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MECHANISM OF THICK METAL WALLS PENETRATION BY HIGH-SPEED MICROPARTICLES

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ПРО МЕХАНІЗМ ПРОБИВАННЯ МЕТАЛЕВИХ ТОВСТИХ СТІНОК ВИСОКОШВИДКІСНИМИ МІКРОЧАСТИНКАМИ

Purpose. Analysis and estimation of physical parameters which create conditions for microparticles penetration into metal microstructure to abnormally big depth.

Methodology. Quantum mechanical three-site model has been used for studying the regularities of electron motion in the field of two Coulomb centres and numerical solution for the problem of the effect of external electrical charge on stability of the chemical bond. Solution was found for the equation of heat conductivity for estimating the temperature of microparticles heating under compression and acceleration by explosively driven accelerator. Stokes's law was used for estimating viscosity of hypothetical medium which can be penetrated by microparticle at a great speed and to a great depth. The research was done with the help of X-ray microanalysis, X-ray crystallography, micrographic investigation, mass-spectrometry and electronic spectroscopy.

Findings. Solution of the quantum mechanical model testifies that electric charges serve as catalysts responsible for the significant reduction of the energy barrier of chemical reactions. To ensure super deep penetration, it is necessary to achieve acceleration of a great number of microparticles in a special explosively driven accelerator. Heating, intensive stirring and friction result in electrification of the surface of the particles, which is known as triboelectric effect. The hypothesis about physical and chemical mechanism of particles penetration into metals resulting from high-speed impact has been put forward.

Originality. The research has established relationship between the sizes of microparticles accelerated by explosion and the density of electric charges on their surfaces, as well as the depth of their penetration into the metal barrier. By experimental research, it was proven that maximum depth of microparticles penetration is directly proportional to the maximum density of surface charges for the particles of the 50...80 μm size. It is assumed that particles penetration into metals to greater depths is conditioned by the reduction of the barrier material viscosity in the zone of particle-barrier contact due to quantum mechanical effects in the solid-state plasma.

Practical value. The value of the work includes creating a new generation of metal composites as well as new prospective technologies of reactive materials utilization.

Keywords: *microparticles, explosion, high-speed impact, crater, plasma, viscosity, penetration*

Introduction. Highly-energetic processing of materials together with other kinds of physical impacts is one of state-of-the-art scientific and technological researches aimed at creating innovative technologies and materials. Application of two or more simultaneous physical impacts can yield new fundamental knowledge and solutions to such cutting-edge tasks as creating innovative energy-saving technologies, developing new energy sources and materials with new physical and chemical properties.

The main idea of complex processing lies in physical impacts on preliminarily destabilized microstructure of materials. Such complex processing may produce the following results: synthesizing monocrystals of metastable diamond under impact compression of preliminarily destabilized graphite-metal system, transformation of graphite and zirconium into amorphous state under simultaneous impact of high pressure and exposure to radiation of heavy ions flows [1], abnormally deep penetration of microparticles into metals resulting in formation of chemical elements [2]. Standard experimental and processing methods were not reported to have yielded any of such results.

Solid bodies are distinguished by high degree of physical and chemical activity and increased scale of transformations in their microstructure even under weak energy impacts, but it is only the case when the initial state of the solid body is characterized by a great reserve of excessive inner energy. In view of this, it is especially interesting to study the effects discovered in metals after superdeep penetration of particles (S.Usherenko).

Analysis of recent research. Research into the collision of microparticles' flow and the metal barrier and into processes of their penetration to abnormally big depths is aimed at solving fundamental problems of substance stability and phase transformations. In the process of microparticles' penetration, we observed formation of nanomodified composite metal material which is in fact a massive metal matrix saturated with parallel-oriented insertions of the new phase with the density (300...1500) × 10^6 m^{-2} as shown in Fig. 1. Fig. 2 presents the remains of microparticles in the barrier microstructure. Such composite material with unique combination of physical, chemical and mechanical characteristics was used for manufacturing and testing the pilot batch of cutters used for destroying coal, potash salt, cutting metals etc. (S. Usherenko).

Microparticles with the impact speed of 500...3000 m/s get into contact with a massive metal barrier and penetrate to more than 10^{-1} m deep. To compare: during detonation sputtering (approximately with the same velocities 300...1000 m/s), there appears a surface deposit [3], and the depth of microparticles' penetration into the barrier does not exceed 6 × 10^{-5} m, according to professor S. I. Buravova . Experiments established that conditions for microparticles' penetration to abnormally big depths arise due to a number of processes brought about by physical peculiarities of forming a bunch of microparticles in cumulative explosively driven accelerator. As a result of microparticles' hitting the surface of a massive metal barrier, there appear the so-called craters reaching 2 × 10^{-1} m deep. The traces of the penetrated particle have the form of a cavity with the length exceeding width by 10^5 times. During particles' penetration at the average impact pressure 0,2...1,0 GPa, the grain size of the metal barrier did not differ from the grain size of the same metal under shock-wave treatment at 50 GPa pressure. For both treatment methods, dislocation densities are nearly the same, which testifies to the same values of additional energy stored by microstructure of the given metal. Thus shock compression and additional high-volume alloying by elements of introduced microparticles dramatically changed the structure and chemical composition of initial metals which acquired principally new physical and chemical properties not to be achieved by any other methods of metal processing.

At present, researches into the studied problem are being conducted not only by the institutions represent-

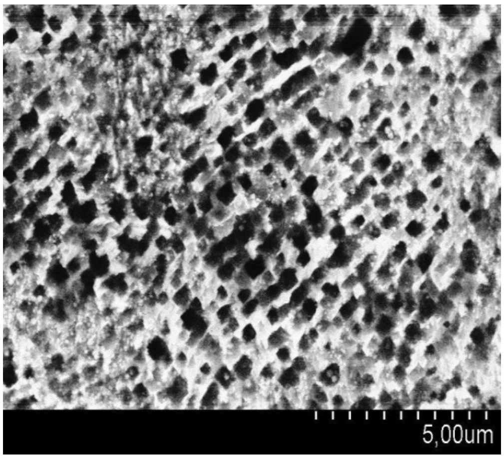

Fig. 1. Transverse section of the copper barrier near the surface. Observable craters of cubic beta-shape have been formed after the impact of silicon carbide particles

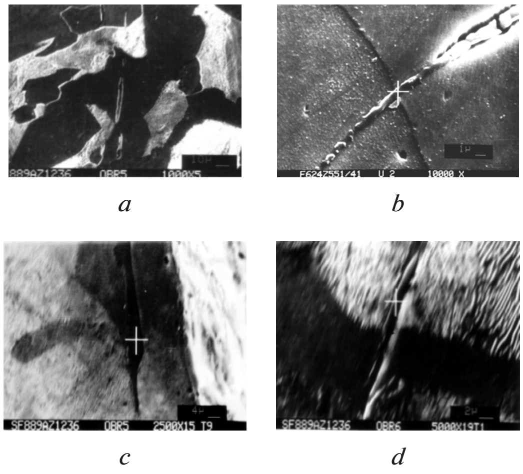
a
b
c
d

Fig. 2. Barrier microstructure of steel 45 with remains of penetrated microparticles:
a — ×1000; b — ×10 000; c — ×2500; d — ×5000

ed by the authors of this paper, but also by the Research Institute of Pulse Processes with Pilot Plant – SRI PIs OP (Belarus) and Samara University (Russia) [4].

In the field of fundamental sciences (synthesis of new materials), analogous results were obtained by the specialists of Scientific-research Electrodynamics Laboratory "Proton–21" (Ukraine) [5], Purdue University West Lafayette (USA); in the field of creating composite materials, new results were received by the team of National Research Center "Kurchatov Institute" (Russia), Polymate Ltd. – International Nanotechnology Research Center, Migdal Ha-Emek (Israel) and Kazan National Research Technological University (Russia) [6] etc. The above researches were related to small depths of particles' penetration (Samara University) and small amounts of the processed material ("Proton–21", "Kurchatov Institute"). Fundamentals for studying the mechanism of solid particles' penetration into the solid body are presented in publications of scholars from SRI PIs OP, Belarus National Technical University, State Scientific Institution "The Institute of Metal Technology" (Belarus) and State Higher Educational Institution "National Mining University" (Ukraine).

Purpose of the research. Study of super deep penetration (SDP) of solid particles into metals is based upon a big amount of statistical experimental data. Various physical and mathematical models of this process developed by G. G. Chornyi, S. S. Grigoryan, A. E. Rakhimov, G. P. Cherepanov, S. K. Andilevko, N. N. Sirota, A. A. Sivkov, L. G. Korshunov and others – do not provide credible arguments in favour of any SDP mechanism.

The present research aims at analysis and assessment of the physical parameters which create conditions for microparticles' penetration into metal microstructure to abnormally big depths. We consider the depth of penetration abnormal if it constitutes $10^2...10^3$ of the initial diameter of a microparticle, while according to classical assumptions the penetration depth should not exceed 10^1. The simplest estimation allows to conclude that the energy consumed by microparticles acceleration to the average velocity 1000 m/s is by several orders of magnitude smaller than the energy required for penetration of one percent of a microparticle to the depth of 10^3 diameters. Research into SDP phenomenon involves studying the previously unknown physical mechanism of a microparticle travel in the solid medium at distances that are sufficiently big in reference to the specific size of this particle.

Materials and equipment. Metal barriers were manufactured from copper, brass, aluminium, silicon-aluminium alloy AK-12, iron, structural steel P6M5. Blasting charges were made of ammonite № 6ЖВ. We also used powders containing microparticles (not bigger than 125 μm) of silicon carbide, lead, copper, and aluminium. The data was received from X-ray microanalysis (DS340 TESLA; Superprobe 733, JEOL), electronic spectroscopy (JAMP-10S, JEOL), mass spectrometry (MI-1201IG), secondary ion mass spectrometry (IMS-4f), X-ray crystallography, and transmission electron microscopy (JEOL JEM-2100). Surface charge density was measured by noncontact induction. Experimental data were processed on the basis of the theory of random errors. For the purpose of the research, we applied a quantum-mechanical model describing dynamics of chemical bond in the field of Coulomb centre (V. Sobolev et al.) and the technique for detecting ionizing radiation during microparticles' penetration into the metal barrier (V. Ovchinnikov et al.).

Summary of the research. Microparticle travel in the solid medium at great distances cannot be presented in the form of conventional hydrodynamic models. The almost absent resistance to solid microparticles' penetration can be related to abnormally low viscosity of the barrier metal. We assume that viscosity changes only within the zone limited by the contact surfaces of the barrier and microparticle. Hence it appears probable that the mechanism of plasma formation may be the reason for stepwise change of viscosity. Such inference is substantiated by the results of experimental research analysis which prove the feasibility of plasma hypothesis:

1. SPD is observed only in the case of acceleration of a great number of particles and does not take place if only one particle hits the barrier.

2. SDP is always accompanied by a strong electromagnetic radiation emitted by the metal barrier which can be explained by the movement of electric charges of high density in microstructure.

3. SDP is characteristic of microparticles with initial size not more than ~100 μm. The probability of SDP sharply drops if microparticle size exceeds a certain range (scale factor). The critical size for penetrating particles is $10^{-5}\text{m} > d_K > 2 \times 10^{-4}$ m. If the barrier is hit by the flow of particles of $10^{-5}\text{m} > d_K$ size, SDP is not observed.

4. SDP does not take place if the speed of microparticles' hitting the barrier exceeds a certain velocity range (0,5...3,0 km/s).

5. As microparticles penetrate the barrier, new phases are being crystallized in the resulting channels from the elements of the barrier, from microparticles and new chemical elements which were absent in the original materials.

Table (V. Sobolev, S. Usherenko) presents the chemical composition of the iron barrier microstructure in the zones adjacent to the channels formed by penetrating microparticles (analogous results have been obtained for copper aluminium and other metals). Element and isotope compositions have been investigated by X-ray microanalysis, laser mass spectrometry and other tools. Experiments showed that the pair of materials forming the barrier and microparticle interacting in the course of SDP determines what new (in respect to the initial ones) isotopes of chemical elements will be formed. Thus, is we used Pb + Fe and Fe + Fe, the resulting element was mostly manganese (up to 59 %). It was observed that the sulphur content has been always smaller than and proportional to man-

Table

Chemical elements content in the iron barrier after lead microparticles' penetration

Analyzed sample or a fragment of its microstructure	Chemical elements, % mass						
	Cr	Fe	Al	Mn	S	Cu	Pb
Initial composition of microparticles	–	–	–	–	–	–	99.91
Initial composition of the barrier	0.004	99.58	–	–	0.007	–	–
Analysis at the depth of 15 mm (Fig. 2, *a*)	–	52.99	0.04	28.83	18.14	0.900	–
Analysis at the depth of 32 mm	–	28.61	13.99	39.17	–	0.55	17.68
Analysis at the depth of 47 mm	0.18	43.83	–	30.39	25.01	0.28	–
Analysis at the depth of 72 mm (Fig. 2, *b*)	–	41.64	0.22	45.74	–	0.12	12.27
Analysis at the depth of 116 mm (Fig. 2, *c*)	–	43.32	0.03	40.00	–	0.54	16.11
Analysis at the depth of 173 mm (Fig. 2, *d*)	–	46.50	0.14	36.22	–	0.43	16.71

ganese content. Stable appearance of new elements' isotopes (Mn, S, Na, Cu, Al, Ne, Rn and others) on a large scale can be caused only by nuclear processes (V. Sobolev, S. Usherenko). The hypothesis about probable nuclear transformations can be proved or disproved only after multiple experiments using maximum number of methods required and possible (for the present specification of experiments) to control intermediate and final results.

The energy consumed by microparticles' acceleration on the one hand, and by breaking chemical bonds between the barrier atoms and new elements' formation – on the other hand, differs by 10^5 times. This estimation could have become a serious reason for pessimism regarding the very possibility of SDP occurrence but for the stability of its effect substantiated by thousands of experiments conducted during the last four decades. The attempts to explain the obtained results using conventional hydrodynamic models usually end in a failure. Thus the task of searching for conspicuous physical processes serving as "supplementary energy sources" stimulating breakage of bonds in the barrier metal, especially – formation of initially absent elements – becomes especially topical.

Experiments proved that microparticles' penetration to great depths is stable if the acceleration velocity (kinetic energy) and microparticles' sizes are of definite boundary values. Another specificity is related to the conditions of forming a bunch of microparticles in the cumulative accelerator where they are subjected to compression, mixing, intensive friction and heating. Microparticles' acceleration in the bunch ensures continuous intensive friction of their surfaces. Maximum time required for microparticles' bunch formation in the cumulative accelerator does not exceed 10 μs. The temperature of iron microparticles' (dia 60 and 120 μm) heating was measured with the help of A. V. Lykov's method. Fig. 3 shows the relationship between microparticles heating and time. Taking into account the obtained regularities and physical properties of microparticles' material, we have selected a design of blasting cumulative accelerator to form a bunch of microparticles in the given time span. All the further descriptions of properties and behaviour of a single microparticle relate to any particle penetrating metal microstructure. Peculiarities of microparticles' compression and acceleration in cumulative accelerator bring about triboelectric reaction. Microparticles' surfaces can be activated not only by reciprocal friction but also by increased temperature and pressure – the surfaces of tossed microparticles acquire electric charges during acceleration in the cumulative accelerator. The density of microparticles' bunch in cumulative accelerator does not differ much from the bulk density.

The average velocity of microparticles' movement is more than three times higher than the speed of sound in the air. High speed and density are the reasons why the known methods of diagnostics cannot be applied to the charged microparticles. Fig. 4 shows the relationship between the distribution of surface charges and microparticles' sizes (surface charges were ac-

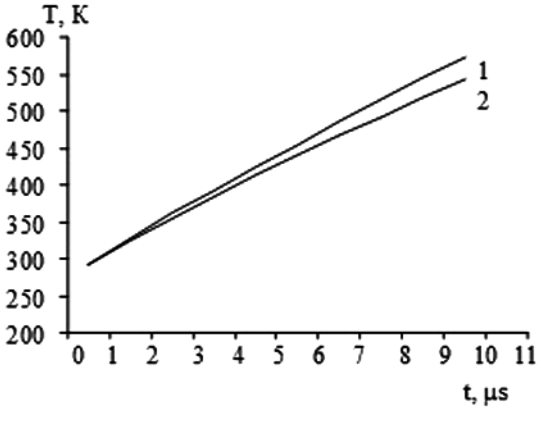

Fig. 3 Relationship between the heating temperature T of the outer layer 10 μm thick consisting of iron microparticles with dia 60 μm (1) and 120 μm (2) and time t

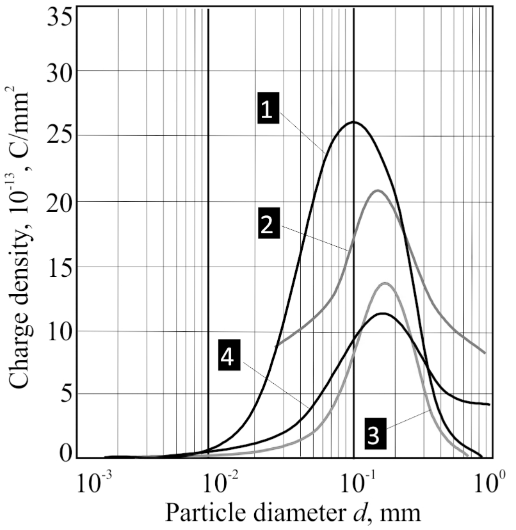

Fig. 4. Relationship between the charge density on the surface of mineral particles and their sizes during blowing:

1 — biotite; 2 — gypsum; 3 — calcite; 4 — microcline

quired by microparticles in "mild" conditions of mechanical interaction).

Hence the first condition for microparticles' penetration to great depths is acquisition of maximum possible density of surface charges before hitting the barrier.

Decrease in stability of chemical bond and its subsequent breakage were studied by numerical modelling (V. Sobolev et al.). Figures 5 and 6 show the specificity of the bond agitation under the influence of negative and positive charges. Research into the system "CO ion-molecule" allows to state that under otherwise equal conditions any molecule's bond is broken at a certain distance from an ion. For example, a strong bond of CO molecule at the temperature 0 K is broken by a point charge at the distance $0{,}16 \times 10^{-9}$ m. As the temperature rises to 600 K (Fig. 3), the distance increases to 2×10^{-9} m. The probability of the bond breakage increases sufficiently as the chemical bond energy decreases, or the temperature rises, ion charge and charge density distribution increase. When approaching charges at a critical distance, chemical bonds are broken with charged particles' formation.

High-speed microparticles hitting the barrier produce shock waves in the front of which, according to W. F. Libby, the barrier substance enters the state of activated complex which is fundamentally different from the initial state. In the moment of each microparticle hitting the surface, there appear localities with newly formed thin plasma layer (P. A. Tissen et al.). After that, 1...3 % of microparticles continue penetrating destabilized mechanically activated microctructure. Microparticles' smooth travel in metal is ensured by the plasma zone of ions and electrons of the barrier chemical elements limited by the surfaces of the barrier and microparticle. The hypothesized pattern of a microparticle penetration into the metal barrier is presented in Fig. 7. Fig. 8 shows the typical state of parti-

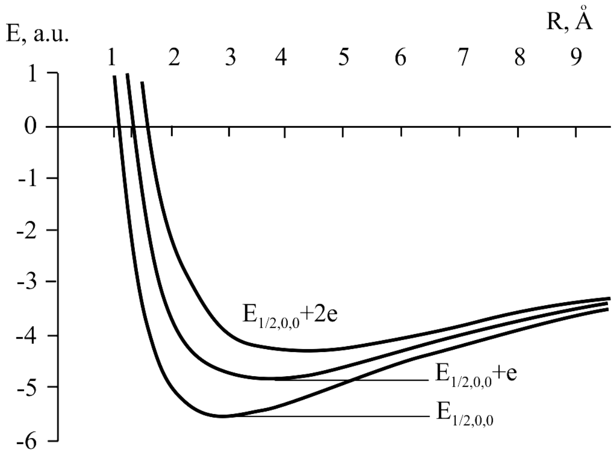

Fig. 5. Alteration of chemical bond energy E related to inter-atom distance R under the impact of one-valent and two-valent negative ion

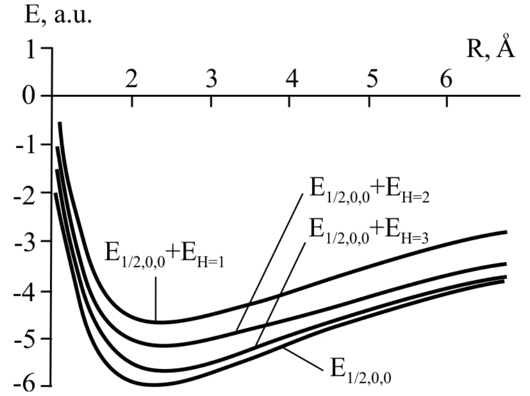

Fig. 6. Alteration of chemical bond energy E related to inter-atom distance R under the impact of one-valent, two-valent and three-valent positive ion

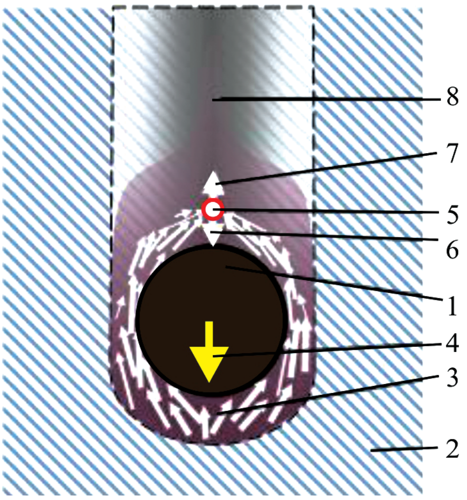

Fig. 7. Formation of the "barrier—penetrating microparticle" system:

1 — microparticle; 2 — metal barrier; 3 — plasma; 4 — direction of microparticle's motion; 5 — "plasma focus"; 6, 7 — plasma jets; 8 — zone of a new phase crystallization

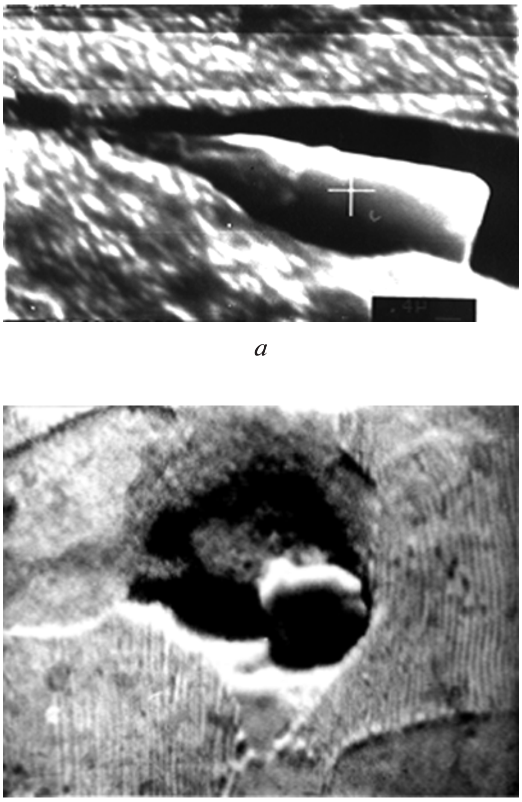

Fig. 8. The shape of some particles that stopped their motion in microstructure of the metal barrier:

a – longitudinal view in the channel; b – cross sectional view

cles at halt. It can be seen that the channel diameter in the area of braking is two times bigger than microparticle diameter.

Let us assume that the initial temperature of the plasma flowing around the microparticle is relatively small – about 1 eV (I. V. Sokolov). The so-called plasma focus is formed behind the microparticle where collisional plasma flows rise plasma temperature to the values of nuclear synthesis reactions – about 10^3 eV. Such temperature can be achieved as a result of redistribution and cumulation of plasma flows' internal energy.

Consequently, the second condition for microparticles' penetration to abnormally big depths is connected to decrease of dynamic viscosity in the localities of microparticles' contact to values approaching 10^{-3}.

Chemical bonds are broken during the period of $10^{-12}...10^{-13}$ s. This time $(0,66...4) \times 10^{-13}$ s is enough for a microparticle moving at a speed of $(0,5...3,0) \times \times 10^3$ m/s to pass through one atom layer 2×10^{-10} m thick. Charged particles (ions, electrons) formed as a result of this passage fill the zone between the surfaces of the barrier and microparticle.The total mass of charged particles entering this zone is directly proportional to the crosswise size of the microparticle penetrating the barrier. New chemical bonds between elements are formed behind the microparticle that is the channel formed by the microparticle passing through the barrier is stopped with new phases.

According to V. Tzariov estimation, the time of charge relaxation in metals is $\sim10^{-15}$ s that is why charge outflow from the zone cannot be compensated by incoming particles during the time of $\sim10^{-13}$ s. If the plasma layer disappears, metal viscosity in the contact zone instantaneously drops to the initial value and the microparticle stops its further motion. For the effect to take place, it is necessary that the time of particles' discharge through metal exceed the time of new charges entering the zone.

Hence, the third condition is about selecting initial sizes of microparticles d_K taking into account the set range 10^{-5} m $> d_K > 2 \times 10^{-4}$ m and the range of velocities of micropartiles' hitting the barrier from 500 to 3000 m/s.

The discharge through the metal barrier is negligible when the barrier microstructure is strongly destabilized, or there appears conductivity of non-metallic type. Microparticles' bunch impact can cause the state of destabilization lasting from 0,2 to 1,2 ms. Dynamic treatment results in different forms of lability: e. g. deformational destabilization including displacement of dislocations and grain boundaries (P. Butiagin). Microstructure disorder brings about formation of strained bonds, new defects (point, linear and planar), which results in electron concentration decrease in conductivity zone.

Studies of magnetic and dynamic effects caused by the motion of ionized high-speed flow of Si_3N_4 microparticles allowed to establish the relationship between the value of magnetic induction and microparticle size (V. Ovchinnikov), Fig. 9. The graph illustrating the relationship between the magnetic induction value and the powder microparticles' sizes indirectly substantiates the particle size influence on the density of charge distribution on the surface and consequently on the probability of plasma emergence. The depth of microparticles' penetration related to their sizes has been many times proved experimentally, Fig. 10.

The character of relationship between the depth of barrier penetration and Si_3N_4 microparticle (Fig. 10) size is typical for other microparticles under study – SiC, Al, Cu etc. Maximum depth of penetration varies depending on the particles' material. One of the main premises of our hypothesis and a mandatory condition of penetrating thick-walled metal barrier is tossing of microparticles with surface charges. By definition [7], charged microparticles of condensed substance are dust plasma characterised by extremely high chemical activity, ability to self-organize and form ordered structures, by fluctuation of particle charges etc. Particles of dust plasma may be charged by the flows of electrons and ions, as well as by way of photo-, thermo-, or secondary emission of electrons from particles' surfaces [7]. If a microparticle captures electrons, the charge value may reach $\sim10^2...10^5$ of elementary charges. Thus average Coulomb energy of particles' interaction greatly exceeds thermal energy. Theoretical

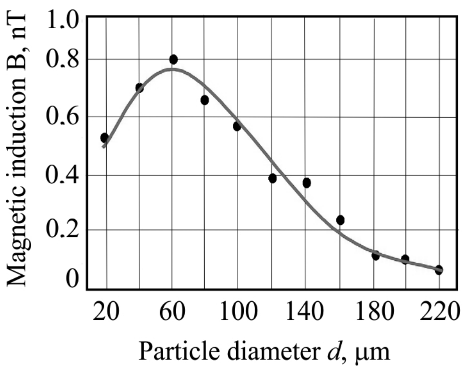

Fig. 9. Alteration of magnetic induction depending on the size of introduced Si_3N_4 particles (according to V. I. Ovchinnikov)

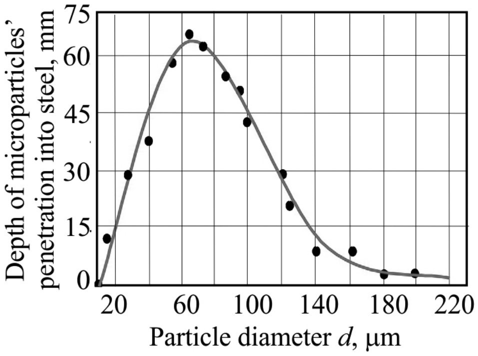

Fig. 10. Relationship between the depth of Si_3N_4 microparticles' penetration and their size

calculations of equilibrium properties of such plasma demonstrate that under certain conditions strong electrostatic particles' interaction and small energy of their thermal motion bring about formation of spatially-ordered structures in particles' location which are analogous to structures in liquids and solids [7]. Microstructure of the section near the barrier surface can testify to spatial orderliness of microparticles in a bunch, Fig. 1.

Stepwise decrease of viscosity is the consequence of quantum mechanical effects. As microparticles hit the barrier, there appears a shock wave propagating at the speed 5100 m/s (for technical iron), while phonons interact with free metal electrons and with electrons forming chemical bonds (P. Platzman, P. Wolf). The time of sound wave for microparticles of 20...120 µm dia is (2...12) × 10^{-8} s. Sound waves, advancing microparticles, interact with chemical bonds and free electrons (interaction between electrons and phonons). As a result, bound electrons and free electrons get agitated, that is go through upward transition. This means that energy of bond decreases by ΔE (Fig. 5). Electron transitions are possible from level 1/2 to 3/2, from 3/2 to 5/2 etc. These transitions are accompanied by emission of energy quanta. Electron transition (agitation) lasts for $t_{agit} = 10^{-12}$—10^{-13} s. Relaxation of valent electrons during downward transition lasts for $t_{relax} = 10^{-4}$–10^{-5} s and relaxation of free electrons takes $t_{frel} = 10^{-12}$—10^{-13} s (A. A. Vedenov). That is we can state that free electrons act as donors of energy which goes onto chemical bonds and loosens them. Bonds receive additional agitation and get opened, while the particle start moving in the the plasma of solid body. Comparing t and t_{relax}, we can assert that not all chemical bonds go through relaxation during the time of microparticle motion. Using Stokes equation $ma = 6\pi\eta rv$, let us estimate the value of viscosity for a hypothetical medium so that a microparticle of 60 µm dia will penetrate to the depth 0,1 m at the average speed 1000 m/s, Figures 11 and 12. The obtained range of viscosity values for the hypothetical medium, which can in principle ensure microparticles' penetration to abnormally big depths, includes known values of water viscosity and low temperature plasma. The research results confirm the hypothesis of plasma formation during misroparticles hitting the metal barrier surface that is SDP mechanism which is based on formation of Coulomb

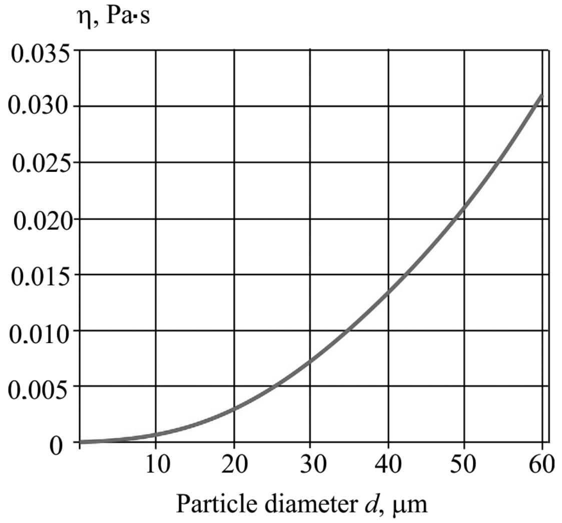

Fig. 11. Relationship between viscosity η and microparticles' size R (v = 1000 m/s) during their penetration to the depth 0,1 m

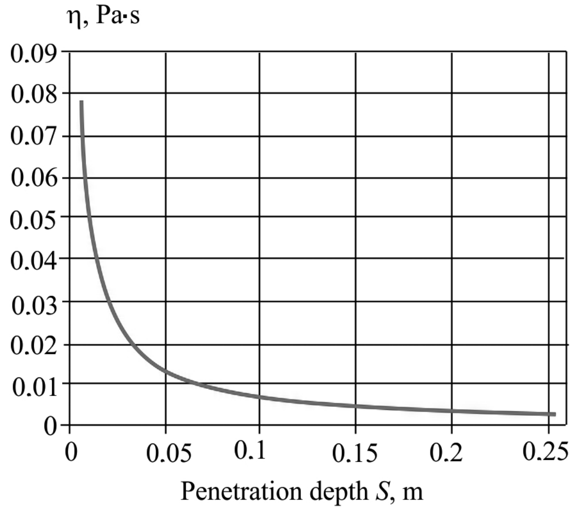

Fig. 12. Relationship between viscosity η and microparticles' penetration depth S. For the particles 60 µm *and their velocity v = 1000 m/s*

potential on microparticles' surfaces. It was experimentally found that microparticle travel in the barrier is accompanied by electromagnetic radiation registered as a light exposure on the X-ray film [8], which can be interpreted as movement of the system "penetrating microparticle – plasma layer" in metal microstructure.

Conclusions. The authors have developed a new physical and chemical model of microparticles' penetration to great depths in metal barriers. The main idea of the model is formation of continuously regenerating plasma between the contact surfaces of penetrating microparticle and the barrier.

Behaviour of conglomeration of charged microparticles is distinguished by the spatial orderliness whose character is analogous to the behaviour of well-studied dust plasma. However, most often we do not observe any signs of ordered disposition of craters in the target microstructure. This phenomenon is related to the value and sign of the charge, microparticle size and relationship between the force of electrostatic interaction of particles and energy of their thermal movement.

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Мета. Аналіз і оцінка фізичних параметрів, що в комплексі створюють умови для проникнення мікрочастинок до мікроструктури металу на аномально великі глибини.

Методика. Використана квантово-механічна трицентрова модель для дослідження закономірностей руху електрона в полі двох кулонівських центрів і чисельного рішення задачі щодо впливу зовнішнього електричного заряду на стійкість хімічного зв'язку. Вирішувалося рівняння теплопровідності для оцінки температури нагрівання мікрочастинок при їх стисненні та розгоні вибуховим прискорювачем. Використовувалося рівняння Стокса для оцінки значення в'язкості гіпотетичного середовища, до якого на велику глибину й на високій швидкості здатна проникнути мікрочастинка. Проведене аналітичні дослідження із застосуванням мікрорентгеноспектрального, рентгеноструктурного й мікроструктурного аналізів; мас-спектрометрії, електронної спектроскопії та ін.

Результати. Рішення квантово-механічної моделі показує, що електричні заряди є каталізаторами, які істотно знижують енергетичний бар'єр хімічних реакцій. Для реалізації надглибокого проникнення необхідно виконати обов'язкову умову, що полягає в розгоні великої кількості мікрочастинок у спеціальному вибуховому прискорювачі. У результаті нагрівання, інтенсивного перемішування та тертя відбувається електризація поверхні мікрочастинок – проявляється відомий трибоелектричний ефект. Висунута гіпотеза про фізико-хімічний механізм проникнення мікрочастинок у метали в результаті високошвидкісного удару.

Наукова новизна. Встановлено взаємозв'язок між розміром мікрочастинок, що розганяються вибухом, щільністю електричних зарядів на їх поверхні та глибиною проникнення мікрочастинки в металеву перешкоду. Експериментально встановлено, що максимальна глибина проникнення мікрочастинок прямо пропорційна найбільшій щільності поверхневих зарядів, характерних для частинок розміром 50...80 мкм. Передбачається, що проникання мікрочастинок до металів на великі глибини обумовлене зменшенням в’язкості матеріалу перешкоди в зоні контакту мікрочастинки з перешкодою за рахунок прояву квантово-механічних ефектів у плазмі твердого тіла.

Практична значимість. Створення металевих композитів нового покоління. Перспективи пов’язані з новою технологією утилізації радіоактивних матеріалів.

Ключові слова: *мікрочастинки, вибух, високошвидкісний удар, кратер, плазма, в’язкість, проникання*

Цель. Анализ и оценка физических параметров, которые в комплексе создают условия для проникания микрочастиц в микроструктуру металла на аномально большие глубины.

Методика. Использована квантово-механическая трехцентровая модель для исследования закономерностей движения электрона в поле двух кулоновских центров и численного решения задачи о влиянии внешнего электрического заряда на устойчивость химической связи. Решалось уравнение теплопроводности для оценки температуры нагревания микрочастиц при их сжатии и разгоне взрывным ускорителем. Использовалось уравнение Стокса для оценки значения вязкости гипотетической среды, в которую на большую глубину и на высокой скорости способна проникнуть микрочастица. Проведены аналитические исследования с применением микрорентгеноспектрального, рентгеноструктурного и микроструктурного анализов; масс-спектрометрии, электронной спектроскопии и др.

Результаты. Решение квантово-механической модели показывает, что электрические заряды являются катализаторами, существенно снижающими энергетический барьер химических реакций. Для реализации сверхглубокого проникания необходимо выполнить обязательное условие, которое заключается в разгоне большого количества микрочастиц в специальном взрывном ускорители. В результате нагревания, интенсивного перемешивания и трения происходит электризация поверхности микрочастиц – проявляется известный трибоэлектрический эффект. Выдвинута гипотеза о физико-химическом механизме проникания микрочастиц в металлы в результате высокоскоростного удара.

Научная новизна. Установлена взаимосвязь между размером микрочастиц, разгоняемых взрывом, плотностью электрических зарядов на их поверхности и глубиной проникания микрочастицы в металлическую преграду. Экспериментально установлено, что максимальная глубина проникания микрочастиц прямо пропорциональна наибольшей плотности поверхностных зарядов, характерных для частиц размером 50...80 мкм. Предполагается, что проникание микрочастиц в металлы на большие глубины обусловлено уменьшением вязкости материала преграды в зоне контакта микрочастицы с преградой за счет проявления квантово-механических эффектов в плазме твердого тела.

Практическая значимость. Создание металлических композитов нового поколения. Перспективы связаны с новой технологией утилизации радиоактивных материалов.

Ключевые слова: *микрочастицы, взрыв, высокоскоростной удар, кратер, плазма, вязкость, проникание*

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