



SURFACE MODIFICATION OF TRIPLEX PVD COATINGS FOR CUTTING TOOLS



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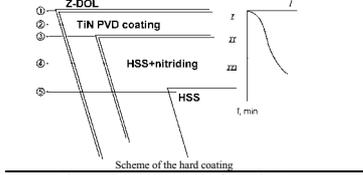
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Changes in chemical composition and fine (at atomic level) structure characteristics of surface during lifetime of cutting tools were investigated. High-speed steel of M2 type was hardened by well-known 'duplex' technology (ion nitriding with TiN PVD coating) in the present work. The top layer of the duplex coating was modified by perfluoropolyether Z-DOL. It was found, that the process of the self-organizing is taking place during cutting on the surface of the hardened material. Several parallel processes are developing during the self-organizing. The processes are: a) dissociation of chemical compounds of the multi-layered coating (TiN and perfluoropolyether) and intensive diffusion of nitrogen into the chip; b) forming of the stable amorphous-like protective layers (secondary structures, of Ti-O and Ti-F types) on the tool surface. For tools with multi-layered coating, containing top anti-frictional Z-DOL layer, the surface damage is minimal in the running-in stage of the wear that results in the improvement of the wear resistance for the tool with studied multi-layered coating.

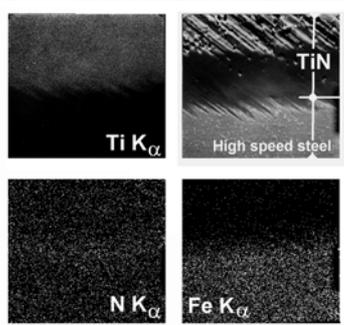
MATERIALS AND METHODS

This work we have studied the 'triplex' coating including ion nitriding of HSS base, nitride PVD coating deposition and top layer of PFPE lubricant. The hard coatings are relatively brittle ones and susceptible to intensive surface damage during the running-in stage of cutting tool wear. Eventually, the main part of the hard coating already destroys at the initial phase of the wear prior to the beginning of the stable (normal) stage of wear when the wear rate is lower by an order of magnitude compared to the running-in stage. This results in critical decrease of the wear resistance. That is why in this work the special anti-frictional (adaptable) top layer with protects the hard coating during the initial (damaging) stage of wear. This is one of the most important goals for the wear resistant coatings. PFPE is currently being used as lubricants in industrial applications. These fluids are attractive as lubricants because of their high thermal stability, low vapor pressures, and chemical inertness. The perfluoropolyether was applied as anti-frictional material to deposit as a top layer on the surface of the hard coating. A 0.5% solution of perfluoropolyether Z-DOL in freon 113. PFPE has the following chemical structure: HO-CH₂-CF₂-O-(CF₂)₆-O-(CF₂)₂₀-CF₂-CH₂-OH. The PFPE film was deposited by dipping into the 'hot' (at the temperature of boiling) solution.

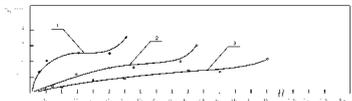
Triplex coating and its wear resistance characteristics



The common characteristics of coated HSS			
an elements / composite materials	Thickness of μm and structure of	Hardness, GPa	
VD-coating	(Ti,Cr)N nitride, stoichiometric composition	6...8	25...27
nitrided layer	Monophase high-nitride martensite	25...35	12...14
use HSS steel	M2 Type		8.0...8.5
perfluoropoly ether			



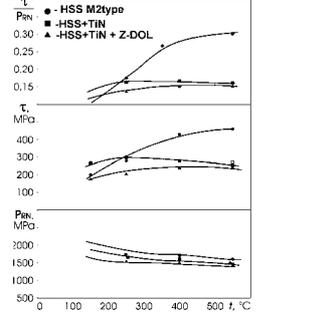
Microstructure of wear resistant coating on HSS



Change of wear value on the face of cutting tool edge (area of wear hollow) during cutting

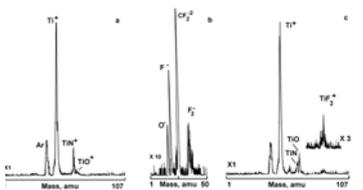
The wear process of cutting tools was studied during turning of 1040 steel. The tools were tested when cutting without and with coolant. Cutting speed was in the range 70 m per minute, depth of cutting 0.5 mm, feed 28-mm/rev. It has been found that the duplex coating efficiently protects cutting tool working surfaces against wear process. As a result, the wear volume of flank surface is minimal during all testing period. At the same time the wear volume at the rake surface is considerably higher.

Cutting tools wear curves are presented in Figure 1. The top (anti-frictional) layer decreases the wear rate at the initial stages of the tool service. So, the normal stage of wear starts at the minimal surface damage and the tool life increases significantly. The damage of the tool surface is minimal. The main function of the anti-frictional layer is the adaptability of the cutting tools with hard nitride coatings. The results of the friction parameter versus temperature study of the surface engineered coatings consists of (PVD (TiN) hard coating+Z-DOL's top layer) deposited on HSS substrate in a contact with 1040 steel show (Fig. 2) that the friction characteristics are improved at the service temperatures (500°C). As a result, the wear rate decreases considerably. The tool life is increased by 2...3 times.

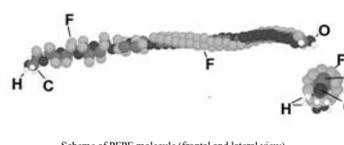


Dependence of friction coefficients of investigated materials on operating temperature.

Tribo-decomposition of PFPE



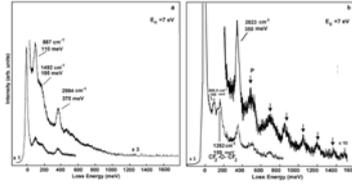
MS spectra of TiN coating with Z-DOL anti-frictional top layer. (a) - spectrum of positive ions (before service); (b) - spectrum of negative ions (before service); (c) - spectrum of positive ions during during 200 s.



Scheme of PFPE molecule (frontal and lateral view).

On SIMS spectra the PFPE Z-DOL gives the following peaks: O⁻ (16); F⁻ (19); CF₂⁻ (25); CF₂O⁻ (33); F₂⁻ (38 amu). These results are testified that the PFPE lubricant is chemical neutral at initial stage of cutting. The composition of the coating is altered during cutting. The small intensity peaks at 64 and 86 amu are appeared after cutting during of 200s. Obviously, we can attribute these peaks with tribo-decomposition of PFPE and TiN and forming of titanium oxide and TiF₂.

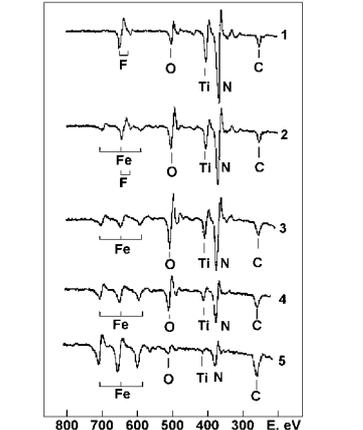
HREELS of PFPE



(a) HREELS spectrum of TiN coating on HSS. (b) HREELS spectrum of PFPE Z-DOL on TiN coating. In both cases the primary energy was 7.0 eV.

Figures shows the vibrational spectrum of TiN coating without (a) with Z-DOL lubricant deposited on tool surface. The surface cleaned prior to examination by heating in high vacuum 1×10^{-10} at 473 K for 15 min. Vibrational energy loss peaks for PVD coating deposited on HSS are observed at 110 and 370 meV. The asymmetric peak (110 meV) is observed at characteristic energy the transverse optical phonons with out-of-plane displacements (in the spectra). In addition, we detected a broad loss peak centred 185 meV due to optical phonons with in-plane displacement, feature in high energy loss portion of the spectrum at 370 meV attributed to an overtone of the loss at 185 meV. Vibrational energy loss peaks for Z-DOL deposited on TiN are observed at 100, 159 meV (See Fig. b). In additional intensity loss spectra was detected at the energies in the range of 350 - 1400 meV. The intensity loss at 159 meV is typical for perfluoropolyethers and associated with the coupled stretching motion of the (CF₂-O-CF₂) linkage [7,8]. The peaks of losses at 100 meV and 350 meV are analogous to 110 meV and 370 meV ones on the TiN spectrum. T softened phonons come from the weakening Ti-N bonds of subst due to the additional chemical bonds of N with H of the (CH₂) groups of PFPE film. Periodical fine structure of the loss spectra in energy range 350-1400 meV is probably overtone phonons spectrum stipulated by collective surface vibrations and explained by high disordered structure of PFPE film.

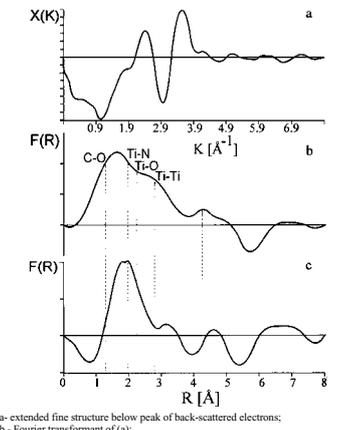
Tribooxidation of the coating



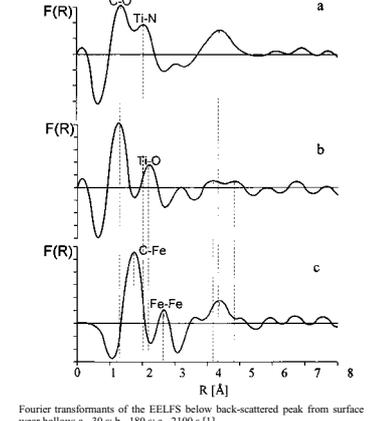
AES spectra from cutting tool surface: (1) TiN coating with Z-DOL anti-frictional top layer before service; (2) 100 s; (3) 300 s; (4) 500 s; (5) 750 s.

Element composition analysis on surface of the crater on the rake surface of the tool carried by means of AES shows that at initial stages of wear in the running-in zone there is a gradual dissociation of chemical compound of TiN-type under influence of considerable local stresses and temperatures generated on the surface of the coating during cutting. This process is observed in TiN coatings with and without using of PFPE top anti-frictional layer. This manifests itself in gradual reduction of nitrogen concentration on the surface at the work-in stage. Simultaneously, the oxygen in the contact zone replaces the nitrogen. These effects are clearly presented by a series of Auger-spectra (1-5), obtained from the surface of wear crater at different time of cutting. Significant increase in intensity of Auger-lines for iron at considerable time of cutting is brought about by the adhesion of steel on the surface of cutting tool and by the destruction of coating at the final stage of cutting. There is a good correlation between the change in wear resistance of cutting tool and the element composition of the coating. Depletion of coating surface by N and its enrichment by O during the transition from the running-in stage to steady stage of normal wear is connected with the dissociation of TiN, adsorption of O from the environment, and development of Ti-O-like compound. The oxidizing of TiN is observed at initial stage of cutting in ordinary TiN coating (SIMS spectra).

Amorphization of the coating

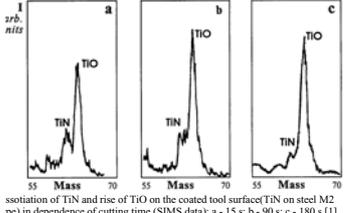


a - extended fine structure below peak of back-scattered electrons; b - Fourier transform of (a); c - Fourier transform of EELFS data below KLL line of N for the same sample.



Fourier transforms of the EELFS below back-scattered peak from surface wear hollow: a - 30 s; b - 180 s; c - 2100 s [1].

Tribooxidation of the coating



Tribooxidation of TiN and rise of TiO on the coated tool surface (TiN on steel M2) in dependence of cutting time (SIMS data): a - 15 s; b - 90 s; c - 180 s [1].

We can suggest the following mechanism of the hard coating wear with the top PFPE layer. The polymer molecule contacts to the surface of the TiN coating by positive polarised hydrogen atoms in the OH and CH groups. Negative polarized atoms of nitrogen in TiN compound could be the centers of adsorption on the surface of a hard coating. Negative polarized fluorine atoms in CF groups push back out of electron cloud surrounding the cutting tool/workpiece interface. The similar process of generation of surface potential under PFPE lubrication was shown elsewhere [9]. Due to this electrostatic effect PFPE lubricant significantly decreases the friction parameter at the cutting tool/workpiece interface. The accumulation of structural imperfections in the tool surface is decreased. There has been established that lubricant degraded at initial stage of cutting. Triboemission of the negatively and positively charged particles and surface potential due to tribocharging and tribochemical composition of PFPE are also shown earlier [9]. This process results in ionic fluorine adsorption and metal-fluoride interaction. After 200 s of cutting TiF₂ is appeared. This process is accompanied with oxidizing of TiN and mass transfer of nitrogen to the chip [1]. Such mass transfer takes place under extreme temperature and stress in the friction zone. The films of titanium-based oxygen compounds are forming on the tool surface during cutting having an amorphous-like structure. Oxide and fluoride of titanium are possesses high anti-frictional properties of coated cutting tool. These processes are the basis of self-organizing under cutting. Hard TiN coating with additional top lubricating layer generates the conditions for the significant decipating of friction energy with, by numerous ways. In this case friction control for engineered cutting tool mean the significant decrease of the surface damage and localization of all external interaction into the thin surface layer at maximal dissipation of energy generated during friction into this layer. The most important phase of the self-organizing process is associated with the running-in stage of wear. During this stage of self-organization, the wear process gradually stabilizes and finally transforms to stable (or normal) stage. It is very important to prevent surface damage and promote self-organization on the surface during the running-in stage of wear using the phenomenon of screening. The less surface damage at the beginning of normal stage of wear, the longer will be the tool life. The initial surface damage often leads to a dramatic decline in the wear resistance of the coating for this reason, a top layer with high anti-frictional properties is a critical component, and can be used to protect the surface of the hard coating. This is one of the most important goals for wear resistant coatings, especially at low and moderate cutting speeds, and for handling hard-to-machine materials where adhesive wear dominates. This can be achieved by applying an anti-frictional top layer on multi-layered coatings. Thus the goal of friction control is to prevent serious surface damage at the running-in stage and transform the tribo-system from its initial state into a self-organizing mode.

The physical mechanism of triplex coating wear

The researches made it possible to represent the change in the structure of complex engineered coating applied to the HSS. Cutting tools steel of M2 type hardened by 'duplex' technology (ion nitriding with plasma TiN coating and top layer of perfluoropolyether Z-DOL) were used in the present work. At the initial stage of cutting the PFPE lubricant decreases the friction coefficient and significantly decreases the structural damages on the tool surface. We can guess that this effect is a result of electro-static screening by the lubricant at the cutting tool/workpiece interface that improves ability of the surface to dissipate energy during friction. Titanium nitride of the hard PVD coating is oxidizing during cutting. The tribochemical composition of Z-DOL is the reason of forming the titanium-based fluoride and oxygen containing compounds on the tool surface. Forming of friction of amorphous-like compounds leads to low friction and heat transfer coefficients of the coating. Formation of the thin films of these compounds improves their thermal and friction conditions at the interface and stabilizes the friction process. Dissociation of TiN coating is accompanied with vigorous diffusion of nitrogen into chips.

Conclusions

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References

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