

Microstructure and microhardness of Ti_3Al matrix composites produced by XDTM synthesis^①

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[Abstract] XDTM method was used to prepare titanium aluminide(Ti_3Al) matrix composites. The phase constitution and the as-cast microstructure of Ti-25Al alloy with different carbon contents have been investigated using XRD and SEM. Microhardness and elastic modulus of the matrix and reinforcements were tested by mechanical property microprobe. In Ti-25Al-0.5C alloy, blocky Ti_3AlC and lath Ti_3AlC were in situ formed as reinforcement, and homogeneously distributed in the matrix. The microhardness and elastic modulus of blocky Ti_3AlC are 14.2 GPa and 281.3 GPa respectively, higher than those of the lath Ti_3AlC about 3 GPa and 60 GPa respectively. When C content is more than 0.5%, dendritic TiC and Ti_3AlC were formed as reinforcement in a core structure, where the TiC core is coated with Ti_3AlC phase. The microhardness and elastic modulus of the reinforcement decrease with increasing distance from the center of the reinforcement and matrix. The maximum microhardness and modulus of TiC and Ti_3AlC are 22.8 GPa, 302.7 GPa and 20.2 GPa, 313.5 GPa, respectively.

[Key words] Ti_3Al ; Ti_3AlC ; TiC; microhardness; elastic modulus

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1 INTRODUCTION

The low density, high elevated temperature strength, high specific strength and excellent creep resistance of titanium aluminides make them particularly attractive for potential high temperature structural materials^[1~4]. During the last decades, Ti_3Al and TiAl alloys with limited room-temperature ductility have been developed, but they still lack toughness and creep strength. A popular alternative approach aimed at overcoming the limitations of titanium aluminides has been the addition of either continuous reinforcements, such as ceramic or refractory metal fibres, or discontinuous reinforcements, such as ceramic or metallic particulates, short fibres, or whiskers^[5]. Several techniques have been used to fabricate titanium aluminide composites, including rapid solidification processing, mechanical alloying, reactive sintering and reactive hot isostatic pressing, and XD synthesis^[5~7]. Among them the XD process affords the flexibility of a powder metallurgy route in addition to the incorporation of a large volume fraction of the reinforcing phase up to 60% (volume fraction) in the matrix material. Alternatively, the ingot metallurgy route can be used to produce XD composites containing up to 10% (volume fraction) of the reinforcement. Recently, some research-

es focus on fabricating Ti_3Al matrix composites with continuous SiC fibres, Ti_5Si_3 and TiB as its reinforcement respectively^[8~10].

In this paper, XDTM technology used to prepare Ti_3Al matrix composites aimed at studying the morphologies of in situ reinforcements and their microhardness and elastic modulus.

2 EXPERIMENTAL

Powders of Ti (99.7% purity, 45 μm), Al (99.6% purity, 29 μm) and black carbon (99.8% purity, < 0.05 μm) were dry ball milled for 24 h. Then they were uniaxially pressed into green compacts and heated in vacuum to synthesize Al/TiC master alloy. The samples were melted in a water cooled copper hearth using a non-consumable tungsten electrode. To ensure chemical homogeneity of the melted alloy, magnetoelectric agitation was used and the ingots were melted at least three times. Compositions of the samples determined by chemical analysis are listed in Table 1. X-ray diffraction (XRD) analyses were carried out using a Rikagu D/max-RB X-ray diffractometer. Microstructures were observed on a Philip S-570 SEM equipped with EDS. The microhardness and elastic modulus were measured by a Nano I-

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etender IITM mechanical property microprobe (MPM). The displacement precision and position precision of press head of MPM was 0.04 nm and 400 nm, respectively.

Table 1 Chemical compositions of samples
(*w*, %)

Alloy	Al	C	O	Ti
Ti-25Al-0.5C	24.5	0.48	0.32	Bal.
Ti-25Al-1.0C	25.5	1.09	0.32	Bal.
Ti-25Al-1.5C	26.0	1.45	0.33	Bal.
Ti-25Al-2.0C	26.5	1.98	0.28	Bal.

3 RESULTS AND DISCUSSIONS

3.1 XRD results and analyses

Fig. 1 shows the X-ray diffraction (XRD) pattern of Ti-25Al-0.5C alloy, indicating that this alloy is composed of Ti₃AlC and Ti₃Al. Ti₃AlC has been in-situ formed as reinforcement in the Ti₃Al matrix. When the C content is more than 0.5%, TiC diffraction peaks have also been found in the XRD pattern besides Ti₃AlC and Ti₃Al diffraction peaks, which demonstrated that the TiC was also formed. Fig. 2 shows the XRD pattern of Ti-25Al-1.5C. The phases in other alloys investigated by XRD are listed in Table 2.

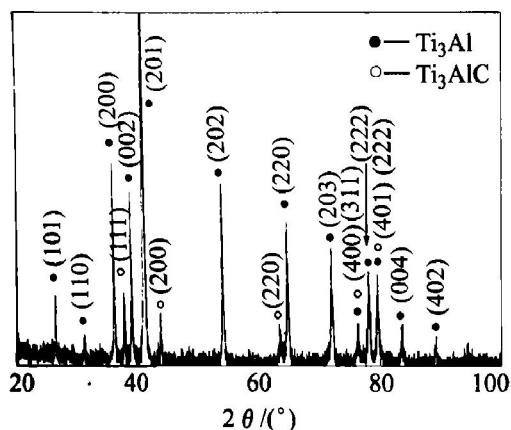


Fig. 1 XRD pattern of Ti-25Al-0.5C alloy

Table 2 Phases present in each sample

Alloy	Matrix phase	Reinforcement
Ti-25Al-0.5C	Ti ₃ Al	Ti ₃ AlC
Ti-25Al-1.0C	Ti ₃ Al	Ti ₃ AlC, TiC
Ti-25Al-1.5C	Ti ₃ Al	Ti ₃ AlC, TiC
Ti-25Al-2.0C	Ti ₃ Al	Ti ₃ AlC, TiC

3.2 SEM microstructures

In the microstructure of Ti-25Al-0.5C alloy, as shown in Fig. 3(a), blocky and fine white phases are

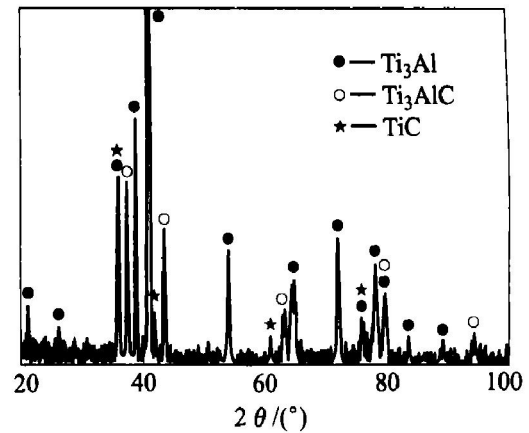


Fig. 2 XRD pattern of Ti-25Al-1.5C alloy

homogeneously distributed in the matrix. It can also be observed that the fine phases have a little tendency to align along the matrix in some areas. In the higher magnification microstructure of this alloy, as shown in Fig. 3(b), the white phase has lath shape. The EDS analyses show that the atom ratio of titanium element and aluminum element of these phases is about 3. Comparing with the result of XRD of this alloy, it can be confirmed that these phases are Ti₃AlC.

Dendrite phases instead of lath morphology phases are found and no aligning tendency exists when the C content is more than 0.5%. As an example, the microstructures of Ti-25Al-1.5C have been shown in Figs. 3(c) and (d). The dendrite phases having an average size of 30 μm are homogeneously distributed in the matrix. However, a “core” structure phase composed of “core” and “shell” can be observed in the dendrite phase (Fig. 3(d)). Fig. 4(a), the electron probe results, shows that there is no Al element in the core phase, but the Al content in the outer layer (shell) is higher. Meanwhile, a little change in Ti content both in the “core” phase and in the “shell” phase can be observed. The Al element image, Fig. 4(b), displays the same result. Combined with XRD results, it can be determined that the “core” phase is TiC and the “shell” phase is Ti₃AlC.

3.3 Mechanical properties

Figs. 5(a) and (b) show the load-depth curves of the lath Ti₃AlC and the blocky Ti₃AlC in Ti-25Al-0.5C alloy, respectively. It can be found that these two kinds of Ti₃AlC almost have the same deformation tendency. However, the maximum compression load of the blocky Ti₃AlC is higher than that of the fine Ti₃AlC at the same compression strain condition, indicating that the blocky Ti₃AlC is relatively difficult to be deformed.

Calculated from these curves, the microhardness and elastic modulus of the blocky Ti₃AlC are 14.2 GPa and 281.3 GPa, respectively, much higher than

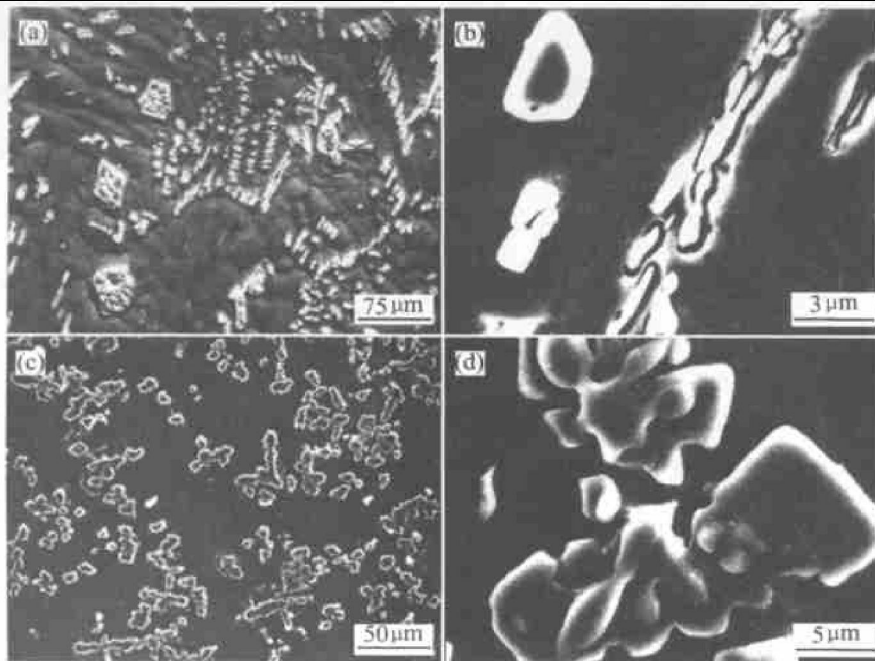


Fig. 3 SEM morphologies of Ti-25Al- x C alloys
(a) and (b) —Morphology of Ti-25Al-0.5C; (c) and (d) —Morphology of Ti-25Al-1.5C, showing “core”

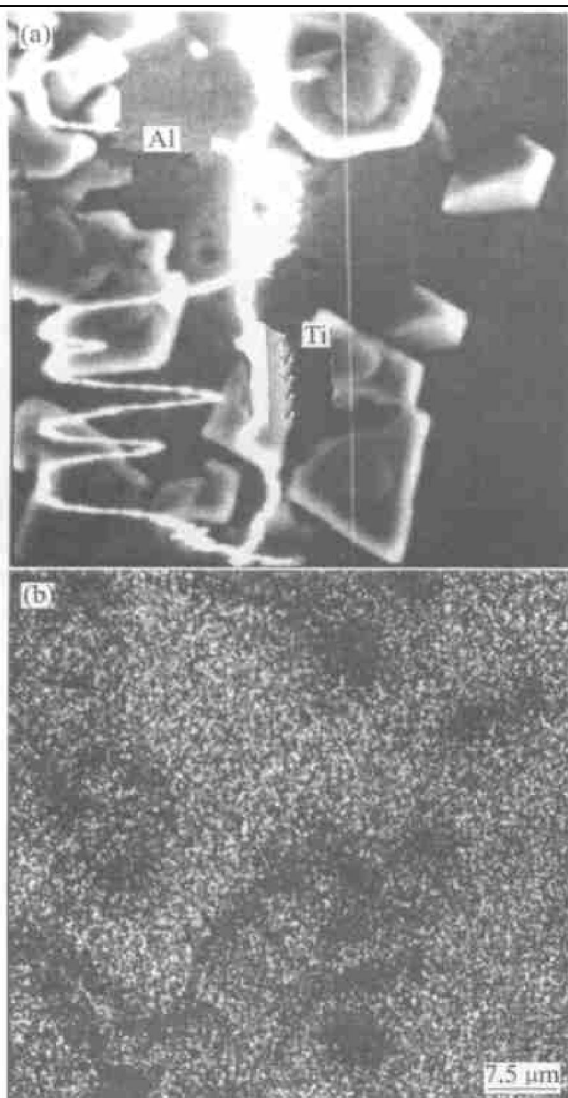


Fig. 4 Electron probe results of core structure
(a) —Ti and Al elements line analysis;
(b) —Al element image

that of the lath Ti_3AlC . Microhardness and elastic modulus of the lath Ti_3AlC are 11.0 GPa and 223.6 GPa, respectively. As for the reason, it may be ascribed to the composition difference between these two kinds of Ti_3AlC , especially the C content difference. The size, and distribution of the ternary carbides phase particles in the as cast structures of this alloy imply that the ternary carbide phase formed during the solidification process. The blocky Ti_3AlC particles were formed as primary phase that nucleates and grows from liquid directly, the lath Ti_3AlC could be interpreted as resulting from the formation of a β + ternary carbide eutectic, $L \rightarrow \beta + Ti_3AlC$. From Ti-Al-C ternary phase diagram^[11], we can know that the Ti_3AlC phase exists in a relatively large range, so it is possible that there has composition difference between two kinds of Ti_3AlC .

The distribution of microhardness and elastic modulus across the reinforcement in Ti-25Al-1.5C alloy is shown in Fig. 6. The nil point is the center of the particle where the phase is TiC.

The results, as shown in Fig. 6, indicate that the average microhardness and elastic modulus of TiC are higher than that of shell Ti_3AlC and Ti_3Al matrix and the maximum microhardness and elastic modulus of TiC and Ti_3AlC are 22.8 GPa, 302.7 GPa and 20.2 GPa, 313.5 GPa, respectively. It can also be found that the microhardness and elastic modulus both of the TiC and Ti_3AlC are not homogeneously distributed. In the TiC phase, from the center to the interface between TiC and Ti_3AlC , the microhardness and elastic modulus decrease gradually. In the Ti_3AlC phase, the microhardness

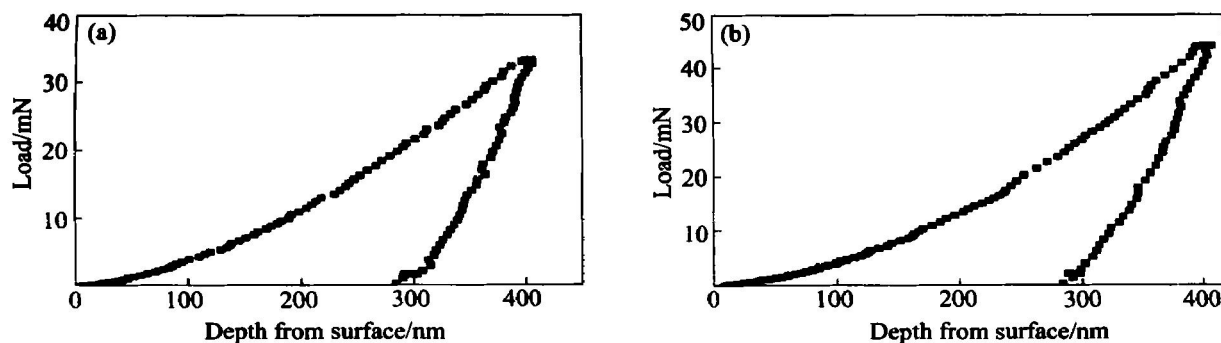


Fig. 5 Load-depth curves of Ti₃AlC in Ti-25Al-0.5C alloy

(a) —Load-depth curve of lath Ti₃AlC; (b) —Load-depth curve of blocky Ti₃AlC

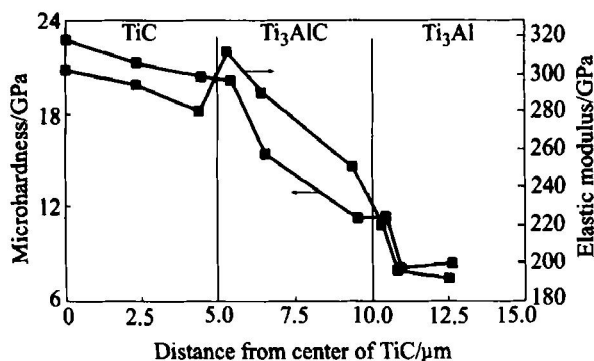


Fig. 6 Microhardness and elastic modulus distribution across reinforcement and Ti₃Al matrix in Ti-25Al-1.5C alloy

and elastic modulus are higher at the position neighboring TiC phase than that of other areas. The testing results of the particles in Ti-25Al-1.5C alloy suggest that the C content in a single TiC_{1-x} and Ti₃AlC_{1-x} varied systematically with different solidification stage. This phenomenon might also occur in other particulate reinforced metal matrix composites, in which particles are formed during solidification process.

4 CONCLUSIONS

1) In Ti-25Al-0.5C alloy, two kinds of Ti₃AlC are formed and homogeneously distributed in the Ti₃Al matrix as reinforcement. The microhardness and elastic modulus of blocky Ti₃AlC are 14.2 GPa and 281.3 GPa respectively, and higher than those of lath Ti₃AlC whose microhardness and elastic modulus are 11.0 GPa and 223.6 GPa, respectively.

2) When C content is more than 0.5%, dendrite TiC and Ti₃AlC are formed as reinforcement in a cored structure, in which the core phase TiC is surrounded by the shell phase Ti₃AlC. The microhardness and elastic modulus of the reinforcement decrease with the

increasing of the distance from the center of the reinforcement, resulting in a gradient change across the reinforcement and the interface between reinforcement and matrix. The maximum microhardness and elastic modulus of TiC and Ti₃AlC are 22.8 GPa, 302.7 GPa and 20.2 GPa, 313.5 GPa, respectively.

[REFERENCES]

- [1] Suryanarayana C, Froes F H. Nanostructured titanium aluminides[J]. Mater Sci and Eng, 1994, A179/A180: 108 - 111.
- [2] Guillard S, Back H. Phase transformations in XDTM TiB₂ reinforced near γ alloy Ti-48Al-2Nb-2Mn[J]. Mater Sci and Eng, 1994, A183: 181 - 194.
- [3] Kim Y. Order intermetallic alloys, Part III: Gamma titanium aluminides[J]. JOM, 1994, 7: 30 - 39.
- [4] Dimiduk D M. Gamma titanium aluminide alloys as assessment within the competition of aerospace structural materials[J]. Mater Sci and Eng, 1999, A263: 281 - 288.
- [5] Kumar K S, Whittenberger J D. Discontinuously reinforced intermetallic matrix composites via XD synthesis[J]. Mater Sci Tech, 1992, 8: 317 - 330.
- [6] Westwood A R C. Materials for advanced studies and devices[J]. Metall Trans, 1988, 19A: 749 - 758.
- [7] Larsen D E, Christodoulou L, Kampe S L, et al. Investment cast processing of XDTM near γ titanium aluminides[J]. Mater Sci and Eng, 1991, A144: 45 - 53.
- [8] Yang W Y, Yi H C, Petric A. Microstructure of the Ti₃Al (Nb)/TiB composite produced by combustion synthesis[J]. Metallurgical and Materials Transactions A, 1995, 26A (11): 3037 - 3043.
- [9] Yang Y Q, Dudek H J, Kumpfert J. Microstructure of interfacial reaction zone in SCS-6 SiC fibre reinforced super α_2 composites[J]. Mater Sci and Tech, 1998, 14(11): 1122 - 1126.
- [10] Gambone M L. SiC fibre strength after consolidation and heat treatment in Ti-22Al-23Nb matrix composite[J]. Scripta Materialia, 1996, 34(3): 507 - 516.
- [11] Pietzka M A, Schuster J C. Summary of constitutional data on the aluminium-carbon-titanium system[J]. J Phase Equilibria, 2000, 15(4): 392 - 400.

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