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Abstract

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STUDY OF THE EQUILIBRIUM OF ALLOYS BASED ON THE γ-SOLID SOLUTION OF THE SYSTEM Fe–Cr–Ni–Mn–Nb–V–Si

For the scientific justification of the choice of optimal compositions of complexly alloyed high-strength iron-based alloys, knowledge of the nature of the chemical interaction of the components entering into the composition of such an alloy is of great importance. This requires a systematic study of the phase diagrams of multicomponent systems. Of considerable interest are iron alloys based on a multicomponent γ-solid solution (austenite). However, the study of such multicomponent systems proves to be a complex and labor-intensive task. Whereas at present methods for studying phase diagrams of metallic systems consisting of two, three, and four components have been well developed and are widely used, the study of the equilibria of five-component and more complex systems requires a considerable complication both of the methods of investigation and of the ways of geometrically representing the results of the investigation; the latter are associated with the use of less accessible principles of multidimensional geometry ([1,2]). In addition, as the number of components in a system increases, the number of its constituent binary, ternary, quaternary, and more complex systems also progressively increases; preliminary knowledge of these systems is necessary for studying phase equilibrium in the selected multicomponent system.

In this connection, simplified methods for studying and representing phase diagrams of multicomponent systems by means of rationally selected partial systems acquire great importance ([3,4]). One such simplified method is the method proposed by I. I. Kornilov ([4]), which is based on the principle of considering the chemical interaction of the elements of D. I. Mendeleev' s periodic system with metals chosen as the basis for the investigation. The interaction of various elements during alloy formation is based on their metallochemical properties, depending on which the elements may either form solid solutions or metallic compounds, or may not form these phases. Knowing the properties of the elements of interest to us with respect to the selected metal, one can calculate the number and limiting concentrations of those elements which, in a certain combination, form with the metal—the base of the alloy—an unsaturated multicomponent solid solution. The latter, if it is in a state of equilibrium, may conventionally be taken as one component. This makes it possible to study the equilibrium between this solid solution of n components and other additionally

Fig. 1. Equilibrium diagram of alloys based on the γ-solid solution of the Fe–Cr–Ni–Mn–Nb–V–Si system for the 1100 isotherm (a–in weight percent, b–in atomic percent). Open points–γ-solid solution. Filled points–heterophase alloys.

Figure 1: Fig. 1. Equilibrium diagram of alloys based on the γ-solid solution of the Fe–Cr–Ni–Mn–Nb–V–Si system for the 1100 isotherm (a–in weight percent, b–in atomic percent). Open points–γ-solid solution. Filled points–heterophase alloys.

introduced elements.

The results of the investigation may be represented in the form of a tetrahedron, the vertex of which corresponds to the composition of the initial homogeneous multicomponent unsaturated solid solution, while along its three edges–x, y, z–the percentage content of the additionally alloying elements is plotted. The possibility of such investigations was demonstrated by examples of the systematic study of alloys of multicomponent nickel-based systems ([5,6]).

As for multicomponent iron-based systems, the literature contains only a few studies on establishing equilibria in partial four-component iron-based systems, as well as studies of the influence of individual elements on the structure and properties of industrial grades of steels and alloys with five or more components ([7–9]).

The present study is devoted to the further development of work on the study of equilibria of alloys in multicomponent iron-based systems and to establishing the dependence of the physicochemical and other properties of multicomponent alloys on the content of titanium, aluminum, and tungsten.

As the basis of the selected object of study, we adopted one composition of a seven-component γ-solid solution of the system Fe–Cr–Ni–Mn–Nb–V–Si, which is given below:

	Fe	Cr	Ni	Mn	Nb	V	Si
Elements	Fe	Cr	Ni	Mn	Nb	V	Si
Wt. %	58.5	15	15	10	0.5	0.5	0.5

This concentration of alloying elements ensured the preservation of a homogeneous γ-solid solution. Taking this equilibrium seven-component γ-solid solution as a single phase, we experimentally investigated the regions of existence of eight- and nine-component γ-solid solutions as a function of the content of titanium, aluminum, and tungsten, and also studied the properties of these alloys, including high-temperature strength.

Fig. 1. Equilibrium diagram of alloys based on the γ-solid solution of the Fe –Cr–Ni–Mn–Nb–V–Si system for the 1100 isotherm (a–in weight percent, b

–in atomic percent). Open points–γ-solid solution. Filled points–heterophase alloys.

For the study of the system, alloys were melted with variable contents of titanium, aluminum, and tungsten along 15 sections at a constant weight ratio of the alloying elements of the seven-component base (in wt. %): 58.5 Fe : 15 Cr : 15 Ni : 10 Mn : 0.5 Nb : 0.5 V : 0.5 Si. This was ensured by using, as charge material, a master alloy corresponding to the composition of the seven-component base under study. In Fig. 1, the points indicate the compositions of the investigated alloys of all 15 studied sections, designated in the figure by Roman numerals. Point A corresponds to the composition of the initial seven-component γ-solid solution.

All the investigated alloys were subjected to homogenization annealing in evacuated quartz ampoules at a temperature of 1100° for 100 h, followed by cooling in air; after this, their microstructure, hardness, microhardness, and specific electrical conductivity were studied.

resistance, and also heat resistance–by the centrifugal bending method [10]. The specimens intended for the study of heat resistance were subjected to the same heat treatment, but for 10 hours. As the criterion of heat resistance, the time required to attain a deflection of 10 mm at 800° and a stress $\sigma = 14$ kg/mm^2 was taken. The properties were studied in parallel on four to six specimens. Analysis of the microstructural-investigation data, as well as of the curves characterizing the change in properties as a function of the component content, made it possible to establish the limits of the ultimate solubility of titanium, aluminum, and tungsten in the initial seven-component solid solution for all the sections studied.

Using the method described above for representing partial multicomponent systems [4-6] and the experimental data obtained, we constructed an equilibrium diagram of alloys based on the seven-component γ-solid solution of the system: Fe–Cr–Ni–Mn–Nb–V–Si for the 1100° isotherm. A representation of this equilibrium in the form of a diagram is given in Fig. 1a, b. As can be seen from this figure, the origin of coordinates is taken to be point A, corresponding to the composition of the initial seven-component solid solution with a constant weight ratio of the components: 58.5 Fe : 15 Cr : 15 Ni : 10 Mn : 0.5 Nb : 0.5 V : 0.5 Si. Point A is the vertex of the proposed tetrahedron with three edges x, y, z, along which the variable contents of titanium, aluminum, and tungsten are plotted.

The curves in the corresponding planes bound the regions of distribution of nine-component solid solutions and the regions of excess phases conjugate with them, as a function of the contents of titanium, aluminum, and tungsten. We experimentally established the maximum solubility of titanium, aluminum, and tungsten in the seven-component γ-solid solution, namely: Ti $\sim$ 2.8 wt.%; Al $\sim$ 3.5 wt.%; W $\sim$ 5.5 wt.%. It decreases upon the combined introduction of Ti and Al, Ti and W, and also Al and W, as is evident from Fig. 1a, b.

As excess phases in the present case, compounds based on iron with titanium, aluminum, or tungsten may form, the exact compositions of which have not yet been established by us. By applying X-ray structural analysis, selective separation, and investigation of these phases, the nature and structure of the complex compounds formed in the system studied beyond the solubility limit of the elements in the seven-component γ-solid solution of iron will subsequently be established.

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