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Gelcasting of silicon carbide ceramics using phenolic resin and furfuryl alcohol as the gel former

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Abstract

A new non-aqueous gelcasting system of phenolic resin and furfuryl alcohol combined with a curing catalyst was developed for casting of reaction bonded silicon carbide ceramics. This gelling system could be carried out in air, and the surface exfoliation phenomenon that seems inherent to the acrylamide gelcasting system could also be eliminated. Polymerization of the premix solutions and rheological properties of the non-aqueous silicon carbide suspensions were studied. After curing and subsequent pyrolysis of the concentrated silicon carbide suspension, homogenous silicon carbide/carbon green body with a relatively high strength of about 18 MPa could be formed. Dense complex-shaped SiC ceramic parts with flexure strength of 300 ± 20 MPa and fracture toughness of 3.87 ± 0.19 MPa $m^{1/2}$ can be successfully produced after reaction sintering at 1700 °C for 30 min under vacuum.

Keywords: A. Suspension; C. Mechanical properties; Silicon carbide; Gelcasting

1. Introduction

Silicon carbide ceramics, due to their refractoriness (high strength at elevated temperatures), good oxidation resistance, high thermal conductivity and adequate toughness, have a significant impact on gas turbine engine components, commercial combustion nozzles, light armor and other advanced applications [1–4]. However, an important aspect of fabrication sequence, which can improve subsequent sintering and final properties of bodies, is to obtain a homogenous structure at the consolidation stage of green body [5,6]. Much attention is, therefore, directed on the colloidal processing method, which may result in a more homogenous green microstructure. Gelcasting is a well-established colloidal processing method for making high-quality, complex-shaped ceramic parts by means of in situ solidification through which a macromolecular network is created to hold the ceramic particles together [7].

The typical route of the gelcasting process is to prepare suspensions with high solid loading and low viscosity, and then solidifying the suspension cast in a pore-free mold. The green bodies prepared with gelcasting process have a similar homogeneous microstructure as the precursor suspensions, so the structure homogeneity and reliability of the final ceramics can be improved [8–10]. The commonly used acrylamide monomer is a neurotoxin and the polymerization is inhibited by oxygen, which limits its industrialization. Therefore, many other gelation chemicals, such as carrageenans [11], gelatin [12,13] and agarose [14,15], have been used. Unfortunately, the results are not encouraging mainly due to two reasons: (1) the difficulty to obtain low-viscosity slurry with high solid loading and (2) the difficulty to obtain high green strength.

In the present work, a new non-aqueous gelcasting system of phenolic resin (PF), furfuryl alcohol (FA) and hardener system was used for casting of reaction bonded silicon carbide ceramics. The advantage of this method is that it can be carried out in air. This suggests a novel field to develop the gelcasting system. The effects of dispersant on the rheological behavior of SiC slurries are investigated. The mechanical properties of green and sintered SiC samples are also studied.

2. Experimental

2.1. Sample preparation

Commercially available α-SiC powders with an average particle size of 3 and 45 μm were used as raw materials, and the morphologies and particle size distributions of these two

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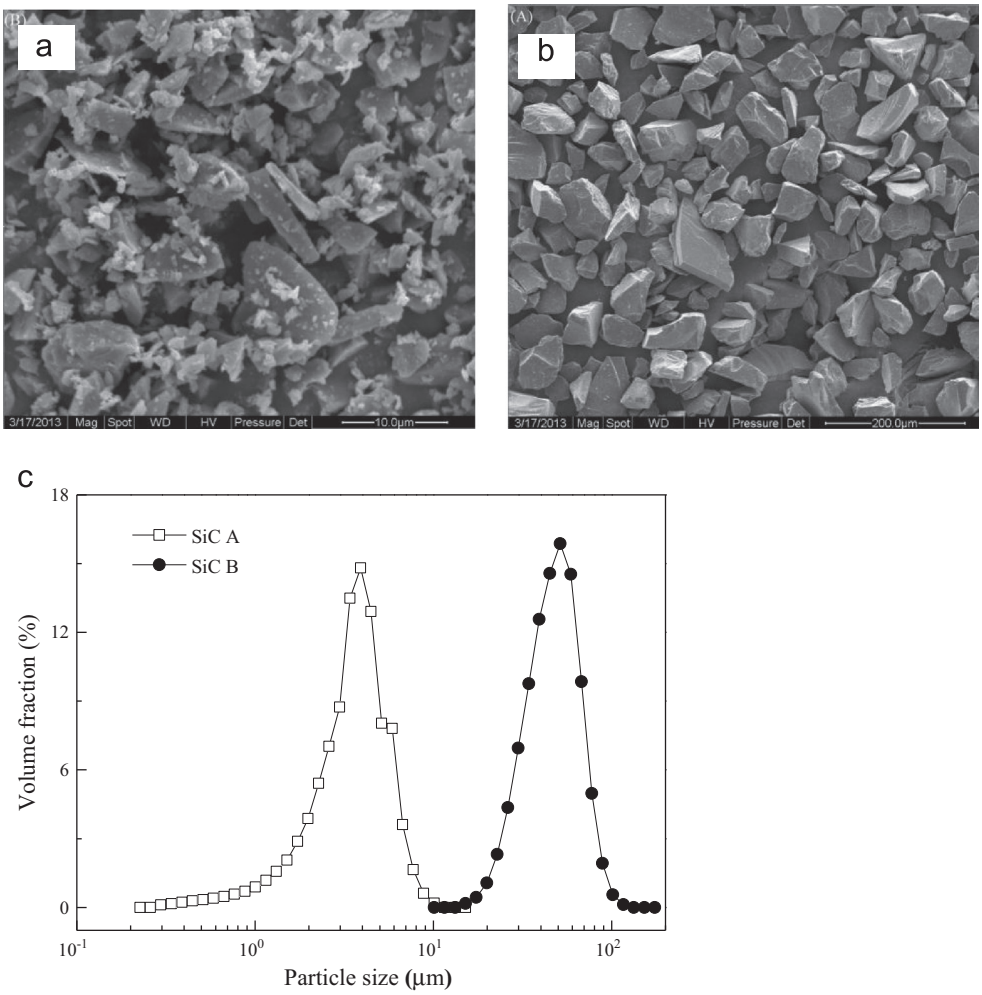

Fig. 1. SEM images of the fine (a) and coarse (b) SiC particles and the particle size distributions of these two powders (c).

SiC particles are shown in Fig. 1. Polyethylene glycol 400 (PEG400) and ethylene glycol (EG) were selected as the dispersant and solvent, respectively. Phenolic–formaldehyde resin (PF) and furfuryl alcohol (FA) were employed to consolidate the slurries. Benzenesulfonyl chloride (BC) was used as the curing catalyst.

The schematic forming process of gelcasting is described in Fig. 2. PF and FA were dissolved in EG to attain a premixed solution. After dispersant was added, the solution was mixed with SiC powders (mass ratio of coarse and fine SiC is 7:3). After mixing with SiC ball (triple mass of SiC powders), the suspensions were ball-milled for 20 h to promote dispersion and admixing process (the rotating speed was 240 r/min). Then BC was added into the slurries, and a further milling for another 2 h was conducted. The obtained slurries were degassed before casting into molds. Then the suspensions were pre-cured at 80 °C for 2 h. After 2 h, the rigid bodies were removed from molds and cured at 150 °C for 16 h. Then the cured bodies were pyrolyzed by slowly heating up to 800 °C in a flowing N_2 atmosphere, followed by cooling naturally to room temperature. At last, the green bodies were infiltrated with liquid silicon at 1700 °C for 30 min. The infiltration was conducted under vacuum at 20 Pa.

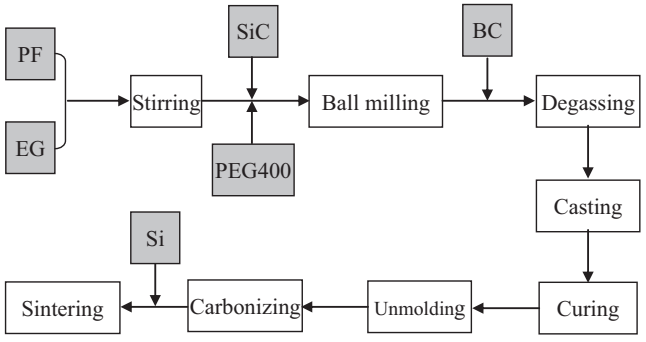

Fig. 2. Flowchart of gelcasting of silicon carbide ceramics.

2.2. Characterization

Weight loss behaviors during polymerization were measured at a heating rate of 5 °C/min in flowing nitrogen using a thermobalance (TGA/SDTA85IE, Switzerland). The apparent viscosity of suspensions was examined by a rotary viscometer (Model NXS-11, Chendu Instrument Plant, PR China). Measurements were carried out at 20 °C. The morphologies of the porous green bodies and the synthesized SiC ceramics were