Available online at www.sciencedirect.com

SciVerse ScienceDirect

Ceramics International 38 (2012) 3063–3068

CERAMICS INTERNATIONAL

www.elsevier.com/locate/ceramint

Preparation of ZTA ceramic by aqueous gelcasting with a low-toxic monomer DMAA

Chao Zhang *, Jian Yang, Tai Qiu, Jian Guo

College of Materials Science and Engineering, Nanjing University of Technology, Nanjing 210009, China

Received 20 October 2011; received in revised form 2 December 2011; accepted 2 December 2011
Available online 9 December 2011

Abstract

The present work reports the development of aqueous gelcasting of ZTA ceramic with a low-toxicity monomer DMAA. The rheological properties and the gelation behaviors of the slurries for gelcasting were investigated. It was proved that the time available for casting the slurry (idle time) can be controlled by the amounts of initiator. The ZTA green bodies exhibited a mechanical strength as high as 21 MPa. After sintered at 1600 °C for 2 h, the highest bending strength and fracture toughness of the sintered ZTA samples were as high as 643.3 ± 75 MPa and 6.3 ± 0.3 MPa $m^{1/2}$, respectively. SEM photographs revealed that the green bodies and sintered part had a uniform microstructure. The volume fraction of tetragonal phase zirconia was as high as 90%. Dense ZTA green bodies and ceramic parts with complex shaped were produced through the new gelcasting system.

Keywords: C. Strength; DMAA; Rheological properties; ZTA

1. Introduction

Zirconia-toughened alumina (ZTA) ceramics are considered as promising structural materials since they have a higher crack resistance than alumina but lower price than zirconia. The applications of ZTA ceramics include bushings, cutting tool inserts, valve seats, wear components, etc. These ceramics components are usually manufactured by die pressing of alumina and zirconia powders, which is followed by sintering at elevated temperatures, then these ceramics are machined to get the desired shapes. However, this process was very expensive for preparation of complex-shaped products. As a new forming process, ceramic gelcasting has rapidly developed in the past decade. Fundamental research has been carried out by Young as well as Omatete et al. [1,2], showing the general feasibility of the process and its advantages. The advantages of the technique include high dimensional accuracy and complex shaping capabilities, as well as reducing the manufacturing cost. In this process, the powders are mixed in a pre-mixed monomer solution to get low viscosity suspension by ball-milling. After adding an initiator the suspension is cast into a mold with the desired shape, then the entire system polymerizes in situ and green bodies with excellent mechanical property but only few percents of polymer can be obtained. Thus, the dried green bodies can be machined easily. However, industry has been reluctant to use the technique because the monomer acrylamide (AM) is a neurotoxin [3]. Many natural materials have been used in gelcasting systems like Na-alginate [4–6], chitosan [7], starch [8], agarose [9], etc., but the strength of green bodies seems inevitable in these systems. Therefore, developing new gel systems which have similar or superior properties to the AM systems, yet low toxicity has become an area of intense interest in the field for many years. N,N-dimethyl acrylamide (DMAA) is a water-soluble low-noxious reagent. Recently Zhang et al. [10] used DMAA as monomer in gelcasting system of SiC ceramics and the flexural strength of green bodies was as high as 13.9 MPa.

In the present work, gelcasting of ZTA powder was studied with DMAA as monomer. Concentrated ZTA slurry suitable for aqueous gelcasting was obtained, and high quality ZTA green bodies and dense ZTA ceramics were prepared by gelcasting and pressureless sintering. The rheological properties of ZTA slurries, and the factors affecting these properties were evaluated. The gelation properties of the ZTA suspensions as well as the properties of ceramics were also investigated.

* Corresponding author.
E-mail address: zhangchao1997@163.com (C. Zhang).

0272-8842/$36.00
doi:10.1016/j.ceramint.2011.12.004

2. Experimental procedure

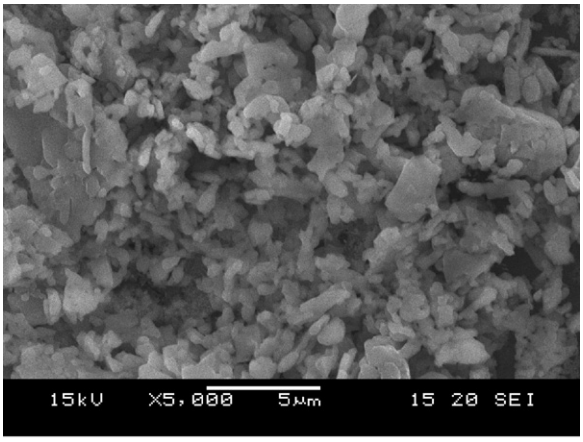
2.1. Raw materials

Commercially available α-Al_2O_3 powder (d_{50} = 0.61 μm) and ZrO_2 powder (5.2 wt% Y_2O_3, d_{50} = 0.19 μm) were used in this investigation (Figs. 1 and 2). The polyelectrolyte SD-03 (ammonium polyacrylate, made by Nanjing University of Technology) was used as a dispersant. The analytical reagent $NH_3{\cdot}H_2O$ was used for adjusting pH value of suspensions.

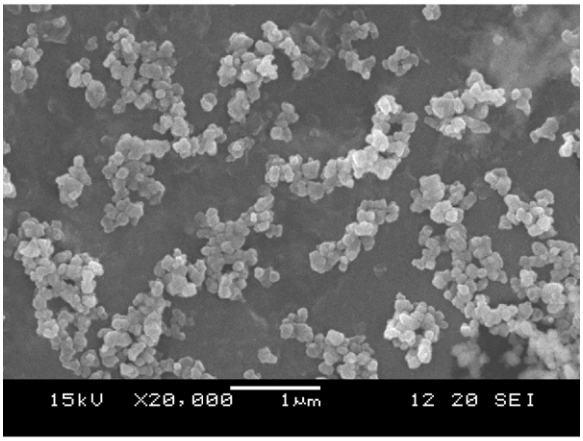
The essential components of the gelcasting process are the reactive organic monomers: mono-functional DMAA (N,N-dimethyl acrylamide, Kowa American Corporation) and difunctional MBAM (N,N′-methylenebisacrylamide). The premixed solution undergoes free-radical-initiated vinyl polymerization by an initiator $(NH_4)_2S_2O_8$.

2.2. Experimental procedure

These monomer and cross-linker were dissolved in deionized water to obtain a premixed solution (H_2O:DMAA:MBAM = 90:10:1, mass ratio). After 0.6 wt% (mass fraction of the Al_2O_3/ZrO_2 powders) dispersant was added, the premixed solution was adjusted to pH 9–10 by adding $NH_3{\cdot}H_2O$. Then the solution was mixed with Al_2O_3 and ZrO_2 powders (mass ratio of Al_2O_3 to ZrO_2 is 3:1). The solid loading was 50 vol%. After mixed with zirconia ball (double mass of the Al_2O_3/ZrO_2 powder), the suspensions were ball-milled for 6 h to promote dispersion, grinding and admixing process. Then 1 wt% (mass fraction of monomer) initiator (10 wt% aqueous solution) was added into the slurries which was followed by a degassing for 10 min. Finally the slurries were cast into a 10 mm × 10 mm × 55 mm stainless steel mold and kept at about 65 °C for an hour. After the monomers polymerized, the green bodies were demolded and then dried at room temperature under controlled humidity to avoid cracking and non-uniform shrinkage. The dried green bodies were sintered at 1600 °C for 2 h.



(a)



(b)

Fig. 1. SEM photographs of Al_2O_3 (a) and ZrO_2 (b) powders.

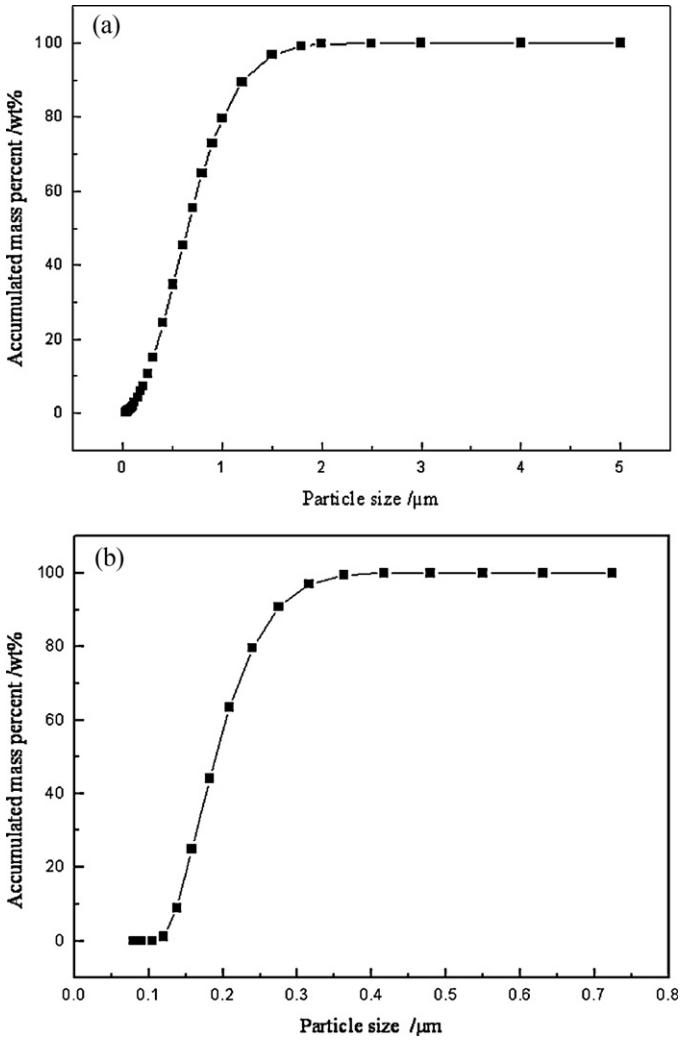


Fig. 2. Particle size distribution of Al_2O_3 (a) and ZrO_2 (b) powders.

2.3. Test method

The rheological behaviors of the concentrated suspensions prepared were measured by a rotation rheometer (BROOKFIELD R/S RHEOMETER) and idle time (the time from the addition of the initiator to the commencement of polymeriza-