MECHANICAL PROPERTIES - MICROSTRUCTURE INTERCONNECTION IN ALUMINA - ZIRCONIA CERAMICS

V.Ivanova-Stankova, V.Petkov, R.Valov, A.Hristova, E.Stoyanov*

Zirconia-toughened alumina has attracted considerable interest because of its favourable mechanical properties both at room and high temperature. We study the influence of the alumina/monoclinic zirconia ratio on the mechanical properties of the ceramic materials. The best physicomechanical properties are obtained when alumina is toughened with 22 wt % monoclinic zirconia. The ceramic microstructures are in good correlation with the obtained mechanical properties. The toughening mechanisms of the ceramics are discussed.

INTRODUCTION

In the recent years the significance of the ceramic materials has greatly increased. A lot of researchers have dedicated their work on the transformation and microcrack toughening of Al_2O_3. Zirconia-toughened alumina has attracted considerable interest as a very durable hard ceramic compound suitable for cutting tools and engineering ceramics. Alloying zirconia to alumina has led to higher strength and increased toughness (Lange and Hirlinger (1), Kladnig and Gritzner (2). This increase in the mechanical properties has been attributed to various mechanisms such as phase transformation toughening, the formation of microcracks or stress deflections (Claussen (3), Haberko and Pampuch (4). Large tetragonal ZrO_2 grains dispersed in Al_2O_3 matrix are transformed from a tetragonal into a monoclinic structure during cooling

---

* Institute for Metal Science and Technology,
Bulgarian Academy of Sciences, 53 Chapaev Str., 1574 Sofia, Bulgaria

after the sintering process. Due to the increase in volume caused by this transformation residual stresses are generated which might increase the fracture toughness (Haug et al. (5). The structure of the small tetragonal ZrO_2 grains is not changed after cooling. When mechanical stress is applied those metastable ZrO_2 grains transform into the stable monoclinic structure. This stress-induced toughening increases the strength and the fracture toughness. To achieve an optimum toughening effect a carefully adjusted microstructure is necessary (5).

The aim of this research is to investigate the physico-mechanical properties and the microstructure of sintered samples with different ZrO_2/Al_2O_3 ratio. These are the first obtained data from a broad and detailed study in the Al_2O_3 - ZrO_2 system.

STARTING MATERIALS AND PREPARATION OF SAMPLES

The used starting materials are alumina powder with particle size less than 10 mm, α-phase content more than 95 % and monoclinic zirconia powder with particle size less than 15 mm. The zirconia powder is not previously converted and stabilized.

The compositions are mixed in a planetary mill for 4 hours in ethyl alcohol media. The mixed and dried mixtures are blended with polyvinyl alcohol binder and pressed uniaxially at 150 MPa. The obtained cylindrical samples with dimensions - diameter 15 mm and height 15 mm are dried at 200°C and sintered by two stages - 1350°C, 1 h and 1650°C, 40 min.

RESULTS AND DISCUSSION

We study the following physico-mechanical properties of the tested samples - bulk density, measured on the basis of the Archimedes' principle, relative density, determined as a ratio between the bulk and the theoretical density, compressive strength and hardness according to Rockwell. The mean values of these properties for the respective compositions are given in Tab .1.

The changes of the compressive strength and the hardness in respect to zirconia content are shown in Fig.1 and Fig.2.

The toughened with 22 wt % ZrO_2 ceramic is characterized with the greatest compressive strength. The mechanical indices decrease in samples with lower or higher ZrO_2 content.

TABLE 1 - Mean Values of Physico-Mechanical Properties

Composition No	Al_2O_3 wt %	ZrO_2 wt %	Bulk density Mg/m	Relative density %	Compressive strength MPa	Hardness HRA
1	68	32	4.27	93.1	1280	81.0
2	73	27	3.96	93.3	1990	81.5
3	78	22	3.92	94.0	2250	82.0
4	83	17	3.85	93.8	2060	82.5
5	88	12	3.78	93.5	1700	83.0

The monoclinic zirconia (m-ZrO_2) while heated changes into the tetragonal form (t-ZrO_2) at 1000 - 1200 C. This change is connected with decrease in elementary crystal cell and densification of the stucture. During cooling the opposite process is observed - part of this t-ZrO_2 returns into the stable at low temperature m-ZrO_2.

Evaluating the experimental data of this study when a monoclinic zirconia is used as a starting material we find out that 22 wt.% is the optimal ZrO_2 content in the Al_2O_3 - ZrO_2 system because:

(1) An optimal t-ZrO_2/m-ZrO_2 ratio in the sintered samples is achieved. When an external force is applied the tetragonal zirconia available on grain boundaries transforms into its monoclinic form thus increasing the toughness of the material.

(2) A prestressed structure of the samples might be obtained. During cooling part of t-ZrO_2 turns into m-ZrO_2 with increasing in volume in the already sintered body.

(3) The greatest relative density is obtained in samples with 22 wt % ZrO_2.

Measuring the hardness we observe a proportional decrease of its values with the increase in ZrO_2 content. This means that the hardness in Al_2O_3-ZrO_2 system is not structure dependant. It depends only on the sample composition. This is also an evidence that no phases other than corundum and tetragonal and monoclinic ZrO_2 are present in the sintered bodies.

The microstructures of the studied ceramic materials in the Al_2O_3-ZrO_2 system are shown in Fig.3. The investigation is made with SEM-RMA SUPERPROBE 733-JEOL. The image is obtained in secondary electrons beam with magnification x600.

As it is seen the samples are characterized with similar structure. The alumina grains in this ceramic have internal voids as a result of an outflow of vacancies and an inclusion of zirconia particles. This is also determined by Gogoci et al (6). Microstructures B and C show that the ceramic toughened with 22 and 12 wt% ZrO_2 has more homogeneous and fine grained structure.

We find out in this study that alumina toughened with 22 wt % monoclinic zirconia shows the best physicomechanical properties. The microstuctures are in good correlation with the obtained physico-mechanical properties.

REFERENCES

(1) Lange, F.F. and Hirlinger, M.M., J.Amer.Ceram.Soc., Vol.67, 1984, 164.

(2) Kladnig, W. and Gritzner, G., J.Mater.Sci.Letters, Vol.6, 1987, 1235.

(3) Claussen, N., Adv.Ceram., Vol.12, 1984, 325.

(4) Haberko, K. and Pampuch, R., Ceram.Int., Vol.19, 1983, 8.

(5) Haug, T., Fandel, M. and Staneff, T., Powder Met. Int., Vol.22, No.5, 1990, 32.

(6) Gogoci, Y.G., Grigoryev, O.N., Orlovskaya, N.A., Babiy, O.A., Homenko, G.E. and Krivoshey, G.S., Ogneupori, No.6, 1991, 2 (in Russian).

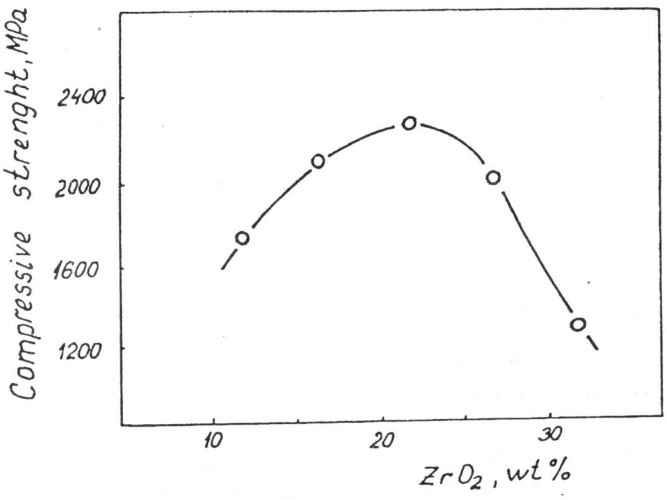

Figure 1. Compressive strength of samples with different ZrO_2 content

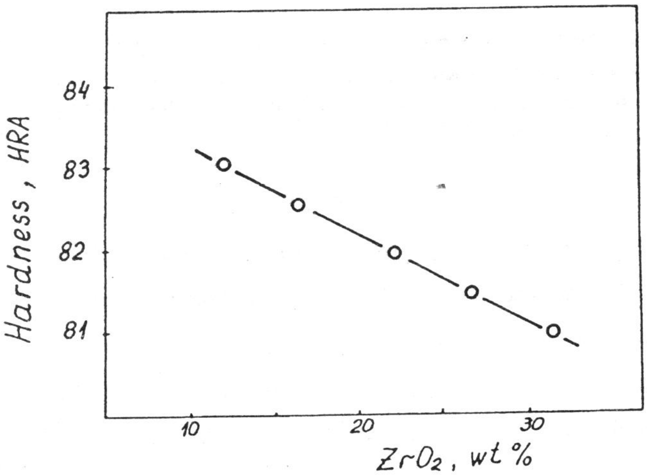

Figure 2. Hardness of samples with different ZrO_2 content

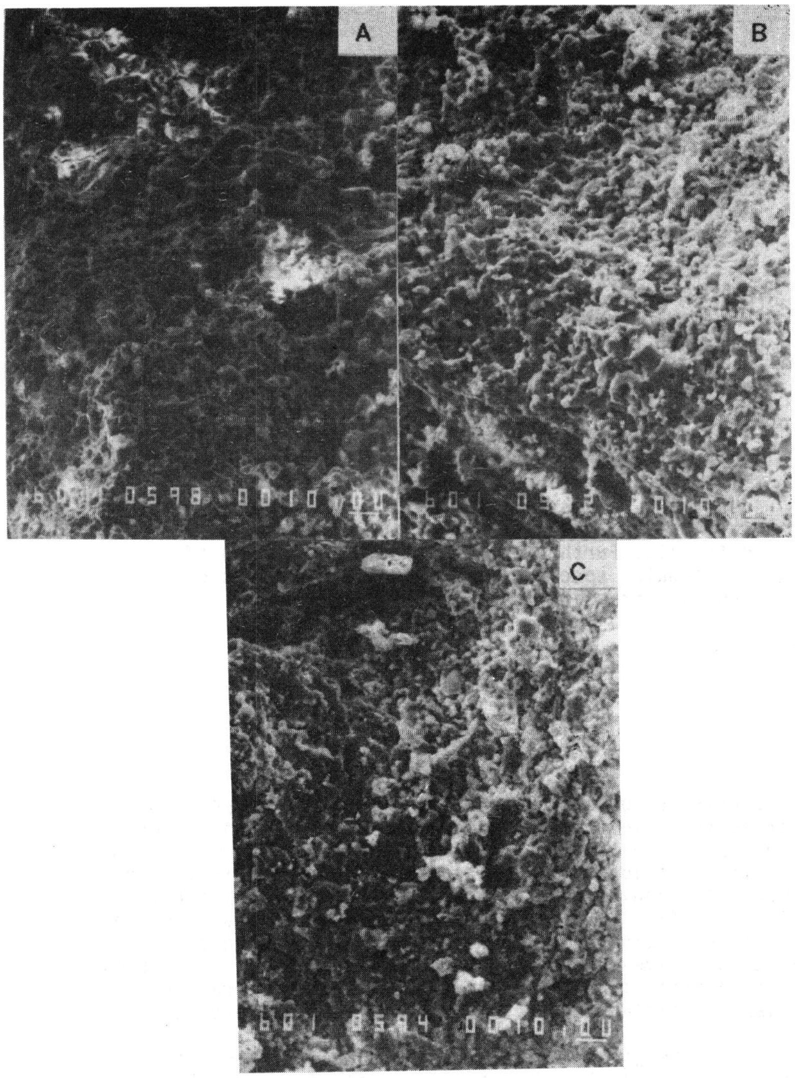

Figure 3. Microstuctures of samples with 32 wt.% (A), 22 wt.% (B) and 12 wt.% (C) ZrO_2 content