Bonding mechanism of X10CrNi18-8 with Ni/Al₂O₃ composite ceramic by pressureless infiltration

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Abstract: An alloy steel/alumina composite was successfully fabricated by pressureless infiltration of X10CrNi18-8 steel melt on 30% (mass fraction) Ni-containing alumina based composite ceramic (Ni/Al₂O₃) at 1600 °C. The infiltration quality and interfacial bonding behavior were investigated by SEM, EDS, XRD and tensile tests. The results show that there is an obvious interfacial reaction layer between the alloying steel and the Ni/Al₂O₃ composite ceramic. The interfacial reactive products are (FeₓAlᵧ)₃O₄ intermetallic phase and (AlₓCrᵧ)₂O₃ solid solution. The interfacial bonding strength is as high as about 67.5 MPa. The bonding mechanism of X10CrNi18-8 steel with the composite ceramic is that Ni inside the ceramic bodies dissolves into the alloy melt and transforms into liquid channels, consequently inducing the steel melt infiltrating and filling in the pores and the liquid channels. Moreover, the metallurgical bonding and interfacial reactive bonding also play a key role on the stability of the bonding interface.

Key words: pressureless infiltration; steel/alumina composites; interface bonding; infiltration mechanism

1 Introduction

Metal matrix composites (MMCs) combine high strength and hardness, wear and oxidation resistance of ceramics with ductility as well as thermal and electrical conductivity of metals. Therefore, they are very suitable for certain applications, e.g. aerospace, military, automotive industry, food and pharmaceutical industry. Among various MMCs, high-melting alloy steel matrix composites reinforced by oxide ceramics (e.g. Al₂O₃ and ZrO₂) not only have various advantages of MMCs but also possess ideal performance at high temperature, which have been produced by melts infiltration [1–9] and tape casting [10]. In comparison with the tape casting, the melts infiltration is a more economic and attractive method. Due to special requirement for common mould caused by high melting point of alloying steel (above 1000 °C), it is difficult to fabricate these MMCs by squeeze casting or gas pressure infiltration. So, pressureless infiltration may be a better choice, which relies on the wettability between ceramic and metal melts [3]. But the contact angle between the steel melt and oxide ceramics still remains above 90° at 1600 °C [4]. This poor wettability was improved by Ti-activated infiltration [1–4] or coating metal layers (e.g. plating Ni) on a surface of alumina ceramic [5]. However, Ref.[1] reported that Ti particles inside the ceramic will block the melt infiltration channels when Ti content increases, and the processing of coating or plating Ni is very complex and expensive. Therefore, it becomes an interesting problem whether a more economic and simple method for the fabrication of alloy steel/alumina composites can be developed or not.

In the past, in order to achieve the infiltrating behavior of steel melts on alumina ceramic and the interface bonding, Ni particles with different contents (5%, 10%, 15% and 20%, mass fraction) were mixed into the ceramic bodies and Ni-containing alumina ceramic based composites were obtained by powder metallurgy method. The pressureless infiltration experiments indicated that when the Ni content was 20%, the firm bonding between the steel and ceramic samples could be formed, the strength reached about 60 MPa and the steel melt infiltration depth was above 400 μm. However, the mechanism for interface bonding and infiltration had not been revealed particularly. The focus of the present work is to analyze the bonding mechanism by using X10CrNi18-8 steel melt and 30% Ni-containing alumina ceramic based composite.

2 Experimental

The compositions of alumina ceramic and alloying steel are summarized in Table 1. A mixture of alumina powders (70%, mass fraction) and Ni powders (30%,...
Table 1 Compositions of alumina ceramic and alloying steel

<table>
<thead>
<tr>
<th>Material</th>
<th>Composition (mass fraction)</th>
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<tr>
<td>95 alumina</td>
<td>SiO₂: 2.5% + CaO: 2.0% + MgO: 0.5% + Al₂O₃: 95%</td>
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<tr>
<td>X10CrNi18-8</td>
<td>Cr: 17.20% + Ni: 8.00% + C: 0.11% + Si: 0.44% + Fe: 71.07% + Others: 3.18%</td>
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mass fraction) were milled for 50 h with a QM-3SP2 ball mill. After that, the mixture powders were dried at 100 °C and held for 4 h, leached by 150 meshes boult, and pressed into column green bodies (diameter: 22 mm, height: 10 mm). The Ni-containing alumina based composite ceramic (briefly called AN30) with a diameter of about 20 mm was prepared by sintering the pressed green bodies at 1450 °C with a dwell time of 2 h in vacuum. The X10CrNi18-8 steel samples were cut into cubes with dimensions of 8 mm×8 mm×8 mm (used for wetting experiments and microstructure observation) and 14 mm×14 mm×25 mm (used for bonding strength tests), respectively. After ground and cleaned with acetone in ultrasonic bath, the steel samples were placed on the top of AN30 plates. Then, the steel-AN30 samples were placed in corundum crucibles (aperture: 20−21 mm, height: 50 mm) for bonding experiment by pressureless infiltration. The infiltration processing was conducted in a graphite vacuum furnace, and the processing parameters were set as heating to 1600 °C at a heating rate of 5 °C/min and holding for 4 h.

The microstructures of the obtained samples were observed by scanning electron microscopy (SEM, FEI Quanta 200) with an energy dispersive system (EDS, IE350MT). The elemental content of metal phase inside the fabricated alloy steel/alumina composite was analyzed by EDS. The microhardness of metal phase on both sides of the bonding interface was measured with a micro-Vickers measurement system (HVS-1000). The interface bonding strength was performed under tensile stress with a universal testing machine (SANS CMT 5105). Both surfaces of the tensile sample (Fig.1) were ground and adhered to special fixtures by an adhesive.

The phase analysis for the bonding interface was studied by X-ray diffractometry (XRD, X’pert Pro MRD).

3 Results and discussion

3.1 Wetting and infiltration analysis

In order to determine the wettability of X10CrNi18-8 steel and alumina ceramic with and without Ni addition, simple sessile drop experiments were made to estimate the contact angle by measuring the specimen after high-temperature infiltration. The contact angle of X10CrNi18-8 steel and alumina ceramic without Ni addition is about (115.5±0.5)°. Meanwhile, interface bonding does not occur. In comparison, the contact angle of X10CrNi18-8 steel and alumina based composite ceramic with 30% Ni addition decreases to (94±0.5)°, as shown in Fig.2, and their interface reaches an excellent bonding. Obviously, the addition of Ni particles in alumina ceramic improves not only its wettability by X10CrNi18-8 steel but also the interface bonding behavior.

3.2 Microstructural observation

Figure 3 shows the BSE image of the sintered AN30 composite ceramic and the SEM morphologies of the cross-section of the alloy steel/alumina composite after infiltration. Figure 3(a) shows that the Ni particles are dispersed homogeneously inside the ceramic, and the particles size of Ni is different because of the existence of agglomerates. It is found from Fig.3(b) that excellent bonding between the alloy steel and AN30 emerges, and there are no cracks and pores at the bonding interface. High resolution observation reveals the formation of a transition interface layer with a thickness of about 6−8 µm, as shown in Fig.3(c). The excellent bonding is further demonstrated by the EDS analysis of alloy particles inside the melt-infiltrated AN30 bodies. After