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Synthesis of an Al_2O_3/Al co-continuous composite by reactive melt infiltration

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Abstract

The route for the fabrication of an Al_2O_3/Al co-continuous composite by reactive melt infiltration was investigated using scanning electron microscopy, energy dispersive X-ray microanalysis and X-ray diffraction analysis. It was found that in the process of molten aluminium infiltration into the SiO_2 preform, the chemical reaction of $3SiO_2+4Al \rightarrow 2Al_2O_3+3Si$ occurred at the infiltration front, and generated a transition zone containing a new type of continuous porosity about 100 μm in width. The reaction continued with further infiltration of molten aluminium alloy into this porosity which reacted with the residual SiO_2 until all the SiO_2 was transformed into Al_2O_3. A comparison was made between this route and that by direct infiltration of molten aluminium alloy into the open porosity of an Al_2O_3 preform. As a result of the increased wetting ability of the molten aluminium alloy by the chemical reaction, reactive melt infiltration took place at a higher rate for the SiO_2 preform than that for the direct infiltration of the Al_2O_3 preform. A fracture surface examination demonstrated a toughening effect provided by the continuous aluminium alloy in the composite.

Keywords: Ceramic/metal co-continuous composite; Chemical properties; Liquid metal infiltration; Preform

1. Introduction

Metal–matrix composites (MMCs) containing high volume fractions of reinforcement are attracting more and more attention because of their comprehensive properties such as low density, high stiffness, low coefficient of thermal expansion, high thermal conductivity, high strength and high wear resistance for applications in various types of packaging, substrates and support structures for electronic devices [1,2] and a number of automobile components including cylinder liners, pistons and brake rotors [3]. Many methods have been found to be suitable to fabricate such composites. These methods include powder metallurgy [4], positive or negative pressure melt infiltration [5,6], vacuum infiltration [7], squeeze casting [8], and the PRIMEX process developed by the Lanxide Corporation [9,10]. In particular, the pressureless spontaneous liquid metal infiltration of porous ceramic preforms is regarded as a more suitable route than other methods for mass production of complex shaped parts. Therefore, much research work has been carried out using this technique [11–16] with various reinforcements such as SiC, Al_2O_3, TiC and AlN in the form of particulates or whiskers, and with certain combinations of molten aluminium alloy composition and environment. This route has been further extended to

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synthesize ceramic/metal co-continuous composites using sintered ceramic preforms with three-dimensional fine and interconnecting porosities throughout their microstructures [13,15,16]. The co-continuous composite is expected to possess outstanding advantages such as a lower coefficient of thermal expansion, higher stiffness and higher wear resistance over the MMCs with the same volume fraction of ceramic reinforcement. It should also have a higher thermal conductivity and higher fracture toughness than the ceramic matrix composite with the same volume fraction of a ductile metal as the toughening phase distributed as discrete, isolated particles in the ceramic matrix [17]. In other words, this kind of composite is expected to acquire good properties from both the continuous ductile metal network and in the ceramic preform.

The infiltration of liquid metal into a porous ceramic preform can only occur spontaneously when the wetting of the molten metal on the ceramic surface reaches a certain value, so that capillary action can be produced within the porosity to lead to the spontaneous infiltration. For example, the direct infiltration of metal into a porous Al_2O_3 preform can be used to synthesize an Al_2O_3/Al co-continuous composite. However, the resulting composite may have inherent microstructural defects, as it is difficult for the ceramic surface to be wetted by a molten metal. To overcome this, many means have been studied to increase the wetting of the molten metal on a ceramic surface. For example, by predoping Mg and Si in the aluminium alloy and using a nitrogen gas environment [10,12,16,18], a chemical reaction at the interface of the molten metal and ceramic can be established [15,16]. So, using a SiO_2 preform, the Al_2O_3/Al co-continuous composite can be synthesized via the chemical reactions of :

$$3SiO_2 + 4Al \rightarrow 2Al_2O_3 + 3Si \quad (1)$$

and

$$\text{metal} + Al \rightarrow \text{aluminide compound} \quad (2)$$

In particular, the wetting ability of the molten aluminium alloy on the ceramic surface is increased.

Although a certain amount of research work has been carried out on the microstructure and properties of this composite [19], it is still not clear what actually occurred at the front of infiltration caused by this chemical reaction.

In the present study, the microstructural changes from the SiO_2 preform to the Al_2O_3/Al co-continuous composite at the infiltration front was studied in depth using scanning electron microscopy (SEM), energy dispersive microanalysis (EDX) and X-ray diffraction (XRD). Also, the difference in the synthesis process between this kind of Al_2O_3/Al co-continuous composite and that synthesized by direct infiltration of porous Al_2O_3 preforms was established.

2. Experimental

Both the SiO_2 and Al_2O_3 preform blanks with a size of 10 × 10 × 50 mm were first prepared by cold pressing homogenous mixtures of ceramic powders with about 10 µm in particle size, and some organic binder at a pressure of 50 MPa. After debindering at 450 °C for 2 h, the blanks were heated up to 1350 °C slowly and sintered at this temperature for 4 h so as to obtain preforms with three-dimensional interconnecting porosities throughout their microstructures. Fig. 1A and B show the fracture surfaces of the SiO_2 and Al_2O_3 preforms respectively, with ceramic powders connected after sintering at this

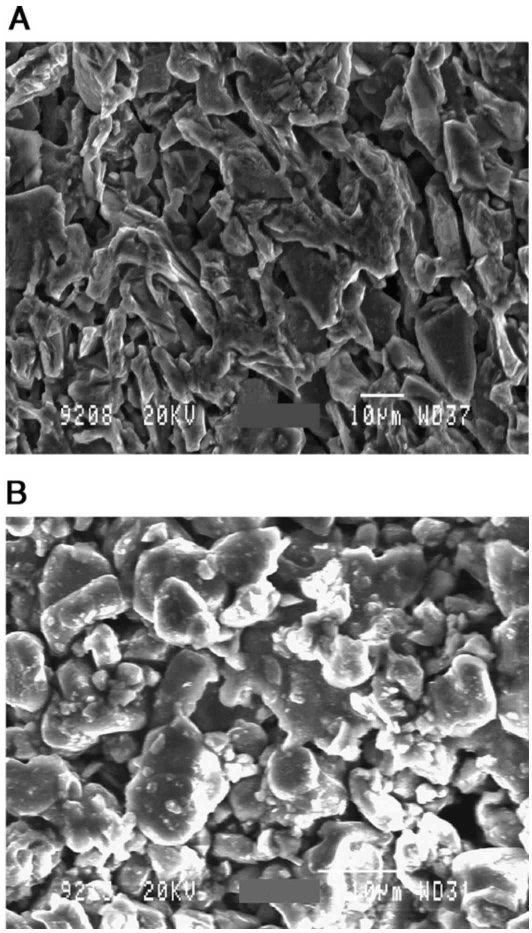

Fig. 1. SEM micrographs of fracture surface of preforms of (A) SiO_2 and (B) Al_2O_3.