REALIZATION OF MHD-ACTION AT MANUFACTURING OF ALLOYS WITH THE SPECIAL PROPERTIES ABOARD THE ORBITAL SPACE STATION

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Abstract: It is set the parameters of the crossed electromagnetic fields (constant magnetic field & alternative electric field), which used for manufacturing of ingots with emulsified structure from alloys of monotectic systems in conditions of microgravity at space orbital station. It is defined, that Earth magnetic field at orbital conditions increases stability of interphase surface in melts consisting of two unmixed volumes. It is promoted the braking of wave disturbances at wave-lengths of 0.01-1.0 m.

1. Introduction

Presently, there are not enough the statistically synonymous experimental data for development of theoretical notions about technological processes in space terms. The authors of report over a long period of time research the processes of manufacturing of alloys with emulsified structure at electromagnetic actions, including in terms simulated the microgravity by electromagnetic balancing of phases [1-3]. Therefore, there are made the scientific experiments for studying the features of determinative physical and chemical processes, in particular, in alloys with immiscibility area of liquid phases at orbital terms, which are different sharply from earthly ones. These researches are directed for development of technological modes, designing and working-off of equipment & its main systems. At that, it is deciding the important task, namely organization in space the manufacturing of unique materials, including metallic alloys with improved properties or with principle new ones. Researches of alloys with immiscibility area at microgravity on near-earth orbit exposed the some features of behavior of liquid and solidifying alloys different from processes on Earth: 1) both monotectic alloys (Bi – Zn) and alloys without immiscibility area (Al – Si, Al – Cu, Al – Zn, Sn – Pb, Zn – Sn, Bi – Sb) were delaminated on two liquids. At that, homogeneous state in castings was not attained because intensifying of segregation of components and additives at acceleration of gravity ca. $1\cdot10^{-3}$-$1\cdot10^{-4}$ m/sec^2, different temperatures and holding time in molten state. This fact is connected with specific of heating (by radiation) and absence of thermal convection [4]; 2) the experiments on mutual diffusion of liquid phases with wide difference in density did not give statistically synonymous results because of remanent accelerations on space orbital objects [5]; 3) more intensive increasing fluctuations of concentration and suppression of formation of nucleus embryos of the dividing phases at melt cooling [6]; 4) at directed crystallization, it is accelerated the influence on the structure of different factors (composition of alloy, thermal gradient, solidification rate, convection instability, size of immiscibility area of phases [7]; 5) increasing role of non-equilibrium processes in the conditions of concrete distinctions of microgravity aboard spacecrafts, that results in different effects at structure formation [8].
At the same time, importance of electromagnetic actions at manufacturing of metallic alloys of monotectic systems with emulsified structure remains unstudied.

2. Presentation of the problem

Data about intensity of magnetic field on orbits for most of spacecrafts are ambiguous in the range 10^{-4}-10^{-6} T. Base of geomagnetic field is constant component. At orbit, it can be accepted ca. $1 \cdot 10^{-5}$ T. Action of magnetic fields (both constant and alternating ones) on liquid and solidifying alloys appears most strongly at phase transformations. At Earth conditions, influences on crystallization of metallic alloys appears already at magnetic field induction ca. $1 \cdot 10^{-3}$ T. Action of constant magnetic field at orbital microgravity on stability of interphase surface of monotectic melts is analyzed on the basis of equation [9]. According to it, there are indignations with the wavenumber *of* $k_w = 2\pi/\lambda$ (λ – length of wave, m) on interphase surface which are repressed by constant homogeneous both vertical and horizontal magnetic field in the range $k_{w1} < k_w < k_{w2}$. For immiscible liquid-metal volumes, it is accepted:

$$k_{w1,2} = \frac{H^2}{8\pi\sigma_{1-2}} \pm \sqrt{\left(\frac{H^2}{8\pi\sigma_{1-2}}\right)^2 - \frac{\Delta\rho\, g}{\sigma_{1-2}}}\,, \tag{1}$$

where H – magnetic field intensity, A/m; σ_{1-2} – interphase tension of immiscible liquid-metal volumes, N/m; g – acceleration of gravity, m/sec^2; $\Delta\rho$ – difference of density of liquid-metal phases, kg/m^3.

As objects for study were selected the alloys covering practically complete range of differences of phases' density: a) copper – cast iron ($\Delta\rho \approx 800$ kg/m^3, $\sigma_{1-2} = 0.025$ N/m); б) Bi – Ga ($\Delta\rho \approx 3400$ kg/m^3, $\sigma_{1-2} = 0.01$ N/m); в) Al – Pb ($\Delta\rho \approx 7700$ kg/m^3, $\sigma_{1-2} = 0.1$ N/m). As main research object, it was selected Bi – Ga alloy (fig. 1 [10]).

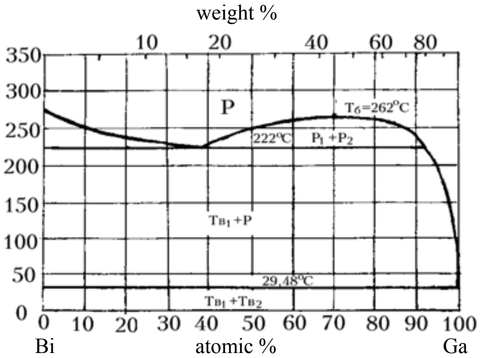

Figure 1: Bi – Ga monotectic alloy structural diagram:
P – area of homogenous liquid condition;
P_1 – Bi base saturated liquid solution;
P_2 – Ga base saturated liquid solution;
T_{B1} – Bi base saturated solid solution;
T_{B2} – Ga base saturated solid solution;
T_6 – temperature of binodal (critical temperature).

The alloy was studied at microgravity [6]. It has prospects for experiments aboard space station, because such alloy needs low energy consumption for melting in comparison with other alloys. Chemical composition of experimental alloy corresponds to immiscibility area of phases in melt (Bi – 75 weight % and Ga – 25 weight %). Base of alloy is Bi, as Ga has low melting temperature 29.5 °C (it exceeds insignificantly the usual room temperature). Moreover, at cooling of melt, it is necessary to utilize a little heat (Table 1, where ρ^e – specific resistance; c – specific heat capacity; q_m – melting heat).

Table 1. Main parameters of monotectic Bi – Ga alloy

Components of alloy	ρ, kg/m^3		ρ^e, Ohm·m		c, J/(kg·°C)		q_m, J/kg
	20 °C	300 °C	20 °C	300 °C	20 °C	300 °C	
Bi	9800	10300	$117 \cdot 10^{-8}$	$132 \cdot 10^{-8}$	1200	3800	$5.2 \cdot 10^4$
Ga	5900	5905	$54 \cdot 10^{-8}$	$30 \cdot 10^{-8}$	377	398	$8.2 \cdot 10^4$

As distinct from earlier orbital experiments, in the presented works it is foreseen heat generation directly in alloy due to heating by alternating electric current. Also, it is provided the creation of optimum thermal & forced processing of liquid alloy by crossed electric and magnetic fields. For providing of accelerated cooling at melt crystallization, it is used the metallic cooler. At Bi – Ga alloy, there is researched the possibility of magnetic field influence on the change of phase transitions in monotectic melt and change of crystallization type, first of all for increasing number of nucleus and crystallization rate in orbital terms. For providing of necessary effects of MHD-actions on the liquid monotectic alloy at microgravity, it is needed to select the proper parameters of magnetic and electric current systems. At development of space equipment, it becomes additionally complicated because of power, gravimetric, overall, and other limitations.

Evolution of wave disturbances on interphase surface of liquid volumes Bi and Ga at microgravity in thermodynamically equilibrium state (clean components A and B) is rated on equation by Birkhoff [11] at $\sigma_{1\text{-}2}$=0.01 N/m. At that, the minimum speed U, corresponding to transition boundary of system from $A(\tau)=A_0$ to $A(\tau)>A_0$ (A_0 – initial amplitude (or amplitude of harmonic disturbance at time $\tau = 0$), m;) connected with wave-length λ for an alloy Bi – Ga:

$$U = \sqrt{\frac{0{,}61\cdot 10^{-4}}{\lambda} + 2{,}8\cdot 10^{-3}\lambda} \tag{2}$$

According to (2), at short waves' range ($\lambda<5\cdot10^{-5}$ m) for evolution of instability on interphase surface of liquid Bi and Ga at microgravity, relative moving speed of volumes must exceed 1 m/sec, and for $\lambda=5\cdot10^{-6}$ m – 3.5 m/sec. Therefore for receipt of fine-dispersed emulsion in Bi – Ga melt at microgravity, it is appropriate to use condensation method (not dispersion).

At the contact holding of sample of alloy and using of most rational heating method by transmission of electric current through alloy, it is necessary to imposition of electric field (fig. 2).

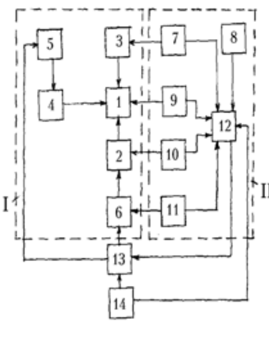

Figure 2: Block-scheme of the apparatus:
1 – technological capsule with alloy; 2 – system creating electric current of heavy density; 3 – magnetic system; 4 – solid cooler; 5 – manipulator; 6 – power supply block of the electric system; 7 – flux density sensor in the electromagnet gap; 8 – geomagnetic field flux density sensor; 9, 10 – alloy temperature and electrode loop sensors; 11 – electric current value sensor; 12 – information apparatus; 13 – control block; 14 – board electric power supply system; I – technological apparatus; II – information block.

Time for transition of alloy into liquid state with finite temperature is determined by active power consumption. The P_Σ power is used for heating of metal from t_0=20 °C to finite temperature t depends on general efficiency of heater η and efficiency of thermoinsulation (total thermal losses of the heated objects). At contact power supply to heated sample of alloy η will make no less than 0.95, and thermal losses P_h at chosen finite temperature t= 300 °C >t_6 (t_6 – temperature of binodal of alloy) it is possible to limit at the level of 0.1 W. At useful power consumption P in two orders less than power provided the power system aboard orbital station (namely ca. 5 W), the specific volume thermal power makes $(P+P_h)/V$=5.1 W/cm^3. The specific volume active power consumption makes $P_a=P/\eta$=5.3 W/cm^3. So, specific energy consumption makes $q=[c(t-t_0)+q_m]$=1158 W·sec/cm^3. Time τ_t for transition of alloy into liquid state with temperature 300 °C will make τ_t=218 sec. For determination of necessary electric current density in melt for providing the required volume thermal power, it is calculated (by additivity rule) average specific electric resistance of alloy ρ^e_a in temperature interval 20-300 °C calculated. It makes $\rho^e_a=1.1\cdot10^{-7}$ Ohm·m. The required electric current density in sample of Bi – Ga alloy makes $j=\sqrt{P_v/\rho^e_a}=215$ A/cm^2. At that, volume of alloy with passing large electric current is the short circuit area. It is expedient to use transformer chart working on AC. In this case, energy to alloy is passed through DC/AC-converter and transformer which has the one-turn secondary winding circuited on volume of alloy (fig. 3, 4).

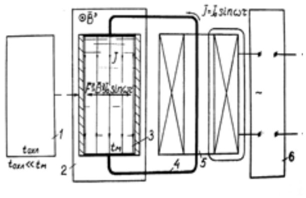

Figure 3: Scheme for creation of the electromagnetic actions on the monotectic alloy with emulsified structure aboard the orbital space station:
1 – cooler; 2 – constant magnet; 3 – alloy; 4 – loop with conductor; 5 – voltage transformer; 6 – electric current converter

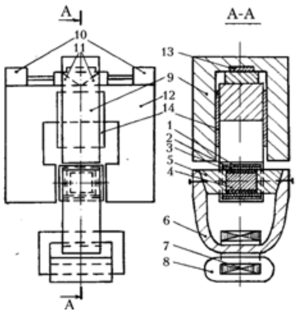

Figure 4: Construction of the technological apparatus:
1 – copper capsule; 2 – ceramic cartridge; 3 – elastic heat-electric insulator; 4 – alloy; 5 – copper electrodes; 6 – electrode bus; 7 – transformer limb; 8 – transformer winding; 9 – solid aluminum cooler; 10 – manipulator of the magnetic type; 11 – electromechanical cotter pin; 12 – constant magnet; 13 – ferromagnetic lamina; 14 – slides of the cooler.

However, at orbital experiments, there are appeared considerable kinetic difficulties during homogenization of monotectic melt over the bimodal temperature. Performed analysis had shown that homogeneity of single-phase fluid can be provided by MHD-actions, in particular, by imposition external magnetic field on alternating current in melt. At that, it is created electromagnetic vibration in liquid alloy. For generation of variable electromagnetic forces at affecting on melt phases at heating, rationally to place the alloy sample in the gap of constant magnet (this one is not required the energy for working (see fig. 3). Interaction of imposed on melt constant magnetic field with induction B with transverse alternating electric current with frequency ω will cause the origin of electromagnetic force in melt. This force acts differentially on the phases in melt with different ρ^e. Thus, according to (2) for the Bi – Ga melt from clean components, the acceleration of Ga volume is in 7.3 times more than Bi volume. After temperature-temporal processing of melt, it is under action of constant magnetic field. Degree and character of influence of constant magnetic field, including geomagnetic one, on stability of interphase surface in monotectic melts is estimated using equation (1). The analysis showed (fig. 5) that geomagnetic field on orbit promotes braking of wave disturbances on interphase surface in monotectic melts in the range of wave lengths $1\cdot10^{-2}$-1.0 m.

At imposition on cooling melt of the homogeneous constant magnetic field with intensity exceeding intensity of geomagnetic field, in liquid monotectic alloy on the space station, there are suppressed the flows, related to micro-accelerations due to inertial random motion.

At successive solidifying of monotectic melt in castings and ingots, there are areas which contain the different by sizes inclusions of second metallic phase. In this connection, for providing of homogeneity of inclusions by sizes and their uniform distribution, it is necessary to realize cooling of melt with optimum speed even in the zero-gravity state (weightlessness).

On base of results of computations and experiments on action of magnetic field on emulsified melts, for the first series of experiments in space terms it is recommended using of constant magnets with induction of magnetic field in the gap ca. 0.1 T. For acceleration of melt cooling after its overheating to 300 °C and homogenization, it can be used the metallic cooler entered into the contact with melt (see fig. 3).

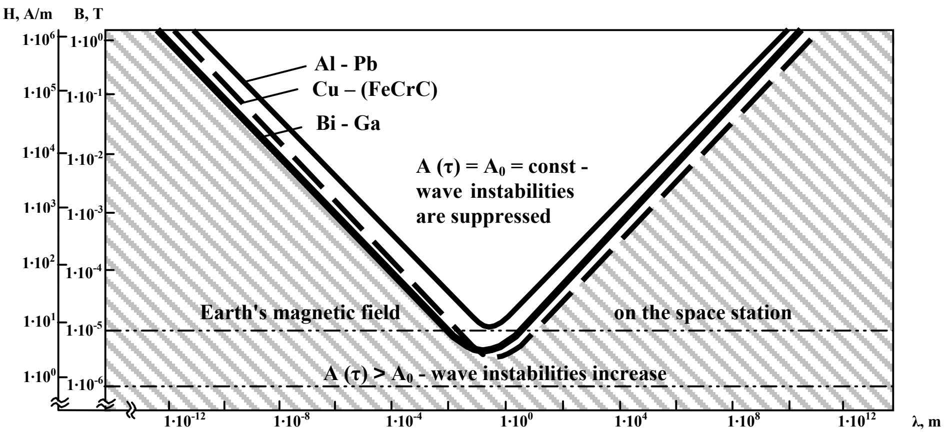

Figure 5: Constant magnetic field action on melts interphase stability at space station.

At the small volume of melt (1 cm^3) and low overheating above ambient temperature, the aluminium cooler by volume of 20 sm^3 will provide cooling rate of 27 °C/sec (according to calculation, heat of overheating relieving ca. 1000 J; heat conductivity coefficient of melt 20 W/(m^3·sec); heat capacity of the cooler $2{,}4\cdot 10^6$ J/m^3; temperature of cooler 20 °C; areas of contact surface of cooler with melt $2\cdot 10^{-4}$ m^2). At cooling, melt fusion will be found in immiscibility area of liquid phases during ca. 1 sec, and sedimentation in melt will not appear.

3. Conclusion

There are defined the terms for using of constant magnetic field (B=0.1 T) crossed with alternating electric one (q=1160 W·sec/cm^3; j=215 A/cm^2) at manufacturing of ingots from monotectic alloys (Bi – Ga) with emulsified structure at microgravity aboard space orbital station. It is set that geomagnetic field promotes stability of interphase surface in double-phase monotectic melts on orbit. It promotes braking of wave disturbances in the range of wave lengths $1\cdot 10^{-2}$-1.0 m.

4. References

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