Abstract:
The process of carbothermal reduction of $\text{Al}_2\text{O}_3$ in a nitrogen flow at temperatures of 1450 and 1600 °C has been studied. It was established that the powder synthesized at 1450 °C is a mixture of $\text{Al}_2\text{O}_3$ and $\text{AlN}$ particles and that the powders synthesized at 1600 °C are mixtures of $\text{AIN}$, $\text{AlON}$, and $\text{Al}_2\text{O}_3$. Amorphous and crystalline $\text{AlON}$ films form on the surface of $\text{Al}_2\text{O}_3$ and $\text{AlN}$ particles. Both synthesized powders contain unreacted residual carbon. In the stage of high-pressure sintering of specimens at a temperature of 1750 °C under a pressure of 7 GPa for 110 s, $\text{AlON}$ decomposes into $\text{AlN}$ and $\text{Al}_2\text{O}_3$. Residual graphite transforms into a crystalline graphite phase, which decreases the strength and increases the fracture toughness. The highest hardness of 19.5 GPa was achieved in the ceramics obtained from the powder synthesized at 1600 °C for 4 h, and the largest fracture toughness of ~7.2 MPa·m$^{1/2}$ was achieved in the ceramics obtained from the powder synthesized at 1450 °C for 4 h.

Keywords: $\text{Al}_2\text{O}_3$–C, $\text{AIN}$, $\text{AlON}$, Powder, High-pressure sintering, Ceramics

1. Introduction

Considerable attention has been given to the synthesis of composite nanopowders based on $\text{Al}_2\text{O}_3$, $\text{AlN}$, and $\text{AlON}$ due to unique properties of composite ceramics of the $\text{Al}_2\text{O}_3$–$\text{AIN}$–$\text{AlON}$ system. Each of these materials is extensively used as monophase structural materials. In particular, aluminum oxide is one of the main ceramic packaging materials used for microelectronics. This ceramic has good electrical and mechanical properties [1]. Among disadvantages of alumina ceramic are the difference between its thermal expansion coefficient and the thermal expansion coefficient of silicon and a relatively low thermal conductivity of 10–30 W/m·K, which does not meet the requirement of new advanced large-scale integrated circuits (IC) [2, 3].

Aluminum nitride ceramics has a sufficiently high thermal conductivity [4–6]. However, its sintering temperature is rather high (above 2000 °C), which increases substantially processing costs. The spinel aluminum oxynitride ($\gamma$-AlON) ceramic is a stable
solid solution material in the Al\textsubscript{2}O\textsubscript{3}–AlN system [7]. It exhibits transparency in visible light, high strength, hardness, and excellent optical properties. This makes it promising for using in infrared windows, domes, and transparent armors [8, 9].

Powders used to fabricate AlN and AlON ceramics are usually synthesized by the following methods: carbothermal reduction and nitriding of Al\textsubscript{2}O\textsubscript{3} in a nitrogen atmosphere [5, 10–14], solid state reaction of Al\textsubscript{2}O\textsubscript{3} and AlN [15, 16], reaction bonding technique [17], sol-gel method [18], microwave synthesis [19, 8], plasma arc melting [20], laser synthesis [21], and burning of aluminum powder [22]. To decrease the sintering temperature and time, additives such as Al, MgO, etc. are introduced into the initial mixtures [18, 23–25], the composition of a gas atmosphere has been varied [17, 26], and mechanoactivation of initial powder mixtures has been used [24, 25].

The cost-efficient carbothermal method is extensively used for the synthesis of aluminum nitride and aluminum oxynitride nanopowders [27, 28] and is promising for the synthesis of composite powders that contain Al\textsubscript{2}O\textsubscript{3}, AlN, and AlON in various ratios and are of interest today [29–32].

The method of high-pressure sintering is used to consolidate ceramic nanopowders that are difficult to compact because high pressures and short sintering times allow one to obtain dense compacts without noticeable grain growth.

The aim of the present work is to investigate phase formation in the Al\textsubscript{2}O\textsubscript{3}–C powder nanosystem during temperature treatment of an initial powder mixture in a nitrogen flow and in the AlN–AlON–Al\textsubscript{2}O\textsubscript{3} system during high-pressure sintering of synthesized composite powders.

**Experimental procedure**

Composite nanopowders of the AlN–AlON–Al\textsubscript{2}O\textsubscript{3} system were prepared by the carbothermal reduction–nitriding method [33]. The components of the initial powder mixture were obtained from a water solution of aluminum nitrate (Al(NO\textsubscript{3})\textsubscript{3}·9H\textsubscript{2}O) and carbon-containing substance (C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}). The initially obtained aluminum hydroxide was mixed with a water solution of sucrose. The mixture was dried in a drying chamber at 100ºC for 5 h and then subjected to pyrolysis in an argon flow at 600 ºC for 4 h. The final product was a mixture of nanodisperse γ-Al\textsubscript{2}O\textsubscript{3} and amorphous carbon (with a particle size of ≤0.1 µm). The carbon content in the mixture was larger than the carbon content required for the formation of the stoichiometric compound 5AlN·9Al\textsubscript{2}O\textsubscript{3} by 30%. The obtained precursor was heat treated in nitrogen at 1450 and 1600 ºC with an isothermal exposure for 2 to 4 h.

Cylindrical ceramic compacts with a diameter of 6 mm and a height of 5 mm were made from the powders synthesized at temperatures of 1450 and 1600 ºC for 2, 3, and 4 h. The high-pressure sintering was performed at a pressure 7 GPa in a high-pressure high-temperature unit in the form of an anvil with a hole, in which pressure is transferred by a solid medium, at a temperature of 1750 ºC for 110 s.

The synthesized products were investigated through the X-ray diffraction (XRD) method in Cu K\textsubscript{α} radiation (Siemens D-500 diffractometer, Munich, Germany). The percentages of crystalline phases were assessed from the intensities of nimsuperimposed peaks of the synthesized phases and the corresponding peaks of standards. IR spectra were recorded with a Specord M 80 spectrometer (Karl Zeiss, Germany) and analyzed the “Spectra Ciphering 20” computer program. This program enables one to perform summing of spectra of different intensities. An electron microscopy study and an electron-probe X-ray microanalysis were performed with a HU-200F type scanning electron microscope. The mechanical properties (microhardness and fracture toughness) were determined with a Leco 300AT microhardness tester and a Vickers indenter under a load of 10 N with a holding time of 15 s.
Results
Characterization of composite powders

According to the XRD data, the powder synthesized at 1450 °C for 4 h, contains two crystalline phases AlN and Al₂O₃ (Fig. 1a). With increases in the treatment temperature and time, the intensity of alumina peaks decreases, peaks of aluminum oxynitride appear, and the intensity of peaks of aluminum nitride increases (Fig. 1). In the powder synthesized at 1600 °C for 3 h (Fig. 1b), the main phases are AlIN and AlON, and in the powder synthesized at 1600 °C for 4 h (Fig. 1c), the AlON phase dominates, and the intensity of peaks of AlN is somewhat lower. These changes coincided with changes in the relative content of the corresponding phases.

For Al₂O₃ and AlN, increases in the interplanar spacings are noted (Tab. 1). This indicates instability of the crystal lattice of aluminum oxide and nitride in terms of their interaction at high temperature. In XRD patterns of the powders synthesized at 1450 °C, a weak broadened line of carbon at $d = 0.3348$ nm ($2\theta = 26.603^\circ$) is present. This suggests that the process of carbothermal reduction of Al₂O₃ at this temperature is not completed and that the most part of carbon is in the amorphous state.

An IR spectrum of the initial mixture (precursor) (Fig. 2a) is a typical spectrum of amorphous alumina ($\gamma$-Al₂O₃) (Fig. 2f) [34]. With increase in the treatment temperature and time, this IR-spectrum (see Fig. 2b, c) transforms into a spectrum of corundum ($\alpha$-Al₂O₃) (Fig. 2g).

This means that the transformation $\gamma$-Al₂O₃ $\rightarrow$ $\alpha$-Al₂O₃ takes place [35]. At a temperature above 1450 °C, the substantial weakening and broadening of absorption bands of $\alpha$-Al₂O₃ are noted (Fig. 2d). This testifies to the disordering and destruction of the corundum lattice and
formation of AlN (see Fig. 2 h). With increase in the time of treatment at 1600 ºC, the IR spectrum changes noticeably (Fig. 2 e). Taking into account the data of X-ray phase analysis, the most probable cause of this change must be the formation of aluminum nitride and oxynitride. From the form of the IR spectrum shown in Fig. 2 e, we can conclude that appearance of absorption band at \( \nu \sim 550 \text{ cm}^{-1} \) may be due to the formation of AlON films [36, 37] (see Fig. 2 i).

**Tab. I**. Change in the interplanar spacing (d) in synthesized powders and ceramics

<table>
<thead>
<tr>
<th>Type of specimen</th>
<th>Conditions of treatment</th>
<th>Alumina</th>
<th>Aluminum nitride</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder</td>
<td>T&lt;sub&gt;i&lt;/sub&gt; = 1450 ºC, 2 h.</td>
<td>d = 0.34936 nm</td>
<td>d = 0.26980 nm</td>
</tr>
<tr>
<td>Powder</td>
<td>T&lt;sub&gt;i&lt;/sub&gt; = 1600 ºC, 3 h.</td>
<td>d = 0.35237 nm</td>
<td>d = 0.27193 nm</td>
</tr>
<tr>
<td>Powder</td>
<td>T&lt;sub&gt;i&lt;/sub&gt; = 1600 ºC, 4 h.</td>
<td>d = 0.35301 nm</td>
<td>d = 0.27215 nm</td>
</tr>
<tr>
<td>Powder</td>
<td>P = 7 GPa, T&lt;sub&gt;r&lt;/sub&gt; =</td>
<td>d = 0.34824 nm</td>
<td>d = 0.26934 nm</td>
</tr>
<tr>
<td>Ceramics</td>
<td>1750 ºC, t = 110 s.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 2**. IR absorption spectra of (a) the initial mixture (precursor) and mixture heat treated at (b) 1450 ºC for 2 h; (c) 1450 ºC for 4 h; (d) 1600 ºC for 3 h; (e) 1600 ºC for 4 h; (f) amorphous \( \alpha \)-\( \text{Al}_2\text{O}_3 \) standard; (g) \( \alpha\)-\( \text{Al}_2\text{O}_3 \) standard; (h) AlN standard; (i) AlON powder standard; (j) AlON powder standard.
Note that a broad band with a maximum in the range 700–900 cm$^{-1}$ is characteristic of polycrystalline AlON [38, 39] (see Fig. 2 j). Thus, it can be assumed that the registered IR-spectra represent a superposition of spectra of different compounds, namely, Al$_2$O$_3$, AlN, and AlON.
To confirm the given speculation, a computer simulation of the superimposition spectra was performed. Superposition spectra were constructed for the following pairs of compounds: $\gamma$-$\text{Al}_2\text{O}_3$ and $\alpha$-$\text{Al}_2\text{O}_3$; $\alpha$-$\text{Al}_2\text{O}_3$ and AlN; $\gamma$-$\text{Al}_2\text{O}_3$ and AlN; AlON crystalline (powder) and AlN; AlN and AlON film; AlON’s crystalline and film; AlON’s crystalline and film and AlN; and composition from AlON’s crystalline and film, $\alpha$-$\text{Al}_2\text{O}_3$ and AlN (Fig. 3). For each pair, the ratio of components was gradually changed.

The superimposition IR spectra constructed for different contents of $\gamma$- and $\alpha$-$\text{Al}_2\text{O}_3$ (Fig. 3 a) illustrate the gradual narrowing of an absorption band of the $\gamma$-phase and the formation of an absorption band of the $\alpha$-phase. The $\gamma$-$\text{Al}_2\text{O}_3 \rightarrow \alpha$-$\text{Al}_2\text{O}_3$ transformation is typical for the temperature range 600–1400 °C [30] and is observed in spectra a, b, c in Fig. 2.

The model spectra of the systems $\alpha$-$\text{Al}_2\text{O}_3$ – AlN (see Fig. 3 b) show that the contribution of $\alpha$-$\text{Al}_2\text{O}_3$ phase can be assessed from the change in the intensity of the band at $\nu \approx 470$ cm$^{-1}$. This band is observed at a corundum content in the mixture up to 10%.

The superposition of the spectra of AlN with $\gamma$-$\text{Al}_2\text{O}_3$ (see Fig. 3 c) or AlION (see Fig. 3 d) is accompanied by the broadening of the absorption band of AlN as the contribution of $\gamma$-$\text{Al}_2\text{O}_3$ or AlION into the spectrum increases. Thus, the broadening of the experimental IR spectra at a temperature above 1600 °C (Fig. 2 d, e) can be attributed to the increase in the contribution of polycrystalline AlION into the spectrum of aluminum nitride and partially to the $\alpha$-$\text{Al}_2\text{O}_3 \rightarrow \gamma$-$\text{Al}_2\text{O}_3$ transformation (as can be seen in Fig. 3 a) in the process of development of carbothermal reduction of $\alpha$-$\text{Al}_2\text{O}_3$ in nitrogen medium.

Taking into account that the nucleation of AlION may begin from the formation of films on the surface of $\text{Al}_2\text{O}_3$ and AlN particles, an IR spectrum of AlN with a AlION film was simulated (Fig. 3 e). It was established that the superposition of a spectrum of AlN with a spectrum of an AlION film leads to the formation of a wide absorption band (or a shoulder) at $\nu \sim 570$ cm$^{-1}$ in the spectrum of aluminum nitride and to its subsequent broadening.
Since AlON may be present in the investigated powder in both the crystalline and amorphous state (in the form of films), the superposition of the IR spectra for these two states was performed. It is seen from Fig. 3f that, as the contribution of the polycrystalline component of AlON increases, the absorption band of AlON films transforms into a shoulder on the main broad band.

From comparison of the simulated and experimental spectra we can conclude that the experimental spectrum of the powder heat treated at 1600 °C for 3 h (see Fig. 2d) is close to the superposition spectrum marked in Fig. 3h by the symbol ●. It consists of predominantly the spectra of α-Al2O3 (~50%), AlN (~15%), crystalline AlON (~10.5%), and an AlON film (~24.5%). The experimental spectrum of the powder mixture heat treated at 1600 °C for 4 h (see Fig. 2e) is close to the superposition spectrum marked in Fig. 3g by the symbol ○. It consists of predominantly the spectra of an AlON film (~49%), crystalline AlON (~21%), and AlN (~30%).

Thus, the performed investigations showed that the powders synthesized at 1450 °C consist of predominantly AlN and Al2O3 particles and that the powders synthesized at 1600 °C consist of AlON, AlN, and Al2O3. A part of AlON is present in the form of amorphous films, and the other part is crystalline particles.

**Characterization of ceramics**

According to the XRD data, after sintering of the powders synthesized at 1450 and 1600 °C for 4 h, two basic phases, namely, Al2O3 and AlN, are observed in specimens (Fig. 1d). Moreover, after sintering of the powders synthesized at 1450 °C, in XRD patterns, graphite lines appear. After sintering of the powders synthesized at 1600 °C, only traces of graphite were observed.

![Fig. 4. Electron micrograph of the powder synthesized at 1600 °C for 4 h.](image)

In Fig. 5, a fine-grained ceramic material with a grain size ranging from 0.5 to 2 µm is shown. Pores are predominantly located on grain boundaries (see Fig. 5b).
The X-ray microanalysis results indicated that, at different places of specimens either Al and O or Al, O, and N were present (Tab. II). Moreover, in specimens made from the powder synthesized at 1450 °C, carbon was detected. In these specimens, the contents of Al and O at the places of their localization did not correspond to those in Al₂O₃. As a rule, excessive contents of Al were fixed. In turn, at the places of localization of Al, O, N, and C, it was rather difficult to determine the phase composition. The X-ray microanalysis showed the absence of places of localization of only Al and N. On the surfaces of specimens made from powders synthesized at 1600 °C, places of localization of N and C were not found. The presence of Al and O with an excessive Al content was predominantly registered (see Tab. II).
Tab. II. Contents of elements at different places of specimens

<table>
<thead>
<tr>
<th>Places of analysis</th>
<th>Contents of elements, wt.%</th>
<th>Phase composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Al</td>
<td>O</td>
</tr>
<tr>
<td>Ceramics from powder synthesized at 1450 ºC, ( t = 3 ) h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>53.2</td>
<td>47.0</td>
</tr>
<tr>
<td>2</td>
<td>65.35</td>
<td>34.65</td>
</tr>
<tr>
<td>3</td>
<td>61.93</td>
<td>38.07</td>
</tr>
<tr>
<td>4</td>
<td>54.38</td>
<td>38.07</td>
</tr>
<tr>
<td>5</td>
<td>38.21</td>
<td>40.86</td>
</tr>
<tr>
<td>6</td>
<td>44.95</td>
<td>35.87</td>
</tr>
<tr>
<td>Ceramics from powder synthesized at 1600 ºC, ( t = 3 ) h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>50.52</td>
<td>31.29</td>
</tr>
<tr>
<td>2</td>
<td>48.23</td>
<td>40.09</td>
</tr>
<tr>
<td>3</td>
<td>51.85</td>
<td>30.93</td>
</tr>
<tr>
<td>4</td>
<td>55.39</td>
<td>32.30</td>
</tr>
<tr>
<td>5</td>
<td>47.60</td>
<td>35.98</td>
</tr>
<tr>
<td>6</td>
<td>55.45</td>
<td>35.54</td>
</tr>
</tbody>
</table>

Mechanical properties of the ceramics

Specimens sintered from the powders synthesized at 1450 ºC had a hardness of 15.2 GPa. For specimens obtained from powders synthesized at 1600 ºC, the hardness increased to 19.5 GPa. This effect is attributed to the higher cohesion between grains generated by the diffusion process and the absence of substantial amounts of carbon in the structure [40].

The fracture toughness (\( K_{IC} \)) of the material was estimated by the formula [35-37]

\[
K_{IC} = 0.016 (E/H)^{0.5} \cdot P/c^{1.5},
\]

where \( E \) is the modulus of elasticity (GPa); \( H \) is the Vickers hardness (GPa); \( P \) is the applied load (N); \( c \) is the average length of a cracks measured from the corner of the indentation to the crack tip (mm). It was established that the fracture toughness was about 7.2 MPa·m\(^{1/2} \) for specimens sintered from the powders synthesized at 1450 ºC and about 6.1 MPa·m\(^{1/2} \) for specimens sintered from the powders synthesized at 1600 ºC.

Discussion

The general scheme of carbothermal reduction of alumina can be represented by the following reactions:

\[
\begin{align*}
\text{Al}_2\text{O}_3 + \text{C} &\xrightarrow{\text{T} \geq 1350 \ \degree \text{C}} \text{Al}_2\text{O} + \text{Al} + \text{CO} \\
\text{Al}_4\text{O}_4\text{C} &\xrightarrow{\text{T} \geq 1650 \ \degree \text{C}} \text{Al}_2\text{O}_3 \text{(solid), Al}_2\text{O}, \text{Al}, \alpha-\text{Al}_2\text{OC} \\
&\xrightarrow{\text{T} \geq 1700 \ \degree \text{C}} \text{Al}_2\text{O}, \text{Al}, \text{CO} \\
&\xrightarrow{\text{T} \leq 1700 \ \degree \text{C}} \text{Al}_4\text{C}_3, \text{Al}_4\text{O}_4\text{C}
\end{align*}
\]
It should be noted that, in the stage of synthesis of powders, the formation of crystalline phases such as aluminum oxycarbide ($\text{Al}_4\text{O}_4\text{C}$) and aluminum carbide ($\text{Al}_4\text{C}$) was not registered. However, the detection of graphite in sintered specimens of «low temperature powder» indicates that the dark color of the powder and sintered specimens are due to the presence of free carbon. Thus, we can state the chosen regime of carbothermal reduction is realized in the framework of formation of $\text{Al}_2\text{O}_3$ and $\text{Al}$ with retention of a certain amount of $\text{Al}_2\text{O}_3$ and $\text{C}$.

The formation of different reduction products in a nitrogen flow indicates the simultaneous realization of different mechanisms of nitride formation. For instance, the nitriding of $\text{Al}$ will result in the formation of $\text{AlN}$ (synthesis from elements), whereas $\text{Al}_2\text{O}_3$ may be the base for the formation of $\text{AION}$ particles.

The substitution of oxygen for nitrogen in the structure of $\text{Al}_2\text{O}_3$ and the substitution of nitrogen for oxygen in structure of $\text{AlN}$ (which is evidently due to the similar sizes of nitrogen and oxygen atoms) form the base of the formation of aluminium oxynitride of different composition on the surface of the corresponding particles [5]. The changes in the interplanar spacings of $\text{Al}_2\text{O}_3$ and $\text{AlN}$ (see Tab. I) is a consequence of the indicated process. Thus, besides single-phase crystalline $\text{AlN}$ and $\text{AION}$ particles, $\text{Al}_2\text{O}_3$ and $\text{AlN}$ particles with $\text{AION}$ surface films must form. This is why, in IR-spectra, which present information predominantly about the surface of a solid body, the spectrum of $\text{AION}$ films is registered. Some variants of formed particles with a complex defective structure are presented in Fig. 6.

![Fig. 6. Simplified models of the defective structure of formed particles.](image)

The formation of fine-grained structure of sintered specimens can be explained by the susceptibility to aggregation of highly disperse particles of the initial powder. The formation of the disperse granular structure can be explained by the features of the sintering process under high pressures, namely, the short time of action, the compression of the treated powder in the first stage of the process, and the retardation of diffusion processes at high hydrostatic pressures. Since the sintering temperature is higher than the synthesis temperature, the process of carbothermal reduction of $\text{Al}_2\text{O}_3$ and $\text{AION}$ films, accompanied by the evolution of $\text{CO}_2$ and pore formation, is initiated again. Taking into account the defective structure of $\text{Al}_2\text{O}_3$ and $\text{AlN}$ particles, it is possible to assume that, first of all, surface oxynitride and oxide layers of particles are reduced. Then, due to the joint action of high temperature and high pressure, crystalline aluminum oxynitride decomposes into aluminum oxide and aluminum nitride [44].
Thus, in the final sintered product, only Al$_2$O$_3$ and AlN are present (see Fig. 1 d).

The obtained composite ceramics exhibit rather high hardness and fracture toughness ($K_{1c}$), which are comparable with those for materials obtained on the base of refractory titanium compounds [45]. It is not improbable that these properties are provided by Al$_2$O$_3$, which exhibits excellent mechanical properties when its grains are in a certain state [46, 47]. The determined decrease in $d$ (Table 2) also indicates this. The specimens containing graphite, which were made of the powder synthesized at 1450 °C, have a lower hardness and higher fracture toughness than specimens obtained from the powder synthesized at 1600 °C. In other words, the graphite phase improves the fracture toughness (crack growth resistance) and decreases the hardness of the obtained ceramics. The grain size in ceramics from powder obtained at 1400 °C has 1,5-1,8 m, and 2,7-3,0 m from powder obtained at 1600 °C. The fairly high hardness of the ceramics is higher than the hardness of aluminum nitride and oxynitride and is comparable with or even higher than the hardness of aluminum oxides (their hardness ranges from ~15 to ~20 GPa), which is the hardest component of the material. Therefore, aluminum nitride and oxynitride phases exert the strengthening effect. The obtained fracture toughness, which depending on the synthesis conditions of the powder ranged from 6.1 to 7.2 MPa·m$^{1/2}$ is rather good for materials of this system. So, for ceramics of the AlON–Al$_2$O$_3$ system, obtained by pressureless sintering in the temperature range 1600–1900 °C had the fracture toughness of 2 to 4 MPa·m$^{1/2}$ depending on the aluminum oxide content and sintering temperature [48].

Conclusions

The processes of carbothermal reduction of γ-Al$_2$O$_3$ with carbon in a nitrogen flow at a temperature of 1450 °C for 4 h and at a temperature of 1600 °C for 4 h were not completed, due to which the products contained free carbon. The main phases of the synthesized composite powders were Al$_2$O$_3$, AlN, and AlON. On the surfaces of alumina and aluminum nitride particles, AlON films form.

In the process of preparation of ceramics by high-pressure sintering, the crystalline AlON phase formed in the powders decomposed completely into aluminum oxide and aluminum nitride, and the free carbon transformed into the crystalline graphite phase. A fracture toughness of 7.2 MPa·m$^{1/2}$ was obtained in the ceramics obtained from the powder synthesized at 1450 °C with the higher graphite content. The highest hardness of 19.5 GPa was achieved in the ceramics with the lowest graphite content obtained from the powder synthesized at 1600 °C.

References

Садржај: Проучен је процес карботермичке редукције Al_2O_3 у водонику на температурама од 1450 и 1600°C. Установљено је да је прах синтетисан на 1450°C смеша честица Al_2O_3 и AlN а прах синтетисан на 1600°C представља смешу AlN, AlON и Al_2O_3. Аморфни и кристални филмови AlON се формирају на површини честица Al_2O_3 и AlN. Оба синтетисана праха садрже нереаговани заостали угљеник. У фази синтеровања под високим притисцима на температури од 1750°C под притиском од 7 ГПа у трајању од 110 секунди, AlON се разлага на Al_2O_3 и AlN. Заостали графит се трансформише у кристалну графитну фазу која смањује чврстоћу и увећава отпорност на лом. Највећа тврдоћа од 19.5 GPa је добијена у керамици добијеној од праха синтетисаног на 1600°C у трајању од 4 сата, а највећа отпорност на лом од ~7.2 MPa·m^1/2 је добијена у керамици добијеној од праха синтетисаног на 1450°C у трајању од 4 сата.

Кључне речи: Al_2O_3–С, AlN, AlON, прах, синтеровање под високим притиском, керамика.