Surface coating metrology of carbides of cutting tools

V D Parfenov, G D Basova

Institute of Industrial Technologies and Engineering, Industrial University of Tyumen, 38 Volodarskogo Street, Tyumen 625000, Russia

Abstract. The coatings were studied by their main sign of the micrometric thickness by means of coating destruction and electron microscopical study of cleavage surfaces. Shock stress ruptures of heated carbides of cutting tools were performed. The discovery of the coating technology and creation of the coating structure for nonuniform and nonequilibrium conditions of the cutting process were dealt with. Multifracture microdestruction of nitride coatings, caused by complex external influences, was analysed to reveal the mechanism of interaction of elementary failures. Positive results were obtained in the form of improving the strength and wear resistance of the product, crack resistance increasing.

1. Introduction
In recent decades, protective-hardening, wear-corrosion-resistant coatings based on both pure metals and their compounds (nitrides, carbides, oxides, etc.) have been widely used. Their physical-mechanical, work-related properties are largely determined by the nature of the microstructure. Much attention is paid to obtaining and studying the properties of nano-microcrystalline coating materials, including those based on nitrides, carbides, borides, etc., which have higher physical-mechanical and work-related properties. It is established that the formation of such structures is associated with the segregation of one phase to the boundaries of the other. In this case, solid grains are not embedded in the matrix of another phase, but are separated from each other or covered with a very thin layer of segregated second-phase atoms. However, the listed structural models do not fully reflect possible structural forms (types) of coatings based on metal-nonmetal compounds. In our early works, the authors reported on the observation of tool coating wear in the process of cutting [3, 4]. This paper is devoted to the investigation of multifracture microdestruction of nitride coatings from complex external influences.

2. Materials, methods of obtaining and studying the coatings
The destruction of the structure of the surface and the design of the material involves consideration of microdeficiency issues. A synergetic study of the process of multi-stage and -level destruction of hierarchically successive dissipative states of dynamic material structures and a quantitative analysis of the features of the surface of fracture surfaces are very modern and profound in the monograph [1].

The studies take into account the work of real structures under severe loading conditions and allow us to consider local disruption, illuminate the micromechanisms of destruction, associate macro- and micro-parameters of destruction, and make an important conclusion about the cooperative interaction of various defects. The systemic influence of the structure dynamics on the resistance of materials to failure with the determination of the characteristics (stress intensity factor-CIN, yield point, etc.) of processes and materials is of special value. Besides, their temperature and velocity dependences and
the connection of the dimension of the fractal structure with the mechanical properties of materials are of great importance. This allowed predicting the complex behavior of materials under conditions that differ from the conditions of service from the test data and recommend powder materials with the ultrafine fractal structure and the possibility of mechanical alloying. For hard alloys and surface coatings, these recommendations are acceptable with refinements and development.

The micrometric thickness is the main feature of the coatings under investigation. The destruction of the coating and the electron microscopic study of the surfaces of the chips help to form an idea of the cross-sectional structure of such a thin object. The state of the transition coating layer from the base is also important. Much information was given in micrometric views of the external face of the coating, studied at some angle. The obtained information on the state of the micro-coating structure helps to correct the coating technology and create a coating structure for nonuniform and nonequilibrium conditions of the cutting process.

The thin micrometric coating film on the cutting tool must have special properties, including those that are non-uniform in space and time, and most of all self-organizing surface-energetic ones. Modern technology, however, provides uniform coverage, which, in addition, is weakly expressed by special properties of more decorative rather than functional nature [2]. Nanometric technology of coating and surface treatment is worth being paid attention to, which is much closer to solving the problem of surface coating of cutting tools, although it is associated with additional implementation difficulties. An increase in the significantly overall thickness of the coating on the cutting tool is hardly advisable, although it can solve some aspects of the problem. Most likely, the solution is in the future cultivation of special technical and information properties of coating through the energy nanostructure and the creation of special compounds of coating materials in self-organizing states.

Unfortunately, the coating technology used in the work is rather rough for creating thin and complex structure. Therefore, the authors will proceed from the construction that can be obtained by this method. In the work [8], an idea was expressed of the foamy state of the multi-dense structure of the coating, as a superhard cermet former with cells filled with solid solutions of cermets. Such representation is created from an analysis of the microstructures of the coating and the surfaces of its destruction. The layering of the micro-coating is also emphasized, each layer has a thickness determined by the dimensions of the microcells, the transition and surface layers of the coating are structurally distinguished. Micro-layers and -cells are organized during formation, but it is possible to influence this process by changing the application modes or alternating the components. Stratification and cellularity are emphasized by microdestruction of stratifications and block-cellular cracking [5, 6]. The boundaries of microlayers and cells are seen, especially at an angle, on the cleaved surfaces of the coating, with a 1000-fold increase on a scanning electron microscope.

Nano-micro-droplet evaporation and ionization of the liquid surface of the solid cathode metal, interaction with the ionized reaction gas with formation of compounds and accelerated sequential deposition of these particles on the surface of the cutting blades predetermines the composition of the micro-coating structure from the cells and layers’ units under certain operating conditions [7, 9, 10]. Comprehensive improvement of the coating formation technology, equipment modernization and finishing of both materials and coated surfaces allows us to develop a fundamentally new concept of surface coating as self-organizing structure that determines the energy separation of the surface substance from the material contact of the medium. Comparing two formats of titanium and zirconium nitrides, which differ visually a bit, but the density of the zirconium nitride substance is larger and this gives certain advantages.

3. Results, discussion
Having carried out the experiment, it was possible to obtain samples where the edge of the crosssectional microcrack in the coating is visible. When considering sections of the edge at a certain angle with different increase (figure 1 a, b), one can judge the cross-sectional structure of the coating obtained under several specific conditions for the possibility to get similar sample and emphasize the marking of certain features of this type coatings. On the cross-sectional surface of the cleavage, it can
be seen that the transition layer is strongly porous. This fact is due to the application conditions during its formation, or even to the conditions of breaking off the coating from the substrate,

![Figure 1](image-url)  
**Figure 1.** Two sections of the edge of a cross-sectional microcrack of a coating made from zirconium nitride on a cutting blade made from VK8: 1 – the surface of the coating, 2 – the end face of the cleavage of the coating, 3 – the surface of the carbide with the rest of the coating after separation; a – x2220; b – x3900.

or even to the conditions of preparing the coating surface or to the processes occurring during the interaction of the hardening coating with the base. It is the porosity of the surface layer that allowed tearing off the mechanically absent half of the coating from the base.

The residual transition layer of the nitride zirconium coating (figure 1, position 3) on the surface is in the form of a frozen wave of pinchers, which is very different from the type of the coating surface, depicted in figure 1, position 1. And it differs even more from the surface of the end face of the coating, presented in figure 1, position 2. On the surface of the residual layer, one may see many elements in the form of balls, round blocks of entangled extended microdroplets, scales, irregularly shaped fragments, etc. The ridges and wavetrough of pinchers were formed during the formation of the layer, similar to the external face of the coating, most likely from impacts of microdroplets, possibly when growing from nanodroplet. On the other hand, the ridges and wavetrough of pinchers could form in the course of any energy movements of the substance before solidification. This then shows incomplete interaction of this layer with the main coating, or ridges and troughs formed as a result of tearing off the coating from the residual layer.

The surface structure of a polished plate from VK8 in the photographs is almost not visible; it is completely different and covered by a residual layer. The residual layer itself is dense and is set on the carbide base and only further mechanical change has violated the bonds of the layers.

The layer of the main coating (figure 1, position 2) is composed of microdroplets stretched from the external face to the base, and probably of nanodroplets, most of them being almost interflowed together. Two sections of the edge of the cross-sectional microcrack of the coating show commonality and some differences in the coverage areas (figure 1a, b). The sizes of the visible microdroplets are very different, which indicates the heterogeneity of the microproperties of the coating elements. The elongation of the microdroplets indicates the direction of motion before solidification. If the thermal energy is greater, the microdroplets can merge more fully, but the unevenness of the energy will still affect the solidification. By photomicrography, the thickness of the coating can be easily calculated. By the size of the microdroplets, the number of layers of the coating can be calculated. The microdrops of the transition layer are larger and are merged into less bound blocks that indicates a lower temperature process during this period. The surface layer, formed under the conditions of the exit from the coating application mode, is particularly distinguished by the evenness of number of microdroplets.

The external face of the coating (figure 1, position 1), considered at an angle, is represented as if in an isometric view, where boundary pits in the form of polyhedron can be clearly observed. They are
obtained either from the impacts of liquid droplets during hardening, or because of energy disturbances of the substance when the coating surface is formed. Underlying layers probably have a similar structure; the transition layer has already been discussed.

Figure 2a shows a top view of the residual layer after separation of the main coating. The wavecrests are considerably blunted, the shapes of polyhedron become more rounded, the remnants of the separation layer are visible, fragments of the last layer are seen on the surface, the size of the ball is 4 µm. It should be pointed out and bear in mind that the connection between the separated layers has been obtained specially weakened, it is impossible to separate the normal coating in this way.

Figure 2. Residual layer after detachment of nitride zirconium coating on the surface of hard alloy VK8: a – view from above, b – side view, x4300.

In the side view, at an angle (figure 2 b), there is a micrograph of the residual transition layer with two surface elements - microsphere with a smaller sphere on the surface and a microblock of several half-fused drop-shaped particles, as well as with two superficial elements – an uneven edge of the overhanging cover flake and an overhanging shive or an outgrowth of the coating in the center. The nano-microdrop mechanism of the coating layer formation determines the structure, in which the cross-sectional cracking of the microcovering is much more likely to exist rather than longitudinal cracking.

4. Conclusions

Investigation of the multifractured microdestruction of nitride coatings because of complex external influences made it possible to reveal the mechanism of interaction of elementary failure. Positive results were obtained in the form of improvement of the strength, wear resistance of the product and an increase of the crack resistance.

5. Literature

[1] Artamonov E V, Efimovich I A 1994 Optimization of processing by details cutting from the hardly processed materials on automatic lathes. (Tyumen, TSOGU) p 83
[2] Artamonov E V, Smolin N I 1993 Combined cutting tool with replaceable many-sided plates (Tyumen, TSOGU) p 109
[3] Parfyonov V D, Yusupova E M, Basova G D 2016 Destruction of cutting plates surface covering. Bulletin of higher education institutions. Oil and gas. 2 103-107
[4] Parfyonov V D 2014 Improvement of cutting process by a tool covering: monograph (Tyumen, TSOGU) p 112
[5] Bolotnikov G V 1994 Modern coverings for the hard-alloy cutting tool STIN 4 33-34
[6] Vereshchaka A S, Tretyakov I P 1986 Cutting tools with wearproof coverings. (Moscow, Mechanical engineering) p 102
[7] Vereshchaka A S 1993 *Operability of the cutting tool with wearproof coverings*. (Moscow, Mechanical engineering) p 326
[8] Makarov A D 1996 *Wear and firmness of the cutting tools*. (Moscow, Mechanical engineering) p 264
[9] Parton V Z 1990 *Mechanic of destruction*. (Moscow, Science) p 240
[10] Fadeyev B S 1993 Low-temperature wear and destruction of the ceramic tool *Machines and tool* 2 26 - 28