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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

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ON THE INTERACTION OF TITANIUM WITH ALUMINUM

(Presented by Academician I. I. Chernyaev on 29 VI 1964)

A considerable number of studies have been devoted to the question of the interaction of titanium with aluminum ([1–3]), but to the present time it has not been fully clarified. The most controversial question in this system is the existence of various metallic compounds or phases based on them in the concentration range from 0 to 40 at.%.

In the present communication we shall not dwell in detail on an analysis of all previous investigations, since there is an excellent review ([8]) on this question, in which the indicated studies are described in detail and an analysis of the literature data is given. We shall note only that, as a result of all preceding work, five different variants of the titanium—aluminum phase diagram have been proposed; these are shown in Fig. 1.

Fig. 1. Variants of the titanium—aluminum phase diagram according to data of different authors. *a*–([1,2]); *b*–([3]); *v*–([4]); *g*–([6]); *d*–([7]).

In work ([8]), on the basis of an analysis of the literature data and the totality of the authors' own investigations, a sixth variant is given, according to which in this system, from the α-solid solution, the compounds Ti_3Al and Ti_6Al are formed; this is supported by data from the study of the concentration dependence of the Hall constant. Between these compounds, in the opinion of the authors ([8]), an eutectoid transformation may possibly occur, analogous to that found in the gold—copper system; however, this question has not yet been fully clarified.

The possibility of the existence of the compounds Ti_3Al and Ti_6Al is also confirmed in the works of S. G. Fedotov ([9,10]) by studies of the dependence of the elastic constants on the composition of titanium alloys with aluminum.

The present work was undertaken with the aim of finally resolving the question of what compounds or phases based on them are formed in this system. For this purpose, the classical method of physicochemical analysis was used, involving the construction of chemical composition—property diagrams ([11]).

Figure 2

Figure 2: Figure 2

An analysis of the experimental methods and heat-treatment regimes of alloys before investigation, which were used in previous works ([1–9]), made it possible to note the following:

1) In all works the process of bringing alloys to an equilibrium state was not controlled by studying any physical property during the annealing period. Meanwhile, using a whole series of systems with titanium, and especially the titanium—tin system ([12]), as examples, it was shown—

known how difficult it is for equilibrium to be attained. In this connection, the durations of homogenizing anneals adopted in works (1-9) were chosen, to a known extent, arbitrarily.

2) In all previous investigations the alloys were prepared by arc melting with a nonconsumable electrode, or by powder metallurgy. In this case the possibility of some contamination of the alloys with oxygen is not excluded. Meanwhile, the presence of oxygen may have a substantial effect on the character of the concentration dependence of the properties and of phase equilibrium in the given system.

Fig. 2. Dependence of microhardness, thermal expansion, and thermoe.m.f. on the composition of alloys of the titanium—aluminum system

3) Finally, in the above-mentioned works the method of physicochemical analysis was used insufficiently fully (what is meant is the insufficient number of alloys prepared for studying their structure and properties).

On the basis of the foregoing, the present work was undertaken, taking into account the experience of earlier work, in order to avoid possible errors associated with the noted shortcomings in the indicated works (1-9).

For this purpose alloys with an aluminum content from 0 to 40 at.% in steps of 1% were prepared—a total of 40 alloys. Iodide titanium (99.9% Ti) and aluminum of grade AV0000 (99.999% Al) served as the starting materials for preparing the alloys.

In contrast to the previous works, the alloys were prepared by the method of crucibleless induction melting in the suspended state. This method, as we showed in a special investigation (13), is favorably distinguished from other methods precisely in the study of phase diagrams. This method proved to be excellent in the study of the titanium—tin system. To bring all the alloys to the equilibrium state, after preliminary deformation by 10-20% they were annealed at 800° in a vacuum of 10^{-4} mm Hg for 2000 h.

Intermediate microhardness measurements were carried out in order to monitor the process of bringing them to the equilibrium state, in accordance with what is described in the monograph (14). As a result, there was complete confidence that the adopted annealing time guaranteed attainment of equilibrium by the alloys at the indicated temperature. After annealing, the alloys were quenched in water.

On specimens obtained by the method described, the microstructure, microhardness, thermal expansion, and thermoe.m.f. were investigated.

The microhardness was measured on a PMT-3 instrument under a load of 200 g, analogously to the way it was done in the case of the titanium—oxygen system (15). As an etchant for revealing the microstructure of the alloys, a mixture consisting of 20 parts HF, 20 parts HNO_3, the remainder glycerin (by volume), was used. The thermoe.m.f. was measured in contact with copper on specially turned specimens 5 mm in diameter and 25–30 mm high. The thermal expan-

expansion was studied in the temperature interval from room temperature to 700° on a dilatometer designed by R. S. Mints.

The results of the measurements are presented in Fig. 2 in the form of chemical composition–property diagrams. On the basis of the studies presented, the following conclusions may be drawn. Microstructural analysis shows that the second phase appears in the alloys at an aluminum content of about 9 at. %. Alloys containing a smaller amount of aluminum have a single-phase structure of the α-solid solution. The microstructural-analysis data correlate with the nature of the change in properties with composition. In the composition–property diagrams (Fig. 2), the moment of appearance of the second phase is recorded by inflections. The microscopic-analysis data convincingly show that alloy compositions corresponding to the compounds Ti_6Al, Ti_3Al, and Ti_2Al, as well as those close to them ($\sim 1 \div 3\%$), are single-phase. From Fig. 2 it is clearly seen that, in the chemical composition–microhardness–thermo-e.m.f.–thermal-expansion diagrams, the compositions Ti_6Al, Ti_3Al, and Ti_2Al correspond to clearly expressed special points.

Proceeding from the general principles of physico-chemical analysis ([11]), on the basis of the data obtained one may draw the unambiguous conclusion that in the titanium-aluminum system, in the concentration interval between 0 and 40 at. % aluminum, three intermediate phases are formed on the basis of the compounds Ti_6Al, Ti_3Al, and Ti_2Al.

Questions concerning the character of formation and the nature of these phases require a special investigation.

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