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APPLICATION OF ELECTROCONSOLIDATION OF POWDER COMPONENTS FOR PRODUCTION OF ULTRADENCED CERAMICS Al_2O_3 AND ZrO_2 (3% Y_2O_3)

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The possibility of application of electroconsolidation for production of ultradenced ceramics based on Al_2O_3 and ZrO_2 (3% Y_2O_3) compounds is studied. As a result of the conducted researches optimum values of process temperature at which the best parameters of Al_2O_3 and ZrO_2 (3% Y_2O_3) ceramic properties are reached: the apparent density – 3.98 and 6.08 g/cm^3, bending strength – 350 and 800 MPa, fracture toughness – 4.0 and 8.0 MPa·m$^{0.5}$ respectively are established. The researches of a ceramics microstructure are found that high parameters of Al_2O_3 and ZrO_2 (3% Y_2O_3) properties are defined by dense and fine-crystalline structure.

Keywords: electroconsolidation, ceramic materials, mechanical properties, thermal shock resistance, microstructure, SEM analysis.

ПРИМЕНЕНИЕ ЭЛЕКТРОКОНСОЛИДАЦИИ ПОРОШКОВЫХ КОМПОНЕНТОВ ДЛЯ ПОЛУЧЕНИЯ ОСОБОПЛОТНОЙ КЕРАМИКИ Al_2O_3 и ZrO_2 (3% Y_2O_3)

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Изучена возможность применения электроконсолидации для получения особоплотной керамики на основе Al_2O_3 и ZrO_2 (3% Y_2O_3). В результате проведенных исследований установлены оптимальные значения температуры процесса, при которых достигаются наибольшие показатели свойств керамики на основе Al_2O_3 и ZrO_2 (3% Y_2O_3) кажущаяся плотность 3.98 и 6.08 г/см^3, предел прочности при изгибе 350 и 800 МПа, коэффициент интенсивности напряжений 4.0 и 8.0 МПа·м^{0,5} соответственно. Исследованиями микроструктуры керамики установлено, что высокие показатели свойств Al_2O_3 и ZrO_2 (3% Y_2O_3) определяются плотной и мелкокристаллической структурой.

Ключевые слова: электроконсолидация, керамические материалы, механические свойства, термостойкость, микроструктура, SEM анализа.

ЗАСТУСОВАННЯ ЕЛЕКТРОКОНСОЛІДАЦІЇ ПОРОШКОВИХ КОМПОНЕНТІВ ДЛЯ ОТРИМАННЯ ОСОБЛИВОЩІЛЬНОЇ КЕРАМІКИ Al_2O_3 та ZrO_2 (3% Y_2O_3)

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Вивчена можливість щодо використання електроконсолідації для отримання особливощільної кераміки на основі Al_2O_3 та ZrO_2 (3% Y_2O_3). За результатами наведених досліджень встановлено оптимальні значення температури процесу, при яких досягаються найбільші показники властивостей кераміки Al_2O_3 та ZrO_2 (3% Y_2O_3): уявна щільність 3.98 та 6.08 г/см^3, міцність на вигин 350 та 800 МПа, коефіцієнт інтенсивності напруг 4.0 та 8.0 МПа·м^{0,5} відповідно. Дослідженнями мікроструктури було доведено, що високі показники властивостей Al_2O_3 та ZrO_2 (3% Y_2O_3) визначаються щільною та дрібнокристалічною структурою кераміки.

Ключові слова: електроконсолідація, керамічні матеріали, механічні властивості, термостійкість, мікроструктура, SEM аналізу.

INTRODUCTION

Recently the technologies of constructional ceramics production for the solution of various technical tasks are widely developed all over the world. One of leading position among studied materials possess ceramic materials based on Al_2O_3 and ZrO_2 (3% Y_2O_3) compounds [1 – 4].

Traditionally ceramic materials are produced from powder materials by various methods using such as formation and sintering. Depending on a form and the size of products, their purpose and the set properties apply different types of pressing, slip casting in plaster molds, extrusion, casting under pressure from thermoplastic slips, etc. [5].

The last operation of ceramics production is high-temperature sintering at which there is a process of consolidation of the formed samples. This process is accompanied by density increase, and also shrinkage of a green body. The kinetics of sintering and final properties of the solid body significantly depends on both properties of original powder from which the product was formed and technology factors such as temperature of sintering, speed of temperature raising, exposure time at the maximum temperature [6].

Last time for production ceramics with high physicomechanical characteristics are using high-disperse powders and ways of high-speed heating which allow to optimize a combination of processes of the maximum consolidation and the minimum growth of grain during sintering process. There are new methods of consolidation of powder materials: the activated sintering under the influence of an external field, high-speed hot isostatic pressing, electropulse sintering under pressure, etc. [7, 8].

Among progressive methods of producing ceramic materials one of perspective is electroconsolidation process. At electroconsolidation heating is carried out by a direct transmission of an electric current through the graphite elastic squeezed medium in which one or several samples are placed. Purpose of the medium is transfer of pressure created by punches, and ensuring heating of preparations due to heat allocated at passing of current. The speed of heating of preparations can reach 200 °C/min. Thus this process allows to carry out quasiisostatic hot pressing of powder compositions for minimum short terms with necessary isothermal endurance at the maximum temperature up to 3000 °C. Means of effective control of process are necessary for the technology using.

In National science center Kharkov Institute of Physics & Technology the equipment for realization of process of electroconsolidation is developed. The equipment provides opportunity to realize technological process of sintering of powder materials of different structure, in the medium of inert gases and in vacuum [9].

The purpose of this work is studying the possibility of application of electroconsolidation for production of ultradenced ceramics on the basis of Al_2O_3 and ZrO_2 (3% Y_2O_3).

EXPERIMENTAL PROCEDURE

As the main raw materials were used powder of alumina (3000 SDP, “Almatis”, Germany) with a size of particles of 0.5 microns; and the powder ZrO_2 (3% Y_2O_3) (PSZ-5.2 YB, Stanford Materials Corporation, USA), with a size of particles of 0.04 – 0.07 microns.

For research carrying out the powders were filled up in forms and formed samples by a method of unaxial cold pressing under pressure of 100 MPa. After formation alumina samples were sintered (electroconsolidation) at a temperature 1500 and 1600 °C, with a speed of heating 100 °C/min and endurance 30 minutes, and zirconia samples were sintered at a temperature 1400 and 1500 °C with similar values of speed of heating and exposure time.

Open porosity and apparent density of samples were defined according to GOST 2409-95.

Bending strength was determined by a standard method in compliance with DSTU 3716-98. Determination of fracture toughness k_{1c} was carried out according to ASTM Standard C 1421-99.

For determination of thermal shock resistance the EN 820-3:2004 standard was used, according to which thermal stability characterized by difference of temperatures *ДT*, at which there was an emergence of cracks in samples.

The researches of microstructure were conducted on an electronic microscope of the translucent type.

RESULTS AND DISCUSSION

Properties of ceramic samples Al_2O_3 and ZrO_2 (3% Y_2O_3) produced at various temperatures, in comparison with analogous properties of import analogs are given in the table. From the provided data it is clear that the samples of Al_2O_3 produced at a temperature 1500 °C, possess open porosity – 3 – 5%, their density makes 3.78 – 3.80 g/cm^3. The samples of Al_2O_3 produced at a temperature 1600 °C, are characterized by smaller porosity and higher values of the density – 3.96 – 3.98 g/cm^3 that conforms to requirements for ultradenced ceramics.

The Al_2O_3 samples produced at a temperature of 1500 °C, possess rather high parameters of the main properties: σ = 260 – 290 MPa, k_{1c} = 3.0 MPa·m$^{0.5}$, ΔT = 300 °C, however is not compared well with parameters of the samples produced at a temperature 1600 °C. The Al_2O_3 samples produced at a temperature 1600 °C, possess properties which are compared well with the parameters of the samples of import ceramics: σ = 350 MPa, k_{1c} = 3.5 – 4.0 MPa·m$^{0.5}$, ΔT = 300 °C.

Table

Properties of ceramic samples Al_2O_3 and ZrO_2 (3% Y_2O_3) in comparison with import analogs

Ceramic brand	Properties of ceramic				
	Open porosity, %	Apparent density, g/cm^3	Bending strength у, MPa	Fracture toughness k_{1c}, MPa·м$^{0.5}$	Thermal shock resistance ДT, °C
Al_2O_3 (1500 °C) NSC Kharkov	3 – 5	3.78 – 3.80	260 –290	3.0	300
Al_2O_3 (1600 °C) NSC Kharkov	0	3.96 –3.98	350	3.6 – 4.0	300
Al_2O_3 Dynamic ceramic (Eng.)	0	3.95	350	4.0	–
NSC Kharkov ZrO_2 (3% Y_2O_3) (1400 °C)	2 – 5	5.80 – 5.86	680	6.0 – 6.4	400
NSC Kharkov ZrO_2 (3% Y_2O_3) (1500 °C)	0	6.04 – 6.08	800	7.6 – 8.0	400
ZrO_2 (3% Y_2O_3) Kyocera (Japan)	0	6.00	750	7.0 – 8.0	400

Similarly properties of ZrO_2 (3% Y_2O_3) samples are changed. With increase in temperature of electroconsolidation from 1400 to 1500 °C, open porosity of samples disappears, their density increases to 6.04 – 6.08 g/cm^3, and the main parameters of properties correspond to level of import ceramics: σ = 800 MPa, k_{1c} = 7.6 – 8.0 MPa·м$^{0.5}$, ΔT = 400 °C.

As properties of ceramics, substantially are defined by its structure, for an explanation of the received results the corresponding researches were carried out.

In fig. 1 and fig. 2 the microstructure of ultradenced ceramic Al_2O_3 and ZrO_2 (3% Y_2O_3) is respectively shown.

From fig. 1 it is visible that the ceramics Al_2O_3 represents very fine-crystalline structure, with a prevailing size of grains of 1 – 3 µm. Thus the minimum size of grains of corundum makes 0.5 µm and maximum – 6 µm. Grains have a crystallographic facet that testifies about completion of process of crystallization at a temperature of 1600 °C. Borders

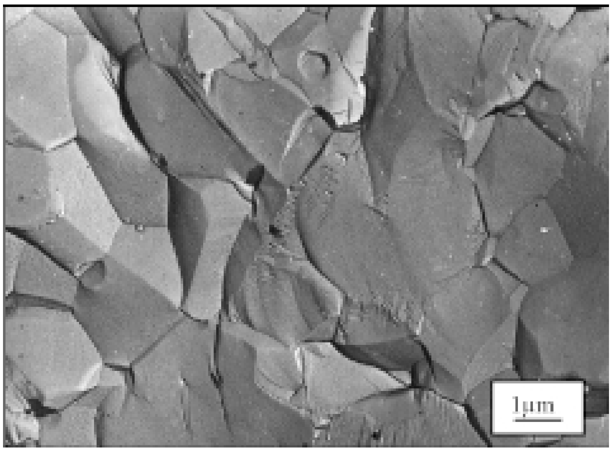

Fig. 1. Microstructure of ultradenced ceramic Al_2O_3.

of grains of corundum are very dense, thus on all volume of a ceramic sample are noticed fine-crystalline grains of spinel ($MgO·Al_2O_3$) with size ≤ 0,5 µm.

From fig. 2 it is visible that the ceramic sample of ZrO_2 (3% Y_2O_3) also has fine-crystalline structure which consists of well crystal grains of 0.2 – 2.6 µm in size, with a prevailing size of grains of 1.5 microns.

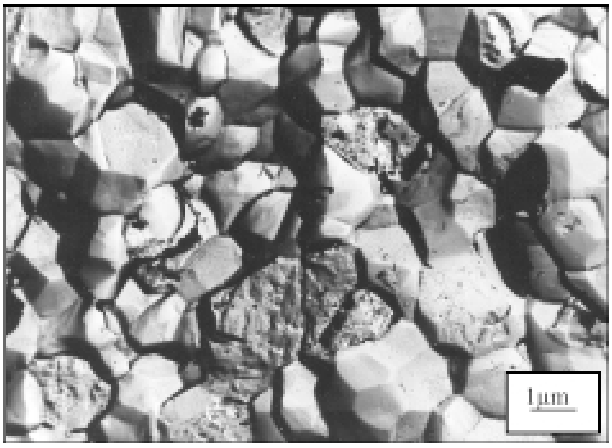

Fig. 2. Microstructure of ultradenced ceramic ZrO_2 (3% Y_2O_3).

As a result of the carried out researches, the possibility of application of electroconsolidation for production ultradenced ceramics Al_2O_3 and ZrO_2 (3% Y_2O_3) is established.

CONCLUSIONS

The possibility of application of electroconsolidation for production of ultradenced ceramics on the basis of Al_2O_3 and ZrO_2 (3% Y_2O_3) is studied. As a result of the conducted researches optimum values of process temperature at which the best parameters of properties of Al_2O_3 and ZrO_2 (3% Y_2O_3) ceramics are reached: the apparent density – 3.98 and 6.08 g/cm^3, bending strength – 350 and 800 MPa, fracture toughness – 4.0 and 8.0 MPa·m$^{0.5}$ respectively are established. The researches of a microstructure of ceramics demonstrate that high parameters of properties Al_2O_3 and ZrO_2 (3% Y_2O_3) ceramics are defined by dense and fine-crystalline structure.

Developed ceramics are perspective for application as constructional materials for various spheres of science and engineering.

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