Low-Temperature Synthesis of Corundum Ceramics. Study of the Influ-Ence of Specially Introduced Nano-Additives on the Sintering Process

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Abstract - The present paper reports for the synthesis of fine-grained corundum ceramics by the method of diffusion dominated solid state sintering at temperature relatively low for corundum materials - 1300 °C, 1450 °C and 1500 °C, using specially introduced additives as follows: 3.0 wt. % TiO_2, graphene nanostructures - 2.0 wt. % GnP or 20.0 wt. % G3 and nanosized Al_2O_3. The initial powders and the ceramics synthesized from them were characterized mainly by the methods of Infrared spectroscopy (FT-IR), X-ray phase analysis (XRD), Scanning electron microscopy (SEM). The results obtained from the conducted research show that the introduction of special additives in a certain amount has an impact on the sintering temperature and recrystallization processes in ceramics. The X-ray phase analysis proved that the main crystalline phase in the ceramics synthesized from blends G1, A1 and C0 was corundum. The main functional groups present in the compositions of the ceramic samples synthesized were determined by FT-IR spectroscopy. Using SEM, it was proved that the introduced nano-additives initiated the formation of fine-grain and fine-pore structure with corundum grain sizes ranging from 0.2 to 2.0 μm. The decreased ceramics synthesis temperature, in this case, was mainly due to the additive TiO_2 (3.0 wt. %) included in the initial blends and the high dispersity of the initial materials. The specific additives introduced into the resulting ceramic (TiO_2, G3, GnP, nano-Al_2O_3) lead to a significant reduction in the synthesis temperature. The corundum-based samples containing additives were studied to determine the more important physical-mechanical properties, e.g. water absorption ($WA, \%$), apparent density ($\rho_{app}, g/cm^3$) and apparent porosity ($P_{app}, \%$). Given the characteristics of the synthesized corundum samples, they can be studied and applied as filtering elements and adsorbents in the purification of wastewater from various pollutants, such as dyes and some heavy metals.

Key-Words: corundum ceramics, solid state sintering, low temperature synthesis, fine-grained ceramics, nano-additives, graphene nanostructures.

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1 Introduction

Aluminum is the third most abundant element in the earth's crust, occurring mostly in a combined state with other elements [1]. Due to its high reactivity, it forms compounds with oxygen, silicon, fluorine, and others. Upon interaction with water at different temperatures, solid products such as Al_2O_3, AlO(OH) and $Al(OH)_3$ are formed, and upon combustion in air - Al_2O_3 [2].

Dialuminum trioxide (Al_2O_3) is fundamental for the production of a wide range of ceramic products. The suboxides Al_2O and AlO exist only in the gaseous state at both high and low oxygen partial pressures. Dialuminum trioxide has hardness (~25 GPa at 20 microindentation hardness), a high melting point (2054 °C), and a low electrical conductivity (~10-12 S/m at 20 °C) [3, 4]. Al_2O_3 exists in a variety of metastable polymorphic forms, which are distinct from the thermodynamically stable corundum form, α-Al_2O_3. They can be classified into two main categories based on the arrangement of oxygen anions: cubic close-packed and hexagonal close-packed. The different polymorphic forms arise as a result of the distribution of cations within

each subgroup. Among the cubic structures of Al_2O_3 are γ, η (cubic), θ (monoclinic) and δ (tetragonal or orthorhombic), while hexagonal structures include the α (trigonal), κ (orthorhombic) and χ (hexagonal) phases. In addition, new monoclinic phases are known and identified: θ', θ'' and λ [5-7]. The cubic and hexagonal arrangement of oxygen anions significantly influence the crystal chemistry and physicochemical properties of the metastable forms of Al_2O_3. Knowledge of their structural differences is essential for the effective application of the different polymorphic forms in technological and industrial processes, as well as for the optimization of their properties by controlling the synthesis conditions and thermal treatment.

Corundum ceramics are an important representative of technical ceramics and are known for their complex of valuable properties: exceptional physical and mechanical properties, excellent chemical resistance, electrical insulation properties, good bio ceramic material, etc., which leads to their versatile application.

Traditionally, the sintering of the corundum ceramics is carried out at comparatively high temperatures. A conventional solid-state synthesis is the most important method because it is simple, pure, and produces high-yield powder materials. This method is most applicable for scale manufacturing. Both the diffusion mechanism and the recrystallization process depend on the temperature and the duration of the sintering, corundum dispersity, the activity of the crystallochemical state of the material, the initial density of the raw material, the organic plasticizers used to obtain forming blends, the presence of impurities or specially introduced additives and the gas environment used during the sintering [8].

In the synthesis of ceramic and composite materials with specific properties, the nanotechnology plays a significant role in preparing the initial components in a finely dispersed state which intensifies the process of synthesis and leads to improved properties [9-11]. The addition of various monodispersed nanostructures to the initial raw components used for the synthesis of such materials might significantly reduce the synthesis temperatures (about 40 %) and ensures the homogeneity of the components and micro additives which, in turn, would guarantee the obtainment of products with desired chemical composition and improved or novel properties [12].

Given the above, the aim of the present work is to realize low-temperature synthesis of fine-grained corundum ceramics and to investigate the influence of specially introduced additives on the sintering process, on the microstructure and on some physical and mechanical properties of the resulting product.

2 Materials and Methods

2.1. Materials

Finely fine-grained corundum ceramic samples were obtained by solid state sintering at relatively low temperatures of 1300 °C, 1450 °C and 1500 °C due to the addition of 3.0 wt. % TiO_2 and different nano additives: graphene nanostructures in concentration of 2.0 wt. % or 20.0 wt. % and 4.0 wt. % nanosized Al_2O_3.

The solid-phase synthesis method, which involves heating the starting components in the solid phase, represents one of the simplest and most widely used approaches for preparing single- and polycrystalline materials [13]. It is an environmentally friendly method that produces thermodynamically stable products, which is the main advantage of this synthesis.

The initial materials, used for the synthesis of the ceramic samples, were highly dispersed Al_2O_3 powder (Sigma Aldrich, purity ≥ 99 %) and the following additives: two sources of graphene - G3 (graphene obtained using combination of chemical and physical (ultrasonic) treatment of the original graphite precursor (purity ≥ 99 %) [6] and GnP (graphene nanoplatelets (Sigma Aldrich), as well as nanosized Al_2O_3 (Sigma-Aldrich, nanopowder <50 nm particles size (TEM)). During the preparation of the blends, 3.0 wt. % TiO_2 (Sigma Aldrich, purity > 99 %) were introduced as additive strongly reducing sintering temperature. Table 1 and Figure 1 presents some of the initial charge compositions for the synthesis of corundum specimens - A1, C0 and G1. The percentages of additives incorporated into the initial formulations are calculated based on the total mass of the mixture.

Table 1. Working charge compositions for the synthesis of corundum specimens

№ Composition	Raw materials, [wt. %]					Firing temperature of the samples, [°C]
	Al_2O_3	Nanoscale Al_2O_3	G3	GnP	TiO_2	
A1	77	-	20	-	3	1450
C0	95	-	-	2	3	1500
G1	91	4	-	2	3	1300

Source: created by the authors.

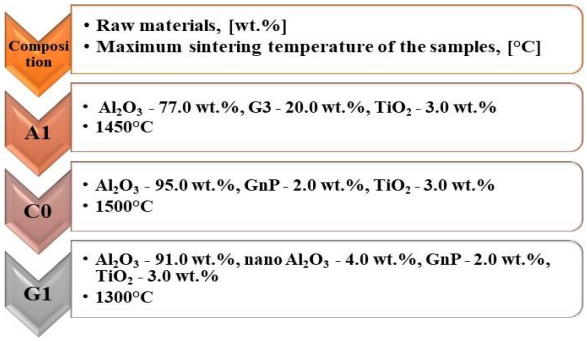


Fig. 1. Working compositions of blends used for synthesis of corundum samples
Source: created by the authors.

Since Al_2O_3 is non-plastic, the preparation of pressing powders, extrusion masses, and hot-casting slips requires the addition of temporary organic binders. Plasticizing materials used in the production of corundum products via semi-dry pressing include polyvinyl alcohol, glycerin, polyethylene oxide, polyacrylamide, and other water-soluble polymers. The quantity and concentration of these temporary processing binders vary, requiring adjustments based on practical experience with specific products and forming methods. Isostatic forming of non-plastic materials, such as corundum ceramics, is effective due to the low moisture or binder content and the achievement of uniform density and a homogeneous structure [8].

The stages of preparation of the ceramic masses and the production of the corundum-based ceramic samples are schematically presented in Figure 2. The preparation of the corundum masses and ceramics in the case under consideration proceeds as follows: the finely dispersed raw materials are weighed and dry-homogenized. Polyvinyl alcohol (4.0 %) is added to the prepared powders as a plasticizer, and the samples are formed via a semi-dry process using a hydraulic press at a pressure of 40 MPa. The drying schedule for the specimens is: 120°C for 70 min and 180°C for 50 min. The firing schedule involves isothermal holds at the following temperatures: 200°C (20 min), 300°C (20 min), 400°C (20 min), 500°C (30 min), 800°C (30 min), 1100°C (30 min), and 1300°C (30 min), followed by a one-hour isothermal hold at the maximum temperatures of 1300°C, 1450°C, and 1500°C, respectively. After the hold period, the furnace is turned off, and the specimens are allowed to cool freely. The objective is to achieve maximum densification based on solid-state sintering of a diffusional nature.

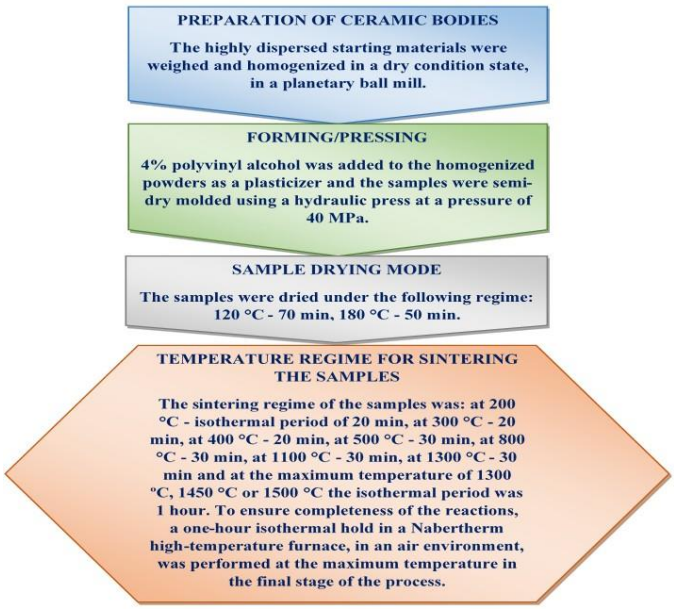


Fig. 2: Scheme of preparation of corundum ceramic samples with added nanostructures
Source: created by the authors.

2.2 Methods

To characterize the synthesized corundum ceramics with added nanostructures, the methods of X-ray structural analysis, Fourier transform infrared spectroscopy and scanning electron microscopy were mainly used.

Fourier Transform Infrared Spectroscopy. The FT-IR studies were carried out on an infrared spectrophotometer Tensor 27 Fourier FT-IR (Bruker, Germany) in the interval 400-4000 cm^{-1} at resolution of 1 cm^{-1}. The measurements were performed at room temperature. The sample (0.3 mg) was pressed into KBr pellet (100 mg) at pressure of 2-4 atm.

X-ray Structural Analysis. The X-ray powder diffraction pattern was taken with an automated computer-controlled X-ray diffraction system D500 Siemens (Germany) under the following regime: 40 kV, 30 mA, monochromatic copper radiation.

Scanning Electron Microscopy. The SEM analyses of the ceramic materials obtained from initial blends G1 and C0 were carried out on a scanning electron microscope Tabletop SEM HIROX SH-4000M, 30x - 60000x, SE&BSE detector, voltage 5 kV - 30 kV, resolution 15 nm. The samples were preliminarily coated with gold for the analysis. The SEM analysis of the ceramic samples obtained from blend A1 was carried out on a scanning electron microscope JEOL - JSM 6390 with EDS analyzer INCA (product of Oxford

instruments) at accelerating voltage of 20kV. The preliminary coating with gold was carried out using the device JEOL JSF - 1200 for 40 seconds.

3 Results and Discussion

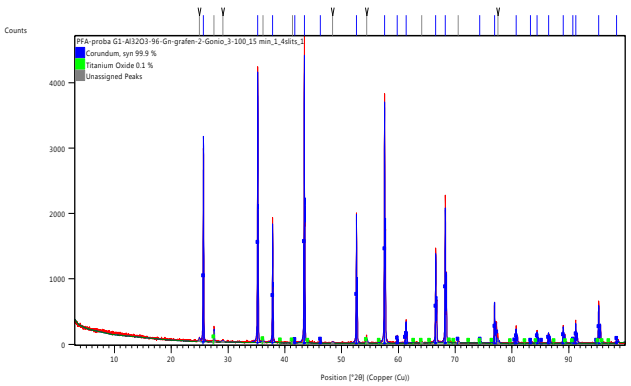
As a result of the conducted research, by the method of diffusion solid-state sintering at relatively low temperatures for corundum materials - 1300 °C, 1450 °C and 1500 °C, fine-grained and porous corundum ceramic samples were obtained. This was achieved thanks to the introduction of special additives into the ceramic masses: 3.0 wt. % TiO_2, graphene nanostructures - 2.0 wt. % GnP or 20.0 wt. % G3 and nanosized Al_2O_3.

The initial powders and the ceramics, obtained from them, were studied basically by Fourier Transform Infrared Spectroscopy (FT-IR), X-ray Structural Analysis (XRD) and Scanning Electron Microscopy (SEM).

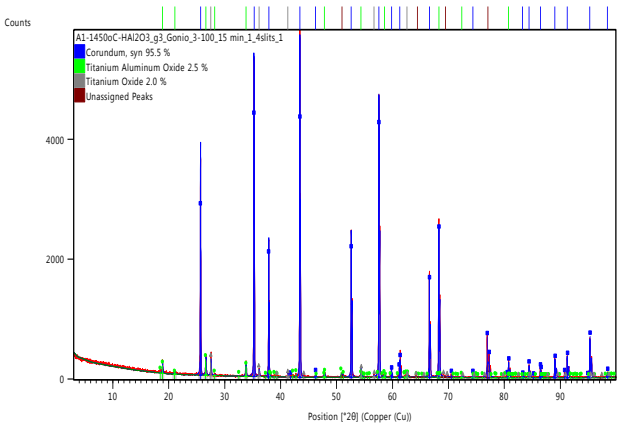
X-ray structural analysis was performed under the following conditions: Configuration=Reflection-Transmission Spinner 3.0, Goniometer=Theta/Theta; Minimum step size 2Theta:0.0001; Minimum step size Omega:0.0001; Sample stage=Reflection-transmission spinner 3.0; Minimum step size Phi:0.1; Diffractometer system=EMPYREAN; Measurement program=C:\XRD Data\Program\General User\Gonio_3-100_15 min_1_4slits.xrdmp, Identifier={CFCB579C-8E48-4157-989C-EE1FDF74539E}; Fine Calibration Offset for 2Theta = 0.0132 deg; PHD Lower Level = 4.02 (keV), PHD Upper Level = 11.26 (keV); Raw Data Origin XRD measurement (*.XRDML); Scan Axis Gonio; Start Position [°2θ] 3.0066; End Position [°2θ] 99.9996; Step Size [°2θ] 0.0130; Scan Step Time [s] 29.0700; Scan Type Continuous; PSD Mode Scanning; PSD Length [°2θ] 3.35; Offset [°2θ] 0.0000; Divergence Slit Type Fixed; Divergence Slit Size [°] 0.2500; Specimen Length [mm] 10.00; Measurement Temperature [°C] 25.00; Anode Material Cu; K-Alpha1 [Å] 1.54060; K-Alpha2 [Å] 1.54443; K-Beta [Å] 1.39225; K-A2/K-A1; Ratio 0.50000; Generator Settings 30 mA, 40 kV; Diffractometer Type 0000000011238959; Diffractometer Number 0; Goniometer Radius [mm] 240.00; Dist. Focus-Diverg. Slit [mm] 144.50; Incident Beam Monochromator No; Spinning Yes.

The X-ray Structural Analysis proved that the main crystalline phases in the ceramics, synthesized from blends G1, A1 and C0, were three: Al_2O_3, Al_2TiO_5 and TiO_2 (Figure 3), with corundum as the main phase.

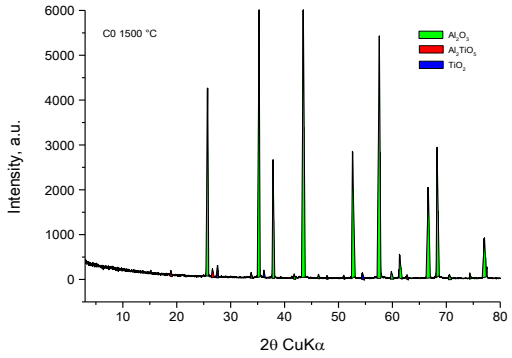
The quantitative content of the corundum phase in sample A1 (Figure 3B) amounts to 95.5%. Concurrently, peaks corresponding to titanium-aluminum oxide (aluminum titanate, Al_2TiO_5 - 2.5%) and residual titanium oxide (rutile - 2.0%) are detected. The presence of these secondary phases confirms that solid-state reactions occurred at the interface between the corundum matrix and titanium dioxide, catalyzed by the carbon environment. The α-Al_2O_3 peaks remain dominant and intense, demonstrating that the carbon phase does not inhibit the fundamental crystallization of corundum. A distinct, relatively broad diffraction maximum is observed in the X-ray pattern at $2\theta \approx 26.4°$. This peak corresponds to the (002) crystal plane of the graphene/graphite structure and serves as direct experimental evidence of the successful retention and "encapsulation" of the nanostructures within the ceramic bulk following high-temperature synthesis.



A) XRD pattern of sample with composition G1 - 1300 ºC



B) XRD pattern of sample with composition A1 - 1450 °C



C) X-ray diffraction pattern of sample with composition C0 - 1500 °C
Fig. 3: Results of X-ray Structural Analysis of ceramic samples containing additives
Source: created by the authors.

X-ray phase analysis of sample C0 (Figure 3C), heat-treated at 1500 °C, reveals that the primary crystalline phase in the material is α-Al_2O_3. Al_2TiO_5 and TiO_2 phases are also detected, indicating the formation of a multiphase ceramic system. The presence of Al_2TiO_5 can be attributed to the interaction between Al_2O_3 and TiO_2 during high-temperature processing, while the detection of TiO_2 suggests that the titanium-bearing phase was not fully converted into the Al_2TiO_5 compound. The predominance of the corundum phase indicates that it retains its fundamental structural role in the material under investigation.

The X-ray diffraction pattern of sample G1 (Figure 3A) is characterized by distinct diffraction peaks, based on the phase identification presented, the primary crystalline phase identified is corundum (Al_2O_3). The legend also indicates the presence of a minor amount of titanium oxide, as well as unidentified diffraction peaks. The resulting diffraction pattern shows a predominance of the corundum phase, but the presence of additional peaks prevents the unambiguous assignment of all reflections to the identified phases.

The introduction of certain type and quantity of additives can affect the sintering temperature and the recrystallization. Among the additives reducing the sintering temperature, the most significant effect was observed with TiO_2.

Technical corundum ceramics undergo pure solid-state sintering via a diffusion mechanism. In such cases, the diffusion coefficient can be influenced by altering the concentration of defects in the crystal lattice. α-Al_2O_3 with a purity of 99.0-99.5% and a particle size of 1-2 μm, without the addition of sintering aids, can achieve a density of 3.75-3.85 g/cm³ after firing at 1700-1750°C. Further increases in temperature or the duration of the isothermal hold do not improve sintering. The porosity of the fired corundum ceramics is predominantly closed and intracrystalline, with spherical pores, this can be attributed to recrystallization. The incorporation of specific types and quantities of additives can influence sintering temperature and recrystallization. In the production of corundum ceramics, the additives used can be categorized into several types based on their effects. Additives that significantly lower the sintering temperature include TiO_2, MnO_2, Fe_2O_3, Nb_2O_5, CeO_2, and others. This effect is most pronounced when TiO_2 is used. The influence of this additive is attributed to the formation of solid solutions, which reduce the firing temperature by 100 - 200°C [8].

In this particular case, the lower temperature of synthesis was due mainly to the introduction of TiO_2 (3.0 wt. %) added to the initial blend and the high dispersity of the initial materials. The influence of the added TiO_2 is explained by the formation of solid solution with corundum, thus creating defects in its lattice and reducing the sintering temperature which finally facilitates the ceramic sintering at lower temperatures. Most probably, the addition of TiO_2 and graphene nanostructures to the samples eases and accelerates the processes of ceramics recrystallization. On the other hand, the increased fineness of the corundum grains results in increased total surface energy and contact area, expanding the defected structure and creating more favorable conditions for solid-state sintering. The strongest influence of corundum material dispersity was observed for samples with composition G1 synthesized at 1300 °C where nanosized Al_2O_3 was introduced.

The initial blends and the sintered ceramic samples were also studied by Fourier Transform Infrared Spectroscopy. The results obtained from the sintered corundum samples are presented in Figure 4.

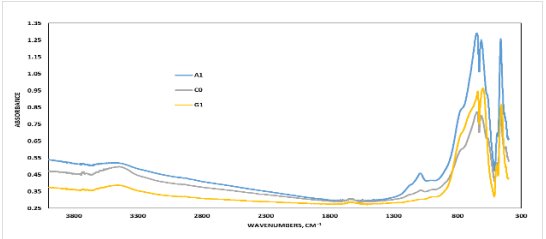


Fig. 4: FT-IR spectra of sintered ceramic samples with specially introduced additives: blends G1, A1 and C0
Source: created by the authors.

The absorption bands observed at ~3450.98 cm^{-1}, ~3448.42 cm^{-1} and ~3447.07 cm^{-1} were attributed to the C-H bond. The vibrations at ~1651.37 cm^{-1}, ~1637.12 cm^{-1} and ~1631.49 cm^{-1} can be assigned to the C=C bond which means that, after the sintering at the highest temperatures, part of the carbon structures is preserved and remain in the corundum ceramics while another part burns out potentially imparting certain porosity to the obtained ceramics. The peaks appearing at ~1070.71 cm^{-1} and ~1058.09 cm^{-1} are characteristic for the vibrations of the C-O bond. The resulting spectra, obtained from the FT-IR analysis, contained large peaks in the frequency range from ~500 cm^{-1} to ~900 cm^{-1}. They are characteristic for vibrations of the Al-O bonds in Al_2O_3. Major part of the absorption bands registered from the sintered ceramic samples were attributed to the vibrations of the Al-O bonds in the high-temperature α-modification of Al_2O_3 (corundum). The absorptions at ~460.08 cm^{-1}, ~456.04 cm^{-1}, ~452.42 cm^{-1} and ~450 cm^{-1} are characteristic for the vibrations of the Ti-O bond. The existence of these phases was also proved by the X-ray analysis.

The SEM analysis of the obtained ceramic samples indicated or fine-grain fine-pore microstructure with corundum grain sizes ranging from 0.2 to 3.0 μm (Figure 5). The SEM images of ceramics containing 2.0 wt. % graphene nanoplatelets GnP showed that the surface of the latter was more homogeneous and with finer grains. Their structure was more uniform compared to the compositions containing 20.0 wt. % graphene G3. Besides, their porosity was finer and more uniformly distributed throughout the whole volume.

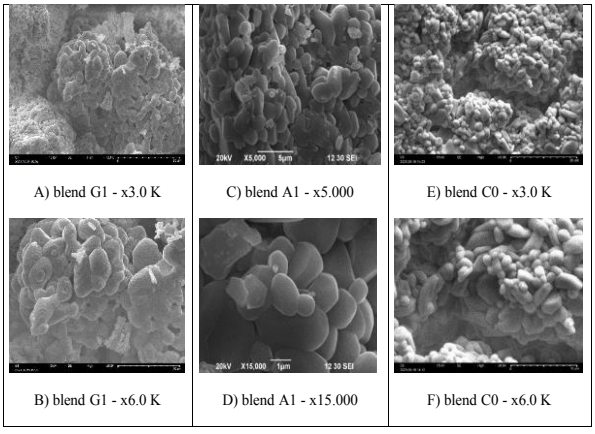


Fig. 5: SEM microphotographs of corundum ceramic samples synthesized at:
Source: created by the authors.
A), B) - 1300 ºC, additives: graphene nanoplatelets GnP, nanosized Al_2O_3, TiO_2;
C), D) - 1450 ºC, additives: graphene G3 and TiO_2;
E), F) - 1500 ºC, additives: graphene nanoplatelets GnP, TiO_2

Some more important physical-mechanical properties of some corundum-based samples containing additives were determined, e.g.: water absorption ($WA, \%$), apparent density ($\rho_{app}, g/cm^3$) and apparent porosity ($P_{app}, \%$). The results obtained for the samples prepared from blends A1 and C0 are presented in Table 2.

Corundum ceramics can be prepared by a technique allowing the achievement of density close to the theoretical one in order to obtain transparent material.

Table 2. Physicochemical properties of the synthesized ceramic samples

№/Blend	$WA, \%$,	$\rho_{app}, [\frac{g}{cm^3}]$	$P_{app}, \%$.
A1	15.52	2.93	45.47
C0	8.43	3.37	28.41

Source: created by the authors.

Under different conditions, however, its porosity can reach up to 90 %. The apparent density is the ratio between the mass of the material and the volume it occupies including the pores $\rho_{app} = \frac{m}{V}, \frac{kg}{m^3}, \frac{g}{m^3}$. The volume of the pores is usually determined by hydrostatic weighing of water-soaked samples. The apparent density of the samples synthesized (blends A1 and C0) was calculated by the expression:

$$\rho_{app} = \frac{m_0.\rho_l}{V} = \frac{m_0.\rho_l}{m_1 - m_2}, \frac{kg}{m^3} \qquad (1)$$

where: m_0 - mass of the dry sample, kg; m_1 - mass of the water-soaked sample, kg; m_2 - mass of the water-soaked sample weighed under water, kg; V - sample volume, m^3; ρ_l - density of the used liquid, kg/m^3.

The apparent porosity is the ratio between the volume of the open pores to the volume of the material including all the pores which it does contain, in %. The apparent porosity is determined by the expression: $P_{app} = WA.\rho_{app}, \%$) and the water absorption - $WA = (m_1 - m_0).\frac{100}{m_0}$, where - m_0 is the mass of the dry material, g; m_1 - mass of material saturated with water at high temperature, g [8].

The results, presented in Table 2, indicate that when 2.0 wt. % minimum amount of graphene nanoplatelets GnP were introduced in the initial blends and the samples prepared from the blend are sintered at the maximum temperature of 1500°C,

the ceramic samples showed higher density, lower water absorbance and apparent porosity compared to the samples prepared by the same method but with 20.0 wt.
% graphene nanostructures (G3) introduced in the initial blend and sintered at 1450 °C.

The density of the samples obtained from blend G1 was determined by the pycnometric method - the sample subjected to density measurement must be finely ground, and the measurement is reduced to finding the volume of the sample according to the liquid it displaced in the pycnometer. The real density of the corundum samples made from blend G1 and sintered at 1300 ºC was calculated by the expression shown blow and it was ρ = 3.798 g/cm^3:

$$\rho = \frac{m}{m - m_1 + m_2} . \rho_l, \frac{kg}{m^3} \left(\frac{g}{cm^3} \right), \qquad (2)$$

m - mass of the sample, g;

m_1- mass of the pycnometer together with the sample and the liquid, g;

m_2- mass of the pycnometer with the liquid, g;

ρ_l - density of the liquid used at 20ºC.

4 Conclusion

Finely fine-grained and porous corundum ceramics were obtained by the method of diffusion type solid state sintering at temperature relatively low for corundum-based materials - 1300 °C, 1450 °C and 1500 °C, due to the introduction of special additives, namely: 3.0 wt. % TiO_2, 2.0 wt. % graphene nanostructures GnP or 20.0 wt. % G3 and nanosized Al_2O_3. The characterization of the initial powders and the ceramics obtained from them was carried out using mainly the methods of Fourier Transform Infrared Spectroscopy (FT-IR), X-ray Structural Analysis (XRD) and Scanning Electron Microscopy (SEM). The XRD study showed that the main crystalline phases in the ceramics synthesized from blends G1, A1 and C0 were Al_2O_3, Al_2TiO_5 and TiO_2, with corundum as a predominant phase. The IR spectra revealed the main functional groups present in the composition of the synthesized ceramic samples while the SEM observations showed their morphology and structure. The results obtained from the studies carried out showed that an introduction of certain type and quantity of additives affects the sintering temperature the recrystallization processes. In this case, the lower sintering temperature was due to the addition of TiO_2 (3.0 wt. %) and to the high dispersity of the initial materials. The dispersity of corundum had the greatest effect for the samples with composition G1 synthesized at 1300 °C which also contained nanosized Al_2O_3. The TiO_2 added to all samples forms a solid solution with corundum, facilitating the appearance of lattice defects and enabling easier ceramics sintering at lower temperatures. Besides, the introduction of TiO_2 and graphene nanostructures in the blends initiates acceleration of the processes of ceramics recrystallization.

Overall, the additives - specifically TiO_2, G3, GnP, and nano-Al_2O_3 - incorporated into the ceramics we produced and sintered at 1300 °C, 1450 °C and 1500 °C, lead to a significant reduction in the synthesis temperature. The SEM observations proved that the nano-additives initiated the formation of fine-grain fine-pore structure with corundum grain sizes ranging from 0.2 to 2.0 μm.

Some important physical-mechanical properties of the corundum-based samples containing the above-mentioned additives were determined: water absorption ($WA, \%$), apparent density ($\rho_{app}, g/cm^3$) and apparent porosity ($P_{app}, \%$). It was found that the introduction of minimal amount of graphene nanostructures (2.0 wt. %) followed by sintering at maximum temperature gave the ceramic samples sufficient density (3.37 g/cm^3), certain water absorbance (8.43 %) and significant apparent porosity (28.41 %). The density of the samples with composition G1 was determined by the pycnometric method. The obtained value ρ = 3.798 g/cm^3 is comparable to the theoretical one for the corundum ceramics. This is most likely a result of the introduction of nanosized Al_2O_3 into the starting batches, which further increased the dispersity of the ceramic masses.

We can conclude that with the introduction of nano-additives, the total surface energy and the contact area between corundum grains increases and the defect structure expands. This helps and facilitates the maximum densification of the material during solid-state sintering and produces a material with good physical and mechanical properties.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) utilized artificial intelligence (AI) technologies solely for the purpose of linguistic refinement and grammatical correction. Following the application of these tools, the author(s) comprehensively reviewed, verified, and edited the resulting text. The author(s) maintain full accountability and responsibility for the accuracy, integrity, and final content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Adriana Georgieva, Krasi Panayotova, Fila Yovkova and Miroslava Valchanova, carried out the experimental work on the synthesis of the series of corundum ceramic simples;
- Adriana Georgieva is responsible for the analysis, discussion and interpretation of the obtained results;
- Fila Yovkova performed some of the analyses of the obtained ceramics;
- Krasi Panayotova participated in the design of the figures.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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