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The Effect of Conformation Method and Sintering Technique on the Densification and Grain Growth of Nanocrystalline 8 mol% Yttria-Stabilized Zirconia

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Uniaxial dry pressing (DP) and slip casting (SC) were used to form green bodies of nanocrystalline 8 mol% yttria-stabilized zirconia powder processed via the glycine-nitrate combustion method. The SC method was shown to be a more efficient, yielding more homogenous green bodies with higher green density (60% theoretical density) which contained smaller pores with narrower distribution. Improved green properties resulted in lowering the sintering temperature of SC bodies by about 200°C compared with DP compacts. Consequently, the grain growth in sintered bodies formed by SC was relatively abated. By taking the benefits of the wet conformation method, the final grain size of nearly full dense (>97% TD) structures was reduced by 39% (i.e. from 2.15 to 1.3 μm). To reveal the effect of sintering technique, DP bodies were sintered via both microwave and two-step sintering methods. While the grain size of two-step sintered samples was <300 nm, sintering via microwave radiation yielded a nearly full dense structure with a mean grain size of 0.9 μm. The results show that conventionally sintered SC bodies posses higher indentation fracture toughness (FT) (~3 MPa·m$^{1/2}$) compared with DP samples (1.6 MPa·m$^{1/2}$). Interestingly, it was shown that, without applying any modified sintering technique, the hardness and FT of SC bodies with coarser structures are completely close to those of samples sintered via microwave heating.

I. Introduction

Among different types of ceramics, 8 mol% yttria-stabilized zirconia (8YSZ), because of its high oxygen ionic conductivity and chemical stability over a wide range of temperature, is a well-known candidate for oxygen sensors, oxygen pumps, and oxide fuel cells.[1–3] Although 8YSZ possesses high ionic conductivity, low mechanical properties (such as fracture toughness (FT)) limit its application, especially when thermal and mechanical stresses are applied under service condition. To enhance mechanical properties, one can use grain refining. To attain this goal, using nanopowders has attracted much attention recently.[4,5] Although using nanopowders offers the possibility of manufacturing dense ceramics at lower sintering temperatures, leading to the formation of finer structures, homogenous green bodies are required.[1] The agglomeration of nanoparticles can result in the formation of flaws, deteriorating the mechanical properties of sintered structures.[6] In order to overcome the interactive forces among nanoparticles and produce homogenous green bodies, one can use wet conformation methods. For instance, Vasylkiv *et al.*[4] shaped zirconia nanopowder via slip casting (SC). They showed that densification at lower temperatures was possible, just when a highly uniform packing of the nanoaggregates was achieved in the green compacts. Shan and Zhang[7] reported that a significantly low green density and large linear shrinkage are the characteristics of the casted bodies of slurries containing nanometric powder. They achieved a maximum green density of about 37% theoretical density (TD) when 53 wt% of solid content was used. Zhang *et al.*[8] produced bodies with a relative green density of ~35% TD by SC of slurries with 53 wt% ZrO_2–15 vol% Al_2O_3 nanopowder. Although there are many reports about SC of nanopowders, the literature has not distinctly reported the efficiency of wet conformation methods in comparison with conventional dry pressing (DP).

In addition to the conformation method, the sintering technique can have considerable influence on the densification and grain growth of nanopowders. For instance, Dahl *et al.*[9] sintered the pressed 8YSZ nanopowder (around 50 nm) by conventional pressureless sintering (CS) and the hot pressing method (HP) at 1500° and 1250°C, respectively. They have reported that the final grain size of nearly full dense (>96% TD) samples produced via the HP method is 32 times less than that of the CS method. While the hardness of sintered samples was found to be independent on grain size, the FT decreased with increasing grain size.[9] Interestingly, Chen and Wang[10] showed that without applying any external force during the sintering of nanopowders, the grain growth would be suppressed significantly through two-step sintering (TSS) method. Fast firing through microwave heating was reported as another efficient technique for hindering the grain growth as well as producing a homogenous microstructure.[11] Referring to the open literature, the effect of conformation method and sintering technique has not yet been systematically investigated where a ceramic nanopowder is used.

In the present study, nanocrystalline 8YSZ powder was synthesized via the glycine-nitrate combustion method. As-synthesized powder was conformed via the uniaxial dry pressing and slip casting methods. The importance of conformation method on particle coordination was explained via pore distribution in green samples. Additionally, in order to reveal the effect of the green state on the sintering path and obtainable mechanical properties, densification, microstructural evolution, hardness, and indentation FT of samples produced by DP and SC were compared. In order to distinguish the effect of sintering technique from the conformation method, microwave heating and two-step sintering were applied on the DP samples. To have a better insight on the conformation technique and sintering method of 8YSZ nanopowder, the sintering paths for different methods were compared.

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