The improvement of the tribotechnical properties of materials and coatings for metal cutting tool

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Abstract. The paper deals with experimental studies of tribotechnical properties (strength of adhesive bindings, wear-resistance etc.) of sintered cutting tools alloyed by the TiC, BN, Al2O3 additives and multilayer wear-resistant TiAlN, TiN, TiCrN coatings and others, which allow significantly increasing the performance properties of the cutting tool for edge cutting machining by forming secondary structures in friction.

1. Introduction
Cutting tool appears to be the most efficient element in the system of activities to improve the cutting process [1-6]. Thus, the problem of improving the cutting tool is considered to be urgent. At the same time, in mechanical engineering tool materials and coatings with controlled adaptation of friction surfaces (CAFS), which, taking into account the conditions of cutting (controlled variability of cutting mode elements, lubricant cooling agent, etc.), allow increasing wear-resistance of the tool due to the course of non-equilibrium processes in friction during metal cutting, are not widely used today [2-5]. It is well-known [1-6] that the major phenomena in friction are concentrated on a thin near surface layer. In the works of B.I. Kostetskiy and L.I. Bershadskiy it is shown that any tribosystem should be considered as an open non equilibrium thermodynamic system, which makes all types of bodies interconnection concentrate in a thin-film object – secondary structures (SS).

2. Experimental studies
To study the characteristic representatives of the processed materials, which possess distinguishing physical and mechanical properties, chemical and structured-phase compositions: constructional steels C45 (НВ 180-200) and 41Cr4 (НВ 200-220); corrosion-resistant steels – 431S29, 301S21, X6CrNiTi18-10, as well as refractory and high-temperature resistant steels and alloys – 15Cr18Ni12Si4TiAl, CrNi73MoNbTiAl (vacuum-arc remelt), were chosen.

High-speed steels were chosen from tool materials: HS6-5-2, HS6-5-2-5, T12008, sintered powder tool materials (SPTM) on the basis of high-speed steel HS6-5-2; hard alloys: HG30, HV10, K10, HT01, HF10, commonly used in machinery production. At the full-scale tests four-sided plates (12x12 mm) and solid bit tools, mills and drills were used. Circular milling was performed by the end mills
from high-speed steel as well as from a hard-alloy material (d = 12; 13 mm; z = 4; 5), and face milling - by single-cutter mills (d = 90 mm), equipped with four-sided plates.

It has been established that SPTMs based on high-speed steel alloyed by titanium carbide possess high wear-resistant properties and can be classified as a new class of self-organizing tool materials. In particular, these may include SPTMs containing titanium carbide as a solid base and high-speed steel (HS6-5-2) – as a binder (SPTM + 20% TiC). With the help of AES (Auger-electron spectroscopy) and SIMS (Secondary-Ion Mass Spectrometry) it was found out that during the cutting process titanium carbides are transformed into thin surface films in the form of a titanium-oxygen composition (figures 1 and 2). This significantly improves frictional properties at operation temperatures of cutting (figure 3) and increases the wear-resistance of the cutting tool (figure 4). The study showed that the wear-resistance of such a tool is 2-3.5 times higher than the wear-resistance of conventional tools from high-speed steel.

![Figure 1](image1.png)

**Figure 1.** The spectra of the SIMS surface of SPTM tool (HS6-5-2 + 20% TiC) depending on the cutting time (steel turning 45: V = 60 m/min; t = 0.5 mm; S = 0.28 mm/r): a – after 4 minutes; b – after 20 minutes; c – after 24 minutes.

The essence of the second alloying principle is in the increase of the screening effect by a stable high-strength secondary structure (simple and complex oxygen-containing phases based on titanium and boron), appearing on the surface of the tool, which is achieved, for example, by adding 2% of BN. The addition of 5% of Al₂O₃ has not practically influenced the composition of secondary structures. The alloying was performed not by adding one or another element, but by adding compounds of the required density and instability at operation temperatures, that allowed using the compounds in relatively small amounts with a minimum possible impact on the volume quality. The application of both principles gives an opportunity to considerably increase the wear-resistance of the tool (for example, by adding 20% of TiCN) (figure 5).

Further improvement of the cutting tools includes applying the multilayer wear-resistant coatings on their working surfaces. Meanwhile, each layer of such a coating must be formed considering changes of the wear mechanism during the periods of running-in, normal (stable) and extremely gross wear.

It is established that the compromise between high wear-resistance and reliability is reached in a multilayer coating applied to the indium-enriched supporting plate. Indium is present in the lower coating layer in the metal as well as in the bound state (In – N). While warming during the cutting process indium partially turns into a liquid state and is partially oxidized (this is testified by the data of
Figure 2. Auger spectra of the surface of the processed material (C45): a) – after 2 minutes of cutting; b) – after 20 minutes of cutting

Figure 3. The influence of the temperature on tribotechnical properties of materials: ● ■ – SPTM (HS6-5-2 + 20% TiC); ○ ● – C45 (HB 180…200); ○ □ – HS6-5-2; □ ■ – C45 (HRC 30..32)

Figure 4. The influence of the processing time on cutting tool wear-resistance on the back surface of the tool at turning C45 (HB 180…200), V = 60 m/min; t = 0.5 mm; S = 0.2 mm/r: 1 – HS6-5-2; 2 – T12008; 3 – SPTM (HS6-5-2 + 20% TiC).

Figure 5. The influence of the processing time on the wear of the end mill Ø12 mm on back surface: 1 – SPTM (HS6-5-2 + 20% TiC); 2 – SPTM (HS6-5-2 + 20% TiC + 2% BN); 3 – SPTM (HS6-5-2 + 15% TiC + 5% Al2O3); 4 – SPTM (HS6-5-2 + 20% TiCN) (the processed material 41Cr4; V = 65 m/min; Sw = 63 mm/min; t = 3 mm; b = 10 mm).
metallographic studies). The liquid state as a lubricant reduces the friction coefficient. Oxygen-containing phases protecting the surface facilitate the prolongation of a normal wear stage, considerably increasing the tool wear-resistance.

It is established that, along with this, the following phenomena simultaneously occur: a – tribosplitting (decomposition) of a thin surface layer; b – formation of a stable amorphous-like protecting layer (of the type Ti-O and Ti-F) on the tool surface. Self-organization processes facilitate the improvement of wear-resistance during the stage of running-in wear, which leads to an increase in wear-resistance of cutters and end mills in 2 or 3 times.

3. Conclusions
The following conclusions can be made for the present studies:
• SPTMs based on high-speed steel, additionally alloyed by titanium carbide, possess high wear-resistant properties and can be considered as a new class of self-organizing tool materials.
• The optimal combination of strength and reliability (characterized by high adhesion of the coating (TiCr)N to the supporting plate) manifests itself in a multilayer coating with a lower layer, enriched by indium (implanted into the supporting plate surface), which facilitates the formation of amorphous-like structures In – N and In – O on friction surfaces and the prolongation of the normal wear stage, increasing the tool wear-resistance in 2.1 to 2.4 times.
• Multilayer coatings including ion nitriding of the lower layer from high-speed steel with further applying the PDC TiN coating, the upper layer of which is modified by PFPE (perfluoropolyether), provide high wear-resistance of the cutting tool.
• The main advantage of magnetic-arc filtration at alloying the coating by the PDC technique is a considerable (TiAl)N grain reduction, which leads to the formation of a surface layer with a grain size from 60 to 80 nm, i.e. within the nanoscale, and provides the possibility to use the cutting tool with such a coating under the conditions of high-speed processing by cutting with an increase in wear-resistance of the cutting tool in 3 or 4 times.

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