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CUTTING CAPACITY AND WEAR RESISTANCE OF Cr_2O_3-AlN NANOCOMPOSITE CERAMIC OBTAINED BY FIELD ACTIVATED SINTERING TECHNIQUE (FAST)

ABSTRACT

Chromium oxide ceramics may be considered as a new generation of ceramic materials for cutting tools with considerably improved high speed cutting performance. The present work is focused on the development of Cr_2O_3 nanocomposite materials fabricated with the Field Activated Sintering Technique (FAST). The main objective of the proposed work is to study the influence of electric field on the densification process during FAST sintering of the materials in the Cr_2O_3-AlN system with nanosize microstructure. Additional objectives are to characterize mechanical properties of the obtained Cr_2O_3 ceramics. The work aimed to develop composite materials based on Cr_2O_3-based nanoparticles for cutting, then to check their cutting properties and to work out the recommendations for their use for processing of various materials, accordingly.

Keywords: *nanocomposite ceramic, cutting capacity, wear*

INTRODUCTION

Nowadays, the number of difficult-to-machine alloys and composite materials has constantly increased. Hard to cut materials generally cause extreme loads, extremely high temperatures in the cutting zone, they create problems in chip formation, which result in excessive wear of the tool [1]. One of the ways to improve performance of cutting tools is to cover their rake surfaces with proper material. It was reported that the layers with diverse physical and mechanical properties can be created using PVD methods [2]. Promising results were obtained after ion implantation of cermet cutting tools with aluminum and nitrogen ions [3]. Numerous surface modification techniques have been adopted to reduce the friction during the hard turning process in order to increase the cutting tool durability [4].

Another direction is to improve the existing cutting tools materials based on diamonds, cubic boron nitride (cBN), cemented hard alloys, ceramics. For instance, the cutting tools made out of nanostructured refractory compounds were reported to perform better properties [5]. Other paper reported important results on gradient cermet composite cutting tools [6]. Various new binding materials are proposed for cBN-based cutting tools [7] and for tungsten carbide cermets [8]. Thus, development of new cheap cutting materials with improved characteristics is a vital necessity.

Traditionally Al_2O_3 is the most extensively used ceramic material for cutting tools. Alumina-based ceramic tools have unique mechanical and chemical properties, but the brittleness and poor damage tolerance set some limits on the wide application of alumina ceramics [9]. In recent years, extensive research Chromium oxide (Cr_2O_3) has a crystalline structure similar to Al_2O_3, but due to stronger bonding has higher microhardness (29 MPa) compared to Al_2O_3 (28 MPa) [10–12]. Since chromium oxide is very difficult to sinter, its application is restricted to use of its powders for polishing only. Using nitrides additives such as AlN, we managed to consolidate Cr_2O_3 to the high density [13–15]. Due to formation of $(Al,Cr)_2O_3$ solid solution on the phase interfaces, the obtained material has high fracture toughness and strength. Synthesis of bulk nanomaterials is a challenge to modern technologies of nanoparticle consolidation, which can be collectively called sintering. In these processes, there are such phenomena as compaction and growth of grains. They are competing and this makes the problem complex.

A primary challenge of sintering nanosized powders is to control grain growth while still achieving full densification [16]. The key task of sintering nanomaterials is to achieve a high density of the material, provided that nanosize grains are preserved in the range where the dimensional effect is observed. As our experience shows, the choice of the consolidation process depends on the structure of grains, their boundaries and interphase boundaries. The residual porosity and imperfect boundaries significantly impair the properties of nanostructured materials.

EXPERIMENTAL

To date, nanopowders obtained by the plasma chemical method are the most promising in the application, since this method makes it possible to obtain remarkably pure substances. But at the same time, the study of the structure formation, the phase composition of plasma-chemical powders with low mutual solubility and their behavior in the formation of nanoceramics are poorly studied and the collected knowledge was not systematized.

In the present study, the nanopowders were mixed using a planetary milling plant ‘Pulverisette 6’ (Fritsch GmbH, Idar-Oberstein, Germany) with isopropyl alcohol for 2 h for a uniform distribution of the particles in the sample. The rotational speed of planetary disk was 160 rpm. To break the agglomerates, alumina milling balls were added to the container.

The Field Activated Sintering Technique (FAST), also known as Spark Plasma Sintering (SPS) is an innovative sintering technology developed at the University of California. It plays an increasing role in the production of various materials e.g. nanostructured materials, composite materials, and gradient materials. FAST employs the application of an electrical field during sintering and causes a considerable decrease of temperature and time of sintering, activating densification mechanisms of sintering and enables to consolidate hard sintered systems. We have successfully applied this technique to a number of nanocrystalline metals

(Fe, Ta), ceramic (TiN, Al_2O_3, $MoSi_2$), and composites (Fe-FeC, Al_2O3-TiO_2) with minimum grain growth [17–19].

Installation for hot vacuum pressing, designed and patented by the authors (Fig. 1), was built to consolidate the powders. This installation, in comparison to the well-known FAST method in Europe, differs mainly because of the possibility that it uses a conventional AC power frequency without special optional equipment pulse generators [20]. This method later in this article will be referred to as electroconsolidation.

The nanopowders were sintered using a hot pressing facility with a direct current under a pressure of 30 MPa and held for 2 min at various temperatures. Further studies were accomplished on molded samples such as tablets of 20 mm in diameter. Sintering curve looks like this: at a pressure of 10 MPa, the temperature was raised at 150°C/min up to a temperature of 600°C; then, at the same pressure, the temperature was adjusted to a holding temperature (1,200°C to 1,400°C). This temperature was held for 2 min. At the same time, the pressure was raised to 30 MPa. After that, the sample was cooled and formed, and the pressure was removed after the final cooling. Full-time consolidation lasted 15 min.

The microstructure of the nanoceramic compositions, obtained by electroconsolidation, was examined by scanning electron microscopy. Similarly, using the same method, the grain sizes of the obtained samples were evaluated. The samples for electron microscopic studies were prepared as shear of sintered tablets.

Using a universal hardness tester, the Vickers hardness (HV10) of the composite was evaluated with a load of 10 kg. The fracture toughness (KIC) calculations were made based on the measurements of the radial crack length produced by Vickers (HV10) indentations, according to Anstis formula [21]. The reported values are the averages of the data obtained from five indentation tests.

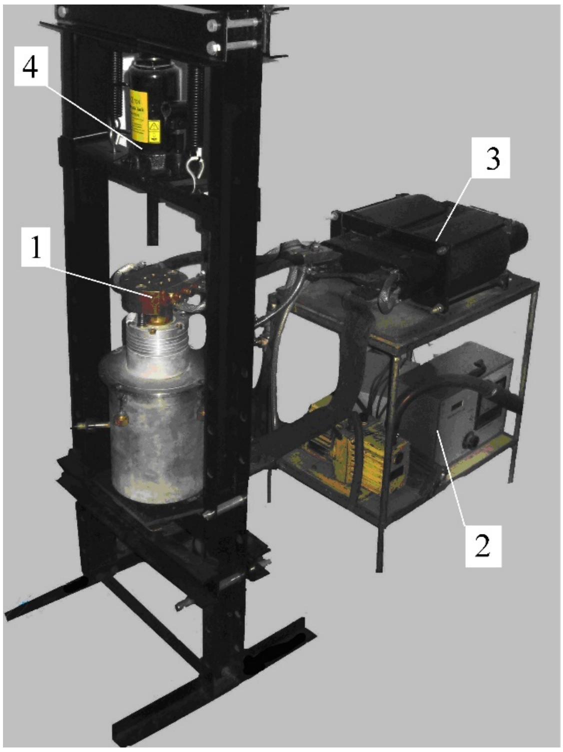


Fig. 1. FAST setting. 1 - hot vacuum pressing chamber, 2 - power supply unit, 3 - transformer TBK-75 with water-cooled current leads, 4 - hydraulic press HLR - 12

Detailed microstructural characterization and phase identification were carried out using a Quanta 200 3D (FEI Co., Hillsboro, OR, USA) scanning electron microscope (SEM) and a Rigaku Ultima IV X-ray diffractometer (Rigaku Europe SE, Ettlingen, Germany) (CuKαradiation, Ni filter).

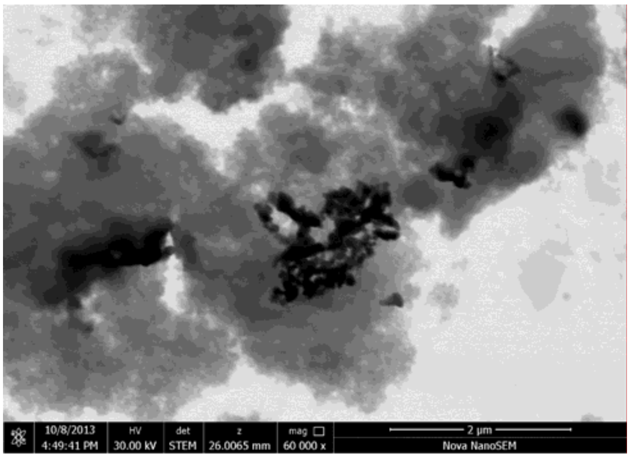
The experiments on the wear resistance determination of new tool material were carried out according to the standard methods [22]. As a criterion of wear resistance of the cutting edge we adopted wear on clearance surface of cutting insert dimensions h_3=0.3 mm.

RESULTS AND DISCUSSION

There are a number of ways to further improve the properties of Cr_2O_3 ceramics. One of the most promising is tailoring microstructure of this type of ceramic on nanograin size level. Our preliminary results are confirming it. A decrease of the grain size to 600 nm exhibits an increase in fracture toughness of Cr_2O_3 ceramics to 14 MPa $m^{1/2}$.

Fig. 2 shows the nanopowder mixture Cr_2O_3-AlN (a), and microstructure which obtained by electroconsolidation at T = 1600°C and P = 40 MPa (b).

a)



b)

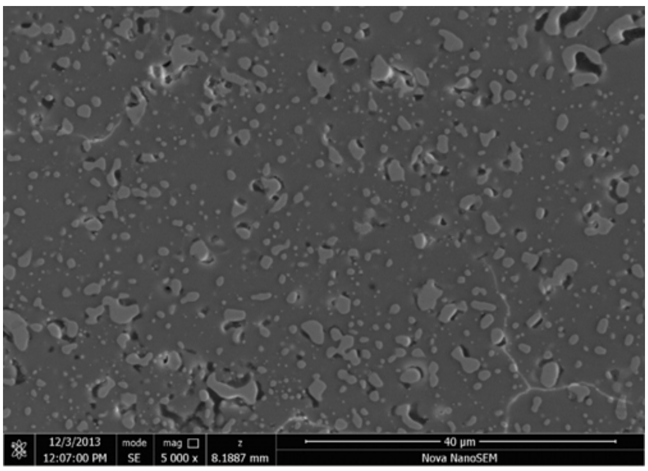


Fig. 2. Nanopowder mixture Cr2O3- AlN (a); microstructure obtained by electroconsolidation (T = 1600°C; P = 40 MPa) (b)

Table 1 shows mechanical properties of obtained Cr_2O_3 based material in comparison with commercially available ceramic materials for cutting tools.

Table 1. *Mechanical characteristics of obtained Cr_2O_3 cutting tool material (Cr_2O_3-AlN) in comparison with some commercially available ceramic materials for cutting tools*

Type of ceramics	CC-650 (Sweden) Al_2O_3	BOK (Russia) Al_2O_3	Silinit - P (Ukraine) Si_3N_4	(Cr_2O_3-AlN) (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
Bend strength , MPa	480	650	500-700	600-800
Fracture toughness, MPa m$^{1/2}$	6.1	5.6-6	4.5	8-10
Grain size, µm	4	2-3	2-3	2-3

The thermal conductivity of new chromium oxide ceramic has very good values: 28 W/mK at 22°C and 35 W/mK at 400°C. A tool equipped with inserts of this material, due to high heat resistance and durability, allows the use of higher cutting speeds. Inserts have a slight tendency to grasp with the material being processed, good resistance to abrasion and wear.

Table 2 shows comparative characteristics of cutting properties in the processing of steel 45.

Table 2. *Comparative characteristics of cutting properties in the processing of steel 45*

Brand	Manufacturer	Cutting Modes			
		v, m/min	f_o, mm/rev	t, mm	T_d, min
CM1	"Walter", Germany	300	0.075	0.5	35
CC650	"Coromant", Sweden	350	0.075	0.5	40
(Cr_2O_3-AlN)	"Cermet-U", Ukraine	350	0.075	0.5	38
ISM	Ukraine	400	0.1	0.5	35

Table 3 shows dependence of the durability time (T_d, min) of some tool materials when turning steel ШХ15 (HRC 60...62) on the cutting speed (v, m/min) with cutting modes: f_m = 0.075 mm/min, t = 0.2 mm.

Table 3. *Dependence of the durability (Td, min) of some tool materials when turning steel ШХ15 (HRC 60...62) on the cutting speed (v, m/min) with cutting modes: fm = 0.075 mm/min, t = 0.2 mm*

Brand	Manufacturer	v, m/min			
		50	100	150	300
CC650	"Coromant", Sweden	360	60	20	10
BOK71	ВНИИТС, Russia	260	120	40	28
(Cr_2O_3-AlN)	"Cermet-U", Ukraine	260	160	80	45
HCI	"Ceramik", Japan	280	175	60	30

From these tables it can be seen that the inserts from Cr_2O_3-AlN have comparable characteristics with the inserts of other firms. New chromium oxide ceramic also shows a significant advantage in the processing of solid steels with high cutting speeds, which ensure high purity of the treated surface.

CONCLUSIONS

Chromium oxide ceramics may be considered a new generation of ceramic materials for cutting tools with significantly improved high speed cutting performance.

Results obtained in this research may lead to some clarification of fundamental aspects of the electric field influence on consolidation of reacting nanosize powder systems during sintering, help to develop nanocomposite materials with high mechanical characteristics and cutting performance, compared to the currently commercially available cutting tools.

Obtained material was found to be very promising for high speed turning of hardened casts, steels and alloys. Tests at "Volkswagen" (Germany) showed that turning by cutting tools made of our Cr_2O_3 based materials make it possible to obtain high quality surface of machined parts, close to the quality able to be obtained after polishing only. Application of our material for turning of details for armored techniques at "Malyshev" Plant (Kharkov), turbines at "Turboatom" Plant (Kharkov), stitches of welded tubes showed very good performance for rafting.

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