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REGULARITIES OF MATERIAL DESTRUCTION OF THE IMPACTOR IN REPEATED SINGLE PUNCH

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The technique and the results of experiments on the study of the laws of the process of the cone-shaped tip of a freely falling impactor made of 38HM, U8, H12MF steels, subjected to typical heat treatment and additionally treated with cold, when they apply multiple (up to 10000) single impacts on granite under conditions approaching hydraulic impactor peaks. To explain the processes, we used the values of stresses $\sigma_к$, arising at the contact area of the impactor and the rock, calculated using the developed mathematical model. It has been established that the process of wear of an impactor with multiple single blows proceeds in three stages separated by critical values σ_c^*, σ_c^{**}, which correspond to the strength characteristics of the material of the impactor demonstrated in these dynamic conditions.

With a small number of strokes ($n \le n^*$) and the small size of the blunting area (stage I interaction) values σ_c exceed σ_c^* of steel and it is exposed to local destruction at the contact site, which is recorded as a significant loss of the impactor's mass; with $n^* < n \le n^{**}$ (stage II) the resulting stresses are not enough to destroy the material, but it is enough for its plastic deformation, accompanied by the movement of metal from the central part of the contact area to the peripheral and the destruction of part of the deformed metal by rock; with $n > n^{**}$ (stage III) arising $\sigma_к$ do not reach the level $\sigma_к^{**}$ and the decrease in the mass of the impactor is determined by the resistance of the steel to abrasion by the products of rock destruction, displaced by the impactor from the well. The treatment of impactors from all tested steels with cold leads to an increase in their wear resistance; The total depth of the holes punctured by the cold-treated H12MF steel impactor at the time of the interruption of the rock penetration is four times higher than that of the 38HM steel impactor subjected to typical heat treatment.

***Key words*:** multiple single blow; cone-type steel impactor; cold treatment; abrasive wear; metal wear

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Introduction. Impact breaking and chipping machines are widely used in mine workings, for dismantling refractory lining in the repair of domain and open-hearth furnaces, in the development of frozen and rocky soils, road pavement, destruction of concrete, reinforced concrete and brick structures, etc. [7]. As a working tool, these machines typically use cylindrical type of peaks in the form of a cone or wedge, sharpened at an angle, usually from 30 to 40° [5]. The process of destruction by such machines begins with the introduction of a tool into an array that has free surfaces close enough to each other, to such a depth that the tensile and shear stresses resulting from the insertion tear a piece of required size from the array. The efficiency of a machine is determined by its ability to inject a percussion instrument to a predetermined depth, and a performance indicator is the rate of penetration [5].

With the use of the tool due to the shock-abrasive wear of its material, the dimensions of the blunting area, which is present in the pointed part of the peak, increase. This leads to an increase in the contact area of the tool with the rock upon impact with a decrease in the intensity of impact destruction. As a result, starting from a certain point, the process of penetration of peak into the rock practically ceases, and its renewal requires replacement or regrinding of peaks. For example, as the experience of the DAEMO B180 hydraulic hammer shows, this moment for this machine occurs when the pointed part of the peak is worn out by about 50 %, as a result peak handles 4-5 regrindings. Taking into account the fact that the replacement of massive peaks and its regrinding are very time-consuming processes, the development of methods that increase the resistance of materials to the impactor and impact-abrasive wear and that, as a result, the peak-to-regrinding time, is an urgent task.

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A considerable amount of research is devoted to the problems of rock destruction by percussion tools and, in particular, hydraulic hammers. On the basis of the laws of mechanics and the classical Hertz theory, classical and wave theories of impact have been developed, connecting the energy, force and time of interaction between a impactor and destructible material with the depth of penetration of a impactor into a rock. Issues related to the mechanism of wear of the material of the impactor and the effect on the performance of hydraulic hammers on the magnitude of the area of the blunting of its tip, which varies with time depending on the wear resistance of the material, have not been studied sufficiently.

In the present work, in conditions approaching the working conditions of the peak of impact destruction machines by blasting and shearing, the regularities of the process of wear of the material of a freely falling impactor are investigated when they inflict single blows on the rock.

Experiment methodology. The object of the study was impactors with a length of L = 25 mm with a cylindrical part (D = 6 mm, l_1 = 13.8 mm) and a cone-shaped point with a vertex angle β = 30 ° at a length of l_2 = 11.2 mm, made of 38HM, U8 steels, H12MF, as the peak of hydraulic hammers characterized by durability and wear resistance. Some of the steels were subjected to typical heat treatment (THT) – quenched from 800-1000 °C in oil and tempering at 200 °C, practiced at the manufacturing plants of the peak, the other – additional processing [4] with cold (exposure at –75 °C) 5 hours) as an operation widely used to improve the wear resistance of tool steels [8, 10, 11, 13]. Using the Zwick / Roell ZHU universal hardness tester, the hardness of the materials of the impactor achieved as a result of thermal treatments was determined.

The tests were carried out on an installation (Fig.1) of a structure close to that described in [2].

Impactor 2, made of steel of one of these grades, after weighing on an analytical balance (±0.0001 g) was fixed in a vertical position in a massive impactor 3 (M = 2.8 kg). A fragment of rock 1 granite with a strength of 6.2 on the M.M. Protodyakonov scale with an aggregate hardness of ~ 450 HV and a hardness of its minerals up to 1200 HV (for quartz) exceeding the hardness of the used materials of the impactor was placed under the impactor.

When a impactor was struck with a pin from a certain height (H = 42 mm), a series of strikes n was carried out with the tip of the impactor to different points on the fragment surface, each hit to a different point. The kinetic energy A_0 and the pre-impact velocity v_0 of the impactor, calculated from the values of M and H, were 1.16 J and 0.91 m/s. After each impact, the impactor was reweighed and measured L (measurement accuracy ± 0.01 mm) with the determination of the mass loss Δm and the length Δl of its tip; the diameter d of the formed blunting area was calculated from Δl taking into account β. When the number of strokes over 40, the establishment of Δm and Δl was made through the interval n (from 10 to 100) and was calculated as the quotient of dividing the total value of the functions for this interval by the number of strokes in the interval. Analyzed the type of holes in the rock

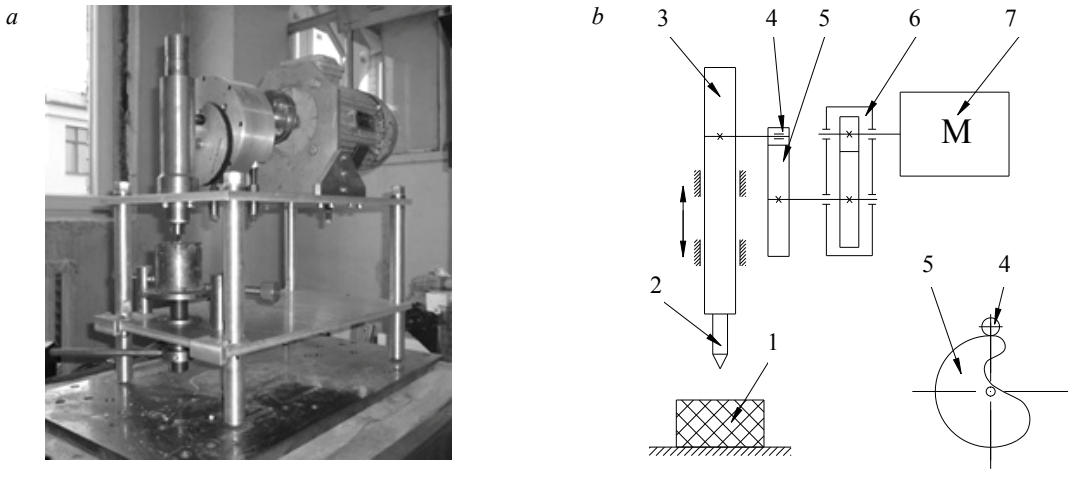


Fig.1. Installation for studying the process of impact destruction of rock and material of the impactor (*a*) and its schematic diagram (*b*)
1 – a fragment of rock; 2 – drummer; 3 – peen; 4 – roller; 5 – cam; 6 – reductor; 7 – electric motor

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with the measurement of their depth h (measurement accuracy of 0.01 mm). Changing the material of the impactor, for each of them, dependences Δl, d, h on the number of beats n were built.

Experiment results. As observations have shown, the process of hitting the granite is accompanied by a slight (by several millimeters) rebound of the impactor. The result of the first strike is the appearance on the pointed part of the impactor of a circular blunting area, the diameter d of which increases as the number of blows increases.

The destruction of granite is characterized by a departure from the zone of destruction of particles and dust-like fragments with the formation of holes of a shape that is close to the configuration of the penetrating part of a impactor of a larger diameter. At the bottom of the wells, a compacted core of powdered degradation products is found, which differs in color (white) from the rest of the rock.

It is established that with an increase in the number of impacts, the values of Δl and h monotonously decrease (Fig.2). Moreover, the curves $\Delta l = f(n)$ for the analyzed steels are located on the graph relative to each other in a sequence opposite to the location of the curves $h = f(n)$ for the same materials.

Typical shape of obtained dependencies $\Delta m = f(n)$ presented in Fig.3. As can be inferred from the type of curves in Fig.3, the process of an impactor mass loss Δm depending on the number of impacts n for all materials analyzed is characterized by three stages. At the first (stage I), including several first strikes up to some critical, different for each steel, the number of strikes $n^* = 8\text{-}10$, value Δm it is calculated in tenth milligrams and decreases with each successive stroke with a noticeable rate (0.3-0.4 mg / stroke). At stage II, starting at $n \geq n^*$ and continuing to the second critical value $n^{**} = 3600\text{-}5400$, value Δm is only a few hundredths of a milligram, and its rate of decline with increasing n slowing down dramatically. At stage III with $n > n^{**}$, continuing until the end of a series of experiments, the loss of mass Δm becomes independent of the number of strokes. This value Δm, determined for each steel, was taken as the speed of impact-abrasive wear K determined for each steel, was taken as the speed of impact-abrasive wear of K material at the steady-state stage

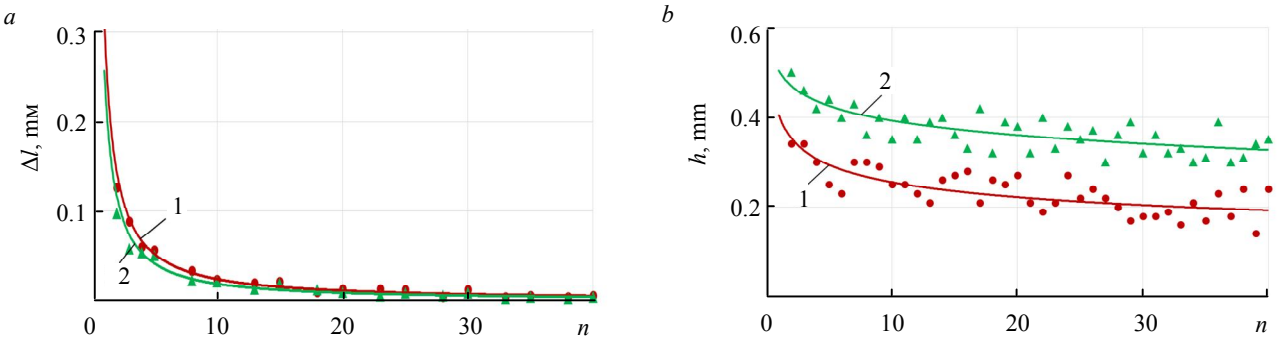


Fig.2. Dependence of the length decrease of the hammer Δl (*a*) and the depths of the hole h (*б*) on the number of beats n for different materials of a hammer

1 – steel 38HM; 2 – steel H12MF$_x$ (hereinafter index x indicates the processing of cold steel)

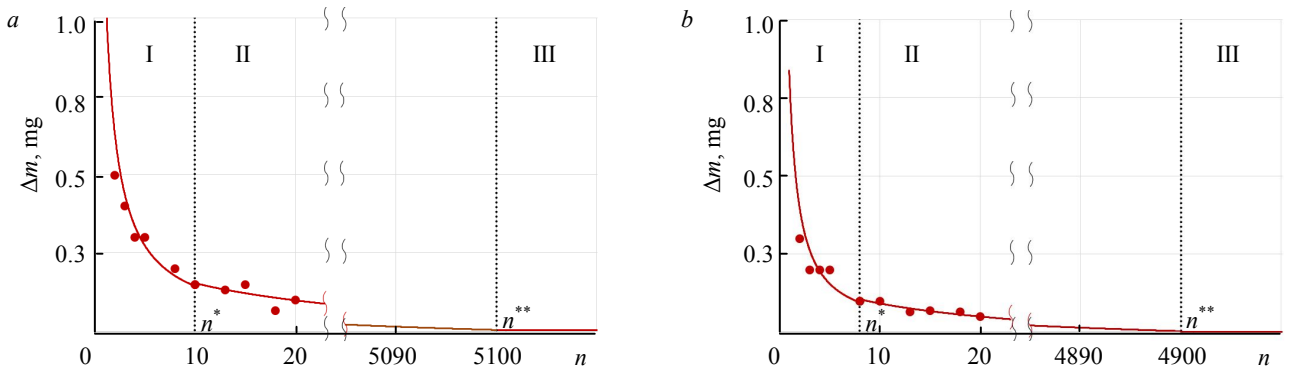


Fig.3. Dependence of the mass loss Δm of the impactor from the 38HM (a) and X12MFx steels (b) on the number of impacts n

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of the wear process, and the value of I, and the reverse of K, as shock-abrasive wear resistance of this impactor material.

To explain the processes occurring at each stage of wear of a impactor, we used the data on the magnitude of the stresses occurring at the contact area of the impactor and the types calculated using the developed mathematical model

Mathematical model of impact rock destruction process under experimental conditions. In developing the model, it was assumed that the impactor, together with the pin, is a structure of relatively short length (L_Σ = 340 mm). It was believed that the influence of wave processes on the impact parameters can be neglected and the process of interaction between the impactor and the material being destroyed can be described by the equations of a two-element classical shock system [5]. As the results of the calculation showed, the condition of applicability of these equations is satisfied

$$t_m \geq 3T,$$

where t_m – stroke time, t_m = 0,6-1,4 ms; T – oscillation period of impactor and pin, T = 0,13 ms.

Based on the outputs of [5] on the existing types of load characteristics of fracture, taking into account our observations of the impact process, it was assumed that the penetration of a impactor into the rock under the experimental conditions is characterized by three main stages:

• elastic deformation of the rock to achieve on the area of its contact with the impactor $\sigma_к$, at which the explosion-like destruction of the rock occurs under the contact area;

• by moving the impactor through the core of the destruction of the rock, displacing some of the products from the well and pressing the remaining products without reaching the bottom of the zone of destruction;

• discarding the impactor by the forces of residual elasticity of compacted fracture products.

The dependence of rock resistance force N on deformation α (Fig.4) for this case corresponds to the load characteristic of type V [5] and consists of three strength functions: loads N_1 during elastic deformation of the rock under the contact area, loads N_2 when the impactor is introduced into the products of rock destruction and discharge N_3, each of which is characterized by its rigidity (g_1, g_2, g_3). Wherein fuctions N_1, N_2, N_3, as for the introduction of the body with a constant contact area, are linear type. The area of the figure in Fig.4 – the work of loading A_l, shaded area – work A_d, spent on destruction.

Maximum strength of rock resistance N_m and penetration α_{pen}, and also time strike t_m for such a load characteristic [5]:

$$N_m = N_d \sqrt{1 - \frac{g_2}{g_1} + \frac{2A_l g_2}{N_d^2}};$$

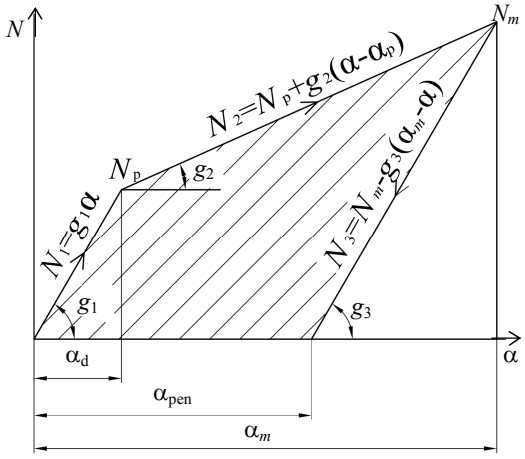


Fig.4. Shape of load characteristic of the system, taken in the calculation of impact parameters

$$\alpha_{pen} = \alpha_m - \frac{N_m}{g_3} = N_p\left(\frac{1}{g_2} - \frac{1}{g_1}\right)\left(\sqrt{1 - \frac{g_2}{g_1} + \frac{2A_d g_2}{N_d^2}} - 1\right);$$

$$t_m = \sqrt{\frac{M}{g_2}}\,\mathrm{arctg}\sqrt{\frac{2A_l g_2}{N_d^2}},$$

where M – falling object mass; N_d – force of contact destruction of rock,

$$N_p = f_{ca}\sigma_{cr},$$

$f_{ca} = \pi d^2/4$ – contact area; σ_{cr} – stress at the point of contact at which tensile and shear stresses occur upon impact σ_p, in the rock lead to its explosion-like destruction under the contact area.

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The assumptions adopted in the calculations:

• for the value of the critical contact stress σ_c the value of the dynamic hardness of the rock can be accepted (for granite 1305 MPa [9]);

• to establish the contact stiffness of the system g_1, as for the circular contact area with a diameter d, following formula is occurred [5]:

$$g_1 = \frac{2E_p d}{3(1-\mu_p^2)},$$

with modulus of elasticity $E_p = 50$ GPa and Poisson's ratio $\mu_p = 0.2$ of granite [5];

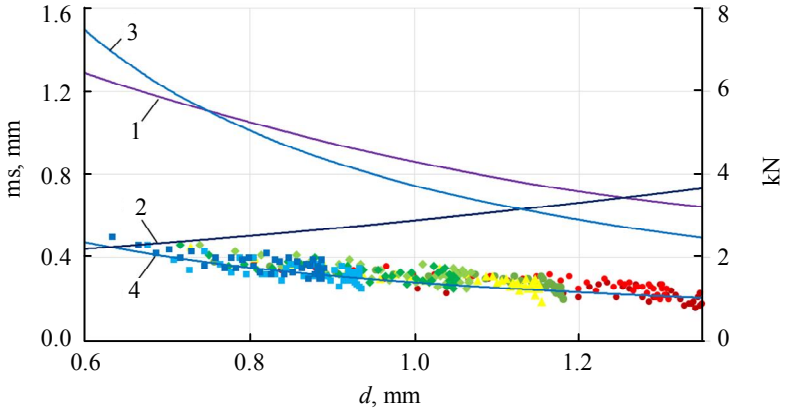


Fig.5. Estimated single impact parameters t_m (1), N_m (2), σ_c (3), α_{pen} (4) depending on the diameter of the contact area d in comparison with the experimentally established depth of the holes obtained for impactors from the steels being analyzed

• by analogy with the stiffness ratio g_2/g_1 and g_3/g_1, which can be established from the analysis of the experimental strength characteristics of contact fracture of fragile rocks given in [6], for the rigidity g_2 in our case, a value equal to 0,16 g_1, and for g_3 – value g_1;

• only about half of the kinetic energy A_0 of the impactor is expended on elastic deformation and destruction of the rock (for granite 58.6 % [5]), the rest of the energy is expended on heat losses to the environment, elastic and plastic deformation of the impactor, and wear of its contact surface [9]), so they took value $A_l = 0.586$, $A_0 = 0.68$ J.

Fig.5 presents the values of the impact time. t_m (cuve 1), maximal rock resistance force N_m (curve 2), contact stress $\sigma_c = N_m/\pi d^2/4$ (curve 3) and penetration α_{pen} of impactor in the breed (curve 4), calculated by value N_p for the interval of diameters d of contact areas taking place in experiments (blunting areas). In Fig.5, for the corresponding values of d, the depths h of the wells, established experimentally (see Fig.2, *b*), are given.

As can be seen from the graph in Fig.5, with a constant impulse of force $M\,v_0 = N_m\,t_m$ with an increase in the diameter d of the contact area (padding of the impactor), the maximum force of resistance of the rock Nm increases monotonically, and the time of impact t_m, maximum contact stress σ_c and depth of penetration α_{pen} of indenter are dropping. As can be inferred from comparing the location of experimental points and curve 4, the regression line is $\alpha_{pen} = f(d)$ shows satisfactory convergence with experimental data for all steels.

The obtained satisfactory convergence of the calculation results and experiment can serve as confirmation of the proposed mathematical model and the validity of the accepted assumptions.

Patterns of destruction of the material of the impactor**.** Set values *K* и *I*, arranged in increasing order of wear resistance of impactors from analyzed steel grades, as well as experimentally determined hardness values HV and calculated yield strengths [12]. $\sigma_т$ and strength $\sigma_в$ of steels for the conditions of static stretching of the samples are presented in table 1. It also shows the number of strokes n^*, n^{**}, at which for a impactor from each steel there is a transition to the next stage of interaction, the corresponding diameters d^*, d^{**} blunting area, stress σ_c^*, σ_c^{**} on the contact area of the impactor with the rock from curve 3 (Fig.5) for d^*, d^{**}.

As follows from the data of Table 1, the installed shock-abrasive wear resistance of steels correlates, in general, with their hardness and strength indicators σ_h, σ_s, amplifying with the increase of these parameters. In this case, the lowest wear resistance is observed for steel 38XM after a typical heat treatment, the highest, 2.7 times greater – for steel X12MF after cold treatment. It can be noted that cold treatment leads to an increase in wear resistance of all other steels (from 11 to 26 %).

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Table 1

Shock-abrasive wear resistance of the studied materials of the impactor in comparison with their strength characteristics and critical parameters of interaction between the impactor and the rock

Steel brand of hummer	K, mg/stroke	I, stroke/mg	HV	σ_h, MPa	σ_s, Mpa	n^*	n^{**}	d^*, mm	d^{**}, mm	σ^*, MPa	σ_c^{**}, Mpa
38HM	0.0027	370	529	1933	1478	10	~ 5100	1.011	2.114	3643	1651
38HM$_x$	0.0023	435	536	1953	1529	10	~ 5400	0.986	2.047	3767	1691
U8	0.0019	526	707	2540	1943	8	~ 3600	0.889	1.763	4340	1915
U8$_x$	0.0017	588	717	2577	1971	8	~ 3900	0.876	1.724	4435	1955
H12MF	0.0013	741	694	2492	1905	8	~ 4100	0.866	1.680	4502	2003
H12MF$_x$	0.0010	1000	708	2544	1946	8	~ 4900	0.836	1.620	4729	2076

It can be seen that as the strength and wear resistance of steels increases, the magnitude of contact voltage σ_c^{**}, σ_c^*, corresponding to the transition from stage to stage of interaction, increase. At the same time between the values σ_c^* and σ_h, and σ_c^{**} and σ_s there is a definite correlation: first ($\sigma_c^*, \sigma_c^{**}$) about the same number of times than the second. From the facts of the presence of three characteristic stages of interaction (see Fig.3) and the existence of this proportion for all steels, it can be assumed that the critical values established by calculation and experimentally are σ_c^*, σ_c^{**} contact stresses correspond to the voltage in the layer of a given material of the impactor adjacent to the contact area, starting from which it is able to collapse under dynamic conditions σ_c^* or plastically deform σ_c^{**}. For the conditions of static stretching of the samples, the analogue stress σ_c^* is the parameter «true breaking stress S_c», and stress σ_c^{**} – yield threshold σ_s of material with values less than the corresponding dynamic characteristics of steels. It can be noted that approximately the same excess of the values of the yield strength σ_s (to 1,1 times) and strength threshold σ_h (до 2 раз), determined at high strain rates, above those established under static compression and tension of the samples, are described in works [2, 6] for technical iron and medium carbon alloyed steel.

With small diameters of blunting area ($n < n^*$, $d < d^*$, stage I) contact stresses developed upon impact $\sigma_к$ are exceeding true dynamic breaking stress $\sigma_к^*$ this steel and on the contact area there are cracks, the development of which leads to chipping of significant volumes of metal, which is recorded in the form of a noticeable loss of the impactor mass. With large diameters ($d^* < d \le d^{**}$, $n^* < n \le n^{**}$, stage II) of the resulting stresses it is not enough to destroy the material of the impactor, but it is sufficient for its plastic deformation, accompanied by the movement of metal from the central part of the contact area to the peripheral one. Based on the fact that there is a noticeable loss in the mass of the impactor at this stage, it can be concluded that a significant part of the metal volume deformed and weakened by cracks is carried away by the moving products of rock destruction.

Such a conclusion about the destruction and significant plastic deformation of the tip of the impactor in the early stages of interaction is supported by the results of tests specially carried out by the authors, in which strikes by the impactor were applied not to the abrasive, but to a smooth plate of a harder material that is not destroyed. As can be inferred from the results of this experiment, shown in Figure 6, with a small number of blows, chipping off of the parts of the impactor tip occurs with the appearance of deformed metal waves directed from the center to the periphery at the contact area. Fig.6 shows the manifestation of the edge effect – chipping of the peripheral areas of the contact area.

The greater the number of beats n in the early stages of interaction and the larger the area of the dumbness of the impactor, the smaller the resulting contact voltage $\sigma_к$ and its excess over σ_c^* or σ_c^{**} steel used, and, accordingly, a thinner metal zone on the contact area subjected to destruction or deformation and, therefore, less Δm. With $n \ge n^{**}$, $d \ge d^{**}$ (stage III), arising contact stresses σ_c do not reach the level σ_c^{**} and the tip of the impactor is not subjected to plastic deformation. The appear-

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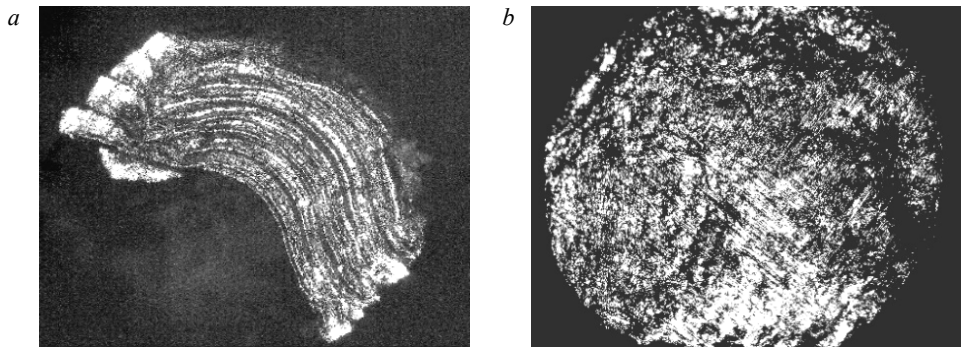


Fig.6. View of a steel hammer blunting area of U8 after striking a solid metal substrate at the stage I of engagement (*a*) and granite at stage III (*b*)

ance of parallel scratches on this site during the transition to impact on the rock suggests that in this case the metal of the site is exposed to moving abrasive particles. The result of scratching is a significantly smaller, compared with stages I, II, loss of metal mass, the value of which is determined by the abrasive wear resistance of the steel used to manufacture the impactor, depending on its hardness and structural features [3]. It should be noted that the presence of holes on the contact area, along with scratches, may indicate that, in addition to wear by the moving abrasive particles, the material of the impactor undergoes impact and the introduction of stationary abrasive particles into it [2], which takes place at the stage of compaction products of rock destruction.

The proportion of energy expended in the destruction of a rock to wear a impactor at the steady (third) stage of its wear was estimated based on the established wear rates of K materials and critical stresses $\sigma_к^*$ corresponding steels. It was assumed that, since in our case, the wear of the material occurs mainly due to the destruction (scratching) of its surface with an abrasive, the specific work A_{sp} this process can be estimated by the formula proposed in [1] for the destruction of metals by stretching samples

$$A_{sp} = \frac{S_c}{\rho},$$

where S_c – true destructive stress of the metal, in accordance with the above assumptions of the authors, for dynamic conditions, equals σ_c^* of particular steel from Table 1; ρ – density, ρ = 7.85 10^3 kg/m^3 for all steels.

Then the work spent on the wear of the material of the impactor per blow,

$$A_{mw} = KA_{sp} = \frac{K\sigma_c^*}{\rho},$$

and the amount of A_{mw} for wear metal in impact energy A_0

$$A_{mw\%} = \frac{A_{mw}}{A_0}\frac{K\sigma_c^*}{A_0\rho}.$$

The work A_{el}, spent on the elastic deformation of the impactor in the course of a single injection into granite at the steady-state stage of interaction III, was calculated as the product of the maximum resistance of the rock N_m for $d = d^{**}$ by the total decrease in the lengths $\Delta l_{\Sigma el}$ cylindrical Δl_{1el} and the conical Δl_{2el} parts of the impactor when it is elastic, when

$$\Delta l_{1el} = \frac{N_m l_1}{S_1 E},$$

where S_1 – sectional area of the cylindrical part; E – Young's modulus, E = 200·10^9 MPa for all steels.

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To determine Δl_{2el} a truncated cone with bases equal to the areas of the cylindrical part of the impactor and the blunting area, the height-varying area of its cross section S_i expressed through the distance x from the top of the cone and the angle $\beta = 30°$

$$S_i = \pi x^2 \mathrm{tg}^2 \frac{\beta}{2}$$

and the differential equation of the relative change in the height of the cone due to the elastic deformation as a function of x was solved

$$\frac{dl}{dx} = \frac{\sigma}{E} = \frac{N_m}{E\pi x^2 \,\mathrm{tg}\frac{\beta}{2}},$$

which was integrated at the current x coordinate from the top of the cone to the blunting area x_1 (Δl at d^{**}) and to seat x_2 (l_2), as a result, the final equation had the form

$$\Delta l_{2el} = \frac{N_m}{E\pi \,\mathrm{tg}^2 \frac{\beta}{2}} \int_{x_1}^{x_2} \frac{1}{x^2} dx = -\frac{N_m}{E\pi \,\mathrm{tg}^2 \frac{\beta}{2}} \frac{1}{x}\Big|_{x_1}^{x_2} = \frac{N_m}{E\pi \,\mathrm{tg}\frac{\beta}{2}} \left(\frac{1}{x_1} - \frac{1}{x_2}\right).$$

Accordingly, the value $A_{el\%}$ equals Ael/A_0.

Assuming that the established rates of impact-abrasive wear of the steels K from Table 2 are maintained with further shocks up to a diameter of 3.55 mm, at which the formation of the well is stopped, the number of impacts n^{***} was calculated and the resulting depth of holes h_Σ to this moment for the hammer of each steel.

Table 2

Energy parameters of the process of shock-abrasive wear and elastic deformation of a impactor of various steel grades

Steel brand	A_{sp}, J/mg	A_{mw}, J	Amw, %	A_{el}, J	A_{el}, %	n^{***}	h_Σ, mm
38HM	0.464	0.0013	0.108	0.114	9.8	~ 68500	3410
38HM	0.480	0.0011	0.095	0.107	9.3	~ 79900	4219
U8	0.553	0.0011	0.091	0.085	7.3	~ 93800	6352
$U8_x$	0.565	0.0010	0.083	0.082	7.1	~ 104700	7376
H12MF	0.574	0.0008	0.067	0.080	6.9	~ 131000	9569
$H12MF_x$	0.602	0.0006	0.052	0.076	6.6	~ 176200	13623

As can be concluded from Table 2, the work $A_{mw\%}$, spent on the destruction of the material of the impactor in the process of a single injection into the granite, is ~ 0.1 % of the impact energy. At the same time, with an increase in the wear resistance of the steel used to manufacture the impactor, $A_{mw\%}$ decreasing. The work $A_{el\%}$ on the elastic deformation of the impactor is a few percent of the impact energy and, as $A_{mw\%}$, decreases with increasing wear resistance of the impactor material. So, if for the least durable steel 38HM it is 9.8% (d^{**} = 2.11 mm, N_m = 5.80 kN, Δl_{1el} = 0.0182 mm, Δl = 3.94 mm, Δl_{2el} = 0.0211 mm), then for the most durable ($H12MF_x$) – 6.6 % (d^{**} = 1,62 mm, N_m = 4.28 kN, $\Delta l_{1упр}$ = 0.0127 mm, Δl = 3.02 mm, Δl_{2el} = 0.0229 mm). As calculations show, with a further increase in the number of strokes (above n^{**}) and a corresponding increase in the diameter of the blunting area (above d^{**}) work quantity $A_{el\%}$ increases and reaches for all steels by the time of complete blunting of the tip of the impactor of ~ 36 %.

From Table 2 it follows that by the time of the termination of the introduction of the impactor into the rock, the total depth of the holes h_Σ, embossed by a impactor from steel H12MFx after cold treatment is four times higher than the same figure for a impactor from steel 38XM due to the significantly greater wear resistance of the impactor from steel H12MFx.

Conclusion. Thus, as shown by calculations and experiments, the wear process of a cone-shaped steel impactor during its single impacts on granite is characterized by the existence of three stages of interaction, each of which is determined by the ratio of the strength characteristics σ^*, σ^{**}, demonstrated by the material of the impactor under dynamic conditions, with the magnitude of the stress σk arising at the contact area of the impactor with the rock and decreasing as the number of impacts n increases. At the last established stage of the interaction, the decrease in the impactor mass with increasing number of impacts practically does not change and is determined by the wear resistance of the steel used, as a result of which the number of impacts until the tip of the impactor is completely blunt and the total depth of holes for the analyzed steels differ by 2.6 and 4.0 times, respectively.

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