TiAl ALLOYS PREPARED BY THERMAL EXTRUSION OF ELEMENTAL POWDER MIXTURES①

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ABSTRACT $\alpha_2 + \gamma$ dual phase TiAl intermetallics had been synthesized with elemental powder mixtures at high temperature. The consolidated samples were prepared by thermal extrusion of steel canned TiAl compacts. The thermal extrusion was carried out at 1 200 ℃, with extrusion ratios of 4, 8 and 16. The study on microstructures and mechanical properties showed that with increasing extrusion ratio, the porosity of the compacts as well as grain size decreased, the bending strength increased. After heat treatment the bending strength of the specimens with the extrusion ratio of 16 could increase to 897 MPa. After the thermally extruded compact had been HIPped, though the density increased slightly, the bending strength decreased partly due to grain size coarsening.

Key words powder metallurgy TiAl intermetallics thermal extrusion elemental powders

1 INTRODUCTION

The TiAl based intermetallics are drawing world-wide attention for its good mechanical properties at high temperatures required for aircraft engines. By means of thermomechanical treatment and alloying, the room-temperature ductility of the TiAl intermetallics has been improved greatly up to date[1]. However, in order to explore the potential of room- and high-temperature properties of these materials, the modern powder metallurgy technology must be used[2]. It is the simplest and a direct way to synthesize TiAl intermetallics through elemental powder mixtures reaction at high temperatures[3-6]. However, in the course of reaction only aluminum atoms diffuse to titanium and vacancies leave on the previous Al site, which leads to the decrease of density of the reaction compacts[4]. Therefore, following consolidation process is needed to remove the excessive porosity. Experiments show that HIP and thermal extrusion are effective means[5, 6], but for the TiAl intermetallics there are still some problems in getting integrated specimens[7]. In this paper, $\alpha_2 + \gamma$ dual phase TiAl alloys have been synthesized with Ti-48Al-2Cr (mole percent) elemental powder mixtures encapsulated in steel cans through reaction at high temperature as well as thermal extrusion. The effects of extrusion ratio and heat treatment on the porosity, microstructures and mechanical properties of the specimens have been studied.

2 EXPERIMENTAL

The studied alloy, Ti-48Al-2Cr, was synthesized by mixing Al powder (purity 99.0%, particle size< 43 μm), Ti powder (purity 99.5%, particle size < 75 μm) and Cr powder (purity 99.0%, particle size 74~ 147 μm) in a V-type mixer for 8 h. After cold isostatic pressing, the compact was encapsulated in a steel can and degassed above 400 ℃. Thermal extrusion was carried out at 1 200 ℃ with extrusion ratios of 4, 8 and 16 (area ratio). The porosity and microstructures were observed by means of optical metallography and SEM. The bending strength

① Supported by the Fund of State Education Commission of China for Outstanding Young Teachers
Received Aug. 19, 1996; accepted Sep. 27, 1996

was measured by means of three-point bending test with the specimens size of 2 mm × 4 mm × 30 mm and a span of 25 mm. Hot isostatic pressing was completed under 1 230 ℃, 170 MPa, 2 h.

3 RESULTS

3.1 Phase analysis

While the elemental powder mixture compact is in the course of degassing, once the temperature increases to the melting point of Al, 650 ℃, the synthesizing reaction takes place and the temperature increases to 1 000 ℃ or higher in no time. The X-ray diffraction spectrum of the as-extruded specimen shows that the phases of the specimen are mainly composed of Ti_3Al and TiAl (Fig. 1).

3.2 Density and porosity

The results of density test are summarized in Table 1. For the specimen with the extrusion ratio of 16, the density is the largest. The experiments also show that the HIP is effective in further increasing the density.

The distribution of the porosity of the specimen after heat treatment is shown in Fig. 2, in which the tiny holes distribute along the extrusion direction and form bands. For the specimen experiencing HIP, the basic character of the porosity distribution almost does not change, but the hole size becomes larger.

Table 1 Influence of extrusion ratio on density of studied material($g\cdot cm^{-3}$)

Extrusion ratio	4	8	16	16+ HIP
Density	3.859	3.844	3.917	3.927

3.3 Microstructures

Fig. 3 shows the optical metallographs of as-extruded specimens. It can be seen that with increasing extrusion ratio, the fibrous character of the specimen becomes more obvious. However, there are still some unbroken lumps, even when the extrusion ratio reaches 16.

Fig. 4 shows the back scattered electron im-

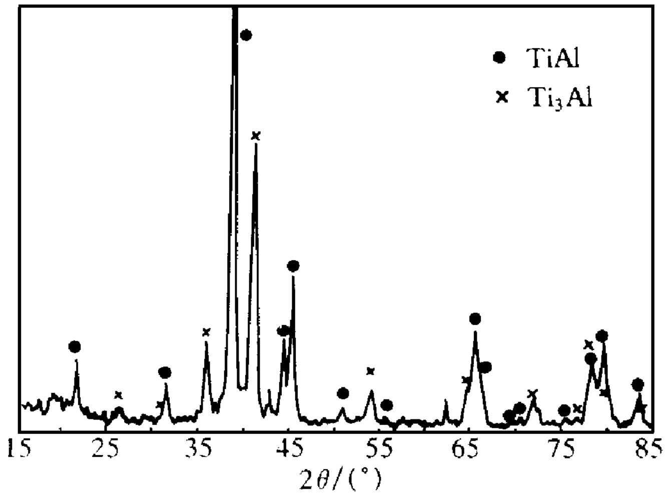

Fig. 1 XRD spectrum for as-extruded specimen

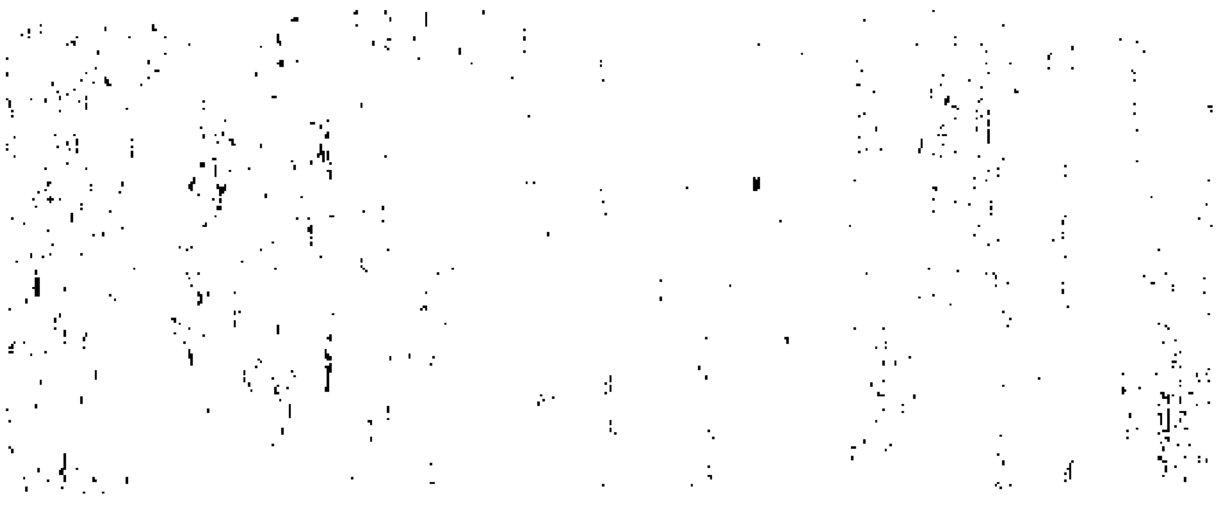

Fig. 2 Distribution of porosity in as-heat treated specimens(without etching)
(a) —extrusion ratio= 4; (b) —extrusion ratio= 16; (c) —extrusion ratio= 16, HIP

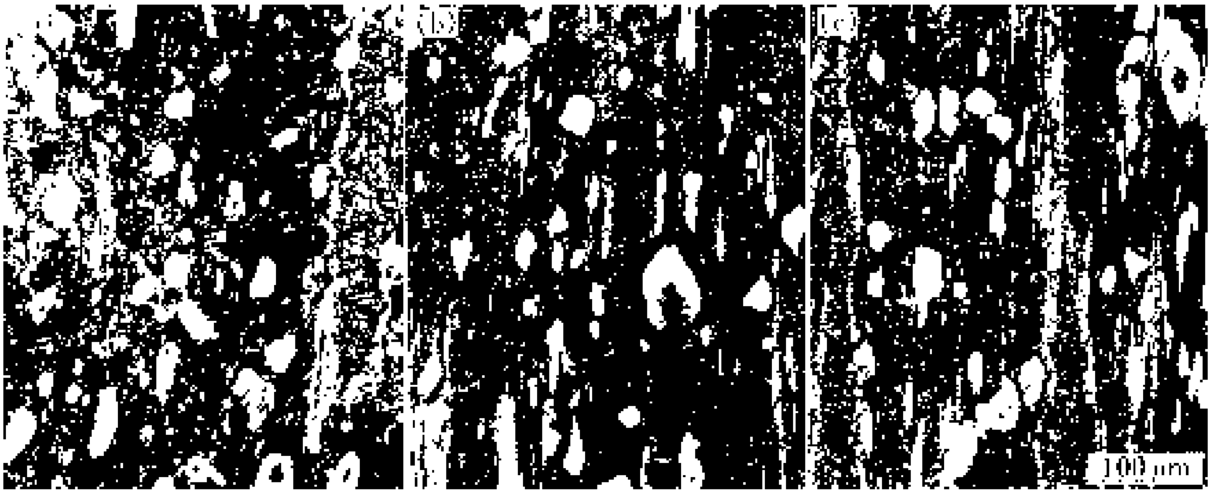

Fig. 3 Optical metallographs of as-extruded specimens (etched)
(a) —extrusion ratio= 4; (b) —extrusion ratio= 8; (c) —extrusion ratio= 16

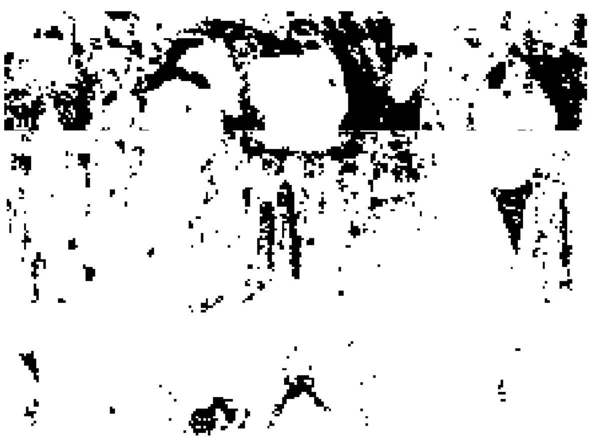

Fig. 4 Back scattered electron image and line scanning of Cr element for as-extruded specimen with extrusion ratio of 16

age of the as-extruded specimen, in which the bright zone corresponds to the unbroken lumps existing in optical metallograph. According to the principle that the ability of scattering electron of the atom increases with the atomic number, we can conclude that the bright zone is the phase full of Ti element. Considering the XRD results, then we can say that the "hard" phase is Ti_3Al. Perhaps the particles in the center of the "hard" phase are the unreacted Ti. The large holes are mainly formed around the hard lumps. In addition, the line scanning of Cr element shows that though the Cr does not diffuse sufficiently, it is deformed with the matrix.

Fig. 5, the optical metallograph of the specimen experiencing heat treatment (1 250 ℃, 4 h + 900 ℃, 10 h), shows that the character of the as-extruded specimen still remains in the microstructure, which consists of coarse lamellar lumps in the Cr diffused area and fine duplex structure. For the specimen experiencing HIP, the volume fraction of the lamellar structure increases and the lamellar lump size becomes large (Fig. 6).

3.4 Bending strength

The experimental result of bending strength is shown in Fig. 7. With increasing extrusion ratio, the bending strength increases evidently, but for the specimen experiencing HIP the bending strength decreases slightly.

4 DISCUSSION

In this experiment, when the temperatures of the elemental powder mixtures were increased to the melting point of aluminum, the temperatures of the materials increased automatically and the self-propagation combustion reaction took place. Because in the course of reaction only did the Al element diffuse to the Ti lump[4], the previous Ti particles became a kind of encapsulated structure whose out part was relatively loose TiAl phase and inner part was relatively dense Ti_3Al. After thermal extrusion, the dense part was enlarged

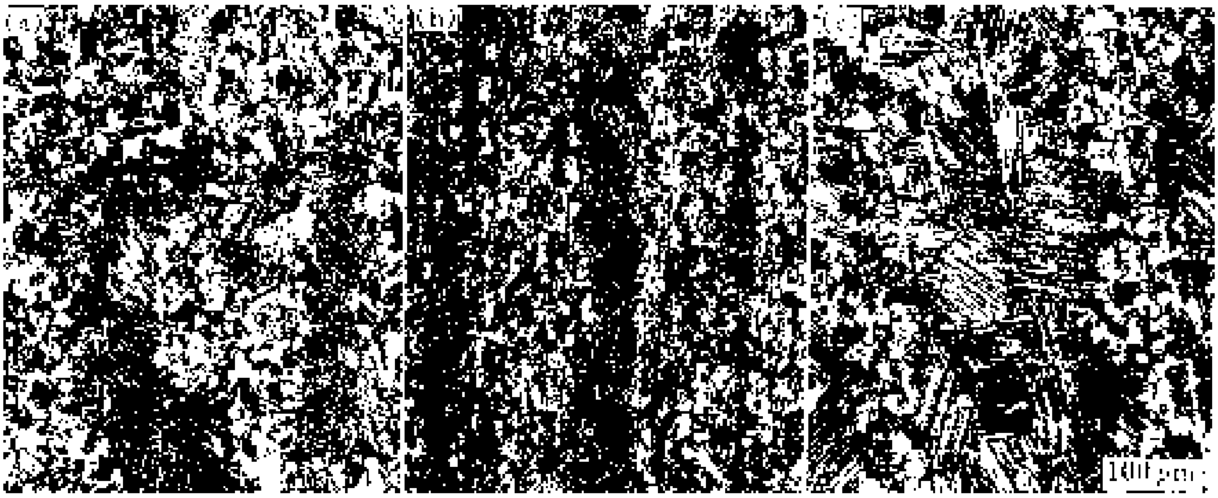

Fig. 5 Optical metallographs of as-heat treated specimens
(a) —extrusion ratio= 4; (b) —extrusion ratio= 16; (c) —extrusion ratio= 16, HIP

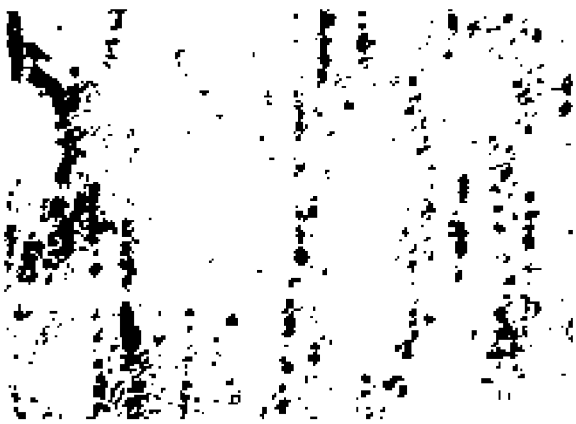

Fig. 6 Back scattered electron image and line scanning of Cr element in as-heat treated specimen(extrusion ratio= 16)

along the extrusion direction. Some lumps were broken but the rest weren't broken even when the extrusion ratio reached 16.

Because there were so-called "hard zones" and "soft zones" in the as-reacted specimen, after extrusion, for the soft zones, a lot of deformation energy was reserved and then in the following heat treatment the recrystalline nucleation probability would be greater than that in the hard zones, which led to the formation of fine grain duplex microstructure at room temperature. However, for the "hard zones", because of high Ti content and low deformation energy, at the temperature above eutectoid point, it was easy to form α phase, which then transformed to the coarse lamellar microstructure at the temperatures below eutectoid point and arranged along the extrusion direction. With increasing extrusion ratio, the character described above becomes more obvious and the specimen is just like the special fibre-reinforced composite materials which take the relatively ductile duplex structure as matrix and relatively strong lamellar structure as fibre. That is the reason why this kind of specimen is of high bending strength.

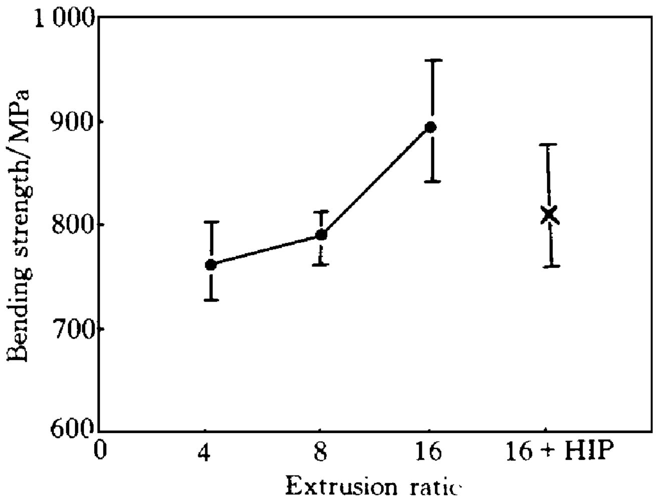

Fig. 7 Influence of extrusion ratio on bending strength

Because the particle size of the Cr powder is too large in the powder mixture, so that it does not diffuse sufficiently in the course of reaction. In the areas full of Cr, at temperatures above the eutectoid point it is easy to form α phase, which then transforms to coarse lamellar structure at the temperatures below the eutectoid point. Since the element Cr diffuses so slowly and it plays an important role in the phase transformation, when Cr is added as an alloying element the particle size of Cr powder should be as little as possible; when Cr is added as an adjusting element of microstructure the holding time at high temperature should be as short as possible.

HIP is already thought as an ideal means in getting fully densified powder metallurgy products. In this experiment, the material's density has been increased, mainly owing to the closing of the large holes under HIP. Unfortunately, owing to the too long holding time at high temperatures the tiny pores size and the grain size increase (Fig. 6) and the fibrous structure character inheriting from as-extruded material is weakened, which leads to decrease the bending strength.

There are many kinds of consolidating means in the powder metallurgy process. The purpose of choosing thermal extrusion method is not only to increase the compact's density, but also to refine the grain size and offer the recrystallization energy needed in the following heat treatment. The experimental results shows that after reaction synthesis the coarse and "hard" Ti_3Al lumps do not favour the realization of the target mentioned above. In order to decrease the size of Ti_3Al lumps, the particle size of Ti powder should be decreased. The microstructure of fibrous character is undoubtedly beneficial to the longitudinal mechanical properties of the specimens. The fibrous character is preserved by the inhomogeneity of concentration. To maintain this kind of inhomogeneity, it is also required to shorten the holding time at high temperature in the following heat treatment.

5 CONCLUSIONS

(1) With increasing extrusion ratio, the distribution of the porosity became homogeneous, the grain size was refined and the bending strength was increased.

(2) The coarse Ti_3Al lumps in the as-reacted compact made thermal extrusion less effective owing to its excessive hardness in the course of extrusion. The particle size of Ti powder in the elemental powder mixtures should be decreased.

(3) For the as-extruded specimens, though HIP could increase the density of the compacts, the bending strength was decreased for the long time holding at high temperature, which led to the increase of grain size.

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(Edited by Peng Chaoqun)