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Improved connectivity of gelcasted and solid-state-sintered SiC foams through synergetic poring mechanism

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ABSTRACT

In order to improve the connectivity between pores of gelcasted and solid-state-sintered SiC (S-SiC) foams, we utilized the synergetic poring mechanism of direct foaming and sacrificial solid template through introducing organic micro-beads into aqueous foamed SiC-B_4C-C suspensions. The addition of micro-beads accelerated the formation of more bubble-derived pores in S-SiC foams, and generated abundant bead-derived pores in the bubble-derived-pore struts and partial-sintering-derived pores between SiC grains as well. This multiple pore microstructures induced excellent connectivity between pores and an ultrahigh porosity of 89.5%. Consequently, an outstanding nitrogen gas permeability of 9.2×10^{-11} m^2 was acquired under the condition of a superior compressive strength of 2.2 ± 0.4 MPa.

1. Introduction

Pressureless solid-state-sintered SiC (S-SiC) foams possess the advantages of both S-SiC ceramics and cellular materials, including outstanding high-temperature strength, excellent chemical stability, high heat-exchange efficiency, large specific surface area, etc. [1–3] These unique features enable them to withstand harsh physicochemical environments and have numerous potential applications in the energy and environment fields, such as catalyst supports [4], high-temperature filters for flue-gas [5], and volumetric absorbers of solar radiation [6]. As a simple and representative preparation method of ceramic foams, direct foaming-gelcasting process consists of surfactant-assisted foaming in aqueous suspensions and then in-situ solidification of foamed slurries by gel reaction, and shows its simplicity and high efficiency in tailoring pore microstructures (porosity, pore size, etc) [3]. Therefore, this method has been widely applied for the production of various ceramic foams, such as Al_2O_3 [7], ZrB_2 [8], and Si_3N_4 [9]. Moreover, S-SiC foams with controllable pore microstructures and high mechanical strengths were successfully prepared through direct foaming-gelcasting process as well, as reported by Mouazer [10], Ganesh [11], Jana [12], and our group [13].

However, those gelcasted S-SiC foams through single foaming mechanism normally displayed inferior connectivity between bubble-derived pores, because of the limited amount and size of windows in the struts of bubble-derived pores [2,3]. Unfortunately, the connectivity between pores shows its extreme importance for the above-mentioned applications to supply fluid channels. Therefore, further research is of great necessity and significance to overcome this conflict. The synergistic pore-forming mechanism of direct foaming and sacrificial solid template has been proved to be effective for acquiring excellent connectivity in gelcasted ceramic foams, and the corresponding schematic diagram is shown in Fig. 1(a). We have successfully realized this synergy approach and achieved the improvement of connectivity in the gelcasted ZrB_2-based foams of ultra-high temperature, and massive solid-template-derived pores of micron size were observed in the struts of bubble-derived pores to form well interconnected-pore microstructures [14]. Nevertheless, up till now, researches on the fabrication of gelcasted S-SiC foams using the synergic poring mechanisms, have been not covered yet.

In the present work, the synergy strategy of direct foaming and

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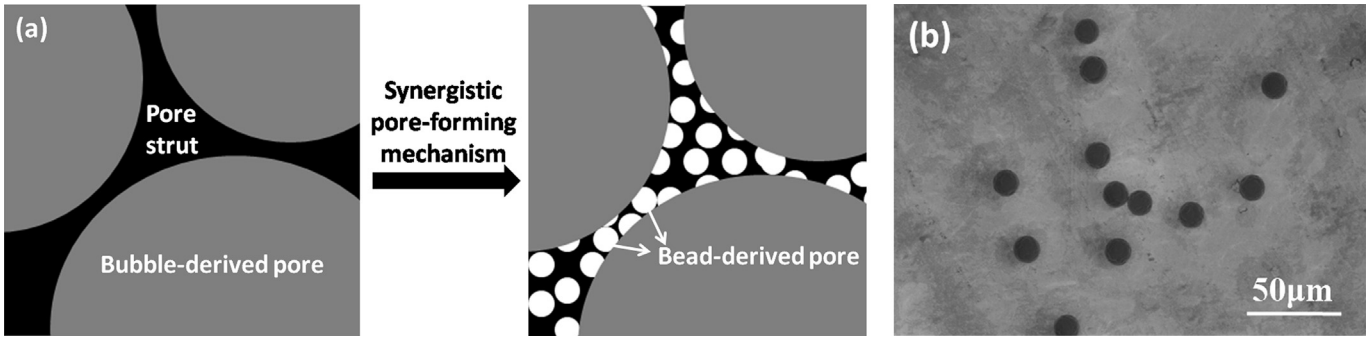

Fig. 1. (a) Schematic diagram of the synergistic pore-forming mechanism of direct foaming and sacrificial solid template; (b) Morphology of PAA beads.

sacrificial solid template was adopted to obtain superior connectivity in the gelcasted S-SiC foams for the first time. Specifically, organic micro-beads (as a solid template) were introduced into aqueous foamed SiC-B_4C-C slurries to create additional bead-derived pores in the walls of bubble-derived pores. Moreover, the effects of the synergetic poring mechanisms on the rheological behaviors of SiC-B_4C-C slurries, as well as the pore microstructures, porosity, compressive strength, and nitrogen gas permeability of S-SiC foams were systematically investigated and discussed.

2. Experimental procedure

2.1. Raw materials

Commercially available α-SiC powders (D_{50} = ~0.5 μm, purity>99%, Pingdingshan Yicheng New Material Co., Henan, China) was used as the starting matrix material, and B_4C powder (D_{50} = ~1 μm, purity>97%, Mudanjiang Jingangzuan Boron Carbide Co., Ltd, Liaoning, China) and carbon black powder (D_{50} = ~200 nm, industrial grade, Anyang Delong Chemical Co., Ltd, Henan, China) served as the sintering aids. Tetramethylammonium hydroxide (TMAH, 25 wt% in water solution) and polyvinylpyrrolidone (PVP) were selected as the aqueous dispersants of SiC (and B_4C) and carbon black, respectively. In the gelcasting process, acrylamide (AM), *N*,*N*′-methylenebisacrylamide (MBAM), ammonium persulfate (APS) and *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TEMED) were utilized as monomer, cross linker, initiator and catalyst, respectively. TMAH, PVP, AM, MBAM, APS and TEMED were all analytically pure and supplied by Aladdin Industrial Corporation (Shanghai, China). Ovalbumin was used as a proteic surfactant for foaming in slurries, and self-made polyacrylic acid spheres (PAA, D_{50} = ~12 μm, ρ = 1.18 g cm^{-3}) served as the sacrificial solid template, as shown in Fig. 1(b).

2.2. Processing

The flow chart of the whole processes is shown in Fig. 2. First of all, deionized water, AM, MBAM, TMAH solution, PVP, SiC, B_4C, carbon black and PAA beads, together with silicon carbide balls, were sequentially poured into jars and planetary milled for 4 h at 300 rpm. The as-received suspension was poured into a beaker and added with ovalbumin, and then acutely stirred for 30 min to

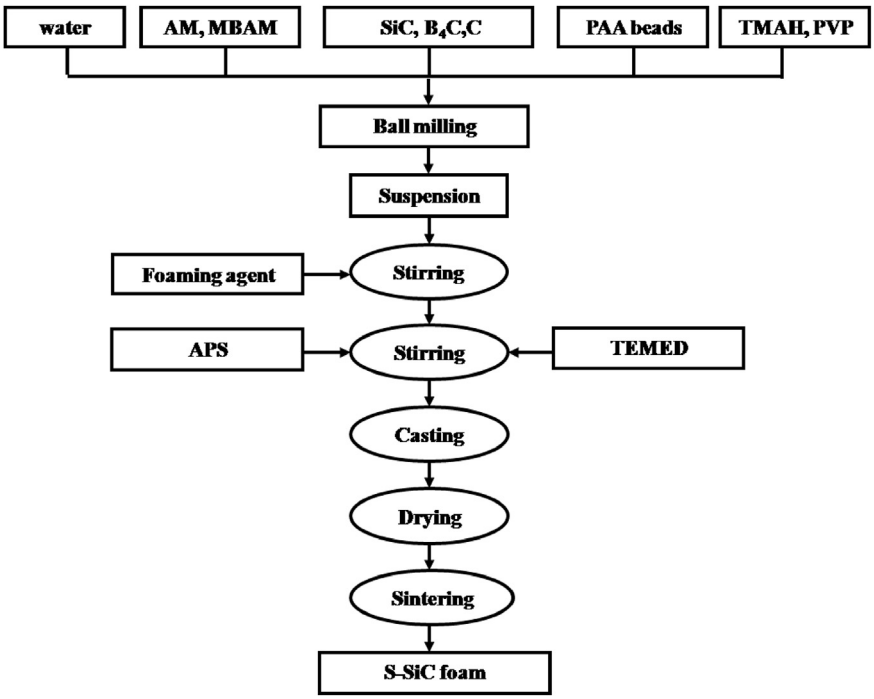

Fig. 2. Flow chart of the whole processes for the preparation of S-SiC foams.