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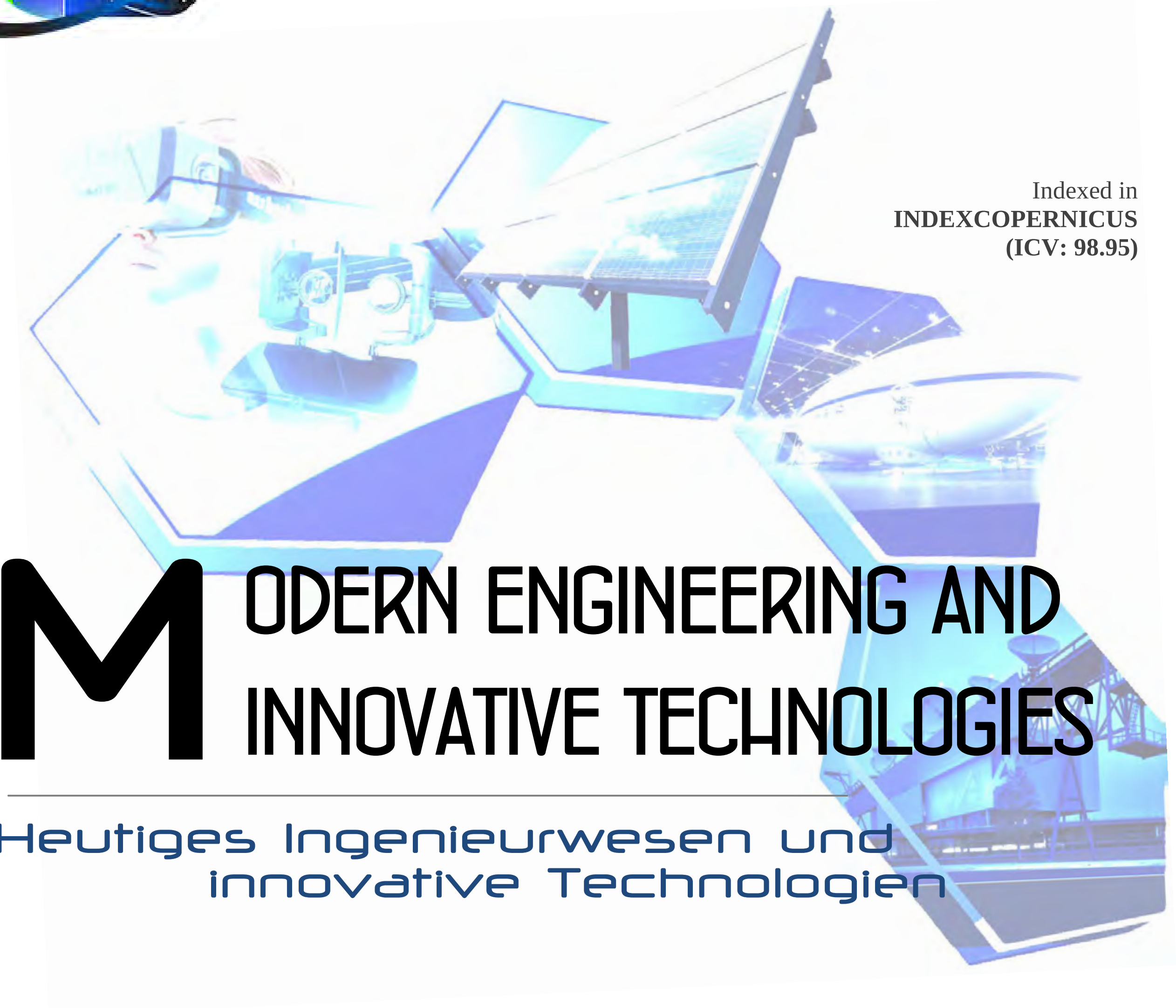

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Periodicity of publication: Quarterly

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Broadcasting young researchers and scholars outcomes to wide scientific audience

Fostering knowledge exchange in scientific community

Promotion of the unification in scientific approach

Creation of basis for innovation and new scientific approaches as well as discoveries in unknown domains

The journal purposefully acquaints the reader with the original research of authors in various fields of science, the best examples of scientific journalism.

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Articles should correspond to the thematic profile of the journal, meet international standards of scientific publications and be formalized in accordance with established rules. They should also be a presentation of the results of the original author's scientific research, be inscribed in the context of domestic and foreign research on this topic, reflect the author's ability to freely navigate in the existing bibliographic context on the problems involved and adequately apply the generally accepted methodology of setting and solving scientific problems.

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All tables and figures in the article should be numbered, have headings and links in the text. If the data is borrowed from another source, a bibliographic reference should be given to it in the form of a note.

The title of the article, the full names of authors, educational institutions (except the main text language) should be presented in English.

Articles should be accompanied by an annotation and key words in the language of the main text and must be in English. The abstract should be made in the form of a short text that reveals the purpose and objectives of the work, its structure and main findings. The abstract is an independent analytical text and should give an adequate idea of the research conducted without the need to refer to the article. Abstract in English (Abstract) should be written in a competent academic language.

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The editors of the journal are aware of the fact that in the academic community there are quite widespread cases of violation of the ethics of the publication of scientific research. As the most notable and egregious, one can single out plagiarism, the posting of previously published materials, the misappropriation of the results of foreign scientific research, and falsification of data. We oppose such practices.

The editors are convinced that violations of copyrights and moral norms are not only ethically unacceptable, but also serve as a barrier to the development of scientific knowledge. Therefore, we believe that the fight against these phenomena should become the goal and the result of joint efforts of our authors, editors, reviewers, readers and the entire academic community. We encourage all stakeholders to cooperate and participate in the exchange of information in order to combat the violation of the ethics of publication of scientific research.

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CUTTING COMPOSITE MATERIAL BASED ON NANOPOWDERS OF ALUMINUM OXIDE AND TUNGSTEN MONOCARBIDE

РЕЖУЩИЙ КОМПОЗИЦИОННЫЙ МАТЕРИАЛ НА ОСНОВЕ НАНОПОРОШКОВ ОКСИДА АЛЮМИНИЯ И МОНОКАРБИДА ВОЛЬФРАМА

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Abstract. *The articale investigated properties cutting tool material of ultrapowders Al_2O_3 - 50 wt. % WC which have got hot pressing method and the study of their properties. To obtain cutting inserts based on aluminum oxide and tungsten monocarbide with high functional capabilities, the phase components of the initial powders are selected and their homogenized during mixing, hot pressing with the selection of optimal sintering modes with the direct passage of a high-ampere current through a graphite mold. The sintering regime has a great influence on the final properties of the ceramic material. The optimum sintering temperature of ceramics depends on the dispersion of the original powder, the presence of impurities, additives and the duration of heating. It was found that in order to reduce fragility and obtain tool ceramics with high reliability, it is sometimes necessary to exclude even the smallest porosity caused by the ingress of dust from the air.*

Key words: *composite material, tool ceramics, alumina, tungsten monocarbide, sintering temperature, hot pressing.*

Introduction.

Numerous tool ceramics are based on aluminum oxide. Along with the advantages (high hardness, especially at elevated temperatures, chemical inertness and, accordingly, high wear resistance, unlimited raw materials), oxide ceramics has a number of disadvantages: high fragility, low resistance to thermal and mechanical shock. Despite this, materials based on aluminum oxide have found application as cutting tools for machining high-hardness metal alloys and other difficult-to-machine materials [1, 2].

The use of hot pressing in the preparation of oxide ceramics makes it possible to reduce the sintering temperature and obtain a material with a density close to the theoretical one. So from alumina of various grades without additives and with the addition of 0.2…0.4 % MgO at a pressure of 50 MPa and temperatures of 1,600…1,700 °C, samples with a density of 98.5…99.5 % can be obtained. Such density during conventional sintering is achieved only at a temperature of 1,800…1,900 °C [3, 4].

Sintering of alumina is a fairly radiated process. It occurs under the influence of the following mass transfer mechanisms: viscous flow, plastic deformation, evaporation-condensation, volumetric, grain-boundary and surface diffusion. In hot pressing, the main mechanisms of ceramic compaction at the final stage are plastic deformation and diffusion [5, 6].

The sintering regime has a great influence on the final properties of the ceramic. The optimum sintering temperature for ceramics depends on the dispersion of the initial powder, the presence of impurities, additives and the duration of heating. So, with a powder grain size of 0.5 …1.0 µm, the oxide ceramic plates are sintered at 1,710 °C for 5…10 minutes. With an increase in temperature 1,780…1,820 °C, exposure can be reduced to 1…2 minutes. It has been established that short exposures at high temperatures are optimal [7, 8].

The work continues the research carried out by the authors in previous years, and is based on the results and scientific heritage, partially published in the works [9–12].

Main text.

The structure of tool ceramics has the following properties: high material density, strength of interphase and grain boundaries, high dispersion and uniformity of distribution of structural components, minimum size of defects that can serve as a source of destruction, absence of low-melting components that reduce high-temperature strength, high hardness and resistance to crack propagation. The mechanical characteristics of oxide ceramics are directly related to the average grain size in the material. The introduction of 15…30 % carbides (TiC, WC, Cr_2C_3, Mo_2C) into aluminum oxide makes it possible to increase the mechanical characteristics due to even greater refinement of the structure [13, 14]. Titanium carbide is the most commonly used tool in the industry.

The data of a comparative study of the kinetics of growth of alumina grains with MgO (0.6 %) and TiC (30 %) additives showed that the introduction of both additives reduces grain growth during hot pressing [15]. Ceramic material is characterized by covalent or ionic bonds; it is difficult to deform due to strong mutual bonds between atoms [16]. When a stress is applied above the ultimate strength, brittle fracture occurs in ceramics with almost no deformation. According to Griffiths theory, the fracture strength of brittle materials is expressed by the equation:

$$\sigma_f = \frac{K_{Ic}}{\sqrt{\pi \cdot C}}, \qquad (1)$$

where K_{Ic} is the fracture toughness; C is the material damage value.

To reduce the brittleness of materials (that is, to increase their strength), it is necessary either to increase K_{Ic}, or to decrease C. In this case $K_{Ic} = \sqrt{2 \cdot E \cdot \gamma}$ (E is Young's modulus, γ is the destruction energy). Therefore, K_{Ic} can be increased by increasing Young's modulus, obtaining a sintered material with a fine texture close to the theoretical density, or by increasing γ, controlling the structure and firing conditions, increasing the uniformity of the structure.

To ensure the reliability of ceramic materials, it is necessary to reduce the scatter of product quality indicators [17, 18]. In particular, for ceramics used as an engineering material, the reliability is increased by reducing the spread of strength. This spread is also closely related to the presence of pores and cracks in the material. Therefore, in order to reduce fragility and obtain machine-building ceramics with high reliability, it is sometimes necessary to eliminate even the smallest porosity caused by the ingress of dust from the air, which was not paid attention to in the manufacture of ceramics by traditional methods. In the production of machine-building ceramics, even if using the same with traditional molding and sintering processes, on the basis of a strictly controlled production process, the formation of cracks and residual stresses arising from the formation of tiny pores due to the mixing of foreign bodies (plasticizing additives) during molding and shrinkage should be avoided during drying and firing. At the same time, the number of dislocations remaining in the fired products should be minimized, ensuring their more uniform distribution. From this point of view, the method of hot pressing by direct current transmission is of considerable interest, since molding proceeds without the use of any plasticizing additives and with a minimum temperature gradient over the section of the graphite mold.

The design of presses for hot pressing is determined by the method of heating and applying pressure, pressing temperatures, the need to use a protective gas environment or vacuum, and a number of other factors [19, 20].

For the manufacture of plates, powders of aluminum oxide Al_2O_3 with a dispersion of 0.06 μm and tungsten monocarbide with a dispersion of 0.07 μm, obtained by the plasma-chemical method, were used. Micrographs of powders are shown in Fig. 1 and Fig. 2.

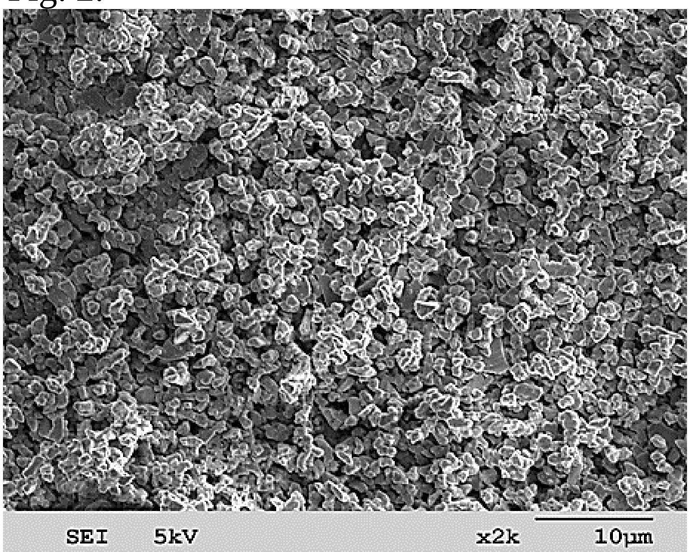

Fig. 1. Aluminum oxide nanopowder

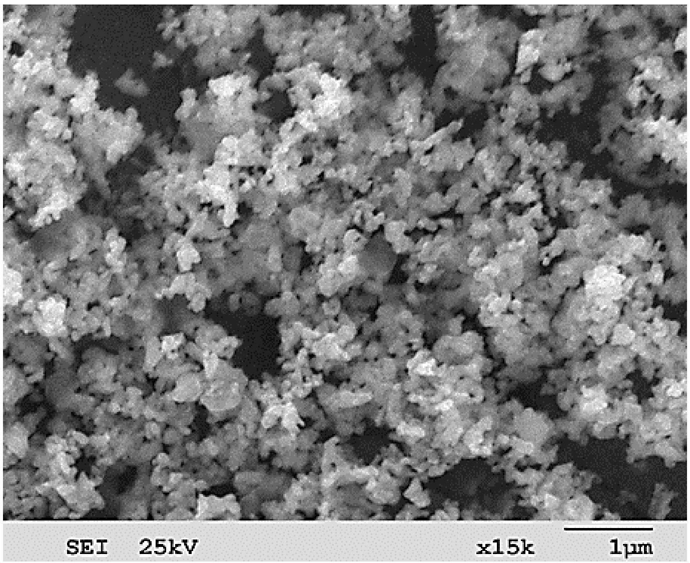

Fig. 2. Tungsten monocarbide nanopowder

The density of the samples was determined by the method of hydrostatic weighing in water. Structural studies were carried out by scanning electron microscopy (JSM-840) on fractures of hot-pressed samples, thin sections, as well as initial powders.

To study the physical and mechanical properties, samples and thin sections were prepared from the central part of the sample. To measure *HRA*, a diamond pyramid was pressed in on a TM-12 hardness tester. The ultimate bending strength is determined by the three-point bending method on the MP-1-0.5 mechanism.

In cemented carbide technology, ISO sintered carbide grades for cutting tools, mining equipment and wear parts are listed in ascending / descending order of hardness / toughness. Toughness is generally determined by transverse fracture toughness and is commonly used to characterize sintered carbide alloys. In the industry, the terms "toughness" and "strength" are often used instead of one another as a measure of a material's resistance to mechanical shock. While shear fracture resistance determines the fracture resistance under three-point bending loading, toughness has been separated from this property because it is a measure of the energy absorbed before fracture.

The principles of fracture mechanics have been used to determine fracture toughness parameters such as K_{Ic} and G_{Ic}, which give an indication of the resistance of a material to fracture in the presence of a sharp notch.

Palmquist indentation cracking tests have been used to describe the toughness of sintered carbide alloys. These tests give a measure of the resistance to indentation cracking of a brittle material along the length of the cracks (L_c) arising from the indentation from the indenter under the applied load P. The total length of surface cracks originating from the indentation angles is:

$$L_c = \alpha \cdot P. \tag{2}$$

The Palmquist fracture toughness parameter of fracture toughness is:

$$W = \frac{1}{\alpha}, \tag{3}$$

where α is a constant (the slope of the graph of the dependence of L_c on P).

Such tests have a number of advantages over conventional shear fracture tests: firstly, there is no need for specially shaped specimens, and secondly, the number of prototypes required for such tests is much less than required for conventional three-point bending tests, and thirdly, during these tests, the hardness is automatically determined.

Tool life during cutting (in minutes) on ШХ15 steel (HRC-58-60) was determined under the following conditions: cutting speed 400 m/min, feed 0.1 mm/rev, cutting depth 0.3 mm.

From the prepared powders, billets with a diameter of 20 mm and a weight of 9 g were pre-tableted. For hot pressing, an МПГ-7 graphite with a maximum pressure of 50 MPa at temperatures above 1,200 °C was used as a mold. At this pressure, the temperature of the beginning and end of shrinkage was determined, which was determined by a displacement and acoustic emission sensor. The beginning of deformation is about 900 °C, and the end of shrinkage is 1,600…1,630 °C. Therefore, the temperature was limited to 1,650 °C. Table 1 presents data on the hot pressing process.

Table 1

Electrical parameters for sintering with direct current

t, min	U_1, V	I_1, A	U_2, V	I_2, A	$I_1 \cdot U_1$, kW	P, MPa	T, °C
1	160	19	3.5	870	3.04	10	180
2	160	29	3.5	1,320	4.64	10	360
3	160	36	3.4	1,690	5.76	10	1,070
4	160	39	3.4	1,830	6.24	10	1,470
5	160	40	3.3	1,940	6.4	50	1,600
6	130	27	2.5	1,404	3.51	50	1,600
10	–	–	–	–	–	50	1,200
20	–	–	–	–	–	50	700
30	–	–	–	–	–	10	300

Cutting plates with dimensions (11.75×11.75×4.75) mm were prepared from the samples and their resistance was determined when cutting hardened ШХ15 steel according to the above modes. The best result is 29 minutes, which is 30 % more than for standard ВОК-71 plates produced by the Svetlovodsk hard alloys plant (22 minutes).

When studying the structures of WOK-71 and the resulting ceramics, the grain sizes of the constituent phases of aluminum oxide and tungsten and titanium carbides are comparable (2…5 microns). However, the density of the obtained ceramics 50 % Al_2O_3-50 % WC – 5.96 g/cm^3 is higher than that of ВОК-71 – 4.2…4.27 g/cm^3, which contributes to more efficient heat removal from the cutting zone and, thereby, lowering the temperature in it. Thus, the use of WC additives instead of TiC in the production of cutting inserts from aluminum oxide seems promising.

Further investigation of the structure and properties of the obtained oxide-carbide ceramics in Table 2 shows some of the physical and mechanical properties of the materials obtained. The microstructure of oxide-carbide ceramics is shown in Fig. 3.

Table 2

Physical and mechanical properties of the obtained materials

№	*P*, MPa	*T*, °C	*ρ*, g/cm^3	*HRA*	σ, MPa	K_{1c}, mn·m$^{-3/2}$	Durability *T*, min
1	40	1,550	5.68	93	530	3.5	22
2	50	1,600	5.96	94	590	5.8	29
3	50	1,650	5.83	93	560	5.2	25

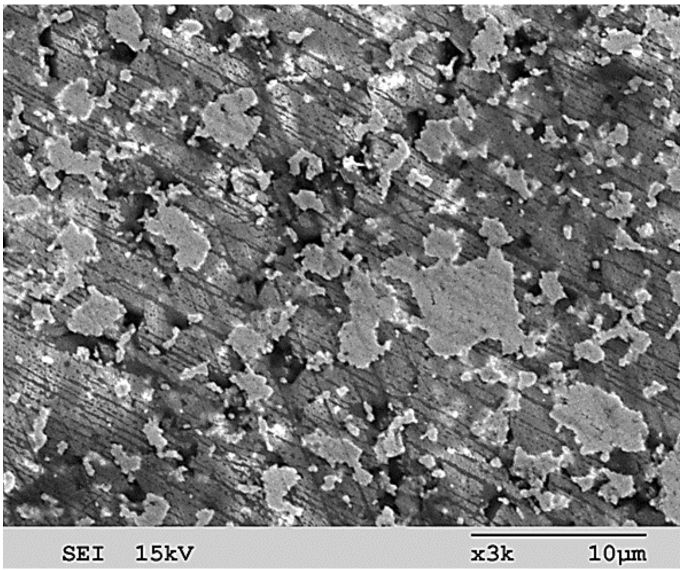

Fig. 3. Microstructure of oxide-carbide ceramics with a composition 50 % Al_2O_3 – 50 % WC

When studying the structure and properties of the obtained oxide-carbide ceramics, the following conclusions can be drawn:

– the optimum sintering temperature of the mixture under a pressure of 1,600 °C (1,550 °C is insufficient for these holding times, and 1,650 °C exceeds the temperature of the WC-Al_2O_3 interfacial interaction, at which CO is released and closed porosity is formed);

– the pressing pressure is limited only by the characteristics of the МПГ-7 graphite and is 50 MPa, and the maximum pressure is applied only when the maximum temperature in the compact is reached (for complete degassing of the sorbed gases). Applying maximum pressure at lower temperatures results in increased porosity due to the presence of sorbed gases;

– the grain size of the structural components of ceramics 2…5 microns is not optimal and was obtained not during sintering, but during preparation of the mixture for hot pressing (apparently dry mixing does not contribute to the destruction of Al_2O_3 and WC agglomerates and obtaining a homogeneous structure, in which it is possible to obtain submicron grains during sintering). Presumably wet mixing with surfactants is required.

Conclusion and findings.

The studies have shown that to obtain cutting Al_2O_3 – WC inserts with high functional capabilities, it is necessary to optimize the ratio of the phase components of the initial powders and their homogenization during mixing, to perform molding by hot vacuum pressing under optimal conditions, to polish the cutting inserts to exclude microcrack nuclei, to optimize the parameters cutting various metals and alloys.

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Аннотация. *Статья посвящена получению инструментальной керамики с ультрадисперсных порошков Al_2O_3 - 50 мас. % WC методом горячего вакуумного прессования и исследованию их свойств. Для получения режущих пластин на основе оксида алюминия и монокарбида вольфрама с высокими функциональными возможностями проводится подбор фазовых составляющих исходных порошков и их гомогенизация в процессе смешивания, горячее прессование с подбором оптимальных режимов спекания при прямом пропускании высокоамперного тока через графитовую пресс-форму. Режим спекания оказывает большое влияние на конечные свойства керамики. Оптимальная температура спекания керамики зависит от дисперсности исходного порошка, наличия в нём примесей, добавок и продолжительности нагревания. Выявлено, что для снижения хрупкости и получения инструментальной керамики с высокой надёжностью бывает необходимо исключить даже мельчайшую пористость, вызываемую попаданием пыли из воздуха.*

Ключевые слова: *композиционный материал, инструментальная керамика, оксид алюминия, монокарбид вольфрама, температура спекания, горячее прессование.*

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