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A study on mechanical properties and microstructure of tetragonal zirconia-based composites

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ABSTRACT

The relative density, bending strength, fracture toughness, and fracture surface microstructure of tetragonal zirconia (t-ZrO_2)-based composites prepared using magnetic pulsed compaction were investigated. The relative density and bending strength of the composites increased with increasing sintering temperature, whereas the fracture toughness increased with the addition of monoclinic zirconia (m-ZrO_2) and Al_2O_3 particles. Scanning electron microscopy images indicate that the m-ZrO_2 particles in the t-ZrO_2 matrix induce residual stress and micro-cracking. Al_2O_3 particles act as barriers to crack growth in t-ZrO_2/m-ZrO_2/Al_2O_3 composites.

Introduction

Zirconia is widely used in various advanced technological applications, such as sliding components and rolling contact bearings for high temperature operation, owing to its remarkable properties such as high hardness, good wear resistance, low thermal conductivity, and good dimensional stability. However, the poor mechanical properties of zirconia severely limit its application in advanced engineering [1–3].

A variety of techniques have been developed to prepare ZrO_2-based composites with improved mechanical properties. Zhang et al. [4] described the preparation of ZrO_2/Al_2O_3 composites, achieving a maximum bending strength for a pretreatment temperature of 700 °C. Ouyang et al. [5] studied the microstructure and tribological properties of low-pressure plasma-sprayed ZrO_2/CaF_2/Ag_2O composites. The results of wear tests indicated that Ag_2O and CaF_2, acting as solid lubricants, effectively reduce the coefficient of friction and wear loss in the composites. Sarkar et al. [6] investigated the microstructure and mechanical properties of Al_2O_3/m-ZrO_2/t-ZrO_2 composites, in which the bending strength and fracture toughness were found to increase with increasing t-ZrO_2 content. Zhou et al. [7] investigated the properties and microstructure of ZrO_2/Al_2O_3 composites with a three-layer structure; the fracture strength and fracture toughness of these materials were 786 MPa and 18.37 MPa $m^{1/2}$, respectively. Liang et al. [8] studied the physical and mechanical properties of ZrO_2/Al_2O_3 composites deposited by air plasma spraying, showing that the interfacial adhesion of the composites increased with increasing nano-Al_2O_3 content. Mukhopadhyay et al. [9] investigated the microstructure and properties of ZrO_2/ZrB_2 composites and showed that composites processed at 1400 °C and 1500 °C exhibit an excellent combination of hardness and fracture toughness. Huang et al. [10] developed ZrO_2/tungsten carbide (WC) composites by pulsed electric current sintering. A composite prepared from a mixture of nano-sized WC and 2 mol% Y_2O_3-stabilized ZrO_2 powder showed a Vickers hardness of 16.2 GPa, a fracture toughness of 6.9 MPa $m^{1/2}$, and a bending strength of 1982 MPa.

Magnetic pulsed compaction (MPC) is an effective technique to press and compact powder through the strong instantaneous force produced by a high pulsed pressure, converting a pulse of electrical energy into the kinetic energy needed to combine the particles. Compared with the static axial press process, the composites prepared by MPC have higher density and can be prepared using a lower binder content.

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In the present study, the MPC method was used to prepare t-ZrO_2-based composites with improved mechanical properties. The relative density, bending strength, fracture toughness, and microstructure of the composites were investigated.

Experimental

Materials

Tetragonal phase zirconia (t-ZrO_2) with a particle size of 60–80 nm was used as a matrix material, which was purchased from Tosho, Japan. Monoclinic phase zirconia (m-ZrO_2) with a particle size of 60–80 nm and Al_2O_3 with a particle size of 300 nm, used as reinforcing agents, were supplied by Sumitomo, Japan. The polyethylene glycol (PEG) binder was purchased from Sigma-Aldrich, USA.

Axial press processing

Designed amounts of t-ZrO_2, m-ZrO_2, and Al_2O_3 powders, and PEG were homogeneously mixed and added into a mold, and then isostatically pressed using the axial press method at a pressure of 400 bar for 10 s. The size of the mold was $40 \times 40\ mm^2$. The samples were sintered for 3 h at temperatures from 1350 °C to 1450 °C and then cooled to room temperature.

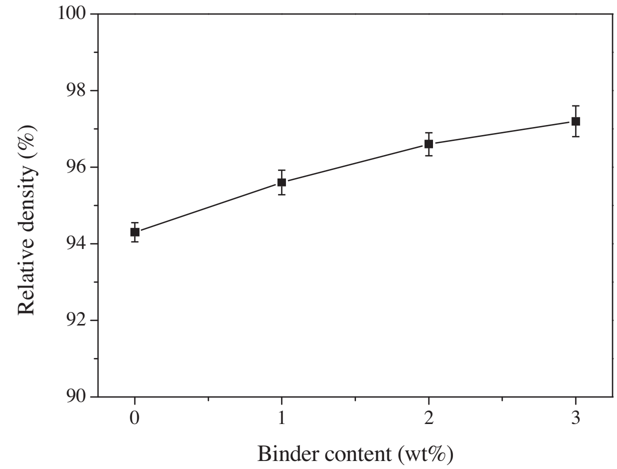

Fig. 1. Relative density of t-ZrO_2 prepared by MPC processing and sintered at 1400 °C for 3 h as a function of binder content.

MPC processing

Designed amounts of t-ZrO_2, m-ZrO_2, and Al_2O_3 powders, and PEG were homogeneously mixed and added into a mold, and then isostatically pressed by MPC at pressures between 1 and 2 GPa, for

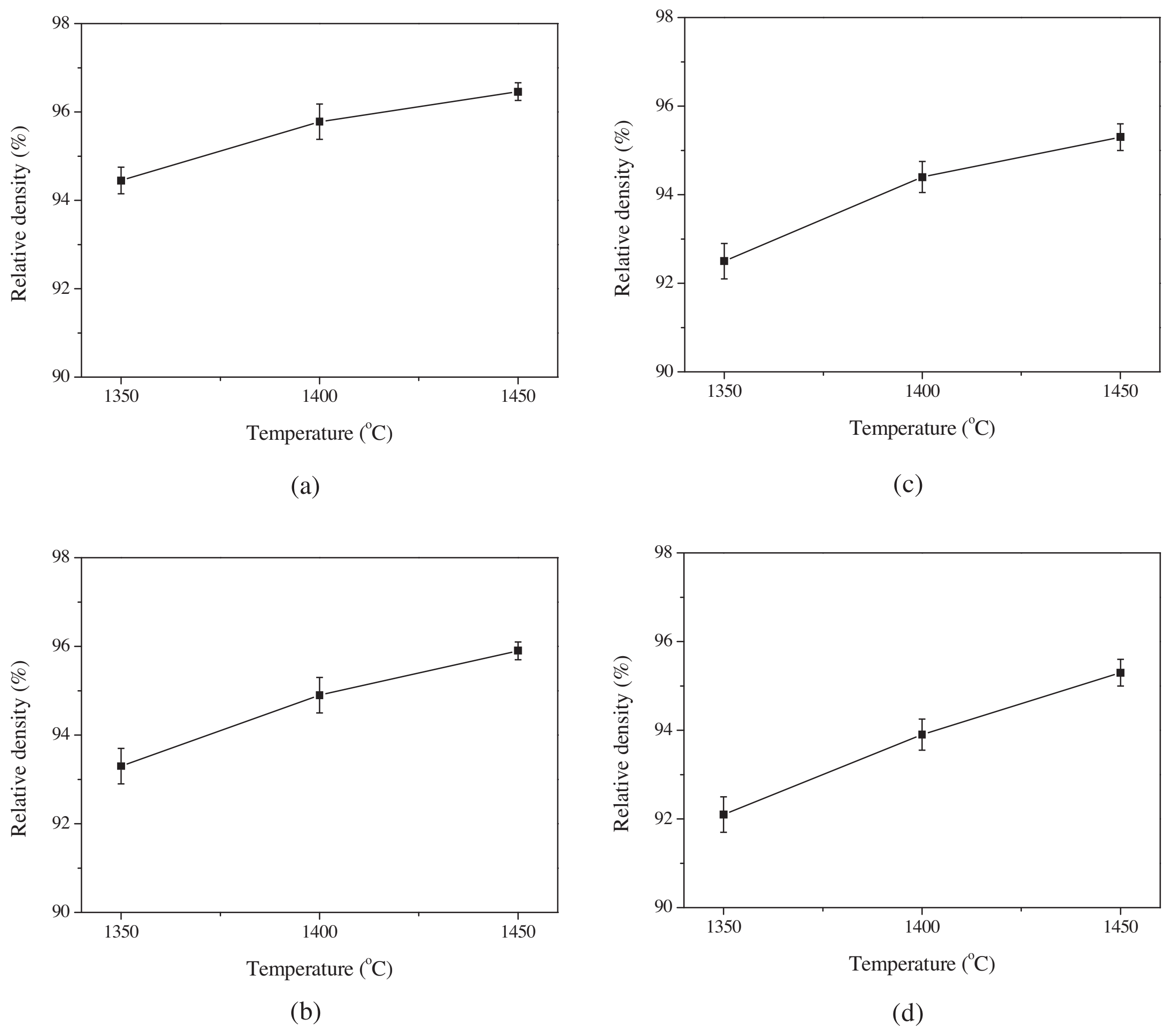

Fig. 2. Relative density of t-ZrO_2-based composites prepared by axial press process as a function of sintering temperature: (a) t-ZrO_2; (b) t-ZrO_2/m-ZrO_2 composite; (c) t-ZrO_2/Al_2O_3 composite; (d) t-ZrO_2/m-ZrO_2/Al_2O_3 composite.