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REVERSIBLE ENGINEERING OF DIAMOND-ABRASIVE TOOL WITH WORKING LAYER OBTAINED IN THE FORM OF CLUSTERS

Oleksandr Salenko*[1], Sergey Klimenko[2], Ihor Shepelenko[3], Mohamed Budar R.F.[3], Eugene Onishenko[1], Muhaylo Molnar[1], Sergii Mahopets[3]

[1]National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
[2]Bakul Institute for Superhard Materials National Academy of Sciences of Ukraine, Kyiv, Ukraine
[3]Central Ukrainian National Technical University, Kropyvnytskyi, Ukraine

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ABSTRACT

The paper considers the approach to increase the reliability of the tool based on the analysis of differences in the interaction of tool surfaces individual areas in the implementation of processing. To ensure that the properties of the surface clusters correspond to the conditions of the tool further operation, it is proposed to perform reversible engineering, which is based on the principle of tool wear analysis during its operation. To this end, a methodology for reengineering a diamond-abrasive tool with a clustered working layer has been developed. The scheme of the tool quality initial indicators formation is constructed. Efficiency evaluation of the tool surface modification on a functional basis was performed on the basis of microcutting phenomena modeling.The basic regularities of loadings change of a working surface parts and functional features of the tool working surfaces clusters are established on which requirements to parameters of a diamond layer are formulated. The efficiency of the tool surface modification on the functional basis is proved and the basic regularities of a diamond drill, a saw of the renovator, a diamond string work during material cutting like KIMF are defined.

1. INTRODUCTION

Currently used diamond tools are designed mainly for processing a wide range of high-strength materials, ceramics, granite, etc. [1, 2]. Having a fairly thin layer of diamonds, the tools provide reliable processing in the operations of cutting, grinding, sampling grooves in the case when the machine time does not exceed a few tens of seconds. Prolonged operations when processing materials without water or liquid cooling (for example, when cutting carbon-carbon workpieces of dense reinforcement) lead to the fact that the diamond-containing layer is actively salted, and the cutting surface destroys, resulting the cutting zone heats up sharply and cutting process may stop [3]. The study of the cutting tool surface proves that the number of diamonds is sharply reduced, and the surface itself is covered with a layer of adhesive sludge (Fig. 1).

These phenomena are especially acute during the processing of modern composite materials, the multicomponent nature and anisotropy of which negatively affect the cutting ability of the tool. Thus, in work [4] it was shown that the productivity of the cutting process begins to decrease sharply during the first minute of processing with a simultaneous increase of temperature in the cutting zone to 700-900°C; further operation of the tool causes its damage, with the destruction and removal of grains.

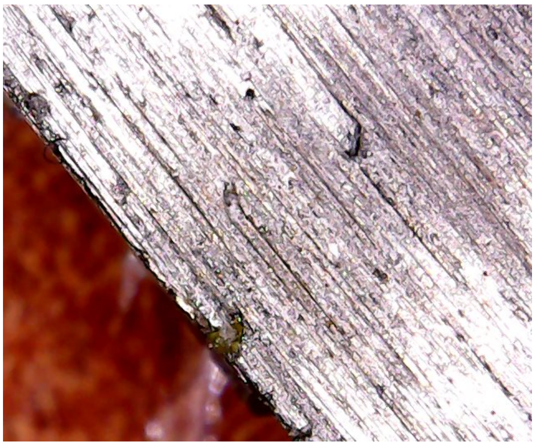
In work [5], the results of research on the treatment of carbon-polymer and carbon-carbon composites with tools with a cluster scheme of grain attachment were presented. This approach improves the dynamic contact with the surface, and the resulting oscillations allow more efficient removal of sludge formed on the cutting surfaces between the edges.

In works [6, 7] it is shown that the main reason for the loss of tools cutting properties in the processing of special carbon-carbon materials and carbon plastics such as KIMF is excessive dust, resulting in changing conditions of diamond grains interaction with the material, and the temperature rises to critical 1100…1200 K.

Increase the reliability of the tool is possible by changing the processing conditions. However, in this case, such a solution requires the use of a special or hybrid tool [7]. According to data [8], this tool can be performed on the basis of reengineering, or on the basis of differences analysis in the interaction of the tool surfaces individual areas in the implementation of processing.

The aim of the work is to develop a methodology for reengineering a diamond-abrasive tool with a clustered working layer.

* Corresponding author. E-mail: salenko2006@ukr.net



a)

b)

Fig. 1. Circle with lost diamond grains (a) and greasy surface of the circle (b)

2. THE RESULTS

The authors [2, 9] note that the formation of product properties is carried out by performing a number of technological transitions, in which there is a complete or partial change in the initial properties of the product (workpiece). Technological transformations of the workpiece into a product are carried out by a purposeful set of technological influences $W_{ij}(t_k)$ of material $S_0(t_k)$, $S_0(t_k) \in R_{nj} \cap M_{nj}$, energy $E_0(t_k)$ and information $I_0(t_k)$ types, which allows to write down:

$$W_{ij}(t_k) = S_0(t_k) \cup E_0(t_k) \cup I_0(t_k). \qquad (1)$$

Having several tools R_i, differing in the shape of the working edges and kinematic properties, the production of a prototype of size $b \times l \times h$ with curved sections of radii r_i from a cubic workpiece of size $B \times L \times H$, can be represented as follows:

$$(R_2)-(R_1);(R_2)-(R_5);(R_2)-(R_4)-(R_5). \qquad (2)$$

Here R_1 – milling; R_2 – abrasive wheel treatment; R_3 – processing by means of reciprocating motion (renovator); R_4 – drilling; R_5 – hydroabrasive cutting. When optimizing the process by the criterion of minimizing processing time for a given level of quality obtained option (R_2)-(R_4)-(R_5), the scheme of which is presented in Fig. 2.

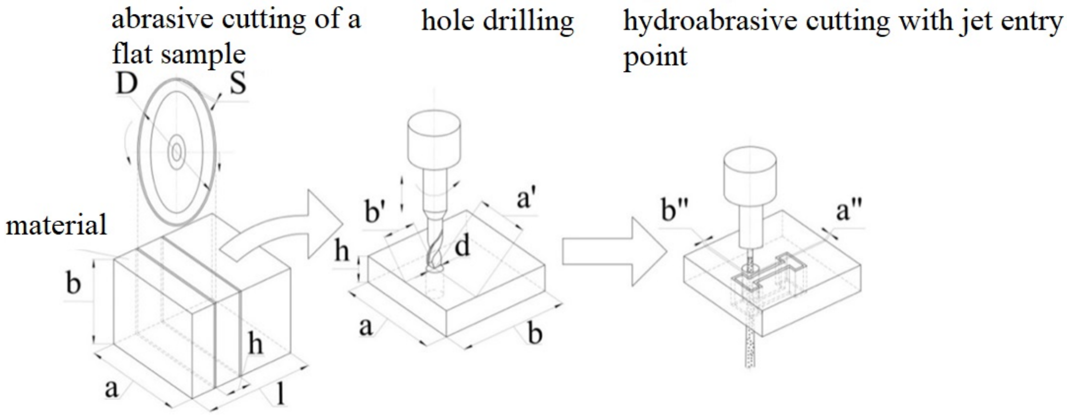


Fig. 2. The sequence of manufacturing products from KIMF material

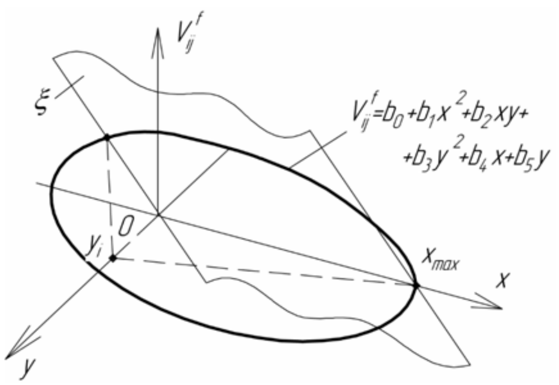


Fig. 3. Changing the properties of the product when changing the properties of the functional zones in a certain direction from the selected starting point

The given illustration proves that during processing the conditions of interaction change practically at each tool. Therefore, taking into account changes in the conditions of interaction in time or position (for individual sites) can significantly increase the efficiency of processing as a whole.

Let the surface P of the part consist of a number of functional zones Z_{ij}, which differ in their properties V_{ij}^{f} and provides performing functions FR_k. The properties of each zone are determined by the operating conditions: power R_{ij}^{xy} and thermal T_{ij}^{xy} loads, the course of chemical interaction phenomena H_{ij}^{a}, damage mechanisms D_{ij}. Since all functional zones belong to one surface (and in the general case – to the volume of the object under consideration), ie $Z_{ij} \in P$, and the surface is given by the function $z = g(x,y)$, which has an area of R definition, moreover $P = \iint_R dR$, for the case of an axisymmetric body

$$P = \iint_R dP = \int_{\alpha}^{\beta}\int_{h(0)}^{g(0)} r dr d\theta \tag{3}$$

and the change in surface properties can be determined on the basis of functional conditionality

$$V_{ij}^{f} = f\left(R_{ij}^{xy} \cdot T_{ij}^{xy}, H_{ij}^{a}, D_{ij}\right) \tag{4}$$

and for any surface of the second order having the form $F(x,y,z) = 0$ and at the intersection by the plane gives the curve equation of the second order in the form $\dfrac{x^2}{\left(a\sqrt{1-\dfrac{h^2}{c^2}}\right)^2} + \dfrac{y^2}{\left(b\sqrt{1-\dfrac{h^2}{c^2}}\right)^2} = 1$ in the projection on the selected axis within $(x_1,y_1);(x_2,y_2)$ can be converted to a view

$$\begin{aligned}
V_R^{f} &= b_0^R + b_1^R x^2 + b_2^R xy + b_3^R y^2 + b_4^R x + b_5^R y;\\
V_T^{f} &= b_0^T + b_1^T x^2 + b_2^T xy + b_3^T y^2 + b_4^T x + b_5^T y;\\
V_H^{f} &= b_0^H + b_1^H x^2 + b_2^H xy + b_3^H y^2 + b_4^H x + b_5^H y;\\
V_D^{f} &= b_0^D + b_1^D x^2 + b_2^D xy + b_3^D y^2 + b_4^D x + b_5^D y;
\end{aligned} \tag{5}$$

Thus, we obtain a family of continuous curves, which belong to the planes intersecting the body at certain angles and which reflect the change of properties in a certain direction from the selected starting point (Fig. 3).

The general scheme of the tool initial quality indicators formation, which directly determine the course of the further processing, is presented in Fig. 4. Changing the properties of the surface on the basis of functional conditionality will look like:

$$V_{ij}^{f} = f\left(R_{ij}^{xy}, T_{ij}^{xy}, H_{ij}^{a}, D_{ij}\right) \tag{6}$$

The difference in the conditions of the tool interaction with a loose strong composite gives grounds to conclude that the tool, as a whole, should be considered as a set of microfragments that work in specific processing conditions.

Each such fragment must have a set of useful features (functions) F_p, the combination of which allows to reach the extremum of the objective function; in the case of a non-rigid diamond-containing tool – maximum productivity q and work reliability $F(t)$.

Since surface fragments may have similar properties, they can be considered as K_i clusters, the combination of which forms a diamond layer. Then from the point of view of the tool operation its imagination in the form of set of surface clusters corresponds to Fig. 5.

Clusters K_i of the tool surface are divided as follows: K_1 – a surface fragment of a certain size with grains of size z_2 (elements E_3, E_5); K_2 – a surface fragment of a certain size with grains of size z_1 (element E_1); K_3 – a surface fragment covering the clusters K_1 and is formed by a set of elements E_3, E_5, …; K_4 – a surface fragment covering the clusters K_1 and is formed by a set of elements E_2, E_4, …; K_5 – a surface fragment that covers the clusters K_1 and is formed by a set of elements $E_1 - E_5 - \ldots$; K_6 – a surface fragment of a certain size with grains of size z_3.

Then $\sum V_{ij}^{f} \to f(FR_k)$, and (5) is a continuous function of the change in the surface layer cutting properties.

The operating conditions of specified tool change significantly during the operating cycle and when changing processing scheme. This change requires the choice of such a method of forming a surface diamond layer, which would allow localizing the effective influence on small surfaces P_{ij}. Then the main requirements for surfaces will be the following:

- compatible surfaces must allow differences in the formed structures;
- compatible surfaces should not have different mechanical characteristics, in particular, KLTR, σ_a, etc., which allows such elements to form a continuous cutting surface;
- the sequence of compatible surfaces should be close to the envelope of a given geometric profile of the product as a whole;
- compatible surfaces should not have gaps in the structure a number of compatible surfaces can form a sector with similar physical-mechanical characteristics.

Let us consider a cylindrical product – a string with applied diamond layer, designed to perform the operations of the initial division of the workpiece into plates, Fig. 6. For a cylindrical long non-rigid product, the requirements given in Table 1, Fig. 7 will be put forward to individual surfaces. Each of the surfaces can be further divided into zones that differ in working conditions, Table 1, and the conditions for the formation of quality indicators will correspond to the graph on Fig. 8.

The localization and possibility of dividing surfaces into microzones proves that the lower level of useful functions formation is the micro level. The macro level provides the application of grains group within the macroplane. Depending on the location of individual zones, the latter can be combined into clusters, while maintaining all the requirements for them.

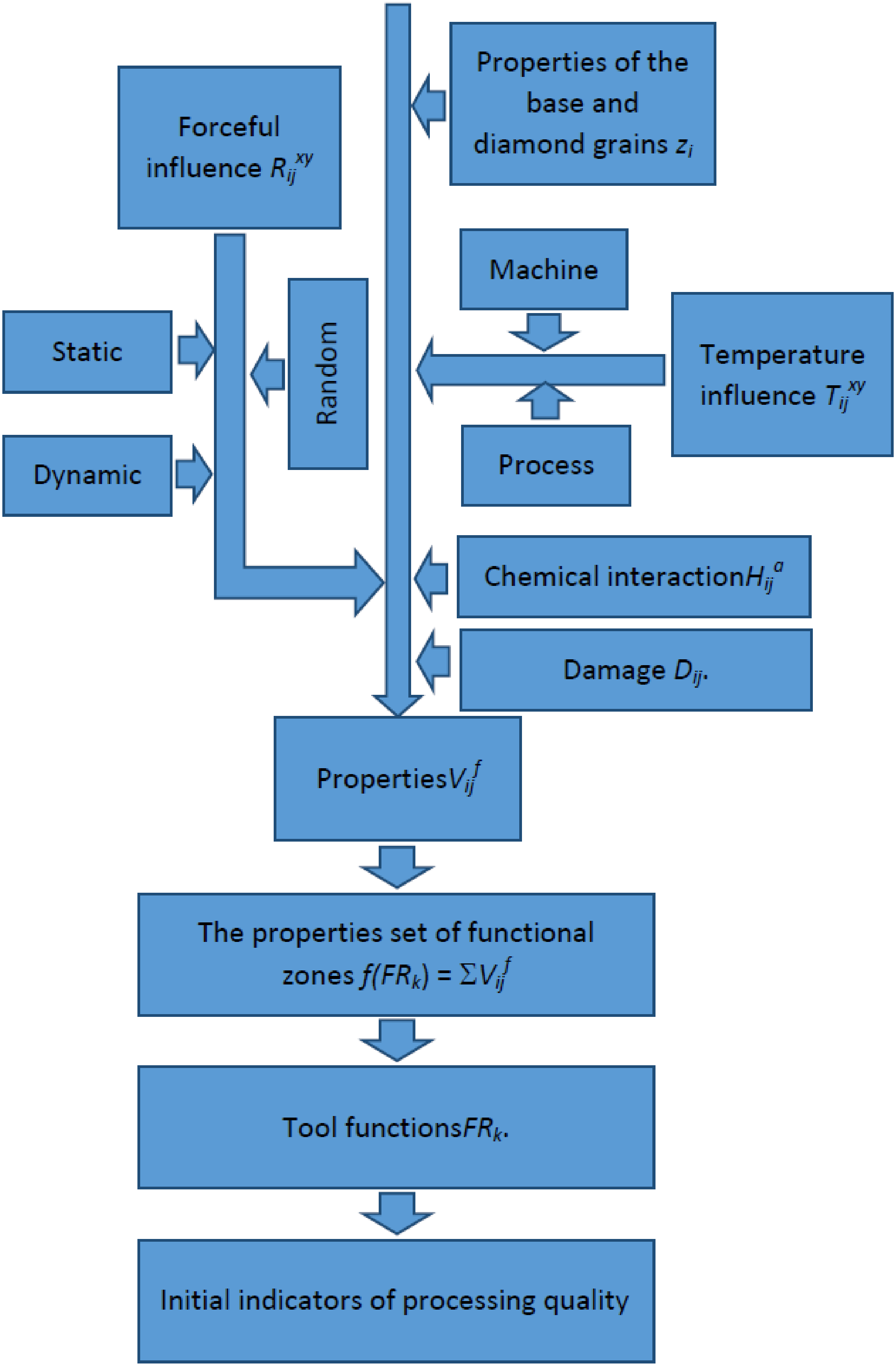


Fig. 4. The scheme of products quality initial indicators formation

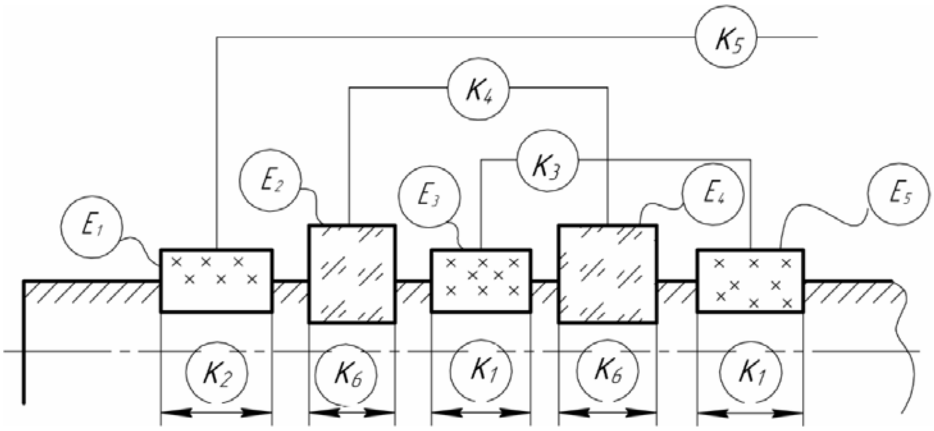


Fig. 5. Clusters of the tool surface with a diamond layer

Fig. 6. Saw machine with KIMF workpiece

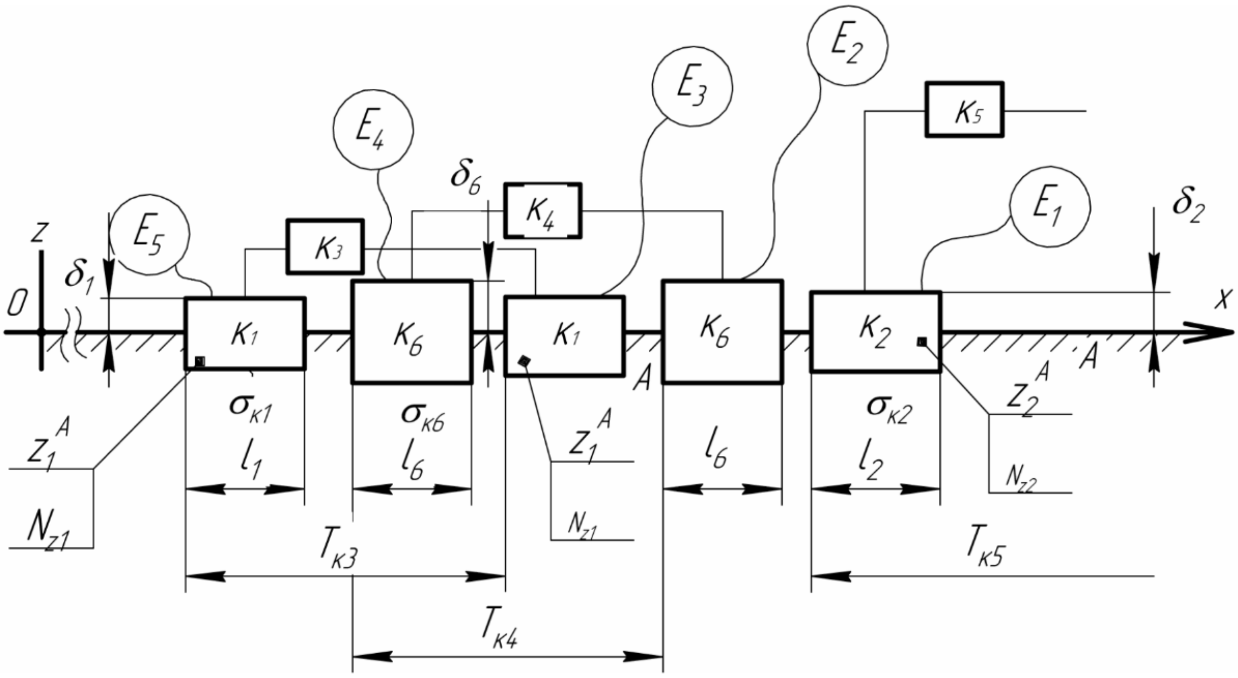


Fig. 7. Division of the product into separate surface elements

Table 1 *Separation of individual surface elements into micro-level zones*

Cluster	Properties			Components of the cluster
	Geometric parameters	Surface layer	Surface area	
K_1	l_1, δ_1, b_1	z_1^A; N_{z1}	σ_{k1}	E_5
K_2	l_2, δ_2, b_1	z_{2A}; N_{z2}	σ_{k2}	E_1
K_3	T_{k3}		Basic σ_{k1}	$E_3 \cap E_5$
K_4	T_{k4}		Basic σ_{k6}	$E_2 \cap E_4$
K_5	T_{k5}		Basic σ_{k2}	$E_3 \cap E_5 \cap E_2 \cap E_4$...
K_6	l_6, δ_6, b_6	z_6^A; N_{z6}	σ_{k6}	E_2

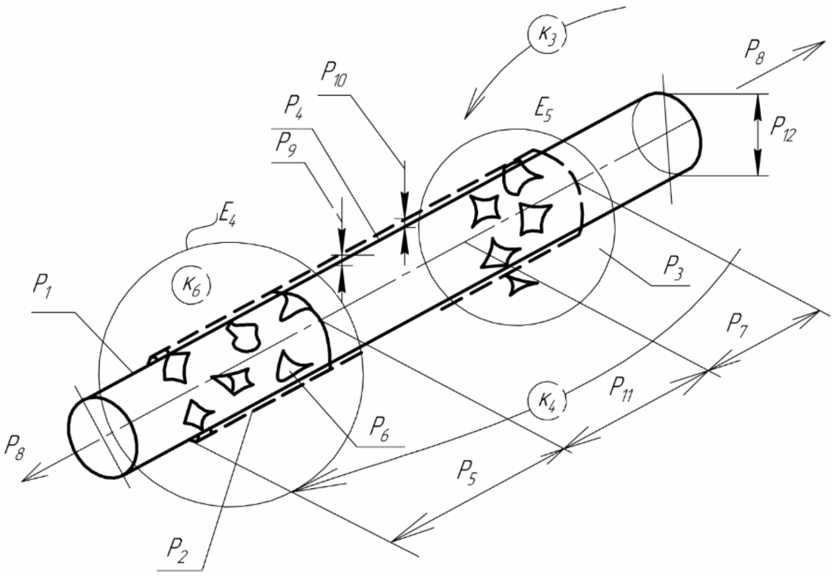


Fig. 8. Providing functions with separate zones of the micro level

From [10] it is known that technological transformations of the workpiece into a finished product are a consequence of purposeful technological influences $W_{ij}(t_k)$ of material $S_0(t_k)$, energy $E_0(t_k)$ and information $I_0(t_k)$ types. Then the scheme of initial properties formation will take the form:

$$W_{ij}(t_k) = S_0(t_k) \cup E_0(t_k) \cup I_0(t_k). \qquad (7)$$

Provided that the technological influences of the tool on the product should be carried out at levels from microzones to the product as a whole, and the product itself is a three-dimensional object, the morphological matrix of the technological actions set will correspond to the following:

$$A_3^{\Pi} = \left\| \begin{matrix} \Pi_{11}^S & \Pi_{12}^S\ldots & \Pi_{21}^S & \Pi_{22}^S\ldots & H_{11}^S & H_{12}^S\ldots & H_{21}^S & H_{22}^s\ldots & E_{11}^S & E_{12}^S\ldots & E_{21}^S & E_{22}^S\ldots \\ \Pi_{11}^t & \Pi_{12}^t\ldots & \Pi_{21}^t & \Pi_{22}^t\ldots & H_{11}^t & H_{12}^t\ldots & H_{21}^t & H_{22}^t\ldots & E_{11}^t & E_{12}^t\ldots & E_{21}^t & E_{22}^t\ldots \\ \Pi_{11}^v & \Pi_{12}^v\ldots & \Pi_{21}^v & \Pi_{22}^v & H_{11}^v & H_{12}^v\ldots & H_{21}^v & H_{22}^v\ldots & E_{11}^v & E_{12}^v\ldots & E_{21}^v & E_{21}^v\ldots \end{matrix} \right\|,$$

where Π_{11}^s, Π_{12}^s, ..., Π_{21}^s, Π_{22}^s, … , Π_{11}^t, Π_{12}^t, ..., Π_{21}^t, Π_{22}^t, …, Π_{11}^v, Π_{12}^v, ..., Π_{21}^v, Π_{22}^v, … – variants of intermittent technological influences on the corresponding axess, tand vcoordinate systems s, t, v; H_{11}^s, H_{12}^s, ..., H_{21}^s, H_{22}^s, … , H_{11}^t, H_{12}^t, ..., H_{21}^t, H_{22}^t, …, H_{11}^v, H_{12}^v, ..., H_{21}^v, H_{22}^v, … –various options of continuous technological actions on axes s, t and v coordinate systems s, t, v; E_{11}^s, E_{12}^s, ..., E_{21}^s, E_{22}^s, ...;–different options for one-time technological actions.

The presence of variants of interrupted technological processes makes it possible to consider the processing of one element of the product in the form of a consistent set of different influences. Since the actions to ensure the conditions of the form minimum error must be carried out without reinstalling the workpiece or changing its position in the device of fixing and orientation, the processes must be hybrid.

Then the hybrid tool, obtained on the basis of morphological search and combining properties principle, will consist of m elements, moreover $m < k + j$, because part of the properties of the original tools can be combined.

The simplest stated can be illustrated by the work of a non-rigid tool – a saw string, on the surface of which is applied a diamond layer.

To establish the rational parameters of the clusters, the modeling of the individual zones interaction process of the saw string with the processed material is performed. Since the tool is an elastic non-rigid base, located diamond grains will perceive the working load differently depending on the velocity vr, perturbation conditions $f(x,t)$, force Q_n, and the line of the working surface elastic deformation, in this case l_i. When cutting a round workpiece, it is easy to distinguish several zones of the elastic line equations, for example, zone I and zone II (Fig. 9). The cutting properties of the grains in these areas will be different.

Since the diamond grains m_i are fixed on a string that has a significant elastic deformability, it can be assumed that there is an elastic connection with the C_i parameter between the fixed XYZ coordinate system and the mobile one connected to the grain center.

Forced transverse oscillations of a string, which can be represented as a movable non-rigid rod with a constant cross section, were described in Euler variables by differential equations in partial derivatives:

$$\frac{\partial^2 u}{\partial t^2} + 2v\frac{\partial^2 u}{\partial x \partial t} + v^2\frac{\partial^2 u}{\partial x^2} - \frac{F_n(t)}{m}\frac{\partial^2 u}{\partial x^2} + \beta^2\frac{\partial^4 u}{\partial x^4} = \varepsilon f(x,t) \qquad (8)$$

where $u(x,t)$ – transverse movements of the carrier with the coordinate x at the flowing moment of time; ε – parameter of small perturbing force in comparison with force of action $\beta^2 = \dfrac{EI}{m}$; m – mass per unit length of diamond string; E – modulus of the material elasticity; $I = \dfrac{Bs^2}{12}$ – the moment of the string cross section inertia relative to the central axis; B, s – width and height of the saw blade cross section; $F_n(t)$ – variable tensile strength of the non-rigid rod, which depends on the cutting conditions.

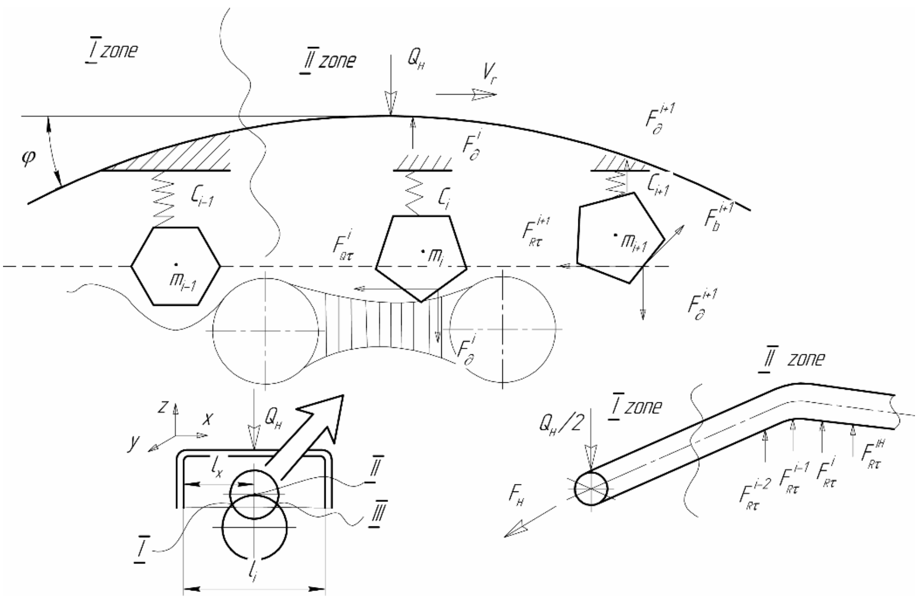


Fig. 9. Scheme of diamond grains interaction located on the cutting blade with the workpiece surface

Since the perturbations of such a dynamic elastic system will be determined by alternating moments of grain contact with the treated fiber plait and the interval $f(x,t) = H\,sin(\omega t)$, where H, ω – the amplitude and frequency of the perturbations, and the variable tension force of the rod is determined by the cutting resistance $F_n(t) = N_0 + \varepsilon N_1 cos(\mu t)$, where N_1 and μ – parameters that depend on the frequency of an individual grain interaction with the surface and the number of grains that are simultaneously in the contact zone, the system of differential equations that describe the parameters of a dynamic system takes the form:

$$\frac{d\alpha}{dt} = -\frac{\varepsilon}{(\omega + 0,5\mu)}\left[\frac{\alpha H_2 \omega^2}{2} sin\,2\gamma + H_3\,cos\,\gamma\right];$$

$$\frac{d\gamma}{dt} = \omega - 0,5\mu - \frac{\varepsilon}{(\omega + 0,5\mu)}\left[\frac{H_2\omega^2}{2} cos\,2\gamma + \frac{H_3}{\alpha} sin\,\gamma\right]. \quad (9)$$

Neglecting the multiphase destruction of the material fibers when the moving grain comes into contact with the plait on the surface, and also believing that the grain is not embossed, during contact a single grain, compressing the fiber plait with a diameter D_v with conditional modules of elasticity E_v and G_v, destroys it by immersion under the action of force F_d, $F_d = \dfrac{Q_n}{N}$, according to the Hertz problem for the value of $\delta^{3/2} = \dfrac{F_d}{K\sqrt{R}}$, where R – the given radius of the fiber plait, $\dfrac{1}{K} = \dfrac{3}{4}\left(\dfrac{1-\mu_1^2}{E_1} + \dfrac{1-\mu_2^2}{E_2}\right)$, $D_v/2 = R$. The volume of material removal provided the convex part destruction of the plait in the form of a segment of height δ, is: $w = \pi\delta^2\left(R - \dfrac{1}{3}\delta\right)$.

Then the removal of sludge, which is formed during cutting with a constant pressing force of the tool, is determined, mm^3/min:

$$W = w\eta\frac{2l_p N_{dr}}{D_v + t_p} N_a t\,, \quad (10)$$

where N_a – the number of abrasive particles involved in contact; l_p – working stroke length, mm; t – flowing time, sec; t_p – step of fibers arrangement, mm; N_{dr} – number of double moves, min^{-1}; η – coefficient that takes into account the redistribution of loads between individual grains.

The modeling was performed in Solid Works environment, the treated environment – KIMF material – was presented as loose. Other parameters are given in Table 2.

The mechanical characteristics of the material are given in Table 3.

***Table 2** Data for modeling*

No.	Parameter	Measurement uits	Value
1	Workpiece size BxLxH	mm	100×50×10
2	String length L	mm	250
3	Grain location step T_1-T_i	mm	1.5…2.5
4	Step between depressions T_p	mm	1.8
5	Depression diameter d_u	mm	1.2
6	Depth h_u	mm	0.2
7	Fraction of diamond grains	μm	150/200
8	Extension over the bundle	μm	50
9	The force of pressing the string on the outer points P	N	80
10	Velocity of motion v_x	m/s	1.2

***Table 3** The main characteristics of carbon-carbon composite materials*

Characteristics of material KIMF	
Bulk (apparent) density, notless than, g / cm^3	1,7
Breaking stress kg / cm^3 during compression a long the axes of reinforcement X (Y), notless	1200
Breaking stress kg / cm^{3}during tension a long the axes of reinforcement X (Y), notless than	240
Breaking stress during shear, MPa, notless	24,5
Breaking stress at bending, MPa, notless	88,2
The coefficient of thermal conductivity (at a temperature of 50° C), kcal / m hour, deg	7
Modulus of elasticity in compression a long the axes of reinforcement X (Y), MPa, not more than	2,45·10^4
The porosity of the material, %	*8,7
Impact strength, kJ / m^3	*10
Electrical resistivity, Ohm· mm^2 / m	30

***Table 4** Data of model in the simulation of interaction*

№	Parameter	Units of measurement	Value
1	The size of the workpiece BxLxH	mm	100×50×10
2	String length L	mm	250
3	Grain location step T_1-T_i	mm	1,5…2,5
4	Step between hollows T_p	mm	1,8
5	Hollows diameter d_u	mm	1,2
6	Depth h_u	mm	0,2
7	Diamond grain fraction	μm	150/200
8	Departure over the connection	μm	50
9	The force of pressing the string on the outer points$P$	N	80
10	Speed of movement v_x	m / s	1,2

The conditions of the non-rigid tool movement as a tool with additional degrees of freedom used in the modeling are given in Table 4.

Evaluation of tool surface modification efficiency on a functional basis was performed on the basis of modeling the phenomena of microcutting with sludge removal and damage to individual diamond grains during processing. Due to the fact that the surface P of the part consists of a number of functional zones Z_{ij}, differing in their properties V_{ij}^f and ensure the performance of FR_k functions, the generalizing function optimized to the maximum by reducing differences in operation, ie when providing load conditions of tool areas almost identical σ_N.

The modeling was performed taking into account the changes in the cutting layer properties of the clusters. Thus, according to [10], the change in cutting depth by single diamond grain passing through the contact zone is determined by the dependence $t_{3i} = t_{3i-1} + \Delta H_{i-1} - \Delta h_{3i-1}$, where t_{3i} and t_{3i-1} – the depth of diamond grain cutting in the main plane when performing the i-th and $i-1$-th turns of the drill; ΔH_{i-1} and Δh_{3i-1} – respectively, the dimensional wear of the tool and the top of the grain during the $i-1$-th working motion.

The amount of relative wear depends on the material of the workpiece, the material of the abrasive grain and the temperature at the point of grain contact with the workpiece material:

$$h_0 = K\frac{\sigma_N}{H_a}$$

where σ_N – normal pressure on the contact surface; K – coefficient determined by the materials of friction bodies; H_a – hardness (microhardness) of the material at friction temperature, $H_a = Ae^{-\alpha\Theta}$, where Θ – the temperature at the point of the abrasive grain contact with the workpiece material; K, α – empirical coefficients.

The temperature at the point of the abrasive grain contact with the workpiece material is determined by the following dependence: $\Theta(z,t)=\frac{aP_0Vt}{\sqrt{\pi}F\Delta t\lambda}2\sqrt{at}$, where a – thermal conductivity of the processed material; P_0 – axial cutting force; V – cutting speed; t – the time of single contact of a diamond grain is approximately equal: $t=d/V$, d – grain diameter; Δt – heat generation time; F – the contact area of the diamond grain is approximately equal to: $F=\frac{\pi d^2}{4}$, where λ – thermal conductivity of diamond. The relative wear will be:

$$h_0 = K\frac{\sigma_N}{Ae^{-\alpha\frac{aP_0Vt}{\sqrt{\pi}F\Delta t\lambda}2\sqrt{at}}} \quad (11)$$

The modeling results are presented in Fig. 10.

It becomes clear that the grains that work immediately after entering the second zone have the greatest load (Fig. 10), ie in the case when they leave I zone. The pressure on the edges of a single diamond grain reaches 1.92 GPa; however, later it begins to decrease, and under the condition of constant clamping force of the string, it first falls to 0.96 GPa, and as the fibers are excluded from the matrix – to 0.46…0.51 GPa.

Over time, these indicators decrease significantly due to changes in the height of grain departure, ie with increasing growth ΔH_{i-1}.

At the same time, the temperature $Q(z,t)$ increases with active damage to the tool edges. The corresponding results of damages analysis are confirmed by us on the basis of studying of tool working edges destruction pictures given in Tables 5-7.

Based on the modeling of the tool behavior, the main changes patterns in the loads of the working surface parts and, accordingly, the functional features of the tool working surfaces clusters, which formulated requirements for the parameters of the diamond layer (Table 8). The value of the tool individual areas wear level is set and it is shown that there is a significant difference in this controlled parameter. The results of processing simulations are compared with the level and types of tool damage obtained in production conditions.

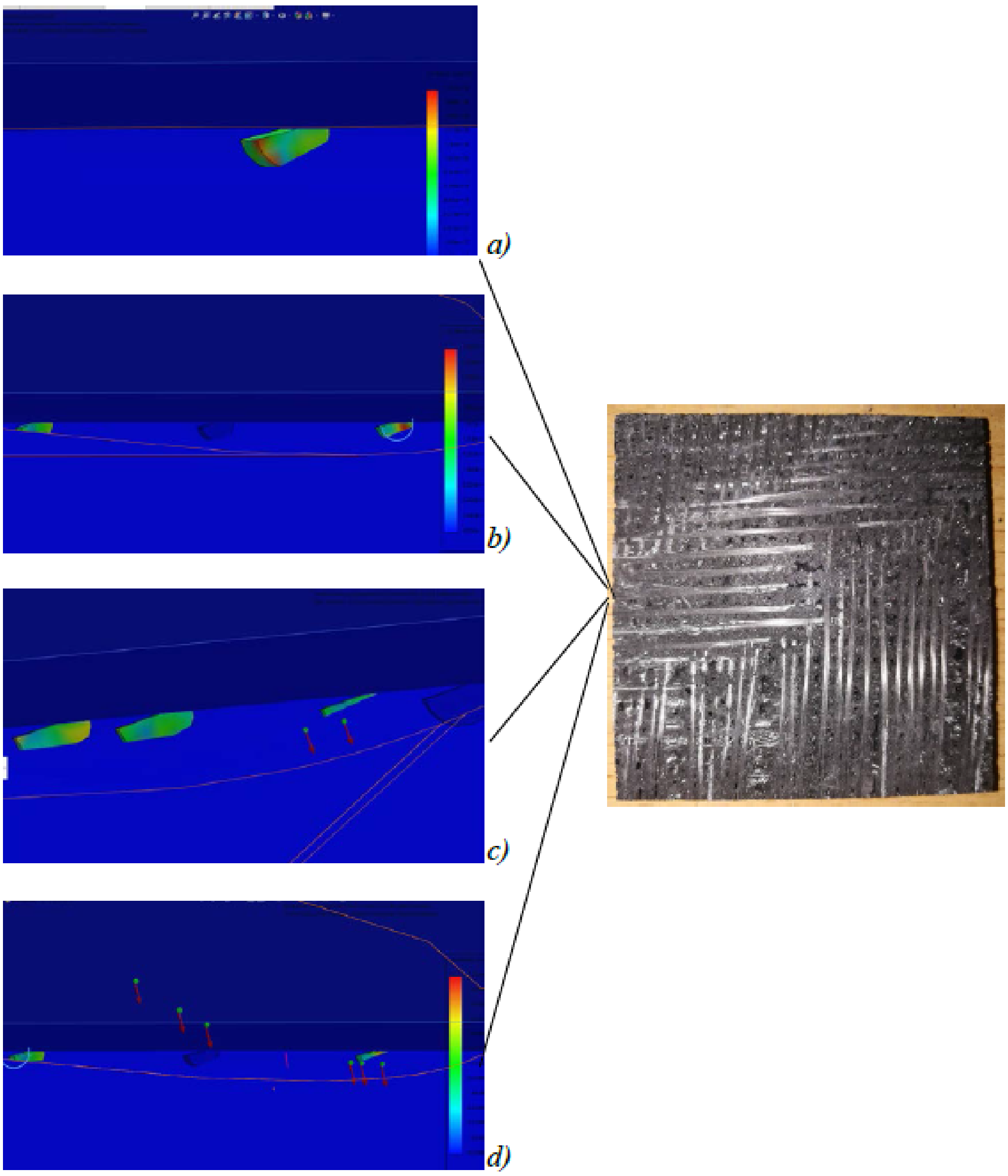


Fig. 10. Grain entry in zone I (a), fiber exclusion and second grain operation (b), grain operation in zone II at the initial time (c) and at exit (d)

Table 5 *Defects of tubular drill surfaces, ∅18.0 mm*

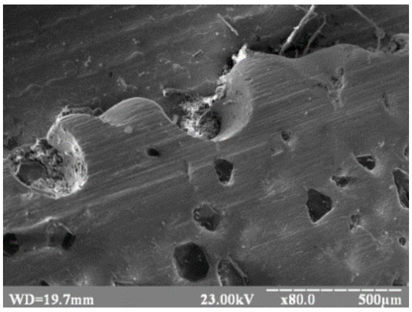
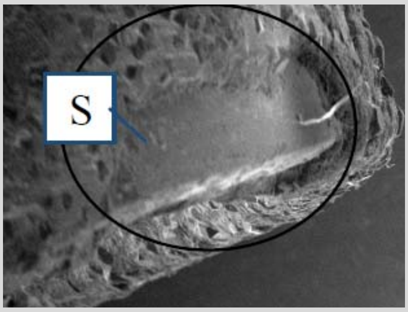
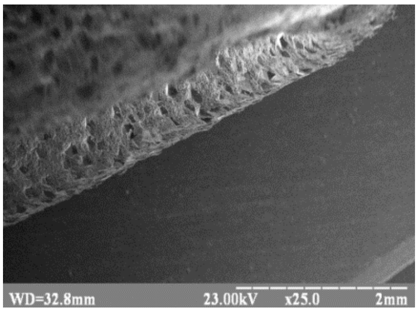
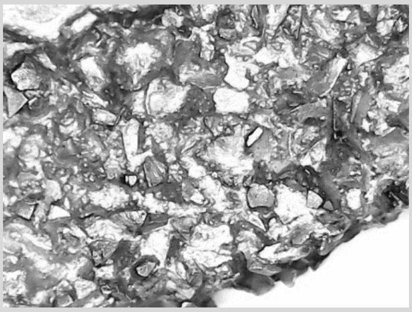
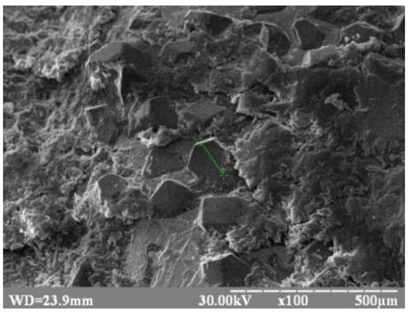
№ i/o	Defect type	Example	Controlled parameter	Number
1	The presence of damage to the diamond-containing layer and the relative area of grain crumbling areas		$N_{avg} = 22\,pcs$ $At\,N_a = 58\,pcs,$ $k_{oa} = \frac{N_a}{N_{avg}} = \frac{22}{58} = 0{,}379$	8
2	The presence of areas of damage to the substrate		$k_{sb} = \frac{S_b}{S_o} = \frac{7}{320} = 0{,}022$	1
3	The presence of a violation of the substrate to the basis adhesive adhesion		$k_{sp} = \frac{S_p}{S_o} = \frac{18}{320} = 0{,}056$	4
4	Uneven wear of the diamond layer, diamond chipping		$k_{oa} = \frac{N_a}{N_{avg}} = \frac{22}{58} = 0{,}379$	

Table 6 *Defects of diamond string surfaces, ∅3.2 mm*

№ i/o	Defect type	Example	Controlled parameter	Number
1	The presence of damage to the diamond-containing layer of grain crumbling		$N_{avg} = 20\,pcs$ $At\,N_a = 56\,pcs,$ $k_{oa} = \frac{N_a}{N_{avg}} = \frac{22}{58} = 0{,}379$	8

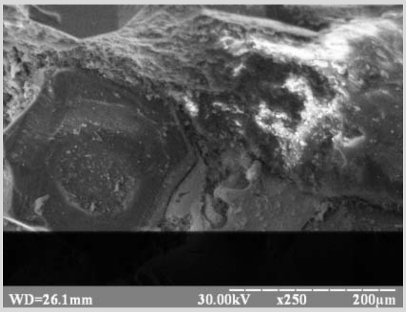
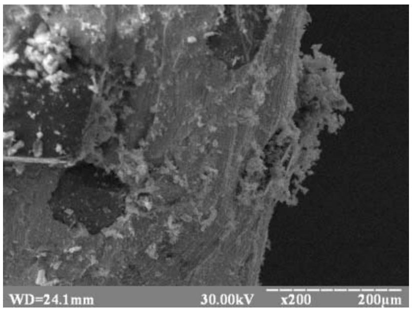
2	Spoiled grains in a layer		$k_{sb} = \frac{S_b}{S_o} = \frac{7}{320} = 0{,}022$	1
3	Salting of the surface			

Table 7 *Typical defects of renovator nozzles (12 pcs., diamond layer thickness 0.25 mm, grain concentration 54-62 units / mm², grain size 0.13-0.15 mm)*

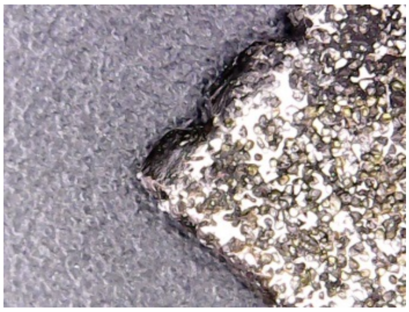
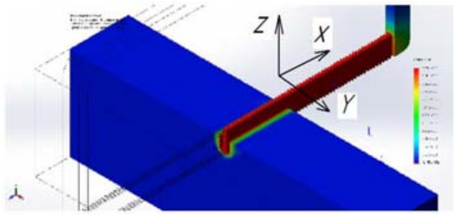
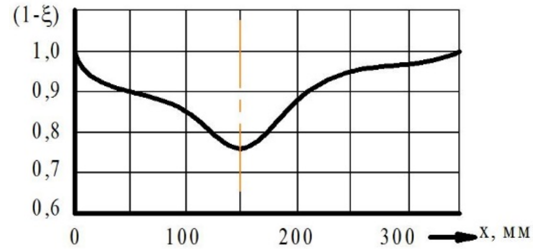
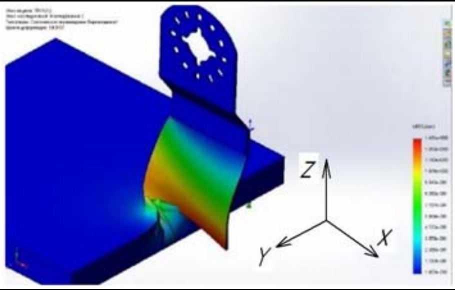
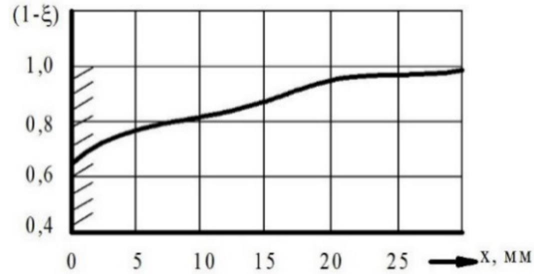
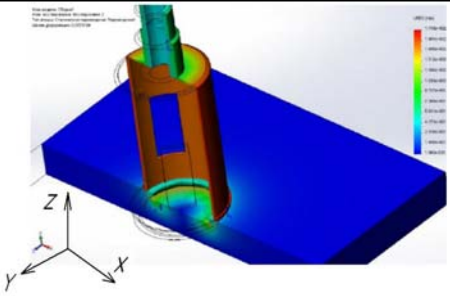
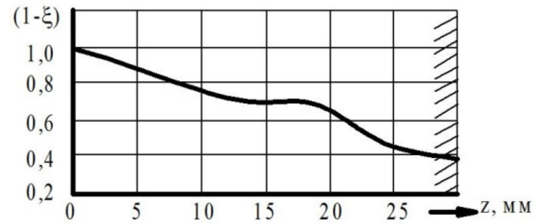
№ i/o	Defect type	Example	Controlled parameter	Number
1	The presence of damage to the diamond-containing layer and the relative area of grain crumbling areas		$N_{avg} = 28\,pcs$ $At\,N_a = 58\,pcs,$ $k_{oa} = \frac{N_a}{N_{avg}} = \frac{28}{58} = 0{,}483$	4
2	Salting		$k_{sb} = \frac{S_b}{S_o} = \frac{161}{227} = 0{,}71$	12
3	The presence of a violation of the substrate to the basis adhesive adhesion	Not found		
4	Deviation of the tool housing geometric dimensions		$k_d = \frac{R_{max} - R_{min}}{R_0} = 0{,}05$	2
5	Deformation and damage to housing	Not found		

***Table 8** Intensity modeling of working surfaces loading at processing*

Modeling conditions	Interaction model (static deformation from Q_n)	Wear of the work surface
$V_p = 0{,}4\,m/s$ $P_h = 80\,N$ $n = 60\,double\,strokes/min$ $d_r = 3{,}5\,mm$		
$V_p = 12\,m/s$ $P_h = 25\,N$ $n = 3200\,double\,strokes/min$ $l_r = 5{,}0\,mm$		
$V_p = 0{,}3\,m/s$ $P_h = 45\,N$ $n = 1500\,rpm$ $d_r = 18{,}0\,mm$		

Thus, the difference in the operating conditions of the tool (in this example – the strings with applied diamond layer) is an important factor that determines both the productivity of processing and uneven wear of the tool working surfaces. The latter is indicated in Table. ξ and is shown as a function of the prevailing linear parameter (for example, for a string – it is its length).

This made it possible to propose an equation for the change in the properties of surface clusters in the main direction:

1) Density of applying W,

$W_1 = const$; $W_2 = b_{01} + b_{11}l + b_{21}l^2$

2) Application step t :

$t_1 = const$; $t_2 = b_{02} + b_{12}l + b_{22}l^2$

3) Application profile h :

$h_1 = const$; $h_2 = b_{03} + b_{13}l + b_{23}l^2$.

Therefore, providing the appropriate temperature modes, consumption of diamonds and the conditions of their application to the surface, we form certain properties of the tool, which in the future ensure the reliability of its operation. The algorithm of reverse engineering of the cutting surface has the following form (Fig. 11).

The application of a functional approach to improving the processes of diamond layer formation using morphological and functional-cost analysis allowed to formulate the basic principles of determining the operational features of the products and to offer material carriers of functions in the form of ways to form such a layer.

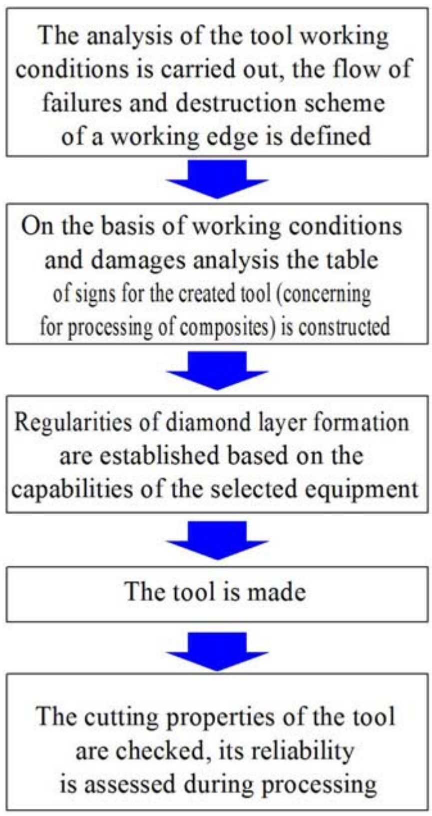


Fig. 11. Algorithm for reengineering the cutting surface

The assumption made, that clustering of tool working surfaces allows to more clearly adapt different cutting modes (individual areas of the tool) to the interaction conditions showed that such adaptation is most appropriate for tools with additional degrees of freedom – flexible non-rigid mandrels able to constantly change the interaction conditions of grains with the material during the process.

Such clustering also allows to take into account the feature of the processed composite structure, its anisotropy and structure, including voids, mechanical properties of components, conditions of deformation and exclusion of reinforcing fibers, etc. At the same time, reengineering allows to reliably and accurately determine the features of clusters on the tool working surfaces, adapting them to work with a specific material.

Thus, we have proposed a universal means of maximum adaptation of the tool working surface to the conditions of its use.

3. CONCLUSIONS

Performing modeling of high-strength composite processing proved the effectiveness of tool surface modification on a functional basis and allowed to determine the basic patterns of diamond drill, renovator saw, diamond string during cutting of KIMF type material. At the same time, the proposed reengineering technique allowed to more accurately determine the features of laying surface clusters, their size and properties.

It is established that the stability of the tool created on the basis of a functional approach using the proposed technique of reengineering is higher than traditional by 20-25% for ring drills, 40-50% – for flexible tools (diamond strings) and 15-20% – for elastic tools (renovator blade).

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