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Colloidal Processing and Mechanical Properties of SiC Ceramics Using Rare-earth Element as Sintering Additive

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1. Introduction

Silicon carbide (SiC) is potentially useful as a high temperature structural material because of its high strength, high hardness, high creep resistance and high oxidation resistance. For the fabrication of dense SiC by pressureless sintering or hot-pressing, sintering additives of metal compounds, or boron and carbon, are needed owing to the high covalency of SiC. In this study, the interaction between colloidal SiC particles and rare-earth ion in an aqueous suspension, rheological behavior of aqueous suspension, and sinterability of consolidated powder compact and resultant mechanical properties were reported to produce the high performance SiC ceramics.

2. Results and Discussion

The amount of Y^{3+} ions adsorbed on SiC particles increased with an increase of pH because of the electrostatic attraction between negatively charged SiC surface and Y^{3+} ions. On the other hand, the amount of polyacrylic acid (PAA, dispersant) adsorbed on SiC particles decreased with increasing pH because of the electrostatic repulsion between negatively charged SiC surface and dissociated PAA. The addition of PAA to the SiC suspension with Y^{3+} ions increased the amount of Y^{3+} ions fixed to SiC particles through the strong interaction between Y^{3+} ions and PAA adsorbed on SiC particles. The adsorption of Y^{3+} ions onto SiC surface enhanced the coagulation of SiC particles through the electrostatic attraction between negatively charged SiC surfaces and Y^{3+} ions fixed. As a result, the apparent viscosity of SiC suspension was increased. Adsorption of neutral PAA onto SiC surface decreased the apparent viscosity of SiC suspension with Y^{3+} ions near the isoelectric point of SiC owing to the steric stabilization effect of PAA adsorbed. The addition of PAA to the SiC suspensions with Y^{3+} ions kept the SiC particles separate during the calcination. That is, the PAA addition contributes to the enhancement of driving force of sintering and to the control of the amount of Y^{3+} ions uniformly fixed to SiC surface.

A SiC powder was mixed with PAA in a 0.3 M-$R(NO_3)_3$ solution (R=Yb, Y, Gd, Sm, Nd and La) at pH 5 to adsorb uniformly the sintering additive (R^{3+} ion) on the SiC surface. The aqueous 30 vol% SiC suspension with 0.52 mass% PAA and 1.50 mass% R_2O_3 (as R^{3+} ion) against the mass of SiC, was consolidated by filtration through a gypsum mold to form green compacts of 50-52 % of theoretical density. The consolidated green compacts were densified with grain growth to 76 - 99 % relative density by hot–pressing under a pressure of 39 MPa at 1950°C for 2 h in an Ar flow. The addition of smaller R^{3+} ion was effective to enhance the sinterability of SiC and also to achieve smaller grain size of SiC. This result was discussed based on the additional experiment result on the chemical interaction between SiC compact and the SiO_2-R_2O_3 liquid. The high sinterability of SiC with smaller R^{3+} ion is due to the high solubility of SiC and the homogeneous distribution of the liquid around SiC particles because of the high wettability or low viscosity. The average flexural strength and weibull modulus of dense SiC were 612 MPa and 5.1, 719 MPa and 7.3, and 731 MPa and 9.8 for Gd, Y and Yb addition, respectively.

3. Conclusions

The negatively charged SiC adsorbed rare-earth ions at pH 5 by electrostatic attraction force. The high sinterability of SiC with R_2O_3 of smaller R^{3+} ion is due to the high solubility of SiC and uniform distribution of the SiO_2-R_2O_3 liquid around SiC particles. The SiC sintered with Yb_2O_3,Y_2O_3 and Gd_2O_3 exhibited high flexural strength and high fracture toughness.

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