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Peculiarities of stress field formation during cutting isotropic material by mining machine cutters

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Abstract: Peculiarities of the cutting process of isotropic material by mining machine cutters are considered. The objective of the studies is revealing regularities of the process of stress field formation in the pre-cutter zone of the breakable massif and assessment of the possibility of purposeful control of cutting process parameters. Taking into account the multifactorial nature and randomness of the process of elementary chippage formation, an experimental method of studies with the use of full-sized cutters was accepted as a determining principle. A stand for cutting an isotropic transparent material with an optical method of observing stress fields in the under-cutter zone, the procedure of conducting studies and results were presented in the paper. The use of quasi-isotropic acryl glass as an object for destruction allowed reducing the influence of multifactorial nature and randomness on the process of formation of the stress field and elementary chippage. The modes, excluding continuous chip formation, determined by, on the one hand, the phenomenon of material creep – at low cutting speeds, and, on the other hand – cutting speed modes by the terms of thermal conditions, were determined. Continuation of experimental studies of the cutting process of quasi-isotropic materials is aimed at revealing the most significant factors and determination of their influence on the change of phase parameters of elementary chippage and at revealing the very opportunity of formation of elementary chippage characteristics.

1. Introduction

High levels of loading dynamics on machine transmission [1], limitedness of the machine application field by hardness of a fractured massif and an operating tool durability [2], high power intensity of the process of a mineral separation from a massif [3], and excessive regrinding of a separable mined rock [4] should be referred to the main problem factors that retained an effectiveness increase of mining machines at all stages of their development.

The modern experimental-statistical theory of cutting rocks and coals by the mining machine cutters [5], despite its long-term development and success, has not allowed so far developing methods, finding methods and ways of effective solution of the problems enumerated above. At that, it should be noted that the diligence of studies and general attention to the specified problems are still maintained today [6-11].

Evidently, solution of these problems is connected with the necessity of extending our knowledge about the interaction of an individual cutter with a rock massif during cutting. The interrelation of strength properties of the destructible massif, the operating mode and cutting parameters are to the fullest expressed in the mechanical characteristic of the cutting process, namely, in the form of the
mechanical characteristic of elementary chippage. It is known that the cutting process of fragile rocks and coal by a single cutter of the executive devices of mining machines occurs in the form of formation of the elementary chippage sequence [5]. A coal massif and the rocks that it contains are heterogeneous (anisotropic) in their structure; therefore, fragmentation of the rock massif is considered as a random process. At that, the form of elementary chippage can be different [5].

Significant influence on the formation of phase parameters of elementary chippage is exerted by conditions of stress field formation in the pre-cutter massif area, conditions of origination, growth and decay of main cracks, a massif anisotropy degree (fracturing, lamination, bedding), the cutter movement modes and potential energy reserve in the cutting drive [6].

Regularities of the formation process of elementary chippage, its elements and their dependence on a cutting speed are insufficiently studied. In this connection, the study of the process of isotropic material cutting, in which chippage parameters can be more stable because of the material properties constancy, is of interest and an opportunity of visual observing the formation process of stress fields in the under-cutter zone of the destructible material occurs.

2. Materials and methods

Studies of the cutting process of different kinds of materials, both isotropic and anisotropic, detection of regularities of chippage sequence formation are labour consuming, large scale, and important for further perfection of the rock cutting theory. Taking into account multifactorial nature and randomness of processes of elementary chippage formation, an experimental study method with the use of full-sized cutters and a real material was accepted. The results of the study of the rock cutting process by a single cutter are quite various and hard to systemize and to classify, while the results of the cutting process of isotropic materials confirm their less variability, greater resistance. Therefore, it is expedient to undertake studies based on isotropic materials and to use the results as a base for comparison. Experimental laboratory research on the study of the cutting process of acryl glass (plexiglas, organic glass, acryl glass, polymethylmethacrylate) can be the most informative. For observing stress field distribution, emerging during cutting an isotropic material, the use of the polarization-optical method, based on the interference phenomenon of polarized light, is possible [12]. Interference of polarized light beams is a phenomenon which occurs during superposition of coherent polarized light oscillations. Beams, emerging from the birefringent crystal plate, interfere only on condition that the light, incident on the plate, is polarized, as well as if both beams are brought to the same plane. At a stressed state, an isotropic material becomes birefringent; the possibility to observe distribution and displacement of stress fields is created. The polarization-optical method is based on the property of the majority of transparent isotropic materials to become optically anisotropic, i.e. on the emergence of artificial birefringence - piezo-optical effect [13]. The polarized-optical method possesses the following advantages: a continuous obvious picture of stresses in real time and at any point of their distribution zone, at that, the observable zone must not necessarily come to the destructible material surface.

Experimental studies of the acryl glass cutting process were conducted on a specially created stand (figure 1). Chippage was implemented on the acryl glass plate of 195×195×35 mm size. For stress filed registration during cutting, acryl glass was illuminated from one side through a special device by linearly-polarized light.

The feed of mobile frame 3 with organic glass to cutter 5 is realised by rotating the screw with handle 4. The cutter with the cutting angle of 50º, outside angle of 10º, corresponding to the reference cutter, was used [5]. The width of the trapezoid cutting edge of the cutting part is 10 mm; the front facet is flat. The section thickness and section place were set by an adjustment device with guides 7, in which cutter holder 6 moves vertically and horizontally. To prevent deformations of guides 2 under the action of load, detachable support 8 is installed between the stand frame and the cutter holder.

It is known that at high speed, the cutting process of acryl glass is characterised by the temperature effect, even section edges, and continuous chip. It was experimentally established that to obtain the chippage type during cutting acryl glass that is identical to that during rock fragmentation (sequence of
elementary chippage) and to eliminate the temperature factor, it is necessary to reduce the cutting speed to 0.05 m/s.

The cutting process was registered by photographing and filming in the polarized light. Figure 2, a presents the start of the cutting process on the plane surface. The section thickness is $h = 2\text{ mm}$. Stress formation in the acryl glass is visible, the stress zone edges are of different colours.

In the cutting process of the under-cutter massif area, an elastic region, zones of residual deformation and fragmentation exist simultaneously, occupying adjacent areas, displacing and subsequently replacing each other during continuous cutter motion.

In front of the cutter, a stress field, which is growing, forms. In the course of cutter motion, stress reaches a critical value, owing to which chippage occurs. When embedding the cutter into acryl glass, a volume stress field forms before the front cutter edge (figure 2, a). Under the influence of the force, exerted by the cutter, two types of tension lines emerge. These are contour stress isolines closing on themselves when travelling along the boundaries of spherical zones with identical sealing, as well as open-ended stress lines, and gradually weakening lines in the material under study. The nature and displacement of the stress field depend on the cutter motion rate. In case of one plane of exposure, two-sided symmetrical breakdown of the cutting furrow occurs. (figure 2, b, c).
3. **Results and Discussion**

Figure 3 presents an acryl glass plate after cutting it by the cutter with the chippage thickness of \( h = 2 \) mm. The form of the elementary chippage resembles the form of a seashell (figure 3) with typical lines of closed arcs. A part of these arcs differs from others by height. Microcracks directed towards chippage formation are observed at the boundary of these arcs. The inner side of the chippage forms along closed lines.

![Figure 3](image_url)

**Figure 3.** Typical sequence of traces of elementary chippage of acryl glass with chippage thickness of \( h = 2 \) mm

On the whole, stable alternation of successive elementary chippage, their forms, and sizes (figure 3), as well as stable phase sequence in the course of each elementary chippage formation, is observed (figure 4).

During cutting, successive formation of stress zones (figure 4, b), emergence and growth of main cracks, formation of elementary chippage phases took place. Maximal stress field 2 emerges in the contact line of the cutter with the massif, and increases in sizes predominantly towards cutter movement, and at the moment of chippage (rapid growth of the main crack), it separates from the cutter and moves along with the main crack boundary 3.

![Figure 4](image_url)

**Figure 4.** Stress field formation in under-cutter zone: a − model; b − experiment: 1 − weak stress field; 2 − maximal stress field; 3 − main crack boundary; 4 − cutter; 5 − elementary chippage trace; 6 − deseaming trace
Figure 4, a shows a model of the observed process, which later can be accepted as initial in the study of more complex models. Here, 1 – weak stress field; 2 – maximal stress field; 3 – main crack boundary; 4 – cutter; 5 – elementary chippage trace; 6 – deseaming trace.

Such peculiarities of formation of stress field and elementary chippage during cutting isotropic material confirm a possibility of effective purposeful formation of the structure and parameters of elementary chippage during cutting, as well as anisotropic materials, in particular, separation of coal and other rocks from the massif by the operating tool of mining machines. Formation of expedient ratios of stress fields (compression, displacement, tension) in the pre-cutter massif zone can provide energy consumption minimisation per elementary chippage cycle.

In the general case, condition parameters of the stress field depend on cutter parameters, its operating mode, as well as on the massif structure, a cutter movement direction relatively this structure, a degree of deformation and displacement of structure elements relatively each other and relatively the cutter. All this can influence the ratio of stress fields of compression, displacement and tension in the near-cutter zone of the massif and on their mutual displacement during cutter movement.

4. Conclusion
Based on the results of conducted studies, it is possible to conclude:

- In the under-cutter zone, it is possible to observe emergence and development of the stress field, main cracks; to determine boundaries and boundary speeds, at which cuts with successive elementary chippage interchange with continuous chip.
- With constant section thickness and cutting speed, stable alternation of successive elementary chippage, their forms, sizes, as well as stable alternation of phases in each elementary chippage, is observed, which implies a phase-energy nature of the decay process.
- Process peculiarities of cutting the quasi-isotropic material (acryl glass) in a varying degree can be also peculiar to the process, which occurs during cutting anisotropic materials, including coal and rocks. The understanding of these processes will allow finding methods and possibilities of active influence on the cutting process.

References
[1] Zagrivniy E A, Basin G G (2016) Formation of external dynamics of mining machines. Transaction of Mining institute 217 140-149
[2] Gabov V V, Zadkov D A, Lykov Yu V [et al] (2008) Peculiarities of running roadheaders in pits of JSC “Vorkutaugol” Mining equipment and electromechanics. 12 2-6
[3] Gabov V V, Zadkov D A (2016) Energy-saving modular units for selective coal cutting. Eurasian mining 1 37-40
[4] Gabov V V, Lykov Y V, Bannikov A A (2010) Analyzing coal breakage while mining at the mines of Vorkuta. International Mining Conference on Advanced mining for sustainable development. 2010 283-285
[5] Pozin E Z (1992) Study of the process of coal fragmentation by mechanical method at mining institute named after A.A. Skochinskiy. Coal 1992 60-62
[6] Zadkov D A, Bolshakov V (2005) Mining machinery: enhancing cutting efficiency Russian mining. 1 19-21
[7] Mitra D, Hagan, R P (2009) Changes in Acoustic Emissions When Cutting Difference Rock Types, (Coal 2009: Coal Operators’ Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy) 329-339
[8] Jerzy Rojek (2007) Discrete element modelling of rock cutting Computer methods in materials science. Informatics in Materials Technology 7(2) 224-230
[9] Khair A W (2001) Research and Innovations for Continuous Miner's Cutting Head for Efficient Cutting Process of Rock (Coal. 17* International Mining Congress and Exhibition of Turkey -
IMCET2001) 45-55

[10] Neskrornn V V (1998) Fundamental Study into the Mechanics of Material Removal in Rock Cutting, Doctor of philosophy dissertation (Irkutsk, IrSTU) p 268

[11] Pavlysh V N, Steblin V V, Topchiy S E, Grodzinskiy P Ya (2014) Study of cutting tool characteristics of executive devices of modern mining machines. Progressive technologies and system of machinery: international proceeding of scientific paper. 2(48) 15-21

[12] Razumovskiy I A (2007) Interference-optical methods of deformable solid body mechanics: manual (Moscpw, MSTU) p 240

[13] Aleksandrov A Ya, Akhmetzianov M H (1973) Polarized-optical methods of deformable body mechanics. (Moscow, Science (Nauka)) p 576