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# Influence of melt preparing technology on the structure of cast aluminum-silicon alloy

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**Abstract.** Influence of melting conditions on the structure of AL30 alloy has been studied. To this end, the temperature dependences of physical properties of liquid alloy has been investigated. It is shown, that the formation of the microhomogeneous and the equilibrium alloy structure during melting process leads to significant decreasing of amounts of eutectic silicon. However, the amounts of primary  $\alpha$ -aluminum solid solution and intermetallic compounds with dendritic form are increasing. Such treatment leads to decreasing of size of primary  $\alpha$ -aluminum solid solution particles. On the base of experiments the physical model of aluminum-silicon alloy solidification was proposed.

## 1. Introduction

Aluminium-silicon alloy AL-30 is included in the group of the most well-known and used materials in industry. Besides aluminium it includes 7,0-8,0 % Si, 1,0-1,5 % Cu, 0,3 - 0,5 % Mg, to 0,7 % Fe, as well as a small amount of nickel, manganese and titanium in the range (0.2 - 0.4)% of each. According to the elements content, the alloy is close to the eutectic composition in the Al-Si system and, therefore, it hardens by a simpler mechanism — only the eutectic transformation occurs. The structural components of the cast alloy are:

- dendrites  $\alpha$ -solid solution based on aluminium;
- based on  $\alpha$ -solid solution of aluminium and silicon eutectic;
- based on  $\alpha$ -solid solution of aluminium and intermetallic phases  $(\text{FeMnCu})_3\text{Si}_3\text{Al}_5$  of skeletal (dendritic) morphology eutectic;
- and  $\text{FeSiAl}_5$  phase needle-like morphology, very undesirable in structure.

Naturally, the alloy components listed structural formation primary is a cause of its chemical composition. However, the nature of the distribution, the shape and size of the structural components is largely determined by the smelting technology, including the preparation of the charge [1].

An objective analysis of the available and accessible technology production data, structure and properties of the alloy, taking into account production specialists opinions, led us to the conclusion that structure with a uniform distribution of the preferred form phases forming it, smaller fragments and etc. is most favorable in all respects.

Long experience studies performed in the direction of optimizing the various steels and alloys structure and properties, has led us to create melt thermo-temporal processing technique (TTPT) during melting or in a special process. TTPT modes are developed based on structure and properties studying results of metal in the liquid and solid states, as well as conclusions about their relationship [2,3].



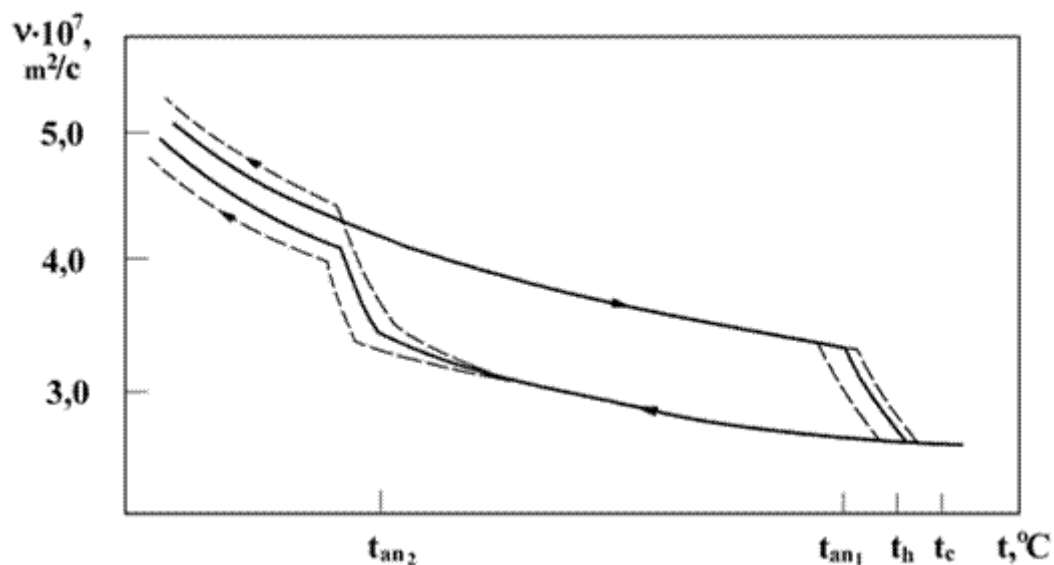
The a priori method, i.e. the development of TTPT modes is based on the accumulated data analysis still faced with great difficulties and errors associated with a wide range of each element in the composition of any alloy and the characteristics of the used charge materials. Among the latter, components in chemical composition and the amount of used “return” variations have a great importance.

In addition to these points, we note one more important factor - the indifferent attitude of the Russian (unlike European, American, Japanese, etc.) specialists in the metallurgical and foundry industry to the problems of product quality regulation. Our experience shows that this can be done due to the directional formation of the initial melt structure and properties before its solidification [4].

## 2. Materials and methods

TTPT melt modes were developed on the basis of kinematic viscosity and melt density polytherm results study. The kinematic viscosity of AL-30 alloy was measured using the oscillating cylinder method during heating and subsequent cooling. The experimental technique and the processing of experimental data have been described in detail [5,6]. The density of a melt was measured by the sessile drop method [7].

The parameters of TTPT turned out to be significantly dependent on fluctuations in the chemical composition of the melt, which is reflected in Figure 1. Therefore, in the course of the smelting company necessary adjustments was made.



**Figure 1.** Temperature dependences of the kinematic viscosity ( $\nu$ ) of the AL30 alloy.

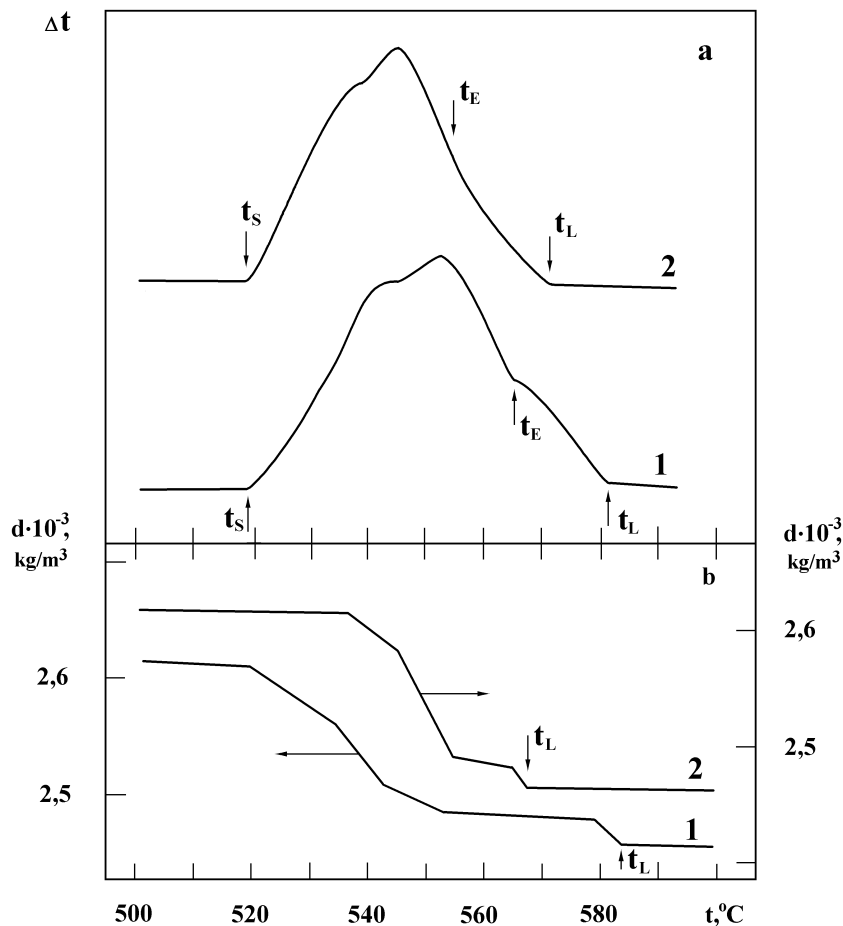
The TTPT influence analysis compound effect on the cast metal solidification process and the structure was performed on samples of two series of melts: the enterprise technology and the technology of TTPT melt. Differential thermal analysis (DTA) and a gamma-absorption densimeter were used to study crystallization processes.

## 3. Results and discussions

The state of the melt before solidification, as noted above, can vary significantly from melting to melting. The difference in the chemical composition of melts within the mark, the differences in the composition and structure of the batch components affect the structural character of the melt changes during heating to high temperatures. In particular, this is reflected in the position of the anomalous temperatures ( $t_{an}$ ) of polytherm kinematic viscosity  $\nu(t)$  of heating and cooling, which are shifted on a scale of temperatures within 40 °C, the critical temperature ( $t_c$ ) remains stable. In the low-temperature

region at  $t = t_{an}$ , there is a sharp jump in  $v(t)$ , but its position is also in the temperature range. As a result, at  $t < t_{an}$ , some uncertainty arises in the mutual arrangement of the polytherm viscosity  $v(t)$  of heating and cooling. All results of our research were obtained on alloy samples, which temperature dependence of the kinematic viscosity is shown in Figure 1 by solid line.

Figure 2 shows the temperature dependences of DTA and density ( $d$ ) obtained in the process of alloy solidification. These results indicate that the melt TTPT does not lead to a change in the crystallization stages, but affects their temperature range. With confidence, we note a decrease in the liquidus temperature ( $t_L$ ) of the temperature of the onset of the eutectic transformation ( $t_E$ ). In this case, the solidus temperature ( $t_S$ ) remains unchanged. The ability of TTPT to increase the supercooling of the metal during solidification is known from many of our previously completed works [8]. The presence of supercooling creates more favorable conditions for nucleation, stimulates the process of solidification and increases its speed.

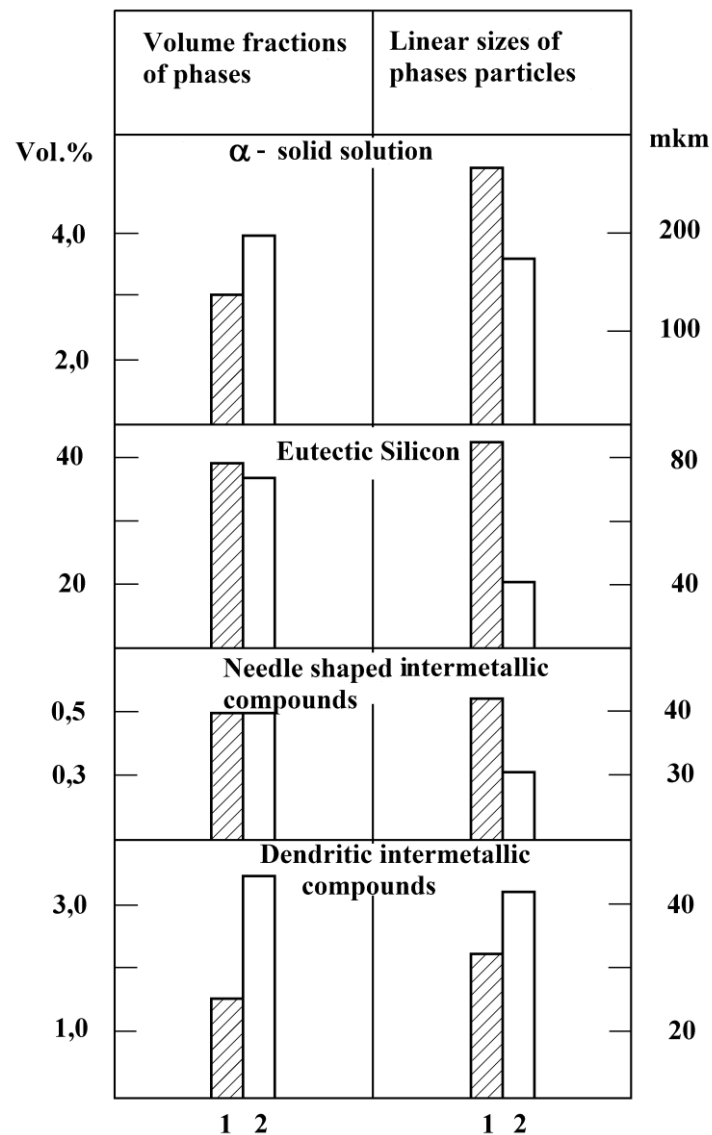


**Figure 2.** The influence of the melting technology of the AL30 alloy on the DTA (a) polytherm and the density (b) of a solid metal: 1 - technology without TTPT of the melt; 2 - technology with TTPT melt.

We carried out qualitative metallographic analysis of cast samples melted without a TTPT melt. We found that the structure consists of large elongated dendrites of  $\alpha$ -solid solution based on aluminium and a multicomponent eutectic, including several types of intermetallic compounds - dark-

colored  $(\text{FeMnCu})_3\text{Si}_3\text{Al}_5$ , single needles of dark-colored  $\text{FeSiAl}_5$  as well as  $\text{CuAl}$  needle-like morphology and light coloring. TTPT melt contributes to the formation of equiaxial dendritic structure of the cast metal, the elimination of eutectic certain large areas and its more uniform distribution over the sample cross section. Particles of intermetallic compounds with skeletal morphology acquire a more branched form. Intermetallic acids of needle-like morphology are allocated in the form of compact colonies, not as separate coarse particles.

Quantitative metallographic analysis showed that TTPT melt does not affect the volume fraction and the linear dimensions of the intermetallic particles based on  $\text{CuAl}$ , while contributing to a significant decrease in the volume fraction of eutectic silicon (Figure 3).



**Figure 3.** The histogram of changes in the alloy structure parameters of AL30 produced by the technology without TTPT melt (1) and using TTPT (2).

However, in the experimental metal volume fraction of primary  $\alpha$ -solid solution based on aluminium and dendritic intermetallics were increased; the linear sizes of the particles of  $\alpha$ -solid

solution and needle intermetallic compounds have significantly decreased; size of dendritic intermetallic compounds - increased.

In our opinion, after melting in the liquid metal there are nanostructured microgroups, inheriting the structural features of the solid phases [3].

Judging by the nature of the change in the temperature dependence of the decay rate of a crucible with a liquid metal [3], the resulting melt is not heterophase, and the nature of its microheterogeneity is determined by the energy spectrum of the chemical bonds of various atoms in the near and far environment. With increasing temperature, a weakening of these bonds is observed and the viscosity decreases. At an anomalous temperature ( $t_{an}$ ), the moment of irreversible destruction of non-equilibrium groups comes and this process ends at a critical temperature ( $t_c$ ). During this period, the number of atomic layers involved in viscous flow decreases sharply [9]. The melt structure becomes equilibrium and microhomogeneous. During the subsequent cooling, the interatomic interaction increases, the melt dissipativity gradually increases, and the viscosity increases up to temperature  $t$ .

The process of crystallization of the alloy begins with the eutectic release (Figure 2). According to the academician Taran Yu.N. [10], the base phase in the Al-Si eutectic system is silicon crystals. In the multi-component alloy AL30, in which structure there are a lot of other phases, the process of solidification may be different. In particular, after the temperature decreases below  $t_{an}$ , an active formation of microgroups occurs. They can become a prototype of crystallization centers with a further decrease in temperature. At the same time, the viscosity of the melt increases dramatically, i.e. the dissipative field of a viscous flow expands. This is possible only with small sizes of microgroups and a significant increase in their number. These factors contribute to the undercooling of the melt, which determines the high speed of the solidification process.

The proposed discussion option is not the only possible. Of undoubted interest is the use of other approaches. In particular, the concept of metastable melt microheterogeneity actively developed in recent years in systems with eutectic [11] and the method for estimating the parameters of a microheterogeneous metal alloy in the context of the concepts of fluctuation free volume [12].

#### 4. Conclusions

Melt thermo-temporal processing technique (TTPT) modes are proposed based on the study of the kinematic viscosity polytherm and the density of AL-30 melt.

The TTPT influence analysis compound effect on the cast metal solidification process and the structure was performed on samples of two series of melts: the enterprise technology and the technology of TTPT melt.

Qualitative and quantitative metallographic analysis showed that TTPT melt contributes to the formation of equiaxial dendritic structure of the cast metal, the elimination of eutectic certain large areas and its more uniform distribution over the sample cross section. Particles of intermetallic compounds with skeletal morphology acquire a more branched form. Intermetallic acids of needle-like morphology are allocated in the form of compact colonies, not as separate coarse particles. In the experimental metal volume fraction of primary  $\alpha$ -solid solution based on aluminium and dendritic intermetallics were increased; the linear sizes of the particles of  $\alpha$ -solid solution and needle intermetallic compounds have significantly decreased; size of dendritic intermetallic compounds - increased.

The obtained results were explained by using the theory of microheterogeneity of the melt and allow us to conclude that it is expedient to use such technology to obtain a favorable structure of cast products.

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