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GAS-DYNAMIC INFLUENCE ON THE STRUCTURE OF CAST OF A356 ALLOY

Physical and mechanical properties of cast metals are known to be dependant on a number of factors. Therefore production engineers and researchers are continuously challenged by the development of production processes aimed to reduce overhead losses of metal and improve its quality.

The best and most stable qualities in terms of cross-section of casts are attained by a fine-grained homogeneous structure. The smaller primary crystals, the better certain important operation and production qualities of casts.

Modification is basically used to achieve this goal, which is a process that involves pressure and introduction of focused energy sources-induced elastic vibrations into alloy [1–14].

This paper deals with an efficient modification of morphology of crystallizing phases at hardening under pronounced non-equilibrium conditions by studying the effects of variable gas pressure on A 356 alloy structure formation, with grains refined and the growth of coarse inclusions of primary intermetallic compounds prevented.

Modification is among the most common ways to obtain a fine-grained homogeneous metal structure.

This paper deals with modification of aluminum-silicon alloys (silumins), which serve as a basis of the majority of cast aluminum compositions, the latter comprising widely used mold castings materials in aircraft industry, construction, transport, etc. Strength properties of silumins are quite poor, especially moldability, due to a special structure of cast alloys, i. e., brittle coarse inclusions of silicon and intermetallic compounds. To improve the structure and mechanical properties of industrial cast aluminum alloys, we need to adjust welding and casting modes, as well as mold crystallization conditions (sand casting, metal casting, casting under pressure, etc.). The most powerful factor of favorable silumin structure formation, however, is modification, which is structure refinement by introducing small additives of modifiers into alloy before casting.

Modifiers acting on primary grain sizes and eutectic silicon inclusion shape are most interesting in terms of silumin ingots production. To modify grains in α Al-solid solution (groundmass), elements of transition groups shall be primarily used. The more d and f unfinished shells they have, the stronger their modification effect will be. At interaction with aluminum, modifiers are forming high-melting intermetallic compounds (TiAl_3 ; ZrAl_3 ; TiB_2 , etc.) with similar crystal lattices, with the size of parameters in certain crystallographic planes matching to that of lattices in α Al-solid solutions. Lots of crystallization centers, as emerging in melts, are attributable to grain refinement in molds. Grains in aluminum alloys can be largely refined by introducing titanium and boron as an Al–Ti–B triple alloying composition ($\text{Ti/B} = 5/1$). 2–6 μm TiB_2 particles serve as crystallization centers. Al–Ti–B triple alloying composition (1 % B; 5 % Ti), so-called «zernolit» (%: $55\text{K}_2\text{TiF}_6 + 3\text{K}_2\text{SiF}_6 + 15 \text{C}_2\text{Cl}_6$) or potassium fluoroborate and fluorotitanate-containing flux (%: 35NaCl ; 35KCl ; $20\text{K}_2\text{TiF}_6$; 10KBF_4) are used to introduce titanium and boron. Titanium and boron are optimally absorbed when using a flux that has a combined modifying-and-finishing effect. Combined modification with zirconium, titanium and boron yields good results [5].

Niobium as Al–10 %Nb alloying composition or K_2NbF_7 salt also can be used as a modifier. NbAl_3 crystal nuclei are stable in aluminum melt. Modification with Al–10 %Nb alloying composition is more efficient, with melt equalizing time after modification longer (versus K_2NbF_7).

Sodium is a traditional eutectic silumin modifier. While its modifying effect is generally recognized, the action of other elements is disputable. The use of Na as a modifier is limited due to some major flaws, such as: a risk of obtaining an undermodified or overmodified structure; higher

gas content, lower flowability, shrinkage porosity (alkaline and alkaline-earth metals reduce aluminum melt density, increase thermal factor of volume expansion and, therefore, volumetric shrinkage on crystallizing); loss of modifying effect after finishing, filtration, and degassing; and fast burning requiring to resume modification every 30 minutes. The latter is particularly harmful in serial and mass cast production, because a melt treated with sodium-containing fluxes provides a fully modified structure solely at the initial period of casting. Therefore, substitution of sodium and its compounds with other modifiers has been considered [5]. The use of Sr as an industrial modifier of Al-Si alloys was studied. Its advantages over sodium are primarily related to a long-lasting modifying effect, which is also maintained after remelting. Optimal concentration of strontium is about 0,04 %, with modifying temperature of 750–770 °C [5]. However, studies have revealed a number of major drawbacks preventing its broad use. Introduction of metal strontium is hindered by spontaneous inflammation, toxic fumes, and the need to increase the temperature of melt, which contributes to its gas absorption. Moreover, the use of strontium is also limited due to its high costs.

Another recognized long-lasting modifier is stibium (~ 0,2 %) [5]. Its modifying effect lasts for up to 4 hours, but superseded by sodium. Increasing the contents of Sb in Mg-containing silumins up to > 0,22 % does not seem reasonable due to formation of a brittle phase of Mg₃Sb₂. Silumins modification with stibium results in higher density of casts, which significantly improves their strength and moldability, especially at higher temperatures. These additives result in no gas porosity even at low hardening rate casting (bulky sand castings). Casts structure and, respectively, their properties are less sensitive to cooling conditions, which is critical for odd-shaped articles.

Today, metal melt structure is not considered homogeneous. While there is no complete mixing of atoms at a certain temperature range, microzones of short-distance order structure, which is inherent in a crystal phase, are emerging. Such formations are called either atomic groups or small islands or atomic complexes or clusters, etc. Their density and sizes depend on the state of melt. As superheating degree grows, they dissociate and get closer to a homogeneous mix of heterogeneous atoms. However, during pre-crystallization and crystallization, atomic groups in the melt induce formation of similar crystals. In Al-Si eutectic melt, «crystallizable» Si clusters of a crystalline-like structure or heretophase complexes of Si atoms, which are actually Si crystals formation base, probably comprise such pre-crystallization atomic groups.

The use of chemical soots (nanopowders) acting as additional crystallization centers, as cast alloys modifiers has steadily growing during the last decade.

Table 1 and table 2 show the chemical composition of synthesized soots and size, crystallographic and physical parameters of compounds.

Table 1

Ultrfine synthesized materials chemical composition

Name	Elemental composition, wt. %									
	Si	Sifree	C	Cfree	N	Al	Alfree	Ti	Tifree	Mg
SiC	60...65	1,0...2,0	30...32	2,5...3,0	0,5...1,0	–	–	–	–	–
AlN	–	–	–	0,1...0,5	30...33	60...65	0,5...2,0	–	–	–
TiC	–	–	18...21	1,0...1,5	–	–	–	76...80	1,0...1,5	–
TiN	–	–	–	1,0...2,0	20...23	–	–	75...78	1,0...1,5	–
TiCN	–	–	15...17	0,5...1,0	19...22	–	–	60...65	0,5...1,0	–
Mg ₂ Si	33...36	1,0...2,0	–	–	1,0...2,0	–	–	–	–	63...65
Mg ₃ N ₂	–	–	–	–	25...28	–	–	–	–	70...75

Table 2

Ultrifine synthesized materials crystallographic and physical properties

Name	Lattice	Crystal system	Phase type	Cell parameter, nm		density, kg/m ³	Melting point (dissociation), °C	Size, nm		Surface area, m ² /gr
				a	c			Interval	Average	
SiC	hexagonal, rhombohedral	hexagonal	interstitial	0,308	1,004	3220	2830 dissociation	50...350	19,0	82,5
AlN	hexagonal	hexagonal	interstitial	0,287	0,932	2350	2200 melting	50...350	18,5	73,0
TiC	cubic	cubic	interstitial	0,432	–	4920	3140 melting	20...55	35,0	25,0
TiN	cubic	cubic	interstitial	0,424	–	5430	2950 melting	25...60	40,5	29,5
TiCN	cubic	cubic	interstitial	0,426	–	4950	3120 melting	20...55	36,5	24,5
Mg ₂ Si	cubic, spheric	cubic	substitution	0,634	–	2920	1170 dissociation	20...75	45	70,5
Mg ₃ N ₂	spheric, cubic	cubic	substitution	0,653	–	2710	1500 dissociation	35...125	78	48,0

Paper [15] studies the possibility of using complex Al–Sr–Ti–B modifier in the form of nanopowders, which are obtained from a corresponding alloying composition by electroerosion dispersion in carbon-containing environment (such as coal oil, circuit-breaker oil). Mechanical properties of complex Al–Sr–Ti–B-modified alloy were better than of those modified with a traditional Al–Sr–Ti–B modifier. Tensile strength and percentage elongation of alloys treated with a nanopowder-based modifier were 380 ÷ 400 MPa and 3 ÷ 6 % for chill-cast specimens and 280 ÷ 320 MPa and 3 ÷ 7 % for cast-cut specimens. Strength and moldability parameters were maintained at a long-term maturation of melt (up to 2 hours).

Morphology of crystallizing phases can be effectively changed by hardening in pronounced non-equilibrium [2–4, 6–13]. This creates conditions for grain refinement, high solubility increase in the solid state, and inhibition of growth of coarse inclusions in primary intermetallic compounds. More particularly, pressure applied to melt at hardening largely affects the nature of crystallization in pressurized crystallization of melts-featured casting. Higher cooling rate makes crystallization rate grow accordingly, the latter varying due to the effect of crystallization pressure on the number of centers and germs growth rate. Cooling rates increase two- or threefold and up to tenfold, all depending on the dimensions of casts and extrusion method [1]. Higher cooling rates of non-ferrous alloys based on partial miscibility systems change the structure and alloyage of solid solutions, which is attributed to coring and quasi-eutectics. The issue of high quality casting by pressurized crystallization, with pressure formed by plunger, movable die or uniform gas pressure, is widely discussed in available literature sources [1, 7, 10]. Performance of all those methods during cast

hardening is inversely related to the thickness of hardened metal layer, since its surface is exposed to internal pressure. In terms of technology, this process features a number of drawbacks, which are related, inter alia, to the need in special-purpose equipment, mass restrictions, type of alloy, cast sections configuration, etc.

Gasodynamic effect is among the most efficient treatment methods used in crystallizing metals [16, 17]. In this method, a solid alloy layer shall be formed on the surface of working space of the casting form before gas feeding, so that layer thickness could ensure leak-tightness of system until the cast is fully hardened.

Effects of variable gas pressure on structure formation of metal have been studied on A356 alloy casts, as shown in Table 3.

Table 3

Al A356 chemical composition, %

Si	Mg	Ti	Fe	Cu	Mn	Cr	Zn	Al
7,0	0,35	0,125	0,12	0,003	0,08	0,001	0,034	rest

Aluminum melts at 770 °C. Afterwards, a special-purpose NaCl, KCl, and NITRAL C 19 (Foseco)-containing powder was applied to the surface of melted aluminum. This was aimed to finish the melt and to protect it from oxidation. Finished aluminum has been kept at 720–740 °C for 3–5 minutes and introduced into the working space of an original design gas feeder, as shown in Fig. 1.

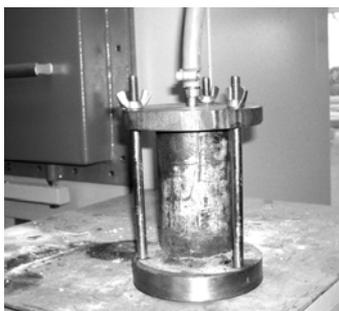


Fig. 1. Special high pressure casting form

Then, the cast has been aged with the feeder for a given period followed by gas (argon) feeding at initial pressure of 1,5–2 Atm, which was later increased up to 13–14 Atm. Afterwards, the cast has been aged under pressure, until fully hardened.

Laboratory tests proved better mechanical properties of cast product and lower porosity of 50 mm diameter and 100 mm high circular casts made of A356 alloy.

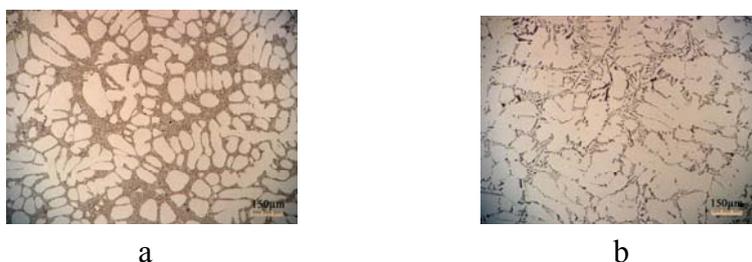


Fig. 2. A356 alloy microstructure before (a) and after treatment (b)

Figure 2 shows A356 alloy microstructure before and after the treatment.

As shown in Fig. 1, primary alloy structure, which consists of disoriented coarse eutectic rough fir-tree crystals of solid solution, is finally transformed into a structure comprised of fine eutectic small round fir-tree crystals.

This case study shows that gaso-dynamic treatment results in refinement of structural components, which provides a 20–25 % improvement of plastic properties of cast product and 8–12 % increase in density. Gase-dynamic treatment of hardening metals therefore creates modification effect, which can be largely enhanced by introducing additional crystallization centers (such as appropriate traditional modifiers or nanocrystal powders produced by mechanochemistry techniques) into the melt. This may reduce the consumption of modifier.

CONCLUSIONS

1. These data support the approach of complex implementation of active hardening metal treatment techniques, which, to a certain extent, makes up for the flaws of each specific method.
2. Gase-dynamic treatment of melts in a casting form provides for steady refinement of crystal structure.
3. Studies aimed to determine the modes of optimal combined use of alloy modification and hardening in non-equilibrium conditions, as provided by an external physical effect, are certainly of a great interest. Such complex approach ensures a more efficient refinement of structural components and significant improvement of physical and mechanical properties of cast products.
4. Combined effect on structure formation aimed to attain the required physical and mechanical properties of cast products will reduce consumption of modifier and time of treatment.

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