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Tuning mechanical properties for *β*(B2)-containing TiAl intermetallics

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Abstract: Based on the analyses of the microstructures and phase diagrams of the TiAl-based alloy, the relationship among the composition, structure and mechanical properties of the B2-containing *γ*-TiAl alloys was reviewed. The refinement of microstructures and improvement of mechanical properties of TiAl alloy through stabilization of the *β*/B2 phase were reviewed. The mechanism of the superplastic behavior of the B2-containing *γ*-TiAl alloys was discussed. With a reasonable addition of *β*-stabilizer, metastable B2 phase can be maintained, which is favorable for fine-grained structure and better high-temperature deformation behaviors. The mechanical properties of the B2-containing TiAl alloy, including the deformability and elevated temperature properties, can also be improved with doping elements and subsequent hot-working processes. The above mentioned researches discuss a new way for developing TiAl alloys with comprehensive properties, including good deformability and creep resistance.

Key words: *β*-stabilizing elements; B2 phase; TiAl-based alloys; phase diagram; grain refinement; thermal processing; superplastic deformation

1 Introduction

With the fast development of modern industry, especially the aerospace industry, how to enable materials to efficiently serve at high temperatures is very essential. It is potential to use lightweight materials to reduce consumption of energy and achieve a sustained development of society. Gamma-TiAl alloy has continued to attract much attention from scientists for its properties of low density, high specific strength and moduli, good resistance against creep, oxidation and corrosion at elevated temperatures. In the last 30 years, the alloy based on *γ*(TiAl) phase with a tetragonal $L1_0$ structure has been extensively studied. It also contains a certain amount of $\alpha_2(Ti_3Al)$ phase with a close-packed hexagonal $D0_{19}$ structure. Gamma-based TiAl alloy, with about half of density of traditional Ni-based alloy, can also be in service durably at elevated temperatures [1−5].

However, its inherent ductility still maintains a problem affecting the forming processes, even at high temperatures. By being alloyed with some strong *β*(B2)-stabilizing elements, such as refractory metals (Cr, Nb, W and Mo), the *γ*-TiAl alloy with a fine-grained structure may maintain a metastable B2 phase (the ordered phase of *β* at low-temperature) in *γ* phase, and have favorable high-temperature deformation ability [2,6−8]. Consequently, the B2-containing TiAl alloy (the *γ*-based TiAl alloy contains a certain amount of *β*(B2) phase) has arisen much concerns.

It is also important to know why and how the *β*(B2) phase can be formed in *γ*-based TiAl alloy, and what is the effect of B2 phase on microstructure and properties. Thus most of researches on the B2-containing TiAl alloy focused on the development of new TiAl alloy which possessed excellent mechanical properties and favourable workability.

In this work, the authors will summarize the recent progresses on the investigation of B2-containing TiAl alloy, including the composition−structure−property relationship, the effect of *β*(B2) phase, the deformation and superplastic behaviors, and the applications. The authors aim to provide useful reference for designing and tuning mechanical properties for the new B2-containing intermetallics.

2 B2-containing TiAl alloy

In the early 1980s, scientists [9,10] have already begun to pay much attention to the existence of B2 phase

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in TiAl alloys. Similar phenomena have been observed in a certain amount of ordered β phase (B2(CsCl) type structure) occurring in refractory metal-containing TiAl alloy system. KIMURA et al [11] investigated the effect of additional elements X(including V, Cr, Mn, Nb, and Mo) on γ-based titanium aluminides. The β phase is stabilized due to phase equilibria among γ(TiAl), $\alpha_2(Ti_3Al)$ and B2 (B.C.C. Ti) [7,12] phases.

The B2-containing TiAl alloys usually have Al concentrations of 44%−48% in mole fraction. INKSON et al have studied some B2-containing TiAl alloys, such as Ti−45.5Al−1.6Fe−1.1V−0.7B [13] and Ti−47Al−4(Cr, Nb, Mo, B) [14]. The existence of β(B2) grains is beneficial for grain refinement and high-temperature deformation. Compared with other TiAl alloys of $\gamma+\alpha_2$ phase, although their strength has not been enhanced definitely, their plastic deformation properties at elevated temperatures have been improved remarkably. Researchers [1,15−20] identified the superplastic behaviors, which are partially attributed to the existence of B2 grains in B2-containing TiAl alloys.

Several applications, i.e. turbine blades and engine-valves made of B2-containing TiAl alloys, have been announced by CLEMENS [21], TETSUI [22] and GE company [23,24]. Most of the components possess satisfactory properties for the applications.

In order to better understand the effect of β(B2) phase, the following aspects for B2-containing TiAl alloy were concerned: 1) Relationship between composition and microstructure, to understand how to control the contents of phases and microstructures through alloying and succedent thermal processing(es); 2) Relationship between structure and properties, to reveal the mechanism of strengthening-toughening, creep and oxidation processes, and to clarify the influence of B2 phase on performances at elevated temperatures; 3) mechanism of deformation and superplastic behavior, to study how to improve the thermal deformation ability and performance by controlling the composition and structure, and to develop a new B2-containing TiAl alloy with proper properties which can be used as a high-temperature lightweight material for industrial applications.

3 Composition−structure−property relationship

3.1 Composition and structure

Phase structure, equilibria and characteristics of B2-containing TiAl alloy should be clearly identified for designing compositions and thermal processing procedures.

3.1.1 Structure and characteristics

According to the Ti−Al binary phase diagram, the β phase hardly occurs as an ordered B2 variant in Al-rich compositions. However, it can appear in Al-lean section, which contains some refractory metal stabilizers.

The crystallographic data of some stable and metastable phases occurring in the Ti−Al−X system are given in Table 1, and the crystal structures of phases present in the B2-containing TiAl alloy are shown in Fig. 1. It has been reported that the position substituted by different β-stabilizing elements in the lattice of B2 phase is varied. Usually, alloys (such as Cr, V and Nb) are easy to substitute the Ti sublattice [25]. Molybdenum appears to substitute either Ti or Al sublattice. CHEN and JONES [26] have shown that when the titanium or aluminium content drops, Mo substitutes the titanium or aluminium sublattice, respectively. The substitution will induce the change of lattice parameters and density of B2 phase.

3.1.2 Phase equilibria and phase diagram

Phase diagrams, including Ti−Al multi-component systems, are useful for the graphical representations of the phase changes, design and control of heat treatment procedures.

The thorough assessment of the binary Ti−Al phase diagram by MURRAY [36] in 1987 has been considered a standard reference, and also reassessed in a comprehensive study using all available experimental

Table 1 Crystal data for Ti−Al−X system

Alloy	Density/ $(mg\cdot m^{-3})$	Cell parameter [27]			Personal symbol	Space group	Crystal structure	Reference
		a/nm	c/nm	γ/(°)				
β(ht Ti)	4.31	0.333	0.333	90	cI2	$Im\bar{3}m$	BCC-A2	[28]
α(rt Ti)	4.12	0.289	0.464	120	hP2	$P6_3/mmc$	HCP-A3	[29]
$\alpha_2(Ti_3Al)$	4.22	0.578	0.465	120	hP8	$P6_3/mmc$	$D0_{19}$	[30]
γ(TiAl)	3.82	0.283	0.407	90	tP2	$P4/mmm$	$L1_0$	[31]
$B2(TiMo_{0.5}Al_{0.5})$	5.63	0.318	0.318					[32]
$B2(TiNb_{0.5}Al_{0.5})$	4.75	0.324	0.324	90	cP2	$Pm\bar{3}m$	B2	[33,34]
$B2(Ti_1Cr_{0.3}Al_{0.7})$	4.55	0.312	0.312					[35]

* $a=b$ and $\alpha=\beta=90°$. The values of density and (a, b, c) will be changed after alloying with some other different elements.