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Dual coating process for a high functional reinforcement phase in metal matrix composites

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ABSTRACT

An inoculant, ferrosilicon, was used as a core particle for the fabrication of a reinforcement phase, which has been generally used in the foundry industry to improve crystal growth of carbon and to restrict formation of cementite. Titanium carbide (TiC) particles were coated onto the surface of the inoculant using an inorganic binder converted into the glass phase by the hydrolysis and condensation reactions. The TiC-coated inoculant was coated again with a nickel (Ni) phase by the attractive force between Ni ions and TiC particles. The coating efficiency and morphology have been investigated with the particle size of TiC and the concentration of Ni precursor. In the case of 1 μm TiC particles, the Ni particles are homogeneously dispersed and coated on the surface of TiC particles without any self-aggregation of Ni particles. When particle size is decreased to 0.02 μm or increased to 4 μm, the Ni particles are mutually aggregated or localized on the surface of TiC particles, respectively. The amount of Ni phase on the TiC-coated inoculant increases upon increasing the concentration of Ni precursor. The reinforcement phase has been successfully prepared through the dual coating process, with an expected increase in the mechanical properties of the matrix owing to the improvement in dispersibility.

1. Introduction

Low fracture toughness, poor wear resistance, and rather high friction coefficients of metals and alloys are limiting factors for many industrial applications. Thus, ceramic–metal composites have been studied to provide high performance to engineering materials in energy technology and automobile industry [1,2]. These composites show a combination of properties, such as hardness of ceramic phase and toughness of metal matrix. In particular, metal matrix composites reinforced with ceramic particles provide high strength and elastic modulus, as well as good high temperature properties, compared with monolithic matrix. Silicon carbide, alumina, titanium carbide (TiC), and titanium boride are well-known ceramic materials used as a reinforcement phase for metal matrix. In particular, TiC has been widely used as a particulate reinforcement phase for the matrix because of its high modulus, hardness, stiffness, strength, and electroconductivity [3,4]. To maximize the effects of the reinforcement phase on the matrix, TiC particles should be well dispersed in the matrix.

In this work, the reinforcement phase has been coated onto an inoculant used in the foundry industry to improve crystal growth of carbon and to restrict formation of cementite, in order to increase coating efficiency through homogeneous dispersion of the phase in metal matrix and to improve the high thermomechanical properties of the matrix. The reinforcement phase was prepared by a dual coating process—the first process is the coating of TiC particles onto the surface of inoculant to improve the mechanical properties of the matrix, and the second process is the coating of a nickel (Ni) phase onto the TiC-coated inoculant to enhance compatibility between the reinforcing particles and the matrix. The coating behavior and morphology have been investigated as functions of TiC particle size, heat-treatment condition, and amount of inorganic binder for the adhesion of TiC particles and Ni precursor.

2. Experimental

2.1. Materials and fabrication of reinforcement phase

The inoculant, ferrosilicon (Fe–Si) of about 1–2 mm diameter provided by a commercial organization (Samjin Electro Metallurgie Co. Ltd., Busan Korea), was used as a core particle. TiC particles, with three nominal particle diameters of 0.02, 1, and 4 μm, were obtained from a commercial supplier (LTS Inc., New York, USA). Nickel nitrate ($Ni(NO_3)_2$, Sigma-Aldrich Korea, Yongin, Korea), existing as Ni cation (Ni^{2+}) in an aqueous solution at a pH value of 12 [5–7], was used as a precursor for the Ni phase—it was used as a coating agent in three concentrations, namely 1, 3, and 5 m. First,

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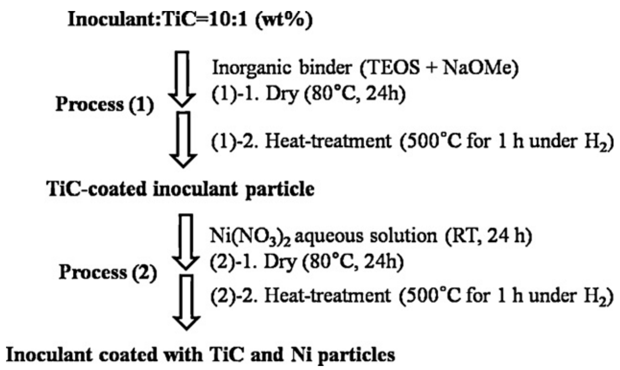


Fig. 1. Schematic diagram for fabrication of inoculant particles with TiC and Ni particles.

TiC particles were mixed with ferrosilicon at room temperature, and then an inorganic binder (composed of tetraethyl orthosilicate (TEOS, Sigma–Aldrich Korea, Yongin, Korea) and sodium methoxide (NaOMe, Sigma–Aldrich Korea, Yongin, Korea)) were added. The mixture was dried at 80 °C for 24 h and heat treated at 500 °C for 1 h (process (1)). The prepared TiC-coated inoculant was added to the $Ni(NO_3)_2$ solution and sonicated for 24 h at room temperature. The prepared mixture was filtered and dried at 80 °C for 24 h, and then heat treated under H_2 atmosphere at 500 °C for 1 h (process (2)). Consequently, the inoculant with a desirable reinforcement particle could be obtained through the dual process. A schematic diagram of the basic process for preparing inoculant particles coated with the TiC and Ni particles is shown in Fig. 1. Table 1 gives the formulations and conditions used to prepare the inoculant coated with the TiC and Ni particles.

2.2. Characterization

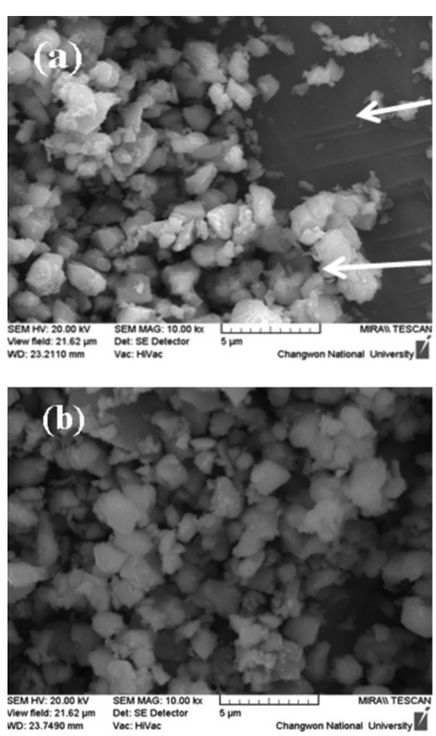
The crystal phase of the particles synthesized here was analyzed using an X-ray diffractometer (XRD; Philips X-pret MPD, Model PW3040, Eindhoven, Netherlands). The morphology and microstructure were observed using a scanning electron microscope (SEM; JEOL Model JSM-5610, Tokyo, Japan). The signals produced by the SEM were made by secondary electrons. Elemental analysis of the inoculant with the TiC and Ni particles was carried out using an energy dispersive X-ray spectrometer (EDS; energy resolution 133 eV, Oxford Instruments, Oxford, UK).

Table 1
Formulations and conditions used to prepare the inoculant with the TiC and Ni particles.

Run number	TiC particle (μm)	Concentration of inorganic binder ($\times10^{-3}$, m)	Concentration of $Ni(NO_3)_2$ (m)	Process
1	0.02	0.48	3	(1)
2	1	0.48	1	and
3			3	(2)
4			5	(1) and (2)
5				(1) without heat treatment and (2)
6		4.8	–	(1)
7	4	0.48	3	(1) and (2)

3. Results and discussion

TiC particles were coated onto the surface of the inoculant with the commercial inorganic binder to enhance the coating efficiency between the heterogeneous particles. TiC particles are well adhered to the inoculant with the inorganic binders made from TEOS and NaOMe, which are converted into a solid phase by the hydrolysis and condensation reactions (called a sol–gel reaction) occurring during process (1). The effect of the inorganic binder on the coating of TiC particles onto the inoculant is shown in Fig. 2, in which arrows 1 and 2 indicate the inoculant and the TiC particle [8–10], respectively. In Fig. 2(b), the TiC particles are uniformly coated on the surface of inoculant, resulting from the solidification of TEOS and NaOMe by the sol–gel reaction. However, the TiC particles shown



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Element	Weight%	Atomic%
CK	45.60	64.48
SiK	58.06	35.11
TiK	1.14	0.40
Totals	104.79	

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Element	Weight%	Atomic%
CK	35.96	70.79
SiK	7.50	6.31
TiK	44.59	22.01
FeK	2.09	0.89
Totals	90.15	

Element	Weight%	Atomic%
CK	23.14	54.56
TiK	76.86	45.44
Totals	104.79	

Fig. 2. SEM images and results of EDS analysis for the TiC-coated inoculant prepared by (a) just mixing and (b) inorganic binder.