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Effect of the overheat temperature and the cooling rate on a structure of Al-Cu system alloys

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У роботі досліджено структурні властивості сплавів системи Al-Cu в твердому та рідкому станах. Дослідження проводили на сплавах із вмістом міді 25,0-34,0 % (мас.), решта - алюміній. Для визначення фізичних властивостей сплавів використовували мікроструктурний, рентгеноструктурний та диференційний термічний аналізи. Було визначено фазовий склад сплавів в залежності від температури нагріву рідини вище лінії ліквідусу та швидкості охолодження.

В роботі показано, що при збільшенні температури нагріву рідини сплавів вище лінії ліквідусу до 150 К відбувається зменшення об'ємної частки первинних кристалів алюмінію та збільшення об'ємної частки евтектики. Перегрів рідини на 200 К призводить до повного пригнічення процесу утворення первинних кристалів алюмінію, що свідчить про відсутність їх мікрокомплексів в рідині сплаву. Отримані результати розрахунків добре узгоджуються з даними інших авторів.

Ключові слова: сплави Al-Cu; евтектика; рідина сплавів.

В работе исследуются структурные свойства сплавов системы Al-Cu в твердом и жидком состояниях. Исследования проводили на сплавах с содержанием меди 25,0-34,0 % (масс.), остальное   алюминий. Для определения физических свойств сплавов использовали микроструктурный, рентгеноструктурный и дифференциальный термический анализы. Был определен фазовый состав сплавов в зависимости от температуры нагрева жидкости выше линии ликвидуса и скорости охлаждения.

В работе показано, что при увеличении температуры нагрева жидкости сплавов выше линии ликвидуса до 150 К происходит уменьшение объемной доли первичных кристаллов алюминия и увеличение объемной доли эвтектики. Перегрев жидкости на 200 К приводит к полному подавлению процесса образования первичных кристаллов алюминия, что свидетельствует об отсутствии их микрокомплексов в жидкости сплава. Полученные результаты расчетов хорошо согласуются с данными других авторов.

Ключевые слова: сплавы Al-Cu; эвтектика; жидкость сплавов.

In this paper there is examined the structural properties of Al-Cu system alloys in a solid and in a liquid state. The investigation was performed for the alloys with copper content of 25.0-34.0% (wt.), the rest is aluminum. To determine the physical properties of alloys we used microstructure analysis, X-ray structural analysis and the differential thermal one. We determined the phase composition of alloys in relation to the temperature of the liquid heating above the liquidus curve and to the cooling rate.

In the paper it is shown that when the temperature of the alloys liquid heating rises above the liquidus curve and reaches 150 K, both the reduction of the volume ratio of primary aluminum crystals and the increase of the eutectics volume ratio occurs. The overheating of the liquid by 200 K leads to a complete suppression of the process of formation of primary aluminum crystals, which indicates the lack of their microcomplexes in alloy liquid. The obtained results of calculations are in good agreement with those of other authors.

Keywords: Al-Cu alloys; eutectics; liquid of alloy.

Introduction

The Al-Cu alloys system was examined due to the wide use of these alloys in the aircraft industry and in transport. According to the state diagram of Al-Cu system proposed by Murray the eutectics is formed at copper content of 33 % (wt.) and aluminum content of 67 % (wt.) and is represented structurally by α-solid solution of copper in aluminum and Al_2Cu compound. The structure of θ-phase (Al_2Cu) is tetragonal [1,2] and can exist in two modifications: θ (Al_2Cu-type) and θ' (CaF-type) [3]. Investigation of the structure of alloys as a result of long-term ageing revealed that up to a temperature of 190°C there is θ-phase (Al_2Cu-type) and when the temperature decreases it turns to θ' (CaF-type) [4].

As it is known, one of methods for determining the presence of microcomplexes in the liquid of Al-Cu alloys is associated with a liquid viscosity change [5-7]. On the viscosity-temperature curves we obtained the hysteresis loops between the heating and cooling curves, which are associated with rearrangement of complexes in the liquid of alloys [8]. For the alloy of eutectic composition (copper content of 17.0 % (atom.)) there is an intersection of the viscosity curves of the heating and the cooling at the temperature of 950°C [8]. The study of alloy copper content

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and temperature dependence of a value of the structure parameter function reveals that for alloy of eutectic composition ($Al_{83}Cu_{17}$) decrease of the structure parameter occurs in the temperature range of 750-980°C; moreover, the availability of acute peak indicates that there is ordered structure [9]. The authors demonstrated that temperature dependence of the structure parameters for alloy of eutectic composition is characterized by certain stability of atomic arrangement within the temperature interval of 835-935 K [10]. Now it is known that at temperatures above the crystallization temperature in the melts of metals and alloys the microconcentration heterogeneity is observed [11-13]. Thus, phenomena, which are appeared in the liquid state of metals and alloys, are intrinsic to the systems that are in a critical state [14]. Typical for such systems is the temperature at which there are no complexes in the liquid.

It is known that increase in the cooling rate to 10^4-10^5 K/s leads to the formation of a supersaturated solid aluminum solution and to the increase in content of Al_2Cu phase in non-equilibrium eutectics [15-16].

Therefore, the objective of this paper is studying of structural properties of Al-Cu system alloys depending on the temperature of alloy liquid heating above the liquidus curve and on the cooling rate.

Materials and methods of investigation

The investigation was performed for the Al-Cu alloys specimens with copper content of 25.0-34.0 % (wt.), the rest is aluminum. To obtain these Al-Cu alloys we used the furnace burden of such composition: aluminum with content of 99.9 % (wt.) and copper with content of 99.9 % (wt.). In order to prevent segregation the alloys were prepared from carefully pre-mixed and pressed powders of furnace burden materials. The smelting of specimens was carried out in Taman's furnace with graphite heater at temperatures of 820-1200 K. The cooling rate of alloys was 10 K/s. Part of the specimens were prepared in a similar way, but after heating were been casted into V-shaped molds, as a result, in the process of cooling in the wide part of the wedge the cooling rate was 10^2 K/s and in the edge it was 10^4 K/s.

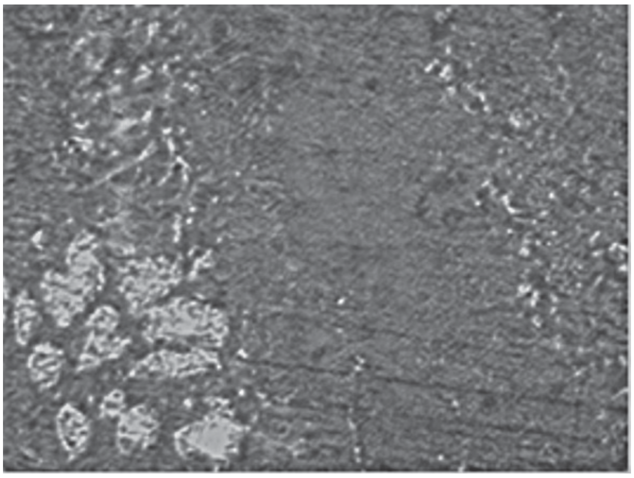
Chemical and spectroscopic analyses were used to ascertain the chemical composition of alloy [17]. Differential thermal analysis by means of derivatograph with heating rate of 2 K/min was used to determine the temperature of the phase transformations.

The phase composition of the alloys was determined by X-ray microanalysis on JSM–6490 microscope, as well as by means of optical microscope 'Neophot-21'. The X-ray structure analysis was performed on diffractometer DRON-3 in monochromated Cu_α radiation.

Results and discussion

Hypoeutectic alloys of Al-Cu system is of such structure: primary Al dendrites and regular $Al+Al_2Cu$ eutectics, which after crystallization is corresponding to the phase composition of the state diagram of the system [1].

The microstructure of hypoeutectic alloys of Al-Cu system, which after heating to the temperature of 850 K were casted in the V-shape mold, consists of uniform-size primary aluminum dendrites (of the size of 30-40 μm). Eutectic is heterogeneous in morphology and is more finely-divided in the center of grains (Fig. 1, a). When the cooling rate rises to 10^4 K/s, the volume ratio and size of primary Al dendrites reduce, and those for the eutectics increase (Fig. 1, b).



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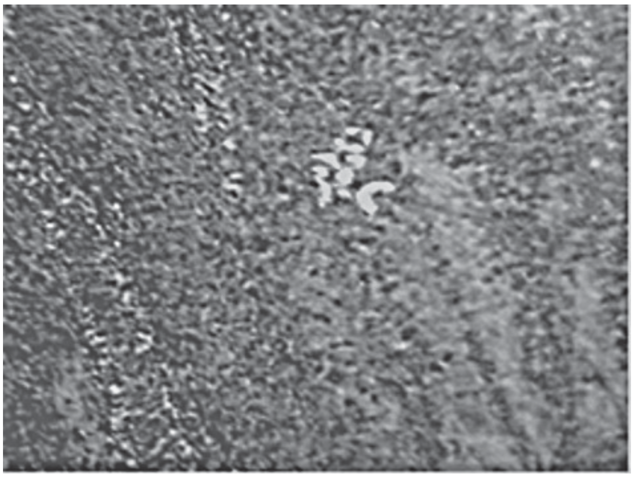
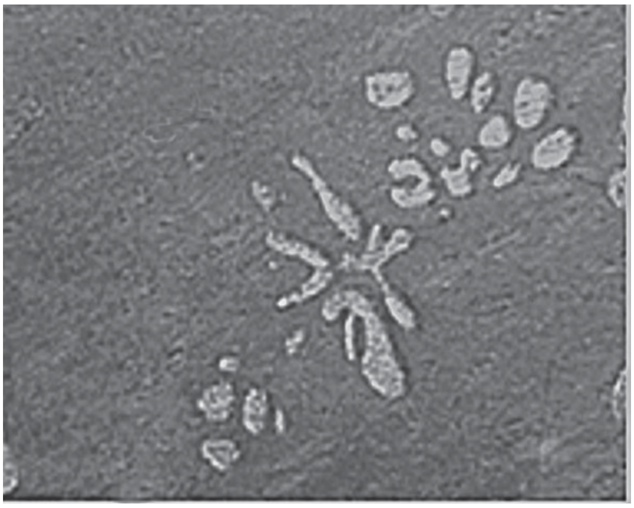


b

Fig. 1. The microstructure of alloy wedge after pre-heating of Al-Cu alloy by 50 K with aluminum content of 71.0 % (wt.) cooled with a rate of: a) 10^2 K/s, b) 10^4 K/s.

When hypoeutectic Al-Cu system alloys are pre-heated to 100 K above liquidus temperature and then cooled with a rate 10^2 K/s, this leads to decrease of the volume ratio of primary aluminum dendrites and increase of the volume ratio of the eutectics. The formation of more homogeneous in morphology eutectics is observed. An increase in the rate up to 10^4 K/s is attended with considerable reduction of the volume ratio and size of primary aluminum dendrites and formation of more finely-divided eutectics.

Pre-heating of hypoeutectic alloys of the system by 150 K leads to the increase in the primary aluminum dendrites size (40-55 μm) in a wide part of a wedge compared with the lower temperature of alloys overheating (Fig. 2, a). The eutectics in morphology is more dispersed and homogeneous.



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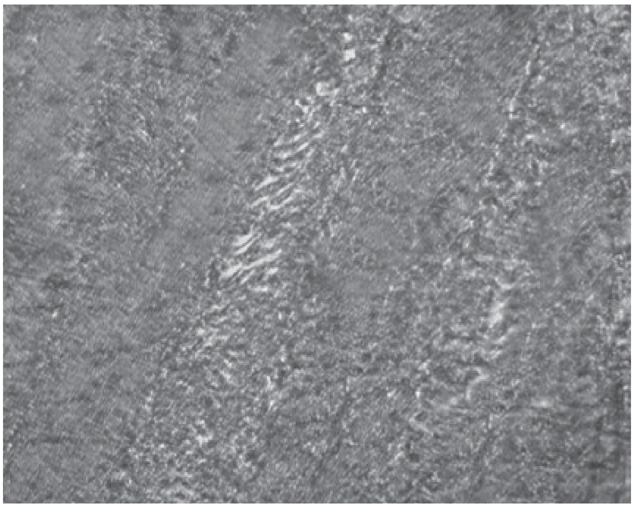

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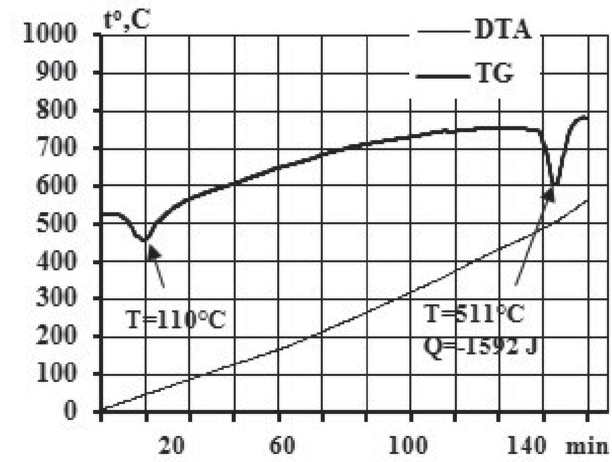
Fig. 2. The microstructure of the wedge of alloy after pre-heating of alloy liquid by 200 K with aluminum content of 71,0 % (wt.) cooled with a rate of: a) 10^2 K/s, b) 10^4 K/s.

Increase in the cooling rate to 10^3 K/s results in the formation of more mixed-sized primary Al dendrites (30-40 μm). The eutectics is of more dispersed structure compared with specimens, which were cooled with a lower rate.

Changes in the morphology of eutectics were observed in the wedge area, which was cooled with a rate 10^4 K/s. In this part of the wedge both lamellar and finely-divided rod eutectics exist and there are no aluminum primary crystals (Fig. 2, b). Besides, the formation of single finely-divided phases is observed.

For the wedge part, which was heated by 150 K above liquidus curve and cooled then with a rate of 10^4 K/s the differential thermal analysis is performed (Fig. 3).



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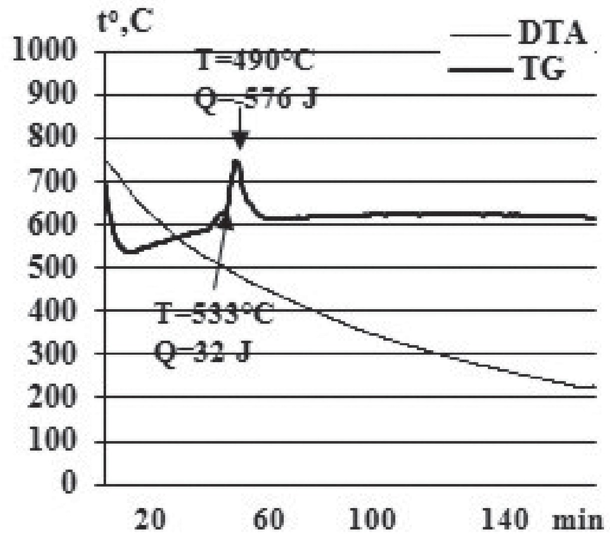

b

Fig. 3. Thermogram of alloy with aluminum content of 71.0 % (wt.): a) heating after cooling with a rate of 10^4 K/s, b) cooling with a rate of 2 K/s after heating of alloy to the temperature of 1000 K.

In the process of heating the hypoeutectic alloy in the thermogram there is two thermal effects at the temperatures 110°C and 511°C. The first one is connected with the fact that at the temperature of 110°C there is a transformation $\theta' \rightarrow \theta$ indicated by authors of the work [4], and the second temperature is melting of eutectics and primary aluminum dendrites at the temperature of 511°C, with a heat release of 1592 J.

As a result of aftercooling of hypoeutectic alloy we obtain a thermogram which indicates the transformations corresponded to the state diagram of Al-Cu alloys [1], such as the formation of primary aluminum crystals with heat release of 32 J occurring at 533°C and formation of eutectics with heat release of 576 J at 490°C.

As a result of X-ray diffraction analysis of Al-Cu system alloys with overheating up to 100 K and aftercooling with a various rates in the range of 10^2-10^4 K/s the phase

composition corresponds to that of the state diagram. The overheating of the liquid of a hypoeutectic Al-Cu alloy by 150 K and aftercooling leads to the fact, that at cooling rates of 10^2 K/s the phase composition shows no change, and the increase of the cooling rate up to 10^4 K/s provides the formation of AlCu phase (Fig. 4).

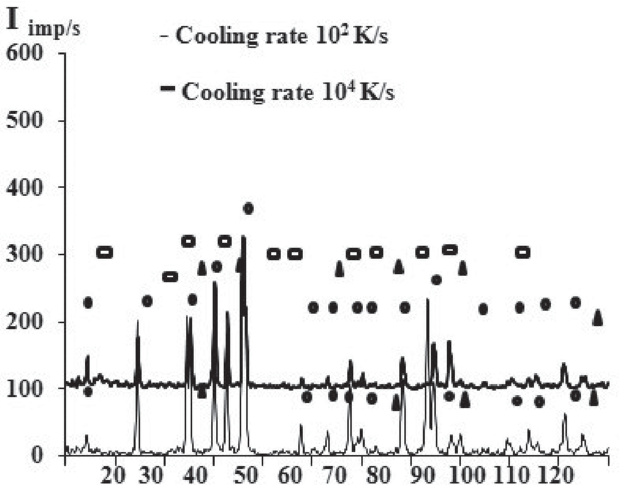

Fig. 4. Diffractogram of hypoeutectic alloy with aluminum content of 71.0 % (wt.): □ - AlCu, ▲ - Al, ● - Al_2Cu.

Thus, depending on overheating temperature the decrease of the volume ratio of the primary phase – aluminum – takes place (Fig. 5).

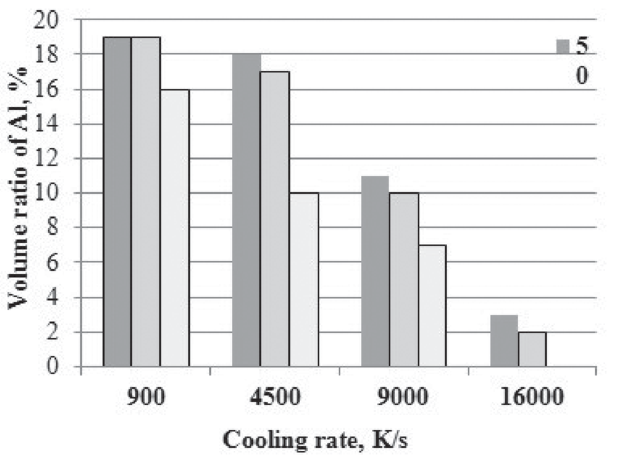

Fig. 5. Volume ratio – cooling rate dependence of primary crystals of aluminum.

Therefore, the overheating of the liquid above liquidus curve to 150 K leads to the reduction of the volume ratio of Al primary crystals and to increase of the volume ratio of the eutectics. At the cooling rate of 10^4 K/s no formation of aluminum crystals occurs at all, which can be explained by the lack of primary phase microcomplexes in a liquid of alloy, that is in a good agreement with results of the papars [5-8]. An analysis of the outcomes shows that the eutectic point has shifted. At the overheating of the liquid above liquidus curve to 200 K and aftercooling of alloys with a rate of 10^4 K/s along with aluminum eutectics and $AlCu_2$ there the formation of finely-divided AlCu precipitations takes place.

Conclusions

So, in the paper it was studied the hypoeutectic Al-Cu alloys with copper content of 25.0-34.0 % (wt.), the rest is aluminum, and the next results were obtained:

1. The overheating of the alloy liquid by 50-100 K above the liquidus curve leads to the formation of finely-divided eutectic arrangement and to suppression of the process of formation of the aluminum primary crystals.

2. At all overheating temperatures and cooling rates of alloys there are observed the increase of the volume ratio of the eutectics compared with specimens.

3. The overheating of liquid by 150 K leads to a complete suppression of the process of formation of the aluminum primary crystals that indicates the lack of their microcomplexes in the liquid alloy. The obtained results agree nicely with data of the other authors.

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