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ON THE MECHANISM OF ROCK FRACTURE WITH TOOLS MADE OF HARD ALLOYS AND POLYCRYSTALLINE SUPERHARD MATERIALS

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Abstract. When studying the process of rock fracture with tools equipped with polycrystalline superhard materials (PSHM) and hard alloys, the main regularities of the fracture mechanism, despite the significant differences in physical and mechanical properties of the used tool materials, are assumed to be identical. This approach not only reduces the efficiency of using the created rock-destroying tools, but also limits the scope of application of polycrystalline superhard materials.

Experimental studies using various methods of obtaining information shown significant differences in the mechanism of rock fracture by hard alloys and polycrystalline superhard materials. The study of the zone of the pre-destroyed surface showed that when cutting rocks with PSTM, the process of destruction is carried out not only by the entire polycrystalline plate, but also by ridged diamond formed on the cutting edge and rear surface of the tool. At the same time ridged diamonds, when embedded in the rock, create high contact stresses and an additional network of microcracks interacting with microcracks formed due to the embedding of the entire cutting edge of the plate. The impact of two independent indenters simultaneously increases the zone of the pre-destruction layer in the rock mass, which leads to a more significant decrease in its strength and, as a consequence, to the intensification of the process of rock destruction by the PSTM tool.

In case of wrong choice of PSTM application area and operation modes, errors in tool design and insufficient cooling, ridges are not formed on the cutting edge and back surface of the polycrystal. As a result, the polycrystalline insert works as a carbide insert and the efficiency of the PSHM tool is sharply reduced.

The use of knowledge obtained as a result of the conducted research makes it possible to create tools equipped with diamond-hard-alloyed inserts, the wear resistance of which is dozens of times higher than that of similar tools made of hard alloy. For example, effective tools equipped with diamond-hard-alloyed inserts have been created and widely introduced into practice for rotary drilling of boreholes, degassing wells, anchoring of mine workings, saw stone cutting, drilling of abrasive permafrost soils and others.

Keywords: polycrystalline diamonds cutters (PDC), hard alloys, pre-destruction zone, rock breaking tools, rock destruction.

1. Introduction

Many authors [1, 2, 3] devoted their works to the study of rock fracture process, in which the mechanisms of rock fracture by tools equipped with hard alloys and polycrystalline superhard materials (PSHM) are considered, and also mathematical models of contact interaction of rock-destroying tool with rock are developed [4, 5, 6].

At the same time, in the majority of studies, the regularities of rock fracture with tools equipped with polycrystalline superhard materials and hard alloys, despite significant differences in physical and mechanical properties of these tool materials, are assumed to be identical.

However, observations on the Camscan-4DV scanning electron microscope of the crack formation process [7] and analytical studies [8] shown that when cutting with polycrystalline superhard materials, rock fracture occurs mainly due to the development of shear cracks, while when cutting with carbide cutters, crack initiation is initiated due to compression stresses. The most important physical and mechanical properties that determine the serviceability of PSHM include [9, 10]: hardness, wear resistance, thermal conductivity, strength and crack resistance, due to which the performance of rock-cutting tools can be significantly improved. Thus, the thermal conductivity of PSHM is 5–6 times higher than the thermal conductivity of hard alloys, which makes it possible to significantly reduce heat stress in the cutting zone, and the wear resistance of PSHM is 200 and more times higher than the wear resistance of hard alloys.

Another feature of rock fracture with tools equipped with polycrystalline superhard materials and hard alloys is different conditions of pre-fracture zone formation.

It is known [11, 12] that when cutting rocks, a layer of destructed rock with a network of microcracks is formed in the underlying layers, as a result of which the tangential component of the cutting force is significantly reduced. At the same time, the measurement of the parameters of chips formed during sandstone drilling with cutters equipped with carbide and PSHM showed that in the case of using carbide tools, the average size of chips is 1.4–1.6 times smaller than when using PDC.

At the same time, in a number of cases, tools equipped with wear-resistant hard alloys can work much more efficiently than tools made of polycrystalline superhard materials. This required additional research to establish the mechanism of rock destruction by tools made of hard alloys and PSHM and to determine the conditions of effective operation of tools equipped with polycrystalline superhard materials.

For this purpose, the pre-fracture surface zones and force characteristics during rock fracture with different tool materials, as well as the ridges of the cutting edge of polycrystals were investigated.

2. Methods

Investigations of the zone of the pre-fractured surface and microrelief of the cutting edge and back surface of the polycrystal were carried out by experimental method with subsequent mathematical processing of the obtained results. For fractoscopic studies the method of scanning electron microscopy on the microscope-analyzer "Camskan-4DV" was used. For sclerometric studies a special device was created on the basis of the UIM-21 instrumental microscope using standard measuring mechanical and electronic devices, as well as a number of specially manufactured mechanical units and electronic blocks. The electrical scheme of the device makes it possible to connect it to a computer for automation of data acquisition.

To estimate the topography of the working surface profiles of polycrystals, the automatic profilograph "Contracer CA-104" with the measuring system "Talysurf" as well as the method of stereoscopic fractoscopy were used, which makes it possible owed to qualitatively and quantitatively evaluate the features of microrelief details.

The study of the degree of surface layer de-strengthening and its depth was carried out using the technique of luminescence defectoscopy of rocks developed by Prof. I.A. Sveshnikov [11].

To establish quantitative values of cutting force, a set of experimental studies on cutting rocks with micro-cutters equipped with PSHM and hard alloy BK6B was performed. The cutters were made in the form of disk sectors with a diameter of 13.5

mm. Micro-cutters with both new carbide and PSHM were used, as well as cutters with inserts having blunting areas on the polycrystalline layer.

The micro-cutting process was carried out at a constant axial load of 1.0 N and 1.5 N. At the same time, scratches were successively applied on one trace with a length of 20 mm until the tangential component of the cutting force Pz stabilized.

3. Results and discussion

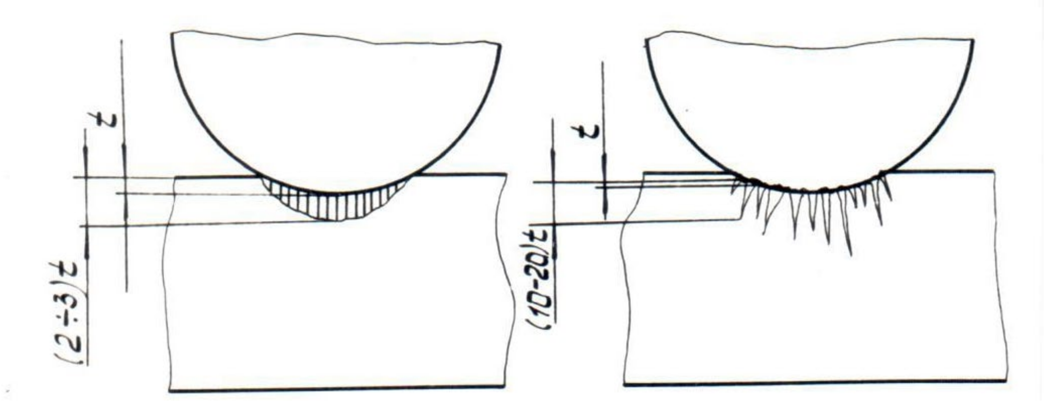
The results of measuring the average values of the tangential component of the cutting force Pz during micro-cutting of various rocks with PDC (with new and a blunting pad), as well as cutters with hard alloy BK6B, showed that during multiple consecutive cutting of rock samples with cutters equipped with PSHM inserts and hard alloy, their resistance to fracture decreases. Table 1 shows data on the average values of the cutting force component Pz during micro-cutting of marble.

Table 1 – Average values of the tangential component cutting forces Pz during micro-cutting of marble

Normal load value, N	Serial cut number	Pz, N					
		New PSHM	Decrease Pz, %	Primed PSHM	Decrease Pz, %	Hard alloy cutters	Decrease Pz, %
1.0	1	1.90	-	1.30	-	1.19	-
	2	1.54	23.4	1.04	20.0	1.08	9.2
	3	1.48	22.1	0.92	29.2	1.00	16.0
1.5	1	2.24	-	1.56	-	1.52	-
	2	1.95	12.9	1.40	10.3	1.24	18.4
	3	1.88	16.1	1.15	26.3	1.22	19.7

As it can be seen from the above data, the reduction of the tangential component of the force Pz in the case of working of the worked PSHM at the third pass is 29% and 26% for the load of 1.0 N and 1.5 N, respectively, while in the case of working of the new PSHM - 2 and 16%, and carbide - 16 and 20%, respectively. Similar results were obtained by repeated sequential cutting of other rock samples.

Based on the performed experimental studies, in order to establish the reason for a more significant decrease in the tangential component of the cutting force Pz when using a lapped insert and to explain the mechanism of diamond-hard-alloyed inserts operation, a hypothesis was put forward that when cutting rocks with polycrystalline superhard materials, the process of destruction is carried out not only by the entire polycrystalline insert, but also by ridged diamond formed on the cutting edge and back surface of the tool At the same time, ridged diamonds, when embedded in the rock, create high contact stresses and an additional network of microcracks interacting with microcracks formed due to the embedding of the entire cutting edge of the plate. As a result of impact of two independent sources of stress concentrations simultaneously, the zone of the pre-destructed layer in the rock mass increases and its lesion, which leads to a more significant strength reduction compared to the impact of only one polycrystal (in the case of a new insert) or only diamond grains (when drilling with diamond tools). The stress fields formed under PSHM and carbide cutting elements can be schematically represented as follows (Fig.1).



a b

Figure 1 – Scheme of stress fields at rock fracture by tungsten carbide plates (a) and PSHM (b)

To confirm the put forward hypothesis, a set of studies was carried out on the microscope-analyzer "Camskan-4DV" to investigate the microrelief of the cutting edge and back surface of the polycrystal in contact with the rock massif during cutting. The studies shown that unlike new plates, there are many ridges formed on the polycrystalline layer of the cutting surfaces of working diamond-hard-alloy plates and syndrill (Fig.2) soldered from rotary drilling cutters. This ridges is formed during the operation of diamond-hardfacing plates made of diamonds of any grain sizes, while in the initial state there are no ridges on the PSHM surface.

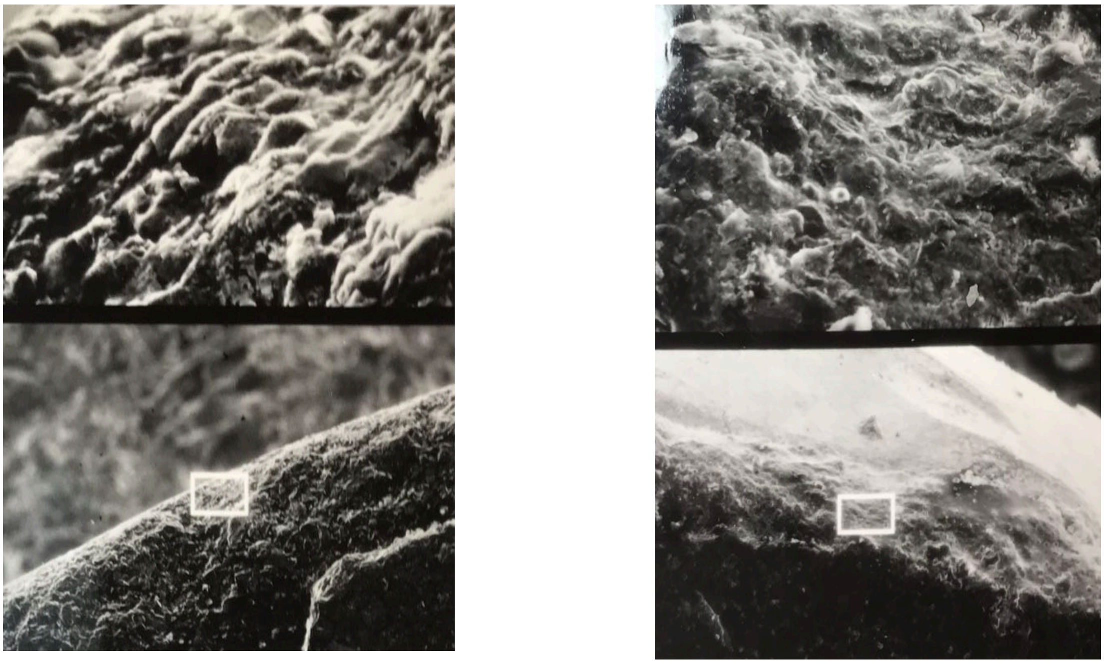


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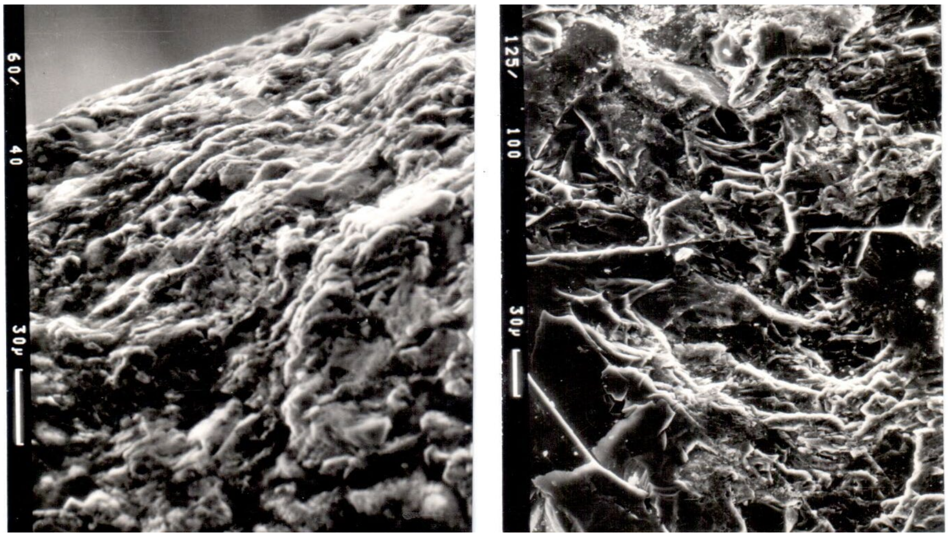
Figure 2 – Cutting surfaces of PSHM (a) and syndrill (b), soldered out from working rotary cutters for rotary hole drilling

The use of stereoscopic fractoscopy method makes it possible to qualitatively and quantitatively evaluate the features of microrelief details.

The results of the research showed that the relief of the cutting surface of the new diamond-hard-alloyed inserts is practically a smooth surface without any ridges of diamonds on the polycrystalline layer. This is explained by the technology of mechanical processing of the plates after sintering in high-pressure apparatuses (diamond-hard-alloy plates are ground with diamond wheels on the ends and cylindrical surface). As a result, a sharp cutting edge with a rounding radius of 0.02–0.03 mm is formed, which is used to cut the rock.

At the same time, the analysis of topograms of the cutting surface of the working PSHM shows that as a result of interaction with the rock being destroyed, the cutting edge of the plate undergoes significant changes, acquiring a relief surface with a multitude of diamond ridges.

Mathematical processing of the results of measurements of profiles of the working surface of polycrystal, obtained on a stereo comparator, showed that the height of these ridges is within 5–25 microns, which is commensurate with the height of diamond grains in fine-grained grinding wheels (Fig. 3).



a b

Figure 3 – Microrelief of the cutting surface of the working PSHM with grain size of initial grinding powders 60/40 (a) and 125/100 (b)

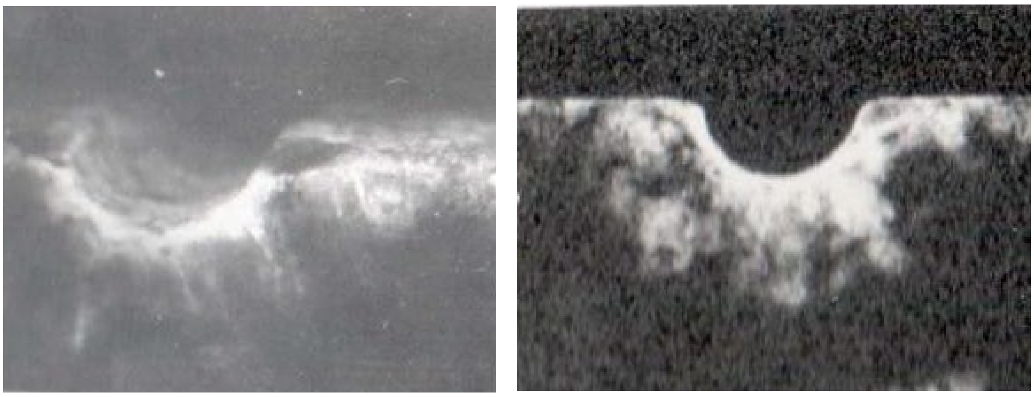
It is characteristic that these ridges are formed on the cutting edge of polycrystal, the sizes of which do not depend on the grain size of the initial grinding powders, but are determined by the conditions of contact interaction with the rock being broken. This is due to the fact that ridges are not individual diamond grains that form the basis of the polycrystal, but their conglomerates.

Accordingly, the work of all inserts made of polycrystalline superhard materials can be represented as the result of the total impact on the rock of the cutting surface of the polycrystal and ridges located on its cutting edge.

In order to establish the influence of ridges on the cutting edge of polycrystal on the process of cutting rocks, the microprofile of the destructed surface was investigated. For this purpose, cutting of the ground surface of a silicon single crystal with a new diamond-hard-alloy plate and a working plate having a blunted area was carried out on a planing machine of 7V36 model. Cutting was carried out at a speed of 0.55 m/s and a depth of 1.0 mm. The stereo pairs of profiles obtained on a Camskan microscope were examined on a stereo comparator. The obtained results showed that the microprofile formed by the previously working PSHM, in addition to the main groove has ridges at the blunting area of the cutting edge of the polycrystal, while in the microprofile formed by the new plate, these ridges are absent. This indicates the active participation in the process of formation of the cutting surface of the cutting edge ridges, which create additional damage in the surface layer of the rock, leading to its de-strengthening.

This conclusion is also confirmed by the results of the study of the degree of surface layer de-strengthening and its depth using the technique of luminescence defectoscopy of rocks.

As it can be seen from the obtained images (Fig. 4), the size and shape of the pre-fracture zone formed when cutting the rock with a diamond-hard-alloy plate and a carbide-alloy plate are significantly different. In this case, when cutting with a carbide insert, the tangential components of the cutting force Pz increase by 1.7–2.5 times because, as shown by earlier studies [7], in this case the crack occurrence is initiated by compression stresses. I.e., fracture by diamond-hard-alloyed inserts requires lower energy consumption, which can be explained by their unique physical and mechanical properties.



a b

Figure 4 – Pre-destruction zones formed during cutting of granite diamond carbide insert (a) and carbide insert (b)

These regularities, which were confirmed in all experiments, indicate the active participation of ridges on the cutting edge of PSHM in the destruction of rock and in the formation of the pre-destruction zone.

This confirms the hypothesis that when cutting strong rocks with a strength of 100–150 MPa with polycrystalline superhard materials, the destruction is carried out not only by the entire polycrystalline plate, but also by diamond ridges formed on the cutting edge and rear surface of PSHM during operation. The influence of these two factors determines the conditions for the formation of the pre-destruction zone and the reduction of the force characteristics of the cutting process.

In our opinion, this is the main difference between the mechanism of rock destruction by tools equipped with diamond-hard-alloyed inserts and hard alloys.

At the same time, studies shown that ridges on the cutting edge and back surface of PSHM may not be formed due to a violation of the thermal mode of tool operation. This may be a consequence of incorrectly selected application area of PDC, incorrect operating modes, errors in tool design, insufficient cooling and other factors.

In this case, the diamond-hard-alloy insert begins to work as a carbide insert and the efficiency of the PDC is drastically reduced.

The use of knowledge obtained as a result of the conducted research makes it possible to create tools equipped with diamond-hard-alloyed inserts, the wear resistance of which significantly exceeds the wear resistance of similar tools made of carbide. Thus, for example, the wear resistance of the created РШ-140 type cutters for rotary borehole drilling is 50–70 times higher than the wear resistance of carbide cutters of РП-42 or БИ-741 type, the wear resistance of drilling tools for drilling abrasive frozen ground is 70–90 times higher than the resistance of serial carbide tools, and when cutting saw stone the increase in the resistance of cutters is 120–150 times.

This made it possible to widely introduce the efficient tools equipped with diamond-hard-alloyed inserts into the coal industry, geological exploration, construction, open-cut and underground saw stone mining.

4. Conclusions

As a result of the conducted experimental studies, it was established that the main difference in the mechanism of rock destruction by tools equipped with polycrystalline superhard materials and hard alloys is that the process of rock destruction by PDC is carried out not only by the polycrystalline plate as by a solid, but also by discrete ridges of diamonds formed on the back surface and cutting edge of the polycrystal.

The ridges formed on the surface of the polycrystal when embedding into the rock create high contact stresses and an additional network of microcracks interacting with microcracks formed due to the embedding of the entire cutting edge of the plate.

It is established that the impact of two independent indenters simultaneously increases the zone of the pre-destroyed layer in the rock massif, which leads to a more significant decrease in its strength and, as a consequence, to the intensification of the process of rock destruction by the PDC.

It is shown that in case of incorrect choice of application area and operating modes, errors in tool design and insufficient cooling, ridges are not formed on the cutting edge and back surface of the polycrystal. As a result, the polycrystalline insert works as a carbide insert and the efficiency of the PDC is sharply reduced.

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ДО ПИТАННЯ МЕХАНІЗМУ РУЙНУВАННЯ ГІРНИЧИХ ПОРІД ІНСТРУМЕНТАМИ З ТВЕРДИХ СПЛАВІВ І ПОЛІКРИСТАЛІЧНИХ НАДТВЕРДИХ МАТЕРІАЛІВ

Красник В.Г.

Анотація. Під час дослідження процесу руйнування гірських порід інструментами, оснащеними полікристалічними надтвердими матеріалами (ПНТМ) і твердими сплавами, основні закономірності механізму руйнування, незважаючи на істотні відмінності фізико-механічних властивостей інструментальних матеріалів, які використовуються, приймають ідентичними. Такий підхід не тільки знижує ефективність використання створюваних породоруйнівних інструментів, а й обмежує сферу застосування полікристалічних надтвердих матеріалів.

Проведені експериментальні дослідження з використанням різних методів отримання інформації показали істотні відмінності в механізмі руйнування гірських порід твердими сплавами і полікристалічними надтвердими матеріалами. Вивчення зони передзруйнованої поверхні показало, що під час різання гірських порід ПНТМ процес руйнування здійснюється не тільки всією полікристалічною пластиною, а й мікровиступами алмазів, що формуються на різальній кромці та задній поверхні інструменту. При цьому алмази, що виступають, при впровадженні в породу створюють високі контактні напруження і додаткову мережу мікротріщин, які взаємодіють з мікротріщинами, що утворюються від впровадження всієї ріжучої кромки пластини. За неправильного вибору області застосування ПНТМ і режимів експлуатації, помилок у конструкції інструменту та недостатнього охолодження мікровиступи на ріжучій кромці та задній поверхні полікристала не утворюються. У результаті полікристалічна пластина працює як твердосплавна вставка і ефективність роботи інструменту з ПНТМ різко знижується.

Використання знань, отриманих у результаті проведених досліджень, дає змогу створювати інструменти, оснащені алмазно-твердосплавними пластинами, зносостійкість яких у десятки разів перевищує зносостійкість аналогічних інструментів із твердого сплаву. Наприклад, було створено і широко впроваджено в практику ефективні інструменти, оснащені алмазно-твердосплавними пластинами, для обертального буріння шпурів, дегазаційних свердловин, анкерного кріплення гірничих виробок, різання пиляльного каменю, буріння абразивних вічномерзлих ґрунтів та інші.

Ключові слова: полікристалічні надтверді матеріали, тверді сплави, зона передруйнування, породоруйнівні інструменти, руйнування гірських порід.