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THE EFFECT OF COOLING RATE ON THE CRYSTALLIZATION OF ALUMINUM ALLOYS UNDER PRESSURE

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I. INTRODUCTION

One of the most important problems directly influencing the efficiency of the use of metal products is the management of structure and properties formation of the applicable metals and alloys at their transition stage from melt (liquid) to solid [1]. In modern technological processes of material working temperature as a physical parameter defines the state in the treated material. This state also depends on pressure. In our case a material state is considered as the function of thermodynamic parameters. It is therefore essential from now on to regard temperature as not so much a ‘degree of hotness’ but as one of the most important thermodynamic parameters that change the structure and properties of treated materials. From this perspective, studying the mechanisms of temperature change and formation of temperature patterns acquire significant practical importance.

Unlike the conventional approach, which tends to use cooling rate as a defining thermodynamic parameter of the crystallization’s mechanism and kinetic, the paper dwells on the influence of the additional factor, i.e. pressure, which when combined with the cooling rate can be used for the targeted change of physical, chemical and mechanical properties of alloys.

The purpose of this study is therefore to expand the concept of possible pattern changes of interatomic interactions and bonds under such conditions, when the pressure of up to 100 MPa/s is being exerted with a fixed speed rate onto the molten metal with the temperature 150..200 K higher than crystallization temperature.

II. METHODS AND RESEARCH TECHNIQUES

The traditional way of elevating mechanical properties of aluminum alloys by way of adding alloying components is studied sufficiently, and its potential is practically exhausted for today. A new solution to the problem of improvement of the alloys properties may be found in an unconventional technology, i.e. in the technology of high-pressure application for the ultrafast crystallization. The paper gives research results on the influence of pressure onto the speed of emission of latent crystallization heat and influence of this factor on the structural properties of AK7 aluminum alloy.

The paper studies amorphization of aluminum-based alloys, which can be reached in 70 mm ingots ∅ 80 mm through programmed high pressure application onto liquid metal with the heat removal at approximately 3..5 K/sec.

An aluminum alloy was produced in graphite crucible under a flux layer in an electric resistance furnace. The form was filled from a 2 dm^3 cup by way of popping the stopper. The cup's room was vacuumed, the residual pressure was 0.01 MPa. The temperature was measured by platinum-rhodium-platinum thermocouples with the electrodes 0.5 mm in diameter and 500 mm operating length. Temperature patterns were measured in two modes: 1 – crystallization under 500 MPa pressure; 2 – crystallization without pressure application. Working fluid pressure in the hydraulic pressure was measured with the help of a strain gauge. Pressure application on the mold was carried out from two sides along the centre line of the blank by two injection plungers moving towards each other. All movements of the plungers during the mold's casting were recorded by induction sensors with the precision +0.1 mm and stroke length up to 150 mm. Pressure was applied till the end of crystallization. A compute information-control system was used to gather and process the experimental data [2].

Figure 1 shows the thermocouples' data in real-time mode. Curves 2-1 and 1-1 give the data from the thermocouples installed into the metal; curves 2-2 and 1-2 correspond to the thermocouples installed at a 8 mm distance from the form's walls. It follows from the cooling curve analysis (Figure 1: curves 2-1 and 2-2 with pressure application, curves 1-1 and 1-2 without pressure application) that crystallization of alloys under pressure is carried under totally different laws. The amount of the applied pressure directly influences the release time of the latent crystallization heat. Such an effect is equal to a fast cooling of a metal in water or any other medium.

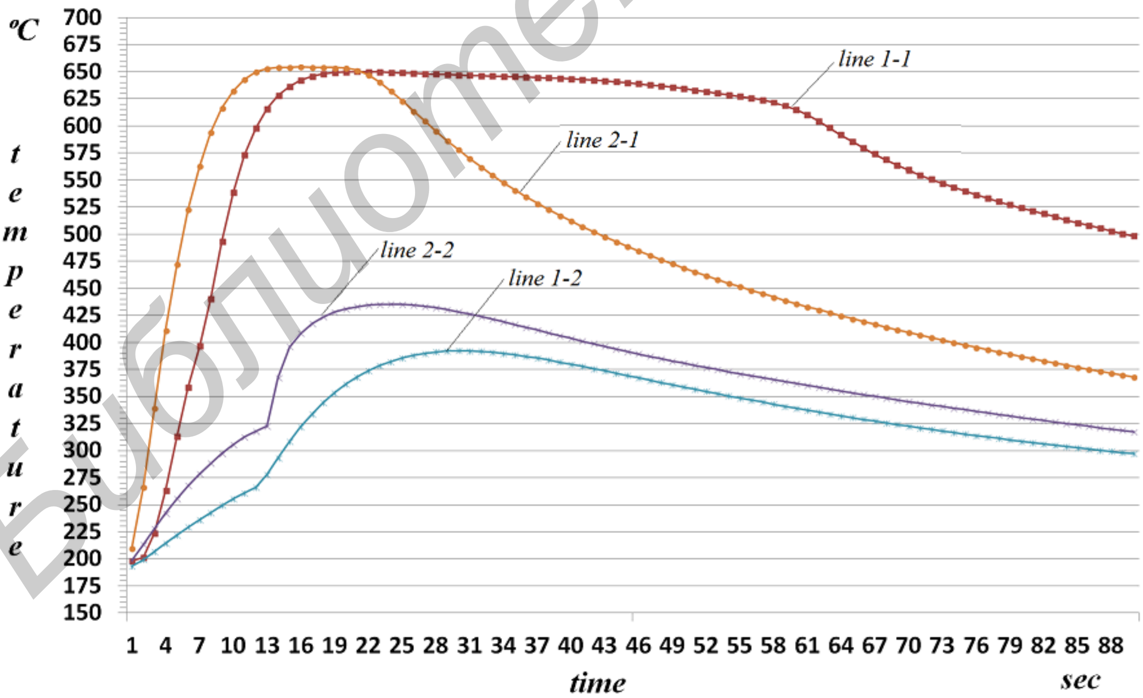
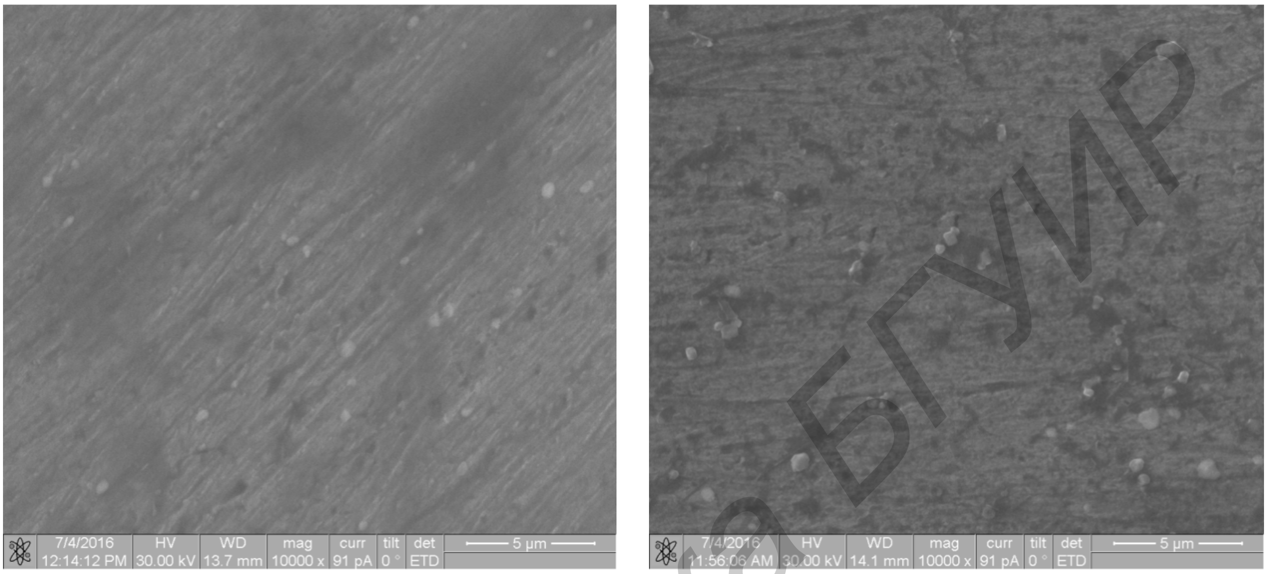


Figure 1 – Cooling curves of the aluminum alloy AK7: curves 1-1 and 1-2 without pressure application; curves 2-2 and 2-2 with 500 MPa pressure application

Output analysis has allowed establishing (Figure 1) that pressure application reduces the time period of latent heat emission from ~ 30 sec. to ~ 8 sec. If the total amount of heat released from the ingot stands in proportion to the area under the cooling curve, then we can establish the fact of evident change of atomic energy levels exposed to pressure. Therefore, the pressure application technology, process parameters and control actions should be directed to the establishment of compensation, contraction of volume in accordance with the quantity of heat abstracted from the melt.

The degree of dispersion of the cast structure increases alongside the increase of cooling rate. All the structural and phase components are also being dispersed: dendrite branches, second-phase particles, pores, eutectic colonies. During ultrafast application of high pressure non-dendritic pattern zones appear. The sample on Img.2a was acquired by ultrafast application of high pressure and represents second-phase precipitates of 0.5 – 2.5 µm. The sizes of such second-phase precipitates in the melt produced without pressure application (Figure 2b) are significantly larger (5-30 µm).



a b

Figure 2 – AK7 alloy microstructure crystallizing under pressure
of 500 MPa (a) and without any pressure (b) (x10000).

Fast pressure application and consequently high cooling rate of metal boost the process of metastable crystallization which manifests itself in the formation of a supersaturated solid solution [3, 4]. It should be noted that the increase of cooling rate during alloy crystallization leads to the additional saturation of the solid solution both in the volume of grains and on their boundaries.

From the results it is concluded that pressure application and cooling may be treated as a working technology for the metal shift from liquid and thus non-structural state into crystalline, quasi-crystalline, quasi-amorphous or amorphous state with the change of properties that such shift entails.

III. CONCLUSION

The use of ultrafast high pressure application technology and further casting under optimum conditions boosts the creation of metal products with the targeted metastability level, 40-60% enhancement of strength characteristics of aluminum alloys while preserving the paste-forming properties on a relatively high level.

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