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Metal Grain Prodaction Bay Hight Density Electric Current Use

S. D. Samuilov

Laboratory of Physics of durability, Ioffe Physical Technical Institute, Russian Academy of Sciences, Politekhnicheskaya ul. 26, St. Petersburg, 194021 Russia

Abstract

Methods of receiving metal grain and granules of high purity are provided. The main advantage of the proposed methods is the possibility of obtaining granules of high purity due to the use of a clean energy carrier - electric current and a clean granulation medium: vacuum, gas, liquid, incl. conductive flux.

Corresponding Author:
S. D. Samuilov
Sam.mhd@mail.ioffe.ru

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1. INTRODUCTION

The sustainability strategy of the world economy in the context of limited resources assumes the development of the effective technologies of receiving materials and semi-finished products with the new level of properties, including waste products [1 - 3]. A perspective way - use as the technology tool of flows of energy of big intensity, including electric current of big density, i.e. current of such size and duration at which course on the conductor or through limit of the section of conductors there are irreversible changes. It is reasonable to use this tool in powder metallurgy, in metallurgy of granules which received a new boost of development [3] now. The powder metallurgy includes two interdependent stages: receiving disperse material and production from him compact or porous procurements; allows to receive materials with higher level of properties and is low-waste. New level of properties of materials can be provided, using other disperse material, for example the granulated material of high purity, or cheap materials, in particular metal shaving which natural properties, such as the developed surface and availability macro and microdefects can be useful during creation of a number of products, for example catalytic filters. The existing granulation methods in which dispersion of metal is performed by water, gas, the rotating blades or centrifugal forces do not provide required purity, are difficult and insufficiently effective. Use for dispersion of metal of the net and convenient energy carrier - electric current, allows to carry out process in the clear protective atmosphere, including in a high vacuum, liquid gumboil and opens a solution of this problem.

2. ELECTROPULSE TECHNOLOGY OF GRANULATION OF METAL MALT

Liquid conductors: streams of metal and a delay which are previously melted by current at rather small size of current collapse due to development of magnetohydrodynamic (MHD) instability of their form [4] (mechanisms of destruction of the condensed conductors are analyzed in work [5]). The method of granulation [6, 7] is as follows (fig. 1.): from capacity with metal which is connected to one of current source poles through an opening in the bottom the metal stream follows, reaches the electrode attached to other pole of a source of current and closes an electric chain. On a stream electric current flows. The magnetohydrodynamic peretyazhechny instability of her form is as a result initiated: in those places where diameter of the conductor it is at least insignificant less, than in next, magnetic pressure more, therefore, the available narrowing (banner) will accrue to a complete separation of the conductor. The stream of metal breaks into liquid disks and electric current stops. The new stream of metal arrives, during her falling the source of current manages to recover the charge, and process repeats.

Depending on conditions of transmission of current, between fragments the gas category during which there is a crushing of metal drops, including due to metal evaporation can develop, however the energy efficiency of this process is extremely small. Such understanding of nature of destruction of the conductor allowed to use "in the pure state" (at the minimum influence of the subsequent gas category) the MHD destruction of a stream of metal as an effective method of her dispersion for receiving metal grain (microingots) and refinement of metal fusions [6 - 8].

Characteristics of process of granulation: the size of electric current is $I = 1,5 \cdot 10^5 \alpha^{0,5} D^{6,5} d^{-6} (A)$ necessary for receiving granules of given size of d (m), from a stream of metal with a diameter of D, and time of destruction of the conductor of the MHD instability: $\tau = 5 \cdot 10^3 \rho^{1/2} D^2 I^{-1} (s)$; α — coefficient of a superficial tension of metal; ρ — its density. The size of the received granules approximately corresponds to diameter of a stream of metal.

Such characteristics of process will be observed under a condition:

$$I_0 = 2 \cdot 10^4 \alpha^{0,5} D^{05} \rangle\rangle I \rangle\rangle 5 \cdot 10^3 \rho^{0,5} D^2 t^{-1},$$

where t – metal falling time. At smaller current process of granulation does not go since time of destruction of a stream is commensurable her falling over time. At I » I_0 process of destruction of a stream goes so quickly that kinetic energy of liquid metal

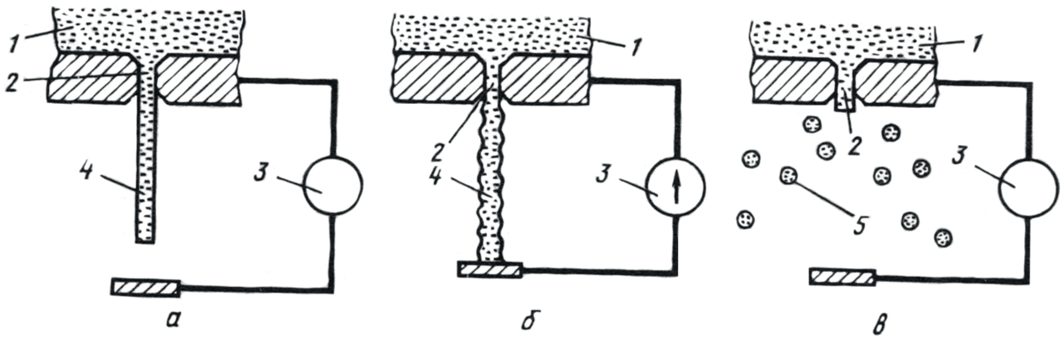

Figure 1: Receiving granules from a fusion stream: 1) capacity with metal; 2) an opening in the bottom; 3) a current source; 4) a metal stream; 5) granules. a) the metal stream coming through an opening to the crucible bottom does not concern an electrode, the chain is not closed, there is no current. b) the stream closes an interval between a crucible and an electrode, the source of current generates a current impulse, the MHD instability of a form of a stream is initiated. c) the stream of metal is dispersed, granules were formed .

on outline border of the liquid disks formed as a result of development of instability becomes sufficient for a separation of this liquid from disks. Granules of two sizes are as a result formed: larger, created from the central part of initial disks and smaller of their periphery (when receiving granules from thin delays such two-phase structure was observed). At $I \approx I_0$ there can be both processes, as a result the particle size distribution of material extends.

This method received granules of tin, aluminum, aluminum alloy (Al, 4,5% of Cu) from metal streams to dia. 1 — 3 mm [6, 7]. Fo r receiving granules experimental installation is made. Dispersion of metal was performed on air, and cooling — in water. As a source of current the condenser battery with a capacity of 2000 μF which was loaded from the rectifier was used. Results of experiences are given in table 1., and distribution of granules of tin by the sizes in table 2

Table 1: Results of experiences.

Material	*d*, mm	*D*, mm	*L*, mm	Calculations		Experiment			
				I, kA	τ, μc	*I*, kA	τ, μc	*U*, V	I_0, A
Sn	1	1	40	3,5	120	3,5	200	80	4
Sn	3	3	100	6,1	600	5–7	250	30	40
Al	1,8	2	100	10	100	10	250	80	40

L — length stream of metal; *U* — voltage on the stream of metal; I_0 — average electrical current, from mains.

Table 2: Distribution of granules of tin by the sizes.

Fraction mm	>3	2–3	1–2	0,5–1	0,2–0,5	0,1–0,2	>0,1
Contain of fraction, %, *D = 3* mm	6	31	32	32	7	1	1
Contain of fraction, %, *D = 1* mm	9	9	38	29	20	2	1

Table 3: Granules of aluminum were analyzed in laboratories of VILS.

Fraction, mm	Mass of fraction, g	Contain of fraction %	Contain of oxiden %	Moisture content 10^{-2} %	Contain of hydrogen cm^3/100 г	Present of porous grain %
+ 2.5	219	19,9	Not do	Not do	Not do.	Not do
+ 2,0–2,5	24	2,2	-»-	-»-	-»-	-»-
+ 1,6–2,0	283	25,7	0,04	-»-	-»-	1,22
+ 1,0–1,6	288	26,1	0,04	4,3	-»-	1,01
+ 0,63–1	152	13,8	0,06	Not do	Not do.	0,49
+ 0,4–0,63	70	6,3	Not do	-»-	1,2	0.13
+ 0,35–0,4	22	2,0	0,25		Not do	Not do
+ 0,315–0,35	2	0,2		*	-	-»-
+ 0,063–0,315	39	3,2	Not do.	-»-	-»-	0,1
+ 0,05-0,063	2	0,2	-»-	-»-	-»-	Not do
–0,05	1	0,1	-»-	->-	-»-	-»-

Granules of aluminum were analyzed in laboratories of VILS (tab. 3.). The sitovy structure of granules (distribution by the sizes) on the Rotan installation is determined. The range of the sizes of granules was quite wide.

Proceeding from theoretical representations the size of granules of $d \sim (\lambda D^2)^{1/3}$, is defined mainly by diameter of a stream of metal and to a lesser extent instability wavelength λ which according to [4] has small dispersion. The wide range of the sizes of granules is connected with availability of additional mechanisms of crushing as in these experiences the size of current of $I \approx I_0$ and insufficiently net conditions of experiences. The analysis of a form of granules consisted in the choice by method of quartation of a hinge plate weighing about 1 g, sorting of granules according to a form (visually) and weighing. A considerable part of granules has the extended or flat form, it also leads to expansion of a range of the sizes of granules. Percentage (for several fractions) gas-forming impurity (H_2, O_2, H_2O) and porous granules is determined.

Content of oxygen was defined by a neutron and activation method, the content of hydrogen — method of vacuum extraction. The humidity was determined by a weight method by the difference of mass of initial granules and after drying at a temperature of 500 °C during 1 h. The percentage of porous granules was defined by weighing of the granules which emerged in liquid with a density of 2 g/cm^3. The analysis of appearance and a research of granules showed that, the form of the received granules, content of gases in granules and quantity of porous granules answer conditions of their forming and cooling [9]. Alloy granules aluminum — copper are disseminated on fraction, mikroshlifa by which the microstructure of granules is determined are prepared. The material grain size is determined by photos of a microstructure of granules of three fractions: 3 — 10 microns, the speed of cooling of granules ~ 10^3 C / is also calculated with, she also corresponds to refrigerating conditions of granules of such sizes [9]. In photos a separate small time is visible. The used method of dispersion of metal did not bring indignations in structure of material of granules. The quality of the received granules in general conforms to requirements [9] imposed to the granules received in similar conditions. Results of experiences show operability of a method and a possibility of his implementation by means of simple technical means, and allow to estimate characteristics of process and the received granules.

In process of this work the theoretical research of the MHD of stability of a liquid stream with current being in the liquid electroconductive environment is executed. Wavelength and a constant of time of increase of instability are removed. It is shown that the instability of a stream can develop even in well carrying out external environment, with conductivity ~ 1/10 from conductivity of a stream [10]. On this basis the method of an intensification of process of electroflux refinement of aluminum is offered and reasonable [8], the size of electric current necessary for dispersion of metal in liquid gumboil is calculated:

$$I \geq 2,5 \cdot 10^{-4} \sqrt{\frac{(1+\alpha)\left(\rho_0+\rho_1\right) D_0^4}{(1-\alpha)^2\, t_{cp}^2}} \tag{A}$$

where α = σ1/σo, σ1 – conductivity of gumboil, σo – conductivity of metal, ρo – density of metal, kg/m3, ρ1 – density of gumboil, kg/m3, Do - diameter of a stream of metal, m, tcp – time for which the stream proceeds between electrodes [8].

3. RECEIVING GRANULES FROM FIRM PROCUREMENT

Other option of this process allows to receive granules from initially firm procurement (fig. 2) [6, 11]. On the surface of procurement melt a thin layer of metal and pass an

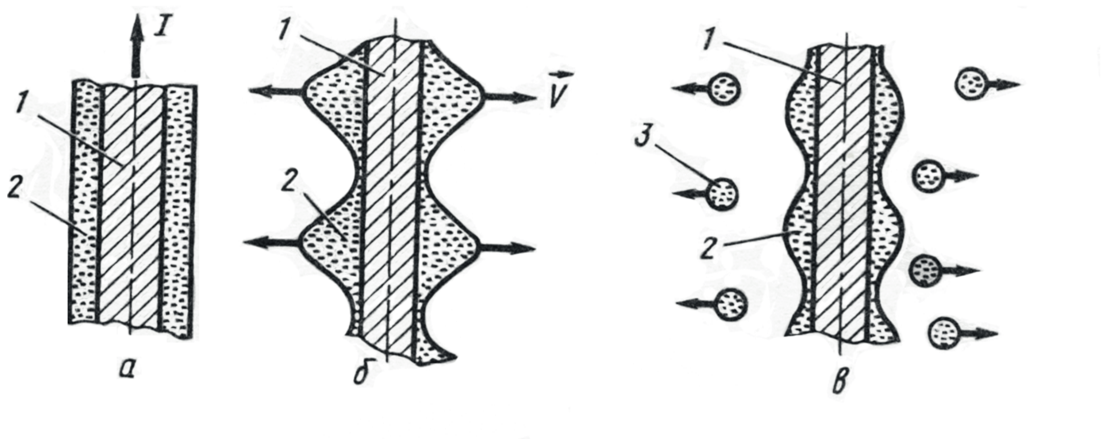

Figure 2: Receiving granules from firm procurement: 1) a firm core; 2) liquid metal which starts moving as a result of development of instability; 3) granules.

impulse of electric current. At transmission of electric current on the conductor on which surface there is a layer of liquid metal the MHD instability is initiated in this layer [12, 13]. The firm core interferes with destruction of the conductor, and liquid starts moving. At the sufficient size of current a part of liquid comes off procurement in the form of drops. Then process repeats, as a result procurement is dispersed layer-by-layer.

The layer of metal can be applied on a core (including dielectric) from the outside, is melted by an external source of heating, or by transmission of high-frequency electric current which at the expense of a strong skin-effect flows only in a thin blanket, or a short powerful impulse of current which performs both melting, and metal dispersion.

The current size necessary for receiving granules of given size, and time of transmission of current are defined from the following expressions:

$$I = 4 \cdot 10^5 (\alpha D^3 \Delta^6 / d^8)^{1/2};\ \tau = 3 \cdot 10^4 (\Delta \rho D / I^2)^{1/2},$$

where α — coefficient of a superficial tension; ρ — density of liquid metal; D — diameter of procurement; Δ — thickness of the melted layer on her surface; d — the given size of granules.

The size of granules is defined by diameter of procurement, thickness of the melted layer and size of the passed current. The minimum size of the granules received by this method — several micron, at the same time the size of grain of material of granules of a share of micron, receiving granules of the smaller sizes is impossible in connection with increase in electric current, necessary for dispersion, and with the insufficient durability of a firm core in comparison with sharply increasing electrodynamic force. For receiving granules of larger sizes there are no basic restrictions, however the energy necessary for melting of a layer of material increases.

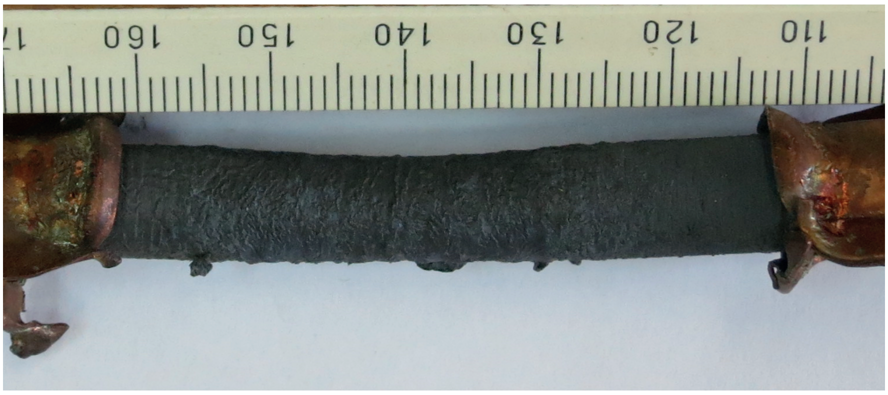

Figure 3: The photo of a sample from stainless steel 20H18X10T after transmission of three consecutive impulses of current.

Installation for receiving granules consists of the camera for cooling and collecting of granules in which the sample, the energy store (the condenser battery) and the rated sportsman is clamped. When giving food the battery is charged up to the set tension at which there is a breakdown of the rated sportsman. In a chain current flows, melting and dispersion of a layer on a sample surface are made. At the complete category of the battery current stops, the rated sportsman is disconnected. Then process repeats before complete dispersion of procurement.

Table 4: Results of experiences.

Material........	Copper	Stainless steel 20H18X10T
D, diameter of procurement, mm....	1,5	9
Length of procurement, mm.....	10	50
Amplitude of pals of current, kA	130	600
Period of current, μc.	4	20
Thickness of the dispers layer, mm	0,02	1
d, size of granules μm.....	60	300

Samples from aluminum, copper, stainless steel were investigated. Results of experiences are given in table 4. In the Figure 3 the photo of a sample from the high-alloyed stainless steel 20H18X10T which can be considered as a close analog of heat resisting nickel alloys, after transmission of three consecutive impulses of current is provided. We see that diameter of a sample in his middle part decreased (by 1 mm), vertical strips clearly are visible. The same strips were observed on copper, aluminum and brass samples. We consider them as a trace of not stability. During experiences 100 samples of stainless steel, a part of the received granules were processed (~ 100 g) it is collected from a bottom of the experimental camera. During the experiment some

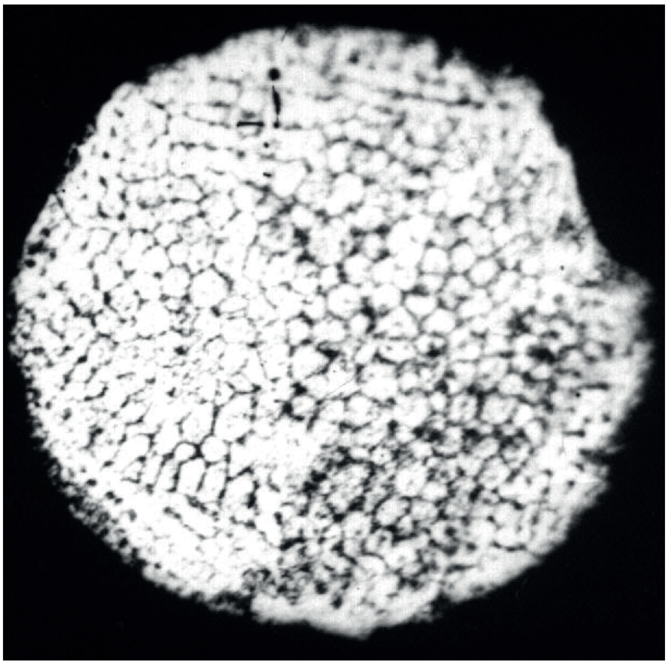

Figure 4: Photo of a Microstructure of a Granule. The size of a granule is 150 microns, the size of grain is 5 microns.

of samples at transmission of current were broken by electrodynamic forces therefore as a part of party of granules large particles of a fragmental form, bound together particles and also a small amount of particles of copper from electrodes contain.

Table 5: Distribution of the received granules by the sizes.

Fraction μm	+400	-400 +350	-350 +300	-300 +250	250 +180	-180 +140	-140 +100	-100 +70	-70
Contein, %	40	13	4	6	12	4	5	4	4

Granules of stainless steel were analyzed in laboratories of VILS. It is established that a form of the received granules, the content of gases in granules and quantity of porous granules answer conditions of their forming. Distribution of the received granules by the sizes is given in table 5. The photo of a microstructure of a granule is provided on fig. 4.

Experiences confirmed operability of a method.

4. RECEIVING GRANULES WITH USE OF ARC MELTING

The third method [6, 18] allows to receive granules in the course of arc remelting (fig. 5). For dispersion of liquid metal the electric current of the arc category proceeding on him and the magnetic field created by the special coil is used. At the same time the

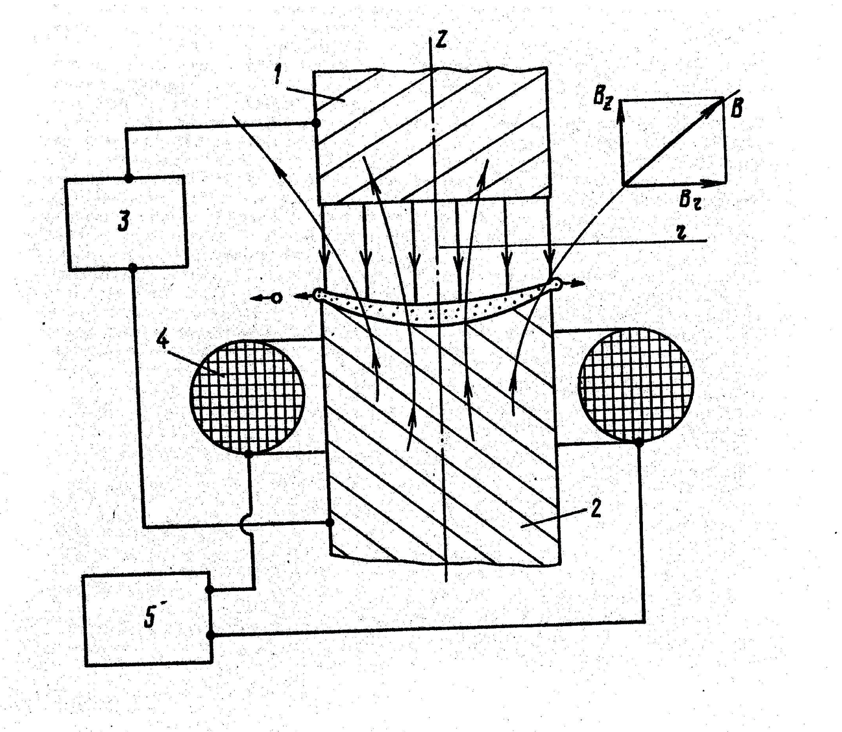

Figure 5: Receiving granules in the course of arc melting. 1, 2 – electrodes, 3 – an arch current source, the 4th coil, 5 – a coil current source.

component of a vector of magnetic field perpendicular to a vector of electric current in the liquid metal which is on a surface of an electrode is set by the following size:

$$B \geq 2\frac{ju^2}{\eta r^2}\sqrt{\frac{0,4\alpha}{\rho D}+\frac{g\rho r}{2ju}} \qquad \text{(T)}$$

where η – viscosity of liquid material, kg / м · с; ρ – its density, kg/m^3; α – coefficient of a superficial tension, *r*.– warmth of melting of material, J/kg; *D* – diameter of an electrode, m; *j* – density of electric current of an arch, A/m^2; *u* – the cathode voltage, V; *g* – acceleration of gravity.

Installation for receiving granules consists of the camera having the sufficient sizes for cooling of granules, of two spent electrodes (or one spent and one not spent) on one of which there is a bathtub of liquid metal and also from the electromagnetic coil.

This method together with NIAT on Balashikha Casting-Mechanical Plant received titanium granules. For receiving granules the vacuum and arc garnisazhny furnace 833 at the bottom of which the electrode and the electromagnetic coil were established was used. Results of experience: diameter of an electrode is 200 mm; current of an arch of 3 kA; the power allocated in an arch, 100 kW; the power consumed by the coil, 5 kW; tension of magnetic field of 0,1 T.

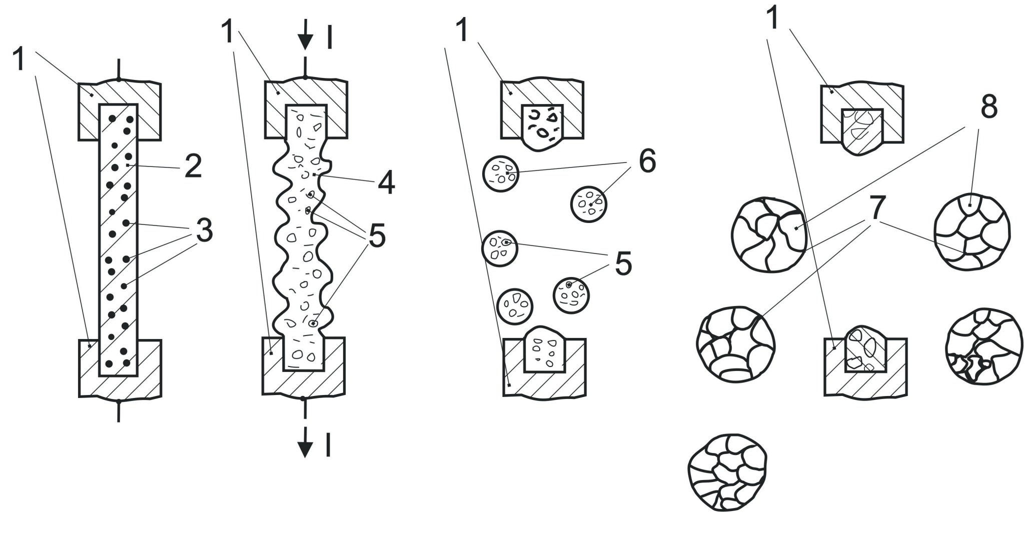

Figure 6: a) the sample pressed from mix of metal powder with a porofor is snugged between electrodes; b) pulse electric current is passed, metal is melted, a time is formed, the Moscow City Duma instability breaks metal into drops; c) scattering and cooling of drops; d) expansion of gas bubbles, crystallization and formation of granules of a penometall. 1. electrodes; 2. sample; 3. porofor particles; 4. liquid metal; 5. vials of gas; The 6th drops of metal with vials of gas; 7. penogranula, metal framework; 8. time.

5. ELECTROPHYSICAL TECHNOLOGY OF RECEIVING GRANULES OF PENOMETALL

Penometalla, first of all penoalyuminy, perspective constructional and finishing material. He has high specific rigidity, small thermal and electric conductivity, does not burn and well is suitable for absorption or damping of energy. Unlike a cellular design of penoalyuminiya can also resist to blow at any angle [14]. In production of products from penometall there is a problem consisting in instability of the forming foam, i.e. in not preserving of a condition of the made foam liquid metal in the course of crystallization [15].

The electrophysical technology of granulation [16, 17] allows to combine transactions of dispersion and foaming of metal and to receive on one simple technology and on one installation of a penogranula of any metals and alloys. The essence of a method (fig. 6) consists that press a compact sample from mix of metal powder with a porofor - substance which when heating allocates the large volume of gas. As a porofor in our engineering procedure take substance which temperature of decomposition is significantly lower than metal melting temperature, in quantity to 1% of metal weight.

For aluminum alloys - hydride of aluminum or алюмогидрид a lity which decay with allocation of a large amount of hydrogen at a temperature ~ 120 °C. Then through a sample pass electric current which size and duration are sufficient for sample material melting. Porofor begins to emit gas even in the course of heating, however the magnetic pressure and inertia of metal prevent expansion of gas bubbles. After melting of a sample the magnetohydrodynamic instability breaks it into drops which extend and crystallize in the course of scattering, forming penogranula. At the expense of the magnetic pressure and high speed of processes of heating and cooling of metal, gas keeps in liquid drops of metal before their crystallization and education penogranut.

If as a porofor to enter particles of water-soluble refractory salt into structure of a sample a similar method it is possible to use for receiving granules with open porosity.

Penogranula can be used in itself: for filling of cavities of details which in this case receive capability to absorb impact energy, for filtering of liquid and gas, etc. By methods of powder metallurgy - by pressing and agglomeration - from them penometallichesky materials and products, including irregular shape with porosity close to porosity of granules, unique composite details from metal and the penometallicheskikh of granules including reinforced can be received, by agglomeration without pressure materials with double porosity can be received: the closed porosity of granules and additional open porosity of mezhgranulny space. Due to the small heat conductivity I penogranut, it is the most reasonable to receive materials with the closed porosity spark-plasma agglomeration, and materials with double porosity by the electropulse method.

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