Український державний університет залізничного транспорту

СУЧАСНІ ТЕНДЕНЦІЇ ТА РОЗРОБКА НОВИХ КЕРАМИЧЕСКИХ ІНСТРУМЕНТАЛЬНИХ МАТЕРІАЛІВ

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CURRENT TRENDS AND DEVELOPMENT OF NEW CERAMIC INSTRUMENTAL MATERIALS

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Nanoscale composite materials based on Cr_2O_3 obtained by the activated electric fields sintering procedure. In the paper, exploitative properties of the sintered system of Cr_2O_3– AlN nanocomposite was examined. Mechanical properties of the material were examined, especially from the perspective of its performance in the cutting tools. In particular, its wear was tested at different cutting speeds, as well as for intermittent hard cutting, and the results were compared with other materials available in the market. Compared to other cutting tools of the same class, Bichromit-P performed the same lifetime for 3-5 times higher cutting speeds, or up to 45% longer lifetime for the same cutting speed. The results lead to the conclusion that composite nanostructure improves substantially exploitation characteristics of the cutting tools.

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However, any additional operation of coating, especially with nanolayers, generates increasing costs. Thus, another way to improve durability and performance of ceramic cutting tools is directed to its microstructure formation.

Since ceramic-matrix composites are outstanding in their ability to withstand high temperatures, in addition their hardness and wear resistance, carbon fiber ceramic-matrix composites are applied, as well as ceramics armed with carbides, nitrides, oxides, and their combinations, including composites with carbon nanotubes and carbon nanofibers.

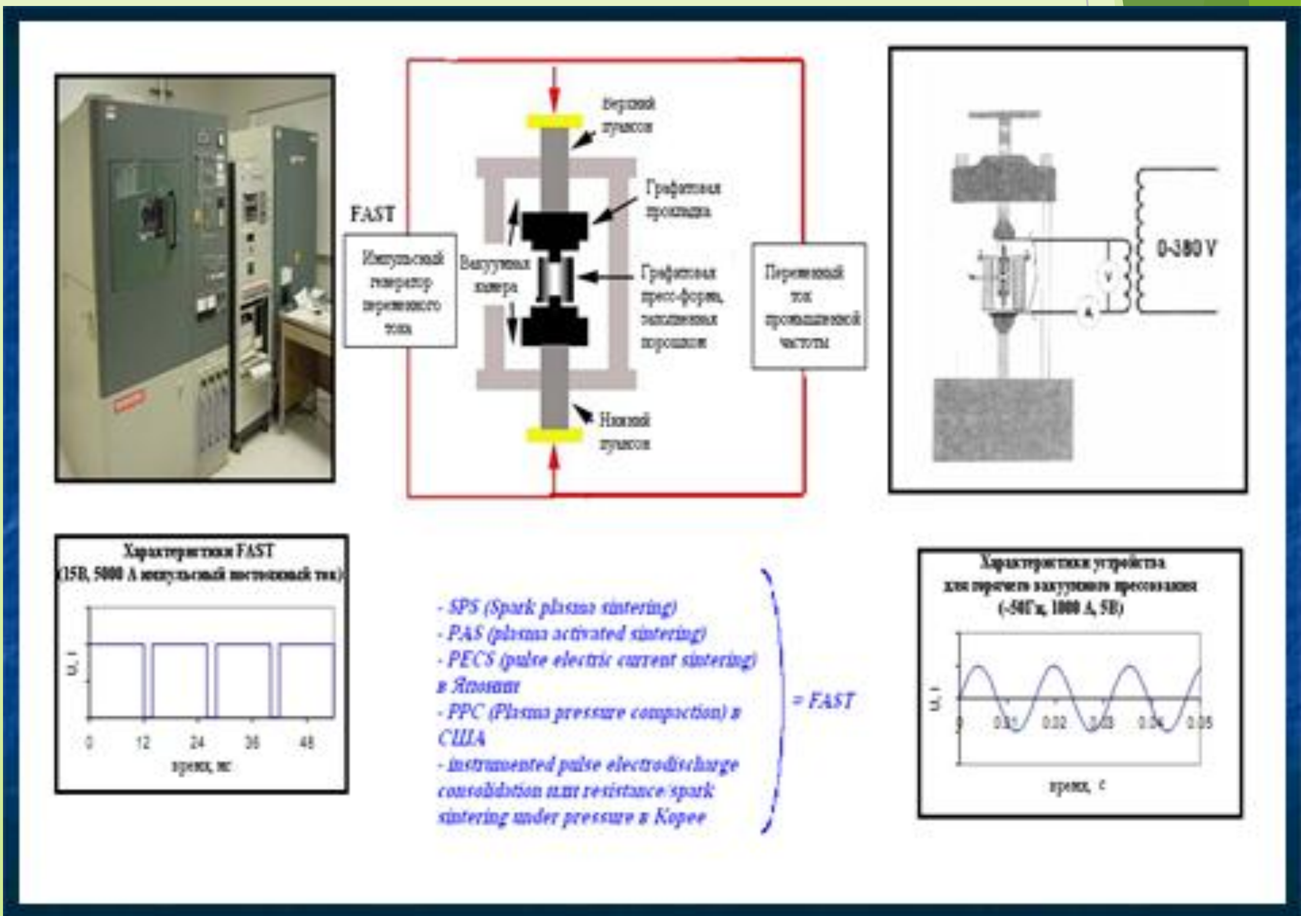
This paper is devoted to the nanocomposite Cr_2O_3 materials produced by the activated electric field sintering procedure. As it will be demonstrated below, its fabrication is cheaper and exploitative properties are better than that of other ceramic cutting tools available in the market.

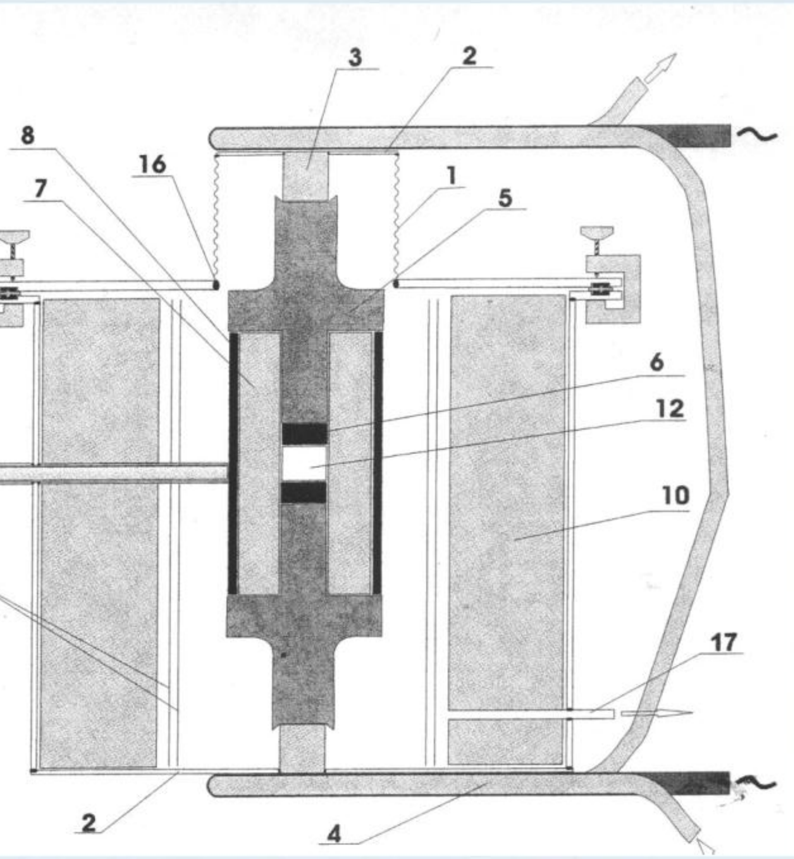
There are various methods for effective nanopowder consolidation available, and they make possible to obtain materials with a nanosize structure. These methods, such as a hot isostatic pressing (HIP), the high-frequency induction heat sintering (HFIHS), rapid omnidirectional compaction (ROC), pulse plasma sintering (PPS), the ultra high pressure rapid hot consolidation (UPRC) are quite fully described in works.

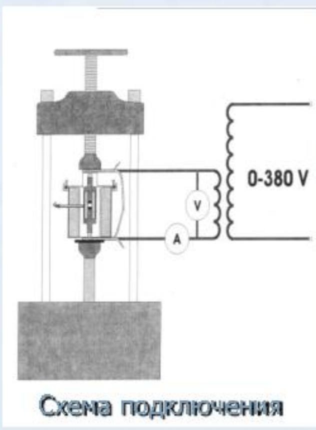
Each of these methods has some advantages and disadvantages in case of sintering

mono and polydispersed electrical conductive and non-conductive nanopowders. Thus, widely applied SPS (Spark Plasma Sintering) method enables to get nanostructured bulk materials from refractory compounds, such as Al_2O_3, SiC, B_4C, $MoSi_2$ etc. In this method, pulses of current are applied during hot-pressing. In the researches, modified patented field activated sintering method was used with alternating current of 1500-2000 A at voltage 5-10 V .

Durability tests were carried out during cutting the details made out of steel ШХ-15 (Russian nomenclature), which corresponded with 521000 (ASTM, USA standard) and with 100 Cr6 (DIN, German standard). Hardness of the samples was HRC 58-62. Other steel was used for the evaluation of overall cutting performance of different tool materials. It was steel 30ХГСА (Russian nomenclature), which corresponded with 5147 H (ASTM, USA standard) and with 55 Cr13 (DIN, German standard) of hardness HRC 58.


FAST
0-380 V
Характеристики FAST
(15В, 5000 А импульсный постоянный ток)
время, мс
Характеристики устройства
для горячего вакуумного прессования
(~50Гц, 1000 А, 5В)
время, с
- SPS (Spark plasma sintering)
- PAS (plasma activated sintering)
- PECS (pulse electric current sintering) в Японии
- PPC (Plasma pressure compaction) в США
- instrumented pulse electrodischarge consolidation или resistance/spark sintering under pressure в Корее
= FAST





Устройство для горячего вакуумного прессования с прямым электронагревом переменным током промышленной частот

Патент Украины на полезную модель №72841 в схематизации рабочего исполнения научно производственным предприятием «Кермет-У

1	Сильфон (Х18Н10Т)
2	Фланцы (Х18Н10Т)
3	Самоохлаждающиеся тоководы (медный сплав)
4	Водоохлаждаемые тоководы (медная трубка)
5	Пуансоны (графит МПГ-7, до 70 МПа)
6	Прокладка (графитовый лист)
7	Разборная пресс-форма (графит)
8	Втулка (углекомпозит)
9	Экраны (молибденовая жесть)
10	Теплоизоляция (муллитокремнеземистое огнеупорное волокно)
11	Термопара ВР–5/20 (вольфрам-рений)
12	Объект консолидации
13	Зажимы (диэлектрик)
14	Прокладка (резина)
15	Прокладка (диэлектрик)
16	Стыковочные узлы вакуумной сварки
17	Ввод к вакуумному насосу

- **The molds rapid heating of to high temperatures, which inhibits the intensive growth of the initial powder grains, which ultimately leads to the formation of more finely dispersed structures**

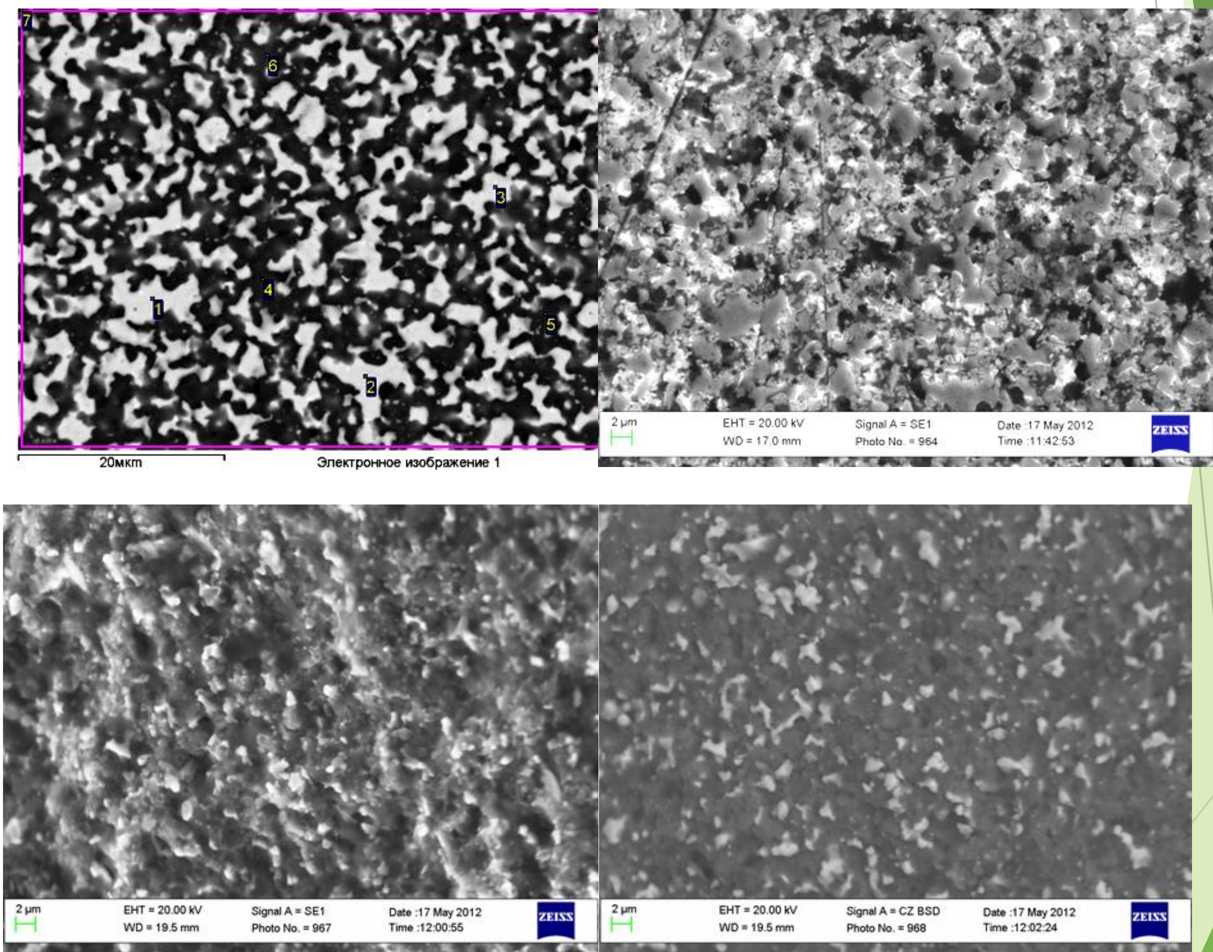
- **Density provides a uniform distribution, including in compacts of complex shapes, without the use of any plasticizers**

- **Compacts are minimized internal stresses, the appearance eliminated of macrodefects (cracks, laminations, etc.)**

- **An installation industrial relative simplicity ;**

- **Powders are used conductive and non-conductive effective.**

Microstructure of composite 65 mas.%Cr2O3-35 mas.%AlN Sintering temperature 1550 C



Mechanical properties

The mechanical properties of the material obtained on the base of $Cr2O3$, called Bichromit-P, were compared with other available ceramic instrumental materials. Since ceramic is a brittle material, increased viscosity is advantageous for its further performance. Figure 1 presents a diagram of stress intensity factors *K1C* obtained for different materials typically used for cutting tools inserts manufacturing. Material Bichromit-P performed *KIC* above 9 MPa $m^{3/2}$ which indicated higher crack-resistance and hence longer durability than Comp-10, DBC or HC2 materials.

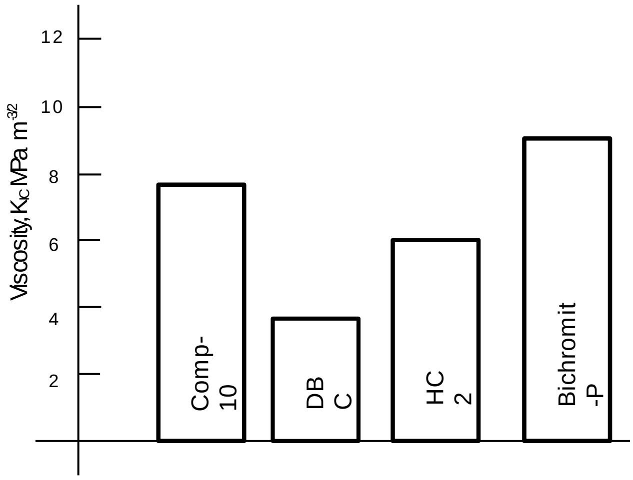


Fig. 1. Fracture toughness diagrams of several cutting tool materials

In the Table 1, there are data on main physical characteristics of some cutting tool ceramic materials, compared to Bichromit-P. It is noteworthy that with similar hardness and grain size, Bichromit-P performs better properties than other materials. Above all, its fracture toughness is almost twice higher than for other materials, which indicates high ability of Bichromit-P to resist fractures during cutting operations. This qualifies it for such applications as high speed cutting of hard-tempered cast irons, steel and alloys.

Table 1. Mechanical characteristics of the Cr_2O_3-based Bichromit-P compared with some ceramic materials

Ceramic type	CC-650 Sweden Al_2O_3	BOK Russia Al_2O_3	Silinit-P Ukraine Si_3N_4	Bichromit-P Ukraine Cr_2O_3
Hardness	93	92-93	92-94	92-94

Density, g/cm^3	3.97	4.52	3.2-3.4	5.6
Compression strength, MPa	-	-	2500	2600-2800
Bending strength, MPa	480	650	500-700	600-800
Fracture toughness, MPa m$^{1/2}$	6.1	5.6-6.0	4.5	8-10
Grain size, µm	4	2-3	2-3	2-3

The cutting tool made out of Bichromit-P was compared with the one from HC-2 series, based on the aluminum oxide with additions of titanium carbide (Al_2O_3-TiC), produced by NTK. This material is designed and recommended for cutting of hardened steels up to HRC65. In the tests, the steel 5XHM (Russian nomenclature) of HRC 60-63, corresponding with 56CrNiMoV7 (Germany) was machined. In Fig. 2, there are graphs obtained during intermittent cutting at feed f = 0.05 mm/rev; a =0.1 mm. Geometry of cutting inserts was as follows: $\gamma_0 = -6°$; $\alpha_0 = 6°$; $\varphi = 75°$; $\varphi_1 = 15°$; $\lambda_c = 0°$; $l_f = 0.2$; r =0.8.

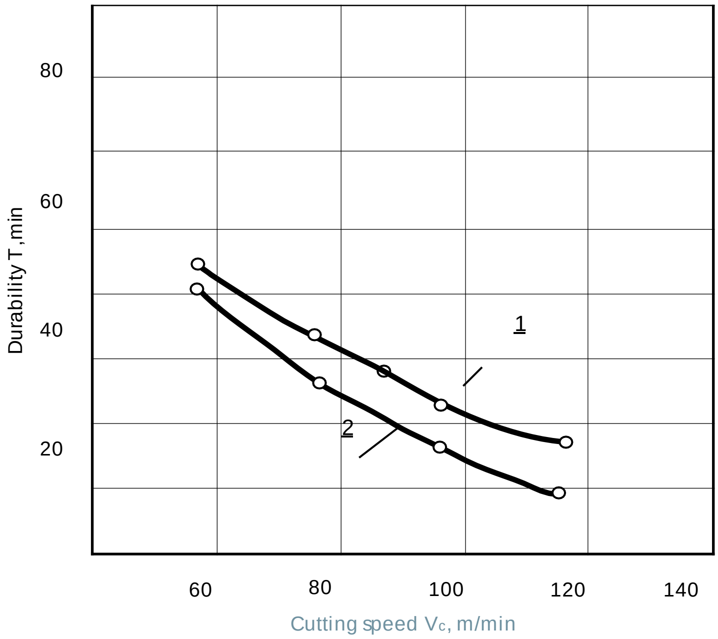


Fig. 2. Durability versus cutting speed during intermittent cutting at feed f = 0.05 mm/rev; a = 0.1 mm; 1 – Bichromit-P, 2 – HC-2

It should be noted that the lifetime of Bichromit-P cutting tools was considerably better than that of HC-2 especially at higher cutting speed. Namely, while at v_c = 60 m/min difference was insufficient, ca. 6%, at doubled speed of 120 m/min Bichromit-P lifetime was ca. 40% longer.

In order to assess the cutting speed influence on the wear of Bichromit-P cutting tools, some tests were carried out. Figure 3 presents the example of results obtained for three different tool materials, namely Bichromit-P, Silinite-P, and BOK-71 (Russian nomenclature). The measure of the wear is the overall path length L [m] of the cut material during machining, before the destruction of the blade. Significantly, the path length ca. L = 20,000 m may be obtained with Silinite-P at cutting speed v_c = 50 m/min, with BOK-71 at v_c = 100 m/min, while with Bichromite-P at v_c = 300 m/min. Moreover, the path length ca. L = 15,000 m may be obtained with Silinite-P at cutting speed v_c = 70 m/min, with BOK-71 at v_c = 130 m/min, while with Bichromite-P even at v_c = 500 m/min. In terms of durability it can be stated that compared with Silinite-P and BOK-71, similar cutting work can be done with Bichromit-P tools, but at the cutting speeds 3-5 times higher.

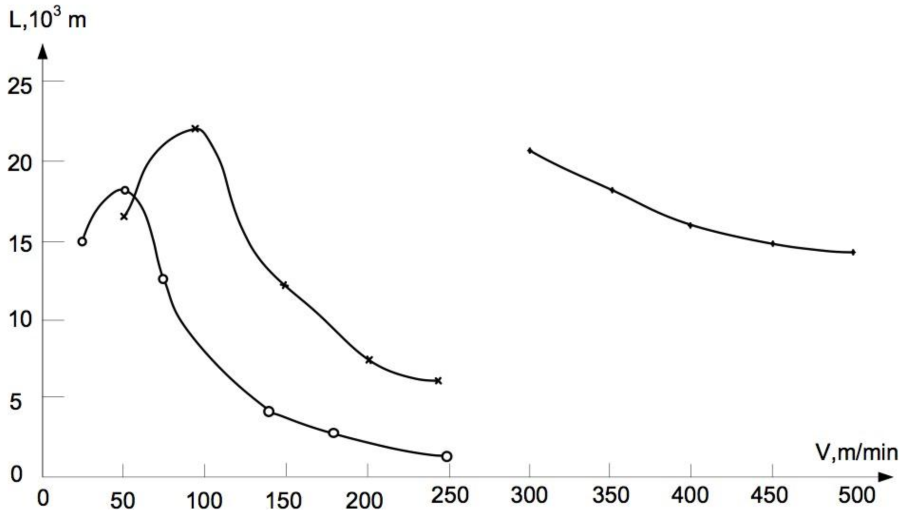
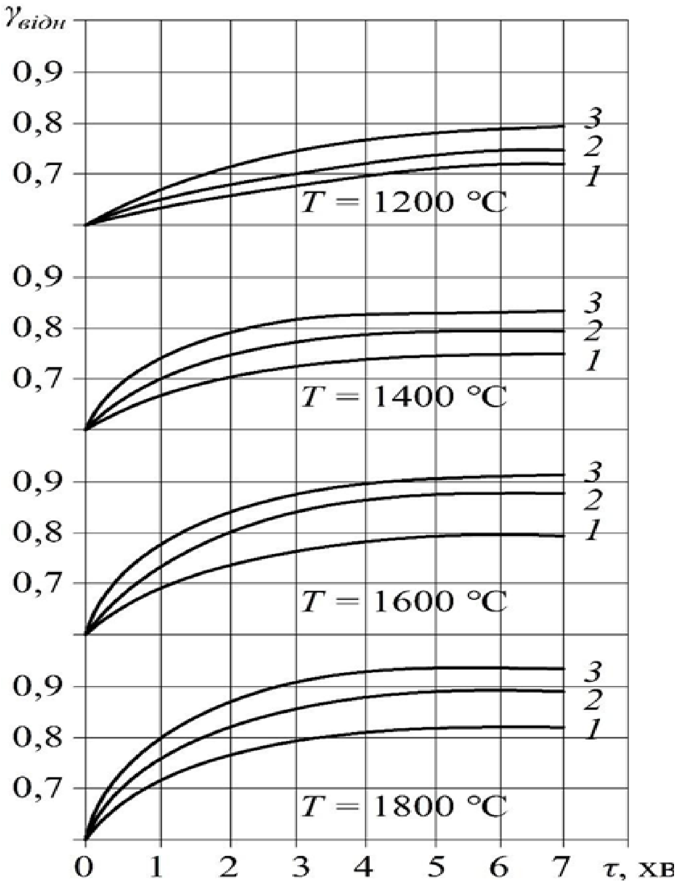


Fig. 3. Cutting speed influence on the wear of a cutting tool h_3 = 0.4mm, during turning of steel ШХ-15 (HRC 58-62) at f = 0.075 mm/rev, and p = 0.2 mm,
-o- Silinite-P; -✕- BOK-71; -•- Bichromite-P

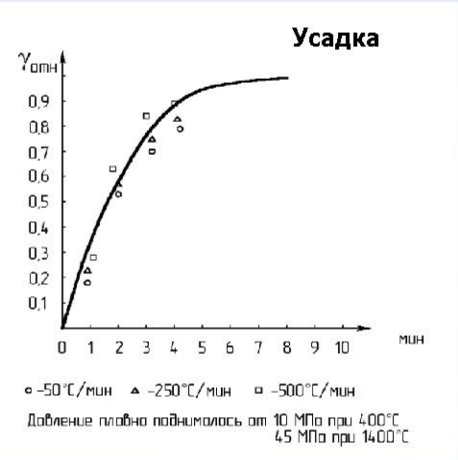
It should be noted that some operational cutting tests were conducted in-situ by the Volkswagen company (Germany), and they showed that machining with cutting tools made out of Cr_2O_3 material provided high quality of the treated surface of details. That quality was close to the one obtainable by polishing. Another industrial tests were performed at the State Enterprise “Malyshev Plant” (Kharkiv, Ukraine) and they demonstrated that in some turning operations Bichromit-P performed better than other materials available in the Ukrainian market, e.g. “Tomal” cubic boron nitride tools. Thus, ceramics on the basis of chromium oxide could be considered as a new ceramic instrumental material with the high-speed cutting characteristics improved considerably. There are several ways of further improvement of performance of Cr_2O_3-based ceramics, mostly directed to the microstructure features, such as nanoscale grains.

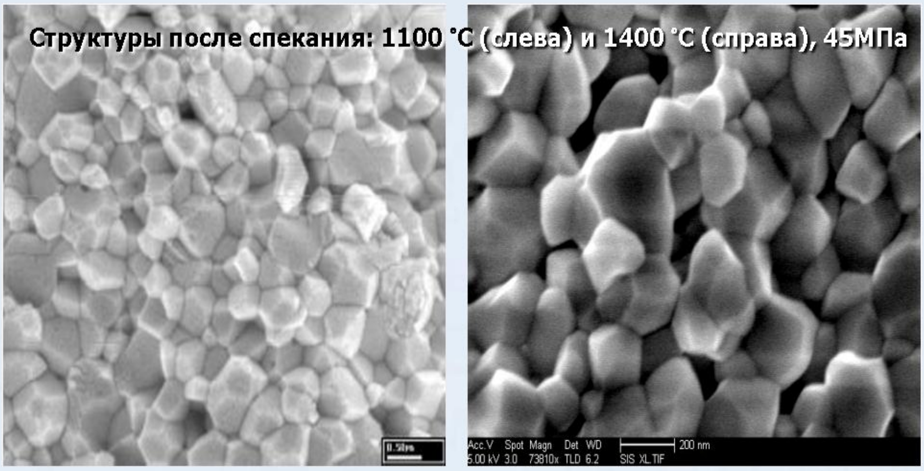
Table 2 presents the comparison of overall performance of different cutting tools in turning operations without cooling at cutting speed v_c = 104 m/min; S = 0.05 m/rev; t = 0.5 mm/rev. The machined material was steel 30ХГСА (Russian nomenclature), similar to 4130 (USA) and 25CrMo4 (Germany) of hardness HRC 58, and the materials of cutting tools inserts were typical ceramics of the same class.

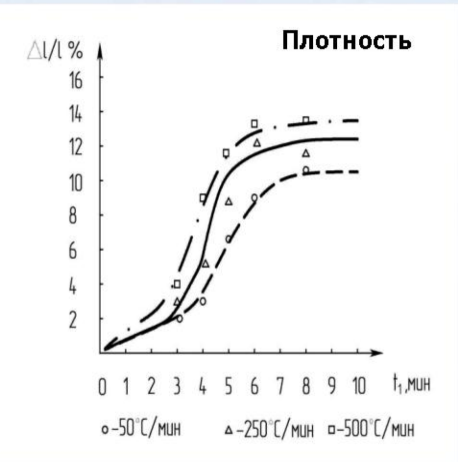
The Cr_2O_3 relative density dependence density from sintering temperature,
Hot pressure and time of hot pressing:
1 - 15 MPa; 2 - 22 MPa; 3 - 30 MPa

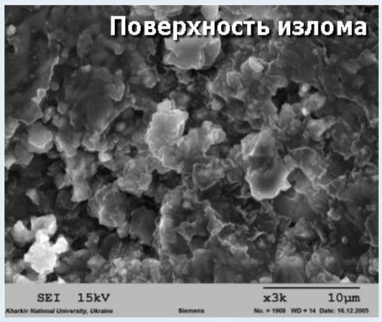


Электроспекание прессованием нанопорошков Al2O3









Примеси в исходном порошке a-Al2O3: зерно 60-80нм (IMC, США), мас.%				
Fe	Si	Mg	Cu	Na
0,009	0,15	0,001	<0,001	0,008

Table 2. Comparative tests of the different instrumental materials during machining of the steel 30ХГСА(25 CrMo4,Gemany), HRC 58…60

No.	Cutting insert	Number of passes	Total time	Obtained roughness, Ra	Wear of the tool's back surface, mm	Comment on operation
1	BOK60	11	63	1.25	0.2	Red spiral cutting chip
2	Valenite (USA)	11	63	0.8	0.15	Red spiral cutting chip
3	Hard alloy ВК6-ОМ	5	31.5	2.5	3	squeal, sparking, crumbling
4	Bichromite-P	20	118	0.63	0.1	Red spiral cutting chip after the 15th pass

The data in the Table 2 demonstrates that virtually all tested parameters were better in case of Bichromit-P. Number of passes and total working time was almost twice better, and wear of the tool's back surface was smaller. As a result, roughness of the machined surface was better.

The abovementioned results are mainly attributed to the high fracture toughness discussed in the section 3.1, ensured by the specific sintering technology at smaller temperature and shorter times. It can be assumed that the nanoscale grains of the composite are mainly responsible for the limited crack propagation and unusually high fracture toughness of a ceramic material.

Presented results of the researches demonstrated prolonged durability, higher cutting speeds, smaller wear and better overall performance of cutting tools made out of high-density Cr_2O_3 with some additives AlN, sintered at lower temperatures for shorter time than usually. Substantial improvement of exploitation characteristics can be attributed to the obtained nanoscale grains inside the bulk material, that are responsible for the increased fracture toughness of a ceramic material, otherwise brittle. Compared to other cutting tools of the same class, Bichromit-P performed the same lifetime for 3-5 times higher cutting speeds, or up to 45% longer lifetime for the same cutting speed.