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Microstructure and mechanical properties of Ti−45Al−5.5(Cr,Nb,B,Ta) alloy sintered at different SPS temperatures

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Abstract: TiAl alloy bulk samples with the composition of Ti−45Al−5.5(Cr,Nb,B,Ta) (mole fraction, %) were prepared by high energy mechanical milling and spark plasma sintering (SPS) and then heat treatment. The microstructure and mechanical properties after heat treatment of TiAl alloy prepared by SPS at different temperatures were studied. The results showed that the morphology of high energy mechanically milled powder was irregular and the average grain size was about decades micrometers. X-ray diffraction analysis showed that the mechanically milled powder was composed of two phases of TiAl and Ti_3Al. The main phase of TiAl and few phases of Ti_3Al and TiB_2 were observed in the SPS bulk samples of Ti−45Al−5.5(Cr,Nb,B,Ta) alloy. For samples sintered at 900 °C and 1000 °C, the microstructure was duplex structure with some fine equiaxed gamma grains and thin needly TiB_2 phases. With the SPS temperature increasing from 900 °C to 1000 °C, the micro-hardness was changed little, the compression strength increased from 1812 MPa to 2275 MPa and the compression ratio increased from 22.66% to 25.59%. The fractography results showed that the compression fracture transform of the SPS Ti−45Al−5.5(Cr,Nb,B,Ta) alloy was rgranular rupture.
Key words: TiAl alloy; powder metallurgy; spark plasma sintering (SPS); heat treatment

1 Introduction

TiAl alloys are attractive engineering materials in the field of aerospace due to their properties of low density, high specific strength and high strength at elevated temperatures [1−3]. However, the practical engine applications of TiAl alloys are limited due to their poor room temperature ductility and formability.

Powder metallurgy (PM) is a favorable process for synthesizing ultrafine grained TiAl alloys and forming near-net shaped components of TiAl alloys, which could overcome the above problems. Spark plasma sintering (SPS) is attractive among multiple PM processes [4,5]. Through SPS the higher heat efficiency could be gained so that the good quality sintered bulks could be prepared through compacting and sintering powder [6,7]. There is an ascending interest in the investigation of preparing TiAl alloys by spark plasma sintering (SPS) due to its specific characters [8−10].

In addition, the application of gamma TiAl alloys requires specific properties in different fields, for example, in aerospace fields excellent properties including fatigue, toughness, creep, etc were needed. Alloying is a primary means to obtain the TiAl alloys with required properties [11].

In this work, TiAl based alloy with alloying elements of Nb, Cr, B and Ta was synthesized by the PM process that combined mechanical milling and SPS.

2 Experimental

The mechanically alloyed TiAl based alloy powder was produced by ball milling a mixture of powders of Ti (99.9% purity, <150 μm), Al (99.9% purity, <70 μm), Cr (99% purity, average particle size of 50 μm), Nb (99.8% purity, average particle size of 50 μm), B (99.999% purity, average particle size of 0.6μm) and Ta (99.98%

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purity, average particle size of 50μm). The powders were fully mixed with composition of Ti−45Al−5.5(Cr,Nb,B, Ta) (mole fraction, %).

The PM100 high energy planetary ball mill was used for milling TiAl based alloy powder. The mechanical milling was done with a stainless steel vial and 75 stainless steel balls with diameter of 12.5 mm in high purity argon atmosphere, and 100 g of TiAl based alloy powder mixture by adding 0.63% stearic acid as a process control agent in one vial. The rotation speed of disc was 100−300 r/min, and that of vial was 200−600 r/min. The mass ratio of ball to powder was 6:1. At first the powders were milled with a low rotation speed of 100 r/min to mix the powders thoroughly, and then the powders were mechanically milled under high purity argon atmosphere with a rotation speed of 300 r/min for 6 h.

The milled TiAl based alloy powder was sintered under pressure of 50 MPa at 900 and 1000 °C by DR. Sinter 1050 SPS furnace. The holding time at the sintering temperature was 5 min. The size of the sintered samples was *d*30 mm×(5−6) mm. The sintered samples were heat treated at 1360 °C for 0.5 h. The Vickers hardness was measured by a HV-5 Vickers tester with a load of 49 N for 30 s. Circular specimens with size of *d*3 mm×5 mm were machined from the sintered samples. The Instron 5500 testing machine was used for compressive tests, and the strain rate was 0.5 mm/s.

3 Results and discussion

3.1 Microstructure and phase composition

Figure 1 shows the SEM image of the high energy mechanically milled Ti−45Al−5.5(Cr,Nb,B,Ta) powder. The grains show unequal shape and the size of grains ranges from several micrometer to scores of micrometers. Figure 2 shows the XRD pattern of the high energy mechanically milled Ti−45Al−5.5(Cr,Nb,B,Ta) powder. From the XRD pattern, it can be found that the Ti_3Al and TiAl are the major phases, which shows that after 0.5 h high energy mechanical milling the powders have almost reacted each other. In addition, the intensity of peaks of XRD pattern indicates that the amount of Ti_3Al phase is more than that of TiAl phase. Both the peaks of two phases are broader and exhibit shoulders, which indicate the trend of transiting of Ti_3Al and TiAl phases to amorphous and decreasing of grain size.

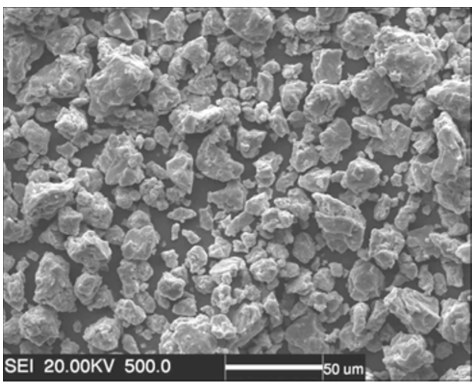

Fig. 1 SEM image of high energy mechanically milled Ti−45Al−5.5(Cr,Nb,B,Ta) powder

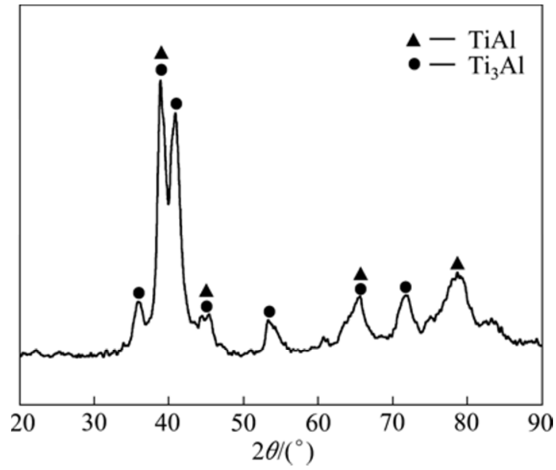

Fig. 2 XRD pattern of Ti−45Al−5.5(Cr,Nb,B,Ta) powder after high energy mechanical milling

Figure 3 shows the SEM images of the bulk samples sintered and consolidated by SPS of Ti−45Al−5.5(Cr,Nb, B,Ta) powder at different temperatures after heat treatment at 1360 °C for 0.5 h. After heat treatment the microstructure is not the equiaxed near gamma grain with some TiB_2 phases as the microstructure without heat treatment as referred in Ref. [8], but the duplex structure with some fine equiaxed gamma grains and thin needle TiB_2 phases. From Fig. 3, it can also be found that the character of duplex structure is obvious in the microstructure of bulk samples SPSed at 1000 °C than that at 900 °C, but the grain size changed a little. The samples SPSed at both the temperatures exhibit compact structure with few pores.

At both the SPS temperature of 900 °C and 1000 °C the full lamellar is not found, which suggests that the T_α (α transition temperature) of this kind of TiAl alloy may be higher than the heat treatment temperature of 1360°, or the holding time is not enough.

Figure 4 shows the XRD patterns of the heat treated bulk samples prepared by SPS of Ti−45Al−5.5(Cr,Nb,B, Ta) powder at SPS temperatures of 900 °C and 1000 °C. The clear diffraction peaks suggest that the sintered samples are both composed of TiAl and Ti_3Al as the major phase, with a minor amount of TiB_2 phase. The reason is that during the process of SPS and heat treatment the milled powder reacted completely.

XIAO et al [8] indicated that with the SPS temperature increasing the peak intensity of TiAl phase

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