THERMAL STABILITY OF METASTABLE PHASES IN RAPIDLY QUENCHED ALLOYS OF THE SYSTEM Al—Cr—Zr

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In the present work* a study was made of the reaction of aluminum with zirconium and chromium in alloys in the equilibrium condition and rapidly quenched from the liquid, and also decomposition of supersaturated solid solutions in rapidly quenched alloys during heating. The importance of this study is connected with the possibility of creating high-temperature and high-strength alloys based on aluminum. The choice of zirconium and chromium as alloying additions is due to the tendency of zirconium towards modification, and the capacity of chromium and zirconium to form supersaturated solid solutions in aluminum with quenching from the liquid state [1].

There are no data in the literature for phase composition of rapidly quenched alloys of the system Al—Cr—Zr obtained with cooling at a rate of 10^{6-7} °K/sec. In binary alloys in equilibrium with α-solid solution there are the compounds Al_7Cr and Al_3Zr [2, 3]. Solubility of chromium and zirconium in aluminum is (in atomic fractions) 0.42% and 0.076% respectively.

Alloys were melted from materials of purity (weight fraction): 99.99% Al, 99.9% Zr, 99.98% Cr. The chemical composition of the alloys and also the composition of intermetallides in the original cast condition (according to x-ray analysis data) are given in Table 1 and in Fig. 1.

In order to obtain an equilibrium condition specimens were annealed in twice evacuated quartz ampules at 550°C for 1440 h. Heat treated alloys were quenched in iced water.

Rapidly quenched alloys were prepared in the form of tape 0.01-0.02 mm thick and 2-5 mm wide by feeding a jet of melt on to the outer surface of a copper cylinder rotating at a rate of about 30 m/sec. The quenching rate was 10^{6-7} °K/sec, and the casting temperature was 1200°C.

With the aim of studying the decomposition process rapidly quenched alloys were annealed in evacuated ampules at 250, 350, 450°C for 6-148 h.

Alloys were studied by means of thermal, x-ray, and hardness methods. Hardness analysis as a result of the small thickness of tape was carried out in a PMT-3 instrument with a load of 0.01 N.

From the results of studying equilibrium alloys a section of the diagram at 550°C was plotted. It was established that in equilibrium with aluminum solid solution there are compounds Al_7Cr (monoclinic lattice) and Al_3Zr (tetragonal lattice).

Thermal analysis of binary rapidly quenched alloys with chromium and zirconium (heating rate 1.3 °K/sec) showed that the peritectic reaction temperature decreased by 5-6°C compared with the equilibrium value.

The boundary of the region for supersaturated solid solutions of the rapidly quenched alloys studied was determined by x-ray phase analysis.

Under quenching conditions at a rate of 10^{6-7} °K/sec the maximum solubility of chromium and zirconium in aluminum is about 6.5 and 0.55% (see Table 1 and Fig. 2). Alloy of the system Al—Cr (8% Cr) contains two phases: supersaturated solid solution and intermetallic Al_7Cr. Alloys of the Al—Zr system (more than 0.7% Zr) contain three phases: supersaturated solid solution based on aluminum, equilibrium tetragonal phase Al_3Zr, and metastable cubic phase $(Al_3Zr)_M$. In ternary rapidly quenched alloys equilibrium phases Al_3Zr and Al_7Cr are present.

*V. S. Romanova took part in this work.

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TABLE 1

Content of element, %		Phase composition of the alloys after annealing				
Zr	Cr	without annealing	250 °C 50 h	350 °C 50 h	450 °C 50 h	500 °C 20 h
—	0,1	α	α	α	α	α+Al_7Cr
—	0,4				α	
—	0,7				α	
—	1,0				α+Al_7Cr	
—	5,0				α+Al_7Cr	
—	8,0	α+Al_7Cr	α+Al_7Cr	α+Al_7Cr	α+Al_7Cr	Al_3Zr
0,1	—	α	α	α	α	
0,4	—	α	α	α	α	
0,7	—	α+Al_3Zr+ +$(Al_3Zr)_м$	α+Al_3Zr + +$(Al_3Zr)_м$	α+Al_3Zr+$(Al_3Zr)_м$	α+Al_3Zr+$(Al_3Zr)_м$	α+Al_3Zr+ +$(Al_3Zr)_м$
1,0	—					
1,2	—					
0,08	0,1	α	α	α	α+Al_3Zr	α+Al_3Zr+ +Al_7Cr
0,3	0,4	α	α	α	α+Al_3Zr	
0,5	0,7	α	α	α	α+Al_3Zr	
1,6	2,0	α+Al_3Zr	α+Al_3Zr	α+Al_3Zr +Al_7Cr	α+Al_3Zr+Al_7Cr	

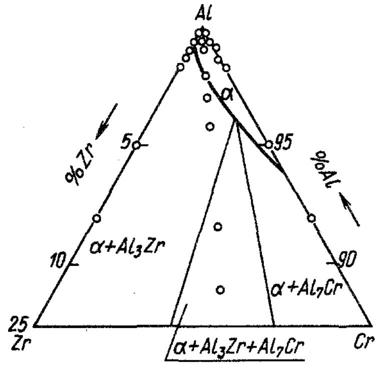

Fig. 1. Phase regions in rapidly quenched alloys of the system Al—Zr—Cr.

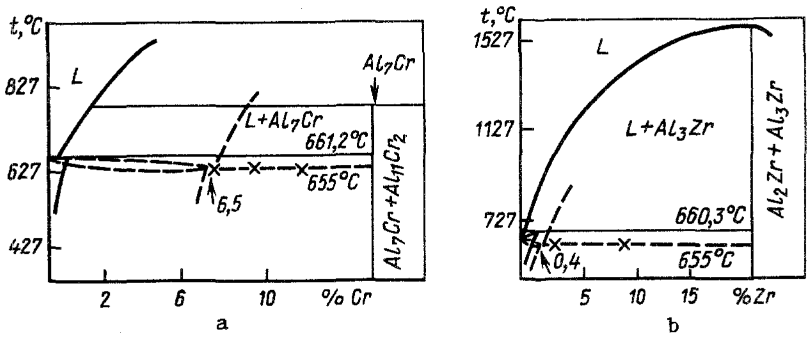

Fig. 2. Part of the phase diagram for the systems Al—Cr (a) and Al—Zr (b) from the Al side: solid lines are the equilibrium phase diagram; broken lines are the metastable phase diagram; × test alloys.

Practical use of the effect of supersaturation of aluminum with chromium and zirconium is governed by the stability of solid solutions.

The phase composition of rapidly quenched alloys after annealing is given in Table 1. For the start of decomposition of supersaturated solid solution the temperature is taken for appearance in diffraction pictures of diffraction maxima corresponding to this phase, and

*In Table 1 and subsequently in the article the content of elements is given in atomic fractions.

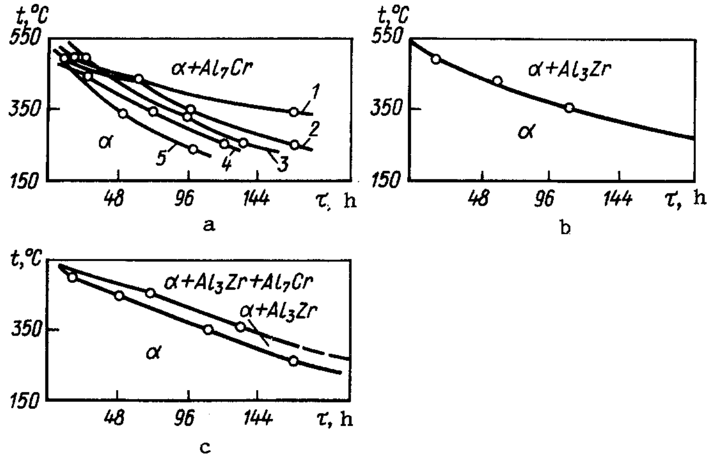

Fig. 3. Diagrams for decomposition of the matrix for rapidly quenched alloys Al–Cr (a), Al–0.1% Zr (b), Al–0.5% Zr–0.7% Cr (c); 1) 0.1% Cr; 2) 0.4% Cr; 3) 0.7% Cr; 4) 1.0% Cr; 5) 5.0% Cr.

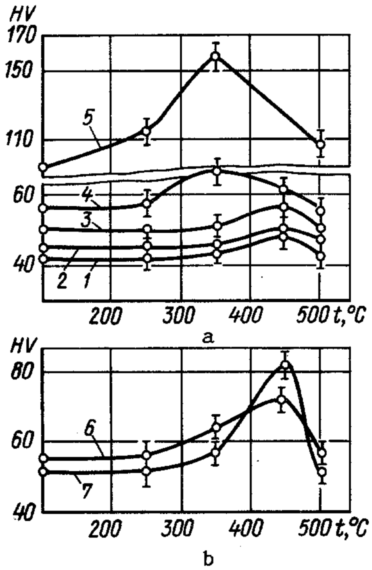

Fig. 4. Effect of annealing temperature on the hardness of rapidly quenched alloys of the systems Al–Cr (a), Al–Zr–Cr (b): 1) 0.1% Cr; 2) 0.4% Cr; 3) 0.7% Cr; 4) 1.0% Cr; 5) 5% Cr; 6) 0.1% Zr; 7) 0.5% Zr; 0.7% Cr.

also the temperature for the change in hardness (Fig. 3). Solid solutions of aluminum with zirconium and chromium exhibit high thermal stability. With an increase in temperature the rate of alloy decomposition increases. The stability of supersaturated solid solution for binary alloys of chromium is greater, the lower the chromium content, and its decomposition proceeds with formation of Al_7Cr phase.

Supersaturated solid solution of alloys with 0.1-0.4% Zr is stable approximately up to 500°C. Its decomposition proceeds by the scheme:

$$\alpha_s \rightarrow \alpha_e + Al_3Zr,$$

where α_s and α_e are supersaturated and equilibrium solid solutions respectively.

In ternary rapidly quenched alloys decomposition of the supersaturated solid solution is described by the scheme:

$$\alpha_{s(Zr,Cr)} \xrightarrow{400-450\,^\circ C} \alpha_{s(Cr)} + Al_3Zr \xrightarrow{500\,^\circ C} \alpha_e + Al_3Zr + Al_7Cr.$$

In contrast to binary alloys with zirconium, in ternary alloys stable phase Al_3Zr precipitates.

With an increase in annealing temperature the microhardness of alloys at first increases, and a dispersion hardening effect is observed, and then it decreases, which is a consequence of coalescence. The maximum hardness in Al—Cr alloys with a low chromium content corresponds to the temperature of 450°C. With an increase in Cr concentration the maximum hardness shifts to 350°C (Fig. 4). The greatest strengthening effect among the rapidly quenched alloys studied occurs for alloy with 5% Cr at 350°C. Its hardness is greater by about a factor of three than for alloy in the equilibrium condition [4].

At low temperatures the time for achieving the dispersion hardening effect increases. For alloy with 1% Cr it is 120 h at 250°C and 96 h at 350°C. The maximum values for hardness excess those obtained at 450°C. This is probably explained by formation of finer and uniformly distributed precipitates.

Thus, it has been shown that solid solutions in rapidly quenched alloys of the systems Al—Zr, Al—Cr, and Al—Zr—Cr exhibit high thermal stability. The maximum effect of dispersion hardening (HV 1520) is observed in alloy Al—5% Cr. It should also be noted that solid solutions obtained in alloys by the spinning method are more stable than solutions forming in granules prepared by atomizing the melt with water (cooling rate 10^3-10^4 °K/sec) [1].

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EFFECT OF GRAIN SIZE ON THE STRUCTURAL STRENGTH OF THE ALUMINUM ALLOY AMg6

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The increased attention that is given to industrial alloys with ultrafine-grained structure [1-6] is due, in particular, to their use for making parts under conditions of superplastic deformation. However, there is only limited information available on the effect of the ultrafine-grained structure on the structural strength of alloys, in particular aluminum alloys.

By preliminary treatment of alloy AMg6 we obtained in it a coarse-grained and an ultrafine-grained structure with mean size of the recrystallized grains longitudinally and transversely d = 42 and 26, 12 and 9 μm, respectively (Fig. 1). The specimens of the alloy were tested under static, dynamic and variable loading.

Impact tests were carried out according to GOST 9454-78 on transverse specimens with stored pendulum energy of 50 J. Fatigue tests were carried out according to GOST 27.502-79 on longitudinal smooth specimens with minimal diameter of the working part 5 mm. Endurance in the low cycle range was evaluated on a machine Instron-1185 under conditions of repeated tension at a frequency of 0.5 Hz. We used a cycle of triangular shape with the coefficient of asymmetry R = 0.1. Endurance in the range of multicycle fatigue was determined on a machine 1710 UI under conditions of pure bending with a frequency of 50 Hz and a coefficient of cycle asymmetry R = —1. The fatigue limit σ_{-1} was determined on a base of $2 \cdot 10^7$ cycles.

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