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ESTIMATION OF DAMAGE DEVELOPMENT AND THE TIME OF FAILURE OF CUTTING INSERTS MADE OF HARD ALLOYS AND SUPERHARD COMPOSITES BY CHEMOGRAPHY METHODS

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The results of theoretical and experimental studies aimed at identifying hidden defects in the structure of hard alloys and superhard composites used in the manufacture of cutting tools in order to control and predict gradual and sudden failures of cutting inserts.

Damage control of cutting inserts is carried out by microscopic analysis. Deeper damage to the structure can be detected using the method of chemographic imaging. The proposed method is based on obtaining photographs of the oxidative reactions of materials of ultra-low concentrations occurring on the surface of solids under thermobaric loading.

Before the moment of a sharp release of the energy of destruction, chemical processes of ultra-low concentrations are activated. Chemography allows to fix the zones where the incipient microcracks and microdefects are ready to actively develop, which can lead to the onset of macrodamage and failure to work.

The chemographic image of the plate obtained as a result of the study is compared with the reference sample, as a result of which it is possible to assess the initial defect state of the material and predict the further period of the plate's operation.

The criterion for the existing defects and imperfections in the structure is the change in the blackness index of the chemographic image, the minimum value of which indicates a minimum of structural defects and internal defects in the material under study.

The results allow to propose a new method for controlling the surface of cutting plates, which can be easily implemented in any machine shop, which makes its application very promising

Keywords: chemography, internal defects, microdamages, coating spalling, failure, gradual wear, low concentration reactions, cutting tool, reliability prediction

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1. Introduction

A modern technological system, which includes a tool with plates made of hard alloys or superhard synthetic materials, is a complex dynamic object, the functioning of which is characterized by a certain ensemble of realizations caused by phenomena of a deterministic and random nature. In this case, the properties of cutting inserts made of hard alloy (HA) or superhard synthetic materials (PCSM) and their behavior during operation are dominant in the manifestation of functional or parametric failures. As a rule, systemic phenomena are associated with wear of the edges of the plates, and accidental – with chipping of the plates or their tops. In the first case, it is possible to talk about the exit of the size of the product formed during processing outside the tolerance field. In the second, a complete violation of the natural course of the machining process occurs – cutting occurs with a critical change in the geometry of the contact zone of the tool or stops altogether.

The reason for the onset of failure lies in the critical growth of internal defects and damage to the structure formed at the stage of manufacturing cutting inserts.

The physicomechanical and chemical properties of sintered hard alloys and superhard composites are determined not only by their composition and structure, but also by the presence of defects in the latter, which necessitates their control. The presence in the structure of materials of various kinds of discontinuities, structural imperfections and other defects affects the performance of tools, ensuring the productivity of processing processes, as well as the reliability of processing operations in general.

Thermobaric loading on the contact surfaces of tools is a determining factor in the development of damage in the structure of their materials. The structures of different tool materials resist this loading in different ways. In a number of cases, there is a latency period when an increase in the number of defects in the structure does not manifest itself in any way and only after passing through a certain activation barrier in the material do elements of destruction appear.

From this point of view, the simultaneous manifestation of sudden and gradual failures in the operation of cutting inserts is obvious, and the efforts of specialists in the field of instrumental materials science and cutting tools are aimed at identifying the patterns of which.

Predicting the reliability and performance parameters of tools made of hard alloys and superhard materials is an extremely important task. There are a sufficient number of control methods. However, they are all costly. As a rule, the methods require special equipment, and the control process can be long in time. All this negatively affects the cost of production as a whole.

From this point of view, the simultaneous manifestation of sudden and gradual failures during the operation of cutting inserts is obvious;

Thus, the search for effective diagnostic methods for such plates, based, in particular, on new methods for fixing changes in the state of the surface layer, on the analysis of statistical indicators of the reliability of their functioning based on information from a sample from a specific batch, is an urgent scientific task. Its solution will significantly reduce costs during diagnostics, as well as prevent the appearance of defects when processing critical products.

2. Literature review and problem statement

It is known that in the practice of machining there are many different ways to diagnose the condition of a tool. Some of these methods can be used in situ, while others are implemented when the cutting process is stopped. They are based on effects of various natures that accompany the cutting process. For example, in [1], an approach to the diagnostics of carbide tools is considered based on the assessment of fractal parameters of the structure of hard alloys and their evolution in the process of operational loading. The authors analyze in detail the changes accompanying the operation of the plates, conclude that the structure parameters are functionally conditioned by the state of the tool before the onset of critical irreversible fracture phenomena. However, this method is very difficult to use in engineering practice, and requires both a powerful modern instrument base and significant labor costs.

In work [2], digital images of worn-out areas of instruments, recorded by vision systems, were considered, and their characteristic fragments were studied using contour segmentation as texture elements, according to the parameters of which the state of instruments was diagnosed. The input parameter for such diagnostics is the images of the working sections of the instrument, and the registration means are the elements of technical vision equipped with special signal processing algorithms.

Such a system, despite the rather high accuracy of predicting the state of working surfaces, has the highest complexity, the need for adjustment, and maintenance of processing conditions. It is clear that such systems are effective in the case of using unique tools, the cost of which or the cost of processing is significant.

A simpler alternative to diagnosing the state of the cutting edges of the tool is the use of methods of acoustic emission, the nature and spectrum of which is indirectly determined by the stability of the cutting process. So, in [3], a system for diagnosing the working capacity of a cutting tool is considered, based on measuring the acoustic emission signal and cutting power, and in [4], a system for diagnosing tool wear is considered based on information contained in the acoustic emission signal.

The authors of works [3, 4] propose to use acoustic (noise) emission as a signal that unambiguously and clearly reflects the conditions of the onset of critical states of the instrument, after which it will fail.

A significant limitation of the use of such systems is the limited level of the useful signal (signal-to-noise ratio), as a result of which the accuracy of diagnosing the state of the instrument can be low.

In [5], the authors propose to use electrical and mechanical parameters of the cutting process in systems for diagnosing the operability of tools.

All of the above methods are based on the phenomena that occur in the zone of contact of the tool with the workpiece surface, and occur at the time of machining.

The authors of this work propose a diagnostic method based on the analysis of the intensity of micro-mechanochemical effects on the contact surfaces of the tool as a reaction to thermobaric loading, taking into account the action of the technological environment. In this case, the action of the environment at the time of diagnosis is not required. The proposed method makes it possible to establish the operability of a tool as a kind of system, the manifestation of sudden and gradual failures in which is described by known relations.

3. The aim and objectives of research

The aim of research is to establish the regularities of chemographic blackness on the surface of carbide plates and plates made of superhard materials, corresponding to the development of micro- and macrodamages, which can lead to the loss of the plate's performance as a whole. This will make it possible to establish dependencies connecting hidden plate defects with the resulting chemography parameter – blackness of images during analysis.

To achieve the aim, the following objectives are set:

– obtaining chemographic blackness when changing the state of the surface of cutting inserts, including those with protective TiN coatings, to establish the effect of blackness the image for the surfaces of TiC, WC, Co;

– revealing the parameter of the degree of blackness and establishing the functional conditionality of the latter by the operating conditions of the plate with developing internal damages;

– assessment of the degree of blackness of chemographic images in terms of density and area before the onset of loss of plate performance.

4. Materials and research methods. Using the phenomena of chemography to diagnose defects on the surfaces of cutting inserts

4. 1. Development of damage to the plate and loss of its performance under thermobaric loading

According to [6], the sought-for parameter of the reliability of the tool's functioning requires the description of the search parameter not as a certain constant, matrix element or deterministic function, but as the mathematical expectation of a random variable in a certain time limit. So, each implementation of the process $x_1(t)$, $x_2(t)$...$x_i(t)$ (Fig. 1, *a*), is a function of time. It is known [6] that in the case when there are two boundaries described by curves A and B, the formed strip will be the area of realization of the random process as a whole.

Since the set of realizations of the random process $x(t)$ for a fixed point in time, which determines a certain section, corresponds to the random value shown by dots (Fig. 1, *b*), with a significant number N of realizations of the random process, a set of random numbers is obtained that form a sample characterizing process at time t [7]. In graphical form, this sample is a collection of points on the numerical x-axis.

The probability distribution function $P(x)$ for a Gaussian process is equal to the probability that a random process has values less than x. The probability that the random process $x^*(t)$ in the section falls into the interval between x_1 and x_2 is determined by the difference in distribution functions, that is:

$$p\left(x_1 \le x^*(t) < x_2\right) = P(x_2) - P(x_1).$$

According to [8], the mathematical expectation of a random process in a section for a known probability density with an infinite number of realizations corresponds to the dependence:

$$m_{2x}(t) = M\left[x^2(t)\right] = \int_{-\infty}^{+\infty} x^2 p(x)\,\mathrm{d}x,$$

$$D_x(t) = \sigma_x^2(t) = M\left[\left(x(t) - m_x\right)^2\right]. \quad (1)$$

Defects found in the materials of tools can be conditionally divided into two large groups [9, 10]:

– defects formed during the formation of the initial material sample: foreign inclusions, volume and surface porosity, structurally free carbon, the presence of an n-phase, uneven distribution of particles of the n-phase, uneven grain size of the α-phase, etc.;

– defects formed in the process of obtaining the final product: delamination, longitudinal and transverse cracks, chipped sections, surface irregularities, corrosion spots, etc.

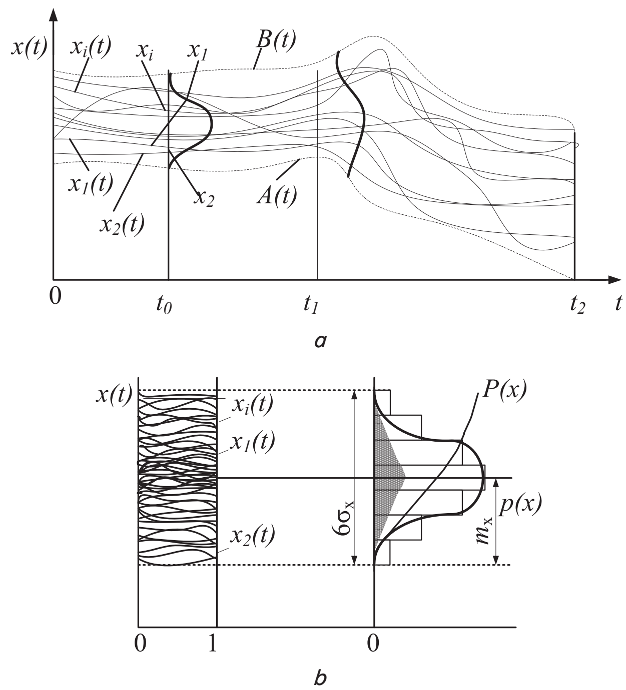


Fig. 1. An ensemble of realizations of a certain random process, defined in the same time interval: *a* – graphic interpretation of random values of the process $x(t)$ in the section t; *b* – statistical processing of the sample

The normal course of the operation of the tool takes place if the tolerance for the resulting size T_b of the product is not exceeded. Let's take into account that the mechanisms of damage of the cutting insert are different and are determined by the structure of its material and the properties of the applied coating. At the same time, damage to the front surface of the tool in the form of chips can suddenly change the conditions for the implementation of the cutting process, and the back one can cause the manifestation of a gradual failure of the tool, Fig. 2.

Based on the representation of the plate as a kind of multicomponent system, the elements of which are characterized by different mechanisms of perception of thermobaric loading and accumulation of damage to the front and back surfaces of the tool, the probability of the normal course of the cutting process can be represented as follows:

$$P(t) = P_c(t) \cdot P_t(t) \cdot P_k(t), \quad (2)$$

where $P_t(t)$ – probability of failure-free operation of the surface layer of the plate or coating; $P_c(t)$ – probability of failure-free operation of the plate base; $P_k(t)$ – probability of the absence of adhesive damage at the «base-coating» interface.

The corresponding components of equation (2) can be obtained on the basis of an analysis of the processes occurring in the system.

For a base made of hard alloy or superhard material, failure can be due to wear under intense thermobaric loading (which leads to the manifestation of gradual failure). Destruction can also be a result of a critical growth of the initial structural defects, which were formed at the stage of plate production. In this case, the catastrophic termination of the normal course of the processing process will determine the emerging chips in the working sections of the tool.

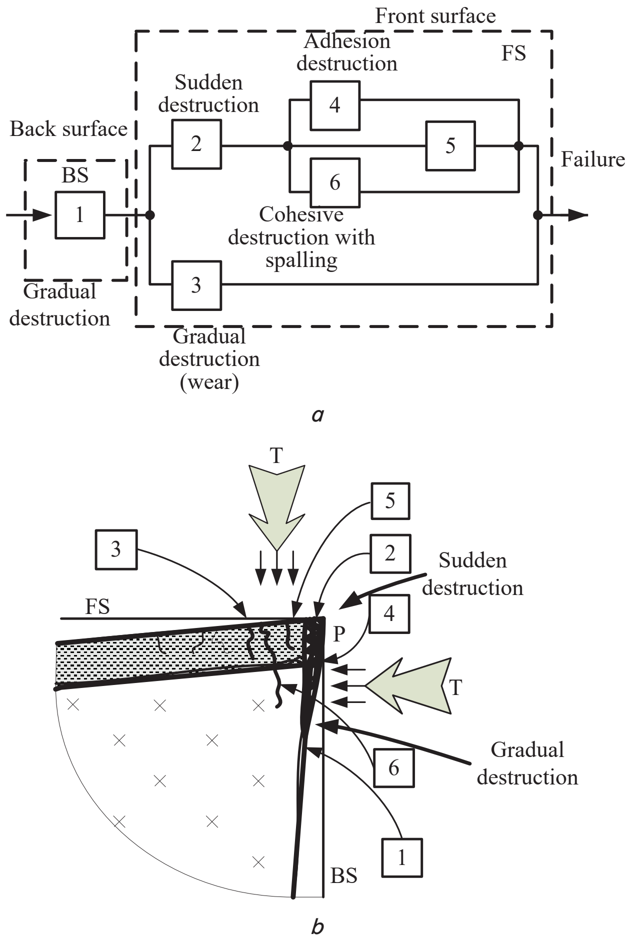


Fig. 2. Diagrams of damage manifestation and failure occurrence: *a* – damage to the front and back surfaces of the tool; *b* – scheme of failure manifestation

In accordance with the provisions of linear fracture mechanics, the rate of energy release through the crack edges is defined as:

$$G=\frac{1-\nu^2}{E}A(V)k^2, \qquad (3)$$

where $k=\sigma\sqrt{\pi a}$ – stress intensity factor, for a given class of materials the growth rate of the crack edges due to the difference (G–R), where R – resistance to cracking, can reach 500–600 m/s, that is, the destruction of a body with a size of 4–6 mm occurs in 5–10 μs – almost instantaneously.

If to consider gradual wear and chip formation as independent events determined only by the presence of defects in the material, the probability of gradual $\left(1-P_n^c\right)$ and sudden $\left(1-P_p^c\right)$ failures allows the probability of failure-free operation to be determined as follows:

$$P_A(t)=P_n^c(t)P_p^c(t).$$

The wear of the plate surfaces manifests itself for a certain time, which makes it possible to write an expression for determining the probability of failure as a complex event $F_t(t)=\left(1-P_n^t(t)\right)\left(1-P_p^t(t)\right)$, and reliability, according to $P^t=1-F^t$, is defined as $P_t(t)=\left[1-\left(1-P_?^t(t)\right)\left(1-P_p^t(t)\right)\right]$.

Then the reliability of the cutting insert as a whole will be determined as follows:

$$P_t(t)=P_n^c(t)P_p^c(t)\left[1-\left(1-P_?^t(t)\right)\left(1-P_p^t(t)\right)\right]P_p^k(t). \qquad (4)$$

Taking into account that the manifestation of a gradual failure is a consequence of the wear process, based on the recommendations of [5], the probability of failure-free operation is determined as:

$$P_1(t)=0.5+\Phi\left(\frac{X_{\max 1}-a_{01}-\gamma_{cp1}t}{\sqrt{\sigma_{a1}^2+\sigma_{\gamma 1}^2t^2}}\right),$$

and the occurrence of an accidental failure obeys the exponential law $P_p(t)=e^{-\lambda t}$, it is possible to write an expression to determine the failure-free operation of the plate:

$$P(t)=\left[0.5+\Phi\left(\frac{d_{c\max}-\bar{d}_c-\gamma_c t}{\sqrt{\sigma_{dc}^2+\sigma_{\gamma c}^2t^2}}\right)\right]\times$$
$$\times\left\{\begin{array}{l}1-\left[0.5-\Phi\left(\dfrac{D_{k\max}-D_{\bar{k}}-\gamma_{Dk}t}{\sqrt{\sigma_{Dk}^2+\sigma_{\gamma Dk}^2t^2}}\right)\right]\times\\ \times\left[1-e^{-\lambda_D t}\right]\end{array}\right\}e^{-\lambda_d t}P^z(t), \qquad (5)$$

provided that $P^z(t)$ is determined based on the analysis of the causes of failure due to coating destruction on the plate.

The geometric interpretation of the onset of failure is shown in Fig. 3. In this case, to calculate the value coating, it is necessary to determine a significant number of parameters, which is difficult and requires a large sample of the studied samples.

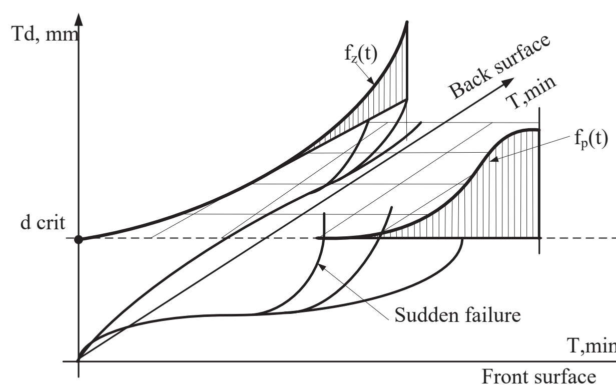


Fig. 3. Geometric interpretation of the onset of failure of an insert mounted on a cutting tool

Based on the representation of the onset of failure (both parametric and sudden) in the form of a curve of change in the criterion T_d, it is possible to conclude that in the general case:

$$T_d=K\prod\nolimits^{i=1\ldots n}S_i(\tau),\quad S_i(\tau)_{P,T}=b_0+b_1\tau+b_2\tau^2, \qquad (6)$$

where S_i – the generalized properties of the plate that determine the resistance to damage, τ – current time.

Establishment of the distribution law of the failure onset time $f(t)$, and, accordingly, the expected period of tool life with a cutting insert is possible using (5) by calculating $F(t)$ for certain time intervals. Then the onset of failure according to (6) is a condition under which $T_d < [T_d]$, $[T_d]$ – the critical level of damage to the plate. Thus, the empirical curve (6) can be obtained knowing the values of the temperature T, the force loading P and measuring a certain parameter S, which reflects the ability of the plate material to resist the development of damage over time.

For equation (5), the parameters characterizing the damage to the plate are γ_c, γ_D, σ_c, σ_D, λ – the rate of development of damage to the plate (base and surface layer) and coating, initial deviations in the properties of plate and coating materials, which determine the rate the development of damage and the flow of failures due to defects in the structure of materials, respectively. The presented parameters make it possible to unambiguously characterize the degree of damage, and when normalizing $P(t)$ – and the expected duration of the plate operation before the failure occurs.

Some of these parameters – γ_c, γ_D can be easily determined by the chemography method, which makes it possible to obtain models of damage development both for a batch of plates and for each plate separately.

Crack detection is usually performed using microscopy (including electronic), using visualization tools. However, the detection of small cracks can be more effective using the chemography method [11, 12]. The essence of the method consists in photographing oxidative reactions of ultra-low concentrations occurring on the surface of solids, and depending on the state of the surface and the conditions of its thermobaric loading at the previous stages.

For the set task of predicting the development of plate damage and, consequently, practical conclusions about the reliability of TOC functioning, the use of chemography is very expedient. The preliminary studies carried out made it possible to reveal significant differences in chemographic patterns for the same plate at different times of its operation. Indirectly, the method allows one to determine the required parameters γ_c, γ_D, σ_c, σ_D. At the same time, the flow of failures associated with chipping and spalling λ can also be determined from the characteristic fragments of chemographic images obtained in the zones most prone to destruction.

4. 2. Applied devices, materials, reagents

Microphotometer, samples of materials under study, X-ray photographic film, chemical reagents for obtaining photographic images, distilled water, abrasive powder M10, glass plate 4–6 mm thick.

4. 3. Obtaining chemographic images of plates made of hard alloy and superhard materials

Plates were used from hard alloy T15K6 DIN HS123, ASTM C70 with TiN coating with a central hole for fixing on the tool and round plates SNMN 090300 made of polycrystalline superhard material (PCSM) «Borsinit». Stainless steel X18H10T, as well as structural steel 40X were processed. Processing modes – v=85 m/min, S=0.07 mm/rev, t=5.0 mm. The outer surface of the shaft-type workpiece was processed. The temperature in the treatment zone was monitored with a Bosch GIS 1000C pro pyrometer.

The thickness of the coating was determined using a NOVOTEST TP-1 thickness gauge equipped with an F-0.3 sensor with a resolution of ±3 % of the measured value (with a measured value in the range of 0–300 µm).

The results of chemographic studies of the wafer surfaces were analyzed together with the results obtained with a scanning electron microscope.

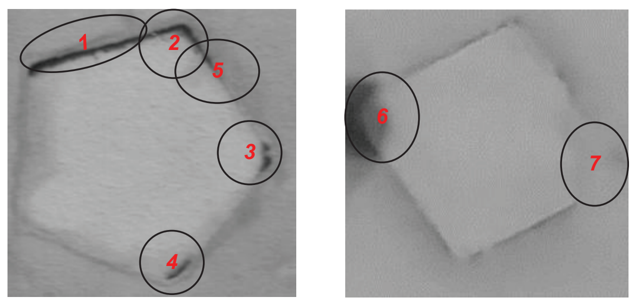
The procedure for obtaining chemographs is described in detail in [13].

5. Conditionality of darkening in chemographic patterns by the action of factors of thermobaric loading

5. 1. Obtaining chemographic blackness when changing the state of the surface of the cutting plates

During operation, the cutting inserts are subjected to various loads of power and temperature nature, as a result of which damage accumulates in the surface layer with the growth of defects. Such defects can subsequently lead to the manifestation of macrodestruction and to the failure of the plates.

Studies of chemographic images (Fig. 4) have shown that chemography can reveal zones on cutting plates that perceived the thermobaric load that occurred during operation (zones 1–4, 6), as well as an incipient main crack (zone 5). At the same time, in some zones (6, 7), blackness effects associated with contamination of the photographic plate were observed [11, 12].



a *b*

Fig. 4. Chemographic images of hard alloy plates: *a* – coated working edge; *b* – blackness degree in the images is associated with the defectiveness of the material and depends on the operating time of the plate

To establish the possible effect of coatings with a thickness of 3–10 µm on the surfaces of a hard-alloy plate on the form of chemographic images, special studies were carried out.

Since the active surface area of the sensor is 9 mm^2, the measurements were performed at fixed points along a line passing through the center of the plate. Thus, the average values of the coating thickness h were obtained, both at the tops of the plate and at its working edges. Coating thickness measurements were carried out on new plates, as well as after a certain period of their operation.

As a result, it was found that after operational loading in almost all working sections of the plate, the coating thickness decreased to 1–3 µm, and the coating was completely removed at the tops of the plate, Fig. 5, *a*, *b*. At the same time, the measurement results obeyed the normal distribution law, which excludes gross errors and allows the measurements to be considered adequate.

The obtained chemographic images of plates with different residual thickness h of the TiN coating practically did not differ either in density or in terms of image resolution. At the same time, the patterns of the surfaces of TiC, WC, Co were identical. This allows to conclude that the applied coatings do not have a predominant chemographic effect in comparison with the defects that are formed during the operation of the plates and which unambiguously determine the performance of the plate in the future.

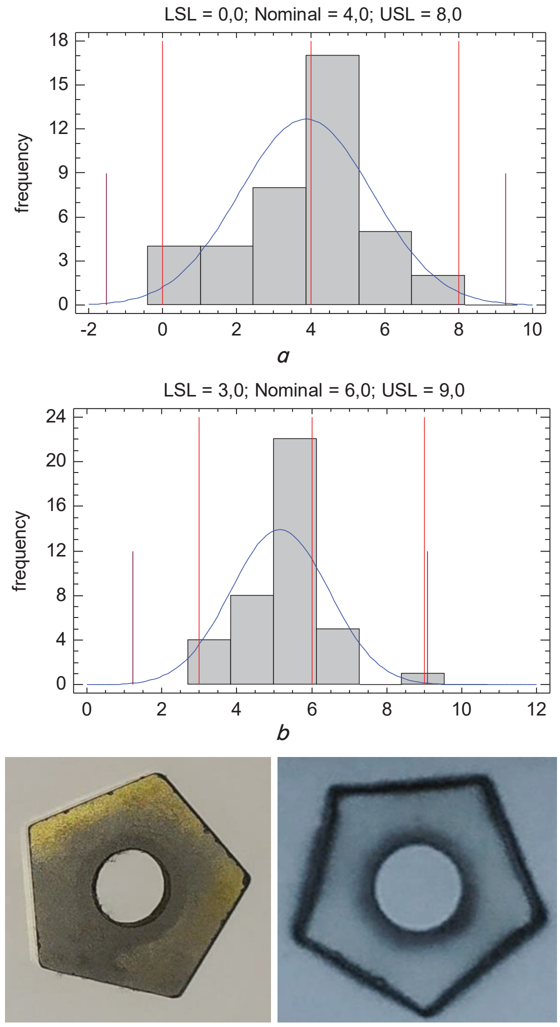


Fig. 5. Distribution of coating thickness and chemographic images of plates: *a*, *b* – distribution of coating thickness on the working surface of the plate; *c* – plate appearance; *d* – chemographic image of the working surface of the plate

5. 2. Identification of the parameter of the blackness degree and the establishment of the functional conditionality of the latter by the operating conditions of the plate with developing internal damage

Since chemographic images differ in the optical density of the image, averaging of shades of gray was used – to assess the degree of influence of the acting factor on the chemographic image, it was proposed to use the relative blackness index, which was calculated by the formula:

$$I_c = \frac{F_i}{100 - F_{\min}}, \tag{7}$$

where F_i – current blackness of a point on the analyzed surface (%); $F_{\min}$ – area of light background, in % relative to the accepted white level.

This made it possible to determine the optimal exposure time τe from the level of the relative blackness index as a function of time τ. The results showed that exposure for τ_e=20 min allows obtaining an image of maximum contrast and revealing individual defects both on the surface and in the near-surface layer of the plate (Fig. 6).

The carbide components of the hard alloy are not prone to active oxidation under normal conditions (at T=20 °C). That is why, in addition, the determination of the maximum possible resolution of the method was carried out, which makes it possible to predict the depth of damage to the layer based on the detected defects. Thus, the performed chemography procedures made it possible to establish a change in the resolution of the method at different liquid temperatures during exposure.

As shown by the results of studies (Fig. 7), at T=20 °C, defects with sizes exceeding 100 μm were clearly recorded, defects less than 50 μm were not unambiguously identified. An increase in temperature to 80 °C allows detecting defects of 30–80 μm in size, which makes it possible to determine developing microcracks.

In contrast to the optical image of the plate shown in Fig. 5, *c*, the chemographic image makes it possible to distinguish clearly defined contours with a width of 0.4–0.9 mm, which is due to the presence of defects in the material. It is concluded that the presence of a thin TiN layer has no significant effect on the density of the black tint of the image. Indeed, a change in the coating thickness (from 2 μm to 10 μm before treatment and from 0 μm to 8 μm after operation) did not lead to a change in the I_c parameter. At the same time, it was found that with an increase in the study time of a single plate, the chemographic picture changes: the boundaries become wider, and the vertex that was not subjected to loading gives less exposure. A worked apex, even without damage to the coating, is more active, and therefore darker. These features depend on the conditions of operational thermobaric loading of the plate, which activate the deformation state of its material and determine the chemographic activity of the investigated surface.

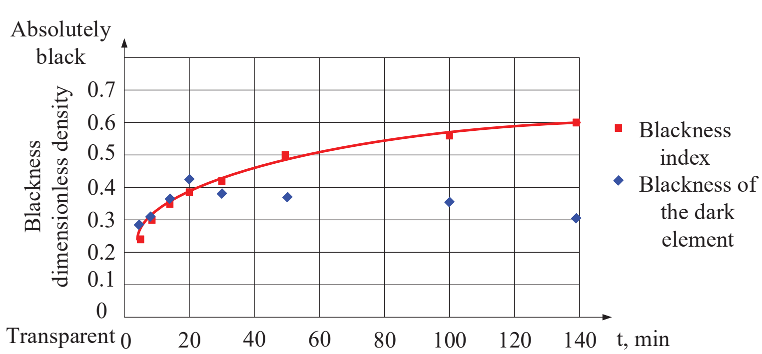


Fig. 6. Change in blackness when changing exposure time

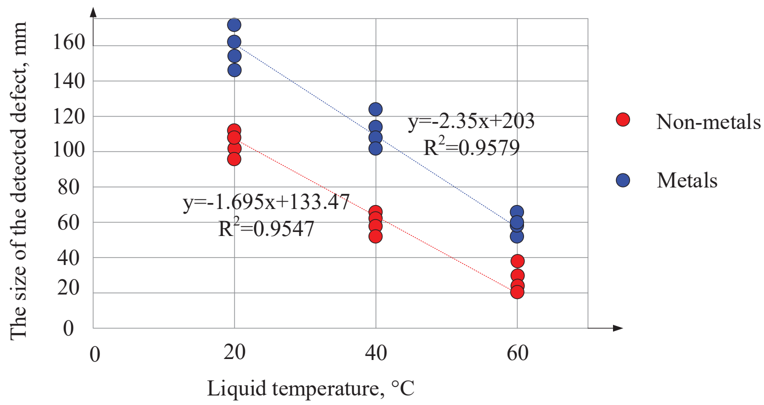
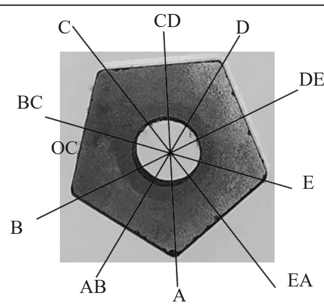
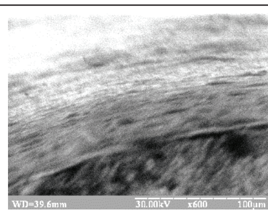
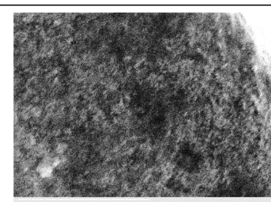
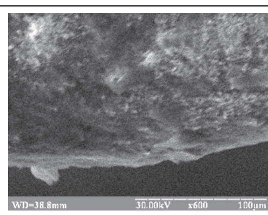
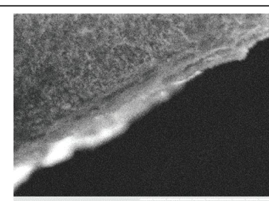
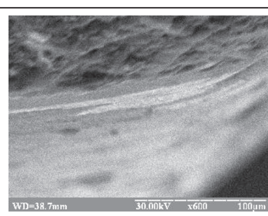
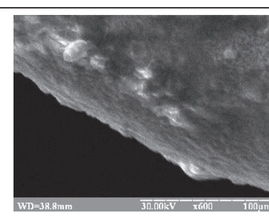
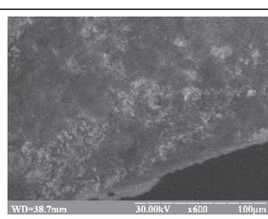
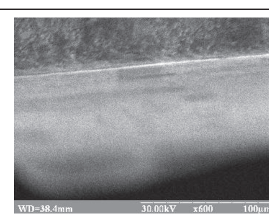


Fig. 7. Change in the size of detected defects depending on the temperature of the liquid

Electron microscopic studies of the characteristic points of carbide cutting inserts (Table 1) showed that the chemographic pattern changes with an increase in size and the accumulation of critical damage in their material. At the initial moment of time, the maximum image contrast was observed only in the places of conjugation of the plate planes. As a result of the action of the operational loading, I_c index increases on those surfaces where the action of the factors of the cutting process was maximum.

Table 1

Results of electron microscopic examination of T15K6+TiN carbide plate

			
Vertex A. Breaking the coverage at the top without changing the geometry		Edge EA. Damage point – material structure visible	
Edge DE. Individual damage to the coating		Point OS. No damage edge	
Vertex C. High quality surface layer		Vertex E. The back surface is coated, on the front there are defects	
Edge AB. Adhesive layer visible		Edge CD. Good quality front and back surface	

However, no direct correlation has been established between the results obtained by chemography and electron microscopic studies. In particular, the coating at the top C was in a satisfactory condition for a long time, and only after reaching a critical damage a chip was formed (Table 1).

At the same time, for the edge EA and apex A, having similar initial damage to the coating, the chemographic images were practically the same. Their optical density, although it was maximum, was also localized. This allows to conclude that chemography fixes a certain activity of the edge of two perpendicular faces simultaneously with developing surface defects.

In general, this corresponds to the results presented in Fig. 5, where the accumulated internal damage in the PCSM plate also outlined zones 1–4, i.e., the places where brittle fracture of the sample can occur later.

Local light points in dark fields, reflecting the presence of edges of the sample under study, can be explained by the fact that the surface practically does not show activity in these zones.

Coated carbide inserts were used to estimate the parameters of model (5) taking into account the onset of both parametric and functional failures (among which gradual ones are determined by the development of internal damage in the near-surface layer).

5. 3. Evaluation of the blackness degree of chemographic images in terms of density and area before the onset of loss of plate performance

The physical basis of fracture of hard alloys and superhard composites is different. However, from the point of view of modern concepts of damage to quasi-brittle bodies and the Griffiths theory, any crack is characterized by an excess of energy. It can be assumed that before the onset of the moment of avalanche-like release of destruction energy, the latter activates chemical processes of ultra-low concentrations. In this case, the growth of a dark spot near the characteristic boundaries of the body will indicate areas where the incipient microcracks are ready to actively develop, which will subsequently lead to the onset of macrodamage and the manifestation of failure.

The results obtained make it possible to qualitatively and quantitatively assess the serviceability of the plates and the intensity of their damage development under operational loading.

Thus, by obtaining a chemographic image of the original plate and comparing it with the reference sample, one can estimate the initial defect state of the material and predict the plate's service life. In this case, the criterion of the existing defects and imperfections of the structure is the change in the blackness index, the minimum value of which according to (7) indicates a minimum of structural defects and internal defects.

For equation (5) with parameters that determine the damageability of the plate material, chemography makes it possible to establish λ – the flow of failures due to the destruction of the surface layer of the plate. The rest of the parameters – γ_c, γ_D, σ_c, σ_D can be determined using metrological measurements (dispersion of geometric parameters that determine the transition performed, wear rate along the front and rear surfaces of the tool).

At the same time, as the main hypothesis, the assumption was made about an increase in the density and area of chemographic darkening of the controlled surface before the onset of critical damage.

If the flow of failures λ is determined on the basis of statistical observation of the operation of N plates from m batches, then based on [1], the majority of sudden failures will obey an exponential law of the form $P_p(t)=e^{-\lambda t}$. Distribution density function have the form $f(t)=\lambda e^{-\lambda t}$. In this case, the parameter of the flow of failures can be obtained from $\lambda=1/T_{av}$, T_{av} – the average time of the onset of a sudden functional failure, in this case, the brittle fracture of the working sections of the plate.

In this setting, the average time to failure correlates with the darkening of the surface during chemographic examination, taking into account that $T_{av}=f\left(1/\left(I_{T2}-I_{m1}\right)\right)$, i. e., the more darkened areas of the plate when comparing two chemographic patterns obtained after a certain time, the shorter will be the time before the failure occurs. If the shaded area is taken into account, then the dependence will be similar.

This hypothesis was experimentally tested by changes in the chemographic patterns of darkening in the area of the working edges of the cutting carbide insert. Chemographic studies were duplicated 10 times. In this case, the density I_c and the area S of darkening on the raster of the working faces (in %) were measured by the software method, and then the dependences of the change in the controlled parameters on the operation time were plotted (taking into account the critical time before the failure) (Fig. 8).

If the dispersion of the parameter I_c was quite significant in the initial period (more than ±12 %), then the parameter S did not have such a feature. It turned out to be more informative for the case when a long period of operation of the cutting insert before the onset of failure is considered. The change in the area of the dark zone for a T15K6 carbide insert is almost linear, which allows to postulate an equation of the form $T=b_0+b_1s$. However, the coefficient b_1, which determines the growth of the controlled parameter, is not constant, but depends on the intensity of the plate operation.

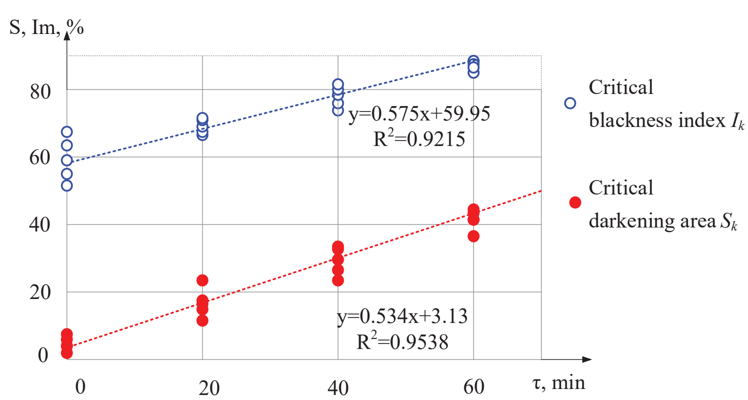


Fig. 8. Change in chemographic parameters depending on the loading time

Taking into account the chemographic patterns of the initial state of the plate and after 60 min of its operation under various conditions, dependence was constructed that characterizes the predicted time before the onset of a sudden failure when the area of darkening of the plate sections changes. It is shown in Fig. 9.

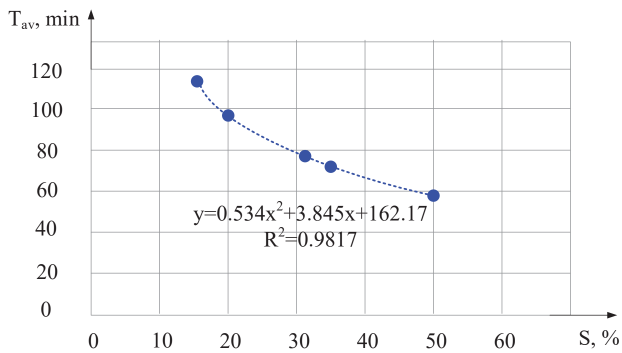


Fig. 9. Predicted time of failure T_{av} of a cutting insert made of hard alloy T15K6, depending on the area of shading in chemographic analysis

The parameter $\lambda = 1/T_{av}$ was calculated from the time of failure, and from it – $P(t)$ and $f(t)$. Statistical processing of the sample using the χ^2 Pearson test showed the correspondence of its distribution to the one-parameter exponential distribution law. This confirms the hypothesis about the possibility of predicting the time of failure of cutting inserts based on the analysis of the parameters of the chemographic patterns from their working surfaces, corresponding to the specific conditions of thermobaric operational loading.

6. Discussion of the results of studying microdefects of cutting inserts using the method of chemographic recording

The results obtained, first of all, prove the possibility of chemographic phenomena occurring even on surfaces with a very low oxidative activity. If with metals that easily form MeO oxides, images are obtained in a few minutes of exposure (for example, for stainless steel –1.0...2.0 min), then for hard alloys the exposure should already be much greater – about 20...22 min. At the same time, neither Co, nor WC, nor TiC had any significant differences in image darkening.

But on the edge of the plates, microdefects (surface microcracks), possessing an excess of surface energy, gave an unambiguous and clear illumination in the image.

Based on the hypothesis of more active darkening of the picture obtained by the method of chemography, on surface defects of adhesive and cohesive nature, a clear deterministic dependence was obtained, having an error of no more than 4...5 % (Fig. 8).

Then on the basis of Table 1, which compares the damage of individual surface elements, faces and edges, the determination of the parameters of damage development by the proposed method is quite accurate, adequate and reliable.

True, now the accuracy of predicting the performance of the plate is 88...93 % (Fig. 9).

It can be considered that increasing the accuracy of the forecast is possible by more accurate performance of the experiment, as well as by using hotter aqueous media.

Despite its versatility, the method also has significant limitations. Since the formation of the image occurs by the contact method, it is difficult to obtain an accurate picture, with the definition of the boundaries of the defect, its clear position on the surface. That is why an increase in the accuracy of fixing defects can be considered an urgent direction for further research.

It should be noted that the functional conditionality of the blackness of the zone of maximum damage (7), which makes it possible to establish the probability of failure-free operation (5), is not significantly influenced by the types and brands of plates used.

Comparison of the results obtained by the method of chemographic analysis of cutting inserts in order to determine the degree of their damage due to thermobaric loading with the expected period before the onset of failure showed that chemography does not require complex and expensive devices.

At the same time, there is no need for the implementation of the treatment process, since the damage is recorded in the plate, which is not installed in the TOC.

Analysis of the state of the plate outside the cutting zone is one of the most important aspects of using chemography.

7. Conclusions

1. The carried out investigations made it possible to establish an unambiguous, reproducible effect of image blackness, indicating the development of surface damage. At the same time, it was found that the time of chemographic exposure significantly exceeds the time of exposure for metals prone to active oxidation. For WC, TiC, Co, the exposure time is 20 min. It is possible to reduce the exposure time and increase the resolution by heating the chemography medium (deionized water).

2. Conducting a microelectronic study on the plates, which were then studied using the chemography method, made it possible to establish the functional conditionality of image blackness by the amount of damage from existing defects and imperfections in the structure. A change in the blackness index of a chemographic image, the minimum value of which indicates a minimum of structural defects and internal defects in the test material, is a reliable characteristic of the degree of damage to the surface layer, on the basis of which one can judge the reliability of the plate operation as a whole.

3. The parameters of the damage development to the plates have been determined and it has been established that a satisfactory result of predicting the time until the failure of the plate is due to the fact that the nature of the development of damage, their mechanism does not affect the image blackness. However, the result of damage will always be reflected by a gradual increase in the blackness of the resulting image. In this case, this effect is determined by the initial imperfection of the surface layer structure (including the presence of defects) and the degradation of the structure of the plate material in the process of operational loading. The proposed model of the probability of failure-free operation can be used to estimate the time of failure, provided that with the development of a gradual failure, the criterion of damage will be an avalanche accumulation of damage on the cutting edges of the tool.

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