



# STUDY OF WEAR OF TOOLS MADE OF PRESSED AND SINTERED HETEROGENEOUS COMPOSITE POWDER MATERIALS BASED ON HSS WITH HIGH MELTING POINT COMPOUNDS

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## ABSTRACT

The study considers some of the methods to impact the friction conditions in cutting of metals through alloying HSS-based sintered powder tool materials of modern generation. The first method involves the reduction of self-organization level through the reduction of the friction coefficient at operating temperatures by addition of 5% aluminum oxide (Al<sub>2</sub>O<sub>3</sub>). The second method is based on the modern concepts of tribology on the possibility to extend a range of self-organization through stable high-strength secondary structure appearing on the surface of the tool. This is achieved by addition of 2% BN (hexagonal). The use of both methods makes it possible to significantly increase the tool life, and it is achieved by addition of 20% TiCN.

**Keywords:** HSS-based sintered powder tool materials, wear of tools, self organization, stable high strength secondary structure.

## INTRODUCTION

Following the results of the study of wear of tools made of pressed and sintered heterogeneous composite powder materials based on HSS with high melting point compounds, it has been concluded that these materials are self-organizing (G.S. Fox-Rabinovich, 1997). During machining, they can form stable high-strength secondary structures that effectively protect from damage the friction surface of the tool (Bershadskiy L.I. 1981; Vereschaka A.S. 1993; Vereshchaka A.A. *et al.*, 2014).

Taking into account the thermodynamic concept of friction, the whole range of processes occurring in friction can be divided into 2 groups, where the first group implies normal friction, and the second group implies catastrophic friction causing complete destruction of an object under friction.

Throughout the whole period of operation under normal friction and relatively normal wear, no macroscopic damage is observed at the surface of tribopair. Meanwhile, self-organization during wear takes place due to the ability of tribopair to organize spontaneously resistant ordered scattering structures that protect the basic material of tribopair from direct contact and damage.

Protective secondary structures represent thin films on the friction surface, which appear in high deformation conditions at heating temperatures causing diffusion, in adsorption, as well as in various reactions of decomposition and assimilation (Bershadskiy L.I., 1981).

This article deals with the problem of alloying HSS-based powder materials to impact the conditions of friction and tool wear. The considered concept is based on

the fact that the alloying significantly affects the chemical composition of secondary phases which arise on the friction surface of the tool. Thus, it is possible to increase wear resistance by extending the interval of self-organization and by increasing the level of self-organization. The first can be achieved through formation of stable high-strength secondary phases with low thermal conductivity, and the latter as a result of decreasing the friction coefficient (Polzer G. *et al* 1988; Adaskin A.M. *et al* 2013; Vereschaka Alexey, 2013; A. A. Vereshchaka *et al.*, 2014).

## Experimental studies

The subject of research was tool materials, the compositions of which are shown in Tables 1-3. Wear resistance of the materials was studied at linear turning of 40H (HB 200, analog 5145H) steel at different cutting speeds with cutters equipped with replaceable many-sided inserts (RMIs) of 12 x 12 x 4.5 mm. Cutting conditions are shown in Table-2.

Chemical composition of secondary phases occurring during cutting on contact areas of the tool of sintered composite powder material was studied by means of secondary ion mass spectroscopy (SIMS). The study examined angle laps of 5° to the upper side of the cutting insert. Taking into account the heterogeneous nature of samples of sintered powder tool materials (SPTMs), we studied average chemical composition of the base surface of the tool and the chemical composition of the wear zone (Schuster L.S. *et al* 2008; Vereschaka A.A. *et al* 2014; Anatoly S. Vereschaka *et al* 2014; Alexey A Vereschaka *et al.* 2014).

**Table-1.** Composition of materials under testing.

Material under testing	Phase composition of alloy		
	Solid phase		Base
	Composition	Content, %	
SPTM with 20% TiC	TiC	20	High-speed steel R6M5K5 (analog S6-5-2-5)
SPTM with TiCN	TiCN	20	
SPTM with TiCN and BN	TiCN BN	20 2	

**Table-2.** Material and cutting conditions during testing.

Material under testing	Hardness, HB	Cutting speed, m/min	Feed, mm/rev	Depth of cutting, mm
Steel 45H (5145H)	180-200	70	0.28	0.5

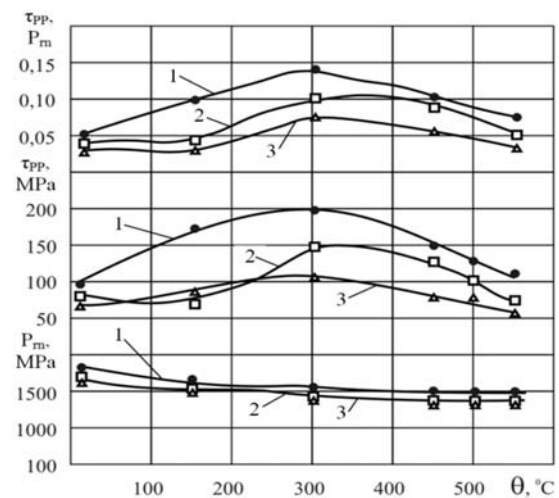
**Table 3.** Properties of materials under testing.

Materials	Thermal processing		Physical-mechanical properties			
	Hardening temperature, °C	Drawback temperature, °C	Hardness, HRC	Bending strength, MPa	Fracture toughness, kJ/m <sup>2</sup>	Thermal stability, °C
HSS + 20% TiC	1210	~550	89	2100	80	655
HSS + 20% TiCN	1210	~550	88	2200	110	640-650
HSS + 20% TiC + 2% BN	1210	~550	88	—	—	—

## RESULTS AND DISCUSSIONS

The paper has studied the effects on friction in tribosystems of "cutting tool-workpiece" through alloying powder tool materials. The SPTM shown in Table-1 was based on high-speed steel. The aim was to increase the tool life by expanding the range of self-organization interval (SOI), by reducing the self-organization level (SOL), as well as by simultaneous changes in these characteristics affecting the self-organization of the tool and its adaptation to the cutting conditions. It was necessary to detect the compositions of tool materials possessing the most favourable properties of friction resistance at the cutting temperature, i.e., to control friction by reducing the self-organization level (SOL).

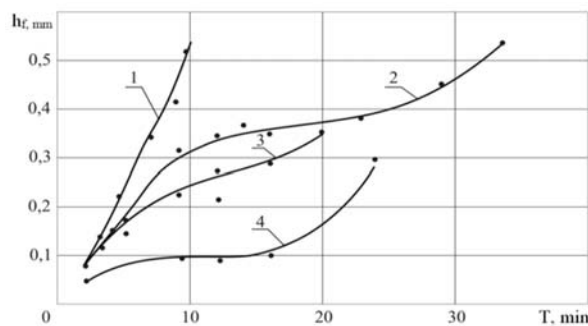
It is found that if TiC in HSS under testing is partially replaced with Al<sub>2</sub>O<sub>3</sub>, one of the phases most stable in cutting, then the adhesion component of the friction coefficient decreases (Figure-1) and that leads to a corresponding increase in the wear resistance of the tool during cutting (Figure-2).

**Figure-1.** Relation between tribological parameters of tested materials of friction pairs and operating temperature:

1 - SPTM + 20% TiC; 2 - SPTM + 15% TiC + 5% Al<sub>2</sub>O<sub>3</sub>;  
3 - SPTM + 20% TiCN.



Presence of  $\text{Al}_2\text{O}_3$  reduces the friction coefficient, and it is important not only for the increase of wear resistance, but also for the reduction of the temperature on the surface of the tool. It is important for HSS characterized by restricted thermal stability. The scope of application of these materials can be extended with the increase in the range of possible cutting speeds. Oxide-based powder carbides are well-known; however, they need optimization of their mechanical and technological properties. During the study, no changes were observed in the chemical composition of the secondary structures after addition of  $\text{Al}_2\text{O}_3$  to the material composition.



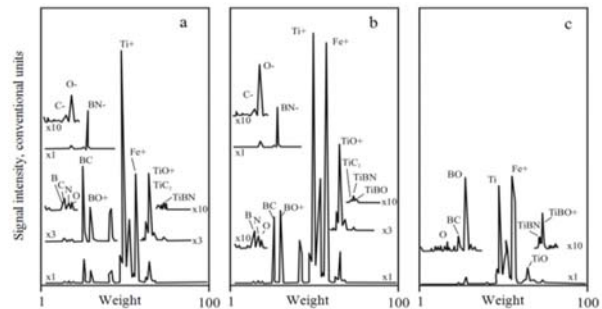
**Figure-2.** Relation between machining time and flank wear of cutting tool.

The paper discusses a technique of alloying powder tool materials as a way to impact friction conditions, mainly by strengthening the secondary phases on the surface. As shown above, that leads to an increase in the hardening coefficient  $K_h$ . Coefficient and self-organization interval, resulting in increased tool life. Alloying was carried out not in the traditional way of adding one or another element, and that could lead to undesirable changes in the properties of the entire volume of the material. The study used a different approach, when composition of the powder material included compounds with necessary density relatively unstable at operating temperatures. The approach allowed using the compounds in relatively small quantities (with mass of up to 2%) with the least possible impact on the quality of volume. The solid lubricant BN (hexagonal) was selected as such a compound for the additional alloying (Schuster L.S. *et al* 2008; Vereschaka A.A. *et al* 2014). In this regard, attention was paid to the high probability of formation of oxygen-containing secondary phases in cutting.

The following physical mechanism of these processes can be assumed. Gradients of temperature and stress localized in subsurface layers appear in the contact zone of "instrument-workpiece". In plastic deformation of high degree and temperatures of up to  $650^\circ\text{C}$ , various processes take place which change chemical and phase composition of SPTM in these microvolumes. These processes include: absorption of oxygen, chemisorption of

oxygen, diffusion of free C and N from the tool to the chip.

Spectrometry of surface layers and EELFS have found out that secondary structures appear on the surface of the tools of powder materials, including material with addition of BN, and these secondary structures appear in the form of simple and complex oxygen-containing phases with amorphous structure (Figure-3).



**Figure-3.** The secondary ion mass spectrum of the sample SPTMs + BN (at different depths beneath the surface of the crater wear after 4 minutes of cutting):  
a - 0.5 microns; b - 0.15 microns; c - surface

Alloying with addition of BN contributes to formation of complex compounds of  $(\text{TiB})_x\text{O}_y$  type, which appear on the surface of the tool apart from simpler compounds of TiO type. Amorphization of secondary structures depends on the composition of SPTM, and it is enhanced in fusion with BN. It can be seen that the wear resistance of the material is increased by 1.8 times as compared with the SPTM of base composition with 20% TiC (compare in Figure 1 and 2).

This indicates the fact that alloying can increase the stability of secondary structures resulting from friction during cutting. This is explained by the presence of compounds of VO type with high chemical resistance, which is much higher than the resistance of the main phase of TiO (see Table-1), and that is of great importance for the tool life. The compound of TiBO type is apparently operates in the same manner. The thickness of the stable secondary structures is small and does not exceed 0.1-0.15 micron.

Following the obtained results, it can be concluded that it is appropriate to carry out additional alloying of SPTMs with the help of the following two methods of impact on friction and wear of the tools made of self-organized materials.

The first method is alloying with compound which can achieve a significant reduction in the self-organization level (SOL) through reduction of the friction coefficient at operating temperatures. Materials of such class are characterized by high wear resistance. However, the number of phases is to be optimized with respect to the

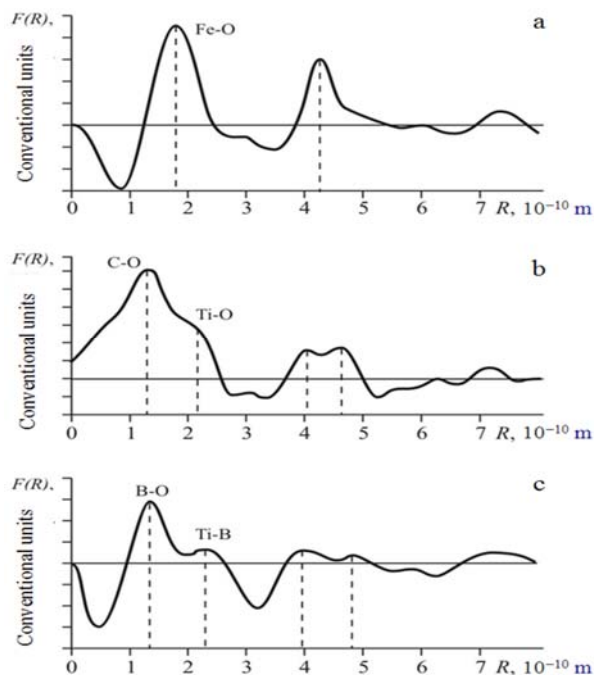


whole complex of functional, mechanical, and technological properties.

The second method is alloying that gives a possibility to extend the interval of self-organization (ISS). This is achieved through the use of compounds which cause transformations in compositions of secondary structures and increase of the hardening coefficient  $K_h$ . In this case, it is necessary to optimize the composition of the material with respect to the whole range of properties.

Supplementary alloying with boron nitride makes it possible to impact friction not only by more stable secondary structures, but also by changing the nature of friction. This is reflected in the transition from secondary structures of the second type (oxide-like phase of stoichiometric composition), formed in difficult conditions in cutting with high speed steel to amorphous-like secondary structure of the first type (Schuster L.S. *et al* 2008; Vereschaka A.A. *et al* 2014). This is followed by the transition to the friction with less force and thermal load, as evidenced by the change in the wear resistance and the wear curve (Figure-2).

Additive BN to SPTM increases amorphization effect (Figure-4, a and b), i.e., it enhances more complete self-organization of the tool.



**Figure-4.** Fourier transforms the extended fine structure of the spectra within the range of 250 eV, close to the line of the elastic scattering with the primary electron energy  $E = 1500$  eV, the electrons are scattered from the surface of the crater wear in the cutting tool made of:

- a - high-speed steel M2; b - SPTM (M2 + 20% TiC);
- c - SPTM (M2 + 20% TiC + 2% BN).

### Impact on friction for heavy-stressed cutting tools is imposed in special circumstances

Impact on friction in using of cutting tools of SPTN doped with boron nitride additive results not only in formation of more stable secondary structures, but also in changes in the character of friction. It is found out that during cutting with a tool of conventional high-speed steel, secondary structures of the second type are formed on the surface. During cutting with a tool of high speed steel with addition of carbides or carbonitrides, amorphous-like structures of the first type are formed. Additional alloying with BN enhances the effect of amorphization, and that results in a more complete self-organization of the tool. It is accompanied by the reduction of friction (friction coefficient, capacity of frictional heat sources decreases, and thermal component decrease), and that ultimately results in a decrease of wear rate and change in the shape of the "wear-time" curve). This type of effect on friction for heavy-stressed tools is exercised in certain conditions. Each of these methods of alloying allows achieving a significant increase in wear resistance of tool materials.

Simultaneous (combined) use of both techniques of alloying is regarded as particularly promising. Combined alloying allows achieving maximum impact on friction during cutting. It not only significantly increases the tool life, but also enhances quality-precision cutting characteristics. This is confirmed by the data obtained from the study of wear rates of tools made of SPTMs based on high-speed steel with carbonitrides. It should be mentioned that the materials under testing have the advantage not only in durability as compared with conventional high-speed steel, but also as compared with the more expensive sintered carbides (at cutting speed of up to 100 m/min) (Schuster L.S. *et al* 2008). The reason is in self-organization arising in friction in cutting conditions with the use of the tool of SPTM. Therefore, an additional intensification of this phenomenon enhances the efficiency of such materials.

### Findings

The study has considered the physical concept of the phenomenon of self-organization in multiphase materials. It examined several approaches to the impact on friction and wear for powder tool materials of modern generation (SPTMs based on high-speed steel). The first method is to decrease the level of self-organization. This can be achieved by adding 5%  $Al_2O_3$  to decrease the friction coefficient at operating temperatures. The second method is to extend the interval of self-organization through stable high secondary structures that develop on the surface of the tool. This can be achieved by adding 2% BN. Both approaches can be realized with the use of the addition of 20% TiCN.



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