

# ALLOYING CAPACITY FOR THE SOLID SOLUTION OF ALLOYS OBTAINED BY CRYSTALLIZING UNDER PRESSURE

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UDC 620.181:669.71'721'3'782

Crystallization of alloys under pressure, currently used in many production processes for casting nonferrous alloys, leads to a nonequilibrium structure which is connected with action on the solidifying metal of high pressure and a high cooling rate. The nature of the effect of these factors on the degree of alloying capacity for solid solution (i.e., the content in it of alloying elements) may be the same or the reverse.

The aim of this work is determination of the effect of pressure during crystallization on the change in content of alloying component in solid solution of alloys based on aluminum and magnesium.

The study was carried out on alloys of systems based on industrial alloys (Al - Si, Al - Mg, Al - Cu, Al - Zn, Mg - Al), and also on aluminum alloys with components used for additional alloying of the industrial alloys of the systems listed above (Mn, Cr, Ti, Zr, Ni, Cd) or in the form of permanent or random impurities (Fe, Sn, Pb).

Billets 40 mm in diameter were obtained by casting with crystallization under a pressure of 0, 100, 200, and 400 MPa in a mold heated to  $T_m = 150-200^\circ\text{C}$ . In the melting temperature range the cooling rate for castings without applying pressure was 3-5 degK/sec, with crystallization under pressure  $p = 100$  MPa it was 8-10 degK/sec, with  $p = 200-400$  MPa it was 13-15 degK/sec. After final crystallization castings were air cooled from 350-400°C. During crystallization without pressure a variable cooling rate was provided by casting alloys in a metal mold with a variable working diameter (10-40 mm), by varying the temperature (20-400°C), and by using a mold of different material (steel, copper). The content of alloying component in solid solution was determined by x-ray analysis. In order to work out the composition of the solid solution use was made of data in [1-4] for the change in crystal lattice parameter of aluminum with alloying, and for alloys of the systems Al - Mg, Al - Cu, Mg - Al use was made of results obtained by us for direct x-ray analysis of quenched alloys. The effect of crystallization conditions (pressure, cooling rate) on the amount of second phase was also determined in specimens of the test alloys by quantitative metallography.

Results of the study (see Fig. 1 and Table 1) indicate that pressure during crystallization in the majority of cases promotes an increase in the content of second component in solid solution; only in alloys of the Al-Mg, Al-Zn, and Mg-Al systems does the amount of

TABLE 1.

| Alloy        | Content of alloying component in solid solution, %, with crystallization under pressure, MPa |      |      |      |
|--------------|--|------|------|------|
|              | 0  | 100  | 200  | 400  |
| Al-9.80% Zn  | 8.80   | 8.20 | 6.40 | —    |
| Al-19.30% Zn | 17.0   | 9.90 | 8.00 | —    |
| Al-0.78% Mn  | 0.20   | 0.40 | 0.50 | 0.60 |
| Al-1.30% Mn  | 0.55   | 0.85 | 1.05 | —    |
| Al-1.56% Mn  | 0.70   | 1.05 | 1.30 | 1.45 |
| Al-0.85% Cr  | 0  | 0.15 | 0.25 | 0.35 |
| Al-0.19% Ti  | 0  | 0.10 | 0.10 | 0.15 |
| Al-0.62% Ti  | 0  | 0.10 | 0.20 | 0.30 |
| Al-0.67% Zr  | 0  | 0.25 | 0.35 | —    |
| Al-1.42% Ni  | 0  | 0    | 0    | —    |
| Al-0.84% Cd  | 0  | 0.15 | 0.20 | —    |
| Al-0.96% Fe  | 0  | 0.10 | 0.15 | 0.15 |
| Al-1.60% Fe  | 0  | 0.15 | 0.25 | 0.30 |
| Al-0.50% Sn  | 0  | 0.20 | 0.30 | 0.40 |
| Al-0.80% Pb  | 0  | 0    | 0    | 0    |

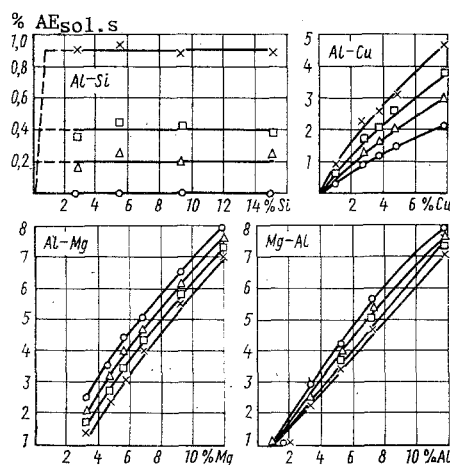


Fig. 1.

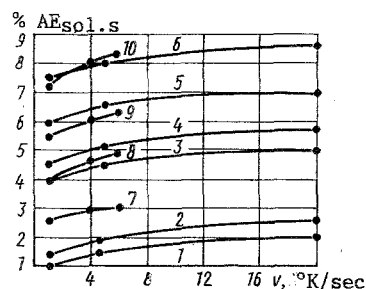


Fig. 2.

Fig. 1. Content of alloying element in solid solution for nonferrous alloys obtained by crystallization under different pressures: o,  $\Delta$ ,  $\square$ ,  $\times$ ) a pressure of 0, 100, 200, and 400 MPa, respectively.

Fig. 2. Change in solid solution concentration for nonferrous alloys in relation to cooling rate: 1) Al-2.8% Cu; 2) Al-3.9% Cu; 3) Al-5.8% Mg; 4) Al-6.8% Mg; 5) Al-9.2% Mg; 6) Al-12.2% Mg; 7) Mg-3.4% Al; 8) Mg-5.2% Al; 9) Mg-7.3% Al; 10) Mg-12.2% Al.

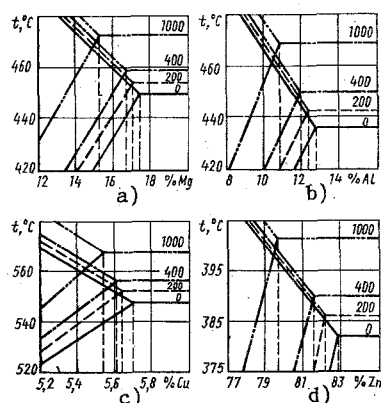


Fig. 3. T-p-C diagrams for Al-Mg (a), Mg-Al (b), Al-Cu (c), Al-Zn (d); figures on the curves are pressure in MPa.

second component in solid solution decrease, and in alloys of the Al-Ni and Al-Pb systems it is practically unchanged. Quantitative metallographic analysis of the test alloys showed that there is also a similar change in the volume content of intermetallic phase in the alloy.

Since the change in solid solution composition for alloys crystallized under pressure is a result of the combined effect of pressure and increased cooling rate, it is of interest to evaluate the individual effect of each of these factors. Results of studying the solid solution composition for alloys of the systems Al-Cu, Al-Mg, and Mg-Al in relation to cooling rate (Fig. 2), and also analysis of data in [5] for alloys of different systems, show that in the range of cooling rates normally used during casting in a metal mold with high cooling rates, the content of alloying components in solid solutions for the majority of alloys increases, and only in alloys of some systems for the cooling rate range being considered is it unchanged.

The effect of pressure was determined on the basis of calculating areas of limiting solubility in T-p-C-diagrams for some alloys and by studying alloys of the systems Al-Mn and

Al-Cu crystallized in a mold heated to  $t_m = 450-500^\circ\text{C}$ . With this crystallization regime, cooling rate for the alloys under pressure and without it is similar. Calculation of T-p-C diagrams was carried out for a model of regular solutions according to equations for phases of the binary system [6] by the procedure in [7]. For the calculations use was made of thermodynamic parameters given in [2, 8-11]. Calculated results presented in Fig. 3 confirm data in [12-14] in which a study was made of the change in solubility of a second component under the action of pressure on the solid phase at temperatures of  $250-450^\circ\text{C}$ .

The T-p-C diagram calculated in [15] for the Al-Si system points to an increase in silicon solubility with increasing pressure, and therefore the data presented in Fig. 1 for the increase in silicon content in solid solution of alloys of the Al-Si system with crystallization under pressure may be explained by the action of the pressure itself. In T-p-C diagrams for Al-Mg and Mg-Al (Fig. 3a, b) the degree of solubility for alloying component increases with an increase in pressure. Therefore data in Fig. 1 for these systems, representing the result of the combined effect of pressure and cooling rate operating in different directions, point to the predominant effect of pressure during crystallization on the amount of alloying component in solid solution. This nature of the effect of pressure and cooling rate on solid solution properties is also observed for alloys of the Al-Cu system, although according to the T-p-C diagram the effect of pressure is small (Fig. 3c), and an increase in the amount of copper in solid solution for these alloys crystallized under pressure is connected with the effect of high cooling rate. This is confirmed by the fact that a reduction in cooling rate during crystallization under pressure leads to some reduction in the copper content of solid solution. With a mold temperature of  $150-200^\circ\text{C}$  the content of copper in solid solution for Al-2.5% Cu alloy with pressure  $p = 0, 100, \text{ and } 200 \text{ MPa}$  is 0.90, 1.15, and 1.35%, and with  $t_m = 450-500^\circ\text{C}$  for  $p = 100 \text{ and } 200 \text{ MPa}$  it is 0.90 and 0.85% respectively.

There is a similar change in the content of solid solution for alloys of the Al-Mn system which are inclined to formation of supersaturated solid solution with accelerated cooling [1-3]. With crystallization in a mold with  $t_m = 150-200^\circ\text{C}$  the amount of manganese in solid solution increases with increasing pressure (see Table 1). At the same time, with a reduction in cooling rate during solidification under pressure the content of manganese in solid solution also decreases. For alloy Al-1.30% Mn crystallized under pressure  $p = 0, 100, \text{ and } 200 \text{ MPa}$  in a mold with  $t_m = 150-200^\circ\text{C}$  the solid solution contains 0.55, 0.85, and 1.05% Mn, and with  $t_m = 450-500^\circ\text{C}$  it contains 0.45, 0.45, and 0.40% Mn, respectively.

For alloys of the Al-Zn system an increase in pressure during crystallization leads to a reduction in zinc content in solid solution (see Table 1), which is confirmed by the results of analysis for the effect of pressure on solubility according to the T-p-C diagram for Al-Zn (Fig. 3d). In alloys of the Al-Cr, Al-Ti, Al-Zr, Al-Cd, Al-Fe systems the amount of second component in solid solution with crystallization under pressure increases (see Table 1). Considering that during casting in a chill-mold (without pressure) supersaturated solid solution does not occur, it may be assumed that an increase in content of the second component in solid solution for the alloys mentioned above is connected mainly with the effect of pressure. In alloys of the Al-Ni and Al-Pb systems dissolution of the alloying component during crystallization under pressure of  $0-400 \text{ MPa}$  is not observed (see Table 1).

A reduction or increase in the amount of alloying component in solid solution under the action of pressure depends on the change in volume of phases during melting, heat of crystallization, and substitution phase energy.

#### CONCLUSIONS

1. During crystallization of alloys under pressure a change in the solid solution composition is the result of the combined effect of pressure and a high cooling rate, whose effects may coincide or be opposite.

2. In alloys of the Al-Si, Al-Cu, Al-Mn, Al-Cr, Al-Ti, Al-Zr, Al-Cd, Al-Fe, Al-Sn systems the content of second component in solid solution with crystallization under pressure increases, and in alloys of the systems Al-Mg, Al-Zn, Mg-Al it decreases. For alloys of the Al-Cu and Al-Mn systems an increase in the content of alloying component in solid solution with crystallization under pressure is caused by the high cooling rate, and for alloys of the rest of the systems by the effect of pressure itself.

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#### THE EFFECT OF MICROALLOYING ON THE STRUCTURE AND PROPERTIES OF Al-Zn-Mg-Cu ALLOYS

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UDC 669.71'5'721'3:620.18:620.17

Small additions of transition metals to aluminum alloys lead to a significant change in their properties and structure [1, 2].

In this investigation we studied the effect of zirconium (0.15%), iron (0.1-0.3%), hafnium, and rare-earth metals (REM) of the ytterbium group on the structure and properties of semifinished rolled strips of the Al-Zn-Mg-Cu system. The iron content in alloys with zirconium, hafnium, and the REM was 0.1%.

Templates made from rod strips with cross sections of 15 × 200 mm underwent a water quench ( $t_w = 20^\circ\text{C}$ ) from  $460^\circ\text{C}$ . This was followed by two stage aging.

For both alloys the regime of the first stage was  $110^\circ\text{C}$  for 8 h. The second aging stage had various durations at  $175^\circ\text{C}$ .

The aging curves of the investigated alloys are given in Fig. 1 and show the change in mechanical properties as a function of the length of the second aging stage in which there is development of the primary phase and coagulation [3].

The introduction of zirconium, hafnium, and the REM leads to an increase both in the ultimate strength  $\sigma_u$  and in the plasticity properties  $\delta$  and  $\psi$  after aging (Fig. 1) in comparison to alloys containing only iron. Changing the iron content from 0.1 to 0.3% did not

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Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 4, pp. 46-48, April, 1986.