The effect of fast crystallization ligature modification on the microstructure of aluminum alloys

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Abstract. One of the ways to improve the mechanical and technological characteristics of aluminum alloys is to introduce modifiers into them, which are divided into two fundamentally different groups. Modifiers of the first kind, which have proven themselves to be positive, include elements such as Ti, Zr, B, Sb. Their addition to the alloy is up to 1% (wt.). Recently, studies have been conducted on the use of powder modifiers: boron carbide, silicon carbide, nitride or titanium carbide and other modifiers. Modifiers of the second kind include sodium, potassium and their salts. The disadvantage of these low-melting modifiers is that after processing the melt with them, the modification effect disappears after 30-40 minutes due to evaporation and oxidation of sodium.

1. Introduction

The use of modifiers of the first and second kind forces to carry out repeated modification operations, which significantly reduces labor productivity, leads to irrational use of equipment, excessive use of salts, and a decrease in casting quality [1-2]. This especially affects the use of such casting methods as: chill casting, low pressure casting, backpressure casting. The reason is the long casting of metal from the transfer case (up to 5-6 hours). Recently, studies have been conducted on the use of powder modifiers: boron carbide, silicon carbide, nitride or titanium carbide and other modifiers [3, 4].

For this reason, attempts are being made abroad to replace sodium and potassium modifiers with other alkaline earth metals: Ba, Sr, Rb, Cs, Fr, Ka [5].

There are several theories of modification, but there is no consensus on solving this problem with regard to aluminum alloys. This is due, firstly, to the complexity of the modification process and its dependence on the conditions of melting and casting, and, secondly, to the influence of uncontrolled impurities and components that can affect the grinding of the initial grain of the alloy. The additive introduced as a modifier must satisfy the following requirements: have sufficient stability in the melt without changing the chemical composition; the melting point of the additive should be higher than the melting temperature of aluminum.

In addition, when modifying pre-eutectic and eutectic silumins, such modifiers as strontium, barium, sulfur, carbonates of surface-active metals, nanopowders of refractory chemical compounds, metal

finely dispersed ligatures containing modifying elements titanium, boron are used. For this reason, much attention is paid to the selection of high-quality charge materials with a positive structural heredity.
The methods for producing and introducing modifiers into the melt have a stronger effect on grain refinement than the physicochemical properties of the modifier and the alloy being modified [6].

2. Materials and methods

The simplest and most reliable method for improving the quality of modifying ligatures is to increase the cooling rate of the ligatures during their crystallization. This contributes to the grinding of modifying intermetallic compounds and an increase in their number. For this, quenching is used, which is carried out with a melt in a liquid state [7]. The cooling rate of the ligature or alloy in the process of their production should be equal to 10 K/s. The methods for producing and introducing modifiers into the melt have a stronger effect on grain refinement than the physicochemical properties of the modifier and the alloy being modified [8]. Thus, the task is to obtain a finer microstructure of the alloy.

The aim of this study is to study the effect of rapidly crystallized ligatures on the microstructure of the AK7M2 alloy, taking into account the duration of the new ligature. For the study, the following materials were used:

- Aluminum grade A85 (GOST 11069-2001).
- Silicon of the Kr0 brand (GOST 2169-69).
- Mg90 brand magnesium (GOST 804-93).
- Copper grade M00 (GOST 859-78).
- Modifying ligatures in the form of bars Al-Sr10 and Al5TiB (GOST R 53777-2010).

Calculation of the charge was carried out on the silicon content in the alloy - 7%; copper - 2.2%; magnesium - 0.5%; strontium - 0.035%; titanium - 0.0 3%. The volume was calculated per 1 kg of alloy. Refining with hexochloroethane C_2Cl_6 in an amount of 0.1% by weight of the heat was also carried out. Melting was carried out in a Tamman furnace (figure 1a). Temperature control was carried out with a thermocouple BP 5/20.

Figure 1. Melting equipment: a - Tamman furnace; b - chill mold.

The samples were poured into metal chill molds (figure 1b). As a non-stick coating, a solution of hydrated lime was used, which was applied with a brush to a work surface preheated to a temperature of 200–250 °C, followed by heating under pouring to 300 °C.

3. Experimental study

To solve the tasks 4 melting was carried out, the description and purpose of the melting is presented in table 1.

Melting 1 was intended for the preparation of the AK7M2 alloy according to standard technology - after the aluminum was melted and heated to a temperature of 920–950 °C, silicon was loaded into the furnace, then copper was added, then magnesium was introduced at a temperature of 720–730 °C, and AlSr10 modifiers were loaded after its melting and Al5TiB.

Table 1. Description and purpose of melting.

Melting number	Description	Appointment
1	Smelting of AK7M2 Alloy Using Conventional Technology	Obtaining samples and ligatures
2	Smelting of fast crystallized Al-Cu33 ligature	Getting a ligature
3	Smelting of AK7M2 Alloy as Conventional technology	For samples with an alloy exposure of 3 hours
4	Smelting of AK7M2 Alloy Modified by Quickly Crystallized Ligatures	For samples with an alloy exposure of 3 hours

Next, refining was performed with hexochloroethane in an amount of 0.1% by weight of the heat. The alloy was poured into a chill mold on "Gagarin" samples, from which samples were subsequently made for studying the microstructure. Quickly crystallized ligatures were obtained by casting the finished alloy onto a steel corner measuring 50 * 50 mm. For subsequent modification, petals of the alloy with a thickness of up to 0.5 mm were selected, crystallizing at a rate of 102 deg/s.

Smelting 2 was used to obtain rapidly crystallized Al-Cu33 ligature, therefore, after the aluminum was melted and heated to a temperature of 950 °C, copper was introduced. Casting and sampling was carried out by the above method.

Smelting 3 was intended for the same purpose as melting 1. But in addition, samples were poured after 1 hour for 3 hours.

Melting 4 was also prepared as melting 1 and 3, but additionally quickly crystallized alloys AK7M2 and Al-Cu33, obtained in swimming trunks 1 and 2, were introduced. The samples were also poured after 1 hour for 3 hours.

The metallographic analysis was carried out by preparing thin sections, etching them and studying them with a Carl Zeiss AxioObserver A1m microscope (figure 2), which allows carrying out the following research methods: bright field, dark field, phase contrast, differential-interference contrast (DIC), warl contrast, polarization, luminescence.

Figure 2. Optical microscope Carl Zeiss Axio Observer A1m.

Axio Vision analyzer software was used to study the samples. Carl Zeiss is an image analysis software that is used to automatically quantify the microstructure, to obtain, process and analyze images, and to control the motorized parts of a Carl Zeiss AxioVision microscope.

In the molten state, the main structural component of all silumins is the (Al) + (Si) eutectic. Its main parameter is the dispersion (thickness of the branches of crystals (Si)). In pre-eutectic silumin, in addition to the eutectic, the main structural component is a solid solution of silicon in aluminum, which is primarily crystallized from a liquid, in aluminum - (a_{Al}). Its volume fraction is usually 30-70%. Dendritic cells (a_{Al}) n pre-eutectic silumins are surrounded by eutectic colonies (Al + Si) or weakly branched crystals of the silicon phase. The leading phase during crystallization is A1. Depending on the chemical composition and cooling conditions, various phases can be present in the structure of silumins, which depending on their nature crystallize either as part of cooperative eutectics or as independent intermetallic compounds [9].

Modification of silumins allows a radical change in the structure of alloys of the Al – Si system. Al-5Ti-B ligature is an effective modifier for pre-eutectic aluminum alloys due to the fact that it simultaneously contains titanium and boron and, therefore, more crystallization centers of the aAl phase are formed in the modifier in the form of TiB2 and (Al, Ti) B2 intermetallic compounds. Grinding of intermetallic compounds TiB2, TiAl3, etc., as well as an increase in their amount on a given unit area, contribute to an increase in mechanical properties and grinding of the microstructure of alloys in castings. Modification of the AK7M2 alloy with AlSr10 ligature causes 2.5 times grinding of eutectic silicon crystals. When a rapidly cooled alloy of the same chemical composition is introduced into the AK7M2 melt, it acts as a modifier for the AK7M2 alloy, since it grinds its structure.

The modifying effect of liquid-hardened AK7M2 alloy on a matrix melt of identical composition can be due to several factors. This is facilitated by the introduction of foreign particles into the melt along with the charge — potential centers of phase crystallization (a_{Al}).

In addition, the formation of new dispersed particles, including aluminum oxide, in the aluminum melt cannot be ruled out. But basically, it is a consequence of the formation in the melt of local dissolution zones of the modifier, which contain small crystals (a_{Al}), which are, in fact, ideal finished crystallization centers (a_{Al}) from the base melt.

When Al-Cu33 ligatures are introduced into an aluminum melt, local regions containing CuAl2 intermetallic compounds are formed in its volume, which has a modifying effect on the structure of hypereutectic silumins, in particular, on the microstructure of AK7M2 alloy.

When Al-Cu33 ligature is introduced into the AK7M2 melt, the primary phase (a_{Al}) is modified due to the transition of CuA12 compounds, the finished crystallization centers of this phase, to the melt from the ligature.

With an increase in the cooling rate of crystallization of Al-Cu33 ligature, its modifying efficiency increases, since its structure is almost completely formed from CuA12 intermetallic compound. The structure of the rapidly crystallized Al-Cu33 ligature is shown in figure 3**.**

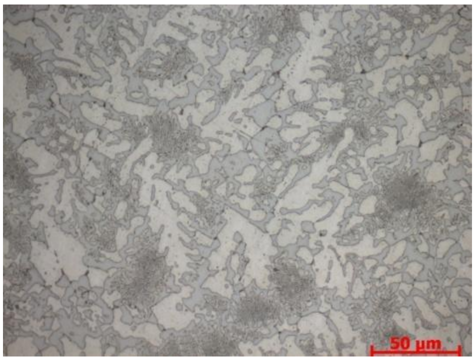

Figure 3. Microstructure of rapidly crystallized Al-Cu33 ligature, x5.

Based on this, the structure of the modified AK7M2 alloy has the following phase composition: a (Al) - solid solution, double eutectic (a (Al) + Si), ϴ-CuAl2, π-FeMg3Si6Al8, W-Cu2Mg8Si6Al5, ferrous a-Fe2SiAl8 and β -FeSiAl5 phase.

The main structural components are dendrites of aluminum solid solution (A1) with a fairly fine differentiation. Strict regulation of the iron content leads to the fact that the β-phase is rarely observed, crystals of the a-phase are found in the form of Chinese characters - skeletal skeletons of the a + A1 eutectic colonies. The copper-containing phases are mainly represented by the Θ phase, the numerous inclusions of which are light with a pinkish tint, which are located in the interbranch spaces, fixing the islands of the degenerate eutectic Θ + A1a. On the basis of the Θ phase, small colonies of the Θ + Mg2Si double eutectic with a finely differentiated structure are also formed. A crystal of the π phase is much less common than eutectic skeletons of the Mg2Si phase [10].

Inside the aluminum grains in a light microscope, dendritic cells are visible, which are sections of individual branches of dendrites. With an increase in x200 using the measuring ruler, in the Axio Vision program, 50 measurements were taken from each sample and the average dendritic cell size was calculated in the middle (figure 4) and at the periphery (figure 5) of the samples.

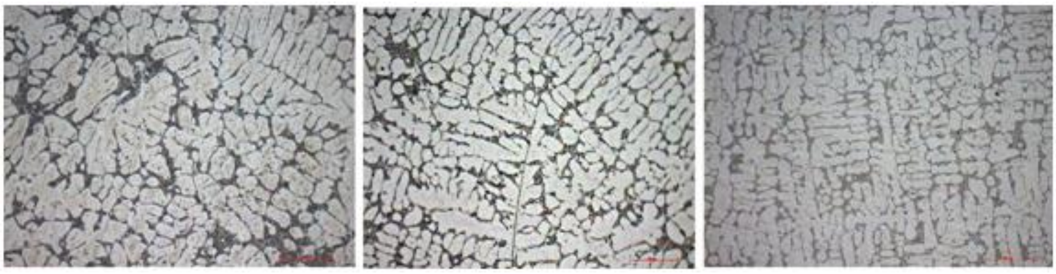

Figure 4. Microstructures and sizes of dendritic cells in the middle of the samples.

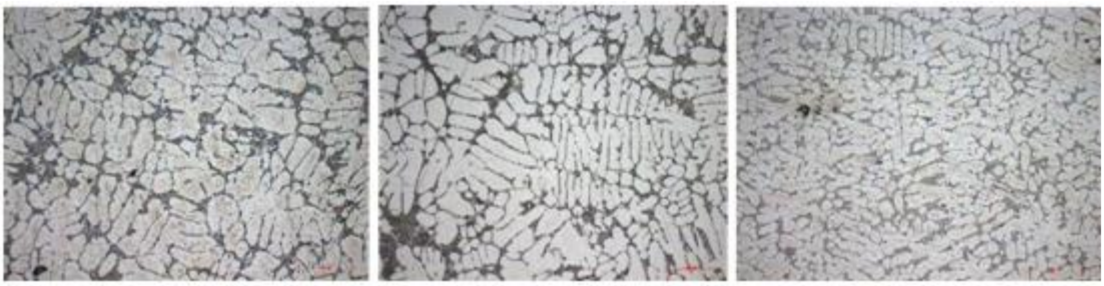

Figure 5. Microstructures and sizes of dendritic cells at the periphery of the samples, x 200: a) sample P1 - 16.8 microns; b) sample P3 - 13.1 μm; c) sample P4 –11.3 μm**.**

The dependence of the sizes of dendritic cells in the middle and on the periphery of the samples is shown in figure 6.

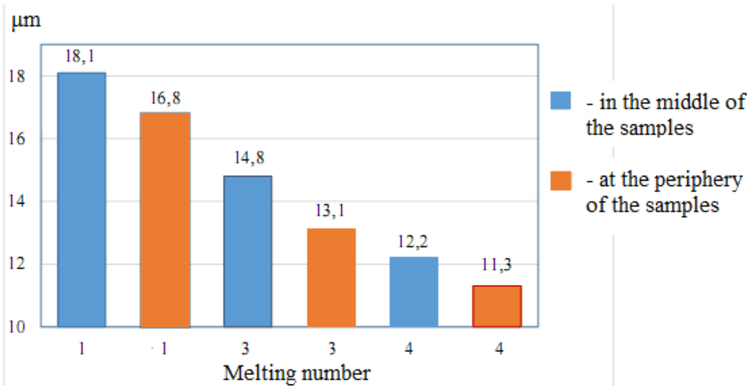

Figure 6. Dependence of the sizes of dendritic cells in the middle and on the periphery of the samples.

In the middle of the samples, the size of dendritic cells is larger than at the periphery, which is associated with the crystallization rate.

The microstructure of dendritic cells in the middle and on the periphery of the samples differs slightly. The largest size of dendritic cells corresponds to heat 1 obtained by standard technology, the smallest size corresponds to heat 4 obtained with aging using rapidly crystallized ligatures. Melting 3, obtained by the same technology as melting 1, with the exposure of the finished alloy for 3 hours, took an intermediate position.

The size of the dendritic cell significantly affects the mechanical properties of the alloy, therefore, to analyze the causes of product breakdowns and inconsistencies in the mechanical properties, it is necessary to study the microstructure of the alloy.

4. Conclusion

It was confirmed that the AK7M2 alloy obtained by quenching from a liquid state has a modifying effect on the base melt of the same composition It was confirmed that the AK7M2 alloy obtained by quenching from a liquid state has a modifying effect on the base melt of the same composition.

For the first time, the effectiveness of the fast crystallized AlCu33 ligature, as well as the fast-crystallized ligature of the same chemical composition as the test alloy, for 3 hours, on the structure and properties of AK7M2 alloy was established.

The study of the microstructures of the experimental melts confirms the modified state of the AK7M2 alloy.

The effect of modifying the AK7M2 alloy with rapidly crystallized alloys lasts for three hours, which allows casting of metal during this time, without loss of casting properties.

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