



Microstructure and evolution of (TiB₂+Al₂O₃)/NiAl composites prepared by self-propagation high-temperature synthesis



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Abstract: (TiB₂+Al₂O₃)/NiAl composites were synthesized by self-propagation high-temperature synthesis, and their phase compositions, microstructures and evolution modes were studied. The microstructures and shapes vary with the TiB₂+Al₂O₃ content in the NiAl matrix. TiB₂ particles take a great variety of elementary shapes such as white bars, plates, herringbones, regular cubes and cuboids. These results outline a strategy of self-assembly processes in real time to build diversified microstructures. Some TiB₂ grains in sizes of 2–5 μm are embeded in Al₂O₃ clusters, while a small number of TiB₂ particles disperse in the NiAl matrix. It is believed that the higher the TiB₂+Al₂O₃ content is, the more the regular shapes and homogeneous distributions of TiB₂ and Al₂O₃ will be present in the NiAl matrix.

Key words: (TiB₂+Al₂O₃)/NiAl composites; self-propagation high-temperature synthesis; microstructure; evolution mechanism

1 Introduction

Due to its low density (5.59 g/cm³), high melting point (1911 K), good thermal conductivity and good corrosion resistance [1], the NiAl intermetallic compounds have a wide application for components in high-temperature and corrosive environments, such as aero-engines, blades of gas turbine, thermal barrier coatings, and corrosion-resisting coatings. However, the low plasticity at room temperature and low strength at high temperature limit their applications in industry and production [2,3].

Up to now, many publications have involved in improving the room temperature plasticity and high temperature strength of Ni–Al intermetallic compounds. Adding different alloy elements such as Mo [4], Ti [5], Cr [6], and rare-earth metals [7] in NiAl is an efficient way to improve its properties. By adding or forming ceramics particles, such as Al₂O₃ [8,9], TiB₂ [10], NbB₂ [11] and TiC [12,13], the strength and creep properties of Ni–Al composite material can also be greatly improved. MICHALSKI et al [14] fabricated a

NiAl–Al₂O₃ composite with different amounts of Al₂O₃ in NiAl through spark plasma sintering and self-propagation high-temperature synthesis (SHS) of Ni and Al, and the results showed that the hardness of NiAl–Al₂O₃ increased and the fracture toughness of it was almost twice that of NiAl. The fabrication of NiAl matrix composites was carried out by a variety of novel processes such as combustion synthesis [11,14], mechanical alloying [13] and high pressure reaction sintering. It has been proved that combustion synthesis has significant advantages, such as low energy consumption, inexpensive fabrication equipment, simplicity of operation and in situ synthesis of composite components, compared with other conventional methods. Via combustion synthesis procedure, a series of NiAl matrix composites reinforced by TiB₂, NbB₂, TiC, Al₂O₃, ZrB₂ [15] and TiN [16] were obtained conveniently.

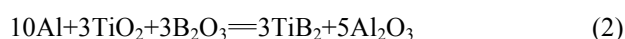
At present, many researches focus on TiB₂ and Al₂O₃ ceramics as a duplex reinforced phase in different matrices because of their similar thermal expansion coefficient, chemical and physical compatibility [17]. By adding TiB₂ into Al₂O₃ ceramics, the growth of Al₂O₃ grains and the propagation of cracks in the matrix can be

prevented. Consequently, the fine and well-distributed TiB_2 phase would help to enhance the strength and fracture toughness of the composite material. Thus, it would contribute to improving the abrasion resistance and fracture toughness in cutting tool materials [18,19].

The study on the previous work indicates that the fabrication of $\text{TiB}_2+\text{Al}_2\text{O}_3/\text{NiAl}$ composite materials through combustion synthesis has not been fully investigated. The fundamental objective of the present study is to investigate the microstructures and their evolution modes when different $\text{TiB}_2+\text{Al}_2\text{O}_3$ contents were formed in the NiAl matrix, using Ni, Al, B_2O_3 and TiO_2 as raw materials, via combustion synthesis. Also, the correlation between the $\text{TiB}_2+\text{Al}_2\text{O}_3$ content, microstructure and properties of the composites was investigated.

2 Experimental

The raw materials are commercial pure Ni powder (99.9%, 38–50 μm), Al powder (99.9%, 75 μm), B_2O_3 powder (98%, 75 μm), and TiO_2 powder (98%, 45 μm). The powder mixtures were considered as two parts: one was Ni+Al in which the mole ratio was fixed to $n(\text{Ni}):n(\text{Al})=1:1$, the other was $\text{Al}+\text{TiO}_2+\text{B}_2\text{O}_3$ in which the mole ratio was fixed to $n(\text{Al}):n(\text{TiO}_2):n(\text{B}_2\text{O}_3)=10:3:3$, and the latter was added into the former in mass fractions of 0, 5%, 10%, 15%, 20%, 25% and 30%, respectively. In order to produce a homogeneous mixture, all the powders were mixed in a three-dimension blender for about 6 h. Then, the mixtures were poured into metal molds with dimensions of $d20 \text{ mm} \times 20 \text{ mm}$ and pressed at a pressure of 150 MPa into cylindrical compacts. Seven typical green compacts were fabricated with different contents of $\text{Al}+\text{TiO}_2+\text{B}_2\text{O}_3$. In order to make the reactants react completely, the green compacts were preheated in an electric furnace at 300 °C for 30 min. After that, the compacts together with the molds were taken out and a small amount of Mg powders was poured onto the surface as the initiating combustion agent. At last the compacts were ignited by live tungsten wire immediately. The reactions between powders in raw materials were as follows:



Under the present condition, the reaction in green compact could self-sustain due to its high exothermic heat (SHS), the process is shown in Fig. 1.

The crystalline phases of the products were characterized by X-ray diffraction (XRD, Model D/Max 2500PC Rigaku, Japan). The morphologies of the fracture and microstructure were observed by scanning electron microscopy (SEM, Model KYKY2800B) and field emission scanning electron microscopy (FESEM,

NOVA NANOSEM 450, FEI). The compositions of samples were analyzed using electron probe microanalysis (EPMA, JXA-8230). The microhardness was measured by FM-700 with the load of 1 N and sustaining for 10 s. For each compound, five indentations were taken in the microhardness test and made an average of these points with a consideration of relative errors.

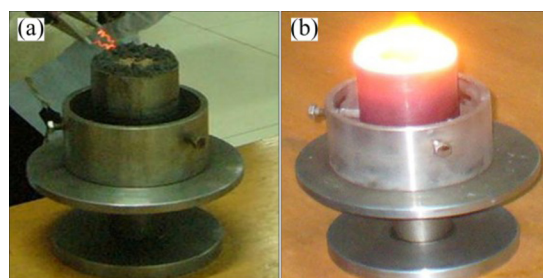


Fig. 1 Schematic diagrams of SHS reaction initiated by electrifying tungsten wire (a) and SHS reaction (b)

3 Results

In the sample without $\text{Al}+\text{TiO}_2+\text{B}_2\text{O}_3$, the Ni+Al reaction wave propagated steadily, and the speed was about 25 mm/s. When adding $\text{Al}+\text{TiO}_2+\text{B}_2\text{O}_3$ into Ni+Al, the igniting delay time prolonged. Once the reaction was initiated, the reaction wave spread rapidly. When the content of $\text{Al}+\text{TiO}_2+\text{B}_2\text{O}_3$ increased to 15%, the spreading speed reached up to 40 mm/s. Thus, the whole reaction in the compacts almost took place at the same time, similar to thermal explosion. After the reactions finishing, the samples were slowly cooled down.

3.1 Phase analysis

Figure 2 shows the XRD pattern of the raw materials. It illustrates that the powder mixture is composed of Ni, Al, TiO_2 and B_2O_3 . Figure 3 shows the XRD patterns of products obtained by adding different contents of $\text{Al}+\text{TiO}_2+\text{B}_2\text{O}_3$.

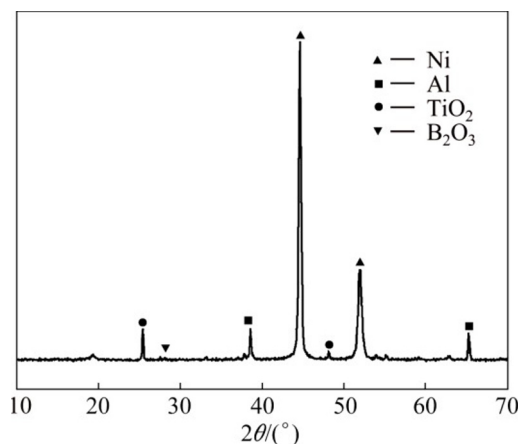


Fig. 2 XRD pattern of reactants

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