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Densification abnormality in reactive hot pressing of Ti and Al elemental powders①

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[Abstract] The densification behavior of a TiAl base alloy prepared by elemental powder metallurgy has been studied. It is found that a densification abnormality occurs at 1 400 ℃, i.e. the compact density decreases with the increase of hot pressing temperature. By microstructural observation, including optical microscopy and TEM, it has been concluded that the densification abnormality can be attributed to the different high temperature creep mechanisms induced by microstructure coarsening in the late period of densification.

[Key words] TiAl base alloy; densification; powder metallurgy; microstructure
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1 INTRODUCTION

Elemental Powder Metallurgy (EPM) is one of the most promising methods to prepare TiAl base alloys, due to its low cost and convenience in adding alloy elements[1~3]. Reactive hot pressing (RHP) is a useful EPM method[4,5]. However, the mechanism of RHP elemental Ti and Al powders is very complicated because the densification process includes chemical reaction, phase transformation, diffusion and creep. Though a few work has been conducted in the densification mechanism of RHP, there are still many uncertainties. In this work, a densification abnormality in RHP of elemental Ti and Al powders is discussed.

2 EXPERIMENT, RESULTS AND DISCUSSION

Ti-48Al (mole fraction, %) elemental powders were hot pressed in Ar atmosphere at a pressure of 40 MPa and temperatures ranging from 800 ℃ to 1 400 ℃ for 1 h[5]. The results show that at temperatures ranging from 800 ℃ to 1 300 ℃, the densification process seems to obey the common rule very well, i.e. the compact density increases with the increase of hot pressing temperature (as shown in Fig. 1). However, as the hot pressing temperature increases to 1 400 ℃, the compact density is lower than that at 1 300 ℃. This densification abnormality is explained as follows.

The general densification process in RHP of Ti and Al elemental powders should be addressed. At a temperature near the melting point of Al, an exothermic reaction will occur between elemental Ti and Al

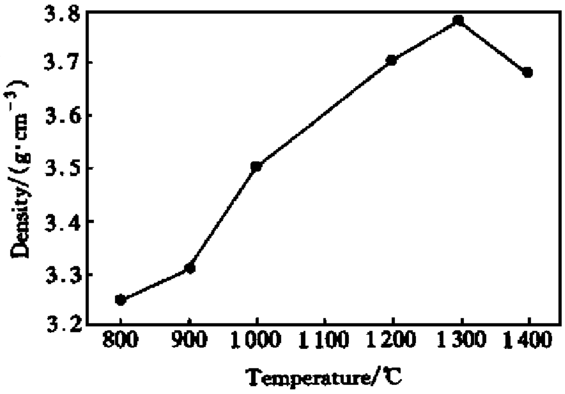

Fig.1 Relationship between compact density and RHP temperature

powders with the products of $TiAl_3$ phase and α-TiAl (or Ti_3Al) phase[1,6]. As the reaction temperature increases, further diffusion and interface reaction will occur between $TiAl_3$ phase and α-TiAl (or Ti_3Al) phase, and such intermediate products as $TiAl_2$ and TiAl phases will appear[7]. In equilibrium, TiAl phase and Ti_3Al phase coexist with varied proportions depending on the raw powder composition and the reaction temperature[8,9]. The exothermic reaction between Ti and Al powders will lead to high porosity and low strength of the compact, owing to Kirkendall effect and the melting of Al powders[10]. Therefore, in the beginning of RHP, the densification proceeds very fast. However, the yield strength of the compact increases with the increase of its density. As the pressure exerted is only 40 MPa, in the late period of RHP the densification process is mainly controlled by high temperature creep. Generally, with the increase

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of hot pressing temperature, the yield strength of the compact decreases and the creep rate increases, hence the compact will be much more densified, as can be seen in the ascending part of Fig.1.

The densification abnormality can be probably explained by analyzing the microstructures of the samples hot pressed at 1 300 ℃ and 1 400 ℃ respectively. The optical micrographs in Fig.2 indicates that hot pressing at 1 300 ℃ leads to an equiaxed microstructure consisting of γ grains and island-like α_2 grain aggregates, while at 1 400 ℃ a much coarser microstructure consisting of large α_2/γ lamellar colonies and γ grains appears. The coarse microstructure can be attributed to two aspects. 1) An excessively high hot pressing temperature accelerates the diffusion rate and grain growth rate in the late period of the densification process. 2) According to Ti-Al phase diagram[4], 1 400 ℃ is near the α transus temperature, that is, α-Ti_3Al should be the only predominant equilibrium phase at that temperature. Therefore, without the competitive growth of γ phase, the growth rate of α grain will be very fast in the late period of the densification process. In cooling period, coarse α_2/γ lamellar colonies will form from α phase through the in situ transformation $\alpha \rightarrow \alpha_2 + \gamma$[11].

Through TEM analyses, the difference in the substructures of the two samples can be more clearly seen. The sample hot pressed at 1 300 ℃ shows fine

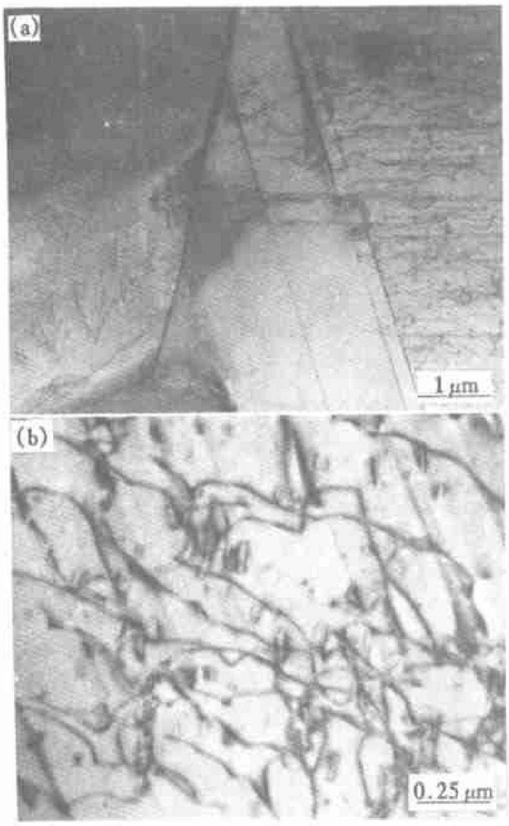

Fig.2 Optical microstructures of hot pressed samples
(a) —1 300 ℃; (b) —1 400 ℃

grains with a low dislocation density (Fig.3). However, in the sample hot pressed at 1 400 ℃, high density of tangled dislocations and twinning can be seen in γ grain boundary area (Fig.4(a)), moreover, in the lamellar colony there also are high density of tangled dislocations, loops and dipoles (Fig.4(b)). Therefore, there should be a relationship between the microstructural difference and the densification abnormality of the two samples.

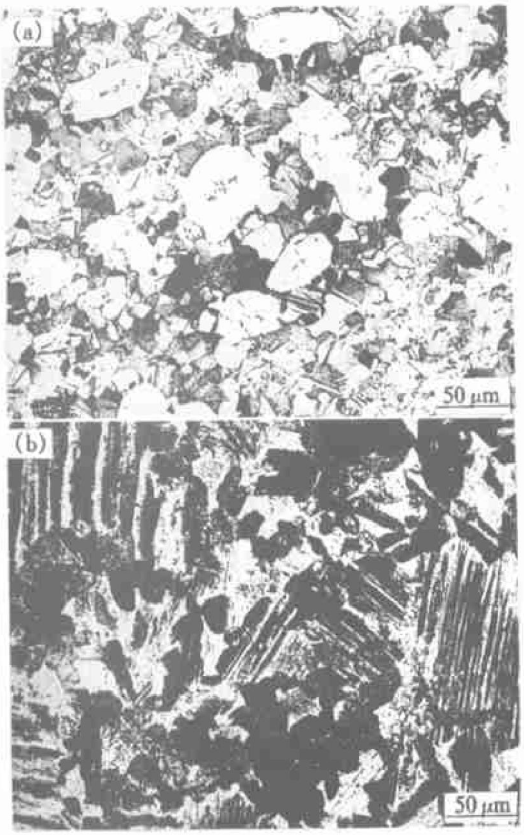

Fig.3 TEM micrographs of sample hot pressed at 1 300 ℃
(a) — γ grains; (b) — α_2 grains

The low density of dislocation in the sample hot pressed at 1 300 ℃ suggests that the creep mechanism be mainly grain boundary gliding due to the fine-grained microstructure. Although it is uncertain whether diffusion creep has affected on grain gliding and densification process, it is true that grain boundaries have effectively accommodated the deformation. In the sample hot pressed at 1 400 ℃, the high density of dislocations inside γ grains and α_2/γ lamellar colonies suggest that the creep mechanism mainly be intra-grain dislocation movement. This should be attributed to two factors: 1) As the microstructure coarsened, the grain boundary strength increased so as to make grain boundary gliding much more difficult. For example, in Fig.4(a) the stress concentration at the triple point of the grain boundaries had induced a large amount of dislocations, but the grain boundaries had difficulty in gliding and absorbing

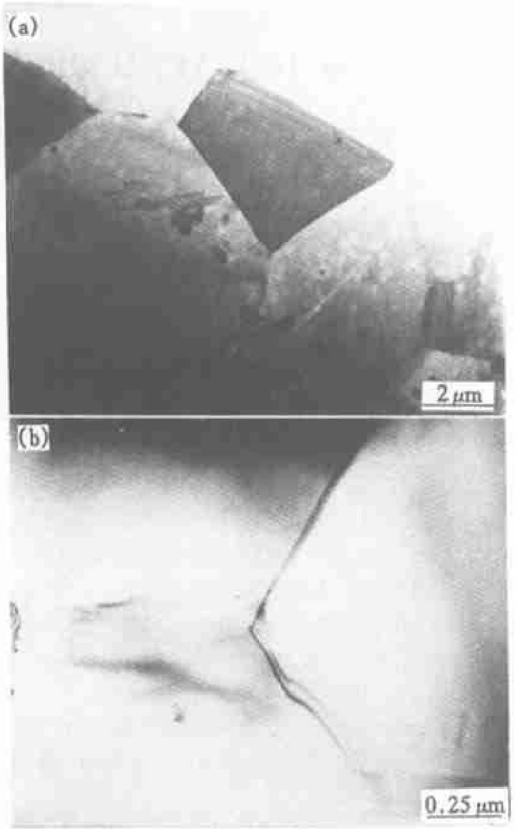

Fig.4 Dislocations in sample hot pressed at 1 400 ℃
(a) —Near γ grain boundaries;
(b) —In α_2/ γ lamellar colony

these dislocations so that subsequent twinning occurred to relax the stress concentration; 2) The yield strength of the grains decreased with the increase of the hot pressing temperature, and this made it easier for the dislocations to be generated inside grains. Therefore, intra-grain dislocation movement should be the main creep mechanism. However, the further movement of dislocations was hindered by the strengthened grain boundaries so that the creep rate was low. In conclusion, the microstructure coarsening has led to the difficulty in grain boundary gliding and dislocation movement, thus impeding the densification process.

3 CONCLUSION

The densification abnormality in RHP elemental Ti and Al powders can be attributed to the different high temperature creep mechanisms induced by microstructure coarsening in the late period of the densification.

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