ENVIRONMENTAL FRIENDLY METHOD OF SUPERDEEP PENETRATION : PHYSICAL BASIS AND PRODUCTION OF NANOREINFORCED COMPOSITES

INTRODUCTION

It was established in the middle of the past century that under any conditions of an impact, the depth of a crater could not exceed six calibers of a striker. A ratio of a crater depth to a striker size (calibre) was taken as a universal criterion of impact evaluation. However, it should be taken into account that a physical limitation exists for an impact process. Numerous investigations made in various countries on barriers punching allowed us to solve the problems of increase in a relative depth of a crater only in the range of six calibers.

As a result it was found that the experimental results, being out of the limit of six calibres cannot be explained with theoretical models of the impact, created during the last two centuries, cannot explain these results. Nevertheless, more and more frequently the data on abnormalities of relative depth penetrations of the calibers < 100 have been published since the twentieth century. However, the experimental results, inexplicable from the point of view of mechanical and hydrodynamical models, were not given. For example, balls of mercury inside thick steel samples obtained in experiments could not be explained, so these samples were thrown out to a dump , There is a problem of reproducibility of such abnormal results. In the planet's conditions, natural processes causing such abnormalities are not known.

When a static strength of the barrier material decreases, the resistance to a striker motion in the barrier sharply decreases too and considerable increase in the depth of striker penetration is observed. It is known that for a shot in sand, it is possible to gain the punching depths of tens of calibres. For a shot in water, what is used in a gun expertise, the maximum depth of penetration can attain 100 calibres.

In 1974, S. Usherenko analyzed the known abnormalities of crater formation. It turned out that the so-called anomalous results have been obtained in a region of micro-objects interaction. Special attention was paid to the fact that the experimentally established physical limit of a relative depth of craters formation is explained by the existence of the known constants of mass- and heat- transfer of the barrier material. Therefore increase in a collision velocity, relative density of the striker material and increase in the angle of impact, cannot lead to an increase in the relative depth of cratering. All these parameters of impact cause the change of magnitude of the kinetic energy. However, the energy excess (in an open system) cannot be stored in the barrier material. The increase in impact energy leads to the increase in velocity of reverse emission of the striker and the barrier materials, melting of walls and of the bottom of a crater, and in extreme regimes it causes intense radiation. In the studied variant of interactions at impact, which can be named "macro-impact", there is no opportunity to realize the phenomena of abnormal and superdeep penetration (SDP). The excess of energy, in one or another way, will be removed from the open system of bodies. The experimental result showed that the limiting value of energy density during macro-impact does not exceed 10^9 J/m^3 [1].

In natural conditions, a SDP process can be observed in the stratosphere and in the free-space, as there are the clots of cosmic dust colliding at high velocity. A principal reason of making difficult detection of SDP on space stations is the absence of reach-through holes and, accordingly, absence of depressurization of the module with the equipment and people. Available information allowed us to assume that in the conditions of SDP implementation, the existing protection of space modules is not effective. Apparently, because of it, on operating space stations, there was a problem with stability of work of computer elements and control systems. The same new factors will represent additional danger for the modules moving with the equipment and people through the regions of the space with high concentration of dust objects.

The set of experimental conditions was determined for which the penetration on relative depths of 100-rl0 000 calibers proceeds stably [1, 2]. After reception of the evidences, that the phenomenon of superdeep penetration exists and that there is a necessity to use physical effects which are observed in SDP conditions, there was a requirement to comprehend a fundamental result. Special attention, for more than thirty years, has been paid to the modelling of a mechanism of effective utilization of the kinetic energy of the SDP process [2-4]. However, the presented concept of the phenomenon of superdeep penetration has not appeared to be a successful one. With the new experimental results obtained, the models of SDP process were rejected because they could not be used for explanations.

BRIEF REVIEW OF THE KNOWN MODELS OF SUPERDEEP PENETRATION

In the first cycle of experimental investigations (1974-l978), the proofs of the existence of superdeep penetration of a clot of particles into the barrier have been obtained. It has been confirmed that it is impossible to explain the results of SDP on the basis of the known models of macro-impact. The known models can be divided into four types. Basically, these models describe the SDP process as interaction of an individual striker with a zone of its movement in the barrier.

The models, in which the energy was expended due to the elastic reaction from the barrier material, are included in the first type of the models. The hypothesis that freezing of plastic deformation occurs at SDP has been given [5, 6]. Authors have assumed that superdeep penetration is realized through a system of cracks. The energy during penetration is spent only on elastic deformation. To explain the experiment results which contradicted the described model, the additional assumptions have been made [7]. A new hypothesis saying that non-planar cracks appear is offered. On the basis of this hypothesis it was assumed that after the collapse of hundreds thousands of unusual cracks, the matrix material can be strengthened and the tops of cracks are melted and deformed. At present, the hypothesis about cracks is used for qualitative explanation of unusual results [8]. For example, this hypothesis explains striker's penetration into the steel at the temperature of 196°C.

It is possible to include the models in which the particles transfer into the barrier, occurs in the special transport elements "solitons" (whirlwinds), to the second type of hypotheses. The hypothesis says that unusual transport of the elements and strikers proceeds with no energy expenditure. In 1998, the hypothesis was offered, that superdeep penetration of the particles is a process of exchange in mass and energy due to the developed instabilities in material [9]. The degree of non-equilibrium at SDP is described by dependence of entropy change on deformation of a matrix material. The hypothesis of hydro-dynamical instability in local areas of the barrier surface, loaded by a stream of micro-strikers, is known [10]. At micro-cumulating, transport whirlwinds are created at the front of a shock wave, initiated by the background shock wave. The striker material is carried by the transport whirlwinds into the barrier. According to the author, recrystallization and amorphisation of the matrix material, as well as the traces of micro-particles material transfer, can be explained by high pressures and temperatures in the zones of micro-cumulating. A hypothesis on creation of volumetric "soliton", in which the striker at SDP moves without the expenditure of energy, has been offered [11].

The third type of hypotheses is based on the assumption that there are special mechanisms of flow, crushing and a loss of strength that were not known earlier. At implementation of special mechanisms, strength of the barrier material is reduced. Thus, as a rule, the static and dynamic strength, macro-deformations of the barrier, crushing of grains and emission, are neglected. For example, the hypothesis on the existence of a specific flow of the micro-striker by a stream from a matrix material is offered [12]. Material destruction in the penetration zones is assumed under various conditions of the stress produced in the elastic-plastic medium [13]. In a regime of free oscillations, in the target, the standing wave is formed with invariable phase and amplitude varying with time. The kinetic energy is thus expended only for crushing of the barrier material. The analogous hypothesis is presented [14,15] . The authors assume that in a volume of the matrix material at SDP, long and narrow zones of tensile stress appear, into which the micro-strikers are propagated. The SDP model, based on a typical mechanism for a cumulative jet is offered [16]. According to the authors, new mechanisms of the penetration reduce by 90% the known expenditures of the kinetic energy.

The authors have developed the concept based on the fourth type of hypotheses. The hypothesis is based on a conception, that at the barrier hit by a clot, variable pressure fields are created. In the barrier, the pressure attains the magnitude that is necessary for the dynamic phase transition. In Ref. [17], for the first time, the hypothesis has been presented that penetration of the particles from a clot into the metal barrier at SDP occurs during the period when the dynamic phase transition is not completed. Special features of such a hypothesis were: barrier material has no long-distance connections, process duration is limited, size and striker velocity and boundaries between various phases are limited too [17]. To confirm this hypothesis, special experiments have been carried out and the time of a dynamic phase transition in the barrier material has been defined. The dynamic losses of the kinetic energy of the strikers were considered. Experimental demonstrations of the implementation of the dynamic phase transition at SDP have been presented much later [18, 19]. The mechanism of the additional energy supplied to the striker [20] has been offered which increases efficiency of the kinetic energy used. In the works [1, 2, 17, 21], the deficiency of the kinetic energy of a clot for superdeep penetration and the possibility of existence of an additional source for energy generation were observed. The possibility of generation of additional energy from the chemical reaction between the introduced substance and the matrix material is reported [22]. The reviews on various attempts to modernize the SDP mechanisms are considered and can be found in the works [2, 3, 17].

New concept of the physics of the superdeep penetration phenomenon [23, 24] is based on consecutive implementations of a set of physical effects. Growth of the energy density (energy accumulation) in local zones of the barrier material results from the system closing and creation of the dynamically stable local zones of high pressure, the level of which is sufficient for a dynamic phase change.

Intensive plastic deformation in the channel elements (high-pressure zones) during the movement of the striker in the barrier material leads to the rupture of long-range connections (loss of static strength) in the material of these zones at the stage of incomplete dynamic changes of a phase. Dense plasma conditions exist in a volume of the channel elements (super-plasticity conditions) and micro-cavities are formed in the channel elements, the collapse of which leads to “hot” points production and energy generation. The direct and return micro-jets of the material of the channel elements (dense plasma) are formed and the strikers are accelerated. A stream of high energy ions (≥100 MeV) is generated from a “hot” point of radiation, and a high-pressure field is produced from a “hot” point, the action of which leads to the expansion of the channel element and extrusion with acceleration of the central zone material of the channel element. Thus, the energy is transferred and the striker is accelerated.

The offered concept predicts formation of a closed system of the channel elements in the barrier material volume. These elements, at the closing process, absorb the energy of the high-pressure field and in a “hot” point, the plasma cavity (bubble) collapses with high velocity (at pressure $10^{11}\div10^{18}$ N/m^2). During the cavitation of the plasma cavity (bubble), the energy is generated, e.g., in the form of nuclear fusion. The energy is released from a “hot” point in time due to the emission (radiation). The barrier material generates a wide spectrum of electromagnetic radiation. A “hot” point is also a source of high-energy ions (energy of an individual ion ≥100 MeV). Simultaneously a “hot” point is a source of high pressure. Expansion of a “hot” point is impeded by inertia of the barrier material in which micro-explosion occurs. When the pressure increases, the dynamic perturbation in the barrier material is absorbed by the adjacent channel elements which are in the opposite phase. In a volume of a primary (initial) channel element, the pressure reduction occurs at the “hot” point expansion. The pressure drops below the critical value and the process of energy generation stops. The channel element is disclosed when the return jet, originating at the successive cycles of the collapse of the channel element along the depth, passes through the channel zone. When high turbulence appears, additional centres of cavitation can be formed in the material of the channel element (dense plasma). Exchange of the pressure occurs between the channel elements. Dynamically stable high-pressure zones (steady-state oscillations of the medium) are important for the energy accumulation in the closed system “barrier - a clot of discrete micro-strikers” [25]. In the system, the strikers material interact with the material of channel elements. The mass losses of the strikers at their penetration into the barrier material are accompanied by the origins of the moving charges, strong electromagnetic fields, controlling streams of the charged particles and microjets of dense plasma. Coincidence of the processes of intensive deformations and strains of highly-energetic ions in time and space causes an amorphous state of the channel elements’ material.

INVESTIGATIONS OF SUPERDEEP PENETRATION (SDP)

The first experimental *condition* of superdeep penetration process was formulated. The craters with a depth-to-striker size ratio of above 6÷10 are recorded at collision of the barrier with a stream of strikers having the sizes less than 500 microns [2,3,26].

The second experimental *condition* of SDP is the presence of a band of impact velocities. Impact velocity cannot be lower than the velocity of superficial perturbations at the barrier's surface. For the impact velocities higher than the velocity of a shock wave passing in the barrier material, the strikers, at first, are broken according to the known mechanism and only then they are in the SDP regime.

The third experimental *condition* of SDP is the existence of a stage of preliminary formation of a pressure in the barrier material.

Consideration of qualitative, semi-quantitative and quantitative aspects of SDP allows us to analyze this unusual process. Figure 1 , [23] shows the schemes of various craters.

For SDP, the hardness of the striker material does not affect essentially the penetration depth. In Figure 2 [23], the zone of retardation of a striker, made of highly plastic material (lead), is shown. By comparison with usual and abnormal craters it becomes obvious that for SDP, the visible diameter of the channel is always smaller than the initial size of striker (Figures. 1 and 2).

The diameter of the channel is called the transverse dimension of a penetration trajectory (penetration zone), which can be seen after polishing and etching processes of a metallographic specimen.

By using, as a striker, very hard ceramic (VC) particles, the same symptoms of superdeep channel formation were observed (Figure 3 [23]).

Similar character of channels formation (zones) at macro-impact is observed for a shot into an elastic material, for example, into rubber. In this case, the zone of a puncture (channel) completely collapses under the action of pressure forces. The fragment we can see as the longitudinal cavity (Figure 3) has appeared as a result of etching solution influence on the activated iron zone. Using the solutions of acids and alkalis of different concentrations, it is possible to gain various diameters of a puncture zone (channel).

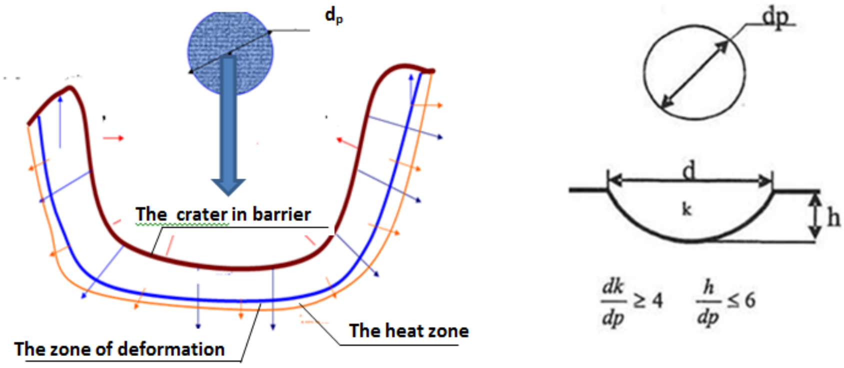
Traces of a bullet (copper or iron) in rubber after its penetration are displayed only on the axis of its movement. On the basis of this similarity, it is possible to explain experimental results of micro-alloying of the barriers at SDP.

At SDP, the channel collapses (closes). It is possible to confirm this assertion in the experiments with lead dust. Lead (Pb), injected into the channel zones, at SDP, during preparation of a specimen for investigation, reacts with the etching solution. However, the products of a chemical reaction do not leave the surface.

The trajectory of motion of lead particles in a barrier in the form of white strings can be seen at a metal surface of a barrier (Figure 4 [23]). Only those sections of a trajectory which are at the plane of a longitudinal cross-section of a barrier are visible.

.We treat similarly the process of punching a rubber barrier by bullets. On this basis, we try to answer the question: what causes a collapse of a channel at SDP? Strong compressive stresses appear in the volume of barrier's material at SDP. What is the reason for these stresses? At usual impact, compression forces (pressure) are not significant and the crater diameter exceeds the striker calibre more than four times. An individual striker cannot give such results.

It is obvious that when a clot of dust particles affects a barrier, the pressure fields appear. The pressure fields in a barrier originate due to the kinetic energy of the impact. Emergence of a variable pressure field explains the presence of velocity gradients and density in the volume of a clot (stream) of separate strikers. After the striker starts to create a channel element, just in this zone the reduction of a pressure field occurs. The channel element closes. Therefore the presence of a pressure field in the volume of a barrier is the necessary condition of superdeep penetration [1,2].



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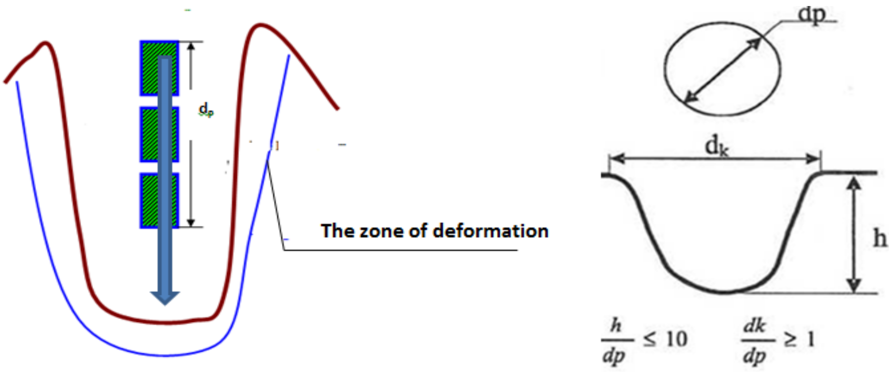

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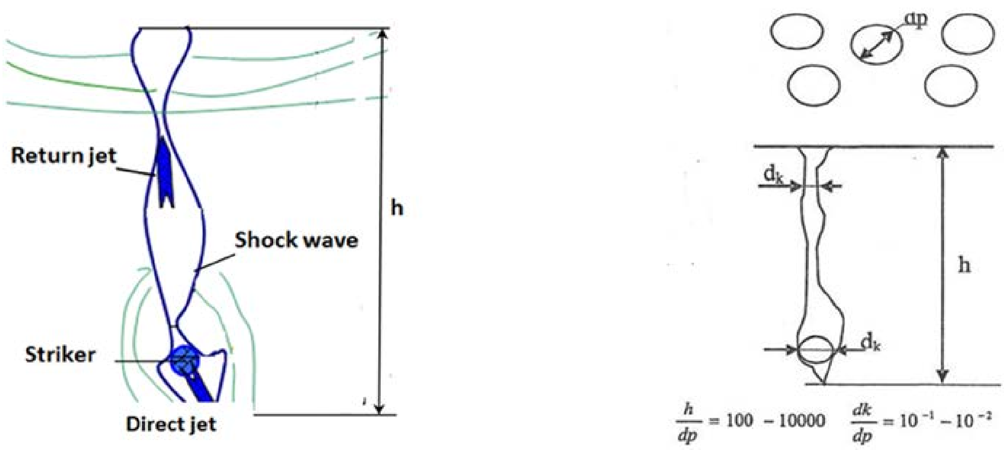

c

Figure 1. Comparison of characteristic features of various impacts with a barrier **a-** Usual; **b-** Anomalous; **c-** Superdeep penetration , ***dp*** - diameter of a striker, d_k - diameter of a crater, and ***h*** - crater depth

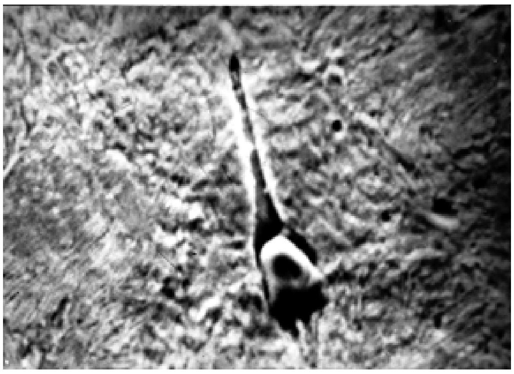

Figure 2. Rest of a lead particle in a steel barrier, x5000.

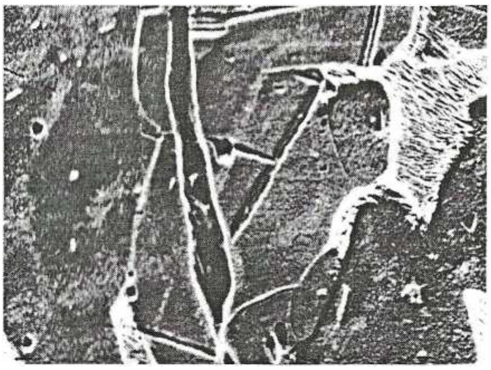

Figure 3. Channel structure in iron barrier, generated by VC particles, x5000**.**

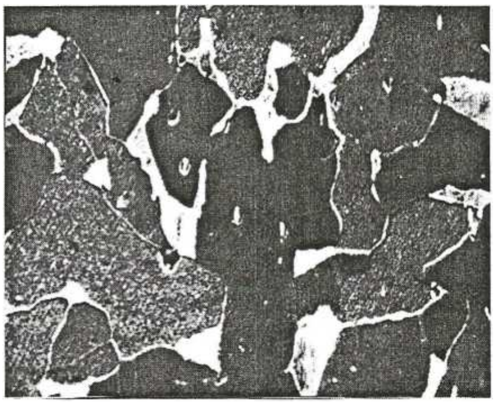

Figure 4. Trajectory of motion of lead particles in a steel barrier, xl000.

Studying these questions has led to a formulation of the second condition of SDP implementation. Superdeep penetration of strikers into a barrier can occur only at the impact of a clot (stream) of micro-strikers. SDP process never occurs for a single particle.

EFFECTS APPEARING AT SUPERDEEP PENETRATION

When a clot of strikers hits the barrier, a variable background pressure is generated in the barrier's material. During the interaction between the strikers and the barrier, separate strikers penetrate into the medium, loaded preliminarily by the hit of other strikers which did not penetrate the barrier but which transferred their energy (pressure) into it. Thus, when the depth of striker penetration is bigger than the striker size, the crater cavity, behind a striker, collapses under influence of the generated background pressure. Since this moment, a qualitative change of the energy reduction has started. During the interaction process lasting $10^{-8} \div 10^{-5}$ s, the power consumption of the closed system sharply increases. As a result, the unusual effects that are characteristic for the SDP conditions should occur.

Interaction Conditions Determining the Cratering Type

Typical cratering for $\boldsymbol{h < 6dp}$ is observed under the following conditions:

- crater cavity (vessel) is open;
- compression of crater walls does not lead to crater collapse and to jet formation;
- expansion of crater walls is significant.

Anomalous cratering for $\boldsymbol{6d_p < h < 10d_p}$ takes place under the following conditions:

- crater cavity (vessel) is opened;
- collapses and formation of both direct and reverse cumulative jets (mainly a reverse one) occur;
- expansion of walls is insignificant.

Superdeep penetration for $\boldsymbol{10^2d_p < h < 10^4d_p}$ occurs when the following conditions are fulfilled:

- crater cavity (vessel) is closed;
- collapse and formation of both direct and reverse cumulative jets (mainly a direct one) occur;
- expansion of walls is insignificant;
- the background pressure $\boldsymbol{P_b}$ operates in the barrier and the material strength $\boldsymbol{\sigma_m}$ in crater's region is low $(\boldsymbol{\sigma_m < P_b})$.
- duration of the background pressure $\boldsymbol{\tau_b}$ is equal to, or larger than, the crater (channel) formation time $\boldsymbol{\tau_c}$ $(\boldsymbol{\tau_b \geq \tau_c})$.

As a result of severe deformation and superposition of variable loads of the crater in the cratering process, the crater's material along the crater walls and its bottom loses its crystalline structure and has no static strength [1,2]. Thus, to change typical cratering into anomalous one, the following conditions should be met:

- the penetration depth into the barrier $\boldsymbol{h > d_p}$
- at the walls compression, the material strength $\boldsymbol{\sigma_m}$ should be lower than the wall compression pressure $\boldsymbol{P_c}$ (elastic after-effect);
- the compression time $\boldsymbol{\tau_e}$ (elastic after-effect) should be longer than the time of walls compression.

An analysis of the experimental conditions, necessary for anomalous cratering has showed different possible variants of these conditions fulfilling.

The use of single micro-strikers [2] causes shortening of the time of walls compression. When a stream of separate strikers is used, the background pressure is generated and the compression time $\boldsymbol{\tau_e}$ is longer than the time of walls compression.

To change anomalous cratering into the superdeep penetration, it is necessary to close a cavity and to ensure $\boldsymbol{P_b > \sigma_m}$ at $\boldsymbol{\tau_b \geq \tau_c}$.

- *The first effect* of penetration at the SDP, due to the presence of a background pressure, is closure of the crater (channel cavity) on the whole distance of the striker movement in the barrier. As a result, the formation of a superdeep channel does not cause any loss of air-tightness of the metal barrier.
- *The second effect* is no direct dependence of the initial hardness of the striker material on the penetration depth. It means that hardness of the barrier material, in the SDP zone, is always lower than that of the striker hardness made of any known material. Such an effect proves that SDP transforms the barrier's material, in a local zone (during interaction $\boldsymbol{\Delta\ \tau < \tau_c}$), into a dense plasma state. The striker's material, which is affected during penetration for the long time $\boldsymbol{\tau_c}$**,** is in a solid or in a liquid state [1, 2, 4, 26].

- *The third effect* is non-uniform distribution of the pressure fields in the barrier's material. Penetration of the strikers occurs in these zones of the material where the pressure is at least of the order higher than the background pressure in the barrier. The pressure fields are mainly in long and narrow zones on the whole barrier thickness. At the beginning of the SDP investigations, this effect has been formulated as a modelling assumption [1,2,26] and then it has been confirmed experimentally [17].
- *The fourth effect*, which directly results from the third effect, it is strong local deformation in the zones of the barrier material [1,4,26].
- *The fifth effect* is the loss of striker's mass at the increasing depth of the striker penetration into the barrier. During the striker passage through the barrier, its initial size decreases by hundreds of times. Decrease in size and mass of the striker is non-uniform along the penetration depth, what proves the changes of SDP conditions in the barrier [2,3,26].

Additional effects arising at SDP, as a result of the collective action of all the before determined conditions are: *appearance of electric charges* at the interaction of materials of the striker and the barrier and appearance *of a wide spectrum of electromagnetic fields* during the movement of a clot of strikers in the metal barrier [18,19].

Simultaneously, in the volume of the barrier material, in the point sources the *flows of massive charged particles*, apparently ions, occur. The energy of such particles is so high that they can pass (starting from "a hot point") through the barrier material. The experiments employing additional filters (protection screens situated at the particles exit from the barrier) have shown that the energy of the particle at the barrier's surface (after its passage through the barrier material) was 100 MeV.

On the back surface of the barrier, at the strikers exit, *microjets of dense plasma* appear. These jets possess high penetrating power. Their velocities attain hundreds of meters per second. The diameter of such a jet is not larger than 1÷2 μm, and its length does not exceed some millimetres . The jets have the charges and interact with the electromagnetic fields.

Interaction between the striker and the barrier materials, in local zones (channel elements), leads to *appearance of chemical elements* [7] which were absent early from this material, and it causes *a synthesis of metastable compositions* [26] which are not shown in the known constitution diagrams. It can be explained by simultaneous action of high pressure, intensive deformations and radiation in the interaction zone [4,7], Neither mechanical, nor hydrodynamical factors of SDP have essential influence on a situation inside the metal barrier.

EXPENDITURE OF ENERGY IN A PROCESS OF SUPERDEEP PENETRATION

The energy expended in the process of superdeep penetration was estimated using a principle of minimization of energy expenditures. Within this approach, at each analysis' stage, the minimal possible estimation of the energy expenditures was accepted. When the energy expenditures were too high, even using a minimization principle, the assumptions for re-use of the spent energy were offered. For the calculations we have used the results obtained experimentally. To compare the introduced and the spent energy, the following approach has been accepted. For calculation of the kinetic energy, injected by a clot of high-speed particles, the overestimated assumptions were taken, and for the calculation of the expenditures of the energy, implemented during the loading - only the assumptions obviously underrating the energy values were accepted. Such an approach allows us to focus on qualitative aspects of the SDP process (Figure 5).

From calculations [23] follows, that 90-98% from the general expenses of energy for crater formation are spent for overcoming of static durability. It is possible to admit, that the barrier material at a combination of some parameters loses static durability. By estimations only dynamic losses of energy on formation of channel zones and channels shutting after penetration of microparticles exceed kinetic energy of impact. At SDP other high-energy effects are realized also.

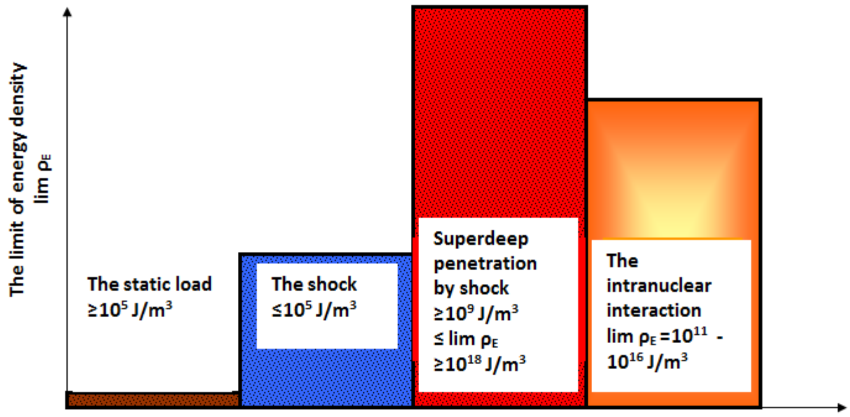

Figure 5 .The diagram of density of energy of various processes (depending on speed of interacting

Estimation of the Kinetic Energy of the Clot of High-Speed Micro-Particles

For calculation of a quantity of the energy gained by the metal barrier as a result of the shock-wave loading with a high-velocity stream of micro-particles, the following values of parameters were used: the mass of the ejected (driven) material $\boldsymbol{m_1}$ = 0.1 kg, the mass of the explosive charge m_2 = 0.2 kg, the velocity of the micro-particles clot - 1000 m/s. For these parameters, the kinetic energy of the ejected (driven) material was 1.5 x 10^5 J.

At the macro-impact, restriction of a relative depth of the penetration is caused by the fact that the impact energy is extended for overcoming the static impact resistance (90÷98%) and the dynamic component of the resistance causes the energy loss of 2÷10%. The dynamic expenditures of the energy originate at the transfer of the striker and barrier materials with some velocity, during ejection of the barrier material from the crater and during the movement of the material of the cavity walls and its bottom [2, 17]. In addition, the dynamic expenditures of the energy at usual impact include the energy expenditures for the dynamic settlement and macro-crater formation..

In Ref. [17], the energy expenditures on macro-changes of the barrier are estimated. The observable changes of the barrier's geometry are shown in Figure 5 [A].

As a barrier material, the cylindrical samples, made from the alloy of iron with 0.4% of carbon, having the diameter of 50 mm and the height of 100 mm have been taken. As the striker materials, the micro-particles of SiC powder of the fraction of 63÷70 μm were used. For this case, the energy expenditure for the macro-crater formation was $\boldsymbol{E_K}$ = 2548 J and the energy expenditure for the dynamic settlement was of the minimum value $\boldsymbol{E_d}$ = 401821 J.

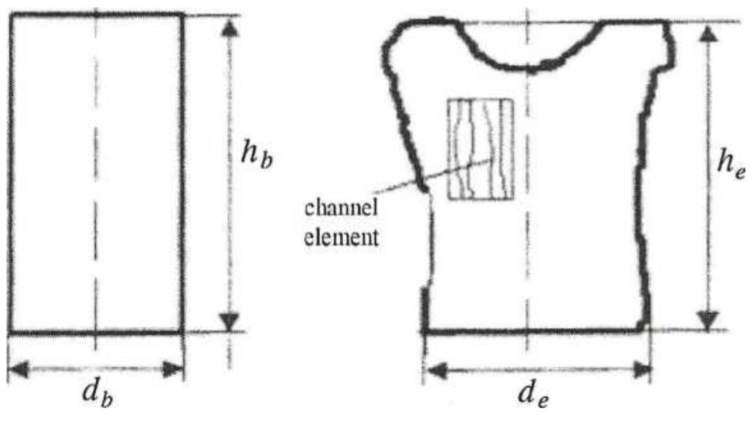

Figure 5. Changes in the metal barrier, arising as a result of its impact with a clot of particles: **a-** initial cylindrical barrier ***h_b*,*d_b***; **b-** the barrier after the dynamic loading (***h_e*, *d_e***)

Formation of a Channel Structure During the Superdeep Penetration Process

In a steel sample, the zones (channel elements) with the changed structure have appeared. Figure 6 shows the scheme of such a channel element (zone). In the channel element zone, the number of defects in the material sharply increases. The maximum number of the structure defects is observed in the central zone of the channel element (Figure 6)[23].

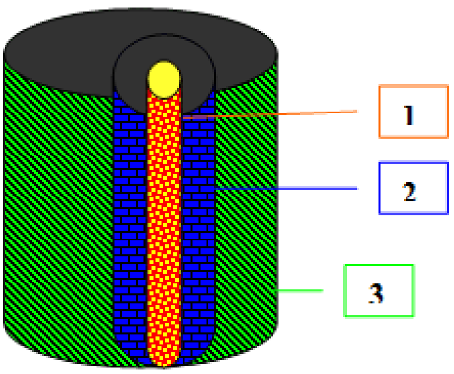

Figure 6. Scheme of a channel zone, **1 -** amorphous material, **2 -** microcrystalline material, **3 -** defective material.

When the special alloying additions are not used, the activated central zone completely disappears (is etched) during metallographic examinations. However, with the decreasing intensity of chemical or electrochemical effects, this zone is filled with a specific material. This specific material is the product of interaction between the injected substance and the matrix material of the barrier.

Two kinds of channel elements can be observed. The first kind represents an element of a crack type with the striker fragments fixed in it. These fragments can be also observed far from the axis of the channel element. As a rule, such kind of the channel element is observed when the striker's substance is a fragile ceramic material. For exam- pie, silicon carbide (SiC) undergoes fragmentation in a pulse regime when it is heated to high temperature. Penetration of the fragments from the central zone of the channel element to other zones of the barrier material occurs in a pulse regime, i.e., it has an explosive character.

The second kind of the channel element is characterized by the maximum number of defects in the central zone. As a rule, the material injected by a clot of separate strikers has higher plasticity when compared with the ceramics plasticity and it intensively interacts with the matrix material. In this case, the material of the central zone of the channel element was a metastable composite of various concentrations of both the injected and matrix substances. For such kind of the channel element, the traces of intensive plastic deformation can be observed. Amorphous state of a thin structure of the central zone was stated due to studying this structure by means of a transmission electron microscope.

In a lot of experimental investigations, nano- and micro-structures were recorded in the central zone of the channel element. It is logical to assume that higher number of defects appear in the narrow zone of the channel material. In our opinion, the existence of various channel elements testifies on various regimes of superdeep penetration.

In such an approach, the difference between two kinds of the channel elements appears because of various regimes of the removal of the central zone material from the channel element. Basing on the study of the first kind of the channel element, it is possible to observe that owing to the relaxation processes in a macro-volume of the barrier material, the number of defects decreases. However, it is necessary to consider the real time of implementation of the process of the channel element formation ($10^{-8} \div 10^{-5}$ sec) and intensity of the process of energy reduction in a volume of the barrier material (metal hardening). In our opinion, more logical is the assumption, that the part of defective material, being formed in the narrow central zone of the channel element, is ejected with the direct and return jets from a solid macro-body. Thus, the difference between the first and the second kind of the channel elements formation results from the mass and velocity of the jets of the ejected defective material. On this basis, it can be stated that the closing (collapse) process of the channel elements is of significant meaning.

For estimation of the energy expenditures on the formation of a zone with the channel micro-structure, the standard assumptions are used: static resistance of the barrier material is equal to null and velocity of the moving walls of the channels is equal to the velocity of an individual micro-striker.

As a result of the channel elements formation, the energy is spent on disclosing of the channels, in the direction perpendicular to the axis of micro-strikers movement, and on their collapsing (collapse of cavitation bubbles) after the particles passage.

Let us estimate the SDP process with employing the energy of the dynamic phase changes. We will consider a case of injection of a clot of TiB2 particles in the iron barrier. Also, we will estimate the minimal volume $\boldsymbol{V}_{\mathrm{iz}}$ of the channel element of the barrier, in which a change of the phase proceeds. It results from the experimental data, that the residual part of the striker (striker rest) has the size smaller or equal to $0.05\boldsymbol{d_p}$.

The experimentally obtained limiting depth is $\boldsymbol{h}$ = 0.3 m. We will assume that the minimal channel volume of the barrier has the cone form. The cone diameter equals $66.5\cdot10^{-6}$ m (a cross-section of the striker) and its height is 0.3 m. In this case, the mass of the barrier material which moves in a dynamic regime will be also underrated because, in a deformation process, the collapse of nearby layers are not taken into account. Then:

$$\boldsymbol{V_{iz} = \pi h d_p^2 \ \frac{1.0525}{12}} \tag{1}$$

where *h* is the barrier (zone) thickness and $\boldsymbol{d_p}$ is the striker diameter.

The cone volume is $\boldsymbol{V_{iz}} = 0.347 \cdot 10^{-9}$ m^3. The material volume $\boldsymbol{V_f}$, in which a dynamic change of a phase proceeds, will be determined by a ratio of the kinetic energy $\boldsymbol{E_p}$ and the pressures of initiation of the dynamic change of the phase $\boldsymbol{P_i}$**:**

$$\boldsymbol{V_f = \frac{E_p}{P_i} = 12.5\cdot10^{-6} m^3} \tag{2}$$

Essential non-uniform distribution of the pressure fields in local zones of the metal barriers and behavior of the phase changes occurring in them have been proved. In particular, $\boldsymbol{\alpha \to \varepsilon \to \alpha}$ transformations are shown using low-alloy steel as an example. The high-pressure phase in them is the $\boldsymbol{\varepsilon}$ -phase. The pressure for initiation of the $\boldsymbol{\alpha \to \varepsilon}$ transition is 12 GPa [18]. The phase $\boldsymbol{\varepsilon}$ is not preserved after the loading removal but the traces of $\boldsymbol{\alpha \to \varepsilon \to \alpha}$ cycle are registered after the micro-structure change. The transverse size of the zones, being tested in a cycle of transformation, changes in a wide range, from a fraction to l÷2 μm [23]

The quantity of the calculated high-pressure zones, formed due to the impact energy of a strikers clot, is:

$\boldsymbol{N} = \frac{\boldsymbol{V_f}}{\boldsymbol{V_{iz}}}$ = 36000 pcs. However, the channel elements are not distributed uniformly along the crater depth.

For the determined conditions, the penetration velocity $\boldsymbol{v_p}$ is: $\boldsymbol{v_p} = \boldsymbol{v_s}\frac{\boldsymbol{\lambda}}{\boldsymbol{1+\lambda}}$ where $\boldsymbol{\lambda} = \sqrt{\frac{\boldsymbol{\rho_s}}{\boldsymbol{\rho_m}}}$; λ= 0.73535. Then, $\boldsymbol{v_p}$ = 127... 1271 m/s. The average penetration velocity is $\boldsymbol{v_{pm}}$ =423 m/s.

The minimal movement velocity in the metal barrier is $\boldsymbol{v_p}$ = 127 m/s and the length of a clot of discrete strikers (distance for acceleration) is 0.15 m. The strikers clot moves to the barrier with the velocity of 300 ÷ 3000 m/s. Due to it, the loading by a jet is realized in the time interval $5.0 \cdot 10^{-5}$ ÷ 5.0×10^{-4} s, i.e., during $\boldsymbol{\tau_l} \approx$ 450 µs. As a clot material we use TiB_2 (titanium boride) particles of the density of $4.38 \cdot 10^3$ kg/m^3 at the melting temperature of 2790°C and the micro-hardness $\boldsymbol{H\mu}$ = 3370 ± 60 kg/mm^2 [17].

The striker moving with the maximum velocity penetrates into the cylindrical barrier during $\boldsymbol{\tau_{p1}}$ = $2.36 \cdot 10^{-4}$ s. The striker with the minimum velocity could penetrate (but it is impossible) during $\boldsymbol{\tau_{p2}}$ = $23.60 \cdot 10^{-4}$ s. The striker, driven with the average velocity ($\boldsymbol{v_{pm}}$ = 423 m/s), could penetrate into the barrier only during the time $\boldsymbol{\tau_{pm}}$ = $7.0 \cdot 10^{-4}$ s. Hence, the strikers having the average and lower velocities during the loading, can penetrate the barrier only to the depth of 0.2 m. It corresponds to the experimental results (Table 1[23]) obtained for the tested steel barrier (HSS) with TiB_2 particles. With the increasing barrier depth, a part of structure defectiveness has decreased by 246 times. Most intensively has decreased the density of the channel elements (2.8 times) and the average (visible) diameter of the channel has increased.

Table 1. Parameters of a structure of the barrier material (HSS steel**).**

Barrier zone	**Striker size d_p**	**Structure defectiveness**	**Average (visible) diameter of a channel**	**Density of channel elements**	**Volume of defective structure V_d**	**Mass of defective structure M_d**
m	10^{-6} m	10^{-3} %	10^{-6} m	mm^{-2}	10^{-8} m^3	10^{-3} kg
Depth 0÷0.2 m	0÷60	6.38	0.576	245	2.504	0.2028
Depth 0.2÷0.3 m	0÷60	0.0259	0.616	87	0.508	0.0411

The quantity of channel elements on the penetration depths from 0 up to 0.2 m is $\boldsymbol{N_{0\text{-}2}} = 4.8 \cdot 10^5$ pcs and $\boldsymbol{N_{2\text{-}3}} = 1.7 \cdot 10^5$ pcs. The volume of the calculated individual channel element on the penetration depths from 0 up to 0.2 m is $\boldsymbol{V_{z(0\text{-}3)}} = 347 \cdot 10^{-9}$ m^3, and the volume of the calculated channel element on the depths from 0.2 up to 0.3 m is $\boldsymbol{\Delta V} = \boldsymbol{V_{z(0\text{-}3)}} - \boldsymbol{V_{z(2\text{-}3)}} = 0.192 \cdot 10^{-9}$ m^3. The volume of the high-pressure zones is $\boldsymbol{V_{zc}} = \boldsymbol{N_{0\text{-}3}V_{iz}} + (\boldsymbol{N_{0\text{-}2}} - \boldsymbol{N_{0\text{-}3}})\,\boldsymbol{\Delta}V = 0.119 \cdot 10^{-3}$ m^3 and the number of cycles of the high-pressure zones appearance $\boldsymbol{N_{cf}} = \frac{\boldsymbol{V_{zc}}}{\boldsymbol{V_f}}$= 9.5. Then, a part of the kinetic energy injected during one cycle into the barrier material amounts to ≈10% of the energy which is required for the loss of static strength (for creation of the high-pressure zone) $\boldsymbol{E_{\Sigma f}} = \boldsymbol{\Sigma E_p} = 1.42 \cdot 10^6$ J. This unusual result was obtained without taking into account the energy expenditures on the channels collapse and in other processes.

Prom the principle of minimization, it is accepted that the high-pressure regions originate 9.5 times in a pulsing regime of the metal cylinder volume.

However, the time of the barrier loading at the impact with a clot of separate strikers $\boldsymbol{\tau_l} \approx 4.5 \cdot 10^{-4}$ s cannot be neglected. The SDP process can be realized only during the barrier loading with a particles clot. Therefore the particles with the minimal velocity cannot penetrate through the whole barrier thickness during the loading process. Then, the time of an individual cycle of a high-pressure action can be estimated as $\boldsymbol{\tau_{imp}} = \frac{\boldsymbol{\tau_{loading}}}{\boldsymbol{N_{cf}}} = 47.2 \cdot 10^{-6}$ s.

For this penetration time, the penetration depth is $\boldsymbol{H_{i1}} = \boldsymbol{v_p}\,\boldsymbol{\tau_{imp}} = 6.0 \cdot 10^{-3}$ ... $60.0 \cdot 10^{-3}$ m. The average penetration depth for one pulse is $\boldsymbol{H_{medium}}$ = 20.0 mm.

During the first pulse, it is impossible to create the channel elements on the whole depth of a metal cylinder. Thus, on the basis of the gained estimations of an average velocity, the number of channel elements on the depths up to $\boldsymbol{H_{medium}}$, formed during the time $\boldsymbol{\tau_{imp}}$ can be determined. A volume of an individual channel's element, from a surface up to the depth $\boldsymbol{H_{medium}}$ is defined from the difference of two cone volumes. The first cone has the base diameter $\boldsymbol{D_1}$ = 66.5 µm and the height $\boldsymbol{h_1}$ = 0.3 m. The second cone has the base diameter $\boldsymbol{D_2}$ = 62.0 µm and the height $\boldsymbol{h_2}$= 0.280 m. Then, if $\boldsymbol{V_f}$ = 12.5 · 10^{-6} m^3, the exact quantity of the channel elements of the first cycle is $\boldsymbol{N_{amend}} = \frac{\boldsymbol{E_f}}{\Delta \boldsymbol{V_{1-2}}} =$190840. The quantity of the channel elements, registered experimentally is $\boldsymbol{N_{0-2}}$ = 480812. During the first cycle, the high-pressure zones, corresponding to the channel elements number $\boldsymbol{N_{amend}}$ are formed on the depth of a metal cylinder. Other channel elements are formed in the next cycles. During ≈ 2.5 cycles, all the channel elements are formed on the distance between the surface and 20-mm crater depth. What will happen next? Will the channel elements exist (pulsate) after $\boldsymbol{\tau_{imp}}$ = 47.2 ·10^{-6} s,

If the channel elements are closed after the striker passage and the further pulsation stops, the return jet is sharply broken. Correspondingly, the blocking of the outlet holes cannot affect the mass transfer process in the SDP regime. Such an assumption contradicts the known experimental results [4].

We accept the underrated assumption that opening of the channel elements proceeds with the velocity equal to the penetration velocity of the strikers into the barrier. In this case, the energy is spent only on the movement of the mass of high-pressure zones with the penetration velocity. Static resistance of the striker material equals null. Then, energy expenditure for the channel elements opening E_{op} can be defined from Eq. (3):

$$\boldsymbol{E_{op}} = \frac{\boldsymbol{M_f\, v_{pm}^2}}{\boldsymbol{2}} \tag{3}$$

where $M_f = N_{exp} V_{iz}\, \rho_m$. Estimating this expenditure, with the average values, we will gain E_{op} = 49366 J.

Let us estimate the dynamic expenditures of the energy on the channels closing. We accept the mass of the barrier material, which moves at the opening and a collapse of the channel, as equal to the cone mass. In this case, the size of the barrier material mass which moves in a dynamic regime will be also underrated if the dynamic mass transfer of a cone material, without involving the nearby layers to a cone, is supposed in the collapsing process. A collapse velocity of the channel element can be calculated according to Eq. (4) [4]:

$$\boldsymbol{v_{com}} = \sqrt{\frac{\boldsymbol{2E_s}}{\boldsymbol{3M_f - 2M_{d1}}}} \tag{4}$$

where $\boldsymbol{E_s}$ it is the energy spent on the channels collapse.

As the barrier can be divided, along its thickness, into two zones, i.e., from 0 up to 0.2 m and from 0.2 up to 0.3 m, the data can be divided into two parts. The volume of an individual cone of the high-pressure zone is $\boldsymbol{V_{z(0-3)}}$ = 0.347 · 10^{-9} m^3 (the zone 0÷0.3 m). A part of the cone in the zone 0.2÷0.3 m (diameter 44.33µm, length 0.1 m) will have the volume $\boldsymbol{V_{z(2-3)}}$ = 0.154 · 10^{-9} m^3 and
$\boldsymbol{\Delta V = V_{z(0-3)} - V_{z(2-3)}}$ = 0.192 ·10^{-9} m^3.

To neglect the influence of the static strength of the barrier material, we have made an assumption that in the cone volume, the high-pressure $\boldsymbol{\Sigma E_p}$ = 1.42 · 10^6 J is produced. For the channel elements opening, the energy $\boldsymbol{E_{op}}$ = 49336 J is spent. Hence, the residual energy is $\boldsymbol{\Delta E = \Sigma E_p - E_{op}}$ = 1.37 · 10^6 J. Taking into account characteristic properties of the zone structures, this energy is distributed proportionally to the volumes of the high-pressure zones $\boldsymbol{\Delta E = \Delta E_{0-2} + \Delta E_{0-3}}$

The estimated parameters of the collapsing channel elements are shown in Table 2.[23]

The energy expenditure on the channel elements collapsing in the barrier is $\boldsymbol{E_{com}}$ = 459245 J and $\boldsymbol{E_{com} + E_{op}}$ = 508611 J.

Table 2. Parameters of a collapsing process of the channel elements**.**

Zone depth	Mass of material under high pressure M_f	Mass of defective residual M_d	Collapsing velocity (v_{com})	Energy (E_{com})	Quantity of channel elements
m	kg	10^{-3} kg	m/s	J	Pcs
0÷0.2	0.751	0.2028	824	254955	480812
0.2÷0.3	0.213	0.0411	1385	204290	170737
0÷0.3	0.964	0.2439	976	459245	

Change of the Barrier Micro-Structure

In the barrier volume, a dislocation pattern characteristic for usual explosive loading appears. The changes of geometry and sizes of the grains and their twinning are observed.

The experiments with the explosive compression (in a cylindrical scheme) have shown that the observable structural changes in the case of explosive compression and for loading of the particles clot give analogous patterns. The total energy of the explosive charge used for the preparation (sample) compression was $E_{com\cdot ex} = 594 \cdot 10^4$ J. We have accepted that the energy spent on twinning, change of geometry and sizes of the grains was only 5% of the total compression energy $E_{com\cdot ex}$. Thus, the energy spent on these micro-structural changes is $E_{ex} = 29.7 \cdot 10^4$ J [21].

Other Factors Causing the Energy Expenditures

Other factors causing the energy expenditures are: formation of micro-jets of dense plasma at the back surface of the barrier [23,24], pulse electromagnetic radiation , and formation of the streams of high-energy ions [23]. Because now there are no reliable quantitative data concerning these processes thus, according to a principle of minimization, the energy expenditures on these processes were neglected.

Energy Balance

The introduced and spent energies will be compared:

$$\boldsymbol{E_p = E_a,} \tag{5}$$

where $\boldsymbol{E_p}$ is the energy introduced during superdeep penetration and $\boldsymbol{E_a}$ is the energy spent on the SDP process.

We consider the expenditures of energy on:

- formation of the macro-crater ($\boldsymbol{E_k}$ = 2548 J);
- barrier settlement ($\boldsymbol{E_d}$ = 401821 J);
- changes of a structure of the barrier material ($\boldsymbol{E_{ex}}$ = 297000 J);
- production of the high-pressure zones ($\boldsymbol{E_{\Sigma f}} = 1.42 \cdot 10^6$ J);
- opening of the channel elements ($\boldsymbol{E_{op}}$ = 49336 J);
- collapse of the channel elements ($\boldsymbol{E_{com}}$ =459245J),

and other expenditures of energy, e.g., on radiation $\boldsymbol{E_{ad}}$ and jets formation.

The sum of the rated expenditures $\boldsymbol{E_a = E_k + E_d + E_{op} + E_{com} + E_{ex} + E_{\Sigma f}} \approx 2.63 \cdot 10^6$ J. However, we will apply a principle of minimization of energy expenditures. According to this principle, it is possible to neglect the expenditures of energy: on formation of the macro-crater $\boldsymbol{E_k}$ settlement of the barrier $\boldsymbol{E_d}$ and the changes of a structure of the barrier material $\boldsymbol{E_{ex}}$, since the energy generated in these processes could be repeatedly used in the processes of the channel formation ($\boldsymbol{E_{op}}$ + $\boldsymbol{E_{com}}$).

Accordingly, $\boldsymbol{E_{op} + E_{com} > E_k + E_d + E_{ex}}$. However, as it has been shown earlier, the processes of the channel elements formation can occur as a result of transformation of the energy of high-pressure fields ($\boldsymbol{E_{\Sigma f} \geq E_{op} + E_{com}}$). We assume that E_{ad} results from the transformation of the energy $\boldsymbol{E_{op} + E_{com}}$. Therefore the minimal necessary energy expenditure for the process of superdeep penetration is assumed as $\boldsymbol{E_a = E_{\Sigma f}} = 1.42 \cdot 10^6$ J.

Thus, in dependence on the extent of the use of the minimization principle,
$\frac{\boldsymbol{E_p}}{\boldsymbol{E_a}} = (5.6...10.5)\cdot 10^{-2}$, i.e., 5÷10%.

Because for estimation the approach of under-stating of the expenditures of the energy and over-estimation of the power consumption has been accepted, the possible mistakes in the given approach cannot be significant. It is obvious, that even 5÷10 times mistake in calculation of the energy expenditures does not change qualitatively the energy balance at the SDP. The probability of the following assumption is high:

$$\boldsymbol{E_p + E_{unk} = E_a} \qquad (6)$$

where $\boldsymbol{E_{unk}}$ is the additional energy emitted during the interaction process.

In this case, even the additional expenditures of the energy for radiation, heating and emission of the barrier material in form of micro-jets can be compensated:

$$\boldsymbol{E_p + E_{unk} = kE_a,} \qquad (7)$$

where $\boldsymbol{k}$ is the coefficient which does not include the energy losses during the superdeep penetration process.

SDP METHOD FOR”GREEN” PRODUCTION TECHNOLOGY OF NANOCOMPOSITES

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Capabilities for obtaining a new material are determined by processing conditions. If to observe narrow group of composite materials - fiber materials, manufacture process can be disjointed on three main stages. Selection and preparation of a large matrix material concerns to the first stage. Selection and manufacture of filaments concerns to the second stage for composite material reinforcement. Process of the assembly of a composite material from the elements created at first two stages of process concerns to the third stage. At each stage of manufacture process of a composite material there are specific engineering and scientific problems. The main problem at composite material creation, as a rule, is essential contradictions between engineering decisions which are used for various stages of process.

The effective solution for a problem of creating a fiber (reinforcing) material with a reinforcing skeleton is making of a frame material from a matrix material with structure on micro and nanolevel . The material on micro and nanolevel has properties which essentially differ from properties of the same material at macro level. The effective solution is a composite material with the macrozones fabricated at various structural levels (Figure 7)

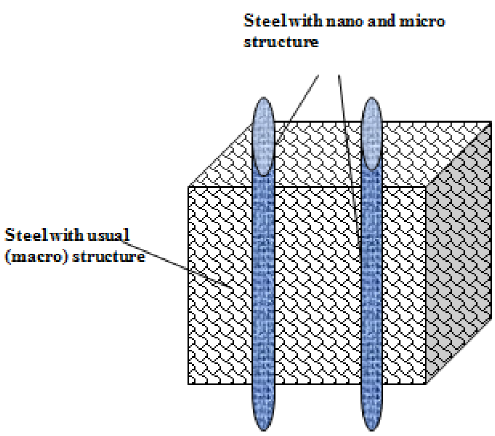

Figure 7. The view of a new composite material

The composite material can be produced if to reinforce a macrostructure devices with nano- or micro particles.

SDP allows to introduce into volume of a solid body any inorganic substance (Figure 8) and to change the structure of a solid body material (Figure 9).

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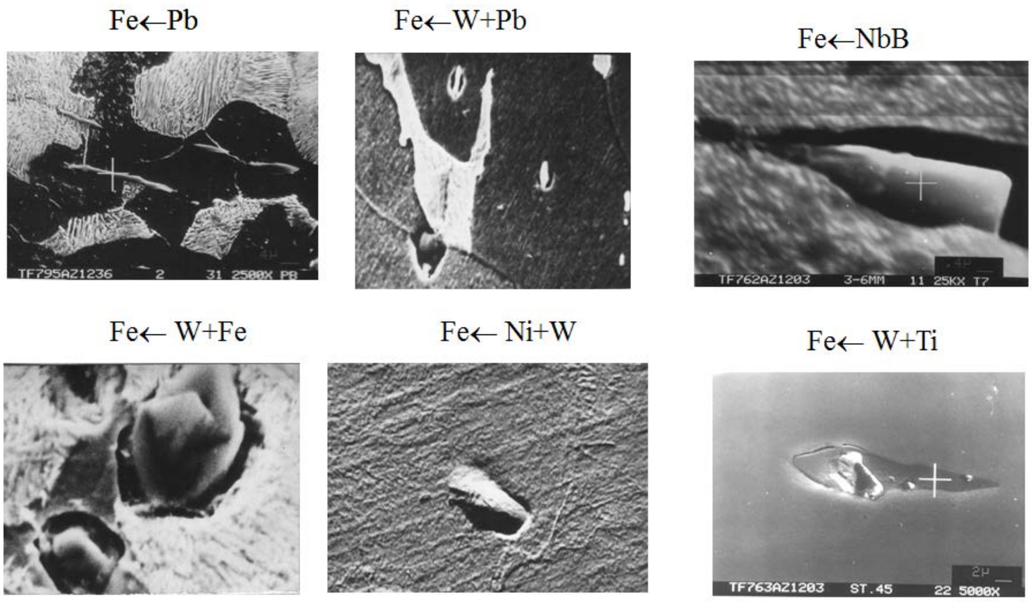

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Figure 8. Microslices of the steel samples after SDP treatment by different kinds of strikers

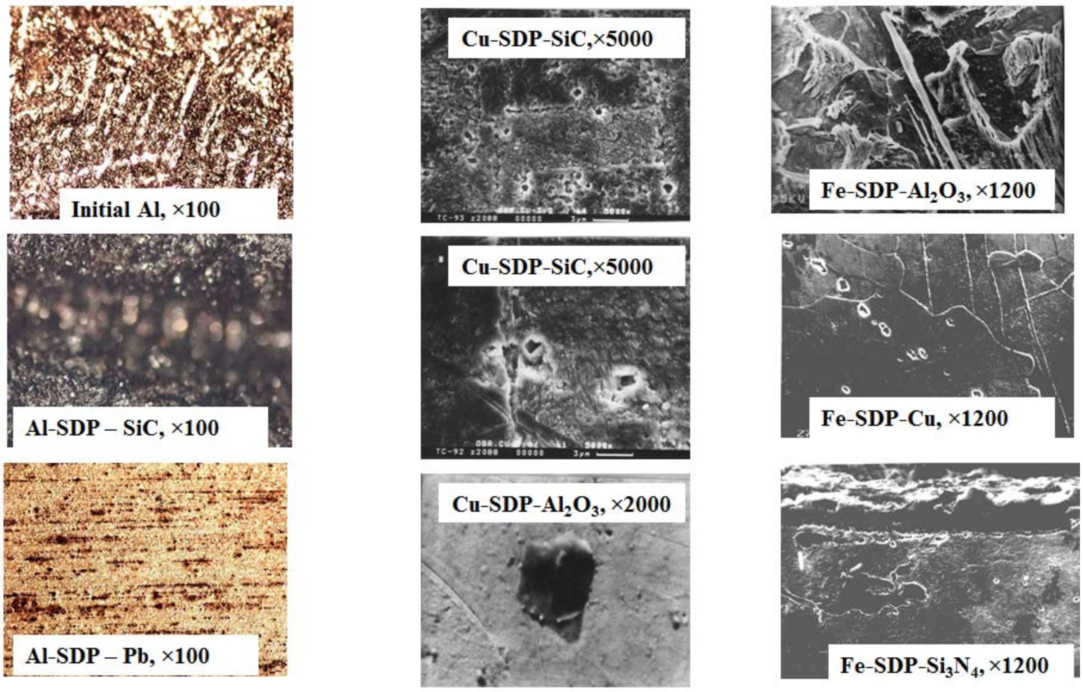


Figure 9. Microslices of the metal samples after SDP treatment by different kinds of strikers

Features of Dynamic Reorganization in Steel at Superdeep Penetration

Qualitative difference of production of composite materials at the use of superdeep penetration from traditional powder metallurgy is that the basic physical tool is the high-speed clot of discrete particles (powder). At SDP, a matrix is the massive high-strength material. At a loading in static conditions in a solid body, a uniform field of pressure is produced. Pressures in static conditions are created up to $\leq 10^5$ N/m^2. On the basis of this information it was assumed, that at the distribution of shock waves and deformation waves into a solid body, approximately uniform field of pressure ($\leq 10^9$ N/m^2) will be produced .

Let us consider a real experiment on shock interaction (Figure 10).

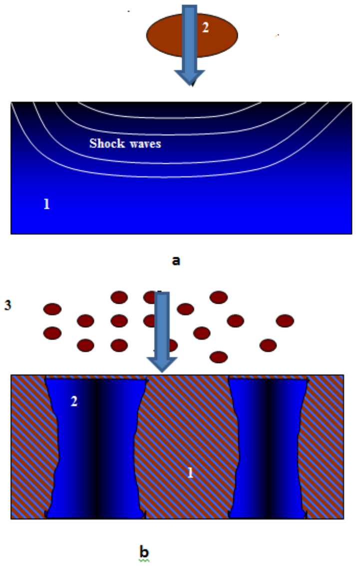


Figure 10. Formation macrozones of high pressure: **a** -Usual impact; 1- barrier; 2- striker; **b** – SDP impact; 1- zone of high pressure; 2- zone of low pressure; 3- disperse striker

Registration of an area of a high pressure we will execute due to the changes of a structure and physical and chemical properties of a barrier material. For the approach to a real geometry at blow the surface of the steel sample was deformed preliminary by a steel sphere with a diameter of 30 mm. Clots of steel powder particles were used as strikers. After the processing of steel preparation (concentration C ≤ 0.45%) a barrier cut in a longitudinal plane, a cut surface was polished and etched with a nitric acid solution (Figure 11[27). The photo of areas of a high pressure (B_1) is shown in Figure 11a]. A background level of the pressure in, massive steel barrier (B_2) was ≤0.2÷1.0 GPa . Thus, in a dark area of a section of the barrier (B_1), the level of pressure of more than 8-12 GPa is obtained

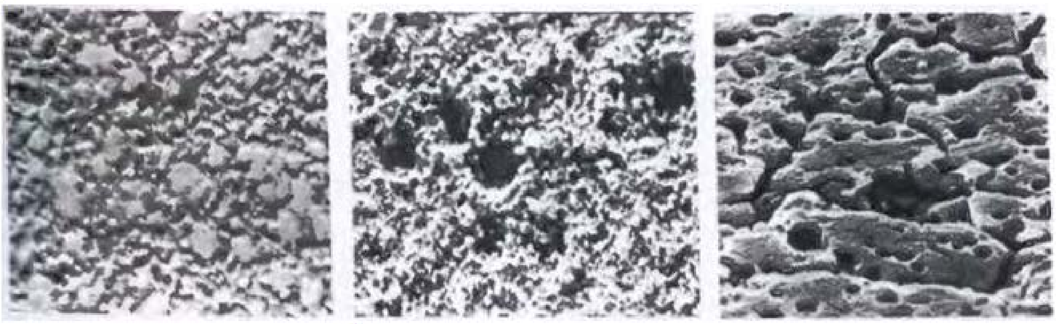
a b c

Figure 11. Distribution of different fields of pressure at impact: **a** – x 0.5; **b** - boundary between sections of high and low pressure, x 200; **c** - crushing of structure elements into area of the high pressure of steel barrier at heat (1,000°C, 1 h), x 200

Between the macroareas of high and low pressure (B_1-B_2), the sharp border is visible, (Figure 1lb]).Therefore in a metal solid body, at the action of clots of dust particles (in SDP mode), simultaneously there are the macroareas of both, low and high pressure. The high pressure area in a solid body volume is surrounded by an area of low pressing. In Ref. [11] it is foretold that at SDP in a solid body there is a steady wave - a soliton. Experimentally such soliton corresponds to the pulsing area of high and ultrahigh pressures. The length of the area of a high pressure (soliton) corresponds to a thickness of a barrier. Tracks have been found out in the areas with various levels of pressure It, apparently, proves, that the narrow area of a high pressure (soliton) arises, as an independent object.

Wide area of the high pressure (B_1) was formed at combination of a considerable quantity of high pressure narrow oscillating solitons. Therefore the area – B_1 has high level of defectiveness. For the proof, after SDP processing, a metal solid body was heated up at the temperature of l,000°C within 1 h. After that the changes in structures of areas of high and low pressures were compared. In a high pressure zone, at the subsequent heating, the set of dot defects has arisen, grains were split up, and numerous centers of recrystallization were appeared (Figures 11b, c]). Growth of grains (Figure 1lc) occurred only after an additional stage of allocation of new structural defects (recrystallization).1 Therefore for increase in the sizes of grains, in a high pressure zone at the subsequent heating, additional time is required. In the field of low pressure, the grains of a barrier material at heating increase in a size faster because there is no stadium of additional structural defects. Therefore stability at heating (red-hardness) of the steel processed in the field of a high pressure is higher, than the same steel processed in the field of low pressure.

Cavities in a cross-section of the preparation are formed after chemical etching by a nitric acid solution. Formation of visible defects (Figure 12 [27) is explained by removal, at etching, the activated zones of structure (Figure 12a). Specificity of these defective zones is also high resistance of the activated material to thermal influence (Figure 12b]). The experiments have shown that defects in steel, created at SDP, do not disappear even after heating for ten hours at the temperature of 1,000°C. After thermal processing in HSS matrix, the borders of grains section are formed and the cross-section size of the activated zones decreases in 10-25 times, (Figure 12c)

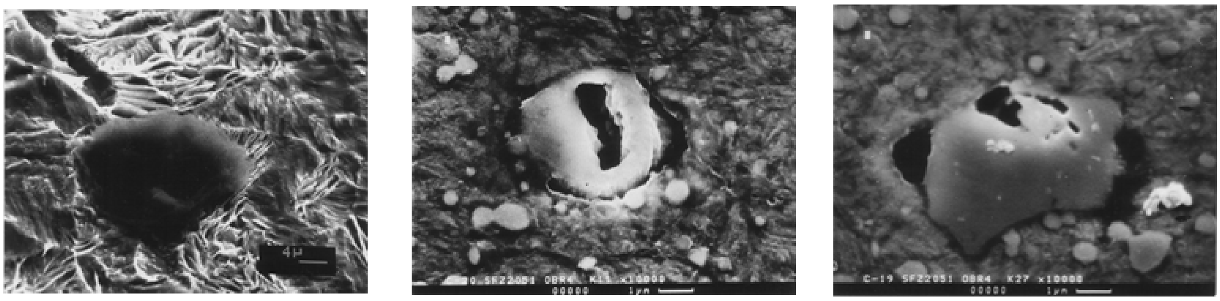


a **b** **c**

Figure 12. HSS steel at different stages of processing: **a -** before processing. x 1,000; **b -** after SDP, x 1,000; **c -** after SDP and heat treatment, x 5,000

Qualitative difference of some new elements of structure, i.e., the zones of strikers movement (channel zones), are local sections of overheated and quenched metal (Figure 13 [27]).

Such elements of a structure are not present in an initial material. These elements can be used for identification of a process of superdeep penetration. Zones of local fusion can be formed round several, closely located "channel" zones (Figure. 13a). Rather large zone is observed when the thermal energy from an individual channel element is insufficient for fusion. But at the big magnifications (≥ 10,000) individual channel elements with overheated elements (Figures 13b,c) are observed. Such elements of a structure have different reflective ability and reaction to etching than a matrix material.

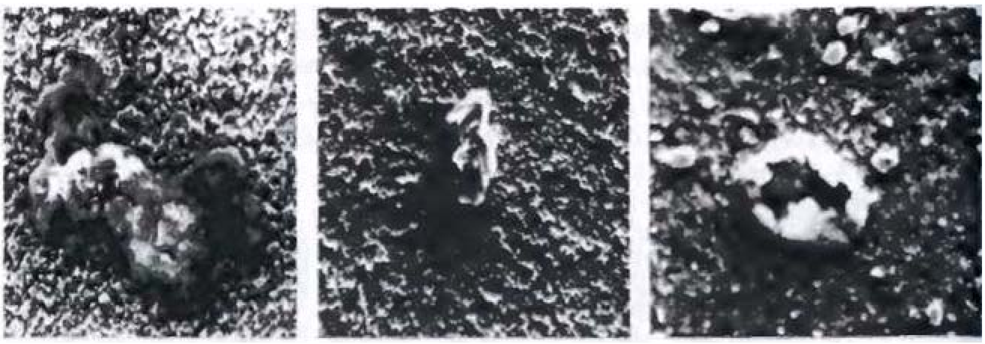


a b c

Figure 13. Zones of local fusion into HSS steel: **a** – x 2,200; **b,c** - x 10,000

In a longitudinal direction inside HSS matrix, the channel sections in a plane do not exceed 0.5 mm. These results are explained due to the fact that in combined steel there are available high gradients of hardness and density in a volume. During the movement into a steel matrix, the strikers oscillate around the axis of their penetration (Figure 14 [27]).

Because of microparticles oscillation, the way of powder particles considerabl;. exceeds the length of the strengthened preparation. The strengthened elements ford! a skeleton similar to a spring. By using special etching it can be seen that a diameter of a zone of interaction between moving particles and a matrix has a variable size (Figure 14a). Chemical and physical properties of a material from the synthesized channel zone essentially differ from the matrix properties. The channel section, which after chemical etching on 4 - 5 µm projects from HSS matrixes, is shown in Figure 14b. Intensive heating of channel zones causes occurrence of smaller structural elements (Figure 14c). The complex consisting of the synthesized fiber elements and the plates from matrix steel, bound with them, creates zones of “influence” which, depending on a mode of superdeep penetration, constitute 3-20% of a volume of a composite material.



a b c

Figure 14. HSS steel - fusion zones: **a** - trail from driving of microparticles, x 2,000; **b** - trail from driving of microparticles, x 1,000; **c** - zone after heating (1,200°C, 1 h), x 4,000

During the movement of a particle in a barrier, the whole complex of physical processes is realized: deformation of materials of a particle and a matrix, friction, pulsation of a field of a high pressure (oscillating soliton), radiation, and heating [1]. After the striker penetration into a skeleton material, the processes of relaxation occur) As a result, the thermal energy from zone interactions (channel) is rejected to a matrix material. At heat rejection (heat-sink cooling), the synthesized material is quenched in a steel matrix. Depending on the total thermal energy and intensity of a heat-removing, various structural conditions can be received in a channel material. The channel element created in the steel ($C \leq 0.45\%$) with a particle from Si_3N_4, is shown in Figure 15[27]. Materials of a channel zone and the braked striker are electron amorphous (Figures 15c,d).

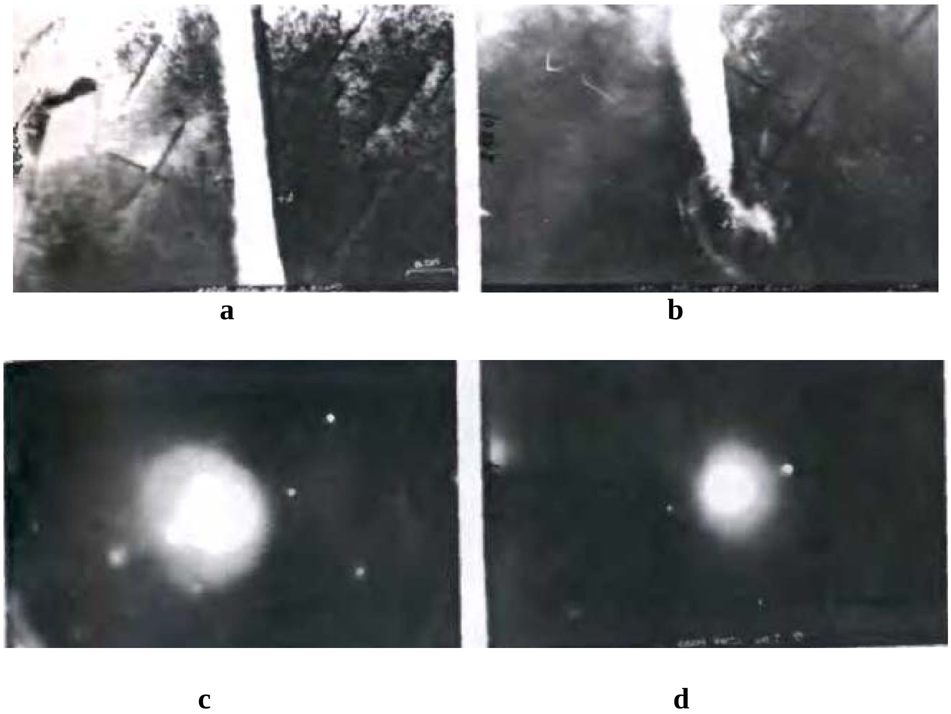


Figure 15. Solid-phase amorphization of a material inside a zone of penetration, x 20,000: **a** - the top part of a channel element (length ≈1.5 µm) with a zone of diffraction (+1); **b** - a zone of braking and the braked striker with a zone of diffraction (+2); **c** - diffraction picture (diffraction pattern) zones (+1); **d** - diffraction picture in the braked striker (+2)

In a mode of superdeep penetration, Si_3N_4 particles intensively interact with an iron matrix and synthesize metastable compounds in an interaction zone (Figure 16[27]).

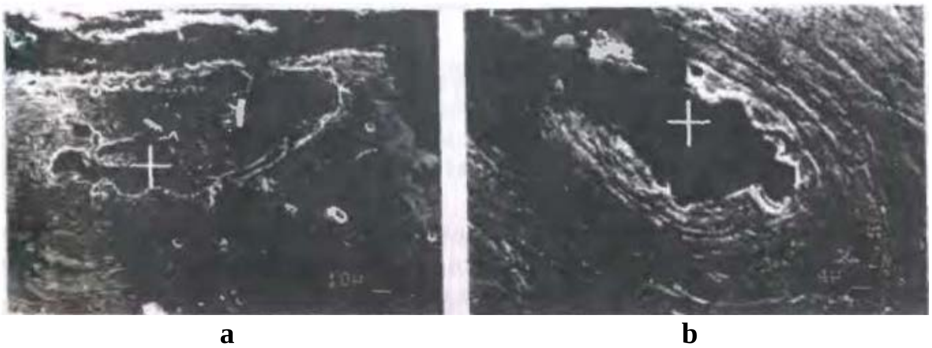


Figure 16. Zones of interaction of Si_3N_4 particles inside an iron barrier **a** - a new structural element to a depth of ≈70µm, x300; **b** - a new structural element on a depth of ≈4.3 mm, x750

Interaction of a striker and an iron matrix, accompanied by additional release of heat. At quenching of the overheated liquid material from an interaction zone in iron, the synthesized material became amorphous (Figure 15).

To check this assumption, in the SDP mode, we will enter silicon particles into an iron matrix. Initial particles of silicon had approximately a cubic form. Interaction of the particles of silicon with an iron barrier is shown in Figure 17 [27].

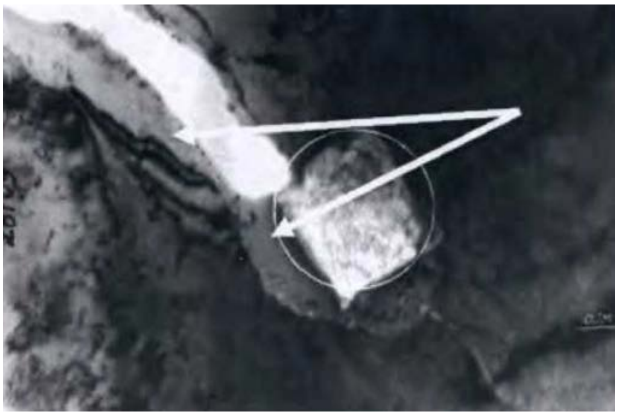


Figure 17. Zone of Si striker of the cubic form, x60.000

Round the etched long aperture and the braked striker, the remains of a material of a channel zone (white arrows) were situated. This material has more light shade and differs from a matrix material (Figure 17). The structure of a material of a channel zone is nano- and micro crystalline. The striker has decreased in size approximately in 100 times, but it has kept the cubic form.

Superdeep penetration proceeds in the time shorter than 1 s. This time is not enough to finish steel reorganization in a composite tool material. The increase in speed of a mass transition in a solid body volume leads to increase in the energy consumption of a process. Therefore it is purposeful to finish formation of a composite material at thermal processing.

Nanostructured Composites Based on Metallic Matrix,

Using of unusual physical features of SDP method for the decision of a practical problem - creations of metal composite materials, is an actual problem for a modern science. The basic features of this method, allowing to predict high competitiveness of technology, following factors are: high speed of process of change of structure of a massive metal material, ecological safety of processes of synthesis of reinforcing materials (synthesis in the closed system of a massive matrix), low power consumption of technology, modifying of a massive metal body in a solid state with special micro and a nanostructural elements. The decision of technological problems we will consider on examples of production of composite materials on the basis of an aluminum and iron matrix and method of strengthening of tool materials.

Generally, the use of tungsten carbide (WC) or cobalt (Co) alloys as materials for the cutting inserts of cutting tools employed in the mining industry is limited by physical properties of the tool per se as well as by relatively low resistance of the WC—Co-based cutting inserts to impacts and flexural loads. Moreover, in Europe WC and Co alloys are regarded as carcinogenic materials unsuitable for production and use. In many cases, the use of tool materials strengthened by reinforcing coatings depends on operating conditions. For example, in the mining industry, coating-reinforced cutting tool inserts cannot be efficiently used because the need for frequent change of such inserts significantly decreases efficiency of the cutting process and mining and impair operating conditions for workers. For the last 70 years, cutting tools have been equipped with cutting inserts made predominantly from WC—Co alloys, which have low resistance to dynamic loads and are ecologically hazardous.

Physical and mechanical properties of known tool materials limit the design possibilities for development of new design tools and for saving energy consumed by cutting and mining processes [28].

The SDP method of strengthening of tool materials consists of impinging the surface of a body of a blank with a high-speed and high-energy pulsating jet of a specific working medium penetrating into and passing through the matrix of the treated material, thus restructuring and reinforcing the material with hard particles (Figures 18, 19) .

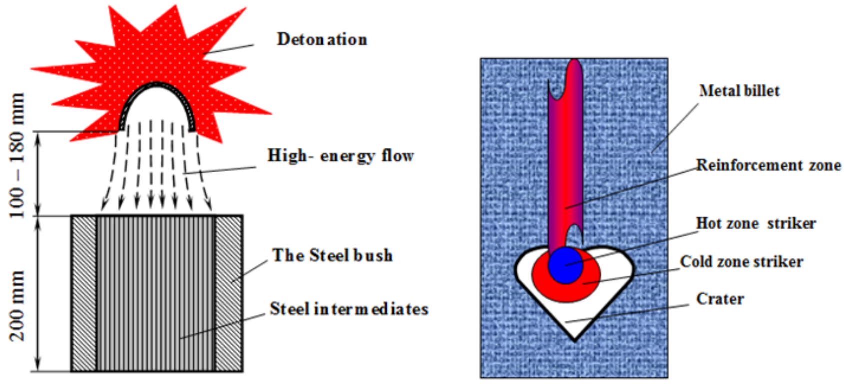
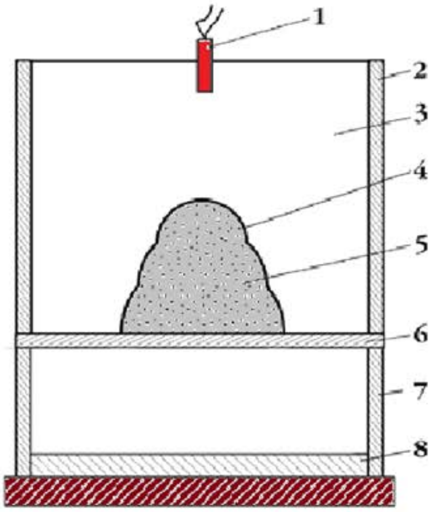


Figure 18. Schematic view illustrating penetration of the flow of working medium in the volume of a preform of initial tool steel for forming the composite steel material .

Use SDP for reception of new tool materials allows during 10^{-3} - 10^{-7} seconds to introduce into solid body volume (a steel of type HSS) alloying elements on depths in tents and hundreds millimeters [23]. At formation into of steel preparation of the fibers having nano- and a microstructure, receive a composite tool material. The material of channel zones (fibers) is alloyed by introduced substance. There is an anisotropy of mechanical properties, characteristic for a composite material. In the process of production it is possible to use cheap impulse accelerators on which receive streams of powder particles with speeds ≈ 1000 km/s.



a b

Figure 19 **a-** The device for bursting alloying:1-detonator;2- metal becket for explosive material 3- charge of explosive material; 4- metal becket for cumulative metal becket for cone; 5- powder composition; 6-plate – bottom of cartridge; 7- regulative abutment; 8- barrier; **b-** Installation for SDP treatment

The important mechanical property of tool steel is wear resistance. Usually increase of level of wear resistance at production of tool steels is reached at the expense of substantial growth of concentration of alloying elements (from 5 to 40 mass %). At a dynamic alloying concentration of introduced alloying elements does not exceed 0.01 – 0.1 mass %. Therefore it is possible to explain increase of wear resistance of tool steel on tens and hundreds percent only by specific structure of a material.

Preparations from a tool composite material are easily processed. The increase in level of mechanical properties occurs after definitive thermal processing. Assumed, that the structural defects arising at pulse processing in metals and alloys, are eliminated at diffusion processes. Heating of the metal preparations subjected to explosive hardening, leads to fast decrease in level of hardness of defective structure of surface layers. SDP does not lead to increase of hardness of surface layers before thermal processing. If steel preparations with the raised level of hardness are exposed to a dynamic alloying then SDP leads to appreciable reduction of hardness by depths to ten millimeters . Researches have shown that the new structural elements resulting SDP are thermally very steady. For elimination of these defects it is necessary annealing of a composite material at a high temperature (≥1000^{o}C) within many hours [29]. Quenching of the tool from steels type HSS lasts minutes and does not destroy composite structure. In the process of tempering of the processed steel there is a possibility of additional hardening due to low-temperature synthesis of strengthening threads (whiskers). The maximum level of mechanical properties of the tool steel exposed to a dynamic alloying is reached at the complex approach, including development of introduced alloying composition, SDP modes and optimization of modes of thermal processing.

Figure 20 demonstrated effective thickness of a metal barrier allowing to stop dust flow.

Composite materials have anisotropy of properties in various directions. Anisotropy of physic mechanical properties increases after thermal processing. In a direction of introduction of a stream of powder particles in preparation from HSS it was possible to raise wear resistance in 1.8 times, and in a cross-section direction on 14 % (Figure 21 [30]).

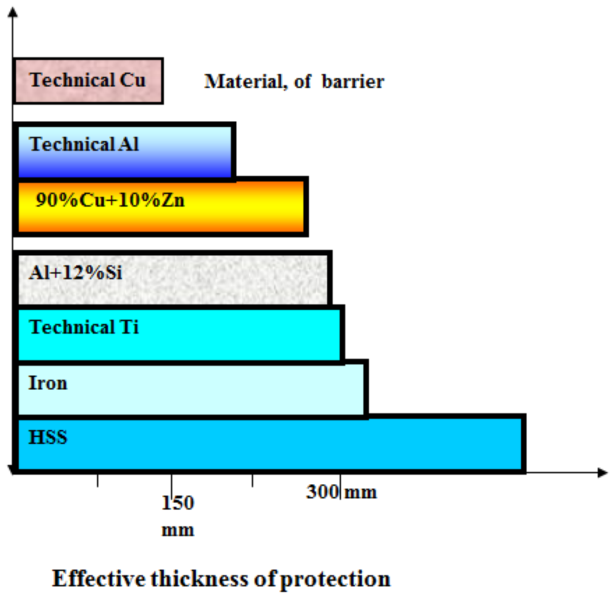


Figure 20. Penetration distance of a dust strikers depending on metal barrier

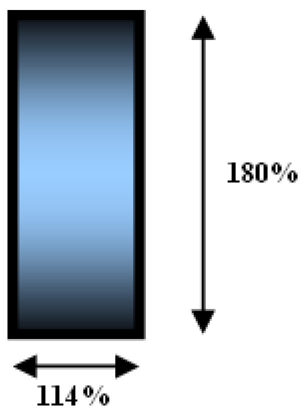


Figure 21. Change of wear resistance

If the tool basically wears out along length its service durability increases repeatedly. Use of this feature in the strengthened tool steel, characteristic for composite materials, allows to solve successfully questions of creation of new constructions of the tool for processing of metals and cutting of rocks. Such approach has been realized at manufacturing of the rotating tool of mining machine for salt extraction. Unexpected results have been received at use as criterion of change of mechanical properties such parameters as shock durability (viscosity). Reception in steel preparations the strengthened and activated zones should lead to wear resistance increase. Such elements of structure should reduce level of shock strength (impact resistance) and bending durability. The skeleton material could be a source for formation of cracks. The increase in specific density of these elements of structure could lower level of physic mechanical properties. However SDP processing has raised shock durability (viscosity) of a composite material in comparison with initial steel on 20-40 % and bending durability on 50 %.

Interesting technological problem is process of zone hardening of large-sized details and change of a thickness of a zone of high hardness at heat treatment [28]. At volume dynamic alloying of large-sized products the structure into big zones (to 200 mm) of the large-sized tool changes. Thus service durability of stamps has been increased on 20-60 % [29] (Figure 22).

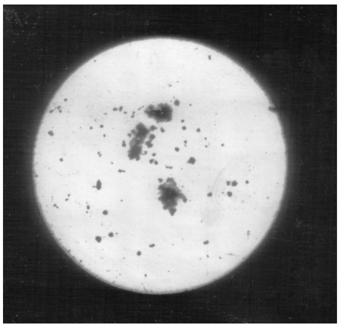


Figure 22. Radioautograph image of the steel 45 specimen on depth 4.3 mm dynamically alloyed by powdered particles W (C + ^{14}C) + Ni

To take two examples of application of SDP method for strengthening of the steel tools (Tables 3-6),[28]

Table 3. Compositions of Working-Medium Mixtures Used for Treating Steel Blanks

Test No.	Composition
1	TiCN (1-100 μm) 60% + Ni (1-100 μm) 30% + Si_3N_4 (0-60 μm) 10%
2	TiCN (80-100 μm) 60% + Ni (10-30 μm) 30% + Ni (10-30 μ +Si_3N_4 (60-80 pm) 10%
3	TiCN (1-100 μm) 100%
4	TiCN (1-100 μm) 50% + Ni (1-100 μm) 30% + Si_3N_4 (0-60 μm) 10% + ethyl alcohol 10%

Table 4. Mechanical Properties of Composite Tool Material after Treatment According to above (Table 3) Compositions of Working-Medium Mixtures

Strength with Reference to Untreated Steel				
Test No.	**Composition No.**	**Resistance to Wear**	**Flexural Strength**	**Impact Strength**
1	-	1	1	1
2	1	1.3	1.15	1.2
3	2	1.05	0.8	0.9
4	3	1.1	0.7	0.65
5	4	1.35	1.1	1

Table 5. Compositions of Working-Medium Mixtures Used for Treating Steel Blanks

Test No.	Composition
1	SiC (3-250 μm) 50% + Ni (1-100 μm) 40% + $A1_20_3$ (20-50 μm) 10%
2	SiC (3-250 μm) 100%
3	SiC (3-250 μm) 10% + Ni (1-100 μm) 20% + $A1_20_3$ (20-50 μm) 70%
4	SiC (3-250 μm) 50% + Ni (1-100 μm) 50%
5	SiC (3-250 μm) 10% + Ni (1-100 μm) 20% + TiB_2 (40-50 μm) 70%

Table 6. Mechanical Properties of Composite Tool Material after Treatment According to above (Table 3) Compositions of Working-Medium Mixtures

Strength with Reference to Untreated Steel				
Test No.	**Composition No.**	**Resistance to Wear**	**Flexural Strength**	**Impact Strength**
1	-	1	1	1
2	1	1.55	1.1	1.25
3	2	1.05	0.7	0.6
4	3	1.1	1.3	1.22
5	4	1.07	1.0	0.7
6	5	1.4	0.5	0.2

The metal-cutting tool from this material at processing of high-strength titanic alloys has shown resistance in 1.8 - 3 times higher, than at the similar tool from an initial tool steel. The rotating tool has been made of composite steel for mining machines for potash salt extraction (Figures 23 [30], 24). The tool used in potash mines of Italy and Belarus. Service durability of the tool has appeared in 1.5-5 times higher, than at the similar tool with cutting inserts from hard alloy on the basis of tungsten carbide [29] (Table 7).

Figure 23. Self-sharpening mining tool and metal blocks from the composite tool material

a **b**

Figure 24 Strengthen tools; **a-** Metal cutting tools **; b-** The tools for cracking of coal

Table 7. Advantages of the new nanocomposites tool steel

`Tools		Wearing resistance	Power-consuming	Fire-safeness	Cancerogenic factor
Analog	Tool Steel HSS	1			
	Alloy:WC+Co	1	1		1
Nanocomposite steel tool		1.5-2	1.2	50	0

Aluminum - one of the most widespread and cheap metals. Without it is difficult to imagine a modern life. Aluminum alloys play a huge role in the space industry . Many constructive elements of space devices are made of alloys of aluminum, including system of aluminum-silicon. Assert that wings of planes are kept in air only by metastable zones and particles. If at heating instead of zones and particles there will be stable phases, wings will lose the durability. It is important that change of properties of aluminum alloys is realized at infusion of additional doping elements with concentrations 0.001 – 0.1 mass %.

Such magnitudes of concentrations can be created in conditions of dynamic processing. Using of effects of superdeep penetration (SDP) allows to provide an additional doping in volume of aluminum and its alloys and intensive dynamic loads simultaneously [31]. Studying of structural transformations in aluminum details at a stepping action of dust particles actual is. Because of clots of a space dust, moving with a high speed (above 5000 km/s) in orbits of the Earth, the probability of their impact with spacecraft is high. Defectiveness of alloys structure determines reliability of saving of physical-mechanical properties. Therefore dynamic changes in structure of aluminum materials can essentially affect on survivability of aircrafts.

Modification of aluminum and its alloys micro and nanoelements at the third stage of manufacture of massive material (detail) in traditional powder metallurgy faces a problem of growth of structural elements. At use SDP process of volumetric modification of massive material (detail) occurs for shares of second that mechanical properties providing at a level of an initial metal matrix. If as criterion for use of a new composite material to use not mechanical, but physical or chemical properties necessity the sintering and high-heat treatment is eliminated. The increase in structural elements by manufacture of massive aluminum material within the limits of complex SDP is not realized.

The basic problem in study of changes of aluminum structure and its alloys after SDP is working-off techniques of preparation of samples from the activated material. Because of high plasticity of aluminum there is a puttying of samples surface. Definition of a mode of etching is executed in view of specific activation of a material. At use of an optical microscope the correct technique for preparation of samples allows to reveal new elements of structure (Figure 25 [30]).

At research by the basic problem detection of structural changes in aluminum and its alloys was. Due to an irregular sampling of powder composition for SDP can intensify process of etching on a surface and in cross-section of a detail. Therefore false representation is created, that the new composite material has up to 50 % of the closed porosity (Figure 25c). In a host material the closed porosity was less than 0.5 % (Figure 25a).

As in a condition of superdeep penetration the powder particles with sizes less than 100 microns were used so the size of a channel zone in a cross-section is less than initial size of striker [23]. Study of such objects can effectively be executed by means of transmission electron microscopy.

Attempts of study stitched at SDP aluminium exemplars without use of etching were not successful (Figure 25b). At use as a powder of the substance decelerating etching (Pb) visible porosity after etching is not observed Figure 25d). Therefore techniques for research of these materials have been modified. At SDP alternatives with use inhibitory material (Pb) and activate material (SiC) and electrochemical etching are observed. At use of optical microscopy it has allowed even to determine noticeable structural changes in the treated materials (Figure 25c,d). At use of an inhibitor became obvious, that in volume of aluminum matrix there are unusual zones of influence (Figure 25c,d). These zones represent matrix aluminum or its alloy stitched by assemblage of tracks (filaments) from a material that synthesized at interaction of a matrix and powder particles. Zones of influence can make 2-50 % from volume of a host material. Created at SDP modifying micro and nanoelements of structure are cooled inside of a metal matrix. Therefore the increase in the sizes of these structural elements at shaping of composite material is not observed.

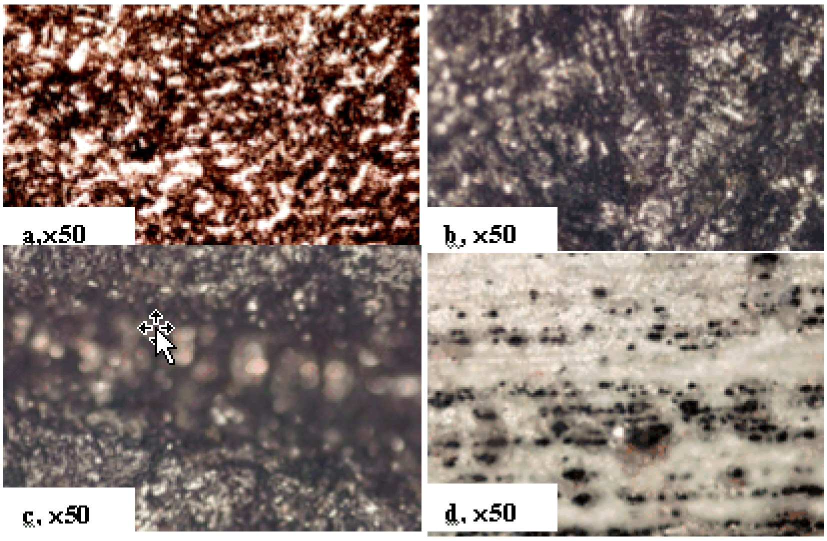


Figure 25. Structure of aluminum alloy Al+12%Si: **a** - after casting; **b** - without etching after SDP; **c** - after SDP - SiC and after electrochemical etching; **d** - after SDP-Pb and after electrochemical etching.

The broaching of aluminum matrix the discrete particles initiates strong distortions in a zone of penetration. Results of initiation are presented in Figure 26 [30].

Electric and electrochemical researches of processed specimens (details) have been executed. Details from aluminium and its alloy were cut in a cross-section and direct direction on macroplates. Researches have shown, that into a detail there is an anisotropy of the examined properties in mutually perpendicular directions twice. In volume of massive detail from technical the aluminum macrozones with a various level of a work function electron [31] are registered. Change of regimes SDP, compositions of a powder material and a metal matrix allows to create new massive composite materials and in a wide range effectively to change their properties.

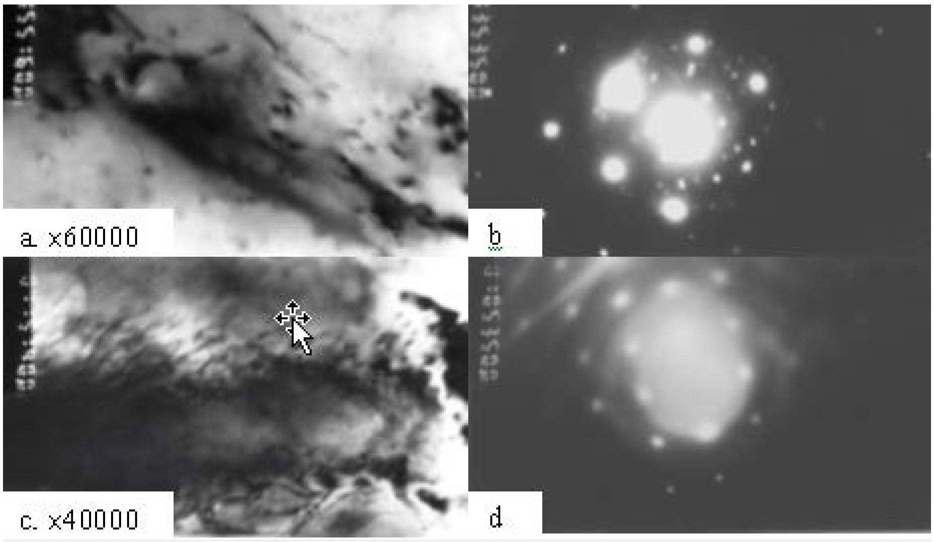


Figure 26. Thin structure of the aluminum processed at SDP: **a** - zone of high concentration of tracks, congestions of dispositions; **b-** electron diffraction pattern of a site «a»; **c**-structure of the central channel microzone; **d-** dim ring electron diffraction pattern in the form of halo of dispersion from a site «c».

.Production of new materials for electrical engineering and electronics is limited by a level of properties of initial materials. Attempt to bypass these restrictions is creation of nanostructured materials. The greatest problems arise at production of fiber reinforced massive composites with high physical mechanical properties. Traditional technological processes do not give the effective decision because of their high cost. New opportunities of massive composite materials preparation arise at use of physical effects which earlier were considered as improbable and exotic.

Reorganization of structure of a massive solid body is possible due to creation in it fields of pressure and gradients of pressure. The more gradient of pressure in a solid body, the more diverse material forming this body, the higher probability of local deformations and dispersion of structure. Formation of fluctuations in a solid body at pulse processes, and also gradients of energy, pressure, temperatures, deformations is a rule in distinction to stationary processes [1].

In the experiments carried out on the accelerator of heavy ions in Darmstadt , the beam of ions of uranium was directed on the sample placed in the chamber . In usual conditions, the high-energy ion, passing through substance, spends a part of energy for braking and makes destructions along the way. As a result the sample of a material after an irradiation appears reinforced parallel and very narrow (10 Å) channels filled with amorphous substance. At the moderate dozes of an irradiation these thin channels are located enough far from each other and don't influence on the common structure and properties of a material . However, at an irradiation under a high pressure the picture has appeared other. At an irradiation of the graphite which is being under pressure of 80 000 atm, channels have not been found out. Dispersing of structure of a material (phase transition) was observed [32].

The physical phenomenon such that intensive electromagnetic radiation and pressure in a range of tens thousand atmospheres are combined is known. In the end of 70th years was found an anomaly in behavior of a clot of powder (dust) particles during the impact with metal barrier. The clot of a dust under SDP operating gets into barrier on depths in tens and hundreds millimeters. At usual impact the ratio of depth of a penetration to caliber of a striker (the defining size) does not exceed 6-10. In case of SDP resistance of a barrier material to penetration of dust particles decreases in hundreds and thousand times [1].

The researches have shown that in the field of penetration of particles the high level of pressure sufficient for dynamic phase transitions is observed. Three-dimensional (type of soliton) zones of a material with pressure not less than 80,000-120,000 atm is revealed for iron barrier [18]. Pressure in the basic part of a barrier material did not exceed 10,000 atm . Therefore structure of a composite material is formed at a superdeep penetration of clot powder particles into massive metal barrier.

Reinforcing fibers in the SDP process are products of interaction of penetrating particles and matrix material. Special conditions of formation of these fiber structures allow to obtain nanomaterials, with physical-chemical properties which cannot be predicted on the basis of known data. Durability of such composite material can be above, than at initial metal and an alloy. Additional thermal processing may not be applied.

As a perspective material for creation of ultradisperse structure we shall consider aluminium and its alloys. Aluminum and its alloys have found wide application in the electrical engineering and electronics industry. However opportunities of qualitative improving of its properties with alloying at moulding are already exhausted by methods of traditional metallurgy . Therefore it is represented actual to realize the processes, allowing to produce details from these materials with formation of their structure on nano-and microlevels.

The purpose of the given research was to reveal specificity of changes of structure and properties of aluminum and its alloys in conditions of dynamic loading in a mode of a superdeep penetration.

The cycle of experimental researches of behavior of various metals and alloys has been lead during interaction with high-energy clots of a dust. As a material of these clots used, for example, powders of silicon carbide. Under the accepted scheme of processing the mode of a superdeep penetration was realized. As a result of researches it has been established, that the aluminum barrier with a thickness of 0.1 m stops a stream of dust particles (fraction 10 - 100 microns). Using of aluminum with silicon and zinc as materials of protective barrier of alloys has demanded for achievement of the same purpose of thickness of 0.16-0.18 m. It is known, that static and dynamic durability of aluminum alloys noticeably higher, than the same characteristics of technical aluminum. It is obvious, that known dependence of depth of penetration for a striker (a clot of discrete particles) from initial static and dynamic durability of a material of the barrier, the macroobjects certain at use, it is not carried out. Researches of the materials, subjected to pulse influence by a clot of dust particles, have shown changes of aluminum and its alloys on submicro-and microlevels.

The channel zones arising at processing consist of a material with essentially distinct from initial physical and chemical properties. Owing to it, at preparation metallographic samples from a material of a protective shell due to a difference in durability and in electrochemical potential (etching) these local section are notabled from volume of a material of a barrier, for example due to reflective ability.

Qualitative difference in structure of aluminum and its alloys at processing by clots of a dust in a mode the SDP have been revealed at greater increases. Studying of the channel zone formed at the SDP, has allowed to find out in volume of massive preparation “amorphisation”, nano-and microstructural sections . In Figure 27[33] the nanostructure of a channel formation in alloy Al+12%Si is shown.

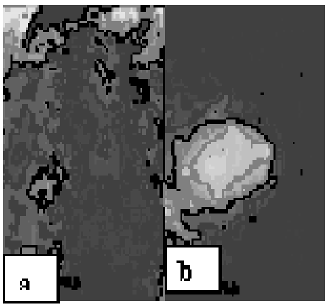


Figure 27, Structure of artificial fiber (canal): **a** - x40, 000; **b-** electron picture

Typical mistake at studying channel zones is their perception as cavities. It is connected by that the material of a channel zone, as a rule, possesses at preparation of metallographic samples the chemical activity differing from a matrix material. Therefore at the same mode of processing of a surface of metallographic samples solutions of an acid or alkali on a place of a channel zone arise a cavity. Simplistically the channel zone can be considered as the composite material consisting from several coaxial located zones. Therefore if cross-section of the central zone to accept for unit, the cross-section of a zone with a defective microstructure makes 4-10 units. Qualitative scheme of a channel zone is shown in Figure 28 [33]. Along an axis in this zone (the section 1) can be observed amorphous or nano-structures. In volume of this section it is possible to register also result of interaction of entered and matrix materials.

Depending on modes SDP and the central section of a zone is possible not to find out used materials. It explains that at SDP due to cumulating of fields of pressure there is an emission of a defective material of the channel zone which are being a condition of dense plasma, in a kind of direct and return microjets. Depending on a level of pressure and time of reduction of the material of the central zone can leave with a different degree of efficiency. This process is influenced also with chosen mode of SDP [34].

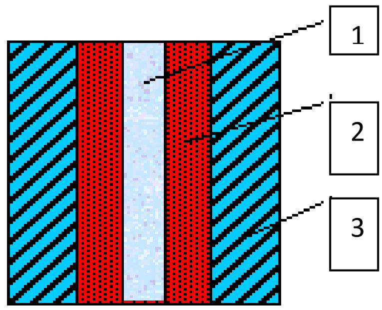


Figure 28. Scheme of canal zones: **1-**"amorphous"or "nano" structure, **2-** microstructure, **3-** imperfect structure

On the basis of calculation of experimental data [33] it is established, that in local volumes the phase of a high pressure has density ρ=1.89 · 10^3 kg/m^3, and the relation of density of phases low and a high pressure makes ρ_1 / ρ_i = 0.70. Such character of change of density of a phase of a high pressure till now was observed only for thorium and uranium. Also it has been established, that the phase of a high pressure in an alloy from 12 % Si has density less than initial - ρ_1 / ρ_i = 0.53 or makes 53.2 % from initial density of an alloy. The relation of density of initial phases in aluminum and an aluminum alloy (12%Si) makes ρ_{A1} / ρ_{AK12} =1.01. The relation of density of phases of a high pressure makes ρ_{A1} / ρ_{AK12} = 1. 34.

Thus matrix aluminum has appeared reinforced, so-called zones of influence (5-10 vol %). The chemical compound of these zones practically meets to structure of an initial material, however has physical and chemical properties essentially differing from each other. In channel zones (the central site of a zone of influence) occurrence of the ultradisperse structure alloyed by the entered material of a clot is observed. The analysis of this site in technical aluminum has shown, that in it contains up to 3 mass % Si. During SDP in a material of a barrier the structure of a composite material is formed. The reinforcing skeleton of this material consists of fiber zones of the reconstructed structure. The scheme of such material is shown in Figure 29 [33].

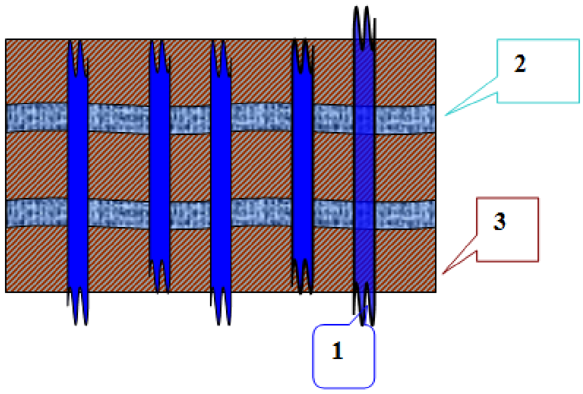


Figure 29. Scheme of structure of composite material: **1-** zones of canals along to astir dust; **2-** zone across to astir dust; **3-** matrix material

Occurrence of the zones reinforcing a material in a cross-section direction, apparently, is connected with turn of a micro striker at braking in a material of a barrier. The share of cross-section channel formations in aluminum and its alloys makes 20-30 % from quantity of longitudinal zones.

Aluminum and alloys on its basis are effectively used as elements of electric machines and electric schemes. In this area the competition to aluminum is made only with copper and silver. It is represented essentially important to receive an additional opportunity of management of its physical properties. Therefore the composite material on the basis of the technical aluminum, received in mode SDP has been used by processing by a dust clot for change of such physical parameter, as electric resistance (Figure 30).

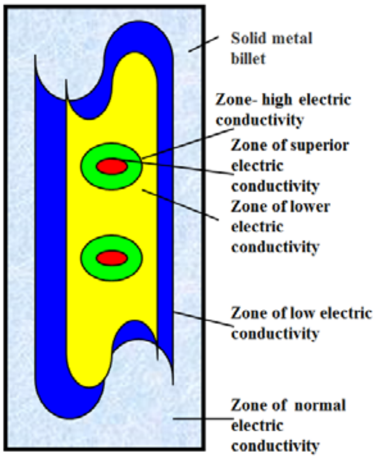


Figure 30 . Distribution of electric conductivity zones at impact

As is known composite materials possess anisotropy of properties, definition of electric resistance was made in mutually perpendicular directions: in longitudinal section (along a direction of a dust stream) and in cross-section section (Figure 31 [33]).

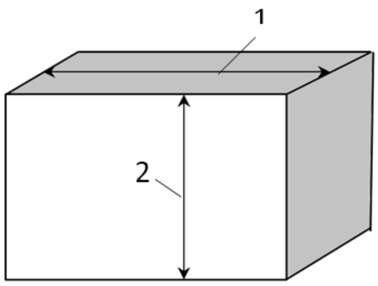


Figure 31. The scheme of measurement of electric resistance in composite material: **1-** along; **2-** across

Cutting of samples for researches were carried out by means of electro spark processing. From each sample in a cross-section and longitudinal direction cut out 4-5 plates. Electric resistance was defined as average value from the made measurements. Comparison of the electric resistance, received on the processed sample, was made with measurements on an initial material.

In a direction 1: Value of electric resistance of technical aluminum $\rho_{Al\text{-}1}= 5.27 \cdot 10^{-6}$ Om·cm; for composite material $\rho_{K\text{-}1} = 4.41\cdot 10^{-6}$ Om·cm. ($\rho_{K1}/\rho_{Al\text{-}1}$=0,835). Thus it is experimentally established, that ρ_1 after processing has decreased for 16.4 %

In a direction 2: Initial average $\rho_{Al\text{-}2}$=$6.42\cdot 10^{-6}$ Om·cm; for composite ρ_{K2}=$9.08\cdot 10^{-6}$ Om·cm ($\rho_{K2}/\rho_{Al\text{-}2.}$=1,41). Electric resistance after processing has increased for 41.2 %.

Note that for initial technical aluminum $\rho_{Al\text{-}2b} / \rho_{Al\text{-}1b.} = 6.42\cdot 10^{-6} / 5.27\cdot 10^{-6} = 1.21$ .Thus the difference of electric resistance in a longitudinal and transversal directions in initial sample is 21.74 %. For composite material after SDP processing anisotropy of electric resistance ρ_{K1}/ρ_{K2}=2.05 times.

Therefore transversal conductance in the processed sample exceeds a longitudinal conductance on 105 %.

The obtained results have allowed to assume that electric properties of new composite essentially differ among themselves on zones. Because of this testing plates for scanning with Calvin's device have prepared. Results of scanning are presented in Figure 32 [33].

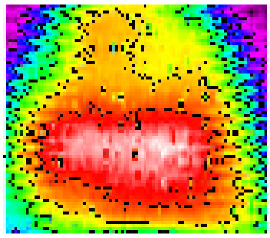


Figure 32. Change of electic resistance into cross section of composite

The central zone which is designated by red color, corresponds the lowest work of an output of electron. Scanning is executed in scale 2 : 1 Attitude conductance of the zones designated by different colors in Figure 32, makes 4- 5 times.

Interaction of a Stream of Particles with Ceramics

As a subject of research used a plate of a monocrystal of silicon and a micro) devices on their basis. Structural specific changes which observed on a surface of a plate from monocrystal of silicon are examined. Conditions of interaction allow to realize stably effect of superdeep penetration in metal barrier. It have wide experience in such researches. Plates of a monocrystal of silicon have high hardness and high fragility. Nevertheless in experiments with using of rigid regimes plates crushing was observed . The example of destruction of a microdevice, in rigid regime at direction perpendicular to action of a stream of particles is shown on Figure 33[34].

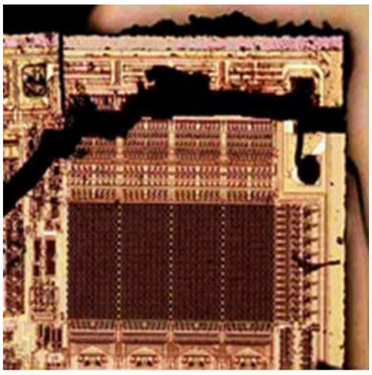


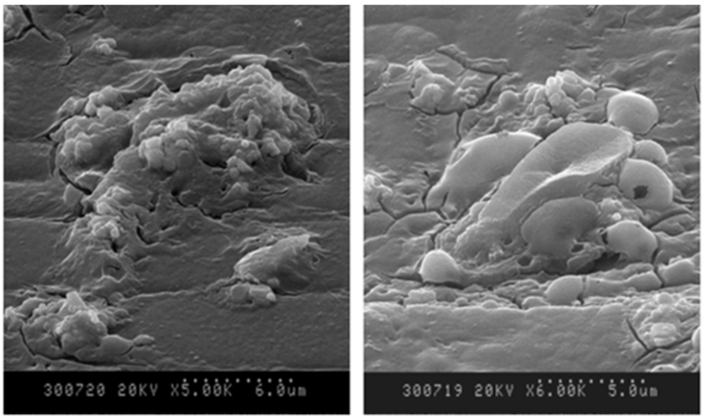
Figure 33. A view of the damaged monocrystal of silicon, x75

Damages of a plastic envelope of the microdevice also have not been detected at use of visual and x-ray methods. Damages have been detected after removal of a protective envelope. Cracks have arisen between knots of an inflection in a plane of section of a plate of a silicon monocrystal. Knots of an inflection have been investigated (Figure 34 [34]) and zones of impact are detected.

In a silicon plate the zone of punching with a diameter in a cross-section less than I pm and depth ~ 180 μm was generated. As a barrier was the fragile material then it is possible to consider that the cross-section size striker does not exceed the size of a zone of punching.

Figure 34. A zone of damage of a silicon plate in a soft mode

. In work [35] it is shown that in a metal barrier there are microjets with a speed in longitudinal direction $\boldsymbol{v_t}$, = 1,482 m/s and in a cross-section direction of a jet are compressed with speed $\boldsymbol{v_{com}}$ = 1,048 m/s. In such conditions ($\boldsymbol{P}$ = 11.3 · 10^{11} N/m^2) the material of a jet exists in a condition of dense plasma. At processing the container with a microdevice the plasma jets pass through gaps. Such gaps are existing in system[1] between an internal surface of a cover and an ampoule, between an ampoule and a covet; of a microdevice, between an internal surface of a cover and a surface of a plate from a monocrystal of silicon. Driving of a jet in gaps is realized in interval of time 0.67 ·10^{-6} ÷ 3.37·10^{-6} s. During this period of time there is a unloading of a jet in a crossi section and pressure in a point of contact varies in a range: 11.3· 10^{11} N/m^2 ·10^{-6} 1.1·10^9 N/m^2. If hardness of Si monocrystal no more than 10^9 N/m^2 then at pressure decrease up to 10^9 N/m^2 the penetration of a jet into a chip stops. Executed calculations [21] show: speed of driving of a jet in a silicon plate is $\boldsymbol{U}$ = 961 m/s, and the length of a jet is $\boldsymbol{L}$ ≥98 μm. If to execute transition from rigid to soft regime of operation of microjets then punching of a plate stops. Affecting of plasma jets on silicon plates gets other kind. Operation in a soft regime is shown on a Figure 35 [34].



a **b**

Figure 35. Segments of local melting on a surface of a silicon plate: (**a)** a zone of formation of of melting; (**b**) a zone of initiation of growth of new monocrystals of silicon

In a soft regime the jet acts on a local area and heats up it. Such action evaporates from a surface of a plate a covering **-** the circuit of the microdevice. In this zone it is possible to see numerous small holes.

Heating of a local area depends on microjet parameters. The temperature of local heat can be above temperature of fusion for silicon (Figure 35). At intensive heating there are bubbles of melt (Figure 35a). Significant overheating of a local area of a silicon plate initiates growth of new monocrystals (Figure 35b).

Bubbles of the fused silicon have traces from punching by microjets. Hence these microjets acted on a barrier after formation of bubbles. Bringing in SDP mode particle on and its chemical compounds, interaction of elements of a stream and a barrier (silicon plate) will be always realized at high temperature and high pressure. The spectroscopic analysis of a surface of a plate before and after processing shows interaction of carbon and silicon. The thick-walled container allows to keep products of interaction in the set atmosphere and also to protect the working personnel from radiation.

Conditions of interaction ensure synthesis of chemical compounds. We observe heat removal into silicon plate. By using of a barrier from carbon (diamond) on its surface it able successfully to synthesize a wide gamma of metastable chemical compounds .Qualitative difference of process of synthesis in SDP mode from other known processes ow energy capacity at a stage of creation of a high-speed stream of discrete particles . Anomaly of this process is the fact that despite of rather low level of kinetic energy at synthesis the high pressure and high heat are realized.

Figure 36 illustrates circuit damage by a microjet border undressed metal - unmetal with subsequent explosive extrusion.

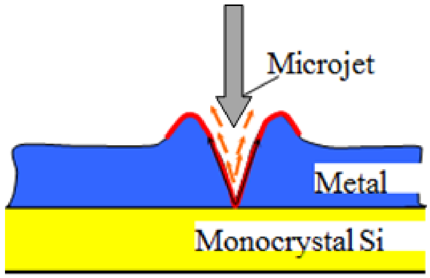


Figure 36 Damage of a microchip in conditions SDP

At using microchips as samples specific processes on metal surfaces are found out (Figure 37[34]). From volume of a metal solid body under action of high pulse pressure the microtubes are squeezed out: lengths of 5-25 μm and diameters of 5-10 μm (Figure 37a). It is obvious , that process of an extrusion happens due to energy from microexplosion of metal. The electroplating can be removed from a surface of a metal element only due to evaporation of a covering (Figure 37b). The cross-section size of pinholes punching is not accompanied by the microexplosion is ~1 μm (Figure 37c). Zones with racks, apparently, arise during a relaxation of residual stresses (Figure 37d). The received experimental results have shown presence of significant additional expenditures of energy at synthesis. These energy expenditures were not considered earlier at calculation of balance of energy of superdeep penetration.

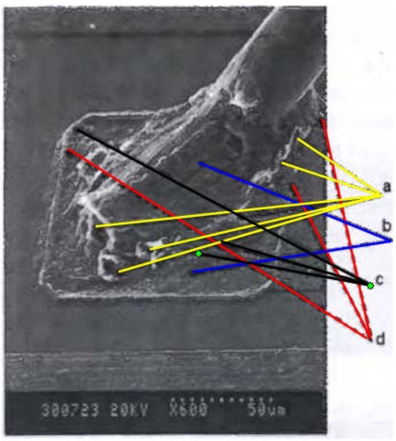


Figure 37. Features of interaction of a metal element of the microchipe with a plasma jet at SDP**: a** - zones of dynamic extrusion of metal micropipes (microexplosions); **b** - a zone with the removed electroplating; **c** - zones with microholes; **d** - zones of microcracks

Features of Interaction of a Stream of Discrete Particles with Plastic

Interaction of discrete streams of microparticles with plastic in SDP mode was investigated for definition of properties of protective shells. So studying of plastic shells of microchips has shown that such shells in SDP mode do not lose herrneticity. At small magnifications by visual observations it was not possible to find out results of interaction Therefore in work [36] traces of interaction between stream of Ni particles and a plastic foil were examined. The shape of traces that strikers have created in a foil is shown in Figure 38 [34].

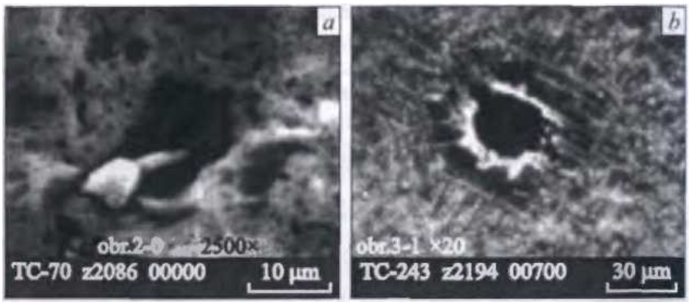


Figure 38. Tracks of damages in plastic films, received in a mode of superdeep penetrating, at processing in the protective container: (**a**) thickness of a barrier of 200 mm, 2 foil; (**b**) thickness of a barrier 50 mm, 31 foil

Traces of inclusions contain material of particles and barrier in different percentage. Observable holes have been received only after etching by an acid solution. Selective etching of zones of puncture proves local activation of plastic in this zone. For definition of the fact of superdeep penetration and efficiency of particles penetration in composite barrier we had been used so-called “foil method” [37]. The choice of this technique explains simplicity of its application. This technique registers traces of penetration. There are traces that leave particles in nonmetallic materials. If to use such materials for a composite barrier as a fluoroplastic and a cardboard, then the analysis of changes of their structure will be difficult for executing. The channel, that the particle creates, “slams” and has diameter from 1μm up to 1 Å. Open cavity can be absent completely then only a track - the deformation area with inclusions of a material of penetrating particle is conserved. Etching of this deformation zone of a track till the size when the track is well visible using of an optical or scanning electronic microscope is necessary- Teflon has high chemical resistance, the cardboard inversely easily etching. In carried out researches were used three kinds of barrier.

The barrier in the first container was made from steel 45 and had thickness 50 mm. The second barrier was two-component “steel - fluoroplastic”. Thickness of layer of the steel located on the side of collision with a stream of particles was 20 mm and following layer - fluoroplastic (teflon (CF_2 - CF_2 - ...)n.) was 25 mm. The three-component barrier consisted from layers in sequence: steel (thickness 20 mm), four sheets of a dense cardboard with common thickness ≈ 6 mm and layer of fluoroplastic (25 mm). Definition of efficiency of penetration of particles into barriers on the determined depth (equal to thickness of a barrier) was made by amount of traces in a foil after penetration. Traces (inclusions) which were qualitatively differed from the initial defects of foils were [37] calculated.

The foils were analyzed on optical microscope. The second, the fourth and the tenth foils from the back side of the barrier were in addition investigated on a scanning electronic microscope “Com - Scan” with the micro x-ray spectrum analyzer. Typical traces of interaction of strikers with a barrier, it is possible to divide into three kinds. In Figure 39[34] a the characteristic trace from “through” punching of a foil is visible. One can see “cork” from the beaten out material of the previous foil after punching of striker (Figure 39 c) . It confirms results of the point analysis of the inclusions that show presence aluminum into cork - a material of foil.

a **b** **c**

Figure 39. Variants of tracks from interaction of striker with the tenth foil: (**a**) through punching of foil, x 5,000; (**b**) rest from striker, x 3,000; (**c**) beaten out "plug" from the ninth foil, x 3,000

For two and three-component barrier on foils the new elements of structure with the spherical form are recorded. Under action of a scanning electronic microscope there is a strain of a surface of a sphere. The surface of a sphere seems to be "spreading". 'Dynamics of change is displayed in Figure 40[34] where inclusion through different time intervals from the beginning of action of scanning electronic microscope is displayed

a **b** **c**

Figure 40. Inclusion on a foil behind the barrier consisting from three layers "steel - cardboard - Teflon": (**a**) after its detection, x 7,000; (**b**) in 10 s, x10,000; (**c**) in 20 s, x 5,000

The analysis has shown that spheres consist of light elements. It is natural to assume, that this material - fluoroplastic (elements of fluorine-carbonic chain (CF_2) of polymer). Fluoroplastic congeals from liquid state taking form with a minimal surface. As at temperature above 260°C fluoroplastic is softening (melts at 327°C) then this assumption well explains occurrence of new spherical inclusions.

Composite barrier regulate process of penetration in SDP mode [36], During

interaction discrete stream of particles with plastic in SDP mode intensive processes of mass transfer are observed. The intensive irradiation of electromagnetic fields and streams of high-energy ions in addition changes properties of plastic.

Production of Polymer Nanocomposites

Polymer nanocomposites are the most effective advanced materials for different areas of application. Any researches of polymer based reinforced nanocomposites , that the polymers filled with small quantities (about 5-7 mass fr.) of nanoparticles demonstrate great improvement of thermomechanical and barrier properties. The most part of published works is devoted to polyolefines filled with nanoparticles of laminated silicates, mainly montmorillonite or bentonite.

The main methods used for production of nanocomposites are the following: polymerization in situ, intercalation from polymer solution, mixing in the melt, sol-gel technology and others. The role of technology of nanocomposites components mixing is very significant. This is due to the small size of nanofillers particles. Providing good compatibility of nonpolar polymers and rubbers with polar nanofillers is especially difficult.

The second problem is hydrophilic surface of natural laminated silicates, what decreases the degree of components compatibility. According to this reasons the mixing in the melt of nonpolar rubbers with polar nanofillers does not provide the high modifying effect.

The unusual physical phenomenon at which a complex of physical effects is simultaneously implemented is known as super deep penetration (SDP): an intensive electromagnetic radiation, an intensive strain, pressure at level from above 8-20 GPa, flows of "galactic" ions and so on [23,38].

The set of experimental conditions was determined for which the penetration on relative depths of 100÷10 000 calibres proceeds stably [2, 3]. After reception of the evidences, that the phenomenon of super deep penetration exists and that there is a necessity to use physical effects which are observed in SDP conditions, there was a requirement to comprehend the fundamental result. Special attention, for more than thirty years, has been paid to the modelling of a mechanism of effective utilization of the kinetic energy of the SDP process [39].

For the first time we use SDP for modification of *nonpolar isoprene elastome*r *by* polar organomodified nanofillers: *montmorillonite* (MMT) and *wollastonite* (WST). The wollastonite surface was modified by alkylbenzildimetilamony chloride and MMT – by quaternary ammonium salts $[(RH)_2(CH_3)N]^+Cl^-$, where R – is a residue of hydrogenated fatty acids C_{16}-C_{18}

The nanofillers WST and MMT were mixed with rubber by use of explosion with ammonite bulk charge with density 0,8-0,9 gr/sm^3 , velocity of detonation is 3800-4200 m/sec. Samples of rubber were located in special container (Figure 41)[40] to prevent their destruction.

Figure 41. The container with rubber samples inside.

As a shooting substance we use a filler (MMT or WST).

By method of differential scanning calorimetry was established that thermostability of rubber based on isoprene elastomer with MMT is essentially higher at the case of SDP use as compared with mixing in melt (Table 8 [40]).

Table 8. The thermostability of rubber based on isoprene elastomer with MMT (Derivatograth "Paulic –Paulic-Erdei" with heat velocity from 0,5-20 ^{0}/ min.)

The method of preparing	T ^{0}C of oxidation	The mass losses,%
SDP	348	28
In melt	339	39

Simultaneously, the conditional tensile strength, tear, hardness elasticity and adhesion to steel cord (Table 9[40]) increase in case of SDP utilization in comparison with traditional method.

Table 9. The physical-mechanical properties of rubber based on isoprene elastomer (SRI)

The properties	The composition and method of processing		
	SRI	SRI+5 mass fr. MMT (in melt)	SRI+5 mass fr. MMT (SDP)
Tensile strength, MPa	15	13	22
Tear, kN/m	43	35	52
Hardness, arbitrary units	59	71	78
Elasticity, %	52	60	70
Adhesion to steel cord, N	9	8	11

By method of X-ray analysis (at difractometer D8 advance) it was estimated (Figure 42[40]), that in rubber samples, filled by SDP method, MMT reflexes at diffractograms are absent. It indicates that the exfoliation of MMT in rubber matrix takes place.

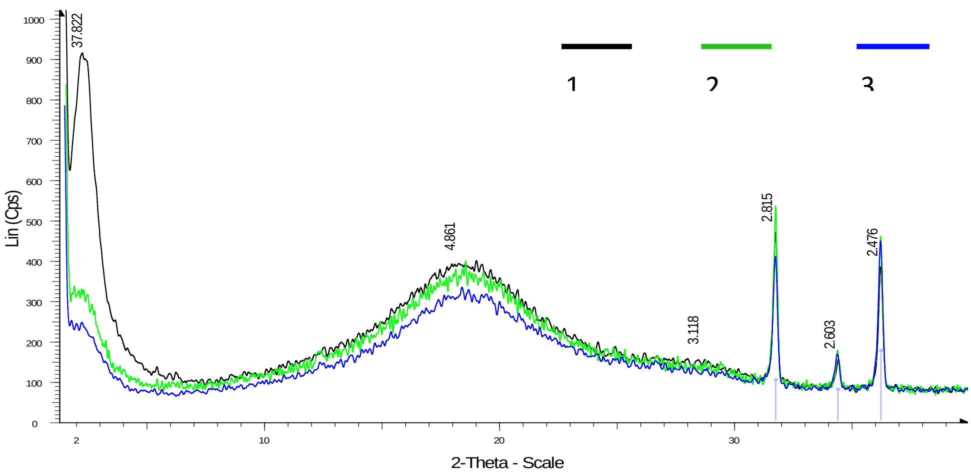


Figure 42. Diffractogram of rubber mixtures based on isoprene elastomer (**1**) and its composition with 1 (**2**) и 3 (**3**) mass.fr. MMT (X-ray method at difractometer D8ADVANCE)

The modification of rubber mixtures by MMT leads to great decrease of ratio of intensivity of the first and the second maximums. This is connected with increase of dispersion of distances distribution between neighboring polymer chains and therefore with penetration of them into interlayer space of MMT

As a nanofiller in isoprene rubber mixtures was used also wollastonite which has the needle-like shape of its particles. The surface of this mineral was organomodified by alkilbenzildimetilammony chloride (Catamine AB).

The structure of rubbers with modified wollastonite was investigated by electron microscopy at the Auriga device ,Zeiss .

The comparison of structure of rubbers, manufactured by SDP and mixing in melt, was shown, that nanofiller particles irregularly distributed in polymer matrix independently of production method. At the same time the greater amount of filler particles with smaller size are formed by use of SDP method as compared to traditional way of component mixing. This naturally increases the surface of phase separation, what positively influences on the complex of physical-mechanical and other properties of rubbers [41].

The maximum of strength and adhesion properties of rubbers are achieved at 3 mass. fr. of described filler content (Figure 43 [40]). The rubber mixtures of this composition are characterized by smaller size of filler particles (Figure 44 [40]).

Figure 43. The concentration dependence of tensile strength and relative elongation of rubber mixtures based on isoprene elastomer.

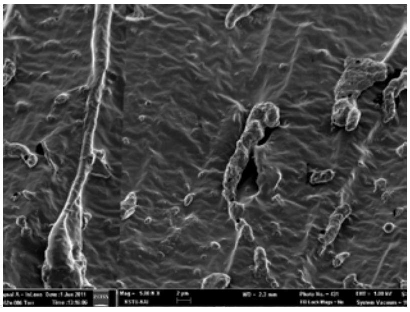
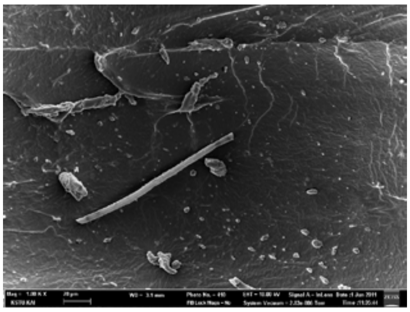
 a  b

Figure 44. The scanning electronic microscope (Auriga device of Zeiss) pictures of structure of rubbers based on isoprene elastomer, modified with 3 mass. fr. of wollastone by SDP method (**b**) and mixing in melt (**a**)

Due to greater surface of phase separation the SDP method provides the best properties of rubber with modified wollastonite in comparison to traditional way of nanocomposite production (Table 10 [40]). So the tensile strength increases by 15% and adhesion to steel cord approximately by the same degree. The tear increases greater than other properties of rubber with wollastonite.

Table 10. Physical-mechanical and adhesion properties of rubber based on isoprene elastomer

The properties	The composition and method of processing		
	Unfilled rubber	rubber+3 mass fr. WST (SDP)	rubber+3 mass fr. WST (in melt)
Tensile strength, MPa	15	28	24
Tear, kN/m	43	53	42
Hardness, arbitrary units	59	68	61
Elasticity, %	52	53	52
Adhesion to steel cord, N	9	15	13

It was also important to estimate the influence of modified WST on vulcanization characteristics of rubber mixtures, because them determine the behavior in the processing of nanocompositions. The data of Table 11[[40] demonstrate that the time of vulcanization beginning increases at 1 mass. fr. of

WST, and at it's optimal content - 3 mass. fr. it is at the level of unfilled rubber mixture. The optimal vulcanization time at 1 mass. fr. of WST greatly increases and at 3 mass. fr. – a little decreases.

Table 11 . Rheometric characteristics of isoprene rubber mixtures

The composition	Min torque	Max torque	T $_{beginning}$, min	T $_{optimal}$, min
Unfilled rubber mixture	18	31	1.25	.,5
Rubber mixture+1 mass.fr. of modified WST	36	45	0.9	13.8
Rubber mixture+3 mass.fr. of modified WST	29	40	1.2	8.0

So, the modified WST does not complicate rubber mixtures processing.

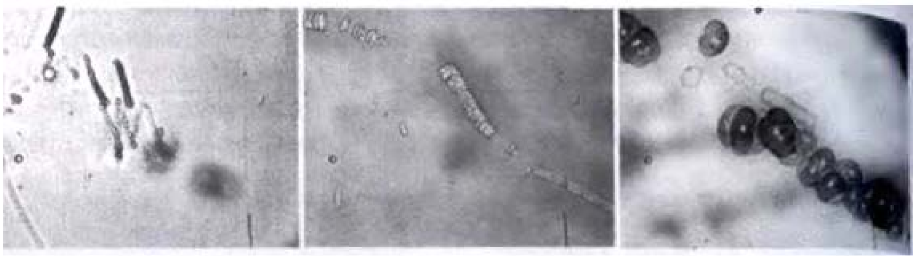
It is important to underline that polar laminated silicates, such as MMT practically don't increase the physical mechanical properties of nonpolar isoprene rubber at mixing in melt. At the same time the SDP method is more effective for production of nanocomposites based on nonpolar elastomers and polar laminated silicates

In the case of WST the great amount of anisotropic particles of nanofiller are formed. They play the role of amplifying elements of polymer structure. So we can say that by SDP method reinforcing effect can be obtained at small amounts of disperse filler.

Development of the New Porous Materials

SDP processing is taking place in the isolated volume as penetration of particles occurs even through thick barrier. Creation of a particle flux and processing of specimens is carried out separately. But because of features of SDP interaction the additional dynamic loads inside of a specimen occur. Changes of interacting materials and SDP regime are changing the process of synthesis of a carcass material. During synthesis inside of a solid body there is a reinforced skeleton material. The matrix material and a material of a skeleton have various physical and chemical properties. Due to this it is possible to delete selectively any element of a construction of a composite material. Let's consider a variant of such technological approach. For this purpose in SDP regime we synthesize a skeleton which material has the increased chemical activity in comparison with a matrix material. As a matrix material we took a glass.

Glass sample etched at different dwell time in a solution of hydrofluoric acid. In Figure 45 [34] change of structure of a glass sample is shown at various conditions of etching.



a **b** **c**

Figure 45. Structure processed in SDP mode of glass sample after various modes of etching x 1,000: (**a**) 30 s, (**b**) 60 s, (**c**) 120 s

The analysis of experimental results has shown, that at SDP regime in fragile| nonmetallic materials there are specific defects [35]. Specific damages arise in fragile materials (glass, silicon) by action of microjets inside of a protective envelop . Microjets have high penetrating ability. Interaction of a jet with glass has high-energy character, leads to occurrence of tracks and change of properties of glass. It is expressed in amplification of activity of defective zones in a glass specimen.

Processing of glass materials it is expedient to execute for the purpose of shaping details in glass with volumetric porous structure. Change of regimes of chemical u electrochemical etching in a range of real time allows to create from a composite material a new porous material with the cross-section size of through pores from nanometers up to ten micrometer.

Production of Polymer Tracking Membranes

Membrane technology is a rapidly growing field having a large economical and ecological consequences and importance. As well know track membranes are more effective [42].

A track membrane is a thin polymer film with through pores which are formed by penetrating a special substance into and through the material of a polymer plate and then removing the traces of penetrated particles from the matrix material thus forming pores. The track membrane may find use in various fields of industry as conventional membrane filters for purification of liquid substances from solid contaminants. In view of low manufacturing cost and only a slight deviation of the holes from the rated diameter (within the limits of 10 to 20%), the track membrane of the invention may be advantageously used as a dialysis filter.

A multitude of straight openings pores in sheets of polymeric materials, formed by homogeneously bombarding the sheet with a source of heavy energetic charge particles to produce damage tracks as have been described in [43] On subsequent stages radiation damaged materials are removed by chemically etching as by immersing the irradiated solid in an etchant. Different chemical reagents (etchants) and etching methods are known as a rule as etchants are used the alkali solution. Without of destroyed materials as produced by high toxic solvents [43]. Its makes the industrial methods of track membrane production non ecological and less technological. Besides, these methods demand the usage of expansive nuclear reactor or accelerates, for example, the cyclotrons [42,43] .

At the same time, there are various methods of treatment of different materials and products, including polymers, with the use of explosive energy. For example [44], discloses a treatment of synthetic polymeric materials by contacting endless sheet-like, ribbon-shaped or filiform polymeric products with 0.1 to 2 mm size particles of sand, glass, corundum or a metal by directing onto the surface a stream of gas carrying the aforesaid particles. This gives the textile structures a rough, woolly, soft feel and they are mat, while films become rough and mat and have a low transparency.

The advantages of track membranes such as high pores density and uncial selection combined with combine with negative factors, for examples, high absorption activity [42,43].

According to this the great scientific and practical interest has the use for track membrane production the method of super deep penetration (SDP) [23,38]. This method permits to realize complex of physical effects such as an intensive electromagnetic radiation , an intensive strain, pressure of 8-20 GPa, flows of «galactic» and so on [38].

So we can propose the possibility of SDP method use for making of open pores in polymer matrix [46].

The method of SDP is carried out by using a matrix material of the membrane and special working substances which interact with the matrix in the form of a high-speed jet generated and energized by an explosion of explosive material.

The special working substance comprises a saturated or supersaturated aqueous solution of water soluble organic salts, or a saturated or supersaturated aqueous solution of water soluble inorganic salts. The organic salts are selected from the group comprising tartrates, acetates, salicylates, benzoates of alkali metals, for example potassium tartrate, sodium acetate, sodium salicylate. The inorganic salts are selected from the group comprising halides of the alkali metals and alkaline earth metals, for example sodium chloride, sodium bromide, potassium fluoride, calcium chloride.

The matrix material comprises an organic polymer material in the form of a solid plate.

As a polymer matrix we can use polyolefin (polyethylene, polypropylene, etc.), polyvinylchloride, fluorinated polyolefin (polytetrafluoroethylene, polyvinylidene fluoride, etc.), polyamide, polycarbonate, polyester, polysulfone, etc.

A device for realization of method comprises a shell in the form of a tube one end of which contains a cartridge with an explosive material and working substance in the form of a solution of solid water-soluble salt or salts. Inserted freely into the other end of the shell is a holder that contains a membrane matrix to be treated in the form of a plate. The open end of the holder is closed by a cover which is attached to the holder, e. g. by screws, whereby the membrane matrix is secured in the holder. The shell with the cartridge that contains the explosive material and the working substance as well as the holder with the matrix of the material to be treated is placed into an explosion-proof chamber, and the explosive material is detonated to cause and explosion.

As a result, the working substance is expelled from the cartridge by an explosive wave in the form of a high-speed jet and penetrates deep into and through the polymer material of the plate. Under the effect of the explosion, the holder with the polymer plate and cover is ejected from the shell into the explosion-proof chamber. The cover is disconnected from the holder, the matrix is extracted, and is subjected to treatments with water that dissolves the water-soluble particles or wash them out from the membrane matrix thus forming microscopic openings that pass through the polymer plate. Then the polymer plate is sliced into thin pieces that can be used, e. g., as filter plates.

For tracking membrane production by SDP method it is necessary to optimize the following parameters:

- the chamber size,
- type and charge construction,
- the explosion power,
- the velocity of detonation,
- the thickness of charge,
- the type and dispersion of working substance,
- the distance from charge end till polymer sample,
- the solvents composition ,
- the material and the size of screen and etc.

So we optimize the above mentioned parameters of explosion chamber, which provide the demanded quality of tracking membranes. As a first step we choose the conditions of preservation of the sample during bombardment. The parameters of explosion chamber used previously for creation of open pores in ceramics matrix cannot be usage due to the difference of elasticity modules of polymer material and ceramics. So we have produced the special protective steel screen with one central and several scattered holes. It provides the part of impact wave energy consumption for destruction of the steel screen.

For preservation of polymer sample during bombardment was produced special steel container with hole in the bottom during which the particles of working substances penetrate into polymer matrix as a charge was used the ammonite of bulk density 0.8-0.9 g/sm^3 (Figure 46 [47]).

The device contains the a tubular plastic shell with both open ends. The height of plastic tube is 200 mm. The device contains a cartridge with the detonatable explosive material and the working substance in the form of a supersaturated solution of water-soluble solid salt. The cartridge is inserted into lower open end of the tubular holder. Detonator is used for detonation of the explosive material. The membrane holder with an open-bottom cavity for receiving a membrane matrix is inserted into the upper open of the shell. The device is placed into an explosion-proof chamber.

The explosion wave that has a detonating nature should impart to the solid particles of the working substance a velocity in the range of 3800 to 4200 m/sec.

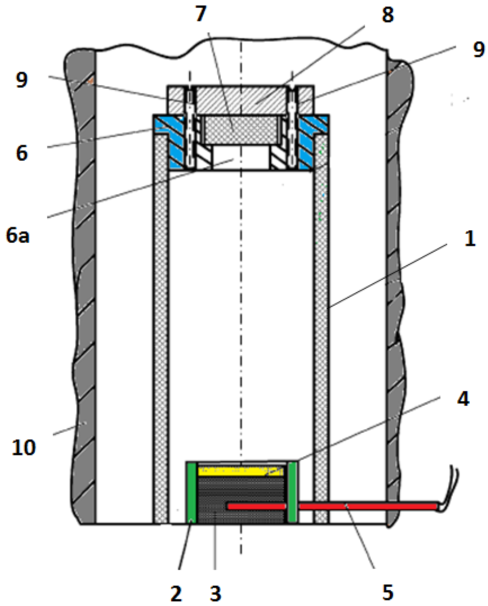


Figure 46. Vertical view of constructed device for membrane production by SDP method. **1-** tubular shell; 2- cartridge; **3-** detonatable explosive material; **4-** supersaturated solution of water-soluble solid salt; **5-** detonator; 6-membrane holder; **7-** cavity of the holder; **8-** cover of the holder; 9-fasteners; **10-** explosion-proof chamber

Some particles deeply penetrate into the membrane matrix material and some particles pierce the body of the membrane matrix from its exposed side. Under the effect of the explosive wave, the holder together with the membrane matrix and the cover are expelled from the shell into the explosion- proof chamber . The cover is then disconnected from the holder and the treated membrane matrix is extracted from the holder 30. However, the membrane matrix will still contain residue of the water-soluble particles of the working substance. Removal of the residual trace particles of the solid substance from the membrane may be carried out in the running flow of water, leaving a pluraly of small-diameter holes. As a polymer matrix firstly we use impact strength polyethylene.

At the same time perspective materials for production of polymer membranes by SDP method are polyethyleneterephthalate, polycarbonate and etc.

The solid plate of matrix polymer materials may have a total thickness in the range of 10 to 20 mm. After removal of the residue of the working substance, the solid plate is sliced into track membrane shaving a thickness of 5 to 50 µm by means of a microtome.

The microstucture of prodused by SDP method membranes is presented in Figure 47 [47].

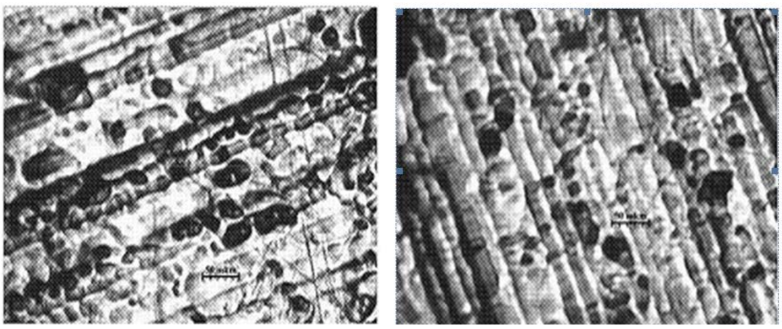


Figure 47. The electronic microscope pictures structure of nanomembranes based on polyethylene.

The picture show section of samples taken parallel to the diameter of the polymeric cylindrec by means of microtome. The black dots in the photographs represent the pores of the sliced samples, which have the size in the range of diameters of 80-100 nm

The actual diameters and the range of the diameters of the holes depend mainly on the velocity of the particles, diameter of the shell, and a distance from the cartridge with the explosive material and the particles to the membrane matrix material in the holder. The through holes produced in the track membrane are oriented in the direction of the jet of particles and occupy from 10 to 20 vol. % of the membrane material volume.

CONCLUSIONS

The process of shock interaction of a clot of high-velocity separate strikers with the metal barriers was analyzed and the expenditure of energy for superdeep penetration was estimated. On this basis, the following conclusions were drawn and a new concept of the physics of superdeep penetration phenomenon is offered.

A new concept of the physics of superdeep penetration phenomenon is based on the successive realization of a set of well-known physical effects, stage by stage leading to creation of a closed energetic system and to the realization of the cavitation process (collapse of micro-cavities in dense plasma) with the additional energy emission.

On the basis of complex research the opportunity of effective manufacture of composite materials by clots of discrete powder particles is shown. Iron, aluminum and alloys as the matrix materials are used.

Regime of superdeep penetration allows to obtain the new composite material de from a massive solid body by modified nano- and microelements. Presence of nano and microelements in a skeleton of a composite material are the reason of significant changes of physical and chemical properties. The material on these levels of structure has physical and chemical properties which considerably differ from properties of this material on mezo- and macrolevels. The directed regulation of physical and chemical properties of massive composite materials is reached.

Manufacturing of a tool composite material on the basis of a high-alloy tool steel1 allowed to rise of a level of properties of matrix steel by tens and hundreds percent and to produce the ecological and competitive metal-cutting and mining tool with, hard alloy. Using the SDP process makes it possible to obtain the reinforcing and hardening depths in iron exceeding 200 mm

Manufacturing of a composite material on the basis of technical aluminum provided anisotropy of electrochemical and electric properties up to 2 times and regulation of electron work function in the given zones of a product.

The SDP method opens the great perspectives for creation advanced nanocomposites based on non polar elastomers and polar nanofillers. This method is more effective than mixing of components of rubber mixtures in melt. The optimization of explosion conditions while using SDP method will provide of further improvement of nanocomposite properties. This new method of mixing nanofillers with polymer matrixes allows to produce smart functional materials based on polymers of different chemical composition and polarity.

The SDP method opens the great perspectives for production of tracking membranes based on polymer matrix. This method is cheaper, more simple and ecological friendly as compared to nuclear industrial methods . It’s use excludes the application of high toxic solvents. Simultaneously it permits to create of polymer membrane with micro and -nanosize open pores and besides provides the absence of oxidation products, which can migrate into filtrate.

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