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Combustion reaction of Ti–Al–C–N system

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Abstract. **The combustion reaction of Ti–Al–C–N system was investigated by using Ti powders and one CN*x* precursor powder as reactant powder blends. The reactant powder blends ratio was adjusted to obtain different materials. The phase composition of the samples was investigated by X-ray diffraction (XRD). The microstructure of the samples was observed by scanning electron microscopy (SEM). The result showed that $Ti_2Al(C,N)$–TiAl*x*, AlN–Ti(C, N) and $Ti_3Al(C,N)_2$–TiC composites can be fabricated by changing the reactant powder blends ratio.**

Keywords. **Combustion reaction; Ti–Al–C–N system.**

1. Introduction

Combustion synthesis technology is of interest because of the perceived savings such as very short processing time, low energy requirement and high yield of pure products. This technology has been widely used for synthesizing different series of materials (Patil *et al* 2002; Aruna and Mukasyan 2008).

During Ti–Al–C–N system, many famous materials such as TiC (Hassan *et al* 2009; Licheri *et al* 2003), AlN (Juang *et al* 2003; Wang *et al* 2001), TiAl*x* (Lee *et al* 2000) and Ti(C, N) (Eslamloo-Grami and Munir 1994) had been synthesized by combustion reaction. The previous researches dealt with binary and ternary systems. To date, there is little report on the study of Ti–Al–C–N system by combustion synthesis.

In our previous study (Li *et al* 2003), we fabricated one novel carbon–nitrogen solid precursor. By using this CN*x* precursor as the reactant powder blends, Ti(C, N) material was synthesized by combustion synthesis (Mu *et al* 2011). In this study, we will study the combustion reaction of Ti–Al–C–N system from Ti/Al/CN*x* powders.

2. Experimental

Ti powder (99·6%, −300 mesh), Al powder (99·0%, −200 mesh) and CN*x* powder (99·0%, −300 mesh) were mixed in different mole ratios. In order to attain a homogeneous mixture, all powders were milled for 2 h in a planetary mill (ND) using agate balls. The jars were made of agate and the rotating speed was 100 rpm. The ratio of balls to powders was 10:1. The mixtures were pressed into 5 × Φ 10 mm rods at room temperature. The combustion reactions were performed on the plasma jet cladding system. X-ray diffraction (XRD) experiments were carried out in a rotating anode X-ray diffractometer (D/MAX-2500PC) with CuKα radiation. Morphology of the product was examined by scanning electron microscopy (SEM) (Model JSM-5500LV), coupled with energy-dispersive spectroscopy (EDS) for chemical analysis (Model Phoenix, EDAX).

3. Results and discussion

Figure 1 shows XRD pattern of the synthesized samples from different Ti/Al/CN*x* reactants. From figure 1(a–d), when the reactant powder blends ratio was designed according to the chemical reaction of $Ti_3Al(C,N)_2$ or $Ti_2Al(C,N)$, $Ti_2Al(C,N)$–TiAl and $Ti_3Al(C,N)_2$–TiC composites were obtained. As can be seen from figure 1(e and f), AlN–Ti(C, N) composites were obtained by using 2Ti/1Al/3CN*x* and

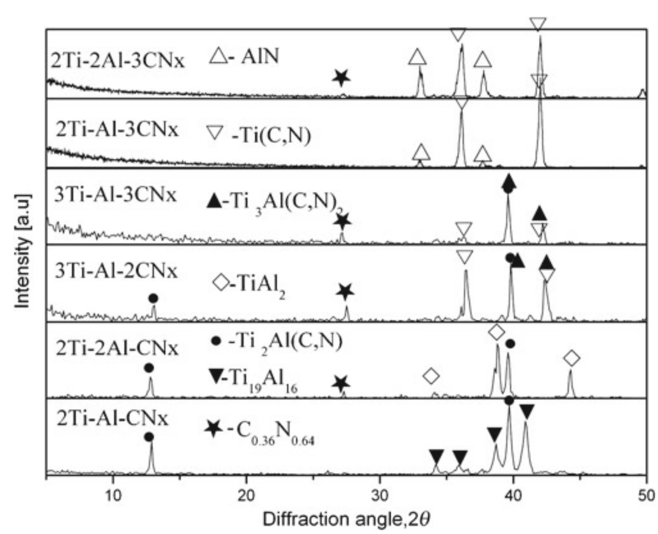

Figure 1. XRD of synthesized samples from Ti/Al/CN*x* reactant powders.

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2Ti/2Al/3CNx as the reactant powder blends. The above XRD results indicated several composites in Ti–Al–C–N system which were fabricated by combustion reaction. Additionally, CNx peak was still observed from some synthesized samples, indicating that many CNx precursor powders did not yet react. Because of very short reaction time, the reactant powder blends were incompletely conversed.

According to literature (Pietzka and Schuster 1996), the thermodynamic conditions, reactions and stability of these compounds in Ti–Al–C–N system was discussed as follows. When Al content was higher, amounts of TiAlx compound were easily formed in the product from 2Ti/Al/(1 or 2)CNx. When C and N contents were higher, AlN and Ti(C, N) formed in the product from 2Ti/(1 or 2)Al/3CNx. When Al content was lower, $Ti_2Al(C, N)$ and Ti(C, N) compounds can easily be formed in the product from 2Ti/Al/(1 or 2)CNx.

Figure 2 shows morphology of the sample from 2Ti/Al/CNx. Figure 2 demonstrated that the sample was composed of $Ti_2Al(C, N)$ platelets and TiAlx phase. $Ti_2Al(C, N)$ grains had an average length of 10 μm. In addition, we can observe the crack propagation in the micrograph. $Ti_2Al(C, N)$ platelets prevent the propagation of cracks, thus toughening the composites. Crack deflection, bridging and cutting caused by $Ti_2Al(C, N)$ platelets are anticipated to occur during the fracture process.

Figure 3 shows morphology of the sample from 3Ti/Al/3CNx. Figure 3 demonstrated that the sample was basically composed of $Ti_3Al(C, N)_2$ lathed grains with a length of about 10 μm. A few amounts of TiC equiaxed grains can be found. Amounts of transgranular fractured $Ti_3Al(C, N)_2$ grains present flat planes. When the basal

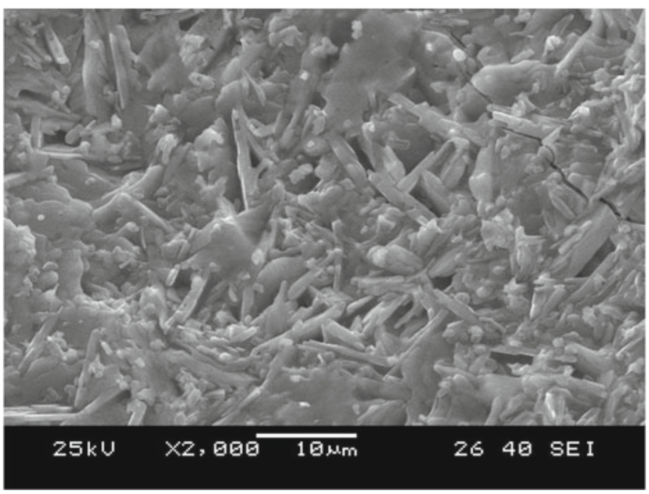

Figure 2. Morphology of synthesized sample from 2Ti/Al/CNx reactant powders.

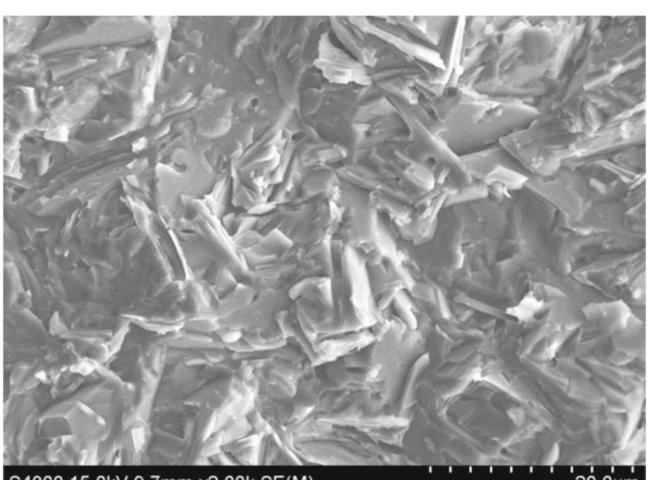

Figure 3. Morphology of synthesized sample from 3Ti/1Al/3CNx reactant powders.

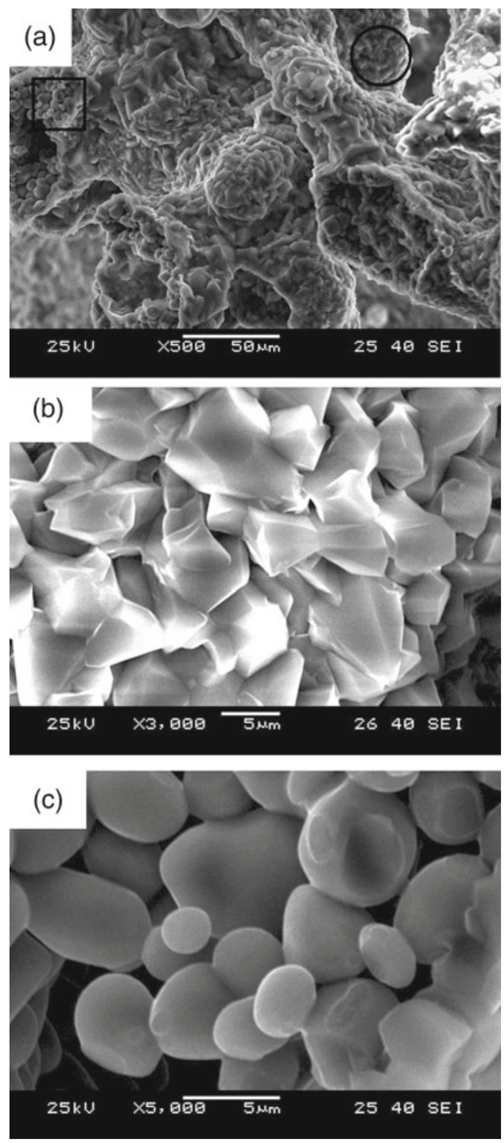

Figure 4. (**a**) Morphology of synthesized sample from 2Ti/2Al/3CNx reactant powders. Also shown are enlargements of (**b**) area circle in figure 4(**a**) and (**c**) area pane in figure 4(**a**).

planes of $Ti_3Al(C,N)_2$ are parallel to the crack propagation, the crack will propagate along the basal planes resulting in its delamination. The deformation of $Ti_3Al(C,N)_2$ grains combined with the formation of delamination is unusual for ceramics. This delamination can redistribute the strain and dissipate the stress concentration, which gives good $Ti_3Al(C,N)_2$ damage-tolerance capabilities.

Figure 4 shows morphology of the sample from 2Ti/2Al/3CN*x*. In figure 4(a), the sample contained many pores. As can be seen from figure 4(b), the sample composed of AlN grains (identified by EDS). As can be seen from figure 4(c), other Ti(C, N) equiaxed grains (identified by EDS) also can be found.

Figures 2–4 show an interesting variation of morphology and microstructure. The morphology of a crystal is determined by both its crystal structure and growth conditions such as temperature. The crystal structure is related to the composition of this crystal. The high reaction temperature, high heating and cooling rates and extremely uneven temperature fields of the combustion reaction synthesis process, usually result in a variety of morphologies of the products. $Ti_2Al(C,N)$ and $Ti_3Al(C,N)_2$ hexagonal crystals can grow as platelets (figures 2 and 3). Under this high combustion temperature, these crystals can easily grow and develop. Similarly, AlN and Ti(C, N) can grow as equiaxed grains.

Several plasma based techniques are routinely used to produce nitride/carbo-nitrides on Ti- and Fe-based substrates (Mukherjee *et al* 2004; Ram Mohan Rao *et al* 2007). In this study, several types of composites were fabricated by combustion synthesis from Ti–Al–C–N system. By using different reactant powder blends ratio, different composites can be obtained.

4. Conclusions

The combustion reaction of Ti–Al–C–N system was investigated. $Ti_2Al(C,N)$–$TiAl_x$, AlN–Ti(C, N) and $Ti_3Al(C,N)_2$–TiC composites can be fabricated by changing the reactant powder blends ratio.

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