PHYSICAL AND MECHANICAL PROPERTIES OF THE SILICON NITRIDE BASED CERAMICS OBTAINED BY COLD ISOSTATIC PRESSING AND FREE SINTERING

Olga LUKIANOVA[1]

Center of structural ceramics and engineering prototyping, Belgorod State National Research University, 85, Pobedy Str., 308015 Belgorod, Russia, sokos100@mail.ru

Abstract

In this paper analysis of the mechanical and physical properties of silicon nitride ceramic were reported. This type of ceramics have a great potential for a large number of applications due to its successful combination of the high temperature and mechanical properties such as strength, hardness, corrosion resistance etc. In our article we used Si_3N_4 based ceramic material with Y_2O_3 and Al_2O_3 additives obtained by cold isostatic pressing (CIP) and free sintering. The results can be summarized as follows: 1. The microhardness of obtained material was 1380 HV0.5 and 970 HK2.5 2. The bending strength σ_{3pb} of the obtained Si_3N_4 based ceramic is 280 MPa. 3. The density of the obtained material is about 2,94 g/cm^3 by helium pycnometry and Archimedes methods. 4. The open porosity of the obtained material is about 0.1 %. The average size of the open pores is about 9.2 μm. The CTE of the obtained silicon nitride based ceramic is $4.6 \cdot 10^{-6}$ K^{-1} up to 200 ^{o}C and $4.8 \cdot 10^{-6}$ K^{-1} up to 900 ^{o}C. The obtained test results of ceramics based on silicon nitride can be used for further investigation of effective applications of this material. Combination of properties of obtained ceramic is attractive for a wide range of technical, structural and engineering applications.

Keywords: Structural ceramics, silicon nitride, cold isostatic pressing, microhardness, density

1. INTRODUCTION

It is well known, that ceramic materials have a lot of attractive properties compared to metals, steel, different alloys and polymers [1]. Due to successful combination of properties, the silicon nitride based ceramics has attracted the attention for the recent years. Particularly, silicon nitride based ceramics are often used to produce bearings, hot-pressing pistons, components for chemical plants, crucibles, drawing nozzles, cutting tools, valves, elements for gas turbines and turbo-chargers, balls for ball bearings, welding tips, thermocouple sleeves, motor engines, cutting tools and many others [1,2]. But, unfortunately, the major disadvantage of the ceramics is brittleness. In the case of the structural application high mechanical properties are the most important criteria for the ceramic materials, particularly, such characteristics as bending strength, hardness and fracture toughness. Furthermore, it should be noted that the mechanical and physical properties of the silicon nitride based ceramic materials depend on the method of obtaining of these materials. For example, the Si_3N_4 based materials obtained by the hot isostatic pressing (HIP) or by the spark plasma sintering (SPS) methods have a significantly higher physical and mechanical properties compared to silicon nitride based materials obtained by the reaction bounding (RB) or cold static pressing (CSP) methods [2]. Silicon nitride based ceramics are one of the most attractive ceramics as structural materials for high temperature application [3]. The purpose of this paper is an analysis of the mechanical properties and some physical characteristics of the CIPed free sintered silicon nitride ceramic structural material.

2. EXPERIMENTAL PROCEDURE

The test material was obtained by CIP and free sintering. For more detail, see [4]. Indentation microhardness of Si_3N_4 ceramic was measured using the Knoop and Vickers indenters. Indentation microhardness measurements of obtained ceramic material were performed with a Indentertest – Device: construction and software self-made microindentation hardness tester at the room temperature. The indenters were used with loads 5 N for Vickers indenter and 25 N for Knoop indenter. The indentation diagonal lengths were measured with Keyence VHX-500 optical microscope. Loads were applied for 15 s to measure diagonals of the indentations. At least ten well-defined impressions were considered. Knoop and Vickers microhardness, HV, was measured on polished cross-section surfaces of the samples. The density of the samples was measured by the helium pycnometry using helium pycnometer Micromeritics AccuPyc 1340. Density of the obtained ceramic was determined by the Archimedes method (based on weighing) in distilled water. The bulk density, apparent density, open porosity, pore size distribution as well as the density was determined by mercury porosimetry. The 3 point bending tests (3PB) were carried out in air using an Instron 300LX testing machine at the room temperature. For this type of tests we used rectangular specimens (typically of breadth b=5.8 mm, height w=7.8 mm and length L=50 mm). The support/ loading distance for 3PB tests is 30 mm. The coefficient of thermal expansion (CTE) was measured used NETZSCH DIL 402 C in the temperature range from 20 ^{o}C to 900 ^{o}C.

3. RESULTS AND DISCUSSION

Ceramic materials based on silicon nitride a priori characterized by high hardness [1]. The obtained material based on silicon nitride is also characterized by high microhardness 1380 HV0.5 (Table 1). The measured Knoop microindentation hardness is about 970 HK2.5 (Table 1). The large difference in microhardness by Vickers and Knoop methods can be explained by the difference of indentation load. The fingerprints from the Vickers and Knoop indenters are shown in Fig. 1 and Fig. 2, respectively. The choice of the indentation load produced experimentally for both methods.

Table 1 The mechanical properties of the silicon nitride ceramics

Microhardness (HV0.5)	**Microhardness (HK2.5)**	**σ_{3pb} (MPa)**
1380	970	280

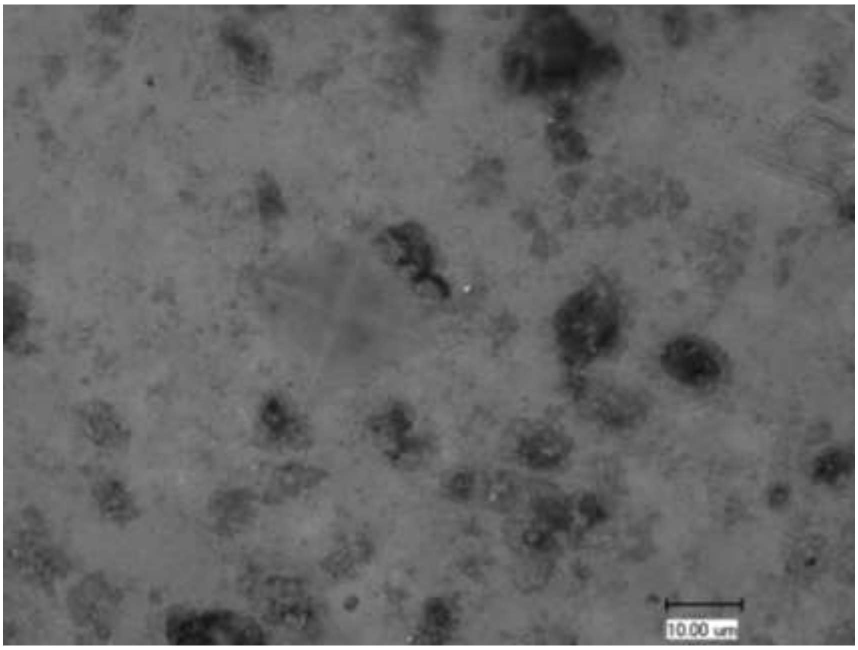

Fig. 1 Vickers indentation image of the Si_3N_4 ceramics.

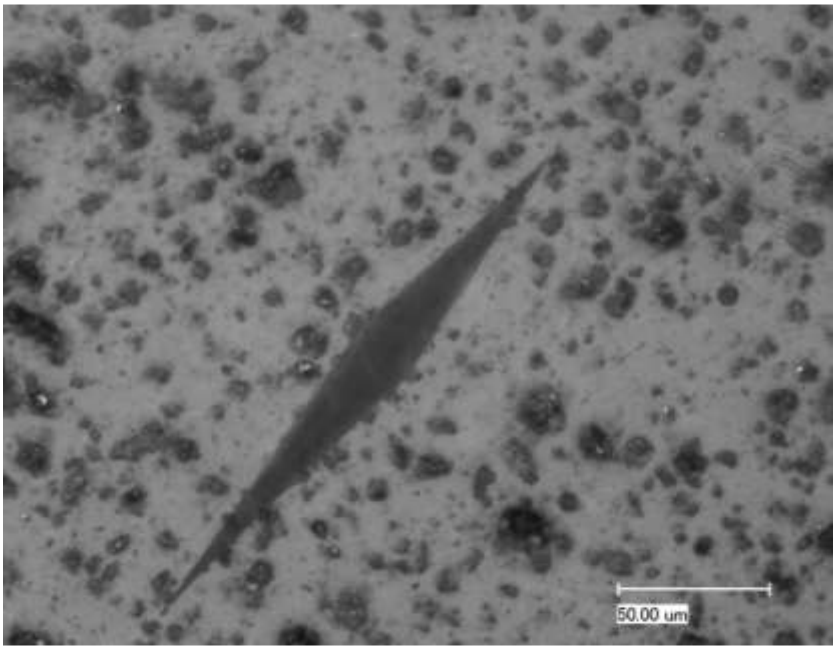

Fig. 2 Knoop indentation image of the Si_3N_4 ceramics.

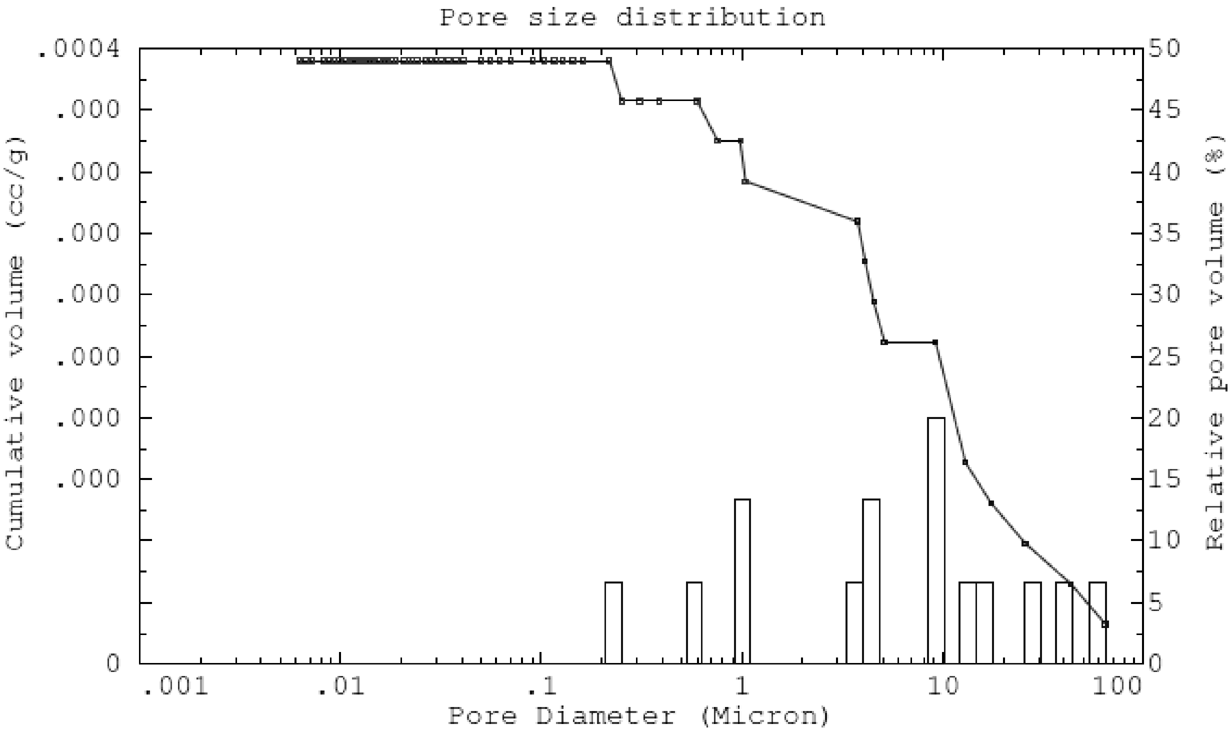

Fig. 3 Mercury porosimetry results of the Si_3N_4 ceramics.

Table 2 The physical properties of the silicon nitride ceramics

Bulk density (g/cm^3)	Apparent density (g/cm^3)	Open porosity (%)	Average pore diameter (μm)
2.938	2.941	0.115	9.213

Bending strength of the obtained ceramic σ_{3pb} was 280 MPa (Table 1). Analyzing the results of the mercury porosimetry tests can be noted that the obtained structural ceramic material is characterized by high bulk density, apparent density, and, consequently, very low open porosity (Table 2). However, the average pore size of the open pores is about 9.2 µm (Fig.3). The same density (2.94) g/cm^3 of the obtained ceramic material was measured by helium pycnometry and Archimedes methods. The CTE of the obtained silicon nitride based ceramic is $4.6 \cdot 10^{-6}$ K^{-1} up to 200 ^{o}C and $4.8 \cdot 10^{-6}$ K^{-1} up to 900 ^{o}C.

CONCLUSION

We measured some physical and mechanical characteristics of the CIPed free sintered silicon nitride ceramic with Y_2O_3 and Al_2O_3 additives. In our study we showed that the obtained material is characterized by high hardness and density, an almost complete absence of the open porosity. The results can be summarized as follows:

1. The measured Vickers and Knoop microindentation hardness of the obtained ceramic samples are 1380 $HV_{0.5}$ and 970 $HK_{2.5}$, respectively.
2. The bending strength, σ_{3pb}, of the obtained silicon nitride based ceramic material is 280 MPa
3. The density of the obtained material is about 2,94 g/cm^3 by helium pycnometry and Archimedes methods.
4. The open porosity of the obtained material is about 0.1 %. However, the average pore size of the open pores is about 9.2 µm. The CTE of the obtained silicon nitride based ceramic is $4.6 \cdot 10^{-6}$ K^{-1} up to 200 ^{o}C and $4.8 \cdot 10^{-6}$ K^{-1} up to 900 ^{o}C.

ACKNOWLEDGEMENTS

This work was carried out on the equipment of the Advanced Ceramics group from the University of Bremen and the Centre for Collective Use of Research Equipment «Diagnostics of structure and properties of nanomaterials» of Belgorod State National Research University within the framework of the «All-Russian open competition for grants of the President of the Russian Federation for study abroad students and postgraduates of Russian universities in the 2013/2014 academic year».

LITERATURE

[1] MUNZ, D. Ceramics: mechanical properties, failure behavior, materials selection. *Springer,* 1999, 298

[2] BOCANEGRA-BERNAL, M. Dense and near-net-shape fabrication of Si_3N_4 ceramics. *Materials Science and Engineering A 500,* 2009, 130-149.

[3] KRÄMER, P. Grain growth kinetics of Si_3N_4 during α/β transformation. *Acta metall, mater*.,1993 V.41, No. 10, 2939-2947.

[4] KRASILNIKOV, V. Investigation of the structure of Si_3N_4–based ceramic with Al_2O_3 and Y_2O_3 additives. *Glass and Ceramics* 2014, No. 1, 17-19.