STRUCTURE AND MECHANICAL PROPERTIES OF Al—Si ALLOYS OBTAINED BY CRYSTALLIZATION UNDER PRESSURE

A. Ya. Shinyaev, A. I. Litvintsev, and O. G. Pivkina

UDC 620.18:620.17:669.715'782

High pressure during crystallization makes it possible to influence the structure and properties of a metal. With crystallization under a pressure of 50-100 MPa the mechanical properties of ingots as large as 120 mm in diameter increase by 20-30 MPa (as much as 10%) [1]. Ingots 30 mm in diameter and 100 mm high of Al—Si alloys were crystallized under hydrostatic pressure of 300 MPa, which improved the mechanical properties 15% [2].

The purpose of this work was to obtain ingots of aluminum alloys by crystallization under pressures up to 1500 MPa and determine the effect of high pressure on the structure and mechanical properties.

An apparatus was developed for crystallization under pressures up to 1500 MPa to obtain ingots 50 mm in diameter and 100 mm high. We used Al—Si alloys, which have been investigated in detail [2, 3], and the components of the basic casting alloys — hypoeutectic Al—5% Si and hypereutectic Al—15% Si and Al—19% Si. Ingots obtained by semicontinuous casting were crystallized under pressures of 1000-1500 MPa from temperatures 50-80°C higher than the liquidus.

We made a metallographic analysis of the alloys, found the distribution of Al and Si by microprobe analysis with the MS-46 analyzer, and determined the solubility of silicon in the α solid solution from the change in the lattice constant of the α solid solution, which was determined from photographs made in the KROS camera. Figures 1 and 2 show the macrostructure and microstructure of Al—Si ingots obtained by various methods. After semicontinuous casting the microstructure is fanlike, which is typical of this method of casting (Fig. 1, Ia, b). The structure of the ingot crystallized at atmospheric pressure is uneven, with shrinkage cavities and clusters of primary silicon crystals (Fig. 1, IIa, b). With crystallization under a pressure of 1500 MPa the structure is uniform and fine grained (Fig. 1, IIIa, b). Analysis of the microstructure of ingots of Al—5% Si showed that crystallization under high pressure produces a dense pore-free structure with smaller sizes of dendrites of the α solid solution (from 20-40 μm in the ingot produced by semicontinuous casting to 8-12 μm) and thinner boundaries of dendritic cells due to the solution of silicon in the α solid solution (Fig. 2a). The microstructure of the Al—19% Si ingot is transformed from hypereutectic to hypoeutectic with rounded dendrites of α solid solution (which points to bulk crystallization of the alloy under conditions of hydrostatic pressure) and no large primary crystals of silicon. The morphology of the silicon precipitates in the eutectic also changes — instead of long needles of silicon in the semicontinuously cast ingot the silicon particles are spherical with a diameter of 2-3 μm (Fig. 2b).

The microhardness of dendrites of the α solid solution and eutectic sections in ingots crystallized under a pressure of 1500 MPa increases in comparison with the original values (see Table 1). The increase in the microhardness of the dendrites of the α solid solution is due to the higher silicon content, as is confirmed by the smaller lattice constant of the solid solution in ingots crystallized under pressure (see Table 1). The microhardness of the eutectic sections increases due to refining of the eutectic structure and the shift of the eutectic point to the silicon side. Local microprobe analysis and measurements of the lattice constant of the α solid solution (with an error of ±0.001 Å) showed that the solubility of silicon in the solid solution in ingots crystallized under a pressure of 1500 MPa increases 4.2% in comparison with other methods of producing the ingot (see Table 1). With crystallization under a pressure of 1500 MPa the eutectic contains > 19% Si, compared with 12.3%

All-Union Institute of Light Alloys. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 2, pp. 44-46, February, 1983.

0026-0673/83/0102-0129$07.50

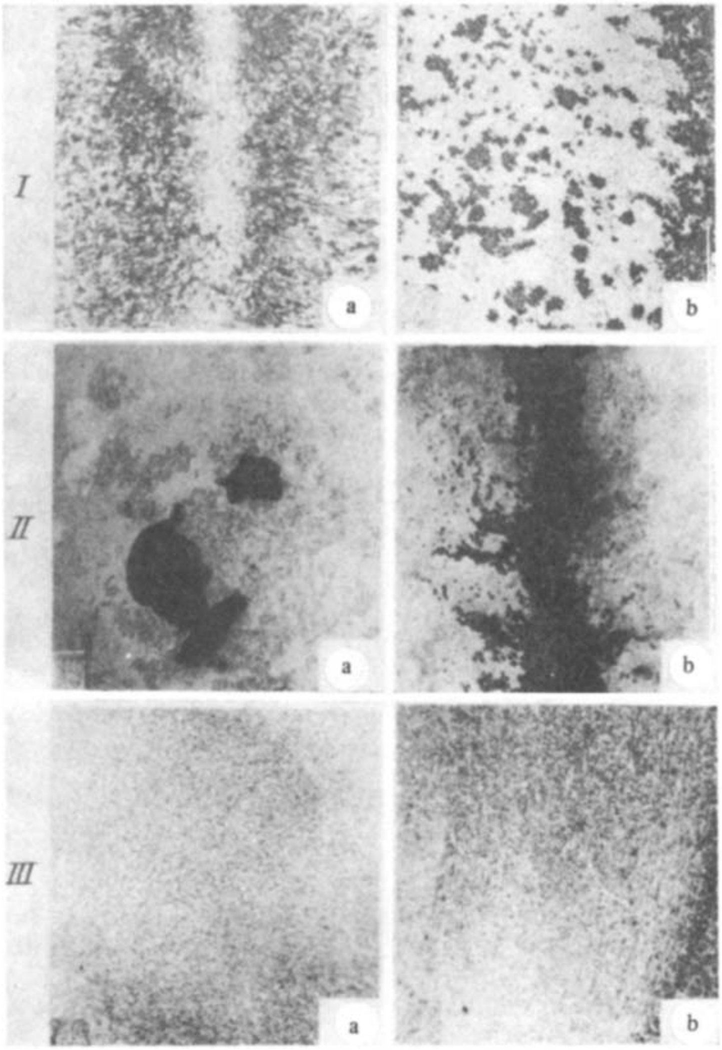

Fig. 1. Macrostructure of Al—5% Si (a) and Al—19% Si (b) alloys obtained by semicontinuous cast- (I), crystallization at atmospheric pressure (II), and crystallization under a pressure of 1500 MPa (III).

with crystallization under atmospheric pressure. This agrees with results from thermodynamic calculation of the line of phase equilibrium and experimental determination of the critical points on Al—Si phase diagrams at high pressures [3].

The mechanical properties of ingots crystallized under a pressure of 1500 MPa, semi-continuous casting, and under a pressure of 300 MPa [2] are also given in Table 1, along with the properties of AL2, which was crystallized under piston pressure [4]. It can be seen that the strength of ingots crystallized at a pressure of 1500 MPa is 1.5-2.3 times higher than that of ingots obtained under a pressure of 300 MPa and 1.3-1.8 times higher than that of the cast alloy of similar composition. However, the ductility of the Al—5% Si alloy decreases by a factor of 1.6 and the yield strength increases by a factor of 2.4.

The increase in the strength of ingots crystallized under pressure is due to reduction of the porosity and changes in the ratio of phases toward larger amounts of silicon. The formation of a uniform structure, refining of the phase components, and increase in the solubility of silicon in the α solid solution lead to an increase in the ductility of the ingots of hypereutectic alloys (relative elongation increases by a factor of 2.5-3.5).

It is known [5] that intensive decomposition of the α solid solution occurs at temperatures above 100-200° in Al—Si ingots obtained by standard casting methods. For this reason,

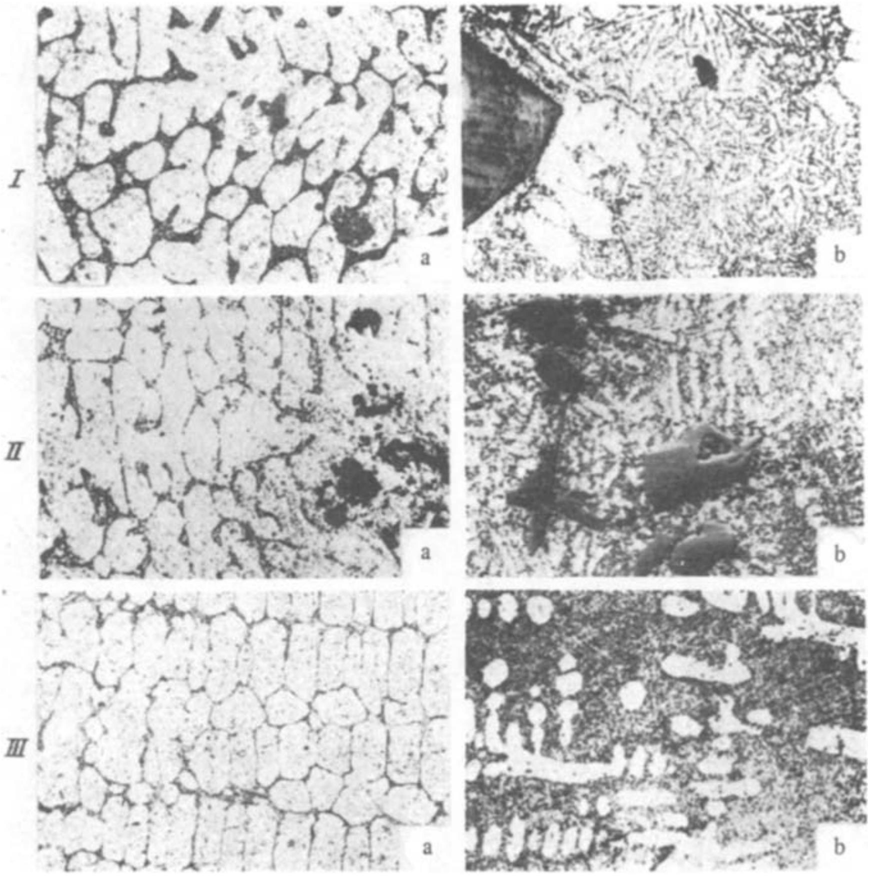

Fig. 2. Microstructure of Al—5% Si (a) and Al—19% Si (b) alloys obtained by semicontinuous casting (I), crystallization at atmospheric pressure (II), and crystallization under a pressure of 1500 MPa (III); ×250.

we also investigated the stability of the supersaturated solid solution resulting from crystallization under pressure. Ingots of the Al—Si system were annealed at 100-550°C for 10 h. Figure 3 shows the effect of annealing on the mechanical properties at standard temperature and the electrical conductivity of Al—5% Si and Al—19% Si alloys crystallized under a pressure of 1500 MPa. The electrical conductivity, measured by the eddy current method, is correlated with changes in the mechanical properties of the alloys [6]. The strength of the Al—5% Si alloy annealed at 150° increases, while no strengthening effect was noted for the Al—15% Si or Al—19% Si alloys (Fig. 3). The changes in the mechanical properties during annealing are in good agreement with the variation of the electrical conductivity with temperature. The plot of electrical conductivity vs annealing temperature shows a low point at 150° for Al—5% Si, which is absent on the plots for eutectic alloys (Fig. 3). This can be explained by the fact that the Al—5% Si alloy contains a substantially larger volume of supersaturated α solid solution than the Al—15% Si and Al—19% Si alloys. When the annealing temperature is raised to 150° a finely dispersed secondary phase (silicon) is precipitated in the Al—5% Si alloy, which leads to strengthening. This is confirmed by the lower electrical conductivity. At higher annealing temperatures the silicon crystals grow and coalesce, due to which the alloy weakens and the electrical conductivity increases. In the Al—15% Si and Al—19% Si alloys, with a smaller volume of supersaturated solid solution, precipitation of finely dispersed silicon particles when the temperature is raised to 150° is hardly observed, which is due to the large percentage of eutectic silicon. Intensive weakening of these alloys begins at temperatures above 300°, where growth and coalescence of silicon crystals occur.

CONCLUSIONS

1. High pressure (up to 1500 MPa) during crystallization of Al—Si alloys produces a dense even structure with supersaturation of the α solid solution and refining of primary

TABLE 1

Alloy	Method of producing alloy	Microhardness H: solid solution	Microhardness H: eutectic	a, Å	Solubility of Si in α solid solution, % (± 0.5%)	σ_b, MPa	$\sigma_{0,2}$, MPa	δ, %	a_1, MJ/m²	HB
Al — 5 % Si	Crystallization at 1500 MPa	68	80,4	4,0457	3,8	210	170	10	0,98	69
	Semicontinuous casting	44	50	4,0482	1,3	170	70	16	1,96	50
	Crystallization at 300 MPa [2]	—	—	—	—	160	—	18	—	—
Al — 15% Si	Crystallization at 1500 MPa	84	92	4,0447	4,2	280	220	8,5	3,92	105
	Semicontinuous casting	46	52	4,0483	1,3	130—180	0—170	0—1,1	2,45	80—87
	Crystallization at 300 MPa [2]	—	—	—	—	180	—	3,2	—	—
Al — 19% Si	Crystallization at 1500 MPa	89	98	4,0450	4,2	290	280	2,4	3,92	120
	Semicontinuous casting	46	52	4,0482	1,3	100—160	—	0; 0,8	1,96	84—87
	Crystallization at 300 MPa [2]	—	—	—	—	130	—	2,0	—	—
Al — (10—13) % Si	Cast under piston pressure [4]	—	—	—	—	220	120	2,2	—	—

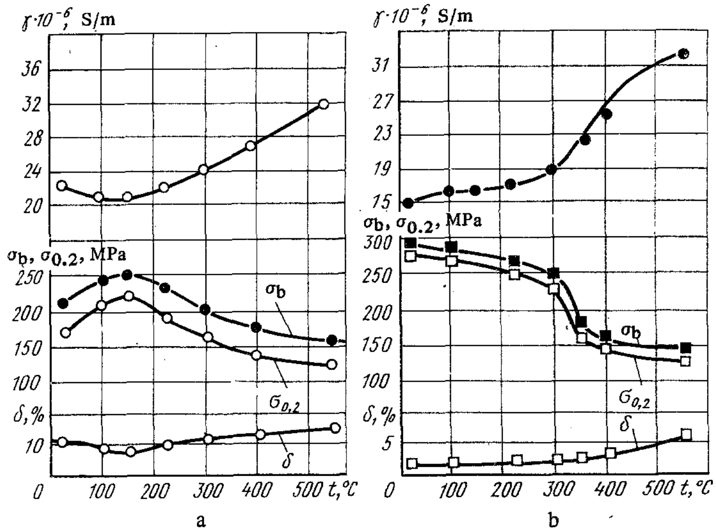

Fig. 3. Mechanical properties (σ_b, $\sigma_{0.2}$, δ) and electrical conductivity (γ) of Al—5% Si (a) and Al—19% Si (b) alloys crystallized under a pressure of 1500 MPa in relation to annealing temperature.

silicon in the eutectic, as the result of which the strength and ductile characteristics of the ingots improve.

2. The improved mechanical properties of Al—Si alloys crystallized under pressure are retained up to annealing temperatures of 300°C due to the stability of the α solid solution. In ingots produced by ordinary casting methods the α solid solution is stable only up to 100-200°C.

LITERATURE CITED

1. A. I. Batyshev, Crystallization of Metals and Alloys Under Pressure [in Russian], Metallurgiya, Moscow (1977), p. 147.
2. H. Tokisue and K. Aoki, J. Jpn. Inst. Light Met., 25, No. 6, 200 (1975).
3. A. Ya. Shinyaev and D. B. Chernov, "Use of high pressure to increase the solubility of metals in aluminum," Tekhnol. Legkikh Splavov, No. 11, 3 (1976).

4. I. N. Fridlyander (ed.), Commercial Wrought, Sintered, and Cast Aluminum Alloys (Handbook) [in Russian], Metallurgiya, Moscow (1972), p. 552.
5. I. F. Kolobnev, Shaped Castings of Aluminum Alloys [in Russian], Mashgiz, Moscow (1953), p. 190.
6. N. M. Naumov and P. G. Miklyaev, "Quality control of aluminum alloy products by means of the eddy current method after heat treatment," Tekhnol. Legkikh Splavov, No. 2, 62 (1968).

MECHANICAL PROPERTIES OF A8 AND A85 ALUMINUM AT ELEVATED TEMPERATURES

V. V. Volga and A. A. Kholodilo

In order to improve the standards and methods of calculating the strength of tanks and equipment made of aluminum, we investigated the mechanical properties of aluminum at elevated temperatures with brief and prolonged loads.

The tests were made after annealing at 380°C for 1 h.

Samples with a reduced section 6 and 10 mm in diameter and a length of 30 and 50 mm cut from a plate 25 mm thick in the transverse direction were tested.

Even heating was achieved with a special heating chamber that ensured a constant temperature for the entire test. The temperature was monitored with the ÉPP-09 automatic electronic potentiometer and a Chromel–Copel thermocouple.

The samples were heated to the desired temperature in about 1 h and held 20-30 min; deviations from the given temperature did not exceed ±3°. We tested five to seven samples for each point.

The test results for A8 and A85 aluminum after statistical treatment [1] are given in Table 1.

Creep tests were made in AIMA-5-1 machines.

Samples with a reduced section 10 mm in diameter and 100 mm long were heated to the given temperature in ∿8 h and held at least 1 h. The testing time was 8000-10,000 h.

TABLE 1

Testing temp., deg C	Sample diameter, mm	σ_b, MPa	$\sigma_{0.2}$, MPa	δ, %	ψ, %
20	6	64/67	25/30	46/42	90/89
	10	66/59	25/24	50/52	90/92
50	6	59/60	23/26	53/45	90/93
	10	62/56	23/23	55/50	91/93
100	6	51/48	21/23	59/48	91/94
	10	52/47	24/22	62/58	92/93
150	6	41/43	19/22	61/51	94/93
	10	42/38	23/20	69/60	93/95
200	6	32/32	18/17	64/58	94/96
	10	34/29	19/16	77/65	95/95

Note. Numerators refer to A8, denominators to A85.

TABLE 2

Alloy	σ_{long}, MPa, at temperature, deg C: 20	50	100	150
A8	46/42	41/38	34/31	26/25
A85	41/38	37/34	30/27	23/21

Note. Numerators refer to tests for 10^4 h, denominators to tests for 10^5 h.

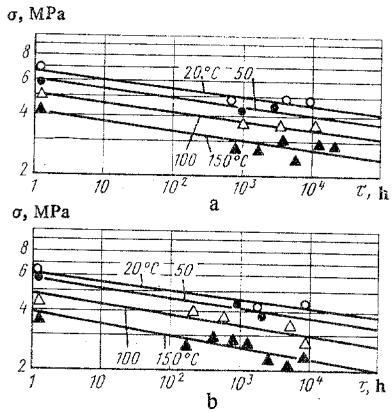

Fig. 1. Creep strength of A8 (a) and A85 (b) aluminum at different temperatures (given on the curves).

All-Union Scientific-Research and Design Institute of Chemical Machine Construction (North Donets Branch). Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 2, pp. 46-47, February, 1983.