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ROOM-TEMPERATURE MECHANICAL PROPERTIES OF TiAl+ Ce ALLOYS①

Chen Shiqi, Qu Xuanhui, Huang Baiyun, Lei Changming
Powder Metallurgy Research Institute,
Central South University of Technology, Changsha 410083

ABSTRACT The microstructures and mechanical properties of the TiAl + x Ce (x = 0.002, 0.005, 0.010, 0.015, 0.020, mole fraction) alloys in annealing condition were investigated. The results showed that the strength and deflection of the TiAl alloys were obviously enhanced by adding a small amount of Ce (e.g 0.002 mole fraction). The analyses show that this improvement was due to the refinement of microstructures and the reduction of the oxygen content in the matrix caused by Ce. However excessive Ce would result in forming coarse particles and a lot of pores, thus lowering the mechanical properties.

Key words Ce TiAl alloy mechanical properties microstructures

1 INTRODUCTION

TiAl alloys with excellent high temperature properties and low density may be considered ideal potential structural materials for applications in advanced aircrafts, but their room-temperature brittleness is one of the key bottlenecks prohibiting their practical applications. In recent years, with alloying such as Cr, Mn, V and microstructural control via thermal-mechanical treatment, their room-temperature ductility has been improved markedly. It has also been reported that the mechanical properties of the TiAl alloys are very sensitive to interstitial atoms such as oxygen. The low-oxygen alloys display higher strength and better ductility[1]. In this paper, the authors attempt to improve the mechanical properties of the TiAl alloys by using Ce as an additive.

2 EXPERIMENTAL MATERIALS AND METHOD

Raw materials used in this work were 99.6% Ti, 99.9% Al and high-purity Ce. The alloys have the following nominal composition (mole fraction): (52Ti+ 48Al) + x Ce(x = 0.002, 0.005, 0.010, 0.020). The alloys were prepared by non-consumable arc-melting in an argon atmosphere. Each alloy was melted four times for homogenization. Bending specimens were prepared by electrodischarge machining, then annealed at 1 100 ℃ for 30 h. Metallographical observation was conducted on a Neophot-2 type metalloscope. Three-point-bending tests were conducted on a WD-100B type electronic tensile testing machine. Dimensions of the specimens were 2 mm × 4 mm × 30 mm. Three specimens of each series were tested at room temperature. The gauge length of the specimens was 25 mm and the cross head speed of the testing machine was controlled at 0.2 mm/min.

3 RESULTS

3.1 Mechanical properties

Fig. 1 shows that the bending deflection and the transverse rupture strength of the TiAl alloy with 0.002 mole fraction Ce increase obviously in comparison with the binary TiAl alloy. But when Ce is in excess of 0.002 mole fraction, the strength and the deflection reduce sharply with increasing Ce content, which indicates that Ce content in TiAl alloys ought to be controlled at 0.002 mole fraction or so, otherwise it will be

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detrimental to the mechanical properties of the TiAl alloys.

Fig. 1 Bending deflection(D_p) and strength (TRS) of TiAl+ Ce alloys vs Ce content

3.2 Metallographic microstructures

Fig. 2 shows the metallographic microstructures of the TiAl+ Ce alloys. It can be seen that the microstructures are still equiaxed grains, but they are much finer and more even than those of the binary TiAl alloy[2]. With increase in Ce content, its refining role strengthens. In addition, Ce promotes the formation of α_2/γ lamellar structures and a certain amount of lamellar structures appears in the alloy with 0.020 mole fraction Ce, see Fig. 2(c).

Fig. 3 is the BEI morphology of the second particles in the TiAl+ Ce alloys. These white phases forming due to Ce increase remarkably with increase in Ce content. Fig. 3 also shows that these phases are dendritic, indicating they are formed during solidification. The elemental analyses demonstrate that this phase is Ce-rich. At present, we are investigating their microstructures and the mechanisms of formation.

3.3 Fracture morphology

It can be seen from Fig. 4 that the fracture of the TiAl alloys with Ce is mainly the transgranular mode, namely, cleavage fracture. But different from the binary TiAl alloys, the ductile fracture features with tearing ridges and tensile facets can be found in partial zones of the fracture. The fracture mode does not change when Ce is up to 0.020 mole fraction. On the fracture of the alloy with 0.020 mole fraction Ce, besides some pores, there are a lot of little dimples in which coarse particles exist. The number and size of these particles and pores increase with increase in Ce content.

Fig. 2 Metallographic microstructures of TiAl+ Ce alloys

(a) —0.002 mole fraction Ce; (b) —0.005 mole fraction Ce; (c) —0.020 mole fraction Ce

Fig. 4 Fracture morphology of TiAl+ Ce alloys
(a) —0.002 mole fraction Ce; (b) —0.020 mole fraction Ce

4 DISCUSSION

The above results show that Ce refines the grains of TiAl alloys and enhances the ductility of the γ-TiAl matrix. This role may be in close relation with the chemical characteristics of Ce. (1) As a surface active element, Ce can reduce the surface tension of liquid TiAl alloys[3], thus reducing the nucleation work required for formation of critical crystallization nuclei, which results in increasing crystallization nuclei. Furthermore the second phase particles may prohibit the growth of the grains. So the TiAl alloys with Ce addition maintain the fine and even grain structures after annealing. (2) As a highly active element, Ce has a strong chemical affinity for oxygen. It has been demonstrated[4] that rare earth elements can capture oxygen atoms from TiAl alloys to form oxide particles, leading to a more clear γ-TiAl matrix. This will reduce the pinning role of oxygen atoms on dislocations, thus improving the ductility of the alloys, see Fig. 4. Because Ce has these favourable roles in the TiAl alloys, the mechanical properties of the TiAl alloys with Ce addition are higher than those of the Ce-free alloys, see Fig. 1.

The results in Fig. 1 also show that the optimum Ce addition is 0.002 mole fraction, when exceeding that value, it would seriously deteriorate the mechanical properties of the TiAl alloys. It is known from the analyses of Fig. 3 and Fig. 4, excessive Ce would form coarse particles and a lot of pores, which are detrimental to the TiAl alloys. The formation of pores results from vaporizing during melting because of the high vapourization pressure of Ce[5]. If the solid solubility of Ce in TiAl alloys is enlarged and a large amount of the pores is reduced by using powder metallurgy rapid solidification process, it can be expected that their properties be further improved.

5 CONCLUSIONS

(1) The deflecion and strength of the TiAl alloy with 0.002 mole fraction Ce were obviously improved. When Ce content exceeding that value, their properties deteriorate sharply.

(2) The property improvement in the TiAl alloys was caused by Ce due to refined microstructures and reduced oxygen content in γ-TiAl matrix. But excessive Ce is apt to form coarse particles and a lot of pores, thus seriously deteriorating their properties.

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velocity and with decreasing the initial height of powder aggregates.

Increasing the BPR and RV values results in high plastic strain of powders, thus, the refinement of microstructures speeds up, and the grain size diminishes faster.

In addition, the fine microstructures shorten the distance of inter-diffusion, and the grain boundary and defects provide many sites for low activation energy diffusion, this coupling effects accelerate the alloying rate for large BPR and RV values, thus the time for obtaining the powders with homogeneous composition is decreased.

4 CONCLUSION

Mechanical alloying has been used to synthesize Al-4.9 Fe-4.9Ni alloy powders from the mixed elemental aluminium, iron and nickel powders. A supersaturated solid solution of iron and nickel in aluminium was formed, and the mechanical milling produced refinement of microstructures with nanocrystalline grain size. Milling intensity has great effects on alloying rate. The increasing of ball to powder ratio or rotational velocity accelerates the reduction of the grain size.

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