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Investigation on addition of ZrO_2-3 mol% Y_2O_3 powder on sintering behavior and mechanical properties of B_4C

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Abstract The effect of ZrO_2-3% Y_2O_3 addition on densification, sintering behavior and mechanical properties of a boron carbide matrix was investigated. When adding 0–30 wt% of ZrO_2-3% Y_2O_3 to B_4C sintered densities were increased from 75% to 98.5%. Sinterability was significantly improved by addition of a small amount of ZrO_2-3% Y_2O_3. As a result of density improvement, mechanical properties such as hardness, strength and fracture toughness were increased remarkably. However, when the amount of ZrO_2-3% Y_2O_3 exceed from 20 wt%. Hardness started to reduce.

Introduction

The properties of boron carbide (B_4C) ceramic such as hardness, resistance to abrasion, and low density makes it attractive for many industrial and strategic applications [1–19]. Its industrial uses include grinding wheels for sharpening cutting tools, super- abrasives in polishing and grinding media and fibers for reinforced ceramic composites. Because of its low specific gravity and high- resistance to piercing, it has also been used as a lightweight armor material [1–8]. However, their relatively low strength and fracture toughness have restricted wider applications as structural materials.

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The main problem associated with the use of this material is its low sintering ability. In addition, since the low self-diffusivity does not allow densification by solid- state sintering techniques, metallic sintering aids such as Al [1], Si [2], Ti [3], Mg, and Fe are frequently added to provide a medium for liquid- phase sintering. However, metallic phases at the grain boundaries generally deteriorate the unique properties of hard ceramics. Nonoxide ceramics such as SiC [4–6], TiC [7], C [8], W_2B_5 [9], CrB_2 [10], Be_2C [11] and TiB_2 [12–17] have also been found to be effective as sintering additives for B_4C. However, in these cases, either large amounts of second phase or high sintering temperatures are required for full densification. Even in presence of commonly used additives such as Mg, Al, C and TiB_2, boron carbide cannot be sintered at temperatures below 2000 °C.

It has been frequently observed that small amounts of oxides are very effective in improving the sinterability of nonoxide ceramics [18, 19]. According to the reports, Shorokhod et al. have been able to densify B_4C–TiB_2 composition to about 90% of theoretical density at 1900 °C [13]. However, for obtaining higher density above 90% it is necessary that sintering to be done at above 2200 °C. Few studies have been done regarding the use of transitional elements oxides such as Cr_2O_3 [10] and TiO_2 [3] to alleviate sintering temperature of B_4C. However, there have been a very limited number of studies using oxides as sintering aids for B_4C. The objective of the present study was to use yutria-stabilized zirconia (Y-PSZ) as the sintering aid to densify boron carbide powder at temperature up to 2150 °C.

Experimental

Boron carbide powder (Chengdu Rong feng china) having average particle size of 1 μm and specific surface area of

14 m^2/gr as the main raw material and ZrO_2-3 wt%Y_2O_3 (TOSOH) powder having average particle size of 0.8 μm and specific surface area of 16 m^2/gr as the additive were used in this study. The ZrO_2 powder with mass fraction of 30% by weight was added to B_4C powder and attrition milled for 8 hrs at 250 rpm in isopropyl alcohol. The green cylindrical samples were shaped using an uniaxial press under a pressure of 80 MPa.

The green samples sintered at 2050 °C and 2150 °C for 1 h under Ar atmosphere using a microprocessor controlled graphite element resistance furnace. The heating of B_4C–ZrO_2 mixtures, under an argon atmosphere, generates B_4C–ZrB_2 composites, because of a low temperature (< 1500 °C) carbide–oxide reaction [19].

The density of the sintered samples was measured using Archimedes method [7, 13, 17, 19].

The hardness was measured according to Vickers micro hardness using a force of 1.96N [19, 20].

The bending samples having $3 \times 4 \times 45$ mm^3 dimensions were cut from original sample by a precision cutter machine. The tensile side of the bending samples polished to a 1 μm surface finish. The corners of the samples were also lapped. The fracture toughness of the specimens was determined by the indentation strength method. The polished surface was indented at 98 N with a Vickers indentor for 15 s. The fracture strength was measured with the four-point flexural configuration [8, 15, 16, 18].

The microstructural examinations were performed using a scanning electron microscope (SEM). The samples, if needed, were electrically etched in 0.1% KOH solution with current density of 0.1 A/cm^2 for about 15 s.

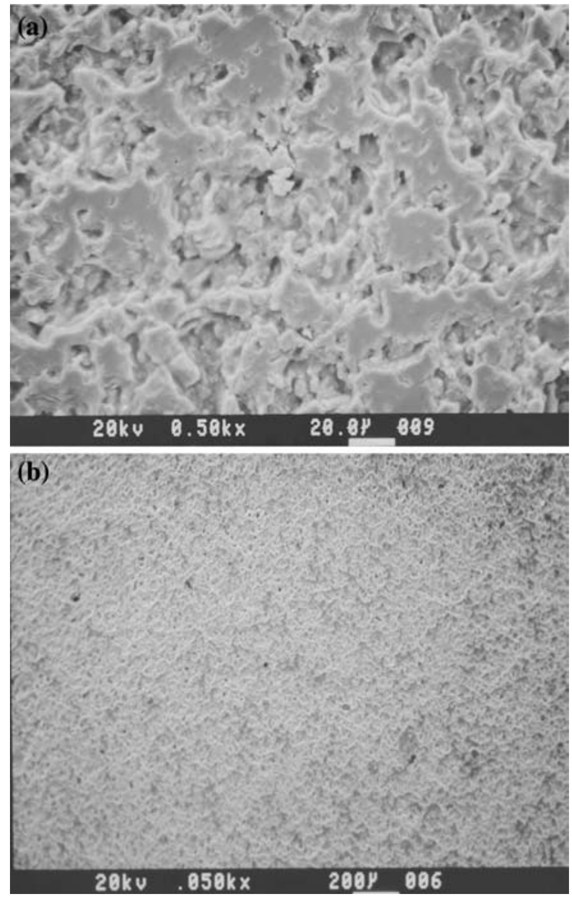

Fig. 1 SEM micrographs of samples sintered at 2050 °C for 1 hr (**a**) B4C-free Zirconia (**b**) B4C-30% (ZrO2-3%Y2O3)

Result and discussion

Figure 1 shows SEM micrographs from the samples having 0–30% ZrO_2 sintered at 2050 °C for 1 h. As it can be seen, by increasing ZrO_2 not only the size of the grains reduces, but also the porosity reduces as well.

Figure 2 illustrates SEM micrographs of the same compositions sintered at 2150 °C for 1 hr. A comparison between Figs. 1a and 2a demonstrates that for pure B_4C samples increasing the sintering temperature have no significant effect on porosity reduction. It is obvious that a grain coarsening has happened for the samples sintered at 2150 °C. Figure 3 shows the effect of ZrO_2 addition on relative density of the samples sintered at 2050 and 2150 °C. It can be seen that by increasing the ZrO_2 content the density increases. The higher amount of density obtained for a composition having 30 wt% in it.

It is also evident that by increasing the sintering temperature relative density increases.

These results are in accordance with the microscopic examinations. It is evident that by addition of 15 wt% ZrO_2 and sintering at 2150 °C samples having 97% of theoretical density can be obtained. However, the densities of ZrO_2-free samples were measured to be about 75% of theoretical density.

The addition of ZrO_2 has also a significant effect on mechanical properties of the samples. In Fig. 4 the hardness of the samples as a function of ZrO_2 percentage has been shown.

The figure shows that by addition of ZrO_2 up to 15 wt% the hardness increases and then starts to decreases by increasing the amount of ZrO_2.

This is due to the formation of less hard ZrB_2 composition. Figure 5 demonstrates the effect of ZrO_2 addition on fracture toughness of the samples having 0–30 wt% ZrO_2 in their compositions. From the figure, it is obvious that by increasing the ZrO_2 content, the toughness of the samples increases. This can be related to the lower amount of porosity, high density, and also presence of ZrB_2 phase in the microstructure of such samples. The effect of ZrO_2

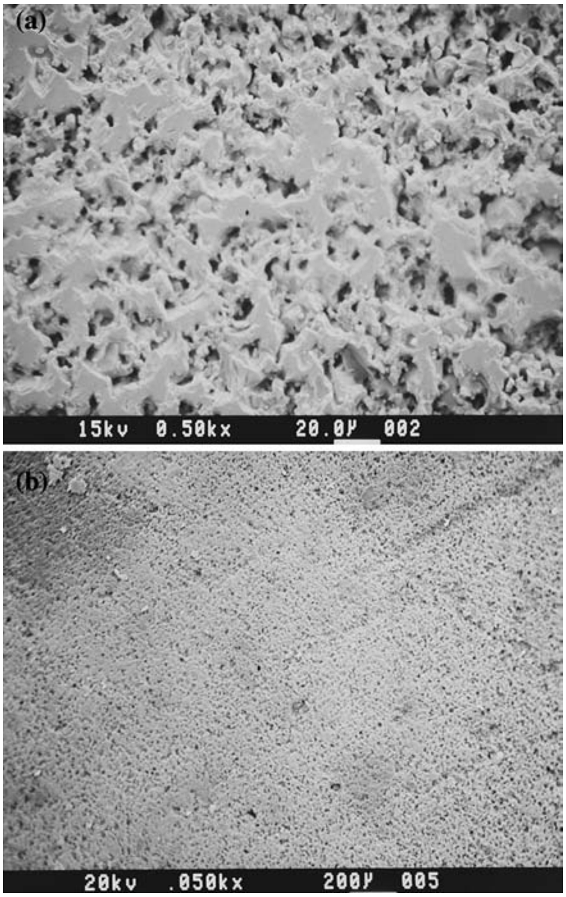

Fig. 2 SEM micrographs of samples sintered at 2150 °C for 1 hr (**a**) B4C-free Zirconia (**b**) B4C-30% (ZrO2-3%Y2O3)

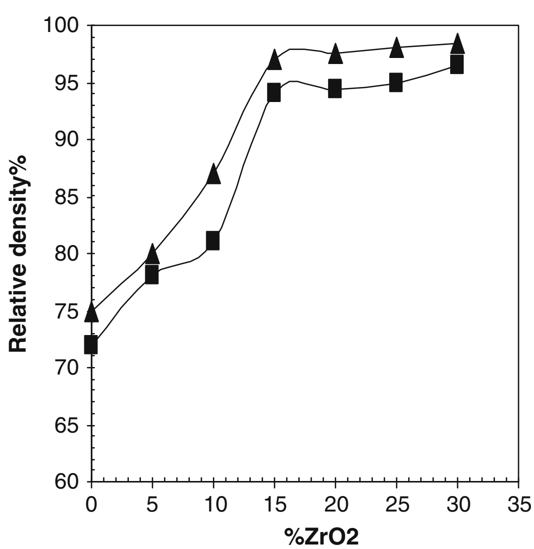

Fig. 3 Effect of ZrO_2 addition on relative density of the samples sintered at 2050 °C (■) and 2150 °C (▲)

addition on bending strength of the specimens has been presented in Fig. 6 in which an increase in bending strength as a function of ZrO_2 percentage can be observed. The

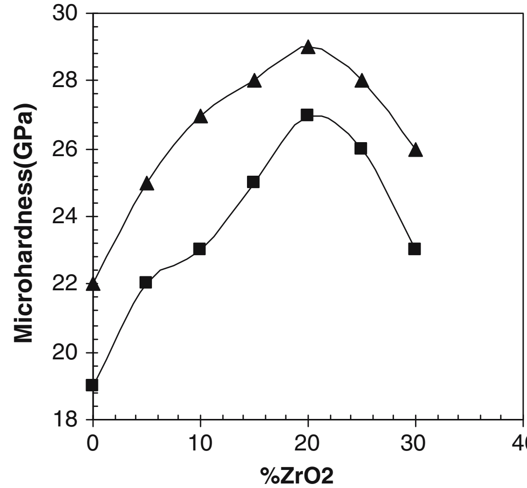

Fig. 4 Effect of ZrO_2 addition on Vickers Microhardness of the samples sintered at 2050 °C (■) and 2150 °C (▲)

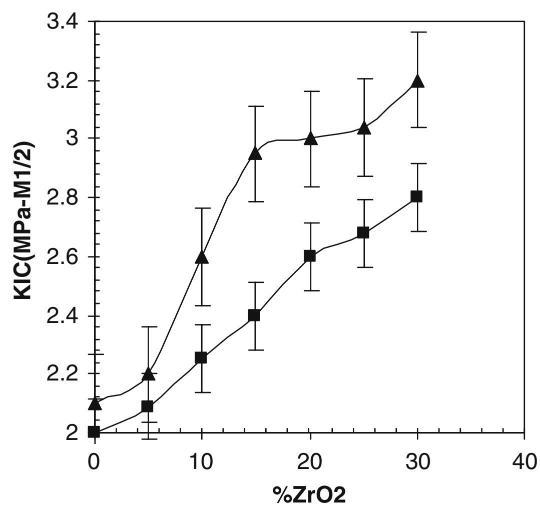

Fig. 5 Effect of ZrO_2 addition on fracture toughness of the samples sintered at 2050 °C (■) and 2150 °C (▲)

same phenomenon affecting the toughness will control the strength as well.

Conclusion

From the results of this study it can be concluded that:

1. Addition of ZrO_2 has remarkable effect on sintering and mechanical properties of B_4C composition.
2. The optimum amount of ZrO_2 for improving the properties of B_4C was found to be about 15 wt%. Addition of higher amount of ZrO_2 reduces the hardness of the samples.
3. Fracture toughness and bending strength increases by increasing the ZrO_2 addition up to30 wt%. The effect of higher amount of ZrO_2 has not been studied yet.

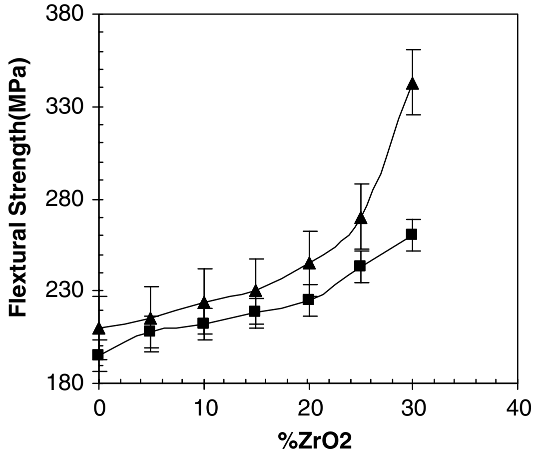

Fig. 6 Effect of ZrO_2 addition on flexural strength of the samples sintered at 2050 °C(■)and 2150 °C (▲).

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