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

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**Abstract.** The influence of pressure on the compressibility of liquid metal and the release of latent crystallization heat is studied. It is found that the pressure application combined with the cooling rate creates metastable structures. It can be used for improvement the properties of metals and alloys.

**Keywords:** aluminum alloy, cooling, crystallization, microstructure, pressure

## 1. Introduction

One of the most important problems influencing the efficiency of metal products is the structure and properties formation of metals and alloys during their transition from melt (liquid) to solid [1]. Unlike the conventional approach, which tends to use cooling rate as a defining parameter of crystallization, the paper dwells on the pressure influence, which combined with cooling rate can be used for target changing alloy properties. We tried to elucidate how the pressure of up to 100 MPa/s, with the temperature of 150 − 200 K higher the crystallization temperature, influences on crystallization and structure of AK7 aluminum alloy. It is known that alloy amorphization is achieved under ultrafast cooling from liquid state. It reduces the possible range of amorphized alloys products to thin foils, bands, fiber less than 0.1…0.2 mm thick [12-17>2-7].

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

## 2. Research technique and results

The aluminum alloy was produced in a 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. The temperature patterns were measured in two modes: 1 – crystallization under 500 MPa pressure; 2 – crystallization without pressure. Working fluid pressure in the hydraulic pressure was measured with the help of a strain gauge. The pressure is applied on the mold from two sides along the centre line of the blank by two injection plungers moving towards each other. All motions of the plungers during the mold 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 [18>8].

Figure 1 shows the thermocouple 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 an 8 mm distance from the form walls. It follows from the cooling

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curve analysis that the crystallization under pressure performs in different way. The value of pressure directly influences the release time of the latent crystallization heat. Such effect is equivalent to a fast cooling of a metal in water or any other medium. The pressure application reduces the time from ~ 30 to ~ 8 sec.

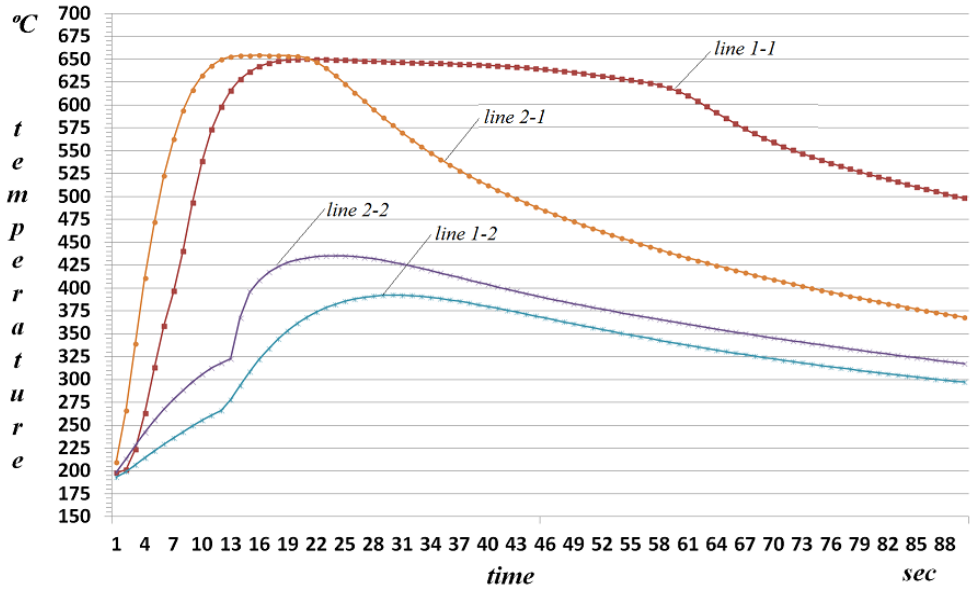
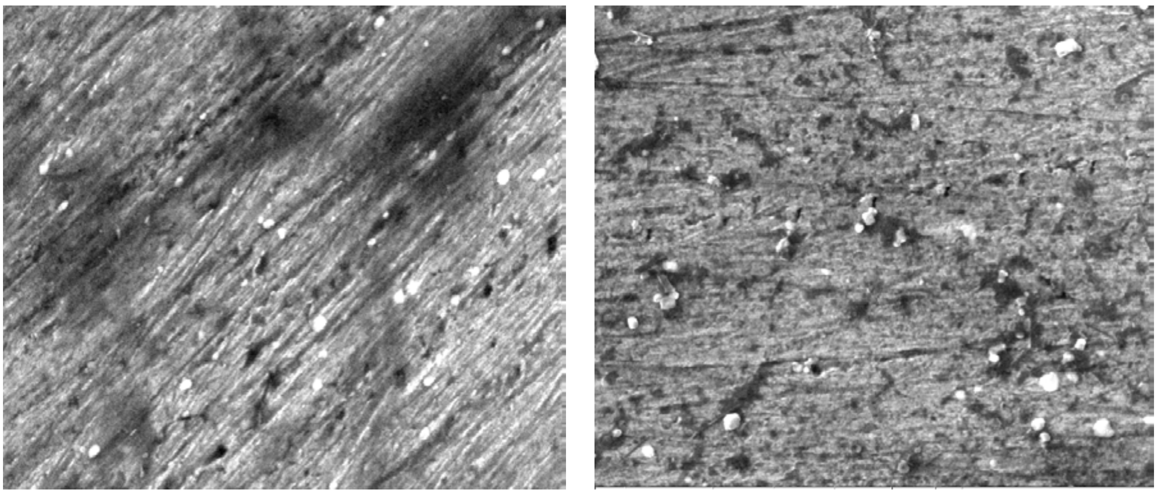



**Fig. 1.** Cooling curves of aluminum alloy AK7: curves 1-1 and 1-2 without pressure application; curves 2-2 and 2-2 with 500 MPa pressure application

The positive influence of accelerated cooling during crystallization onto the structure and mechanical properties of metals and alloys is well known [19, 20>9, 10]. Cooling rates of $10^4$-$10^6$°C/sec allow boost properties of different alloys. The degree of dispersion of the cast structure increases with the growth of cooling rate. The sample shown in Figure 2a was obtained by ultra fast application of high pressure; it represents the second-phase precipitates of 0.5 – 2.5 µm. The sizes of such precipitates in the melt produced samples without pressure application (Fig. 2b) are significantly larger (5-30 µm).



a) b)

**Fig. 2.** AK7 alloy microstructure crystallized under pressure of 500 MPa (a) and without pressure (b) (x10000)

From the results it follows that pressure application and cooling can be treated as a working technology for metal transition from liquid to crystalline or amorphous state with the property change that such transition entails. The presented technological cycle of the alloy casting production can be commercialized in order to produce alloy castings equal in their strength properties to foreign leading aluminum alloys of medium and high-strength.

## 3. Conclusion

The pressure applied onto the liquid aluminum alloy before and during crystallization affects the latent crystallization heat release. The applied pressure decreases significant (80 to 100 times) the grain medium diameter (0.5-2.0 μm). Alongside the grain disintegration metastable phases appear. The use of ultra fast 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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## References

[1] Belov NA. *Phase Composition of Commercial and Production Oriented Aluminum Alloys.* Moscow: MISIS; 2010.

[2] Yunjia S, Pan Q, Li M, Huang X, Li B. Effect of Sc and Zr additions on corrosion behavior of Al–Zn–Mg–Cu alloys. *Journal of Alloys and Compounds*. 2014;612: 42–50.

[3] Mei LC, Qian CZ, Min ZS, Pu CN, Xiao CT. Intermetallic phase formation and evolution during homogenization and solution in Al–Zn–Mg–Cu alloys. *Science China*. 2014;56: 2827–2838.

[4] Ozbek I. A study on the re-solution heat treatment of AA 2618 aluminum alloy. *Materials Characterization.* 2007;58(3): 312–317.

[5] Novy F, Janecek M, Kral R. Microstructure changes in a 2618 aluminium alloy during ageing and creep. *Journal of Alloys and Compounds.* 2009;487(1/2): 146–151.

[6] Pue HL. *Mechanical Properties of Materials under High Pressure*. Moscow: Mir; 1973.

[7] Mikhaylovskaya AV, Kotov AD, Pozdniakov AV, Portnoy VK. A high-strength aluminium-based alloy with advanced superplasticity. *Journal of Alloys and Compounds*. 2014;599: 139–144.

[8] Denisov MS. Development of computer driven control system of casting under pressure. *Computational Nanotechnology*. 2016;2: 146-152.

[9] Osintsev OE, Konkevich VU, Nikitin SL, Betsofen SY. Influence of the main components and transition metals on the structure and properties of Al-Zn-Mg-Cu fast-crystallizing high-strength aluminum alloys. *Metals.* 2012;1: 93–98.

[10] Osintsev OE, Konkevich VU. Al-Zn-Mg and Al-Zn-Mg-Cu high-strength aluminum alloys. *Light alloys technologies.* 2010;1; 157–163.