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Processing of silicon carbide–boron carbide–aluminium composites

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Abstract

The aim of this work was to shed light on the wetting mechanism in the SiC–B_4C–Al system and to explore processing routes that enable infiltration of Al alloys into these ceramic powder mixtures without the formation of the deleterious reaction product Al_4C_3. For this purpose, powder mixtures consisting of SiC and pre-treated B_4C were pressureless infiltrated with Al alloys at relatively low temperatures under an inert gas atmosphere. Depending on the characteristics of the starting powders fully infiltrated composites were achieved in the temperature range of 935–1420 °C. It was observed that addition of pre-treated B_4C to SiC enabled complete infiltration of the ~0.6 cm thick preforms. The bulk density of all produced composites was >98% of the X-ray density. By controlling the surface chemistry and particle size of the starting powders as well as the processing conditions, the wetting behaviour and reaction kinetics of this system could be tailored so as to render fully dense SiC–B_4C–Al composites devoid of Al_4C_3.

Keywords: Composites; Carbides; SiC; Armour; Infiltration

1. Introduction

Wettability can be defined as the ability of a liquid to spread on a solid surface, and it represents the extent of intimate contact between a liquid and a solid.[1] Unfortunately, the wettability of ceramic particles with liquid Al alloys is generally poor.[2]

Lack of wetting is usually attributed to the presence of contamination, moisture, or a gas layer that covers the ceramic particle surface, to the Al_2O_3 layer that covers liquid Al and/or to the native SiO_2 layer that ordinarily covers SiC particles. In all these cases the molten metal matrix is hindered from coming into contact with the surface of the individual particles.[3–7]

Various procedures have been recommended to improve the wetting of ceramic particles by liquid metal, and include: (i) increasing metal liquid temperature,[8] (ii) the addition of some surface-active/reactive elements such as Mg, Li, Ca, Ti, or Zr into the matrix alloy,[9–13] (iii) coating or oxidising the ceramic particles,[14–18] and (iv) cleaning the particles, for example by preheat treatment.[19–21] The principle methods to improve wetting are based on (1) increasing the surface energy of the solid, (2) decreasing the surface tension of the liquid alloy, or (3) decreasing the solid–liquid interfacial energy, at the particle–matrix interface.[22,23]

Two of the major problems frequently encountered in the processing by the pressureless infiltration method are (i) the presence of considerable levels of residual porosity and (ii) the development of unwanted reaction products (Al_4C_3, Al_4SiC_4).[24]

Residual porosity is related to an inadequate wetting of SiC by molten Al and unwanted reactions/phases developed from the dissolution of the SiC reinforcement by the liquid Al.[25–27] At temperatures above the melting point of Al, and under atmospheric pressure, SiC becomes thermodynamically unstable; interfacial reactions may occur and result in reaction products such as Al_4C_3[25,27–34] and Al_4SiC_4.[35–37] Because the solubility of C in liquid Al is very low, the threshold C activity values for Al_4C_3 formation are small. The C atoms that go into solution will react almost immediately with Al to form Al_4C_3 either as a continuous layer or as discrete precipitates around the SiC particles.[38] Not only does this reaction cause the dissolution/degradation of the SiC reinforcing particles and result in weakening of the composite, but also both Al_4C_3 and Al_4SiC_4 are thermodynamically unstable and have

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a tendency to hydrolyse slowly with the atmospheric moisture to form Al-hydroxide thereby enhancing crack propagation in the composite by the moisture-induced corrosion of the Al_4C_3 phase.[35,38,39]

2. Aim of the current study

B_4C–Al composites are potential candidate materials to be used, for example, in impact applications. Although novel processing routes such as pressureless melt infiltration already have ensured fabrication of these composites at low processing costs, the relatively high cost of B_4C powder limits their widespread usage.

SiC, on the other hand is being produced in larger scales and it also has a wider field of application areas when compared with B_4C. The price of SiC powder, accordingly, is lower than that of B_4C while its ballistic performance is close to that of B_4C.

Therefore, the main driving force to conduct this work was to produce SiC–B_4C–Al composites with as low a B_4C content as is possible that may be used for impact applications and explore processing routes that preserve the cost-effectiveness of the pressureless melt infiltration method.

Another important goal of this study was to show that B_4C addition provides an alternative, effective and simple approach to improve the wettability of SiC by Al. That is why the starting SiC powders were not coated or oxidized prior to the infiltration process and a Si-deficient alloy with a relatively low Mg content was used as a source of Al.

3. Experimental

The SEM micrographs of the starting powders are shown in (Fig. 1).

Passivation of starting B_4C powders was achieved by heat-treating them in the absence of free carbon at 1370 °C for 2 h under an Ar gas atmosphere prior to the infiltration process.[40]

SiC and B_4C powders were planetary ball milled in alcohol media. After milling, the slurry was dried in a rotary evaporator.

Preforms were prepared by uniaxially pressing the SiC–B_4C powder mixtures at 100 MPa. Polyethylene glycol (PEG) was used as a binder.

SiC–B_4C–Al composites were produced by melt infiltrating 7075 Al alloy blocks into porous SiC–B_4C preforms under an Ar gas atmosphere. Infiltration temperatures were chosen between 935 and 1420 °C. Heating rate applied was 5 °C/min up to 900 °C and 10 °C/min onwards up to the infiltration temperature. Cooling rate from the infiltration temperature to 900 °C was 10 °C/min and then 5 °C/min down to room temperature.

X-ray diffraction (Rigaku Rint 2200, Tokyo, Japan) was performed using monochromatic Cu-Kα radiation (λ = 1.5406 Å).

Microstructural studies of the composites were performed with scanning electron microscopes (ZEISS EVO 50 EP and ZEISS SUPRA 50 VP, Germany) both attached with an energy dispersive X-ray spectrometer (Bruker AXS XFlash, Germany and Oxford Instruments Inca Energy model 7430, England, respectively).

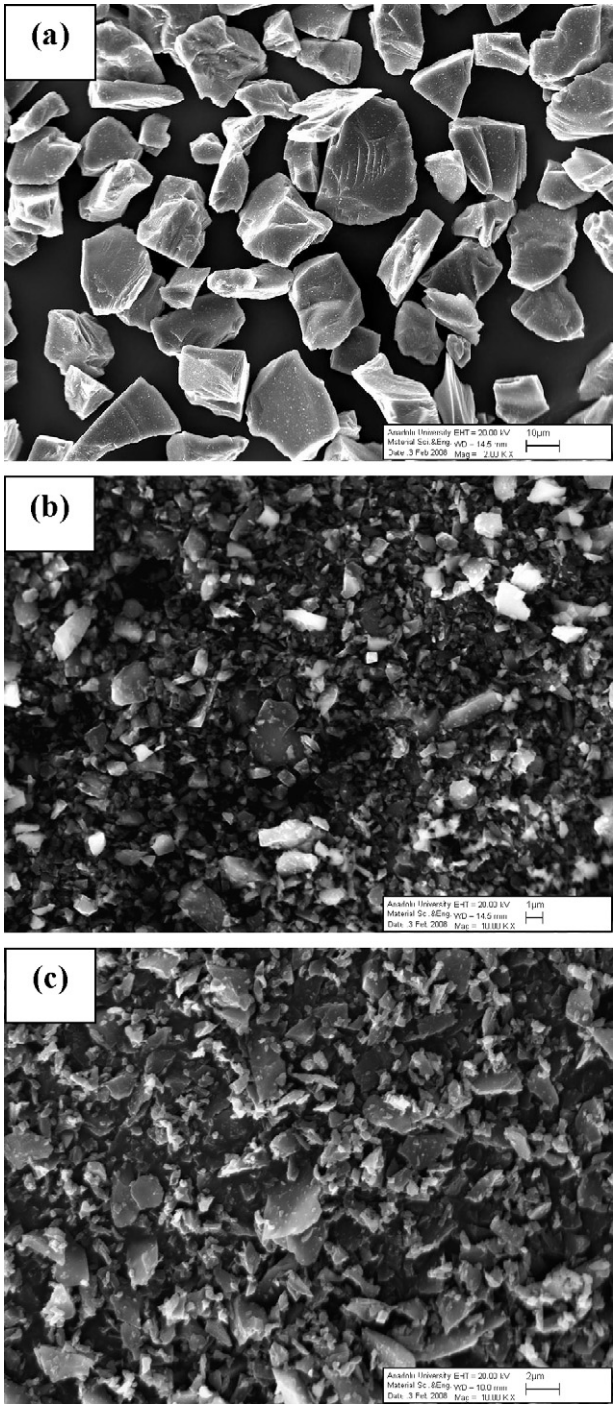

Fig. 1. SEM micrographs of starting powders. (a) coarse SiC, (b) fine SiC and (c) fine B_4C.

4. Results

The lowest infiltration temperatures and infiltration times of the prepared compositions to result in full infiltration of the ~6 mm high pellets are given in Table 1. Among the produced composites 80S20B has the lowest infiltration temperature of 935 °C but at the expense of higher infiltration time. Similarly, the compositions 60S40B and 70S30B have the lowest infiltration times but at the expense of somewhat increased infiltration