CHEMISTRY

1960

SovietRxiv

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Abstract

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CHEMISTRY

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EQUILIBRIUM DIAGRAM OF THE TERNARY SYSTEM

Ti–Al–Sn

(Presented by Academician I. I. Chernyaev, December 7, 1959)

Aluminum and tin are the most important alloying elements in titanium alloys. On the basis of α-solid solutions of the ternary system Ti–Al–Sn, certain alloy compositions have been developed that are distinguished by high thermal stability ([1]). However, in the literature known to us there are no data on the equilibrium diagram of the ternary system Ti–Al–Sn.

The purpose of the present work was to study the equilibrium of alloys of the ternary system Ti–Al–Sn in the region bounded by the partial ternary system Ti–Ti_3Sn–TiAl. Consideration of the binary systems Ti–Al and Ti–Sn that constitute this ternary system shows that in these systems the formation of limited solid solutions based on α-titanium is observed, according to a peritectoid reaction between the β phase of titanium and the γ phase (based on the compound TiAl) at 1240° in the Ti–Al system, and between the β phase of titanium and the δ phase (based on the compound Ti_3Sn) at 890° in the Ti–Sn system, respectively.

Fig. 1. Phase diagram titanium–aluminum–tin at 600°

Recently a number of papers have appeared in print on the study of the constitution diagram of the Ti–Al system ([2–5]), in which data are given on the possible existence of new compounds (Ti_3Al, Ti_2Al) in the region of the α-solid solution, the extent of which, according to work ([6]), was considered initially–

initially up to a concentration of 25% Al. In accordance with the available literature data ([3,4]), it may be assumed that in the Ti–Al system there exists an ordered phase Ti_3Al, probably with a broad homogeneity range (12-25% Al), with the same distribution of atoms as in the ordered Ti_3Sn phase in the Ti–Sn system ([7]). In the present work, microstructural and X-ray methods of investigation were used, as well as study of the hardness of alloys.

Fig. 2. Microstructures of alloys, 200×: a—18% Sn; 10% Al—$\alpha(\delta)$-phase; b—27% Sn; 2.5% Al—$(\alpha + \delta)$-phases

Figure 2: Fig. 2. Microstructures of alloys, 200×: a—18% Sn; 10% Al—$\alpha(\delta)$-phase; b—27% Sn; 2.5% Al—$(\alpha + \delta)$-phases

For preparing the alloys by melting in an arc furnace with a nonconsumable electrode, iodide and magnesiothermic titanium of grade TG-00, aluminum of 99.99% purity, and tin of 99.9% purity were used. Since equilibrium in the Ti—Al—Sn system is attained very slowly in undeformed specimens, all alloys (with the exception of alloys of the Ti_3Sn—TiAl joins and through 30% Al) were forged. The aim was to accelerate the process of attaining the equilibrium state of the alloys.

The alloys were subjected to the following stepwise heat treatment in vacuum: homogenization at 1200° for 100 h and annealing according to the schedule: at 1100°—50 h, 1000°—200 h, 800°—300 h, 600°—500 h, followed by cooling with the furnace. Alloys of the Ti_3Sn—TiAl section were annealed for a longer time according to the schedule: at 1000°—500 h, 800°—1000 h, 600°—1200 h, followed by slow cooling to room temperature. Most of the studied alloys in the as-cast state show a plate-like or acicular structure of the α-phase. On the basis of the data from microstructural and X-ray investigations, a phase diagram of the studied part of the Ti—Al—Sn system at 600° was constructed (Fig. 1).

Fig. 2. Microstructures of alloys, 200×:
a—18% Sn; 10% Al—$\alpha(\delta)$-phase; *b*—27% Sn; 2.5% Al—$(\alpha + \delta)$-phases

As a result of these investigations, the presence of the following phases was established in the Ti—Al—Sn system:

1) a solid solution of aluminum and tin in α-titanium (α);
2) a solid solution based on the chemical compound TiAl (γ);
3) continuous solid solutions of the compounds Ti_3Al—Ti_3Sn, corresponding in structure to the α- or δ-phases;
4) a solid solution based on the chemical compound Ti_3Sn (δ).

The studied part of the phase diagram of Ti—Al—Sn, corresponding to the isothermal section at 600° for annealed alloys, is shown in Fig. 1. As is evident from Fig. 1, the main part of it is occupied by the single-phase region of the ternary $\alpha(\delta)$-solid solution based on titanium and the quasibinary section Ti_3Al—Ti_3Sn. It is noteworthy that, in the annealed state, all alloys of the sections Ti_3Al—Ti_3Sn and through 22% Al have a single-phase polyhedral structure of solid solution (Fig. 2a), which confirms the existence of continuous solid solutions between these two compounds. The X-ray diffraction patterns of the annealed alloys of these sections are identical for all the alloys studied and show no other lines except those characteristic of the α- or δ-phases. The formation of continuous solid solutions in the annealed state between the δ-phase (based on Ti_3Sn) and the homogeneous α-phase of the Ti—Al system can most likely be explained by the possible presence in this system of an ord-

ordered phase Ti_3Al, isomorphous with Ti_3Sn. In the chemical behavior of these compounds of aluminum and tin with titanium there is much in common. The compounds Ti_3Al and Ti_3Sn possess an isomorphous crystal structure and, apparently, the same type of chemical bonding; consequently, all the necessary conditions are fulfilled for the formation of continuous solid solutions between the compounds Ti_3Al and Ti_3Sn.

Consideration of the equilibrium diagram of Ti—Al—Sn at 600° shows that the $\alpha(\delta)$ solid solutions cover a broad region of the concentration triangle (see Fig. 1).

Alloys having a two-phase structure: $\alpha + \delta$ (Fig. 2b), in view of the possible formation of continuous solid solutions between α-titanium and Ti_3Sn[8], were subjected to additional annealing at 800° for 1000 h. This heat-treatment regime led to some change in the microstructure of the indicated alloys. Thus, for the given conditions of attaining the equilibrium state (the annealing regime is indicated above), the equilibrium diagram is characterized by the presence of a two-phase region $\alpha + \delta$ adjacent to the Ti—Sn side (Fig. 1).

From the data of microstructural and X-ray phase investigations, the limits of the extent of the γ region (based on the compound TiAl) in the ternary Ti—Al—Sn system were also established. As is evident from the diagram, a considerable extent of the γ-solid-solution region is observed ($\approx$ up to 18% Sn). The remaining part of the equilibrium diagram studied is occupied by the two-phase region: $\alpha + \gamma$.

In the studied part of the equilibrium diagram at 600°, no three-phase region was detected by microstructural and X-ray methods.

Institute of Metallurgy named after A. A. Baikov
Academy of Sciences of the USSR

Received
22 VI 1959

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Note: Figure translations are in progress. See original paper for figures.