THE COMPUTER ANALYSIS OF PHASE TRANSITIONS IN HYPEREUTECTIC AL-SI ALLOYS IN VIEW OF INFLUENCE OF MELT TEMPERATURE PROCESSING

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Abstract

The problems of adequate computer modeling of solidification processes for casting of any configuration are considered. The computer thermal analyses method was used for experimental investigation of hypereutectic Al-Si alloys, including influence of temperature processing of alloys in a liquid state on temperatures of phase transitions, an interval of crystallization and morphology of solid phases formed at solidification. The change of a temperature mode of melting leads to change of temperature of the beginning of crystallization of primary silicon, the general interval of crystallization, the sizes and morphology of eutectic and primary phases in hypereutectic alloys. For the adequate computer modeling of solidification, the corresponding account of influence of temperature processing of an alloy in a liquid phase is required.

The purpose of the present work was studying influence of melt temperature on phase transitions and an interval of crystallization of Al-Si hypereutectic alloys. Parameters of crystallization and microstructures of alloys after their temperature processing in a liquid state at various overheats from 720 ^oC up to 870 ^oC were studied. As object of research Al-16%Si alloys were used which melt in the electric furnace of aluminum and following base alloy: 30-32 % of silicon, 0,8-1,2 % of iron, the rest - aluminum. For research of influence of melt temperature on character of distribution and morphology of crystal phases was used a method of the microstructure analysis of samples of alloys by optical microscope after the thermal analysis of the test probes with diameter of sample 30 mm, weight about 35 gram, rate of cooling in a liquid state is 1,8-2 C/with.

As a result of work by the methods of computer thermal and microstructures analyses the experimental data about influence of temperature processing hypereutectic Al-Si alloys in a liquid state on temperatures of phase transitions, the interval of crystallization and morphology of phases formed at solidification have been received.

The results of the microstructures analysis testify that change of a temperature melting leads to appreciable change of parameters of crystallization and a microstructure of an Al-Si alloy. It is established, that the temperature of the beginning of crystallization of primary silicon in hypereutectic Al-Si alloys at solidification raises at increase of overheating of melt from 720 ^oC up to 870 ^oC. The general interval of crystallization of an alloy on 20-25 ^oC for investigated Al-16%Si alloys also increases.

Processes of formation of crystal structure hypereutectic Al-Si alloys at solidification also change in dependence of modes of temperature processing of melt. Change of a temperature of melting causes to change of the size and morphology as eutectic, and primary

phases of hypereutectic Al-Si alloys. Overheating up to 790-830 ^{o}C causess to formation mainly more thick plates of eutectic silicon, rise in temperature of melt up to 870 ^{o}C leads to appreciable growth of the sizes of crystals of primary silicon and their strong concentration in the central part of the casting.

Obtained data testify that for the adequate computer modeling of solidification of hypereutectic Al-Si alloys at use of the dependences connecting quantity of a solid phase and temperatures of phase transitions with diagrams of a condition of alloys, is necessary to consider influence of a temperature overheating of an alloy in a liquid state on parameters of crystallization.

INTRODUCTION

Incessant improvement of cast alloys production quality requires wide use of computer systems for modeling foundry processes at the industrial enterprises. In the world market of software packages for modeling foundry processes, such as "ProCAST", "MAGMA" and others successfully are used.

Despite of the significant successes reached last years in the field of computer modeling of phase transitions, the problem of adequacy of applied models and efficiency of use of computer models in many cases remains unresolved. In spite of the fact that the general questions of the theory of material science of Al-based alloys, including thermal and hydrodynamic processes at cooling and solidification of metal system, are well developed, the majority of applied problems of computer modeling of phase transitions and prediction of alloys properties has no strict analytical decision.

At acceptance of some assumptions, adequate analytical models only for geometric systems of the elementary configuration is usually possible. The most effective way of the decision this problems are using numerical methods on the basis adequate thermo-physical and physical properties of the liquid and solid phases.

Numerical methods allow to solve a problem of cooling and solidification of metal system of an any configuration on the basis of the equation of non-stationary heat conductivity with corresponding boundary conditions:

$$Kx\frac{\partial^2 T}{\partial x^2} + Ky\frac{\partial^2 T}{\partial y^2} + Kz\frac{\partial^2 T}{\partial z^2} + qv = Cv\frac{\partial T}{\partial t},$$

$$T = T(S,t),$$

$$Kn(\partial T/\partial n) = -qn,$$

$$Kn(\partial T/\partial n) = -\alpha(T - Tenv),$$

where

x, y, z - coordinates in the field of the space limited by surface S;

n - normal to surface S;

t - time;

T - function of temperature distribution in space of coordinates x, y, z, t;

Kx, Ky, Kz, Kn - heat conductivity in a direction of axes x, y, z and normal n accordingly;

qv - volumetric capacity of internal sources of heat;

Cv - volumetric thermal capacity;

qn - boundary thermal stream (on a normal to S);

α - coefficient of boundary convection heat transfer on environment with temperature Tenv.

It is the most important for computer modeling to provide the account of allocation of the latent heat in an interval of temperatures of solidification and using of adequately values of temperatures of phase transitions and an interval of crystallization of an alloy. Application for this purpose the various functional dependences connecting quantity of a solid phase with diagrams of a condition of alloys, is often ineffective and inadequately models the valid character of a thermal emission for real non-equilibrium conditions.

Prospects of the computer analysis of phase transitions are defined by an opportunity of the decision of a problem of adequate modeling thermal-physical and physical properties of liquid and solid phases of the multi-component alloys existing in an interval of crystallization. These properties and as consequence, structure and properties of received cast products, depend not only on a chemical compound, but also from conditions of preparation of an alloy in a liquid state. Condition of an alloy in a liquid phase and as consequence, processes of formation of structural components of an alloy at crystallization can essentially change depending on conditions of melting: temperatures and speeds of heating, time of melting at the certain temperature, etc. The significant experimental material saved up in last years testifies that changes of modes of temperature processing of melt lead to essential changes of morphology and the sizes of phases allocated at crystallization, the sizes and distribution of shrinkable and gas defects, mechanical properties of alloys. It is especially important for alloys of system Al-Si, as of the majority of industrial aluminum alloys.

The purpose of the present work was studying influence of melt temperature on phase transitions and an interval of crystallization of Al-Si hypereutectic alloys.

THE BASIC PART

Properties of Al-Si alloy are mainly defined by individual physical properties, a volume fraction, morphology and distribution of its basic phases: α-Al solid solution and crystals of silicon (Si). In industrial Al-Si alloys the maintenance of silicon is at a level from 5 up to 23 % (weights) and as follows from the equilibrium diagram of a condition, the structure of these alloys can be pre-eutectic, eutectic or hypereutectic. The crystals of silicon which are present in industrial Al-Si alloys, can have various morphology: primary, compact inclusions in hypereutectic alloys and the branched plates or fibers in eutectic.

It is established, that after melting Al-Si alloys are non-equilibrium systems, which properties depend not only on a chemical compound, but also from conditions of preparation of an alloy in a liquid phase. Temperature processing Al-Si alloys in a liquid state leads to significant change not only properties of melt, but also to change of properties and structures of cast products after solidification of alloys. This interrelation is found out and proves to be true practice of casting production of Al-Si alloys.

The special interest was to investigate influences of temperature of melt on phase transitions, the interval of crystallization and morphology of phases after solidification of Al-Si alloys. Parameters of crystallization and microstructures of alloys after their temperature processing in a liquid state at various overheats from 720 ^{o}C up to 870 ^{o}C were studied.

As object of research Al-16%Si alloys were used which melt in the electric furnace of aluminum and following base alloy: 30-32 % of silicon, 0,8-1,2 % of iron, the rest - aluminum.

The system of the thermal analysis has been developed for research of process of crystallization, constructed on the basis of microprocessors and a personal computer which basic characteristics are presented:

- the range of measurement of temperature: 0 - 1600 °C,
- admissible range of ambient temperatures of operation of system: 0 – 50 °C,
- step-type behaviour of measurement of temperature: 0.1 °C,

- the period of time between measurements: 0.4 - 3.2 sec.,
- absolute error of measurement, no more: 0.1°C,
- information capacity of operative memory: 2046 measurements of temperature,
- nformation capacity of non-volatile memory: 20 cooling curves.

Conventional thermal analysis is carried out during the solidification of the samples to study the parameters of the cooling curve and its derivatives. For the purpose, the setup used to result the experimental data consists of a cup measuring with a thermocouple (1), microprocessor device (2) and personal computer (3) for output data treatment (Fig.2).

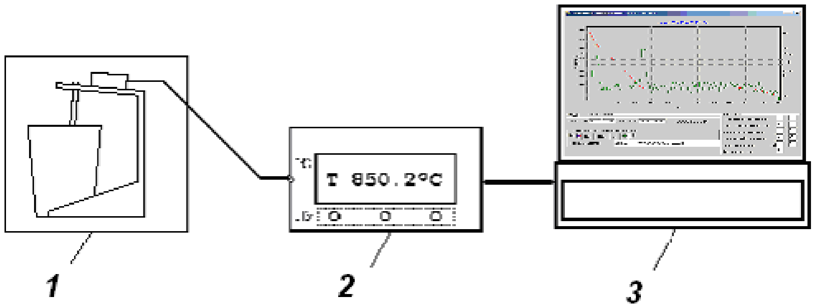


Fig. 2. *The thermal analysis system based on the cooling curve method*

The signal from the thermocouple was transformed to a digital code and measurements of temperature during process of crystallization of alloy were carried out at regular intervals (0,4-1,2 with, depending on the general duration of solidification). Received data were transferred for processing in a personal computer by means of the interface of data transmission.

For research of influence of melt temperature on character of distribution and morphology of crystal phases was used a method of the microstructure analysis of samples of alloys after the thermal analysis (diameter of sample 30 mm, weight about 35 gram, rate of cooling in a liquid state is 1,8-2 C/with) by optical microscope.

As a result of the thermal analysis it has been established, that with increase in temperature of an overheat of melt there is a tendency to increase in temperature of the beginning of crystallization (figure 1) and, accordingly, increase in the general interval of crystallization of an alloy (figure 2).

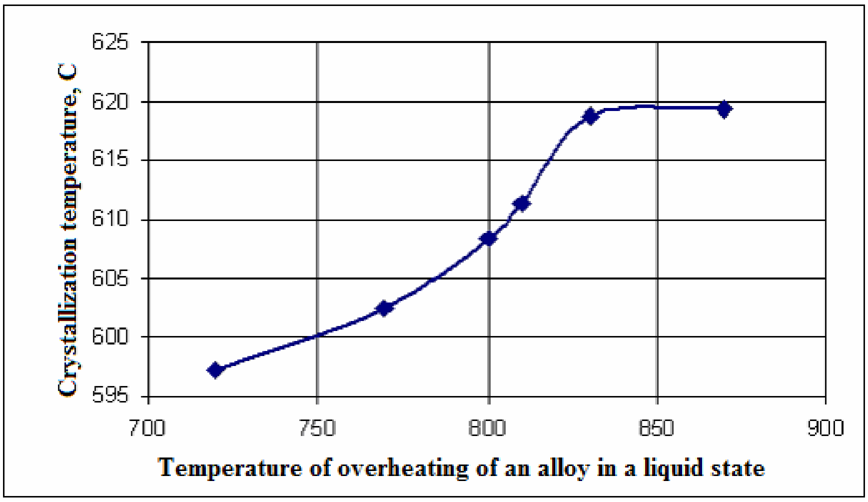


Fig. 1. *Change of temperature of the beginning of crystallization of alloy Al-16%Si on temperature of overheating of an alloy in a liquid state*

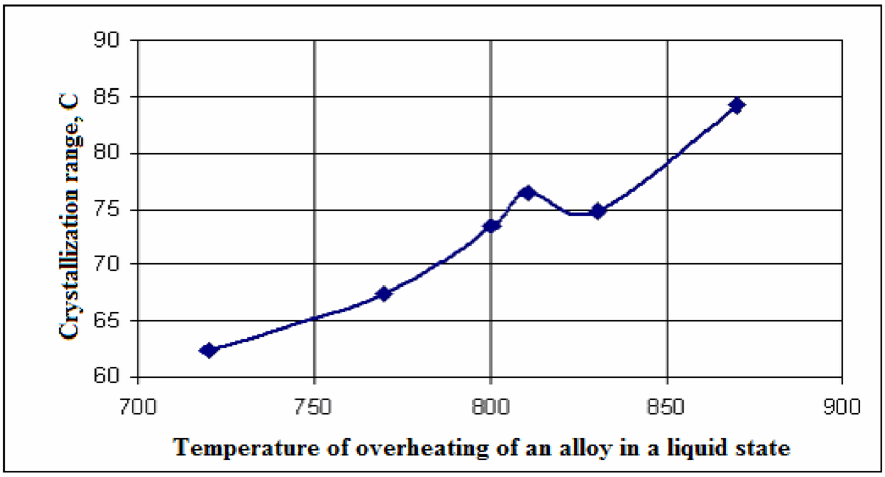
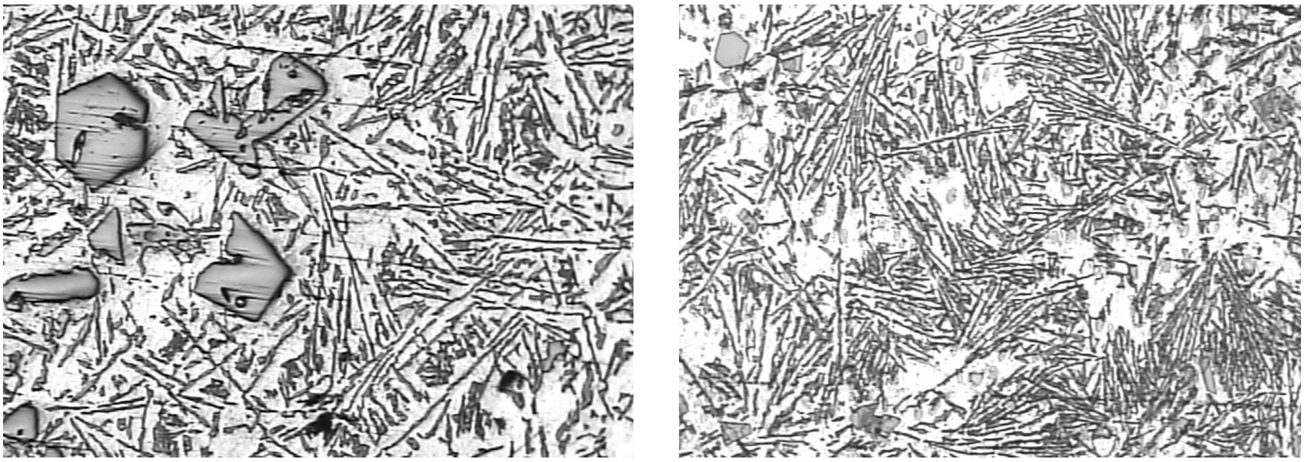


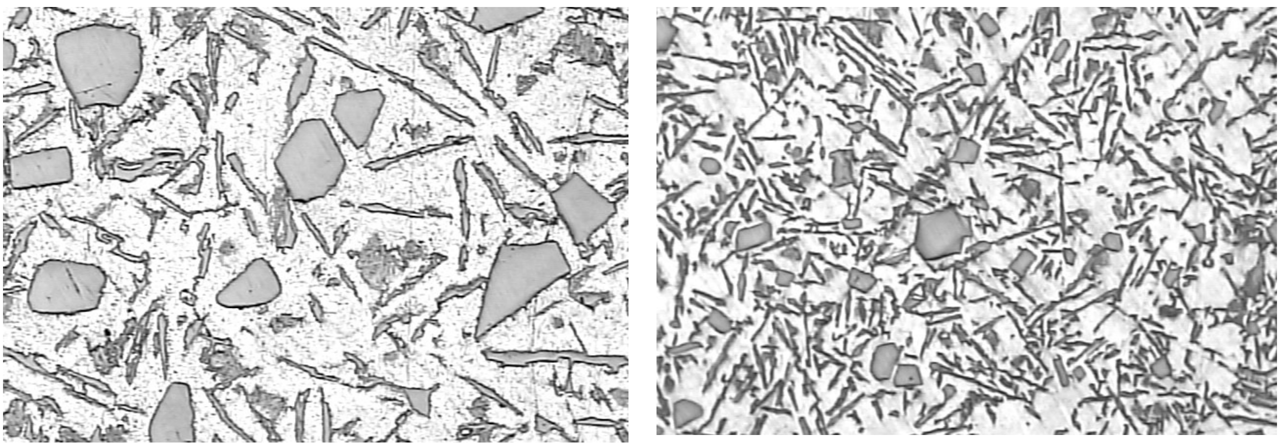
Fig. 2. *Change of an interval of crystallization of alloy Al-16%Si on temperature of overheating of an alloy in a liquid state*

The microstructures of the investigated alloys are presented in figures 3 - 6.



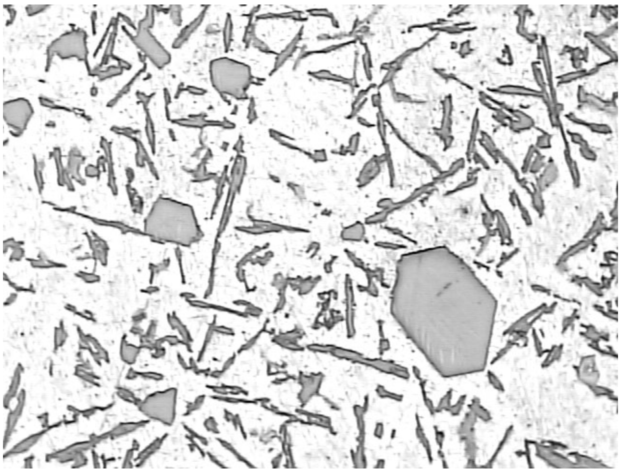
a) b)

Fig. 3. *Microstructure of alloy Al-16%Si after overheating in the furnace at temperature 720 ^{o}C, a - the central part of the sample; b - peripheral part of the sample (x125)*

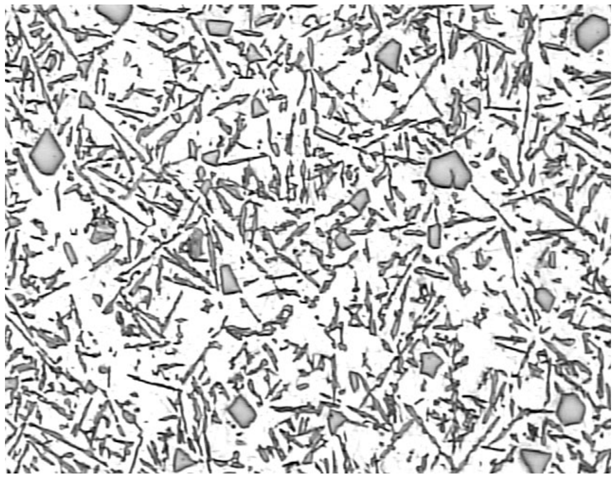


a) b)

Fig. 4. *Microstructure of alloy Al-16%Si after overheating in the furnace at temperature 790 ^{o}C, a - the central part of the sample; b - peripheral part of the sample (x125)*

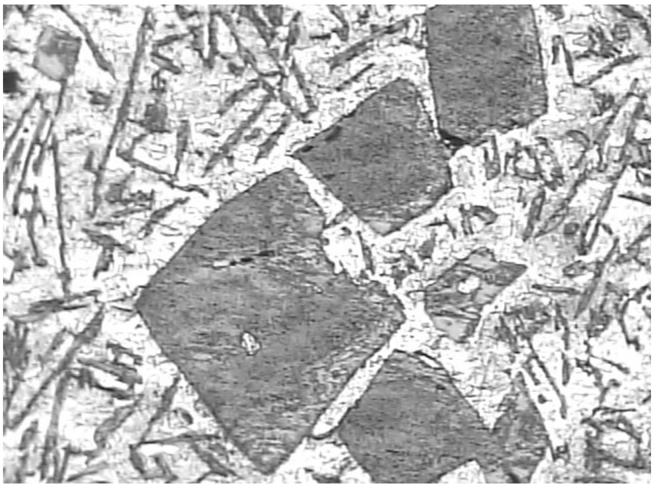


a)



b)

Fig. 5. *Microstructure of alloy Al-16%Si after overheating in the furnace at temperature 830 ^{o}C, a - the central part of the sample (x250); b - peripheral part of the sample (x125)*



a)

b)

Fig. 6. *the Microstructure of alloy Al-16%Si after overheating in the furnace at temperature 870 ^{o}C, a - the central part of the sample (x250); b - peripheral part of the sample (x125)*

The results of the microstructures analysis testify that change of a temperature melting leads to appreciable change of parameters of crystallization and a microstructure of an Al-Si alloy. Thus the mode of temperature processing influences the size and morphology as eutectic, and primary phases. At rather small overheats (100^{o}C above liquidus) eutectic has fine and even in separate sites fibrous morphology (figure 3), primary silicon is formed mainly in the form of compact concerning small crystals.

It is established, that rise in melt temperature up to 790-830 ^{o}C leads to formation mainly thick plates of eutectic silicon, smaller extent in comparison with alloys which temperature of heating in a liquid state did not exceed 720^{o}C (figure 4, 5). Thus for samples, especially for their peripheral part, presence concerning small in the sizes compact crystals of silicon that can be favorable for operational properties, for example, wear resistances is characteristic. The further rise in temperature of melt up to 870^{o}C causes to appreciable growth of the sizes of crystals of silicon and their strong concentration in the central part of test sample (figure 6). The morphology of eutectic essentially does not change, silicon crystallizes in eutectic of various form, from small grains up to separate long plates.

THE CONCLUSION

As a result of work by the methods of computer thermal and microstructures analyses the experimental data about influence of temperature processing hypereutectic Al-Si alloys in a liquid state on temperatures of phase transitions, the interval of crystallization and morphology of phases formed at solidification have been received.

It is established, that the temperature of the beginning of crystallization of primary silicon in hypereutectic Al-Si alloys at solidification raises at increase of overheating of melt from 720^{o}C up to 870^{o}C. Thus the general interval of crystallization of an alloy (on 20-25 ^{o}C for investigated Al-16%Si alloys) also increases.

Processes of formation of crystal structure hypereutectic Al-Si alloys at solidification also change in dependence of modes of temperature processing of melt. Change of a temperature of melting causes to change of the size and morphology as eutectic, and primary phases of hypereutectic Al-Si alloys. Overheating up to 790-830 ^{o}C causess to formation mainly more thick plates of eutectic silicon, rise in temperature of melt up to 870 ^{o}C leads to appreciable growth of the sizes of crystals of primary silicon and their strong concentration in the central part of the casting.

Obtained data testify that for the adequate computer modeling of solidification of hypereutectic Al-Si alloys at use of the dependences connecting quantity of a solid phase and temperatures of phase transitions with diagrams of a condition of alloys, is necessary to consider influence of a temperature overheating of an alloy in a liquid state on parameters of crystallization.