Mechanical properties of ceramic materials SiC-BeO

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Abstract. High-density ceramic based on silicon carbide with the addition of beryllium oxide compositions (1-2)\% wt. With a step of 0.2 was obtained. X-ray diffraction studies of SiC-BeO ceramics showed changes in the lattice parameter of SiC “c” with the addition of beryllium oxide, the minimum value of which was observed for a composition of 1.4\% wt. BeO. For compositions greater than 1.4\% wt. BeO was observed only polytype 6H. The grain size of sintered ceramic materials reached up to 20 microns. The elastic moduli, microhardness, and shear strength for hot-pressed SiC-BeO ceramic materials are determined.

1. Introduction

Ceramics based on silicon carbide, due to its useful properties, is one of the most promising materials for various branches of mechanical engineering. It has high mechanical strength, resistance to oxidation at high temperature, high heat resistance and thermal conductivity. However, the implementation of these useful properties is possible upon receipt of high-density silicon carbide materials. One of the modern technological methods for producing high-density ceramic materials based on silicon carbide is hot pressing [1-4].

Due to the covalent nature of the Si-C bond, sintering of silicon carbide without the use of sintering activators ends when a density of about 70\% of theoretical (TP) is reached, which sharply reduces the strength properties of ceramics.

It is known that materials with high solubility in SiC and forming solid solutions with it are an effective additive for sintering silicon carbide. Among these compounds are, in particular, beryllium oxide having a wurtzite structure characteristic of alpha-modification of silicon carbide and, as a result, forming solid solutions [5].

Ceramic materials SiC-BeO are interesting in a combination of high thermal conductivity and electrical resistance [6]. Adding a small amount of beryllium oxide (~ 2\% wt.) To silicon carbide leads to an increase in thermal conductivity up to 270 W m·K, and a specific resistance of $10^{13}$ $\Omega$·cm.

2. Materials and Experimental Methods

SiC-BeO ceramics was obtained from green powder of 6N modification silicon carbide, with a dispersion of 2.4 microns with the addition of beryllium oxide powder with a fineness of 1 micron, by hot pressing at a temperature of 2420 K and a pressure of up to 35 MPa for 1 hour in an atmosphere of $N_2$. SiC and BeO powders were mixed in a ball mill for 8-24 hours. The shear strength was measured by the four-point method, and the microhardness was indented by the Vickers prism. To measure the
flexural strength, the samples were prepared in the form of beams (7x7x70) mm. Microhardness was studied on samples of silicon carbide ceramics with BeO additives in the form of a cylinder with a diameter of 20–40 mm and a thickness of 10 mm. The surface of polycrystalline samples was previously ground and polished with a diamond tool.

We calculated the elastic moduli from the measured values of the density and propagation velocities of the longitudinal $C_l$ and transverse $C_t$ ultrasonic waves. The propagation velocity of ultrasound is measured by pulsed and resonant methods. Pulse measurements were carried out using an acoustic tester in the “On passage” mode at a frequency of 5 MHz at a temperature of $20 \pm 2 \, ^\circ C$. The frequencies of natural bending and radial vibrations of the disks were measured according to the method described in [7]. The speeds $C_l$ and $C_t$ are calculated from these frequencies. We used samples in the form of washers with a diameter of 20 mm and a thickness of 7 mm.

The structure of the obtained ceramics was studied by the integrated X-ray intensity of CuKα on a DRON-2.0 diffractometer at an accelerating voltage of 20 kV. X-ray structural analysis of SiC-BeO-based ceramic samples was carried out both on pressed washers and on powders made from hot-pressed samples. Powders were made by abrasion of pieces of samples in a sapphire mortar. The results of the decoding of the X-ray diffraction patterns were compared with the two closest polytypes of SiC (data taken from the ASTM file cabinet). The microstructure of SiC-BeO ceramics was studied by cleavage (without selective etching) using a JSM-T300 microscope.

### 3. Results and Discussion

Density data for the hot-pressed silicon carbide ceramic SiC-BeO are presented in table 1.

A general regularity for SiC-BeO ceramics obtained from -SiC powder is to increase the matrix density to certain composition values (~ 2% by weight). This behavior of the density dependence on the composition for SiC-BeO ceramics is associated with two simultaneously proceeding processes: filling the intergranular phase with beryllium oxide and dissolving beryllium oxide in silicon carbide during the diffusion interaction of SiC and BeO powders.

| №№ | Density $\rho$, g/cm$^3$ | Porosity $P$, % | Polytype | Temperature $T$, K | Composition, weight % BeO |
|----|----------------|-------------|-------|---------|----------------|
| 1. | 2.77 | 13.7 | 6H,15R | 2420 | 1 |
| 2. | 2.78 | 13.4 | 6H,15R | 2420 | 1.2 |
| 3. | 2.815 | 12.3 | 6H,15R | 2420 | 1.4 |
| 4. | 2.795 | 12.53 | 6H | 2420 | 1.5 |
| 5. | 2.85 | 11.2 | 6H | 2420 | 1.6 |
| 6. | 2.85 | 11.2 | 6H | 2420 | 1.8 |
| 7. | 2.98 | 7.16 | 6H | 2420 | 2 |

Figure 1 presents a spectrometric analysis of the dispersion of energy of a ceramic SiC-BeO composition (2% wt. BeO). The analysis showed the presence of a phase of silicon, carbon, oxygen and the absence of beryllium.

The study of the parameters of the crystal structure of SiC-BeO on the composition showed that in the range of (0.5-2) % wt. The peaks in the diffraction patterns inherent to pure SiC were shifted by (0.1–0.2)$^\circ$ toward small angles, which indicates a change in the crystal lattice parameter. This indicates the formation of a solid solution of SiC-BeO. From the dependence of the unit cell parameter “c” of SiC-BeO ceramics on the composition, it was found that the minimum value of the parameter is observed for samples with additives of (1.4-1.5) % wt BeO. As shown by the results of x-ray phase analysis, under conditions of activated sintering in the presence of beryllium oxide, polytype transitions 6H, 15R→6H occur.
The microstructure of SiC-BeO ceramics was studied by cleavage (without selective etching) using a JSM-T300 microscope (Figures 2,3).

![Spectrometric analysis of the energy dispersion of SiC-BeO ceramics (2% wt. BeO)](image)

**Figure 1.** Spectrometric analysis of the energy dispersion of SiC-BeO ceramics (2% wt. BeO).

The structure of sintered SiC-BeO represented α-SiC grains up to 20 μm in size. The study of the microstructure showed that sintering is activation in nature, due to the mechanical activation of the powders. The content of beryllium oxide ~ (1.4–1.6% wt.) is optimal for obtaining the most dense material with a uniform fine-grained structure.

![Microstructure of SiC-BeO Ceramics (1.4 wt% BeO)](image)

**Figure 2.** Microstructure of SiC-BeO Ceramics (1.4 wt% BeO)

![Microstructure of SiC-BeO Ceramics (2.0 wt% BeO)](image)

**Figure 3.** Microstructure of SiC-BeO Ceramics (2.0 wt% BeO)

The results of measurements of the longitudinal and transverse velocities of ultrasound and elastic moduli for SiC-BeO ceramic materials are presented in Table 2 and Figure 4.

Figure 4 shows the correlation field of Young's modulus (E) and porosity obtained on several batches of samples of silicon carbide ceramics. The confidence interval with a probability of 0.95 contains unaccounted systematic and random errors in measuring the propagation time of ultrasound.
in the sample and the length of the sample. A study of the elastic moduli of SiC-BeO ceramic materials showed that porosity is the main factor affecting their elastic properties. In [1,4], a Young's modulus of 513 GPa was obtained in samples of theoretical density at room temperature. In our samples, the porosity of which varies from 7% to 13%, small additives of beryllium oxide (up to 2% wt. BeO) do not strongly affect the elastic properties.

| №№ | Cl, m/c  | Ct , m/c | μ    | E, GPa | M, GPa | G, GPa | wt % BeO |
|-----|----------|----------|------|--------|--------|--------|----------|
| 1   | 11527.6+110 | 7373+30 | 0.153 | 374    | 180    | 162    | 2        |
| 2   | 10909.0+90  | 7034+20  | 0.145 | 322    | 151.17 | 141    | 1.6      |
| 3   | 10532.95+80 | 7272+25  | 0.131 | 333    | 150.406| 147    | 1.5      |
| 4   | 11293.0+110 | 7293+50  | 0.143 | 342    | 153.664| 150    | 1.4      |
| 5   | 10874.0+110 | 7071+30  | 0.136 | 316    | 144.7  | 139    | 1.2      |
| 6   | 10898.7+150 | 7058+50  | 0.136 | 316    | 145.03 | 138    | 1        |
| 7   | 9196.6+90   | 6030+80  | 0.124 | 253    | 91.3   | 92     | 0        |

Figure 4 shows that the elastic modulus for SiC-BeO samples decreases in SiC-BeO ceramics with increasing porosity. A good correlation of the elastic moduli with porosity allows the use of acoustic measurements to expressly evaluate the porosity of the resulting SiC-based ceramic. On the other hand, knowing the elastic properties of the sample and its porosity, it is possible to evaluate the elastic properties of the ceramic matrix and draw conclusions about the influence of a particular impurity on its properties.
In the study of microhardness by the indentation method, no cracks were observed on the fingerprints, due to the presence of porosity. The maximum microhardness falls on the composition region (1.4–1.5) % wt. BeO and amounted to 17 GPa. This indicates a change in the bond strength between the atoms, which is usually observed during the formation of a solid solution. This is also confirmed by a decrease in the lattice parameter in SiC-BeO ceramics, and by attaining a minimum in the region of SiC concentration + 1.4 wt. %. BeO.

The shear strength data are presented in Figure 5. It can be seen that, up to a temperature of 1300 K, the tensile strength remains constant.

![Figure 5](image.png)

**Figure 5.** The temperature dependence of the tensile strength of hot-pressed ceramic SiC-BeO of various compositions on temperature.

The shear strength at temperatures of 300 K and 1700 K for ceramic compositions SiC + 1.4% wt. BeO and SiC compositions + 1.5% wt. BeO was 230 MPa and 160 MPa, respectively. The fall in the value of the shear strength of ceramics with the composition SiC + (1.4–1.5)% wt. BeO less than pure hot pressed SiC Moreover, the value of the ultimate shear strength in ceramics of SiC + compositions is (1.4–1.5)% weight. BeO at a temperature of T = 1770 K is retained and even a slight increase is observed in comparison with pure silicon carbide. The effect of the addition of beryllium oxide on the value of the shear strength is not as great as in the case of microhardness.

4. **Conclusion**

Dense ceramic was obtained in the SiC-BeO system by hot pressing. X-ray diffraction studies of SiC-BeO ceramics showed changes in the lattice parameter on the composition of beryllium oxide, as well as the activation character of sintering of SiC-BeO ceramics. The grain size as a result of recrystallization increased to 20 μm. The main factor influencing the elastic properties of SiC-BeO ceramics is porosity. The maximum microhardness was observed at concentrations of 1.4–1.5% wt. BeO and amounted to 17 GPa. The shear strength remains constant up to a temperature of 1300 K and varies between 200 and 250 MPa.

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