COMPOSITE MATERIAL ON THE BASIS OF NANO ALUMINIUM

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Structural changes on macro-, micro - and nano levels, typical for superdeep penetration (SDP), in aluminium and alloy Al-12% Si are detected. Zones of "influence" (8-10 %) in which the matrix is stitched by filaments from the doped material, are determined. Chemical and electrochemical properties of these zones differ from properties of a base material and are regulated at SDP. On this basis the composite material is created. On an example of technical aluminium the massive composite material is received, reinforced by fiber zones with reconstructed structure and anisotropy of electroconductivity in mutually perpendicular directions in 2 times .

INTRODUCTION. Aluminium - one of the most widespread and cheap metals. Without it is difficult to imagine a modern life. Aluminium is well workable by forging, punching, rolling, drawing, pressing. At duraluminium after hardening - sharp cooling from 500°C up to a room temperature and aging at this temperature within 4...5 day - multiply increase durability and hardness. The picture became obvious, due to the electronic microscopes, allowing to scan thin metal films. During ageing Cu gathers in sections in the form of a disk with width in 1...3 atomic layers and diameter nearby 90 Å, forming zones Ginie - Preston. These zones have the distorted crystal structure of a hard solution; the area of a solid solution adjoining to a zone is also distorted. Changes and distortions of a crystal lattice at formation of zones Ginie - Preston (zonal ageing) are the reason of rise of duraluminium durability at natural ageing. The same changes increase electric resistance of an alloy. By rise in temperature of ageing instead of the zones having structure, close to structure of aluminium, the smallest particles of metastable phases with own crystal lattice arise (phase ageing). Such change of structure leads to sharp increase of resistance to small plastic deformations.

The combination of the heightened strength and good plasticity, corrosion stability and high-temperature strength, substantial growth of electric resistance and reduction of temperature coefficient do using of solid solutions as a basis of constructional aluminium alloys profitable. However heightening of durability of aluminium alloys by a doping is restricted to inability of aluminium to form solid solutions in a wide interval of concentrations. Infusion even small amounts of doping elements leads to formation of primary intermetallic bonds in the form of rough inclusions. Result is heterogeneity (dissimilarity) of structure, reduction of strength and plasticity, lowering of corrosion stability, deterioration of a surface of semi finished items.

Qualitatively new alloys appear then only when detect new reinforcing phases [1]. Phases are chemical bonds - intermetallic compounds, forming in an alloy and influencing on its properties. Different phases differently increase durability, corrosion stability and other adjectives of an alloy. However in aluminium it is discovered very few phases – less than ten. Assume, that new phases can be created under condition of *solubility of proper elements in aluminium* only.

Aluminium alloys play a huge role in the space industry [1]. Many constructive elements of space devices are made of alloys of aluminium, including system of aluminium-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 aluminium 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. For example, using of effects of superdeep penetration (SDP) allows to provide an additional doping in volume of aluminium and its alloys and intensive dynamic loads simultaneously [2]. Study of structural transformations in aluminium details is actual at impulse impact of dust particles. 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 aluminium materials can essentially affect on survivability of aircrafts.

The purpose of the present work is research of changes of structure and properties of aluminium and its alloys under the influence in condition of SDP on these materials.

1. CHANGES IN STRUCTURES OF ALUMINIUM AND ITS ALLOYS IN THE CONDITION OF SUPERDEEP PENETRAHION.

The basic problem in study of changes of aluminium structure and its alloys after SDP is working-off techniques of preparation of samples from the activated material. Because of high plasticity of aluminium there is a puttying of samples surface. Definition of an etching condition is executed subject to specific activation of a material. The correct technique for samples preparation allows to reveal small structural elements (figure 1) using an optical microscope.

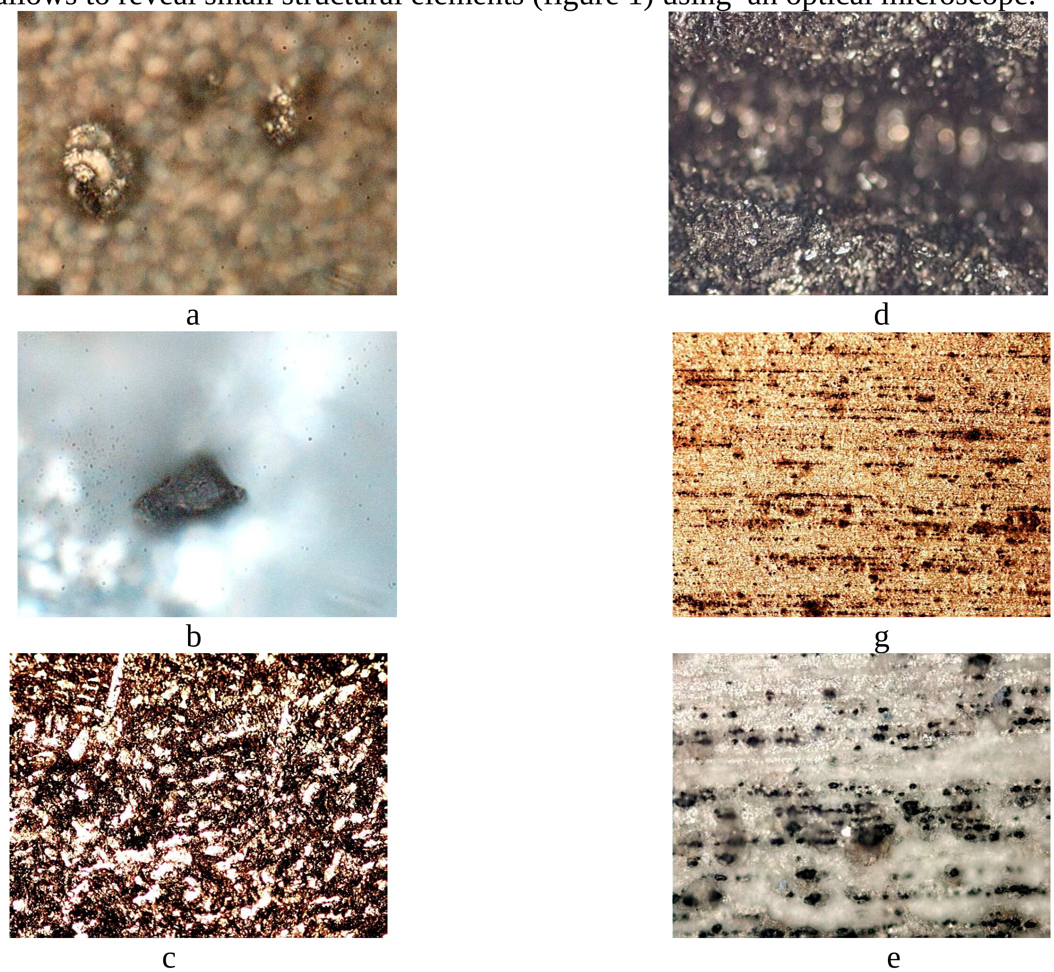
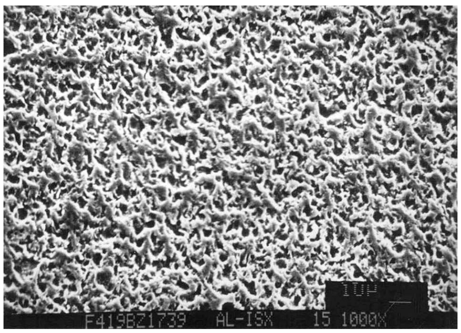


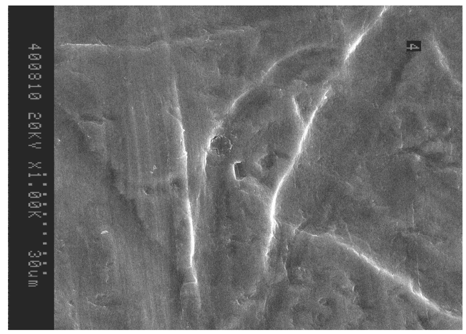
Figure 1. Structures of the aluminium processed in SDP mode: **a** - SiC→Al in a cross-section, ×3000; **b** - Pb→Al in a cross-section, ×3000; **c** - basic alloy Al-12%Si, ×100; **d** - SiC → alloy Al-12%Si in longitudinal section, ×100; **g** - Pb → alloy Al-12%Si in longitudinal section, ×100; **e** - Pb → alloy Al-12%Si in longitudinal section, ×400.

By insertion of SiC powder in Al matrix there is a strong activation of zones of "influence" (figure 1,a). At electrochemical treatment these zones dissolve more quickly, than matrix Al (figure 1). We see these zones, as cavities in a surface of a sample. The zones saturated with Pb have reduced etching (figure 1,g). These zones jut out above a surface of Al sample. In alloy Al-12%Si zones of "influence" include the whole system of tracers (channel microzones). The matrix material is stitched by tracers. The part of zones of "influence" achieves 8-10 volumetric %. The different powders entered into aluminium and its alloys at SDP allow to change etching of received material. It is possible to increase etching the activated zones or to lower this etching due to infusion of inhibitors. Relative to matrix aluminium etching of zones of "influence" it is possible to change in many times.

Using a scanning electronic microscope for researches does not diminish value of process of etching from a surface of a sample. In figure 2 features of structure of aluminium materials are shown.



a



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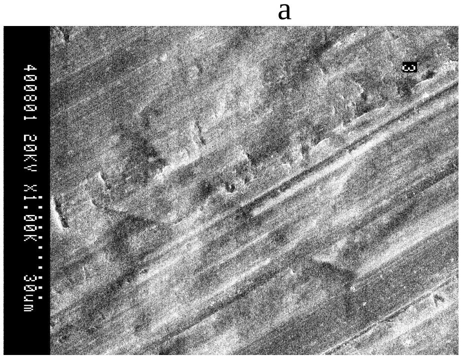

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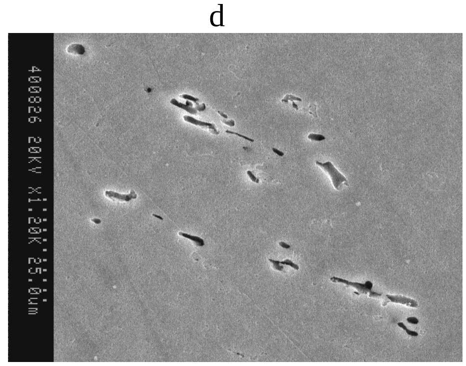

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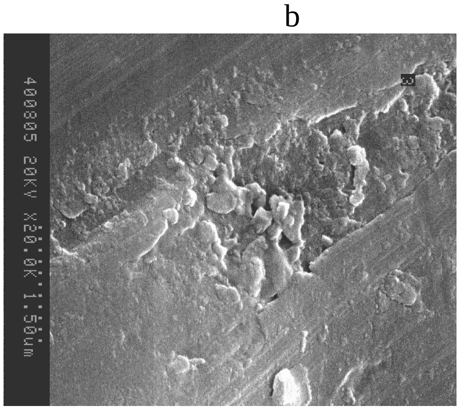

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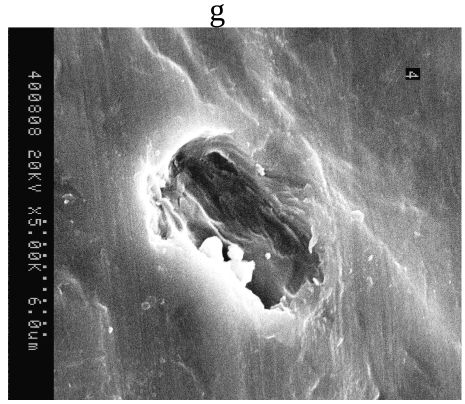

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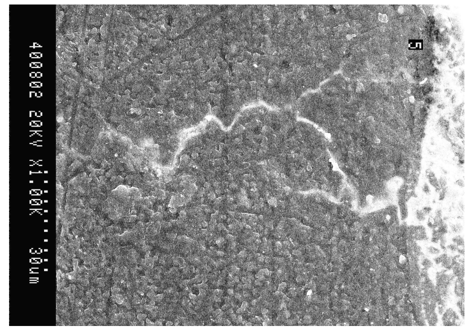
Figure 2. Structures of aluminium samples after processing in SDP mode: **a** - basic Al after etching; **b** -Al (SDP) without etching, ×1000; **c** - Al (SDP) without etching, ×20000; **d** -Al (SDP) with etching, ×1000; **g** -tracks in Al (SDP) with etching, ×1200; **e** -defective (channel) zone in Al (SDP) with etching, ×5000.

Studying samples of aluminium after SDP without etching has shown (figure 2b), that it is impossible to observe changes in structure. Therefore long time scientists considered, that the phenomenon of superdeep penetration in aluminium is not realized. Even at significant increases (figure 2c, ×20000) on a surface of a sample it is not possible to reveal specific structural defects. Using of weak etching has allowed to show single (figure 2,d) and collective (figure 2,g) structural elements. It is obvious, that study of these defects with small magnification (×1000) does not give the information on their specific character. Study of defects with magnification ×5000 (figure 2,e) has allowed to detect strongly distorted structure of a new microzone.

The technique which facilitating detection of defective (channel) zones in aluminium, there is using powder materials at SDP which are not interacting with aluminium matrix. In figure 3 the longitudinal elements of structure received at SDP are shown.

a



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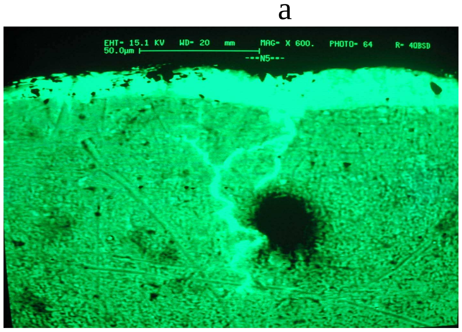

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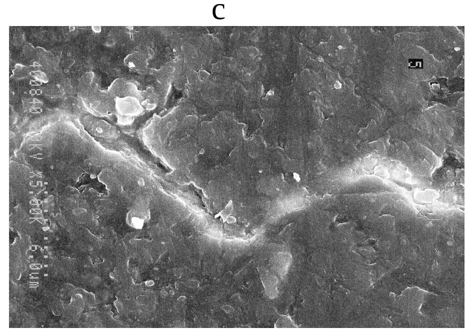


d

Figure 3. Channel longitudinal elements of the structure, created in aluminium at Pb infusion: **a** - 1 defective zone (luminescence);**b** - 2 defective zone (luminescence); **c** - 2 defective zone, × 1000; **d-** a track, ×5000.

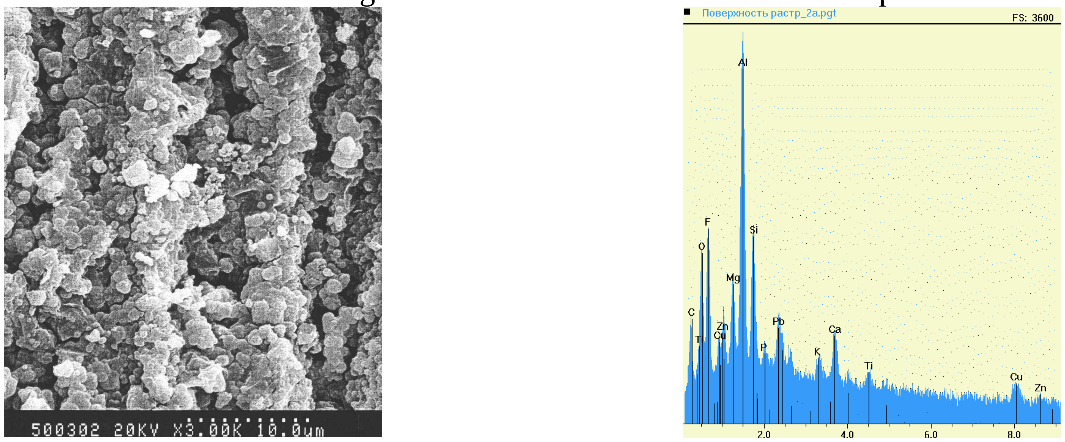
Using of lead (Pb) allows to inhibit a zone of interaction in aluminium and to show this zone on a surface of metallographic section. Besides introduction Pb as a heavy element, allows to reveal a new element of structure with electronic methods.

2. FEATURES OF NEW ELEMENTS OF STRUCTURE.

The modern equipment allows to define special zones in volume of an aluminium matrix. In these zones there was an interaction of entered substance and a metal matrix. For this purpose it is possible effectively use the microanalysis. Alloy Al-12%Si, and also technically pure aluminium for a samples casting was prepared in the inductive crucible furnace with graphite crucible so far as inductive heat provide uniform hashing and eliminates liquation of doping elements in volume of melt.

As subject of research we use alloy Al-12%Si. This material after insertion of particles of lead Pb has been subjected to electrochemical treatment (figure 1,d,g,e). Results of scanning and microanalysis are presented in figure 4.

However, such shape of information demonstration is not convenient for the numerical analysis. Therefore, as a rule, for this purpose use the concentration results gathered in the tables. The received information about changes in structure of a zone of influence is presented in table 1



aa бb

Figure 4. Structure of alloy Al-12%Si after superdeep penetration of lead (Pb) and electrochemical treating: a - structure of zones of influence; b - the raster analysis of an aluminium matrix (200×300 micron).

Table 1. Concentration of chemical elements in a zone of influence (mass %).

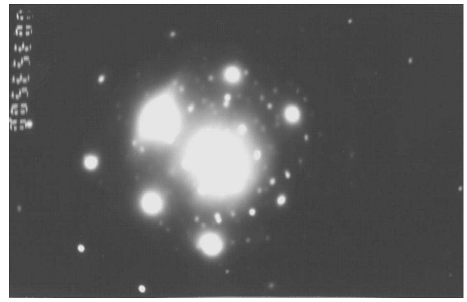
№ п/п	Al	Si	Ca	K	Pb	Mg	Fe	Mn	Ti	Zn
1	61,41	12,44	7,50	3,64	10,54	2,24	0,88	0,50	0,80	0,00
2	94,64	1,41	0,05	0,06	1,19	2,17	0,10	0,35	0.01	0,00
3	69,87	13,43	4,54	3,22	5,49	2,08	0,24	0,00	1,11	0,00
4	79,49	0,33	0,24	0,07	0,60	0,00	7,65	0,05	1,84	0,00
5	75,72	2,26	0,27	0,00	1,66	0,00	9,82	7,48	0.06	2,71
6	1,94	14,48	0,49	3,14	2,35	0,25	76,86	0,25	0,06	0,15
7	51,30	3,92	0,63	0,00	5,36	0,00	9,93	4,62	0,14	24,08
8	86,9	12.75	0,00	0,00	0.03	0.01	0.13	0.06	0,00	0.05

The note. №1-averaging on a surface 200x300 micron; №8- initial analysis after casting of workpiece.

In a zone of influence there is a great quantity of doping elements. Doping elements which were absent in basic material are detected. For example, potassium and calcium (K and Ca) have been detected. These elements during manufacture (casting) by the technological reasons are eliminated from basic material. Concentration Ca in various points of a zone varied from 0.05 up to 7.5 mass %. Concentration K varies from 0.00 up to 3.64 mass %. At the given analysis the possible error does not exceed 0.4 mass %. Concentration Pb in a zone of influence in all analyses is from 0.60 to 10.54 mass % that exceeds the background contents in basic alloy (0.03 mass %). In range of points of zone of "influence" concentration Mg varies from 0.00 up to 2.24 mass %. In basic alloy Al-12%Si concentration Mg (the average content) does not exceed 0.01 mass%. Concentration Fe in a zone varies in a wide range - 0.1 – 76.86 mass % and, as a rule, exceeds background value in basic alloy (0.13 mass %). Change Mn concentration in a zone of "influence" is less appreciable. Mn has changes of concentration 0.00 – 7.48 mass%, and background concentration is 0.06 mass %. The titan was absent in basic alloy. Concentration Ti in a zone of influence fluctuates from 0.01 up to 1.84 mass %. Zinc was in basic alloy as an impurity – 0.05 mass %. In a zone of influence in 4 points of analysis Zn has not been detected. However, Zn concentration in two points of the analysis has appeared considerably higher than background value – 2.71 – 24.08 mass %, therefore it is impossible to explain results as an instrument error.

The piercing of aluminium matrix with jet particles should lead to strong distortions in a zone of penetration. Results of this research are presented in figure 5.

a



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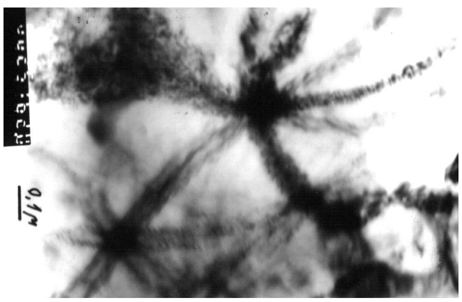

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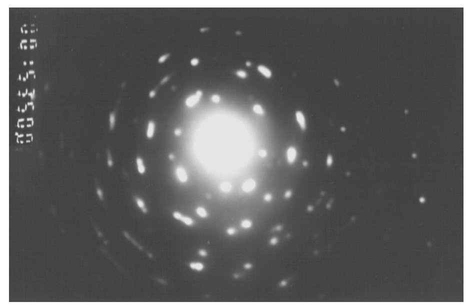

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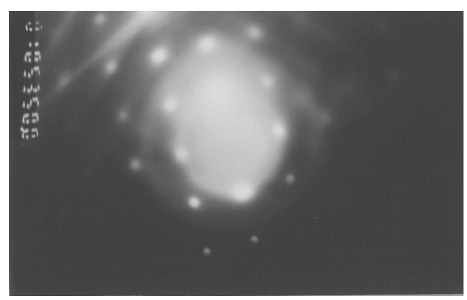

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Figure 5. Thin structure of the aluminium processed at SDP mode: **a** - a zone of high density of tracks, congestions of dislocations, ×60000; **b** – electron-diffraction pattern of area "**a**"; **c** - bending extinction contours which going from edges of channels, created by the penetrated particles, ×60000; **d** - electron-diffraction of a site of structure "**c**"; **g** -structure of the central channel microzone, ×40000; **e**- diffused circular electron-diffraction in the form of halo dispersion from an area «g».

So far as in a mode of the superdeep penetration powder particles with the sizes less than 100 microns were used then the size of a channel zone in cross section should be much less than initial size of striker [2]. Studying of such objects can effectively be carried out by means of transmission electron microscopy. Therefore researches was carried out on electronic microscope EM-125 at an accelerating voltage 125 кV.

Aluminium and alloys on its basis are effectively used as elements of electric machines and electric schemes [3]. In this area the competition to aluminium 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 aluminium, received in mode SDP has been used by processing by a dust clot for change of such physical parameter, as electric resistance. As we know, that 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 (a figure 6). Cutting of samples for researches carried out by means of electrospark 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.

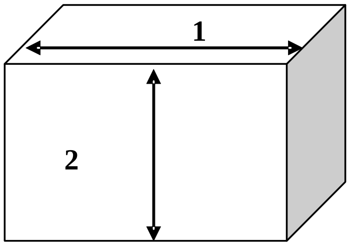

Fig.6. Scheme to take measurement for electric resistance of composite: 1- across, 2 - along

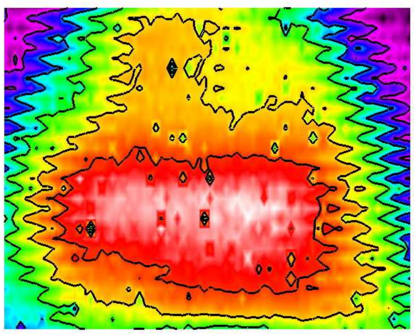

Fig.7. Change of electric resistance into across section of composite

In a direction 1: Size of electric resistance of technical aluminium $_{Al-1}$= 5,27 $\cdot 10^{-6}$ Om·cm, Composite ρ_{K-1}=4,41$\cdot 10^{-6}$ Om·cm. Then ρ_{K1}/ρ_{Al-1}=0,835. Thus it is experimentally established, that ρ_1 after processing has decreased for 16,4 %

In a direction 2: Initial average ρ_{Al-2}=6,42$\cdot 10^{-6}$ Om·cm. The composite 1 ρ_{K2}=9,08$\cdot 10^{-6}$ Om·cm. Then $\rho_{K2.}/\rho_{Al-2.}$=1,41 times or electric resistance after processing has increased for 41,2 %.

Change of electric resistance on section occurs non-uniformly. We shall consider, whether there is an anisotropy of electric resistance in initial technical aluminium. For this purpose rAl$\rho_{Al-2b.}/\rho_{Al-1b.}$=6,42$\cdot 10^{-6}$ Om·cm /5,27$\cdot 10^{-6}$ Om·cm =1,21 Om·cm =1,21 time. Thus, due to moulding the difference of electric resistance in a longitudinal direction concerning cross-section on 21,74 % is provided. Electric resistance in cross-section direction $\rho_{K1.}$= 4,41$\cdot 10^{-6}$ Om·cm. Then $\rho_{K2.}$= 9,08$\cdot 10^{-6}$ Om·cm. Anisotropy in a composite material makes ρ_{K1}/ρ_{K2}=2,05 times. Electroconductivity in a cross-section direction in the processed sample is above, than in a longitudinal direction on 105 %.

The received results have allowed to assume, that electric properties of preparation essentially differ among themselves on zones. Therefore testing plates by scanning Calvin's device has been lead. Results of scanning are presented in figure 7. 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 of electroconductivity of the zones designated by different colors in figure 7, makes 4- 5 times.

3. THE ANALYSIS OF THE EXPERIMENTAL RESULTS.

Process of the superdeep penetration occurs as a result of unusual deep penetration of discrete particles. As far as microstrikers move in aluminium and its alloys, practically not meeting resistance that is unusual effect. It was possible to expect unusual changes of structure [4]. Obvious difficulty at research there is the problem of revealing of these structural changes in aluminium and its alloys. Many scientists because of this problem thought, that in aluminium the superdeep penetration is not realized. At intensive etching these materials have visible porosity (figure 2,a). SDP very often leads to an additional intensification of process of etching and creating of a material with 8-10 % of visible porosity. Attempts of studying stitched at SDP samples without use of process of etching were not successful (figure 2,b). Besides for research of new defects in Al and alloy Al-12%Si are required, as a rule, substantial magnification (figure 2,e) of object of research.

Therefore methods for research of these materials have been modified. Variants with use at SDP inhibitory (Pb) and activate (SiC) substances are viewed, and also electrochemical etching. It has allowed even to reveal by using of an optical microscopy appreciable structural changes in the treated materials (figure1). By using of inhibitor became obvious, that in volume of an aluminium matrix there are unusual zones of influence (figure 1,d, g). These zones represent matrix aluminium or its alloy stitched by set of tracks (filaments) from the material which has arisen at interaction of a matrix and particles of powder. Zones of influence as has shown using of electrochemical treating, are 8-10 % from volume of basic material. Insertion of heavy elements in volume of aluminium and its alloys allows to make also visual channel zones in a metal matrix due to use of special modes of electronic scanning microscopes (figure 3,a,b).

Penetration of powder microparticles in Al and alloy Al-12%Si forms a composite material with the anisotropic structure (figures 1,3,4). Electrochemical properties of a composite material are evidently anisotropic (figures 1 ,d, g, e; 4,a). Unusual result of reorganization of structure at SDP is the considerable intensification of a doping of channel zones and zones of "influence". In particular, high concentration of some chemical elements which in basic metal matrix were impurities or missed completely is found out (table 1). It allows to predict essential influence of these zones on mechanical properties of producible composite aluminium materials.

The superdeep penetration causes the strong distortions in structure of a material on macro-, micro-and nano- levels (figure 5). Bending extinction contours going from edges of channels, amorphous microzones, high concentration of dislocations in narrow and long elements of structure (channel elements), earlier were observed at SDP research in iron and its alloys [5]. These specific defects are the characteristic structural attribute of SDP implementation. At present such structural elements cannot be gained in volume of a metal solid body by other methods of static and dynamic treating.

On the basis of calculation of experimental data [6] it is established, that in local volumes the phase of a high pressure has density $\rho=1.89 \cdot 10^3 kg/m^3$, and the relation of density of phases low and a high pressure makes $\rho_1/\rho i =0.70$. 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 - $\rho_1/\rho i =0.53$ or makes 53.2 % from initial density of an alloy.

The relation of density of initial phases in aluminium and an aluminium alloy (12%Si) makes $\rho_{A1}/\rho_{AK12} =1{,}01$. The relation of density of phases of a high pressure makes $\rho_{1\ A1}/\rho_{1\ AK12} = 1{,}\ 34$.

THE CONCLUSION**.** Research of structural changes in aluminium and alloy Al-12%Si subjected to processing has allowed to record a number of the structural elements with typical for this high-energy action (SDP) and to do following basic conclusions:

Due to modification of known techniques in aluminium and alloy Al-12%Si it was possible to reveal unusual zones of "influence". The zone of "influence" is the matrix material stitched by fibers of synthesized at SDP metastable material.

1. The material of a zone of "influence" differs from a metal by matrix specific reaction to chemical and electrochemical etching. Due to difference in chemical and electrochemical properties it was possible to establish, that the part of zones of "influence" is 8-10 % from volume of a sample of the material.

2. The opportunity of regulation in SDP mode chemical and electrochemical properties of a zone of "influence" is shown. The material of zones of "influence" can be activated or inhibited in comparison with a metal matrix, using various powders.

3. It is established, that the quantity and concentration of doping elements in a zone of influence turned out essentially higher, than at basic matrix material.

4. In channel zones of particles penetration in a matrix which are the part of zones of "influence", the strong distortions are found in structure of a material on micro- and nano- levels. These specific defects are the structural attribute, proving realization of SDP in volume of aluminium and alloy Al-12%Si.

5. Aluminium and alloy Al-12%Si at SDP are reinforced in volume by zones of "influence" from the reconstructed material and get structure and properties of a typical composite material.

6. The dynamic phase change in Al in conditions SDP and at presence of the additional factor - the ionic irradiation has been found out. There was the phase of high pressure with density (70 %) lower, than at the phase of low pressure.

7. Change of aluminium and its alloys, in particular electric conductivity, allows to receive preparations for new electric and electronic devices.

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