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The effect of solid volume fraction on properties of ZTA composites by gelcasting using DMAA system

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ABSTRACT

The effect of solid volume fraction in slurries on properties of zirconia toughened alumina (ZTA, mass ratio of Al_2O_3–ZrO_2 is 75:25) green and sintered bodies prepared by gelcasting process was investigated. A low-toxicity gel system based on the polymerization of low-toxicity N,N-dimethyl acrylamide (DMAA) was used for the gelcasting. Effect of monomer mass fraction on viscosity of slurries and effect of solid volume fraction on properties of green and sintered bodies were investigated. The solid loading of suspension that can meet requirements for the casting process is as high as 54 vol.%. However, it is found that the highest bending strength and fracture toughness of ZTA composites can reach 643.3 MPa and 6.3 MPa $m^{1/2}$, respectively, when the solid loading was 50 vol.%. The reason for this phenomenon is that the microstructure of the sintered samples is to a large extent determined by the rheological behavior of the suspension. SEM photographs revealed that the green body and sintered ZTA composites had a uniform microstructure when the solid loading was 50 vol.%. When the solid loading was over 50 vol.%, hard agglomerations formed which had a significant influence on the mechanical properties of ceramic bodies.

1. Introduction

Zirconia-toughened alumina (ZTA) ceramic is considered as promising materials since they have a higher crack resistance than alumina and lower price than zirconia. The applications of ZTA ceramic include bushings, cutting tool inserts, valve seats, wear components, etc. These ceramic are made by die pressing of alumina and zirconia powder, after sintering at elevated temperatures, these ceramics are machined to get the desired shapes [1]. However, this process was found to be very expensive for making complex shaped products. Recently, ceramic gelcasting has rapidly developed in the past few decades. Fundamental research has been carried out by Young as well as Omatete et al. [2], showing the general feasibility of the process and its advantages in comparison with other liquid forming processes. The advantages of the technique include dimensional accuracy and complex shaping capabilities, as well as reducing the costing of manufacturing [3–5]. 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 mould 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 most frequently used monomer acrylamide (AM) is a neurotoxin. Many natural materials have been used in gelcasting systems like Na-alginate [6,7], chitosan [8], starch [9], agarose [10], etc., but low 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. DMAA (N,N-dimethyl acrylamide) is a water-soluble low-noxious reagent. Recently Zhang et al. [11] used DMAA as monomer in gelcasting system of SiC ceramics and the flexural strength of green bodies was as high as 13.9 MPa.

So far, most of the researches on gelcasting have focused on the preparation of suspensions [12] and the process control of gelcasting [13]. However, little attention was placed on the relationship between the rheological behavior of the suspension and mechanical properties of the sintered ceramics [14]. Jiao et al. [15] investigated the effect of solid volume fraction of slurries on properties of ZTA composite ceramics by gelcasting. Their results indicated that pore size distribution of green bodies prepared by slurries with high solid volume fraction exhibits the characteristic of double peaks. Sun et al. [16] investigated the formation mechanism of agglomerations in suspensions and their influence on microstructures and properties of sintered bodies. They found that the structural uniformity of sintered ceramics was influenced by the properties of suspension because the agglomerations in the suspension are cured in situ and transmitted to green bodies. In the present

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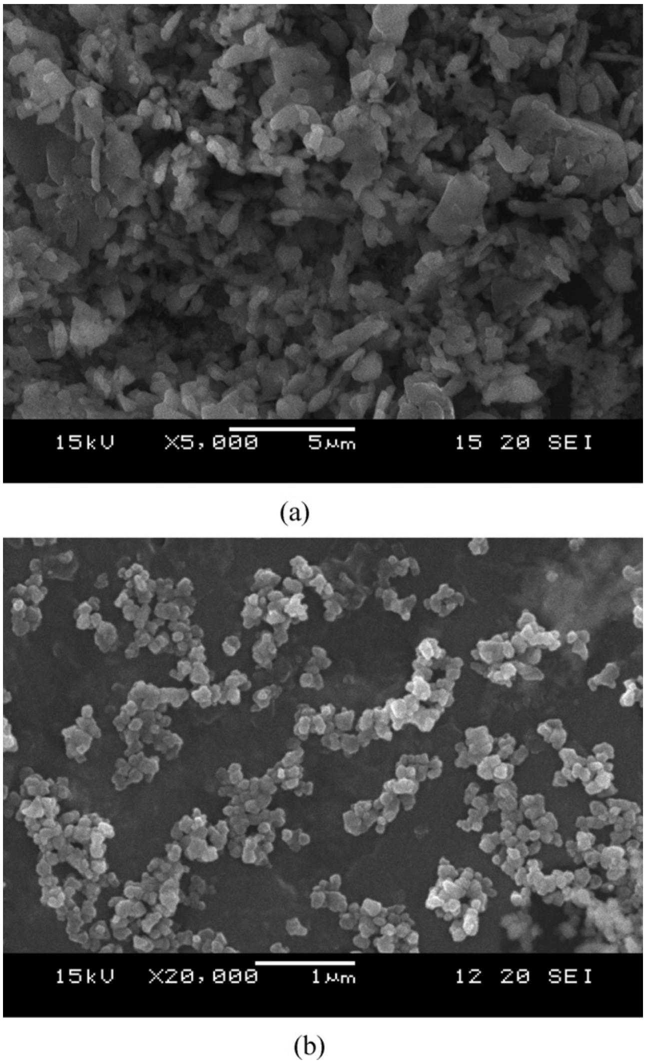

Fig. 1. SEM photographs of Al_2O_3 (a) and ZrO_2 (b) powders.

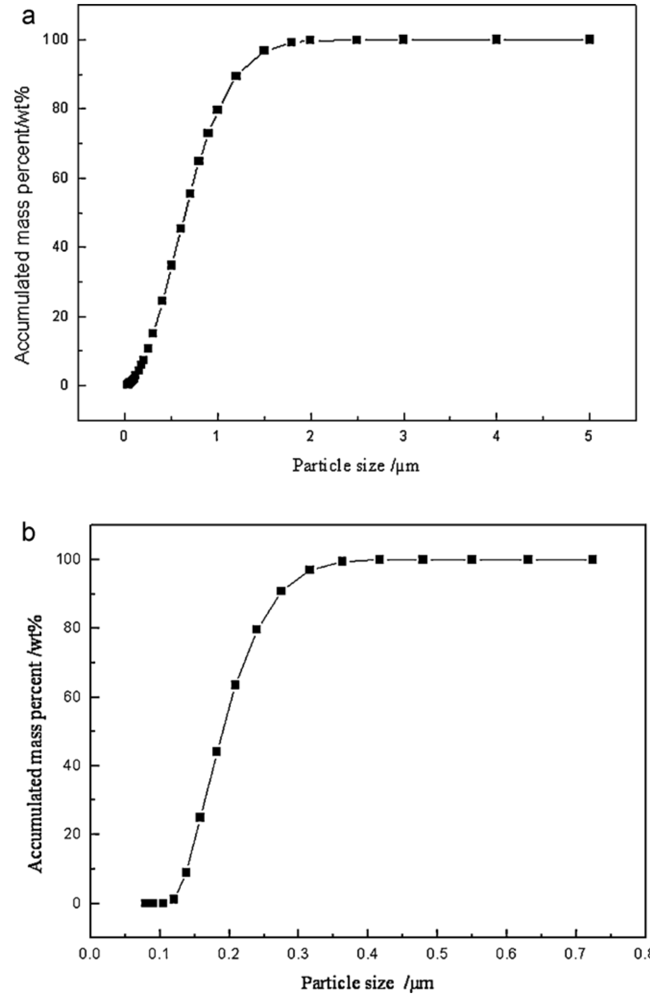

Fig. 2. Particle size distribution of Al_2O_3 (a) and ZrO_2 (b) powders.

work, ZTA composites were prepared by gelcasting using DMAA as monomer which was followed by pressureless sintering. The effect of solid volume fraction in slurries on mechanical properties of ZTA composites is investigated. The results show that the rheological behavior of the suspensions as a function of solid volume fraction has a critical effect on the mechanical properties of the sintered bodies.

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 polyelectrolytes SD-03 (ammonium polyacrylate, made by Nanjing University of Technology) were 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 $(NH_4)_2S_2O_8$.

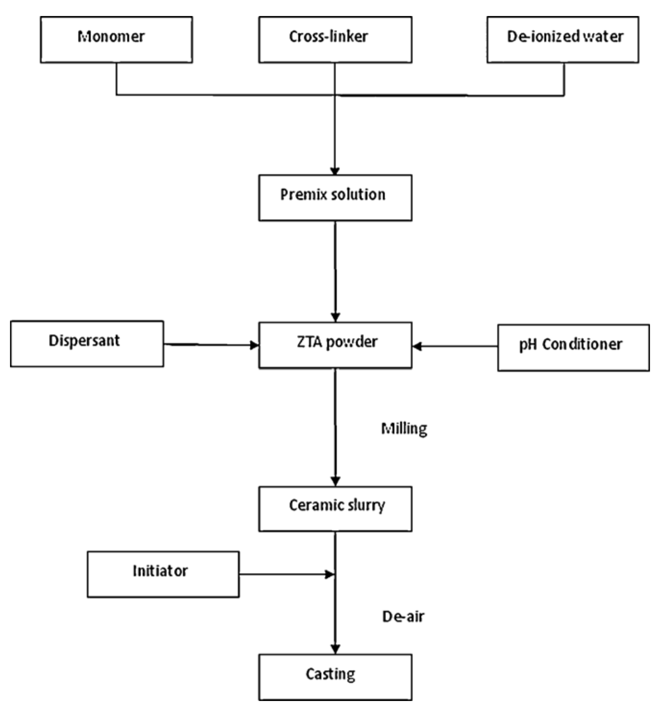

Fig. 3. Schematic of gelcasting process.