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ALUMINUM ALLOYS

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CASTING OF ALUMINUM ALLOYS WITH PRESSURE CRYSTALLIZATION. PART 2

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The first part of the paper published in No. 11, 2011 was devoted to the stages of the development of the method of casting with pressure crystallization (CPC) of aluminum alloys, the special features and conditions of forming of such castings by the main pressing techniques. In the second part of the paper the results of studies of the structure and properties of aluminum alloys after CPC and the features of production of various articles by this method are considered.

Key words: aluminum alloys, castings, casting with pressure crystallization, cooling curves.

Compaction of Preforms in Solidification

Compaction of a casting produced with pressure crystallization (CPC) is characterized indirectly by the displacement of the plunger (upper end of cylindrical casting solidifying under pressure). We computed the displacement of the plunger under the condition that during compaction of the solidifying casting it is directly proportional to the shrinkage of the alloy in liquid state, during solidification, and in solid state. The dependences obtained allowed us to compute the displacement of the upper end of a casting formed due to CPC and then to take these computations into account when we adjusted the control equipment mounted on hydraulic presses.

For castings of a flange type the computation gave us the following mathematical dependence:

$$h_{ç}/H = \varepsilon_{æ}(t_{çàë} - t_{ëèê}) + \frac{\varepsilon_v K_{к}}{H}\sqrt{\tau_{з}}, \qquad (1)$$

where h_s is the displacement of the upper end of the casting under the action of pressure at the moment of the end of solidification (mm), H is the height of the casting (mm), t_{cas} and t_{liq} are the temperatures of casting and liquidus of the alloy (°C) respectively, ε_{liq} and ε_v are coefficients of shrinkage of the alloy in liquid state and in solidification respectively, K_s is the solidification coefficient (mm/sec$^{0.5}$), and τ_s is the time of solidification of the casting (sec).

The data of the experiments and the results of their mathematical processing confirm the assumption used in the computation that the displacement of the upper end of the casting from the moment of application of pressure and the volume shrinkage of the alloy in the corresponding periods are directly proportional. Table 1 presents the computed (by formula (1)) and experimental values of h_s/H for a casting 50 mm in diameter and about 100 mm high from aluminum A7 and alloy AK22 at a rated pressure of 100, 200, and 300 MPa.

However, the displacement of the upper end of the casting does not allow us to predict the occurrence of displace-

TABLE 1. Relative Displacement of the Upper End of a Casting h_s/H at the Moment of End of Solidification

Material	t_{cast}, °C	p_r, MPa	h_s/H	
			Computed	Experimental
Aluminum A7	720	100	0.098	0.096
		200	0.109	0.104
		300	0.111	0.106
Alloy AK12	680	100	0.062	0.063
		200	0.064	0.066
		300	0.065	0.068

Notations: t_{cast} is the casting temperature; p_r is the pressing pressure; h_s is the displacement of the upper end of the casting under the action of pressure at the moment of end of solidification (mm), and H is the height of the casting (mm).

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TABLE 2. Characteristics of the CPC Process for Aluminum, Aluminum Alloys, and Composite Materials (CM)

Material	τ_s, sec	δT_{cr}, °C	p_0, MPa	$(h/H)_s$
Aluminum A7	6.2	10	95	0.099
CM Al – 5% SiC	10.2	5	55	0.043
CM Al – 10% TiC	6.8	6	35	0.053
Alloy AK12	6.9	8	140	0.066
CM AK12 – 5% SiC	7.1	4	100	0.045
CM AK12 – 5% TiC	10.2	5	110	0.075
Alloy Al – 4.5% Cu	9.2	11	50	0.120
CM Al – 4.5% Cu – 2% Al_2O_3	13.0	8	140	0.108

Notations: τ_s is the time of solidification of the casting; δT_{cr} is the growth in the crystallization temperature (liquidus) under the action of pressure; p_0 is the pressure at which the crystallization temperature of the metal (alloy) starts to grow; $(h/H)_s$ is the relative displacement of the upper end of the casting at the moment of end of solidification.

ment of individual layers (zones) located at different distances from the upper or lower ends over the height.

To study the displacement of individual layers of a casting solidifying under pressure we used a method developed at the Moscow State Open University (MGOU). For this purpose small permanent magnets are mounted on the vertical walls of the die on the side of the working cavity at fixed distances from the bottom before casting the melt. The melt is poured so that the stream does not wash them off. The difference between the distances of each magnet from the bottom of the die and from the lower end of the casting after its cooling to room temperature corresponds to the displacement of each magnet and of the respective layer of the casting under the action of pressure.

The use of this method for studying commercial alloys and aluminum allowed us to establish that the displacement of the layers, and hence the compaction of the solidifying casting, is the highest in the upper zone adjoining the plunger and lying at a distance of about 1/3 of the height of the casting from it. This confirms the results obtained earlier for other alloys at the MGOU and Nizhny Novgorod State Technical University (NGTU). As the distance from the upper end of the casting (the place of application of pressure) increases, the displacement of the layers decreases obeying an almost parabolic dependence. The absolute values of the displacement of each layer depend on the pressing pressure, on the volume shrinkage, and on the mechanical properties of the alloy at high temperatures.

CPC of Composite Aluminum-Base Materials

We studied solidification and cooling in the process of CPC of castings from composite materials with a matrix of aluminum and aluminum alloys AK12 and Al – 4.5% Cu. The hardening additives were titanium carbide, silicon carbide, and aluminum oxide. It turned out that the mathematical dependences obtained earlier for aluminum and aluminum-base alloys remained true for the composite materials, but with other numerical values. It should be noted that the introduction of hardening particles into a metallic melt changes the properties of the alloys and their susceptibility to compaction during solidification (Table 2). Castings from composite materials are compacted to a less degree than castings from traditional aluminum alloys.

Macro- and Micro-Structure of Silumin "Crusts" Growing on the Side of the Plunger

On the surface of detachment of "crust" from nonsolidified remainder we detected light and dark regions with no principal difference in the structure. In these regions we observed "branches" of eutectic silicon (alloy AK12) growing horizontally along dendrites of the α-solid solution. The number of the protruding dendrites growing faster than the eutectic was inconsiderable. We also observed regions of spherical shape bounded by a light band; these regions had a structure no different from that of the near-lying regions consisting of dendrites of α-solid solution and an eutectic. In individual regions of the surface of the "crust" we found regions shaped as an elongated drop. These regions seem to have been formed after detachment of the "crust" from the not solidified remainder due to squeezing of the liquid phase from dendrite spacing or due to the action of the forces arising on the "melt – solidification front" interface upon detachment of the "crust."

The microstructure of the "crusts" in their cross section has a directed pattern (in accordance with the removal of heat), i.e., is directed from the plunger to the surface of detachment of the crust from the not solidified remainder. In this transition the size of a dendrite cell increases in direct proportion to the distance from the external surface (by a linear law).

The "crusts" have the following mechanical properties (cast state, the axis of the rupture specimens is perpendicular to the applied pressing pressure): σ_r = 175 – 180 MPa, δ = 11.4 – 12.0% for alloy AK12 and σ_r = 202 – 209 MPa, δ = 14.2 – 18.0% for alloy AK7ch.

Structure of Cylindrical Castings

In the present work we obtained data confirming the fact that under conditions of CPC the structure of castings from various nonferrous metals is refined. This is promoted by the elevated rate of cooling and by the action of pressure both on the conditions of appearance of crystallization centers and on the growing crystals.

The most substantial refining of structure (by a factor of 2 – 3) was observed in the pressure range from atmospheric one to about 100 MPa. Subsequent increase in the pressure to 300 – 400 MPa also caused considerable decrease in the

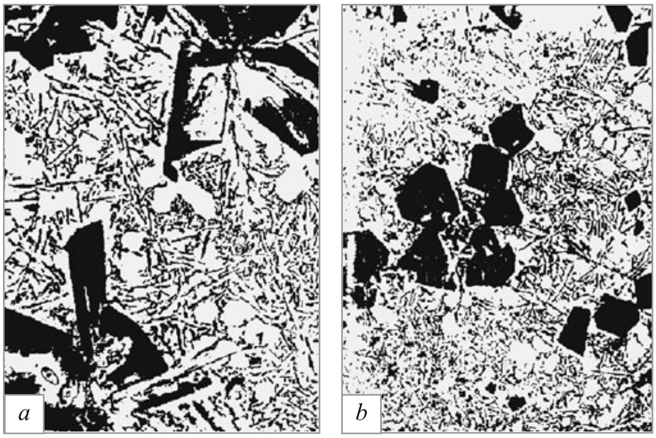

Fig. 1. Microstructure of castings from alloy Al – 25% Si solidified at atmospheric pressure (*a*) and at a pressure of 320 MPa (*b*).

grain size but it was much lower than in the first pressure range.

The structure of the castings from hypoeutectic silumins is characterized by the presence of dendrites of α-solid solution and a eutectic (α + Si). The structure of the castings from alloy Al – 13% Si solidified at atmospheric pressure contains crystals of primary silicon (CPS) and a eutectic. In CPC the sizes of CPS decrease upon growth in the pressure. The area occupied by them also decreases, which indicates a shift of the eutectic point to the right, i.e., toward silicon. In castings from hypereutectic silumin (with 25% Si) growth in the pressure during crystallization is also accompanied by refining (crushing) of the CPS (Fig. 1). In chill casting the sizes of silicon crystals d_{CPS} = 70 – 75 μm, whereas solidification under a pressure p_r = 320 MPa yields d_{CPS} = 20 – 23 μm. The configuration (shape) of the CPS does not change.

Shifting of the eutectic point to the right, refining of the eutectic, growth in the solubility of silicon in aluminum, and the observed elimination of shrinkage porosity in castings formed due to CPC raise their mechanical properties. The simultaneous growth in the characteristics of strength (σ_r, HB) and ductility (δ) of silumins after CPC is explainable by refining of dendrites of the α-solid solution, CPS and components of the eutectic, as well as by the thermophysical properties of the eutectic.

A study of the microstructure of silumins with 13 – 25% Si has shown that the SPC located in the α-solid solution have a different structure (Fig. 2), which does not affect markedly the mechanical properties of the silumins. The principal factor here is not the structure of the CPS but rather their sizes that change under the action of pressure on the solidifying casting. The pressure promotes refining of the CPS but does not affect substantially their configuration.

The microstructure of alloys of the Al – Cu and Al – Mg systems under pressure crystallization also undergoes substantial changes that cause a change in the solidification and compaction parameters and in the mechanical properties of the castings. For example, pressure crystallization of alloys of the Al – Cu system produces marked refining of the α-solid solution and of the $CuAl_2$ phase. In the alloys with composition close to the eutectic one, which crystallize in a typically dendritic form, we detected a considerable decrease in the sizes of dendrite cells and used these data to compute the cooling rate equivalent to the acting pressure.

Growth in the crystallization pressure promotes refining of the structure of castings from alloys of the Al – Zn – Mg system (for example, AL24P) both in cast condition and after heat treatment T6. The microstructure of castings from these alloys in cast condition is characterized by the presence of dendrites of α-solid solution and various phases, the number and the volume of which changes noticeably over cross sec-

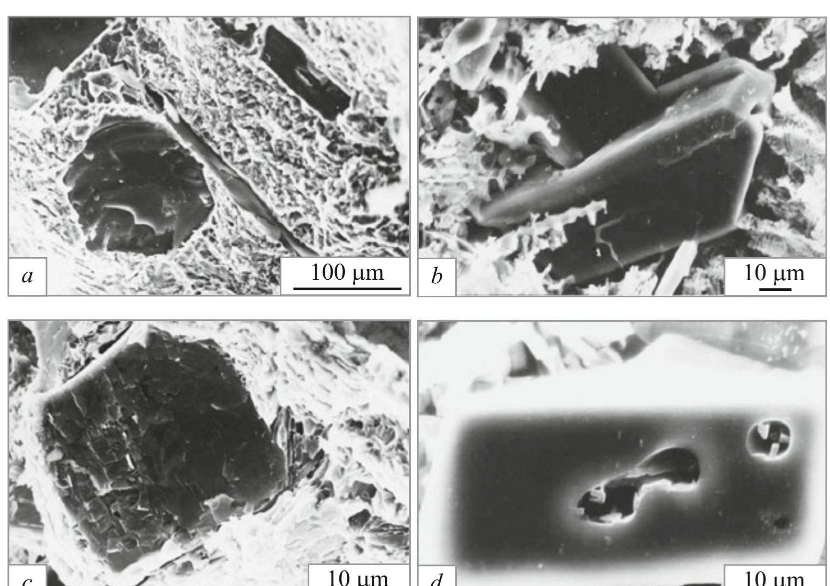

Fig. 2. Crystals of primary silicon with different shapes (*a* – *d*) in castings solidified at a pressure of 160 – 320 MPa (alloy Al – 17% Si).

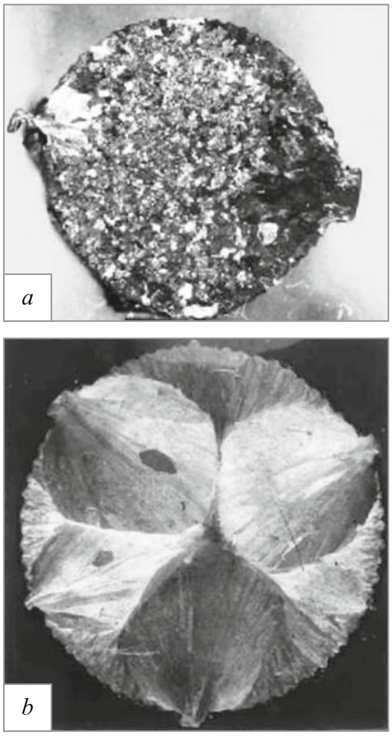

Fig. 3. Macrostructure in cross section of cylindrical castings (D = 50 mm, $H \approx$ 100 mm) produced at atmospheric pressure (a) and by the method of CPC at p_r = 150 MPa (b).

tion and over the height of the preform. Upon growth in the pressure the distance between second-order dendrite arms decreases and the content of the $MgZn_2$ phase increases in the upper zone of the casting. In the middle zone the distance between the second-order dendrite arms decreases over the height upon growth in the pressure, and the location of the $MgZn_2$ and T ($Al_2Mg_3Zn_3$) phases changes.

In cast condition growth in the pressure is accompanied by continuous increase in the strength characteristics (σ_r grows from 96 to 275 MPa); after heat treatment by regime T6 the strength properties "jump" only upon transition from atmospheric pressure to mechanical one (σ_r increases from 430 to 450 MPa and $\sigma_{0.2}$ increases from 360 to 375 MPa). The ductility parameters increase both in cast condition (from 2.1 to 11.3%) and after heat treatment by regime T6 (from 4.9 to 9.0%).

Thus, growth in the CPC pressure raises noticeably the mechanical properties of castings from all the alloys studied, especially the ductility characteristics.

Combined Structures in Castings

We studied deformation of castings in partially heat-insulated molds in CPC of aluminum alloys. A deformable alloy with composition close to that of pure aluminum was cast into the die of a press mold insulated on the side of the working cavity by sheet asbestos with a thickness of 1 – 5 mm.

TABLE 3. Mechanical Properties of Castings from Alloy B1T (Cast State)

Zone of casting	p_r^*	$\sigma_{0.2}$, MPa	σ_r, MPa	δ, %
Coarse crystals	150	117	173	19
	300	143	182	27
Fine crystals	150	122	208	27
	300	144	214	28

* Pressing pressure.

Slots with a width of 1 – 8 mm were made in the asbestos to almost the whole of the height of the die for direct contact between the melt and the walls of the die. A typical macrostructure of cylindrical castings in presented in Fig. 3.

It can be seen that the zone of coarse crystals growing on the side of the uninsulated surfaces of the die has an almost circular configuration. In the castings solidified at atmospheric pressure (Fig. 3a) these crystals are much smaller than in the castings solidified under the pressure of a piston (Fig. 3b). When the width of the zones of contact between the melt and the die increases, the sizes (the width) of the zones of coarse crystals grow. The presence of different zones affects the mechanical properties of the castings (Table 3).

Thus, the data obtained show that it is possible to create in castings combined structural zones with different mechanical properties by controlling the pressing pressure, the thickness of the heat-insulating coating, and the conditions of cooling of individual parts (or zones) of the preform.

Metallographic studies of castings of a nozzle type (plunger pressing) have shown that the macrostructure of castings from aluminum A7 is represented by columnar crystals elongated in the direction of the heat flux, i.e., to the external and internal sides of the walls of the "nozzle" bounded by the heat center. The width of the crystals increases upon growth in the thickness of the wall of the casting (other conditions being equal).

The macrostructure of castings with wall thickness X_{cast} = 10 and 15 mm from alloy AK7ch is similar to the macrostructure of castings from aluminum A7. The heat center in the castings with X_{cast} = 15 mm from alloy AK7ch shifts to the internal surface. In the castings with X_{cast} = 10 mm the macrograins at the internal surface of the wall are 3 – 4 times thinner than at the external surface. In the castings with X_{cast} = 5 and 20 mm fine and round macrograins are observed over the whole of the height of the wall. Only at the lower part at the external wall the casting with X_{cast} = 5 mm bears coarse crystals elongated toward the die. The heat center in them is located at an equal distance from the vertical surfaces. In all castings from alloy AK7ch the macrostructure of the bottom part consists of primarily coarse macrocrystals.

The macrostructure of castings from alloy AK12 contains a crust on the side of the external surfaces, which has formed prior to the introduction of the plunger into the melt. The uniformity of the structure over cross section of the casting is mostly affected by the temperature (t_{cast}, t_m) and time (τ_d) parameters. For example, at $t_m < 50°C$ and $\tau_d > 3$ sec a crust of a considerable thickness forms on the sides of the side surface and bottom of the die prior to the introduction of the plunger into the melt; the crust is partially eroded by the melt squeezed by the plunger.

The macrostructure of castings from alloy AK18N also has a crust on the side of the external and internal walls; the crust is poorly manifested only in the casting with $X_{cast} = 20$ mm. The structure of the central zone is homogeneous and fine-grained, just like the structure of the bottom part of the casting.

The microstructure of nozzle-type castings from alloys AK7ch and AK12 consists of dendrites of α-phase and an (α + Si) eutectic; the microstructure of castings from alloy AK18N is represented by CPS and a eutectic. The microstructure of castings of the same alloy does not change when the thickness of their wall is increased and over the height of a wall of the same thickness. For example, the distance between the second-order dendrite arms d_{II} increases from 30 to 40 μm (alloy AK7ch) and from 25 to 32 μm (alloy AK12) upon growth in the wall thickness from 5 to 20 mm. Upon transition from the external surface to the internal one the value of d_{II} decreases over the thickness of the wall inconsiderably (by about 5 μm). In the upper zones of the wall d_{II} is commonly less by 10 – 5 μm than in the lower zones. For example, in castings from alloy AK7ch with wall thickness 5 mm $d_{II} = 20$ μm in the upper zones and $d_{II} = 35$ μm in the lower zones; in the castings with wall thickness of 20 mm $d_{II} = 25$ and 40 μm respectively. In casting from alloy AK12 this difference is lower; for wall thickness of 5 mm $d_{II} = 25$ and 30 μm, while for wall thickness of 20 mm $d_{II} = 25$ and 35 μm in the upper and lower zones respectively.

The hardness of castings from different alloys varies as follows: 70 – 100 *HB* for AK7ch, 70 – 120 *HB* for AK12, 105 – 140 *HB* for AK18N, and 111 – 121 *HB* for AK8M3ch.

The mechanical properties of the alloys (Table 4) were determined for nonstandard specimens cut from vertical walls of castings, which preserved cast surface on both sides. The specimens had a length of 55 – 60 mm and a thickness of 9 – 10 mm.

We analyzed the location of the place of failure (rupture) of the specimens with respect to the lower end of the castings. We have mentioned that plunger pressing may yield junctures propagating from the external surface into the depth of the wall over the level of pouring of melt into the die. In our tests of castings with wall thickness of 10 mm this level was located at 38 ± 2 mm from the bottom of the die (and hence from the lower end of the casting); the thickness of the bottom was 10 ± 3 mm. The specimens ruptured at the following distances from the lower end of the casting: 24 – 29 mm (aluminum A7), 25 – 48 mm (alloy AK7ch), 26 – 28 mm (alloy AK12), and 21 mm (alloy AK17N). These results show that the rupture went not over the level of pouring of melt into the die but lower, which is an indirect indication of absence of junctures in the castings.

TABLE 4. Mechanical Properties of Nozzle-Type Castings Produced by the Method of CPC at $p_r = 150$ MPa (Cast State)

Metal, alloy	X_{cast}, mm	$\sigma_{0.2}$, MPa	σ_r, MPa	δ, %	h_{rup}, mm
A7	5	39.0	63.5	30.2	24
	10	40.0	68.5	35.5	25
	20	47.0	65.0	35.6	29
AK7ch	5	106.5	217.5	7.5	25
	10	53.5	210.0	2.0	28
	15	86.0	200.0	2.6	25
	20	63.0	180.0	2.8	43
	GOST 1583	–	≥ 150.0	≥ 0.5	–
AK12	5	54.0	197.8	2.95	28
	10	102.5	215.0	5.0	28
	15	65.5	220.0	9.0	26
	20	111.0	213.0	7.3	27
	GOST 1583	–	≥ 160.0	≥ 2.0	–
AK18N	5	47.5	145.5	4.0	21
	10	114.5	170.0	0.6	21

Notations: X_{cast} is the thickness of the wall of the casting; h_{rup} is the place of rupture of the specimen (distance from the lower end of the casting).

The intense external thermal and force action on liquid and crystallizing hypereutectic silumins in CPC is an effective factor of refining of structure and growth in the mechanical properties. A high level of structural parameters and properties in hypereutectic silumins is provided by a complex treatment that includes inoculation with phosphorus in addition to the external thermal and force action.

We studied the mechanical properties of barrel-type castings with $X_{cast} = 15$ mm from sparingly alloyed high-strength aluminum alloys of the Al – Zn – Mg – Ni system (nikalins) produced by the method of CPC ($p_r = 50$ MPa). The results were as follows. Heat treatment by regime T4 yielded $\sigma_{0.2} = 321 – 333$ MPa, $\sigma_r = 430 – 466$ MPa, δ = 5.4 – 5.8%; heat treatment by regime T6 yielded $\sigma_{0.2} = 518 – 541$ MPa, $\sigma_r = 551 – 572$ MPa, δ = 0.42 – 0.52%.

We studied the possibility of obtaining a thixotropic (spheroidized) structure in nozzle-type castings and established that it depended on the intensity of the motion of the melt in the cavity of the press mold, which depended in its turn on the configuration and sizes of the casting.

Plunger-piston pressing makes it possible to obtain quality castings. However, the defects arising in some of them (especially in castings with complex configuration) affect the properties of cast parts. We studied the quality of castings in the form of nozzles with ribs and flanges in the internal cavity. The castings were produced from alloy AK7ch by plunger pressing (the external wall) and plunger-piston pressing (the internal cavity with ribs and lugs).

Analysis of the data obtained showed scattering of the properties of specimens cut from various lug zones. In ruptures of low-strength specimens we detected quite large flaws of a gas shrinkage origin. The flaws were of two types, i.e., some had a lustrous surface and others had a light somewhat rough surface (these flaws were more numerous). Microchemical analysis of the surface of flaws of the first type represented by light regions against a dark background of aluminum oxide showed the presence of a wide spectrum of elements not contained in the alloy; such flaws were blisters of an exogenous nature formed upon squeezing of not solidified alloy by the pressing plunger (into its working cavity) in final shaping of the casting, because the plunger had gas-removing channels.

The roughness of the surface of flaws of the second type is explainable by the presence of dendrites uncovered too early. One part of the surface of a blister consists of only dendrites of α-solid solution and the other part consists of dendrites of α-solid solution with fine plates of eutectic silicon in between. It seems that such flaws appear due to deficit of liquid alloy during solidification of this zone of the casting.

We detected crystals of primary silicon on some rupture surfaces, which is not typical for hypoeutectic silumins. This is a very brittle structural component that breaks by chipping prior to the failure of the specimen itself, as a result of which the strength of the alloy decreases. The formation of crystals of primary silicon seems to be connected with the appearance of local zones of high pressure, which displaces the eutectic point toward silicon.

Despite a whole number of advantages over other special casting methods CPC requires careful analysis of the structure and mechanical properties of the castings. This is especially important in the case of noticeable differences in the parameters of mechanical properties of one and the same casting in different zones. This concerns castings shaped by plunger and plunger-piston pressing, when considerable masses of not solidified alloy are moved by the pressing plunger. The blisters form after entrainment of air by the moving metal, which is not emitted from the forming casting and remains on its walls. Any kind of ventilation of the press form does not provide total removal of such blisters, but the presence of gas-removing channels is necessary (especially for the plunger-piston technique).

Feeding of individual elements of castings in CPC is provided by additional mechanical pressure. The presence of pipes and pores in some zones of a casting indicates that the pressure in this zone has been insufficient or inefficient. This means that the design of the casting or the scheme of the pressing should be changed.

Other conditions being equal, higher pressing pressure corresponds to higher mechanical properties in castings fabricated by the plunger or plunger-piston techniques.

Structure and Properties of Castings after Several Cycles of CPC

We studied the effect of three successive cycles of “remelting – crystallization under pressure” in CPC of silumins (the castings were cylindrical preforms with $D = 50$ mm and $H = 60 – 70$ mm). After the first cycle the mechanical characteristics were as follows (cast state): $\sigma_r = 255$ MPa, $\delta = 16\%$ (alloy AK12, $p_r = 150$ MPa). After the second cycle of the treatment these properties decreased inconsiderably, i.e., $\sigma_r = 242$ MPa, $\delta = 0\%$. After the third cycle $\sigma_r = 226$ MPa, $\delta = 9\%$. Consequently, several successive CPC cycles of a charge from 100% scrap in the absence of out-of-furnace treatment of the melt resulted in some decrease in the mechanical properties of the preforms. This is explainable by contamination of the melt in repeated remelting without out-of-furnace treatment. However, even after the third cycle of the treatment the mechanical properties of the preforms exceeded the requirements of the GOST 1583–89 standard ($\sigma_r \geq 150$ MPa, $\delta \geq 2\%$). Addition of 50% alloy not subjected to CPC into the charge did not affect noticeably the strength characteristics of the products ($\sigma_r = 241 – 242$ MPa) but reduced the ductility δ from 10.8 to 5.8%.

Application of three successive cycles of “remelting – crystallization under pressure” in the mode of plunger pressing to nozzle-type castings ($D = 60$ mm, $H = 60$ mm, $X_{cast} = 15$ mm, $p_r = 150$ MPa) showed that in the transition from the first cycle to the third one the mechanical properties changed as follows (cast state): σ_r changed from 207 to 212 MPa (alloy AK7ch) from 183 to 200 MPa (alloy AK12), and from 165 to 153 MPa (alloy AK18N); δ changed from 8.6 to 5.4%, from 4.5 to 7.%, and from 1.4 to 0.7%, respectively. The crystals of primary silicon were refined noticeably in the castings from alloy AK18N after the third treatment cycle; the number of coarse crystals of primary silicon was almost halved.

CPC of High-Strength Aluminum Alloys

A CPC process has been developed for high-strength aluminum alloys AL24P and AL9M for special-purpose cast parts. Press-molds have been designed and modes of CPC worked out for thin-wall castings of “Bell” and “Piston” types. The “Bell” castings have the following mechanical properties (after heat treatment T7): ($\sigma_{0.2} = 265 – 295$ MPa, $\sigma_r = 310 – 410$ MPa, $\delta = 4.6 – 2.5\%$; the “Piston” castings possess $\sigma_{0.2} = 300 – 318$ MPa, $\sigma_r = 390 – 435$ MPa, $\delta = 10.6 – 16.3\%$.

CPC of Deformable Alloys

We studied the laws of formation of castings in CPC of a deformable aluminum alloy with composition close to pure aluminum and low additives of nickel, titanium and iron. The alloy is used for parts produced by die forming. We tested preforms in the shape of a small solid cylinder and a nozzle. We used specially designed press-molds with a block die frequently used at plants. We worked out process modes for CPC of a deformable low-alloy aluminum alloy; the structure obtained in the castings was equiaxed and fine-grained; the parts were produced from them by the method of cold extrusion.

CPC of Antifriction Alloys

A CPC process has been developed and studied for antifriction aluminum alloys AK6M7 (without additive and with an additive of 1 – 10% Pb) and AO3-7 used for making cast parts for gear-type pumps. We studied the properties of cylindrical castings 50 mm in diameter and 40 – 105 mm high. We determined the heat and force conditions of the CPC providing dense castings with high mechanical and operating properties including the coefficient of sliding friction in the "shaft – bushing" system.

A study of segregation processes in castings has shown that in CPC the tin and lead contained in aluminum alloys are susceptible to reversible segregation or density segregation. The compositions of the alloys were optimized with respect to the lead content. Casting of melt at a temperature exceeding 750°C yields an inhomogeneous structure over the height of the casting. For this reason we recommend the following characteristics for piston pressing: $t_{cast} = 720 – 740$°C, $t_m = 200 – 220$°C, $p_r = 150 – 200$ MPa, $\tau_d = 3$.

CPC of Bushings

Bushings for a gear-type pump of type NSh-32U are produced from antifriction aluminum alloy AO3-7 (GOST 14113–78). This alloy has been designed for monometallic friction bearings (bushings, inserts, etc.) operating under conditions of friction with a lubricant. Alloy AO3-7 should possess the following mechanical properties: $\sigma_r \geq 170$ MPa and 75 – 117 *HB*. The value of σ_r is determined for specially cast test pieces, and the hardness is determined on the wide end of the bushing after heat treatment by regime T1.

In the case of plunger-piston pressing the casting acquires the final shape during the introduction of the pressing plunger into the melt, when a part of the not solidified alloy is squeezed by the plunger above the level of pouring into the cavity formed by the plunger and by the hole-making rod. In most castings fabricated by this pressing scheme we have detected reverse segregation and inhomogeneity of structure over cross section. In the thin part formed by the melt squeezed during shaping of the casting we observed zonal segregation. The main components of the segregate were oxide scabs of an Al_2O_3-type and of a more complex composition and tin. The change in p_r, t_{cast}, and t_m within the ranges studied did remove fully the structural inhomogeneity over the height of the bushing but allowed us to outline the ways for localizing and lowering the segregation. These ways are lowering of t_{cast} and raising t_m.

In the case of piston pressing the thin part of a "Bushing" casting was located at the bottom and could solidify prior to the application of pressure. For this reason we strove to perform the tests at τ_d of 3 – 4 sec.

TABLE 5. Consumption of Alloy AO3-7 for a "Bushing" Casting

Method of casting	Mass, kg			CUM*
	part	casting	intakes and risers	
Chill casting	0.156	0.270	0.110	0.58
CPC		0.215	–	0.73

* Coefficient of utilization of metal.

The study of the microstructure of the castings showed the presence of zonal segregation. The structure of the castings became coarser with growth in the casting temperature. Casting of melt at a temperature exceeding 750°C yielded an inhomogeneous structure over the height of the casting. Therefore, we recommend $t_{cast} = 720 – 740$°C for the case of piston pressing.

Comparative data on the consumption of aluminum alloy AO3-7 for a "Bushing" casting for the cases of chill casting and CPC are presented in Table 5. It can be seen that the transition from chill casting to CPC decreases the mass of the casting (CPC into a single-cavity press mold) by 0.055 kg, removes completely intakes and risers, and thus saves 0.11 kg more per one preform.

CPC of Compensators

"Compensator" is a part of a gear-type pump. Its flat end surface mates rotating steel gears and the side surfaces with a seal adjoin the walls of the internal cavity of the body of the pump. The casting has a shape of an "eight" with two openings. Grooves are made on the flat end surface and a bead is made on the opposite side for fixation of a rubber seal. The side surface has a complex configuration and is not subjected to mechanical treatment. The sizes of this surface have an allowance for assembly of the gear pump. The mean thickness of the wall is about 8 mm.

We tested three schemes of pressing of formed castings and chose the plunger-piston variant. The CPC regimes were varied within the following ranges: $t_{cast} = 650 – 750$°C, $t_f = 80 – 270$°C, pressing pressure 0.6 – 1 MN, time of holding of the forming casting under pressure 5 – 20 sec, interval from the end of pouring of the melt into the die to the start of the loading 3 – 12 sec.

We studied the structure and mechanical properties of castings produced by CPC from an alloy of the following composition (wt.%): 7.2 Si, 6.3 Cu, 0. Mg, 0.28 Mn, 0.9 Fe, 0.2 Zn, 0.08 Ni, the remainder Al. The mechanical properties were determined for nonstandard specimens cut directly from cast "Compensator" preforms (perpendicularly to the action of the pressing force).

Figure 4*a* presents the microstructure of a cast "Compensator" preform. The alloy contains the following structural

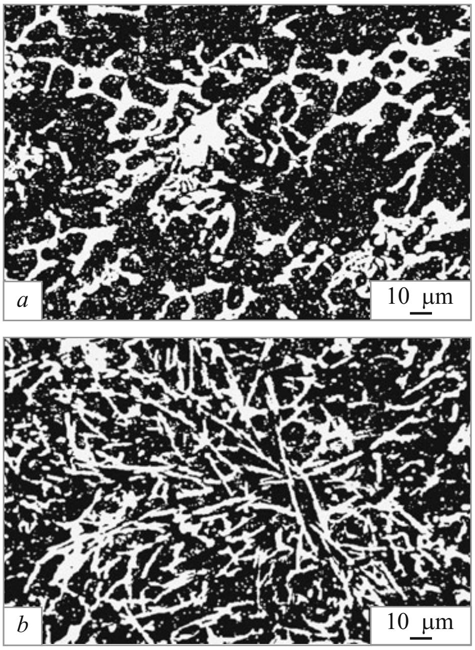

Fig. 4. Microstructure of cast parts of "Compensator" type produced from copper silumin by the method of CPC (*a*) and by injection casting (*b*).

components: aluminum solid solution (α-phase), β-phase $[(FeMn)_3Si_2Al_5]$ in the form of a coarse light net, *W*-phase (Cu, Mn, Ai, Si) in the form of gray inclusions against a white background, and an Al – Si eutectic. The mechanical properties of the castings (cast condition) are $\sigma_r = 180 - 187$ MPa, $\delta = 2.7 - 2.9\%$, 115 *HB*.

For comparison we present in Fig. 4*b* the microstructure of a casting obtained by injection casting from an alloy of the following composition (wt.%): 5.5 Si, 5.6 Cu, 0.13 Mg, 0.16 Mn, 0.73 Fe, 0.20 Zn, 0.2 Ni, 0.01 Pb, the remainder Al. The microstructure of the casting is represented by the same structural components as that of the castings produced by CPC. It should be noted that the segregations of the β-phase have the form of light needles, which is less favorable and causes lowering of the mechanical properties, i.e., $\sigma_r = 164 - 172$ MPa, $\delta = 1.9 - 2.6\%$, 98 *HB*.

The CPC process for preforms of "Bushing" and "Compensator" types has been installed at the "Gidromash" Company.

CONCLUSIONS

The data presented allow us to infer that a wide use of the method of casting with crystallization under pressure (CPC) at machine-building plants should promote substantial growth in the quality of castings at considerable saving of the materials and power for their production.