EFFECTS OF Ca ADDITION ON TiAl-BASED ALLOYS①

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ABSTRACT The influences of Ca addition on the microstructure and room temperature mechanical properties of as-cast TiAl based alloy were investigated. The results showed that Ca addition could improve markedly crystalline. the strength and ductility of TiAl at ambient temperature. Microstructure of Ca-doped TiAl alloy was dendric crystalline. Fracture mode of Ti-Al-Ca ternary alloy was a mixed mode, including cleavage cracks vertical to lamellar direction and "river" pattern in γ single phase. In addition, a lot of tear ridges were found in the fractured surface.

Key words TiAl-based alloy alloying mechanical properties fracture

1 INTRODUCTION

The ordered intermetallic compound γ-TiAl has great strength-to-werght ratio, high modulus of elasticity and good creep resistance at elevated temperature. These attractive features make TiAl based alloys potentially viable engineering materials for high temperature structural applications. However, the brittleness at ambient temperature and poor hot formability hinder their industrial utility[1]. Alloying could decrease tetragonality ratio c/a value. Decreased c/a value may then reduce covalency bond and/or decrease the magnitude and anisotropy of the Peierls stresses, thereby enhancing the activity of 1/2< 110] unit dislocations[2-5]. The previous studies have shown that interstitial impurities such as oxygen, nitrogen and carbon can reduce the ductility significaltly. For example, Kawabata T *et al* [6] have reported that Ti-48Al with a duplex microstructure exhibits a room temperature tensile ductility of 2% with 800×10^{-6} oxygen and 2.7% with 370×10^{-6} oxygen. There has been speculation that the α_2 phase or the addition of erbium can scavenge oxygen in γ phase. The effects of calcium addition on the microstructure, room temperature mechanical properties, phase structure and fracture behaviour were investigated in the present study.

2 EXPERIMENTAL

Ti(99.6%), Al(99.7%) and Ca(99.9%) were melted by nonconsumable arc melting in argon on a water cooled copper hearth to prepare some 30 g button ingots. The nominal composition is Ti-34Al(%), with Ca contents of 0.5%, 1.0%, 1.5%, 2.0% respectively.

There-point bending tests were conducted using CSS-112 material test machine. The ascast specimens, which were sized 2 mm × 4 mm × 30 mm, were cut from the button ingots. The span length was 25 mm and the cross hesd speed was 0.2 mm/min. The metallographic observation was done under Neophot-II optical microscopy (OM). The fracture morphologies were analysed by means of an X650 scanning electron microscopy(SEM). The phase structure was determined by Rigaku 3041 X-ray diffractometer.

3 RESUL

3.1 Mechanical properties

The results of three-point pending tests at ambient temperature for as-cast TiAl based alloys were depicated in Fig. 1. It is obvious that the Ca-doped ternary alloys have more excellent room temperature mechanical properties than Cafree TiAl binary alloy with the same Ti and Al contents. The 0.5% Ca addition can improve

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bending strength by 30%, deflection by 100%. Increasing Ca contents in TiAl, the strength (TRS), deflection(f) and ductility(D_p) will be improved. The mechanical properties reach the maximum with Ca concentration of 1.0%. The strength (TRS), deflection (f) and ductillty (D_p) of Ti-34Al-1.0Ca increase by 59%, 120% and 50% respectively, compared with Ti-34Al binary alloy. Therefore, calcium in one of the effective alloying elements for TiAl compounds. Ca Can remarkably improve the room temperature properties of gamma TiAl alloys.

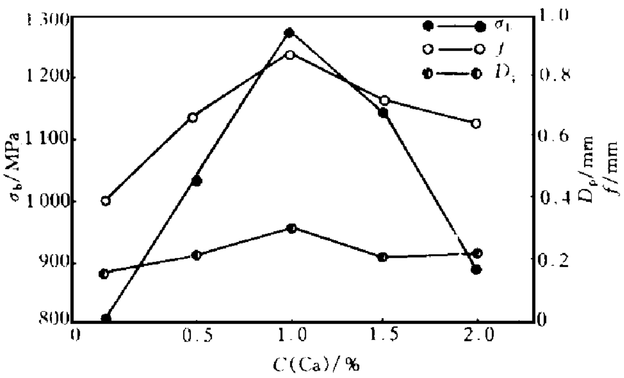


Fig. 1 Mechanical properties of TiAl+ Ca alloys at room temperature

3.2 Microstructure

Fig. 2 shows the metallographs of as-cast TiAl based alloys with different Ca contents. The microstruncture of Ti-34Al is the coarse columar reains with obvious lamellar feature, as shown in Fig. 2(a). The small Ca addition, e. g. 0.5% Ca, changes the coarse columar grains into fine dendric grains (Fig. 2(b)). The grains size decreases with the increasing Ca concentrations(Fig. 2(c). Even with 2.0% Ca content, fine dendric grains can be found, companied by some gamma phase precipitation(Fig. 2(d)).

Fig. 3 is the relationship between secondary arms spacing and Ca contents. The secondary arme spacing of Ti-34Al-1.0 Ca (%) is the finest.

3.3 Phase constitution

Powder specimen of 200 mesh was used in X-ray diffraction ananlysis. Fig. 4 is the XRD spectra of TiAl and TiAl+ Ca alloys. No new phases can be detected in Ca-doped TiAl ternary

Fig. 2 Effects of Ca addition on the microstructure of TiAl alloy

(a) – 0% Ca; (b) – 0.5% Ca;
(c) – 1.0% Ca; (d) – 2.0% Ca

alloys. But Ca addition leads to the changes in γ phase call structure. For Ti-34Al compound, the lattice tetragonality c/a is 1.019 and the unit cell volume ca^2 is 6.521×10^{-2} nm^3. With the 1.0% Ca concentration, the lattice c/a and cell volume ca^2 decrease to 1.018 and 6.484×10^{-2} nm^3 respectively. Hence, Ca addition can decrease γ phase cell tetragonality and cell volume, decreasing Peierls stress in γ phase to increase the activity of super dislocations and unit dislocations.

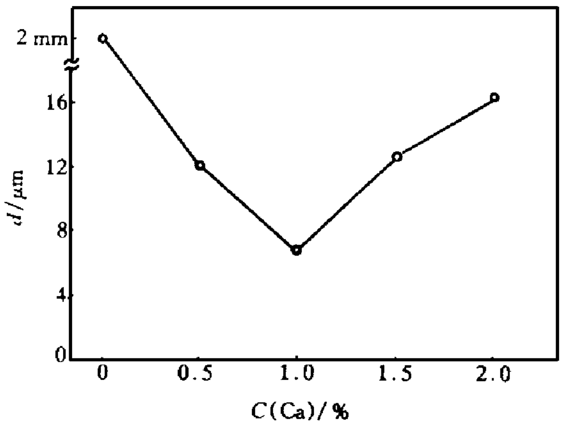
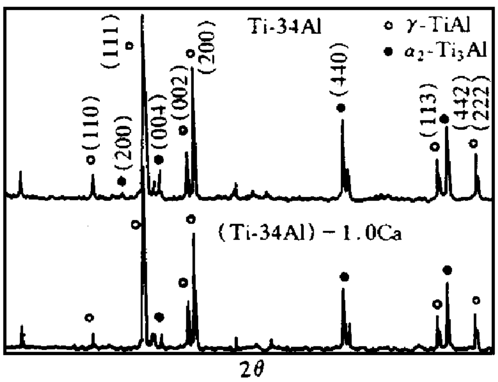


Fig.3 Secondary arms spacing of TiAl alloy



ig. 4 XRD spectra of TiAl+ Ca alloy

3.4 Fractographs

The fractographs of the TiAl-base alloy with different Ca contents are shown in Fig. 5. For the Ti-34Al binary alloy, the cracks were propagated along the normal direction of lamellar structure. The fracture mode is transgranular cleavage and the cleavage steps are very smooth, a;, pst mp tear rodges cam be found in the fractured surface, as shown in Fig. 5(a). Markable variation of fractograph takes phace due to the addition of calcium. For Ti-34Al-0.5Ca(%) alloy, the fracture mode is a mixed mode, inclunning transgranular cleavage and intergranular cleavage. The cleavage steps are more steep, and some tear ridges can be observed in the fractured surface(Fig. 5(b)). As the amount of Ca is raised to 1.0%, the tear ridges are much more than that of TiAl-0.5Ca. In addition, smoe parts of fractured surface show the "river" patterns Although the fractograph of TiAl+ Ca alloy is still of characterization of cleavage fracture, the cleavage cracks can propagate a long distance in single γ phase, forming some river patterns. Thereby, Ca addition can enhance the ductility of TiAl base alloys.

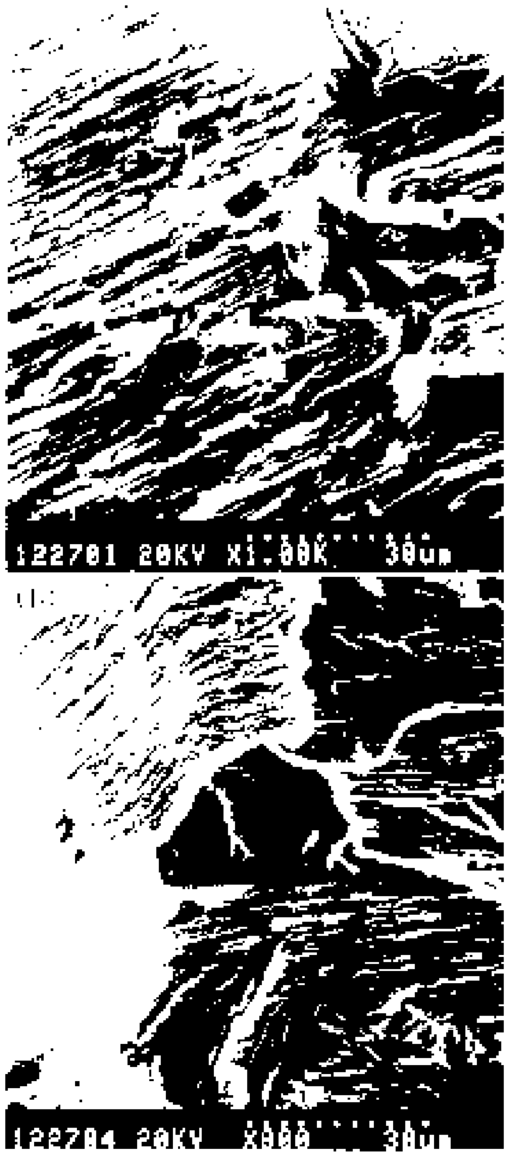


Fig.5 **Fractgraphs of TiAl+ Ca alloy (a)-0% Ca; (b)-0.5%Ca**

4 DISCUSSION

Is is known that the ambient temperature mechanical strength and ductility of TiAl+ Ca ternary alloys are more excellent than those of TiAl binary alloy. The reasons lie in two aspects: the effect of Ca addition on the change in microstructure and the effect on the fracture mode.

Calcium, a kind of surface active elements, can decrease the surface tension of liquid metal melts, decreasing the nucleation energy of embryos with critical grain size, thus, increase crystal nuclei number during solidification process. In addition, small amount of CaO resulted from the reaction between Ca and oxygen, acts as heterogeneous, nuclei, refining crystal grains. Therefore, as-cast microstructure changers from coarse columar grain into fine dendric. Strength and ductility of alloy increase with decreasing grain size.

Ca has great affinity with oxygen. From Kawabata's experiment it will be speculated that the addition of calcium can clean oxygen in the matrix of alloy, thereby increasing the purity and thus the ductility of TiAl compounds. When the content of Ca exceeds 1.0%, the properties decrease due to the casting defects resulted from Ca volatilityprobably.

TiAl binary alloy exhibits pure cleavage fracture feature, otherwise TiAl+ Ca ternary alloys show part ductile fracture features. The tearridges and river pattern can be found in the fractured surface.

5 CONCLUSIONS

(1) Ca addition can remarkably improve the strength and ductility of TiAl based alloys at ambient temperature.

(2) The microstructure of as-cast TiAl+ Ca alloys shows fine dendric grains.

(3) The tetragonality ratio *c/a* decreases with Ca addition.

(4) TiAl+ Ca alloys exhibit the characteristics of mixed fracture feature, including cleavage of lamellar colonies and cleavage of gamma single phase. Many tear ridges can be found in the fractured surface.

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