JOURNAL OF MATERIALS SCIENCE **37** (2002) 1809–1812

Microstructures and mechanical properties of as-cast TiAl alloys with higher C additions

ZUNJIE WEI, HONGWEI WANG, YUNYUE JIN
School of Materials Science and Engineering, Harbin Institute of Technology, Harbin150001, People's Republic of China
HU ZHANG
Department of Materials Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100083, People's Republic of China
SONGYAN ZENG
School of Materials Science and Engineering, Harbin Institute of Technology, Harbin150001, People's Republic of China

TiAl alloys with higher C additions were fabricated using a XD^{TM} method. The results investigated by XRD, OM and SEM indicated that in Ti-34Al-0.5C alloy, single phase TiC particles and particles having a "core" structure in which the TiC phase was coated by Ti_3AlC phase were formed and they uniformly distributed at the grain boundaries. However, when C content is more than 0.5%, the particles with a plate-shape were single phase Ti_2AlC and TiC phase coated by Ti_2AlC phase. These results suggested that in TiAl alloys with higher C additions, the primary is TiC, and the Ti_3AlC and Ti_2AlC result from peritectic reaction, L + TiC. The results measured by MPM show that with the increasing of C content, the microhardness both TiC, Ti_3AlC and Ti_2AlC is higher than that of the matrix Ti_3Al and TiAl. However, the elastic modulus of particle phases and matrix has little variation and no change tendency can be found with increasing C content.

1. Introduction

TiAl-based intermetallic alloys having low density, higher melting point and good high temperature properties make them attractive for high temperature structural and engineering materials [1]. Minor amounts additions of carbon can improve the creep resistance of titanium aluminide alloys and the effects of carbon additions have been investigated [2–5]. Carbides precipitated in a number of TiAl-based alloys containing various carbon additions have been characterized and categorized as P-type (Ti_3AlC-perovskites) and H-type (Ti_2AlC-hexagonal) carbides [6, 7]. Almost all of the studies concentrated on the minor amounts additions of carbon and the precipitation strengthening effects of P-type and H-type carbides. However, the P-type and H-type carbides have relatively high stability when competing with the extremely stable binary carbides such as TiC_{1-x}, VC_{1-x}, or Cr_3C_2 and good wear resistance [8, 9]. The potential of P-type and H-type carbides as reinforcement in TiAl alloys has been widely overlooked.

The purpose of this study is to investigate the microstructures and mechanical properties of as-cast TiAl-based alloys with higher C additions.

2. Experimental procedure

The ingots used in this investigation were prepared by melting sponge titanium, aluminum and Al/TiC master alloy in a water cooled copper hearth using a non-consumable tungsten electrode. The Al/TiC master alloy was produced using self-propagating synthesis (SHS) method by dry ball milling high pure titanium powder (99.7%, 45 μm), high pure Al powder (99.6%, 29 μm) and carbon powder (99.8%, 0.05 μm), and then uniaxially pressed them into green compacts. To ensure the chemical homogeneity of the melted alloy, the ingots were melted at least three times. The phase constitutions of alloys were performed using a Rigaku D/max-RB X-ray diffractometer (XRD). The microstructures were observed on a BHM-UMA optical microscope, and a Philip S-570 scanning electron microscope (SEM). Microanalysis using energy dispersive X-ray spectroscopy (EDS) was done using scanning electron microscopy. The microhardness and the elastic modulus were measured by a NANO INTENDER II^{TM} mechanical property microprobe (MPM) and the results were an average of at least three indents. Table I listed the compositions of the samples determined by chemical analysis.

3. Results and discussion

The X-ray diffraction spectrum, in Fig. 1, indicates the Ti-34Al-0.5C alloy consists of TiAl, Ti_3Al, TiC and Ti_3AlC.

TABLE I Compositions of the alloys determined by chemical analysis (wt%)

Alloys	Al	C	O	Ti
Ti-34Al-0.5C	33.7	0.49	0.26	Bal.
Ti-34Al-1.0C	34.2	1.05	0.28	Bal.
Ti-34Al-1.5C	33.5	1.46	0.34	Bal.
Ti-34Al-2.0C	33.1	1.95	0.32	Bal.

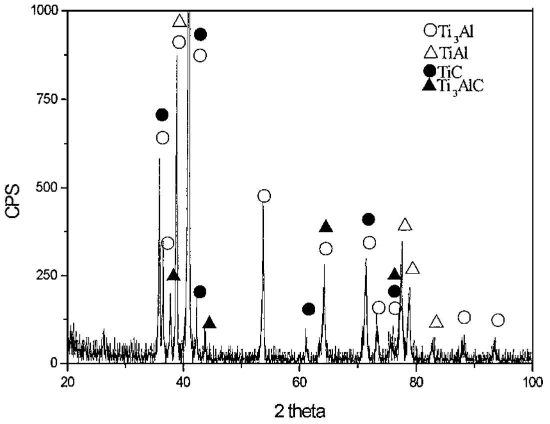

Figure 1 XRD pattern of Ti-34Al-0.5C alloy.

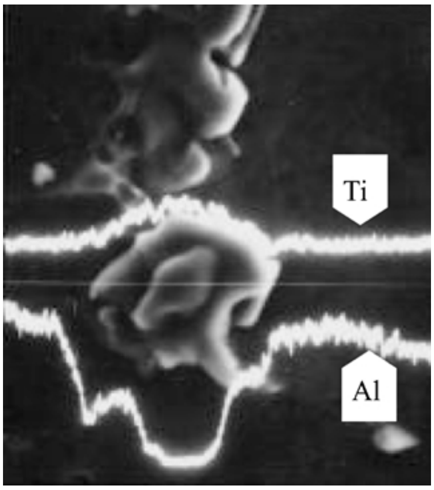

Figure 3 Microanalysis of a core particle.

Optical micrographs of the microstructures of Ti-34Al-0.5C alloy are shown in Fig. 2. Fig. 2a reveals particles homogeneously distributed at the grain boundaries, but some particles can also be found inside the grain. Coalescence of particles can be frequently observed and they locate at the triangle grain boundaries. Fig. 2b indicates that the particles at grain boundaries have a "core" structure, in which the core phase is coated by a shell phase. The core phases with an average size $<2\ \mu$m are spherical shape and the shell phases are almost exclusively faceted shape. The average size of this kind of particles is around 5 μm. Aggregate particles distributing at the triangle grain boundaries and having a chrysanthemum-shape morphology, as shown in Fig. 2c, have two types of morphologies, the "core" structure and without "core" structure particles.

In Fig. 3, the electron microprobe analysis results display that Ti element can be observed both in the core phases and in the shell phases. However, there is no Al element in the core phase, and the Al content in the shell phase is higher. The atomic ratio of Ti element and Al element in shell phases measured by EDS using the point counting technique is about 3. Comparison with the XRD results in Fig. 1, it can be confirmed that the core phases are TiC and the shell phases are Ti$_3$AlC. Compositions of carbides without the "core" structure were also measured using the point counting technique and the results demonstrated that these carbides are TiC and Ti$_3$AlC.

The "core" structure of the carbide phase particles in the as cast microstructure implys that in Ti-34Al-0.5C alloy the primary phase is TiC, followed by the reaction of $L + TiC \rightarrow Ti_3AlC$ peritectic. The observation of primary TiC enveloped in faceted Ti$_3$AlC could be

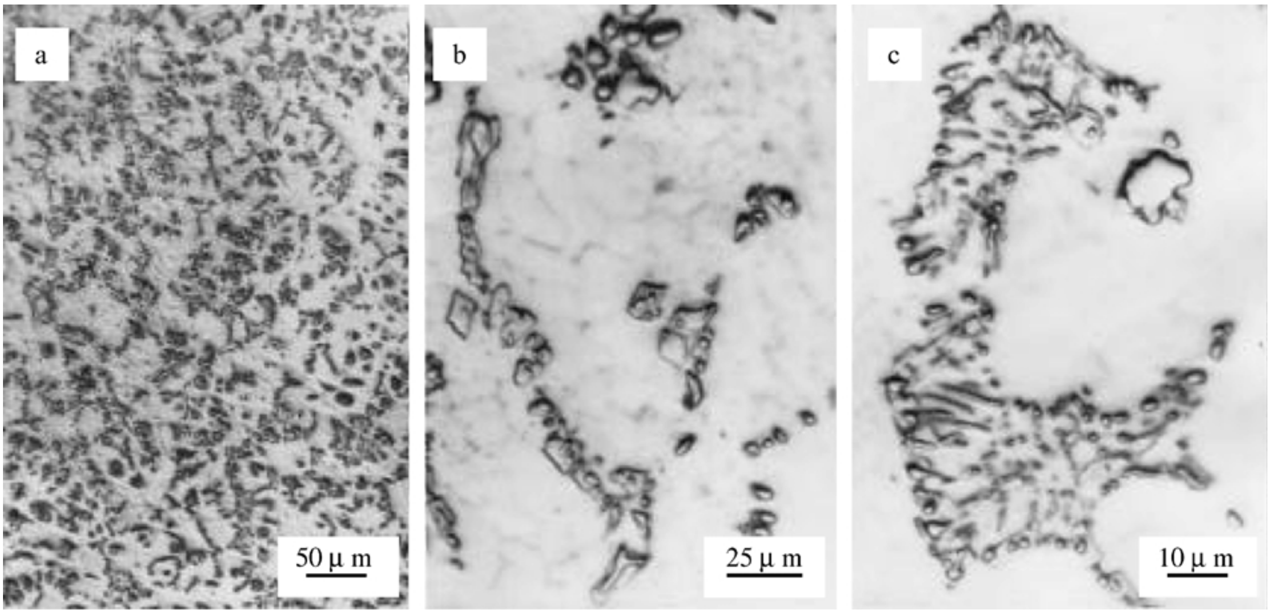

Figure 2 Microstructures of Ti-34Al-0.5C alloy. (a) Particles homogeneously distributed at the grain boundaries, (b) "Core" structure particles at grain boundaries, (c) Chrysanthemum morphology.

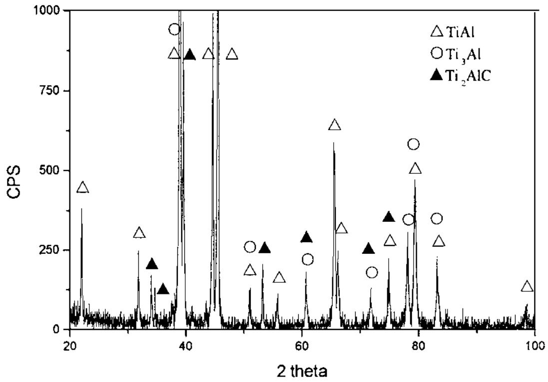

Figure 4 XRD pattern of Ti-34Al-2.0C alloy.

the result of an incomplete peritectic reaction due to the fast cooling role of the water-cooled copper hearth.

The shape, size, and the distribution of the carbide phase particles in the as cast microstructures of the Ti-34Al-0.5C alloy suggest that on the one hand, some particles were pushed by β-Ti dendrites and then were entrapped in interdendritic regions; on the other hand, some particles were located at a position within the liquid which would become interdendritic regions during the growth of the β-Ti dendrites. Also, spherical particles with smaller size were pushed more easily than particles showing a random shape. Then, the residual melt at triangle grain boundaries occurs $L \rightarrow \beta\text{-Ti} + \text{TiC}$ eutectic reaction. So, the chrysanthemum morphology is consisted of single phase TiC and TiC phase coated by Ti_3AlC phase.

For alloys with C additions more than 0.5%, X-ray diffraction patterns indicate the phase constitutions are Ti_3Al, TiAl, and Ti_2AlC. Fig. 4 shows the XRD pattern of Ti-34Al-2.0C alloy.

The microstructures of these alloys are shown in Fig. 5. It can be seen that the Ti_2AlC particles have plate-shape morphology, and with increasing C content the size of Ti_2AlC particle become smaller.

In Ti-34Al-1.0C alloy, some particles indicated by arrow in Fig. 6 also have a "core" structure.

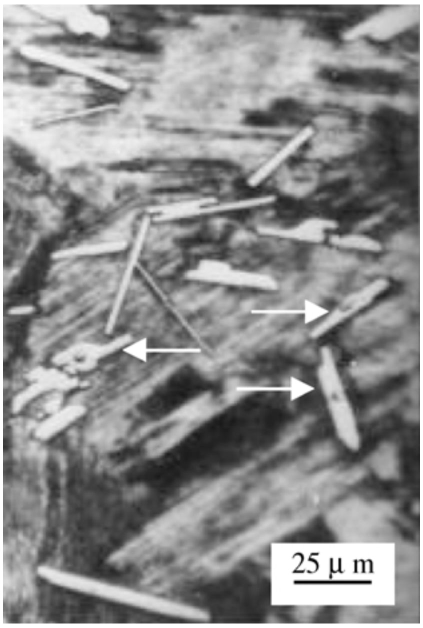

Figure 6 Some particles in Ti-34Al-1.0C alloy have a "core" structure.

This occurrence was also found in Ti-34Al-1.5C and Ti-34Al-2.0C alloys. The electron microprobe analysis results of this "core" structure are similar to that of the "core" structure in Ti-34Al-0.5C alloy, indicating that the core phases are TiC and the shell phases are Ti_2AlC, although the TiC phase hasn't been detected by XRD. It demonstrated that the primary phase is TiC, and Ti_2AlC phase results from peritectic reaction, $L + \text{TiC} \rightarrow Ti_2AlC$. These results confirmed the suggestions proposed by Schuster *et al.* [8] that ternary carbides form well above 1000°C by peritectic reaction of $L + \text{TiC}$.

The microhardness and the elastic modulus of particles and matrix in these alloys were measured by a NANO INTENDER II^{TM} mechanical property microprobe (MPM). The average values are listed in Table II.

It can be found that the microhardness and the elastic modulus both of TiC, Ti_3AlC and Ti_2AlC are higher than that of Ti_3Al and TiAl matrix in Ti-34Al-0.5C alloy. However, with the increasing of C content, although the microhardness of Ti_2AlC is higher than that of matrix, the elastic modulus both of particles and matrix

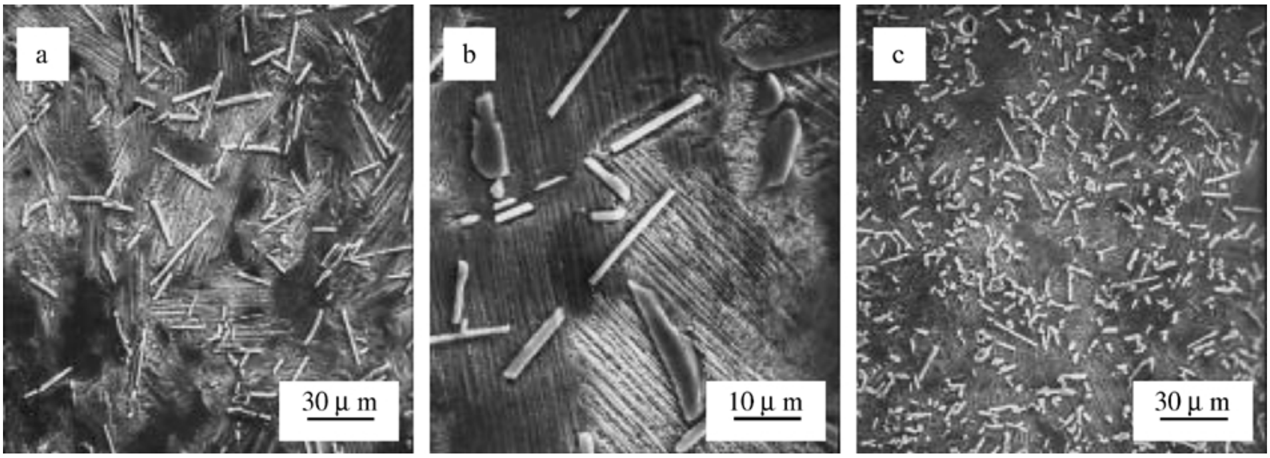

Figure 5 Microstructures of Ti-34Al alloys with C additions more than 0.5%. (a) Microstructure of Ti-34Al-1.0C alloy, showing larger Ti_2AlC particles, (b) Microstructure of Ti-34Al-1.5C alloy, showing plate-shape Ti_2AlC, (c) Microstructure of Ti-34Al-2.0C alloy, showing smaller Ti_2AlC particles.

TABLE II Microhardness and elastic modulus of particles and matrix

Nominal composition	Phases	Microhardness (GPa)	Elastic modulus (GPa)
Ti-34Al-0.5C	TiC	21.5	310.2
	Ti_3AlC	11.3	261.4
	Ti_3Al	8.1	205.0
	TiAl	7.0	220.5
Ti-34Al-1.0C	Ti_2AlC	8.6	216.5
	Ti_3Al	8.1	228.6
	TiAl	7.2	227.4
Ti-34Al-1.5C	Ti_2AlC	8.3	245.8
	Ti_3Al	7.9	220.3
	TiAl	6.8	216.0
Ti-34Al-2.0C	Ti_2AlC	8.4	224.2
	Ti_3Al	7.8	195.0
	TiAl	6.9	228.9

has little variation and no change tendency can be observed.

4. Conclusions

The investigated results for the microstructures and mechanical properties of as cast Ti-34Al alloys with higher C additions are summarized as follows.

1. In Ti-34Al-0.5C alloy, there are two types of particle phases, single phase TiC and TiC phase coated by Ti_3AlC phase. The distribution and shape of particles suggested that a dendritic solidification front during the solidification process and entrapment of the particles between the growing dendrites which lead to particles incorporation at a later stage of the solidification had occurred. Alloys with C content more than 0.5%, single phase Ti_2AlC particles having plate-shape are formed besides some particles having a TiC core and Ti_2AlC shell in duplex Ti_3Al and TiAl matrix.

2. The "core" structure of particles in these alloys confirmed that TiC is primary phase, and that Ti_3AlC and Ti_2AlC phases result from peritectic reactions, $L + TiC$.

3. The results measured by a NANO INTENDER II^{TM} mechanical property microprobe (MPM) show that the microhardness of particles in Ti-34Al alloys with higher C additions are higher than that of the matrix in these alloys, and no change tendency in the elastic modulus of particles and matrix can be observed with increasing C content.

References

1. J. D. WHITTENBERGER, R. RAY and S. C. FORMER, *Intermetallics* **2** (1994) 167.
2. J. D. WHITTENBERGER and R. RAY, *Scr. Metall. Mater.* **33** (1995) 1505.
3. B. D. WORTH, J. W. JONES and J. E. ALLISON, *Metall. Mater. Trans.* **26A** (1995) 2961.
4. P. I. GOUMA, S. J. DAVEY and M. H. LORETTO, *Mater. Sci. Eng.* A **241** (1998) 151.
5. H. S. PARK, S. W. NAM, N. J. KIM and S. K. HWANG, *Scripta Materialia* **41** (199) 11.
6. S. CHEN, P. A. BEAVEN and R. WAGNER, *Scr. Metall. Mater.* **26** (1992) 1205.
7. W. H. TIAN, K. HARADA, R. NAKASHIMA, T. SANO and M. NEMOTO, *J. Japan Inst. Metals* **57**(11) (1993) 1235.
8. J. C. SCHUSTER, H. NOWOTNY and C. VACCARO, *J. Solid State Chem.* **32** (1980) 213.
9. T. NODA, M. OKABE and S. ISOBE, *Mater. Sci. Eng.* A **213** (1996) 157.

*Received 11 April
and accepted 11 December 2001*