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Fabrication of Ti-Al complex with superior deformation capability by pressure infiltration

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Abstract: Ti-Al complex with a network microstructure was successfully fabricated by pressure infiltration. The fabricated Ti-Al complex was investigated and analyzed by OM, XRD, SEM and EDS. The temperature of pressure infiltration was reduced by using Al-Si eutectic alloy instead of pure Al, which can effectively decrease non-diffusion reaction between liquid Al and solid Ti particles. The reaction thickness can be controlled at about 3 μm. The primary reaction product is $TiAl_3$ intermetallics. As Ti atoms dissolve into the Al-Si liquid phase and Si atoms enrich on the surface of Ti particles, $TiSi_2Al$ is formed in Al phase of Ti-Al complex and outside the surface of Ti-Al reaction layer. The microstructure of the as-extruded Ti-Al complex indicates that the prepared Ti-Al complex possesses a superior deformation capability.

Key words: pressure infiltration; Ti-Al complex; Al-Si eutectic alloy; microstructure

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1 Introduction

TiAl alloy is one of the most promising high-temperature materials due to its excellent high-temperature properties such as anti-creep [1], antioxidant [2], high stiffness [3], and high yield strength [4]. However, the application of TiAl alloy is limited because of its poor capability of the plastic deformation [5-8]. Using Ti and Al powders as the cold rolling material, TiAl alloy plate has been fabricated by cold rolling Ti-Al complex and heat treatment reactive synthesis [9]. However, a lot of pores were formed inside the prepared TiAl plate. Although TiAl alloy has been successfully fabricated by infiltration combustion by using pure Al and Ti powder at high temperatures, this route cannot solve the processing difficulty in deformation [10].

In the present work, a novel Ti-Al complex with a network microstructure is successfully fabricated by pressure infiltration and selecting Al-Si eutectic alloy and spherical Ti powder in order to solve the processing problems. In addition, the formation mechanism of reaction layer is discussed and analyzed.

2 Experimental

Spherical pure Ti powder (purity 99.5%) with a mean particle size of 100 μm was pressed as a preform (pore rate 44% and dimension *d* 60 mm×48 mm). Al-Si eutectic alloy (melting point 578 °C) was placed on the Ti preform. Then, it was heated to 600 °C in vacuum of 10^{-2} Pa for 20 min. After that, the melted Al-Si eutectic alloy was pressed into Ti preform under a pressure of 20 MPa and the billet of Ti-Al complex was fabricated after furnace cooling. At last, Ti-Al complex was heated to 500 °C for 20 min and hot extruded to fabricate Ti-Al complex rod with an extrusion ratio of 25:1.

Microstructure characterizations of the prepared Ti-Al complex were performed by an optical microscope (OM, Olympus PMG−3) and a scanning electron microscope (SEM, HITACHI S−4700). The phase composition of the complex was identified using a Philips X'Pert X-ray diffractometer with Cu K_α radiation and the energy dispersive spectrometer (EDS) installed on HITACHI S−4700 SEM.

3 Results and discussion

3.1 Microstructure observation of Ti-Al complex by OM

Figure 1 shows the OM micrographs of the Ti-Al complex billet. It can be observed that Ti particles distribute homogeneously and Al fills the voids among Ti particles as continuous phase with a network microstructure, as shown in Fig. 1(a). The continuous Al phase is beneficial to the subsequent deformation of the

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complex. The reaction layer is about 3 μm due to the low infiltration temperature and the short infiltration time, as shown in Fig. 1(b). It is well known that, the component of the reaction layer is mainly $TiAl_3$ intermetallics which are harmful to the subsequent deformation [11−12]. It is worth pointing out that the harmful reaction layer can be decreased by selecting Al-Si eutectic alloy instead of pure Al in the present study.

3.2 Phase composition of Ti-Al complex by XRD

Figure 2 shows the XRD pattern of Ti-Al complex billet. It can be seen that only Ti and Al phases can be detected in the complex and no other reaction compounds are found. This phenomenon indicates that the chemical reaction between Ti and Al can be significantly decreased by selecting the Al-Si eutectic alloy instead of pure Al, which is mainly attributed to the decreased pressure infiltration temperature of 600 °C. It is certain that the Ti-Al complex with a decreased chemical reaction is beneficial to the subsequent deformation.

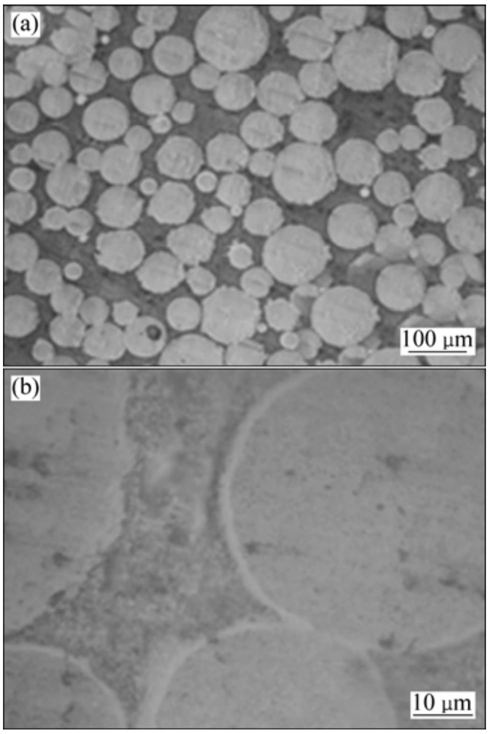

Fig. 1 OM micrographs of Ti-Al complex billet: (a) At lower magnification; (b) At higher magnification

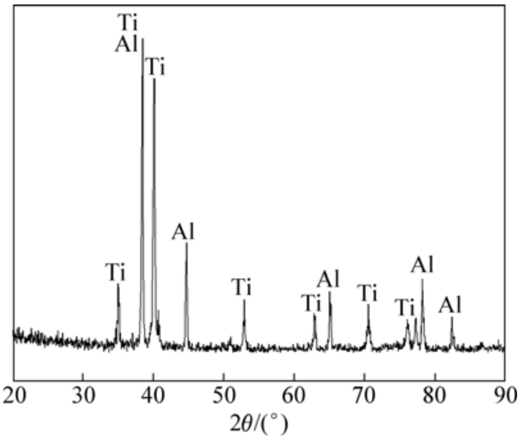

Fig. 2 XRD pattern of Ti-Al complex billet

3.3 Microstructure analysis of complex by SEM and EDS

Figure 3 shows the backscattered SEM micrographs of the Ti-Al complex billet, and two reaction phase layers with different contrasts can be observed on the surface of Ti particles as outer and inner layers. It can be observed that the inner layer is dark and the outer layer is gray, as shown in Fig. 3. In addition, some polygon particles which have the same phase contrast with the outer layer are observed in Al-Si eutectic alloy around Ti particles.

Figure 3 also shows the compositions of the reaction layer analyzed by EDS. According to the well-known theory, the composition of the primary reaction layer is $TiAl_3$ [11−12]. But, it can be observed that the molar ratio of Ti to Al is not consistent with $TiAl_3$ due to the existence of Si. The molar fractions of Ti, Al and Si in the inner layer are 32.13%, 41.66% and 26.22%, respectively. Some Si atoms are dissolved in $TiAl_3$ instead of Al atoms. Figures 3(b′) and (c′) show that the composition of the outer layer is similar with that of the polygon particles, which indicates that the outer layer and the polygon particles belong to the same phase. Furthermore, the molar fraction of Si is higher than the limit of the solid solution of $TiAl_3$ [13]. Therefore, the phase of the outer layer and the polygon particles is $TiSi_2Al$ intermetallics according to the similar molar fractions of Ti, Al and Si, as shown in Figs. 3(b′) and (c′).

In the reaction between Ti and Al-Si eutectic liquid, the Ti atoms on the surface of Ti are dissolved into Al-Si eutectic liquid. Therefore, the chemical potential of Si is reduced in the Al-Si eutectic liquid because of the high affinity between Ti and Si [14]. And Si atoms are enriched around Ti diffusion couple by uphill diffusing. A ternary Ti-Al-Si mixture liquid system is formed by the dissolution of Ti atoms and the enrichment of Si atoms. As analyzed above, the reaction layer of $TiAl_3$ is primarily formed on the surface of Ti particles. Then, the $TiAl_3$ phase which contacts the Al-Si eutectic liquid reacts with the liquid according to the reaction: $L+TiAl_3 \leftrightarrow TiSi_2Al$, forming $TiSi_2Al$ intermetallics in the outer reaction layer. The $TiSi_2Al$ phase is also formed in the ternary Ti-Al-Si mixture liquid as the reaction: $L \leftrightarrow TiSi_2Al+Al+Si$ [15].

Figure 4 shows the SEM micrographs of the as-extruded Ti-Al complex. In Figs. 4(a) and (b), it can

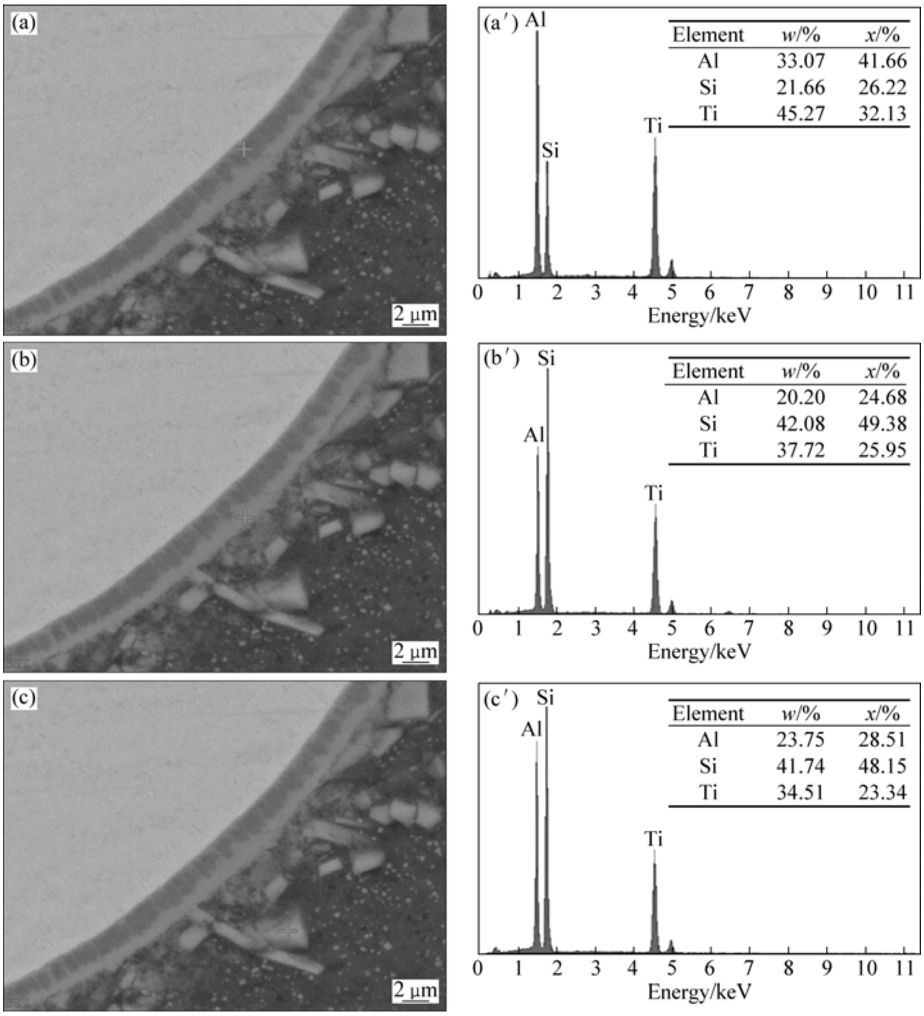

Fig. 3 SEM micrographs and EDS results of reaction layer of Ti-Al complex billet: (a), (a′) At inner layer; (b), (b′) At outer layer; (c), (c′) At polygon particle

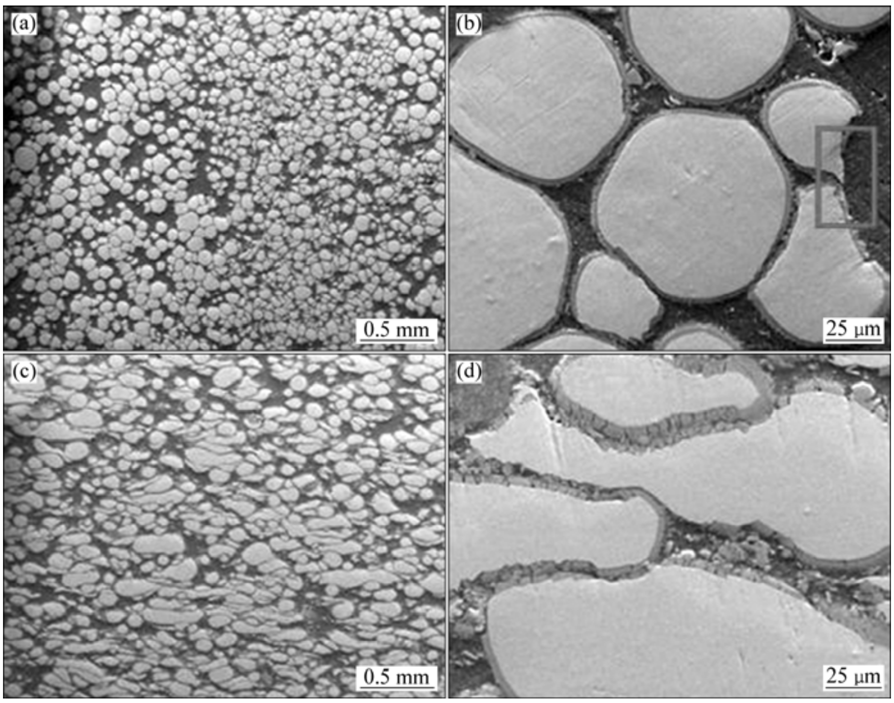

Fig. 4 SEM micrographs of as-extruded Ti-Al complex: (a), (b) Along cross section; (c), (d) Along extrusion direction

be observed that the Ti particles have been deformed by hot extrusion, even fractured in the seriously deformed local region. Moreover, no reaction layer is observed on the fractured section, as marked in Fig. 4(b). In Figs. 4(c) and (d), it can be observed that the Ti particles have been stretched along the extrusion direction and the reaction layer has been fractured by hot extrusion. That is to say, the shape of the Ti particles is changed from the ball to the rod and the diameter is decreased from 100 μm to 40 μm, the continuous Al phase retains as a continuous phase and the reaction layer around the surface of the Ti particles is fractured. These phenomena indicate that the Ti-Al complex fabricated by selecting the Al-Si eutectic alloy and spherical Ti powders and the pressure infiltration process at a low temperature possesses a superior deformation capability.

4 Conclusions

1) The dense Ti-Al complex is successfully fabricated by using Al-Si eutectic alloy and spherical pure Ti powders. The pure Ti powders are homogeneously distributed and Al-Si alloy is infiltrated into the voids of Ti powders and forms a continuous network intergranular phase.

2) The thickness of reaction layer is controlled at about 3 μm due to the low infiltration temperature, which is beneficial to the subsequent deformation.

3) During the process of pressure infiltration, a ternary Ti-Al-Si mixture liquid system is formed by the dissolution of Ti atoms and the enrichment of Si atoms which constitutes the reaction layer with the inner layer of $TiAl_3$ and the outer layer of $TiSi_2Al$.

4) The prepared Ti-Al complex with a continuous network Al phase shows a superior deformation capability.

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压力浸渗制备具有优异变形能力的 Ti-Al 复合体

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摘 要：采用压力浸渗法成功制备网状结构的 Ti-Al 复合体，使用 OM、XRD、SEM 以及能谱仪对制备的 Ti-Al 复合体进行组织观察与分析。采用共晶 Al-Si 合金代替纯 Al 可有效降低压力浸渗所需温度，降低液态 Al 与 Ti 颗粒表面接触而发生的非扩散控制反应的剧烈程度。反应层厚度控制在 3 μm 左右，最先反应产物为 $TiAl_3$ 相。压力浸渗时，Ti 原子溶于 Al-Si 液相及 Si 原子向 Ti 颗粒表面富集使得在反应层外侧及 Ti-Al 复合体 Al 相中形成 $TiSi_2Al$ 相。挤压变形组织显示制备的 Ti-Al 复合体具有优异的变形能力。

关键词：压力浸渗；Ti-Al 复合体；Al-Si 共晶合金；微观组织

(Edited by YANG Bing)