Fabrication and Mechanical Properties of TiC/TiAl Composites *

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Abstract: TiC/TiAl composites with different TiC content were fabricated by rapid heating technique of spark plasma sintering (SPS). The effect of TiC particles on microstructure and mechanical properties of TiAl matrix was investigated. The results indicate that grain sizes of TiAl matrix decrease and mechanical properties are improved because of the addition of TiC particles. The composites display a 26.8% increase in bending strength when 10wt% TiC is added and 43.8% improvement in fracture toughness when 5wt% TiC is added compared to values of TiC-free materials. Grain-refinement and dispersion-strengthening were the main strengthening mechanism. The improvement of fracture toughness was due to the deflection of TiC particles to the crack.

Key words: TiC/TiAl composites; mechanical properties; SPS sintering technique

1 Introduction

Titanium aluminide based on TiAl(γ) has shown excellent potential to become one of the most important aerospace materials because of its low density, high specific strength, high melting temperature and environmental resistance at elevated temperature. At present, the brittleness at room temperature and low strength at high temperatures have hindered its practical use. Reinforcing TiAl intermetallic with ceramic particles is an effective method to overcome these limitations. Usually TiC can be regarded as a good choice for its high elastic modulus, hardness and stability at high temperatures. The existence of second-phase particles can prevent the movement of grain boundary, restrain the growth of grains and improve the heat-resistance stability materials.

As a new rapid sintering technology in materials science and engineering with high sintering speed, high reproducibility, safety, and reliability, spark plasma sintering (SPS) is receiving increasingly attention and used to fabricate the Functionally Graded Materials, metal matrix composites and intermetallics. In this paper, TiC/TiAl composites were synthesized by using SPS technique and the effect of TiC particles on microstructure and the mechanical properties of TiAl matrix were investigated.

2 Experimental

2.1 Preparation of specimen

TiC particles with the size of 0.3μm were provided by shijiazhuang High-tech Nanometer Ceramic Material Factory. The Ti-50Al(at%) powder was sieved after being synthesized by combustion synthesis technique. XRD analysis showed that the powders were composed of TiAl and little Ti3Al phase.

TiAl and TiC powders were blended for 24h at a mixer with 5wt%, 10wt%, 15wt% and 20wt% TiC, respectively, then put into the SPS furnace (model-1050, Sumitomo Coal Mining Co., Ltd., Tokyo) in a graphite mould of Ø32mm in vacuum. The sintering temperature was shown in Table 1. The sintering pressure was 30 MPa and the holding time was 10 min.

2.2 Microstructure analysis and mechanical properties test

The relative densities of the sintered samples were tested by means of the buoyancy method. X-ray diffraction (XRD) was used to characterize the product phases, while scanning electron microscopy was used to examine the microstructure.

The sintered samples were cut into strip specimens and then polished to a diamond surface finish of 1.5μm. Sizes of all strip specimens were 3 x 4 x 26(mm) and 2 x 4 x 26(mm), respectively. The 3 x 4 x 26(mm) specimens were used for measuring the three-point bend strength with a span of 20 mm and a crosshead speed of 0.5 mm/min at room temperature, while 2 x 4 x 26(mm) specimens were supplied to measure the fracture toughness using a single edge notch method with a span of 20 mm and a crosshead speed of 0.05 mm/min at room temperature. Both of bend strength and fracture toughness were calculated as the average of six specimens.

3 Results and Discussion

3.1 Relative density and microstructure

Table 1 shows the relative density and sintering tem-
The theoretical densities of TiAl and TiC are 3.9 \text{g/cm}^3 and 4.8 \text{g/cm}^3, respectively. For TiC/TiAl composites, the theoretical density can be calculated from formula (1):

$$\rho = V_m \rho_m + V_p \rho_p$$

where \(\rho_m\) and \(\rho_p\) are the theoretical densities of TiAl and TiC respectively, \(V_m\) and \(V_p\) are their volume fractions. Due to different melting points of TiAl and TiC so in order to keep composites sintered well sintering temperatures would be increased correspondently with more content of TiC added. From Table 1 it could be seen that the compaction of all composites was more than 98%.

The XRD patterns of samples sintered at different temperatures with different compositions were shown in Fig. 1. It could be seen that the product contained TiAl, TiC and little Ti_3Al phases and no other phases were found.

### 3.2 Mechanical properties

The hardness increased with the increase of TiC addition as shown in Fig. 2. The hardness of the sample with 20wt% TiC reached as high as 12.3 GPa, which was two times than that for binary TiAl (5.6 GPa).

The bend strength and fracture toughness \((K_{IC})\) of composites was shown in Fig 3. It could be seen that with the addition of TiC, the bend strength of composites increased and attained a maximum (815.5 MPa) at the addition of 10wt% TiC, which was 26.8% higher than that of binary TiAl matrix. When TiC content reached more than 10wt%, the strength decreased. Moreover, the sample with 20wt% TiC showed lower strength than the value of binary TiAl product.

The variation trend of the fracture toughness \((K_{IC})\) was similar with that of the bend strength. For the sample with 5wt% TiC added, the toughness got to 17.4 MPa$\cdot$m$^{1/2}$, which was 43.8% higher than the value of binary TiAl matrix. When the TiC content was over 5wt%, the fracture toughness decreased gradually. For the samples with 15wt% and 20wt% TiC, the fracture toughness was evidently lower than the value of binary TiAl.

### 3.3 The mechanism analysis of strengthening materials

#### 3.3.1 Special sintering mechanism of SPS technique

Excellent mechanical properties of materials firstly lied on high compaction. The rapid temperature-elevating rate was one of significant advantages of SPS technique, which could reach as high as 300°C/min. Therefore during sintering process the grains of material had been sintered well before their further growth and it took only about 10min to reach the sintering temperature of materials. Holding 10min at sintering temperature nearly full compaction could be achieved. Usually sintered materials showed excellent compaction over 98% with lower porosity. Comparatively traditional sintering Technique such as hot pressing in vacuum showed some limitations as follows. Lowes elevating-temperature rate as quick as only 20°C/min easily gave rise to further growth of grains; Moreover the compaction of materials was less than 98%. Compared to SPS technique extra 150-200°C was elevated to keep materials sintered well when sintering same materials.