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DETERMINATION OF THE WEAR MECHANISM OF THE DIAMOND TOOL MATRIX BY ANALYSIS OF WEAR PARTICLES

Purpose. Determining the contact zone of microindentors from the rock side with the surface of a non-diamond element based on the Ni-Sn system (6 wt%) and in comparison with the contact zone of the specified microindentors with the surface of a similar bond of a diamond-containing element, under dynamic loading.

Methodology. To select the wear products of the experimental element material, made by resistive electro-sintering and the core of abrasive sandstone as a result of short-term contact between their surfaces, the tests were performed on a stand created on the basis of the screw-cutting lathe ДІП–200 according to the parameters of technological conditions that simulate the drilling process. The sludge suspension was selected and examined using a ZEISS EVO 50 XVP scanning electron microscope with an Oxford Instruments Ultim Max energy dispersive X-ray analyser. Also, the worn surface of the diamond-free element was subjected to microscopic examination using Lomo Metam R-1 microscopes with a Digital KOCOM CCD video camera and Bausch & Lomb, mod. Gemolite.

Findings. The result of the study involves the determination of the direct point of contact between the microindenter on the rock side and the surface of the non-diamond element in the wear particle. The point of direct contact of the specified counterbodies has the form of an elliptical groove, which is the epicenter of the formation of a system of microcracks. The morphometric identity of the wear particles of the studied element and the diamond tool bond indicates the similarity of one of the mechanisms of microindentation from the side of the rock.

Originality. Determination of one of the sources of damage to the working surface of the diamond tool element opens up prospects in the study of all stages of the bond wear mechanism depending on changes in its chemical composition or technological parameters of the tool use.

Practical value. Determination of the chemical and morphometric features of the wear particles of the diamond tool bond will allow assessing its wear resistance and developing wear resistance criteria, which is reflected in the saving of resources.

Keywords: *rock, diamond tool, wear particle, brittle wear*

Introduction. One of the main technological methods of geological exploration of mineral deposits is diamond drilling. Therefore, increasing the wear resistance of the matrix material is an important aspect in the design and production of drilling tools, including in order to save resources. The presented study is devoted to determining the features of wear of the material of the bond of a diamond rock-breaking tool due to dynamic contact with the rock, that is, the friction pair is represented by the rock surface – the matrix surface of the specified tool.

Wear is damage, gradual removal or deformation of material on solid surfaces. The causes of wear can be mechanical, chemical ones. Metal wear occurs by plastic displacement of surface and near-surface material and separation of particles that form wear debris [1]. Typically, the wear intensity of a diamond drilling tool is calculated as the ratio of the tool mass that it lost during operation to the volume of the resulting cuttings [2]. In addition, the wear resistance of a diamond drilling tool is calculated as the ratio of its linear wear to the depth of the well [3].

The use of these methods for studying the wear resistance of a rock-breaking tool does not involve determining the configuration of a particle of worn matrix material, which can serve to expand ideas about the mechanism of mass loss of the tool binder material. The mathematical model of damage to the diamond-containing matrix of a diamond drill bit [4], as a result of which scratches are formed on its working surface, equipped with synthetic diamonds, is built on the basis of ideas about the simultaneous pressing of spherical particles of sludge into the matrix.

Continuing the definition of the shape of the sludge particle in the work [5], O. M. Isonkin analyzes the granulometric composition and appearance of sludge particles of Korostyshevsky granite, formed as a result of drilling with diamond-impregnated crowns of the БС-01 type. As the authors note, all particles had an irregular shape; however, they have outlines resembling the shape of an elongated ellipsoid of rotation. Larger particles in the sludge sample are almost spherical in shape, while the smaller ones are needle-shaped.

Therefore, scratches on the surface of the matrix are formed, according to the mentioned work, due to the indentation of both spherical and needle-shaped sludge particles. However, the configuration of microgrooves on the surface of the matrix material and discrete particles of its wear products were not considered by the authors.

The height of the diamond protrusion was adopted as a parameter that evaluates the microgeometry of the wear of the working surface of the matrix of a diamond-impregnated drill bit; however, the configuration parameters of microgrooves on the surface of the matrix material of the bit were not studied by the author [3].

In the images of the end of the impregnated drill bit at a 56-fold magnification [6] and in SEM images of the surface of diamond-impregnated drill bits after drilling

rock with them under conditions close to production conditions, parallel discontinuous microgrooves on the surface of the matrix material were recorded. The authors explain their formation as a result of micro-splitting of scaly fragments from diamonds, as a result of high temperature loads on the surface of diamond grains during direct contact with rock during its destruction with their subsequent movement in the gap between the bottomhole and the tool matrix, which causes the likelihood of their scratching on a metal bond.

Similar views are expressed in the printed edition by Zybinsky P.V. and co-authors: in addition to diamond grains and their fragments, particles of sludge, breaking off chaotically and involuntarily from the face, also fall into the specified gap and cause wear of the drilling tool.

Similar characteristics of the surface of the matrix of a diamond drilling tool with damage features in the form of discontinuous parallel microgrooves are observed in images of the surface of a diamond drill bit sector after drilling hard, strong rock [7, 8].

The presence of similar wear microgrooves is observed in illustrative material on the working surface of diamond wheels, in which an alloy of the Fe-Ni-Cu-Sn system was used as a matrix material (M6-26 bond), equipped with single crystals and polycrystals of diamond during the destruction of steel (Steel 3). and M300 concrete [9]. As the authors note, a feature of the morphology of the surface of the matrix of diamond wheels during the processing of concrete and steel is that on a microscopic scale, it is flat, with separate grooves oriented in the processing direction, with depressions of various sizes (10–40 μm).

In order to model the damage of a diamond composite on a tungsten-cobalt alloy (Co – 6 %) bond by indenters and to determine the mechanism of its wear, the authors [10] performed a study by scratching the specified composite with a Rockwell diamond indenter under varying loads. They noted that with increasing load, the width of the bond damage path increased.

However, the authors do not comment on the discontinuity of the microgrooves shape in the context of the evolution of the configuration of the microimprints that form it. A similar, discontinuous microgroove is formed under the influence of dynamic loading on a nanosphere-conical indenter on the surface of a hard alloy sample. At the same time, the authors also did not note that the microgrooves consist of a large number of discrete microholes.

The reason for the formation of microgrooves on the surface of the above materials is the chipping off of dispersed particles of the material that has undergone indentation under dynamic loading; however, the literature review of the analysis of their morphometric features goes beyond the study of the wear mechanism of diamond rock-breaking tools, due to the lack of information on their receipt and further study and due to the fact, as it turned out, the emphasis of researchers on the fragmentation of dispersed particles of wear products and, sometimes, the identity of the configurational features of wear particles of hybrid friction pairs with different physicochemical characteristics.

To determine the mechanism of material removal from a fused quartz sample [11], a brittle material, during grinding or cutting of which the formation of surface [12] and subsurface cracks [13, 14] was observed, the authors [11] applied mechanical processing in the plastic mode [15, 16], because, at a very small cutting depth, in brittle materials, the material removal mode is plastic processing [17], namely, nanoscratching of its surface was carried out using a HYSITRON Ti 950 triboindenter, a nanoindenter and a Berkovich diamond indenter. When the scratching depth was above the critical one, microcracks formed on the surface of the sample, and with an increase in the scratching depth, lateral cracks, fractures and chips were formed. The destruction process changed to brittle and a particle of material was chipped off, although the authors do not focus on its characteristic triangular shape presented in the image.

In the electronic images obtained by scanning electron microscopy of the friction surfaces of the Al_2O_3 – 5 %C composites on ceramic and steel counterbore bodies, the formation of a system of discontinuous microgrooves similar to each other is observed, which consist of microholes, 7–15 μm wide, which have a triangular shape according to the images presented by the authors, [18]. To determine the wear mechanism, MG– metallographic and MRS (micro X-ray spectroscopy) and RF (X-ray phase) – analyses of the friction surfaces were used. The steel sample had a scaly surface of the chip; however, the shape of the scales or the hypothetical mechanism of their formation were not considered by the authors.

The microstructure of the friction surface areas of hardened steel samples (Steel 45) with and without an air-fuel wear-resistant coating [19] in images obtained using a Camebax SX-50 electron microscope is a scaly surface. The wear, as the authors indicate, is of the oxidative type, and the friction surface of the steel sample is characterized by a significant number of areas of adhesive bonding, tears in the surface layer are formed on the friction surface, and signs of adhesive wear are realized. However, the authors, indicating a scaly surface, do not comment on the shape of the scales in the SEM images, which form microgrooves on the surface of the samples. As a result of the research on the regularities of tool wear during longitudinal turning of cylindrical samples from hardened steel grade ShKh15 with tools equipped with polycrystalline superhard materials (PSTM) based on cubic boron nitride (CBN), the authors [20] concluded: grooves are formed on the contact areas on the back surface of a single-edged tool, which have an orientation that coincides with the direction of the vector of the resulting cutting speed. These defects form a microrelief of the area of the back surface of the cutter, which is copied on the machined surface in the form of similar in shape, repeating microroughnesses. The authors explain the formation of parallel microgrooves, chipping of individual PSTM sections and the appearance of notches on the cutting edge of the tool by the deterioration of the processing quality. The authors of the mentioned work focus their attention on the fragmentation, as a result of microchipping, of wear products during the cutting process. They indicate, hypothetically, brittle microcracking of fragments of the tool composite, causing accelerated tool wear, due to some increase in hardness and decrease in strength of the material itself.

A dispersed particle of Al_2O_3 + TiC ceramic sludge (VOK60), obtained as a result of its grinding with a dia-

mond wheel 12A2-45°, 150 × 10 × 3 × 32, AC4 160/125–B1-13–100, and examined using a CILAS granulometer, mod. 715 E482 (France), the author of the work [21] considers as a result of compaction of small particles of sludge. However, its configuration has characteristic configurational features of particles of rock destruction by diamond drilling and stone-working tools [22] and particles of matrix material with Ni-Sn (6 %), obtained after turning a block of sandstone of the Torez deposit with a cylindrical diamond rock-destroying element, as it turned out, when using a scanning electron microscope (SEM) ZEISS EVO 50 XVP, with an energy-dispersive X-ray analyzer Oxford Instruments` Ultim Max 100 [23, 24]. Indeed, regardless of the chemical composition of the material: tungsten-cobalt alloy, intermetallic or rock [22], the nature of the damage on its surface: by a separate indenter [24, 25], or during destruction by a diamond, drilling, stone-working tool, with dynamic loading of its surface by microindentors from the rock side, microgrooves are formed on the specified surfaces as a result of micro-chipping of dispersed particles of wear material, which are characterized by the indenter depression zone, side and end parts, and also have a general shape similar to a "dovetail" [26] and are the result of their "brittle" chipping off from the massif. These signs may, hypothetically, indicate a similar mechanism of separation of particles of ceramic material from its surface as a result of dynamic loading of diamonds of a diamond wheel on it. So, in all the works considered, discrete particles of wear or material destruction are formed as a result of their brittle chipping off from its surface layer, even the plastic material of the diamond tool bond, according to the technological parameters specified by the authors. After all, as the authors note [27], the resistance to deformation depends on the nature of the deformed material, temperature, degree and rate of deformation and the nature of the stressed state of the material, whether it is plastic material or fragile.

Different alloys are characterized by different values of the resistance to deformation, which is associated with their chemical composition, atomic and crystal structure. The increase in the role of tensile stresses leads to a decrease in plasticity.

From the deformation curves of alloys based on the Ni-Sn system given in [28] under static loading at a speed of 0.5 mm/min it follows, that this alloy behaves as a plastic with a strain rate of 0.0002 s^{-1}, but when the strain rate increases to 102,260 mm/min which occurs when this alloy is deformed in a diamond composite bond in a functional element for a rock-breaking tool when cutting a rock core (93 mm in diameter at 350 min^{-1}), the strain rate increases to 40.904 s^{-1}, i.e. 5 orders of magnitude more, and according to the aforementioned studies of the effect of strain rate on the mechanical properties of steels and nickel alloys, their fracture becomes brittle.

Selection of previously unsolved parts of the general problem. For the reason that, namely, the loss of bond material in a diamond rock-breaking and stone-working tool is predominant, in comparison with the level of mass loss of diamond grains as a result of processing, according to the results of the work of Tsypin N. V., the study of the mechanism of its wear is dominant in the process of studying the mechanism of wear of a composite diamond-containing material.

Formulation of the purpose of the article and setting tasks The purpose of the study is to determine the contact zone of sharp microindentors from the rock side with the surface of a diamond-free, experimental element based on the Ni-Sn system (6 % by mass) under dynamic loading and in comparison with the contact zone with the corresponding sharp indentors with the surface of the bond of the rock-breaking diamond- tool through the study of the chemical and morphometric features of discrete wear particles of the specified experimental element.

Methods. To compare the process of separating discrete particles of the bundle material from the working surface of a diamond-containing functional element for a rock-breaking tool based on a bundle of the Ni-Sn system (6 %), and from the wear surface of a diamond-free experimental element an experimental element was manufactured from the material used to manufacture the bundle of a functional element of a diamond rock-breaking tool. A sample with a diameter of 10 mm based on the Ni-Sn system (6 %) without diamonds was manufactured by resistive electrosintering with subsequent holding under pressure for 3 min (pressure $P = 300$ MPa, sintering duration $t_c = 14$ s, current $I = 1.3$ kA, voltage $V = 2.4$ V at a temperature of up to 700–850 °C), which provided a material density of 7.875 g/cm^3 [29].

To select the sludge (which contains wear products of the functional element material from Ni-Sn (6 %) and rock) due to short-term contact of its surface with the surface of a cylindrical core of rock of abrasive sandstone of the Torez deposit of the IX drillability category, which has stable physical and mechanical properties, high abrasiveness – 35 mg, and the hardness according to the stamp of which is $Psh = 2.90$ GPa, tests were performed on a stand created on the basis of the DIP-200 screw-cutting lathe [29, 30].

The experimental sample, fixed in the tool holder of the caliper of the DIP-200 screw-cutting lathe, was pressed against the surface of the rock core with a force close to 300 N, while cooling the experimental element with a coolant (5 l/min), moving along the core during the working process. As a result of short-term (1 min.) interaction of the experimental cylindrical diamond-free element with a feed rate of the support (Table) of 0.148 mm/rev of a screw-cutting lathe with an abrasive sandstone core rotating at a speed of 355 min^{-1} – according to the parameters of technological conditions that simulate the process of drilling a well with a diamond rock-breaking tool in the Torez sandstone, the slurry in the form of a suspension was collected in a slurry sampling device [30], dried and examined using: and a ZEISSEVO 50 XVP scanning electron microscope with an Oxford Instruments' Ultim Max energy-dispersive X-ray analyzer. In addition, the worn surface of the experimental diamond-free element was subjected to microscopic examination using microscopes Lomo Metam P–1 with a Digital KOCOM CCD video camera and Bausch & Lomb, mod. Gemolite.

Results. The image of the entire surface of the spent experimental diamond-free element allowed to reproduce the microscope Bausch & Lomb, mod. Gemolite [30].

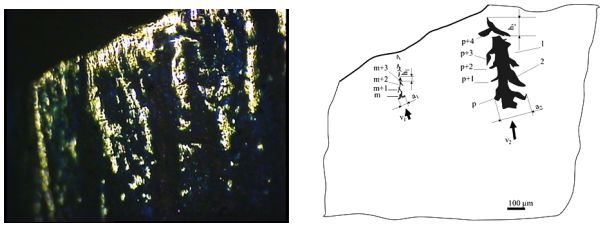
The undamaged surface in the process of working out the diamond-free element is exposed to the sharp edges of quartz grains from the side of the rock, forming individual microholes, combined into chains of microgrooves.

As it turned out, the configuration of microgrooves on the worn surface of the diamond-free element based on the bond of the Ni-Sn system (6 %) is identical to the configuration of microgrooves on the worn surface of the diamond functional element for a rock-breaking tool [23].

Microgrooves on the wear surface 1, consisting of a chain of microholes 2, as shown in the image of a fragment of the surface of an experimental diamond-free element obtained using a Lomo Metam P–1 microscope with a Digital KOCOM CCD video camera, Fig. 1, *a*, and in the schematic image of the surface under consideration, Fig. 1, *b*, in order to emphasize self-similarity, both smaller microholes, with a number of m+n in the chain, with a width of a_1 – up to 100 μm, and larger ones, with a width of a_2 – more than 100 μm, completely cover the surface of the experimental element, as selectively shown in the figure, with a step of h_1, approximately 35 μm and h_2, approximately 120 μm, respectively, and the direction of their formation, v_1 and v_2, coincide.

A microimprint or micropit is a carrier of information about its overall dimensions and configuration, which can indicate the degree of wear intensity of a given material both by one sharp indenter during the period of time of a single chipping off of one discrete wear particle, and by a large number of indenters from the side of the rock. when chipping off a large number of wear particles, which contributes to the formation of micropit chains.

Microscopic studies of the counterbody with which the experimental element – the surface of the rock – had a short-term interaction, using the specified microscope, indicate the presence on its surface of indentors protruding from it by 5–10 μm, sharp and thin, with a radius of curvature of 2–5 μm, sharp edges of quartz grains, the hardness of which on the Mohs scale corresponds to a value of 7 units.



a *b*

Fig. 1. The general view: a fragment of the wear surface of the experimental element after a short-term interaction with a sandstone block of the Torez deposit, obtained using a Lomo Metam P–1 microscope with a Digital KOCOM CCD video camera (a); a schematic image of the specified fragment of the wear surface:

1 – undamaged part of the contact surface of the experimental element with the rock block, 2 – wear microholes; a_1, a_2 – width of wear microholes in two chains of microholes, respectively; h_1, h_2 – length of the specified microholes in two chains, respectively; $m + n$, $p + n$ – the number of microholes in the specified chains, respectively; v_1, v_2 – velocity vectors of microindentors from the rock side, forming chains of damage to the contact surface of the experimental element (b)

As can be seen from the schematic image of the microhole presented in Fig. 2, *a*, the photographic image of which is considered in [30], on an enlarged fragment of the worn surface of the experimental diamond-free element, reproduced by a Bausch & Lomb microscope, mod. Gemolite, its configuration characteristics: the shape of the main part in the form of a "dovetail", the indenter penetration zone 1, the residual zone of indenter penetration 1'; the side parts 2, the end part 3 and the dynamic characteristic, the indenter velocity vector from the rock side v, completely coincide with the specified characteristics of the discrete particle of the material from which it was made, extracted from the sludge after a short-term working out of the diamond-free experimental element, presented in the image, Fig. 2, *b*, obtained using a scanning electron microscope.

It was determined that the chemical composition of the specified wear particle of the diamond-free experimental element coincides with the composition of the material from which the diamond-free element was produced – Ni-Sn (6 %) [30].

Moreover, its chemical composition in the central zone of the particle, namely, in the zone of deepening of the indenter 1, indicates the content, in addition to 71.37 % nickel, of 5.42 % tin, which is as close as possible to the tin content in the material – 6 %, with the maximum nickel content on the particle surface – 84.08 % and tin – 3.74 %. In addition to determining the chemical composition of the wear particle of the experimental element, the use of an emission microscope allowed us to identify important details related to the direct contact of the sharp indenter from the rock side with the surface of the material from which the experimental element was made.

The indenter penetration zone of the particle, in the case under consideration, consists of two parts: the direct indenter penetration zone 1, thickened, as shown by the arrows, Fig. 2, *b*, above the contact groove with the sharp microindenter from the rock side and the residual zone of indenter penetration 1'. The last part of the wear particle is usually lost, hypothetically, for many reasons: with increasing fragility of the material, due to the high rate of deformation in the material that wears out under dynamic loading on the indenter, with the achievement of the corresponding values of the specific load of the indenter on the surface of the material, from which it breaks off at the moment of direct contact of the indenter with the surface of the counterbody, due to the complexity of the path of movement of a discrete wear particle – in the process of sludge selection and its magnetic separation, during the use of various types of optical equipment.

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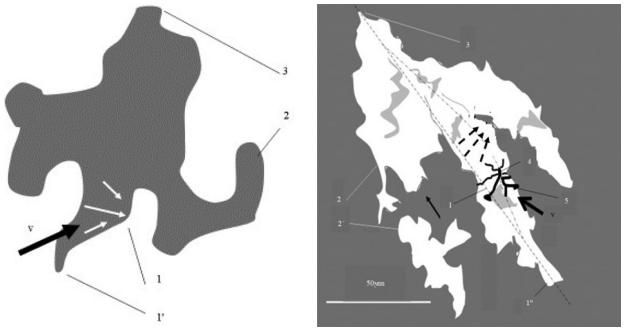


a *b*

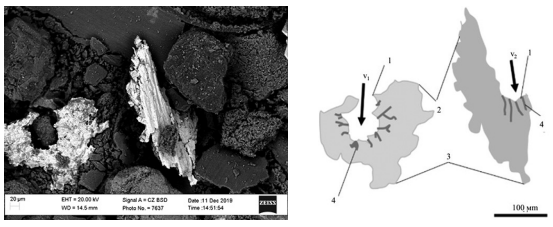
Fig. 2. Schematic representation of:

micropit on the wear surface of the experimental diamond-free element, 1 – indenter depression zone; 1′ – residual zone of indenter penetration; 2 – side parts; 3 – end part; v – indenter velocity vector from the rock side of a particle of NiSn (6 %); discrete wear particle of the experimental diamond-free element, 1′ – indenter penetration zone; 1 – residual zone of indenter penetration; 2 – main side part; 2′ – separated side part; 3 – end part; 4 – point of contact in the form of an elliptical groove of the sharp edge of the microindenter from the rock side with the surface of the experimental element; 5 – system of microcracks in the indenter depression zone; v – velocity vector of the microindenter

path of movement of a discrete wear particle – in the process of sludge selection and its magnetic separation, during the use of various types of optical equipment.

The system consists of microcracks 4, Fig. 3, *b*, formed in the zone of indenter penetration 1 in the wear particles of the bond material with Ni-Sn (6 %), Fig. 3, *a*, mentioned in [29], which have, in addition to the specified one, other configurational features: side parts 2, and end part 3 against the background of sludge particles after mining the diamond-containing element with, diamond grain size at their relative diamond concentration of 100 % –200/160 in the image obtained using SEM.

This system demonstrates the case of, namely, a direct, "microimpact" of one microindenter with a speed v_1 and v_2 from the side of the rock with the bond material of the functional element of the rock-breaking tool, that is, it indicates the destruction of the residual zone of the wear particle of the matrix material in the process of contact of the sharp indenter with the surface of the bond



a *b*

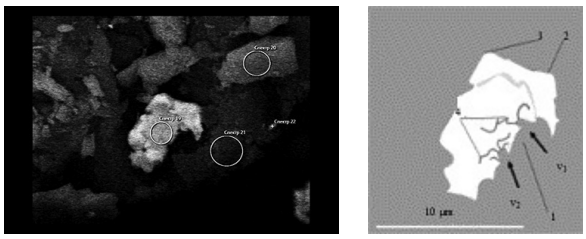
Fig. 3. The general view of:

image obtained using SEM, wear particles of matrix material based on the NiSn system (6 %), against the background of sludge particles after mining a diamond-containing element with a diamond grain size of 200/160 and their relative concentration of 100 % in a rock block (a), schematic image of the specified wear particle, 1 – indenter penetration zone; 2 – lateral part; 3 – end part; 4 – microcrack system; v_1, v_2 – indenter penetration velocity vectors (b)

of the tool. A similar system of microcracks in the indenter penetration zone occurs in a wear particle, of a Ni-Sn (6 %) bond material, formed during the destruction of rock by an experimental rock-destroying element with a significantly different diamond concentration of 500/400 at the same relative concentration [24].

However, microindentation can be caused not by one, but by several microindentors: two sharp edges of one quartz grain, or a system of two microindentors from the rock side, as shown in Fig. 4, the image obtained using the specified emission microscope and, namely, a discrete wear particle of the material of the non-diamond element, with characteristic configuration features, the indenter penetration zone 1, the side parts 2 and the end part 3, the chemical composition of which is presented in the Table against the background of the sludge, the configuration of the indenter depression zone informs about the number of microindentors that moved with speeds v_1 and v_2, as a result of which "microimpacts" into the array of the insert material, microcrack systems 4 were formed in the microholes.

A similar loss of the residual zone in the indenter 1 penetration zone and a similar system of microcracks 4 are observed in the fracture particle of Torez sandstone



a *b*

Fig. 4. The general view of: image obtained using SEM of a wear particle of a diamond-free experimental element against the background of sludge particles after short-term dynamic contact with a rock block (a), schematic image of a wear particle:

1 – indenter penetration zone; 2 – lateral part; 3 – end part; 4 – microcrack system; v_1, v_2 – velocity vectors of two microindentors from the rock side (b)

Table

The chemical composition of the sludge, obtained after short-term dynamic contact of an experimental diamond-free element with a rock block containing a wear particle whose indenter penetration zone is formed by two microindentors

Spectrum label	Spectr. 19	Spectr. 20	Spectr. 21	Spectr. 22
C	14.02	27.43	52.33	43.47
O	1.92	38.49	35.46	18.20
Na	–	1.67	–	–
Al	–	6.86	1.20	0.98
Si	–	19.09	3.39	2.23
K	–	5.17	2.47	0.55
Ca	–	–	–	0.44
Ni	84.06	1.31	5.16	34.11
Total	100.00	100.00	100.00	100.00

by a diamond rock-breaking tool considered in [22], which is characterized by the configuration parameters indicated in relation to the matrix material wear particle, in addition to the following: lateral parts 2 and end zone 3, Fig. 5, broken off from the rock face by an indenter–single diamond grain, fixed in the matrix of the drilling tool.

So, presented in Fig. 2, *b*, the particle of wear of the experimental element with a sharp edge, hypothetically, a quartz grain, from the side of the rock has an axis of symmetry; moreover, all geometric parameters, in particular, the shape, in the form of a "dovetail" of its main part, as well as the overall dimensions (width and length – about 90 and 150 microns, respectively) and the direction of movement of the indenter that chipped off the wear particle, correspond, not only, to the configuration parameters of the particles of wear of a functional element made of a composite diamond-containing material [23, 24], but also to the geometric parameters of the particle of fracture of a brittle rock by a diamond functional element [22], which indicates brittle wear of the surface of the bond based on the Ni-Sn system (6 %) by sharp microindenters from the side of the rock.

Particular attention in the image under consideration is drawn to the point of direct contact of the sharp indenter with the surface of the experimental element in the indenter penetration zone 1, moving at a speed *v*, Fig. 2, *b*, in the form of an elliptical groove with major and minor axes of 4.2 and 0.8 μm, respectively, which is the epicenter of the formation of a system of microcracks 5, which divide the surface of the particle in this zone into approximately equal sectors.

The point of contact of the sharp indenter from the side of the rock with the surface of the material of the experimental element is characterized by a slight "thickening" in the form of a "rise" (the direction of which is shown by arrows) of the particle surface above the sludge surface, which may indicate the moment of resistance of the material to detachment, during which, probably, the formation of two new surfaces occurred: the surface of the microhole in its volume and the reverse surface of the chipped particle.

A similar "thickening" in the residual zone of indenter penetration is observed in the wear particle of a diamond rock-breaking element, the wear products of which were considered in [23], in the image obtained

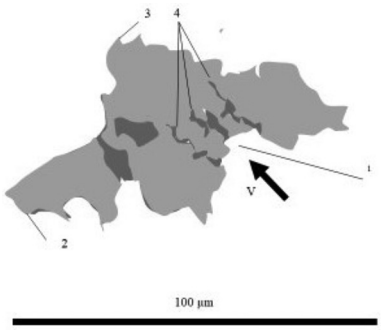


Fig. 5. The schematic representation of a rock fracture particle:

1 – the zone of indenter penetration (diamond grain in the tool); 2 – side part; 3 – end part; 4 – microcrack system; V – vector of indenter penetration velocity

when using the DiaInspect OSM device from Diamant Vollstadt GmbH. In addition, the "thickening", shown by arrows in Fig. 2, *b*, in the form of a "lift" of the ligament material, takes place in the image of the wear microhole, Fig. 2, *a*, though in the form of a "deepening", reflected, mirro-rimage, in the opposite direction, also shown by arrows, on the surface of the experimental element after the removal of the wear particle, which indicates the deepening of the microindenter from the side of the rock, precisely at this point.

Therefore, the correspondence of the configuration components of discrete wear particles of the experimental diamond-free element based on the Ni-Sn system (6 %), obtained during its short-term, dynamic interaction with the sharp edges of microindentors from the rock side, to all configuration features of wear particles of the bond of the diamond functional element of the rock-breaking tool and to all configuration features of a discrete particle of rock destruction by a diamond rock-breaking and stone-working tool in which diamond grains are "fixed" indentors, taking into account the postulates of the theory of similarity of Kirpichev M. V., according to which similar processes must have the same physical nature and the similarity of the conditions of uniqueness must be fulfilled, namely: geometric, kinematic, dynamic and thermal similarity, confirms the hypothesis of Blinov G. O. that one of the sources of damage to the surface of the bond of the diamond-containing functional element of the diamond rock-breaking tool, are fixed sharp edges of microindentors from the side of the rock, and the process of wear of the diamond tool is inseparable from the process of destruction of the rock, which can be considered as the process of its wear, as noted in their printed edition by Solovyov M. V., Chikhotkin V. F., Bogdanov R. K. and Zakora A. P. Therefore, a more complete idea of the mechanism of mutual damage of the tool and the counterbody can be given by studying not a separate element of the friction pair, but the mechanism of their interaction, as a whole. Therefore, determining the identity of the configuration of discrete wear particles of both the diamond tool and the rock is evidence of a single mechanism of their separation from the massif.

Conclusions.

1. A discrete particle of friction pair wear is a witness and, at the same time, a participant in the loss of mass of counterbodies; therefore, its study by both optical and chemical methods can be informative regarding the wear mechanism itself, as a process that has a certain duration.

2. Taking into account the plastic properties of the material under consideration, which is used as a bond of the functional element of the rock-breaking tool, namely, the chipping off of discrete particles, of an empirically determined configuration – "dovetail", which is characteristic of particles of rock destruction by a diamond functional element, indicates the brittle nature of this wear under the specified technological conditions of development, because, namely, the stressed state of the material affects the state of the solid under the corresponding conditions of dynamic loading, which loses its plastic properties and becomes brittle as a result of this state.

3. Spectral analysis of particles extracted from the sludge, obtained during the short-term dynamic interac-

tion of an experimental diamond-free element based on the Ni-Sn system (6 %) with a block of abrasive sandstone, confirmed the identity of the chemical composition of the extracted particles and the material of the experimental sample, which indicates, exactly, the correspondence of its morphometric characteristics to the morphometric characteristics of both the wear particles of the diamond-containing functional element and the particles of rock destruction by the diamond functional element.

4. The point of direct contact of the sharp microindenter from the side of the rock surface with the surface of the experimental diamond-free element has the form of an elliptical groove, which is the epicenter of the formation of a system of microcracks that divide the surface of the particle in this zone into approximately equal sectors, which indicates a uniform distribution of the load on the surface of the experimental element.

5. The point of contact of a sharp microindenter from the rock side with the surface of the counterbody material in a wear particle, both of an experimental diamond-free element based on the Ni-Sn system (6 %) and in a wear particle of the bond material surface in a diamond-containing functional element, is characterized by a slight "lifting" of the particle surface, which indicates the resistance of the material, during which the formation of two new surfaces occurred: the surface of the microhole in the volume of the material and the reverse surface of the chipped discrete particle.

6. One of the methods of microindentation of the surface of the bond material based on the Ni-Sn system (6 %), in a diamond functional element under dynamic loading is the contact of sharp edges from the rock side, which are "fixed" microindentors, with the bond material of the functional element of a diamond rock-breaking tool, which causes brittle chipping of discrete particles of the bond material, and their morphometric parameters correspond to the shape indicators of the wear particles of the functional element of a diamond rock-breaking tool.

7. Determining the source of damage to the working surface of the functional element of a diamond rock-breaking tool opens up new prospects in studying the mechanism of wear of the bond of the specified tool and makes it possible to develop criteria for its wear resistance, which is reflected in resource savings.

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Визначення механізму зношування зв'язки алмазного інструменту за аналізом частинок зношування

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Мета. Полягає у визначенні зони контакту мікроінденторів з боку гірської породи з поверхнею безалмазного елементу на основі системи Ni-Sn (6 %мас) й у порівнянні із зоною контакту зазначених мікроінденторів із поверхнею аналогічного зв'язку алмазовмісного елементу при динамічному навантаженні.

Методика. Для відбору продуктів зношування матеріалу експериментального елементу, виготовленого методом резистивного електроспікання й керну абразивного пісковику внаслідок короткочасного контакту їх поверхонь, випробування виконувались на стенді, створеному на базі токарно-гвинторізного верстату ДІП–200 за параметрами технологічних умов, моделюючих процес буріння. Шлам відбирали й досліджували із застосуванням скануючого електронного мікроскопіа ZEISS EVO 50 XVP з енерго-дисперсійним рентгенівським аналізатором Oxford Instruments' Ultim Max. Також, мікроскопічному дослідженню підлягала зношена поверхня безалмазного елементу за використання мікроскопів Ломо Метам Р–1 із CCD відеокамерою Digital KOCOM і Bausch & Lomb, mod. Gemolite.

Результати. Результатом дослідження є визначення безпосередньої точки зіткнення мікроінденторa з боку гірської породи з поверхнею безалмазного елементу у частинці зношування. Точка безпосереднього зіткнення зазначених контртіл має вигляд еліптичного пазу, що є епіцентром утворення системи мікротріщин. Морфометрична ідентичність частинок зношування досліджуваного елементу та зв'язки алмазного інструменту свідчать про подібність одного із механізмів мікроіндентування зв'язки з боку гірської породи.

Наукова новизна. Визначення одного із джерел пошкодження робочої поверхні елементу алмазного інструменту відкриває нові перспективи у вивченні всіх етапів механізму зношування зв'язки в залежності від зміни її хімічного складу або технологічних параметрів використання інструменту.

Практична значимість. Визначення хімічних і морфометричних особливостей частинок зношування зв'язки алмазного інструменту дозволить оцінювати його зносостійкість і розробляти критерії зносостійкості, що відображається на економії ресурсів.

Ключові слова: *гірська порода, алмазний інструмент, частинка зношування, крихке зношування*

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