Alloy

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Abstract: Ti5553 (Ti-5Al-5V-5Mo-3Cr) not only has high strength, but also has good mould filling fluidity, which is a typical high strength casting titanium alloy. The mechanical properties and deformation behavior of Ti5553 alloy mainly depend on the coupling effect of α phase characteristics and residual β matrix. The current research mostly focuses on the deformed alloy and the dependence of the mechanical properties of cast Ti5553 alloy on α phase characteristics is still unclear. In this paper, the room temperature tensile deformation behaviour of cast Ti5553 alloy and its relationship with α precipitated phase characteristics under different heat treatment process are investigated. The results show that: the HCP+FCC structure within the α lamellae of the alloy in the hot isostatic state activates numerous slip systems and the coordinated deformation of α twins and FCC phases leads to yield strength, tensile strength, and elongation of 955 MPa, 1020 MPa, and 10%, respectively; After solid solution aging, a large number of fine acicular α phases precipitate on the β matrix, and the alloy has high strength but very low ductility; the double annealed state alloy has the best strength-ductility match, and the yield strength, tensile strength, and elongation reach 1020 MPa, 1080 MPa, and 8%, respectively. The multiscale α lamellae intralaminar slip shear and α twins are the structural roots of their good strength-ductility.

Keywords: Cast Ti5553 alloy, α phase characteristics, Tensile properties, Deformation behavior

1 Introduction

Metastable β titanium alloys have great potential for application in fields such as aerospace and biomedicine due to their high specific strength, good fatigue resistance, and excellent processing performance[1,2]. Ti5553 alloy is expected to become a typical high-strength cast titanium alloy. The mechanical properties and deformation behavior of Ti5533 alloy actually depends on the characteristics of the α precipitated phase and the coupling of residual β phase. They are highly sensitive to heat treatment processes. In recent years, the strength-ductility of metastable β alloys is mostly improved by heat treatment to obtain the multiscale α phase[3]. Currently, most of the related studies focus on deformed alloys, and the dependence of the mechanical properties of cast Ti5553 alloy on the characteristics of α precipitated phases is not clear. Therefore, in this paper, the room temperature tensile deformation behaviour of cast Ti5553 alloy under different heat treatment process and its relationship with α precipitated phase characteristics are investigated.

2 Experimental procedure

The cast Ti5553(Ti-5.27Al-5.15V-5.25Mo-3.16Cr-0.22O) alloy used in this study, was prepared through investment casting. To address the hole defects in the casting process, a hot isostatic pressing treatment (HIP,820 °C/130 MPa/2 h) was applied to the Ti5553 alloy cast ingot. Three kinds of heat treatment processes, annealing (700 ℃/2 h/AC), double annealing (865 ℃/30min→600 ℃/4 h/AC) and solid solution ageing (880 ℃/30 min/AC+600 ℃/4 h/AC), were carried out on the HIP-Ti5553 alloy.

3 Result and discussion

Microstructure and mechanical properties

The average thickness of the α lamellae in the HIP-Ti5553 alloy is 0.74±0.20 μm, and there is no fine acicular α phase on the β matrix. The α lamellae within the β matrix are slightly coarsened after annealing. After double annealing, β matrix precipitated lamellar α with "fibrous root morphology"[4] and fine acicular α phases. The average thickness of the α lamellae reaches 1.16±0.20 μm, and the thickness of the fine acicular α-phase is about 150~250 nm, and the length is 0.75~1.25 μm. After solid solution aging, a large number of V-shaped or triangular fine acicular α_s phases precipitated in the β matrix The average thickness of the fine acicular α_s is below 100 nm, and the length is about 0.1-0.3 μm. The mechanical properties of the alloys in different states are shown in Fig.1. Annealed alloys have the highest elongation but low strength; the alloys after solid solution ageing have the highest strength but almost brittle fracture; the alloys in the double-annealed state had the best strength-ductility match, with yield strength, tensile strength and elongation up to 1020 MPa, 1080 MPa and 8%, respectively.

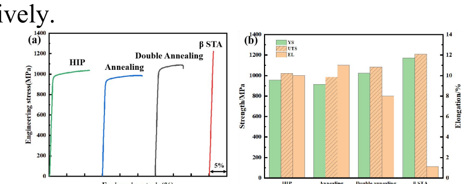

Fig. 1 Comparison of tensile stress-strain curves (a) and properties (b) for cast Ti5553 alloy after different

heat treatment process

4 Deformation behaviour

In order to further analyze the reasons for the good matching of strength-ductility of the HIP-Ti5553 and double annealed Ti5553, the near-fracture microstructure was analyzed by TEM. Fig.2 shows the microstructural characterization of the HIP-Ti5553 with different strains. Due to the high temperature and high pressure environment provided by the hot isostatic pressure, there are a small number of α twins and FCC phases in the α lamellae of the HIP-Ti5553 before tensile deformation. A large number of dislocations and slip bands can be seen in both the α phase and the β matrix when the tensile strain is 2%, in which the α phase is surrounded by neatly arranged misfit dislocations. When the tensile strain is increased to 6%, not only a large number of dislocations are found within the α phase of HIP-Ti5553 alloy, but also parallel distribution of α twins are observed. When the alloy is stretched to fracture, tiny twins of interconnected and zigzag shapes appear within the α phase, and there is a high density of stacking fault within some of the α twins and the α matrix between α twins. The α twins and stacking fault can form the Lomer- Cottrell lock[5]. The initially existing FCC phase deformed during tensile process, resulting in FCC twins. The HCP+FCC structure within the α lamellae activates numerous slip systems and the coordinated deformation of α twins and FCC phases resulting in an ideal strength- ductility match.

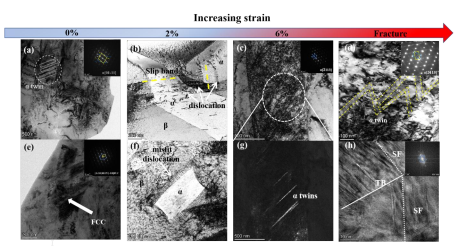

Fig. 2 TEM images of HIP-Ti5553 with different tensile strains:(a,e) 0%;(b,f) 2%;(c,g) 6%;(d,h) Fracture

Fig.3 shows the near-fracture microstructure of the double annealed alloy, which can be clearly seen that there are a small number of twins in the fine acicular α phase, and the coarse α lamellae has obvious slip shear bands and dislocations, which also verifies that the α phase with the "fibrous root morphology"[4] has good deformation ability, and there are high-density dislocations near the fine acicular α. The "fibrous root morphology" α and a small number of α twins ensure the ductility of the alloy, and the distribution of fine acicular α to dislocations in a vertical or parallel manner can better impede the alloy's strength improvement.

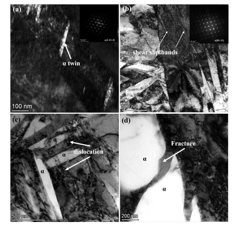

Fig. 3 TEM images of near fracture surface of cast Ti5553 alloy after double annealing: (a) α twins; (b) shear slip bands (c) fine acicular dislocations near α phase; (d) Fracture of α phase

5 Conclusion

After double annealing, the cast Ti5553 alloy has a best strength- ductility match by precipitating multi-scale α phase and inducing α twins with room-temperature tensile yield strength and elongation up to 1020 MPa and 8%.

6 Acknowledgments

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