NONFERROUS METALS AND ALLOYS

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TIME-TEMPERATURE SECTION OF THE PHASE DIAGRAM OF THE Al – Sc – Zr SYSTEM AT 500°C

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The prospects for the use of scandium and zirconium for alloying aluminum alloys with the aim of increasing their high-temperature strength make it necessary to investigate the interaction between aluminum and these metals. The present work is devoted to a study of phase equilibria in the Al – Sc – Zr system at 500°C by methods of physico-chemical analysis and of the effect of a third component on the principal characteristics of binary intermetallic compounds.

Phase equilibrium in the Al – Sc – Zr system at 500 – 600°C in the aluminum-rich region has been studied in [1 – 6]. It has been established that the $ScAl_3$ and $ZrAl_3$ phases are in equilibrium with Al. The aluminum-rich region does not contain intermetallic compounds, but it has been shown in [6] that up to 15% Zr[2] can dissolve in the $ScAl_3$ phase at 550°C and up to 2.5% Sc can dissolve in the $ScAl_3$ phase. The presence of such phases with a variable composition can exert a considerable effect on softening processes in the alloys, which makes it necessary to study phase equilibria in the Al – Sc – Zr system in greater detail. In the present work we plotted the time-temperature section of the phase diagram of the Al – Sc – Zr system in the entire range of aluminum concentrations at 500°C.

The alloys for the investigation were melted in an electric arc furnace in an argon atmosphere. The specimens were subjected to a homogenizing annealing for 110 h at 500 – 750°C (depending on the composition of the alloy). Then the firing temperature was decreased to 500°C. The firing at 500°C was conducted for 400 h.

The charge was prepared from aluminum of grade A99, scandium of grade S_kM, and zirconium iodide. The compositions of the studied alloys are presented in Fig. 1. The composition of the alloys was controlled by emission spectral analysis using an ISP-30 spectrometer. The analytic pairs of Sc – Al lines (at wavelengths $\lambda = 269.9$ and 266.0 nm, respectively) and Zr – Al lines (at $\lambda = 339.2$ and 305.0 nm, respectively) were used for the spectral analysis of the contents of Sc and Zr.

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[2] Here and below we use the element atomic fraction.

The microstructural analysis was conducted using a Neophot-2 metallographic microscope (at a 200-fold magnification). The specimens were etched in a 10% solution of HF and in a mixture of 5% solutions of HF, HCl, and HNO_3. The x-ray phase analysis was conducted by a powder method in

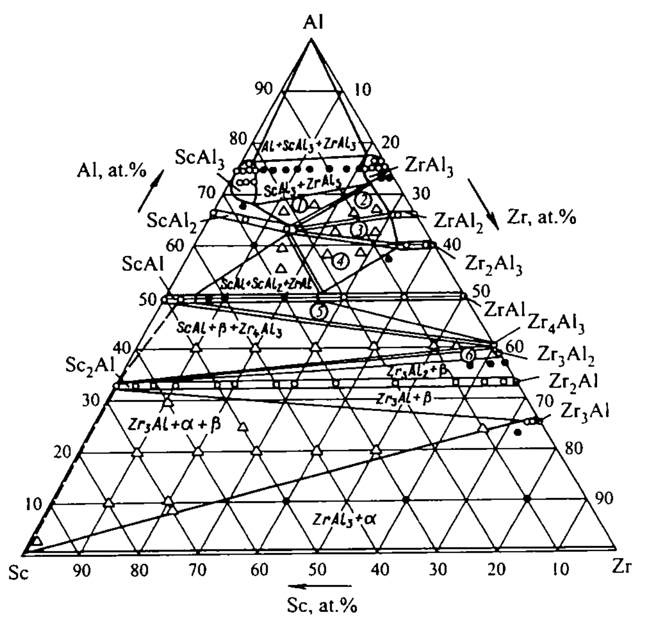

Fig. 1. Time-temperature section of the phase diagram of the Al – Sc – Zr system at 500°C: ○) single-phase alloys; ●) double-phase alloys; Δ) triple-phase alloys; *1*) region of $ScAl_3 + ZrAl_3 + ScAl_3$; *2*) $ZrAl_3 + ScAl_2 + ZrAl_2$; *3*) $ScAl_2 + ZrAl_2 + Zr_2Al_3$; *4*) $ScAl_2 + Zr_2Al_3 + ZrAl$; *5*) $ScAl + ZrAl + Zr_4Al_3$; *6*) $Zr_3Al_2 + \beta + Zr_4Al_3$; β) a continuous series of solid solutions between Sc_2Al and Zr_2Al; α) a continuous series of solid solutions between α-SC and α-Zr.

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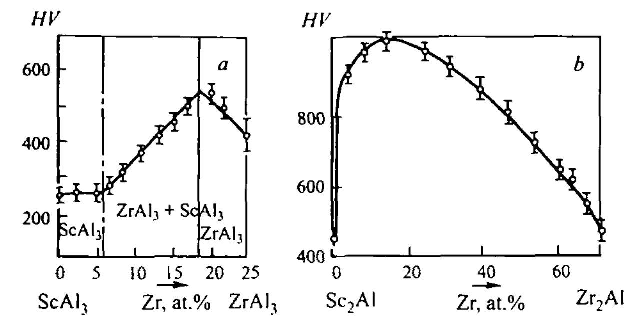

Fig. 2. Dependence of the hardness on the composition of alloys of the Al – Sc – Zr system corresponding to the following sections: *a*) $ScAl_3 - ZrAl_3$; *b*) $Sc_2Al - Zr_2Al$.

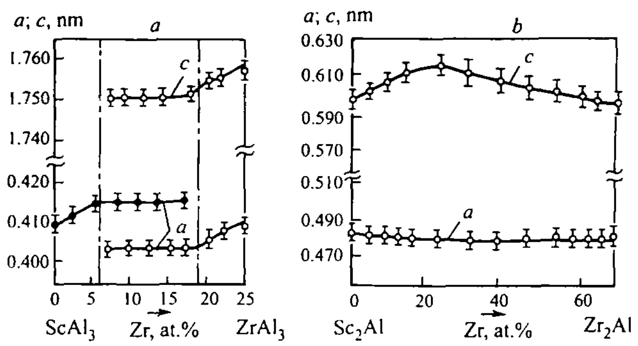

Fig. 3. Dependence of the lattice parameters on the composition of alloys of the Al – Sc – Zr system corresponding to the following sections: *a*) $ScAl_3 - ZrAl_3$ [(•) $ScAl_3$; (○) $ZrAl_3$]; *b*) $Sc_2Al - Zr_2Al$.

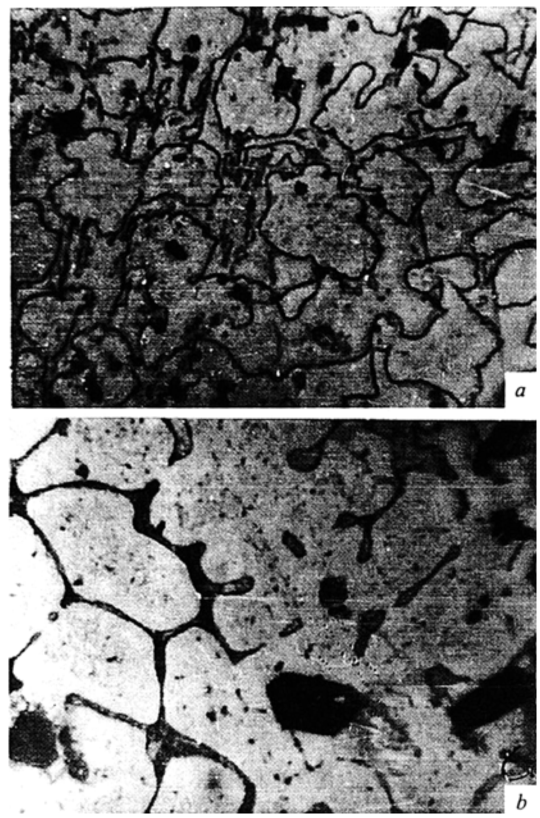

Fig. 4. Microstructure of the Al – 5% Sc – 20% Zr (*a*) and Al – 8% Sc – 17% Zr (*b*) alloys.

copper K_α radiation using an URS-60 x-ray installation and a DRON-3 x-ray diffractometer. The Vickers hardness was measured by a PMT-3 device under a load of 8 – 10 N.

The results of the study are presented in the form of a time-temperature section of the phase diagram of the Al – Sc – Zr system at 500°C (Fig. 1).

It has been established that phases with a crystal structure differing from the structures existing in binary systems do not form in ternary systems. The $ScAl_3$ and $ZrAl_3$ systems are in equilibrium with aluminum (Fig. 1). A double-phase region of $ScAl_3 + ZrAl_3$ has been shown to exist between the $ScAl_3$ and $ZrAl_3$ single-phase regions (Fig. 1), which confirms the behavior of the curves of the concentration dependence of the lattice parameters of the intermetallic compounds on the hardness of alloys with a constant aluminum content (75%) (Figs. 2 and 3).

Based on an analysis of the results of the conducted investigation we determined the boundaries of the regions of homogeneity of intermetallic compounds in the Al – Sc – Zr system (see Fig. 1 and Table 1). It seems that in the transition from a binary to a ternary system the atoms of the third component replace statistically not only the atoms of the *d*-transition element, but aluminum atoms too. In turn, this widens the region of homogeneity of phases with a constant $ScAl_3$ and $ZrAl_3$ composition and, possibly, $ScAl_2$.

Figure 4 presents the microstructure of an Al – 5% Sc – 20% Zr alloy corresponding to the single-phase $ZrAl_3$ region, and of an Al – 8% Sc – 17% Zr alloy that is a part of a double-phase $ZrAl_3 + ScAl_3$ region.

With the addition of zirconium the region of homogeneity of the $ScAl_2$ intermetallic compound deviates from the time-temperature 66.7% Al concentration curve towards lower aluminum concentrations. It seems that the concentration stability of this phase increases too. Such a widening of the regions of homogeneity can be explained by the fact that scandium and zirconium have favorable size ($r_{Al}/r_{Sc, Zr}$ = 1.1) and electron factors (the difference in the Hordy electronegativities amounts to 0.1) [7].

TABLE 1

Intermetallic compound	Region of homogeneity, at.%*	Intermetallic compound	Region of homogeneity, at.%*
$ScAl_3$	6.0 ± 0.5	Zr_2Al_3	7.5 ± 2.5
$ScAl_2$	15.5 ± 1.5	ZrAl	25.0 ± 5.0
ScAl	6.0 ± 1.0	Zr_4Al_3	2.5 ± 2.5
$ZrAl_3$	6.5 ± 1.5	Zr_2Al_3	2.5 ± 2.5
$ZrAl_2$	2.5 ± 2.5	Zr_3Al	2.5 ± 2.5

* Atomic fraction of the third component.

It should be noted that such a widening of the regions of homogeneity of the $ScAl_3$ and $ZrAl_3$ phases, and probably the $ScAl_2$ phase, opens a possibility for replacing the expensive scandium by the cheaper zirconium while preserving the structural effects.

We established the existence of a continuous series of solid solutions between the Sc_2Al and Zr_2Al intermetallic compounds (Fig. 1). This was not unexpected, because it has been known from [8, 9] that these phases have the same type of structure (Ni_2In) with a lattice of a hexagonal crystal system and close parameters. The existence of a continuous series of solid solutions between the $ScAl_2$ and $ZrAl_2$ phases is confirmed by the even behavior of the dependences of the hardnesses of the alloys and their lattice parameters (Figs. 2*b* and 3*b*) on the zirconium content.

CONCLUSIONS

1. The $ScAl_3$ and $ZrAl_3$ phases in the Al – Sc – Zr system at 500°C are in equilibrium with aluminum.

2. The $ScAl_2$ and ZrAl phases have the most extended homogeneity regions in the Al – Sc – Zr system at 500°C.

3. The concentration stability of the $ScAl_3$ and $ZrAl_3$ phases increases with the addition of a third component, which widens their regions of homogeneity.

4. With the addition of zirconium the region of homogeneity of the $ScAl_2$ phase deviates from the time-temperature 66.7% Al concentration dependence towards lower contents of aluminum.

5. A continuous series of solid solutions exists between the Sc_2Al and Zr_2Al phases in the Al – Sc – Zr system.

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