Chemistry

1961

SovietRxiv

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Abstract

Full Text

Chemistry

L. I. Pryakhina

Studies in the Field of Multicomponent Nickel Systems

(Presented by Academician I. I. Chernyaev, 12 II 1961)

In studying the interaction of metals in multicomponent systems, difficulties are encountered in the geometrical representation of complex equilibria and phase diagrams of these systems.

The methods of sections and projections used for constructing phase diagrams of multicomponent systems have so far found only limited application in the study of real metallic systems. The most promising is the projection method proposed by V. P. Radishchev ([1]) and F. M. Perel' man ([2]), who developed this method in the direction of selecting optimal projections. Regular simplex figures serve to represent the composition of metallic systems: a triangle for a ternary system, a tetrahedron for a quaternary system, a pentatope for a quinary system, a hexatope for a senary system, a heptatope for a seven-component system, and so on.

It is possible to make a section of a simplex that will give a figure of one lower dimension. Thus, for example, by means of three successive sections of a heptatope (representing a 7-component system), one can obtain a tetrahedron (representing a 4-component system). The sections can be made in such a way that one of the vertices of the tetrahedron will represent the composition of 4 components in a definite proportion (in accordance with the three sections made).

Fig. 1. One of the sections in the 7-component system Ni—Cr—W—Mo—Nb—Ti—Al at 1100°.

Figure 1 shows one of the sections in the 7-component system Ni—Cr—W—Mo—Nb—Ti—Al. The vertex of the tetrahedron obtained represents the composition of 4 components: Ni, Cr, W, Mo (in a definite proportion).

Figure 2. Microstructure of alloys after heat treatment (1100°—400 h, cooling in air): 1—four-component nickel solid solution (γ_4), 2—metallic compound Ni_3Al, 3—the same, Ni_3Ti, 4—the same, Ni_3Nb.

Figure 2: Figure 2. Microstructure of alloys after heat treatment (1100°—400 h, cooling in air): 1—four-component nickel solid solution (γ_4), 2—metallic compound Ni_3Al, 3—the same, Ni_3Ti, 4—the same, Ni_3Nb.

Since in the present investigation we were interested not in all alloy compositions generally possible at any ratios in the system Ni—Cr—W—Mo—Nb—Ti—Al, but only in those alloys that are a multicomponent nickel solid solution or phases adjoining it, one more section of the tetrahedron was made through the compounds Ni_3Nb, Ni_3Ti, and Ni_3Al, as shown in Fig. 1.

Consequently, for the study of nickel-rich alloys in the 7-component system Ni—Cr—W—Mo—Nb—Ti—Al, we limited ourselves to studying a quasi-quaternary system: a 4-component nickel solid solution (which we have conventionally denoted γ_4)—Ni_3Ti—Ni_3Al—Ni_3Nb (instead of the large number of 2-, 3-, 4-, 5-, and 6-component systems included in this complex 7-component system).

In doing so, we assumed that both the metallic compounds (Ni_3Ti, Ni_3Nb, and Ni_3Al) and the nickel solid solution (γ_4) remain unchanged in the course of the investigation.

Proceeding from the fact that solid solutions constitute a single phase in the equilibrium state ([3], [4]), one may take as one component of a binary—

Fig. 2. Microstructure of alloys after heat treatment (1100°—400 h, cooling in air): **1**—four-component nickel solid solution (γ_4), **2**—metallic compound Ni_3Al, **3**—the same, Ni_3Ti, **4**—the same, Ni_3Nb.

a ternary or more complex solid solution based on one or another metal or metallic compound (with a definite ratio of the initial metals).

This, in a number of cases, makes it possible to reduce the study of multicomponent systems to an investigation of the equilibrium between a multicomponent solid solution and one, two, or three elements or their chemical compounds, as was shown by us in the example of studying a partial phase diagram of the five-component system Ni—Cr—W—Ti—Al[(5)] and one section in the eight-component system Ni—Cr—W—Mo—Nb—Ti—Al—C, representing a quasi-binary system: six-component nickel solid solution (γ_6)—TiC [(6)].

The purpose of the present investigation was to establish the region of distribution of the nickel solid solution in the quasi-quaternary system γ_4—Ni_3Ti—Ni_3Al—Ni_3Nb and to determine the phase composition in the regions adjoining this solid solution.

The research methods used were mainly microstructural, X-ray structural, and intermetallic analyses.

The alloys for the investigation were melted in an arc furnace in an argon atmosphere or in a crucibleless levitation melting furnace in a helium atmosphere. To prepare the alloys, the metallic compounds Ni_3Al, Ni_3Nb, and Ni_3Ti (of exact stoichiometric composition) and γ_4 (the exact composition of a four-component nickel solid solution) were first melted in an arc furnace; subsequently these served as charge materials. It was previously established by microstructural and X-ray structural methods (see Fig. 2, 1—4) that the melted metallic compounds, as well as the nickel solid solution (γ_4), after the appropriate heat treatment (1100° —400 h, air cooling), are single-phase.

On the basis of the investigation carried out and of literature data, schematic phase diagrams (at 1100°) were constructed for four quasi-ternary systems, which are the four faces of the tetrahedron studied by us: 1) γ_4-Ni_3Ti—Ni_3Al, 2) γ_4-Ni_3Al—Ni_3Nb, 3) γ_4-NiTi—Ni_3Nb, 4) Ni_3Ti—Ni_3Al—Ni_3Nb.

The studies showed that in six-component alloys of the above-mentioned quasi-ternary systems there is one-phase, two-phase, and three-phase equilibrium. More than three phases in the alloys investigated were not established in the solid state. To confirm the data on the phase composition of the alloys obtained by the microstructural method of investigation, X-ray structural* and intermetallic** analyses of individual alloy compositions were carried out. The data of the X-ray structural and intermetallic analyses generally confirmed the results obtained in the microstructural investigation.

Figure 3 gives a projection of the tetrahedron of the quasi-quaternary system γ_4-Ni_3Ti—Ni_3Al—Ni_3Nb onto one of the coordinate planes, on which the three lateral faces of the tetrahedron with a common vertex corresponding to the γ_4 nickel solid solution are clearly visible. In Fig. 3, the phase diagrams of the three quasi-ternary systems investigated by us are clearly visible; the numbers of the alloys (they are placed in circles) on which intermetallic analysis was carried out are indicated. From the region of the γ-nickel solid solution, three alloys were investigated: Nos. 1, 3, and 4. The composition of alloy No. 1 corresponds to the exact composition of γ_4. From the single-phase region of the γ-phase, three alloys were also investigated: Nos. 13, 17, and the compound Ni_3Al.

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* The X-ray structural analysis of the alloys was performed at the Central Scientific Research Institute of Transport Machine Building by S. A. Yuganova and co-workers.

** Intermetallic analysis was carried out at the Institute of Metallurgy of the Academy of Sciences of the USSR by R. B. Golubovich and at the Central Scientific Research Institute of Transport Machine Building by L. A. Nudza.

During anodic dissolution of all these alloys, no precipitate was separated. This confirms that the indicated alloys are single-phase solid solutions. X-ray structural investigation also confirmed that alloys Nos. 13 and 17 are solid solutions based on the compound Ni_3Al.

Fig. 3. Projection of the tetrahedron of the quasi-quaternary system γ_4-Ni_3Ti-Ni_3Al-Ni_3Nb. Point 1 (γ_4), Ni–81.0, Cr–10.0, W–6.0, Mo–3.0 wt.%

Figure 3: Fig. 3. Projection of the tetrahedron of the quasi-quaternary system γ_4-Ni_3Ti-Ni_3Al-Ni_3Nb. Point 1 (γ_4), Ni–81.0, Cr–10.0, W–6.0, Mo–3.0 wt.%

From the two-phase regions of the diagram, the following alloys were subjected to intermetallic analysis: from the $\gamma + \gamma'$ region–alloys Nos. 6, 12, and 20; from the $\gamma + \beta$ region–alloys Nos. 8 and 21; from the $\gamma + \eta$ region–alloys Nos. 7 and 22.

During anodic dissolution, a precipitate of the second phase present in them was separated from all these alloys. On the basis of microchemical and X-ray structural analyses of the precipitates separated from alloys Nos. 6, 12, and 20,

Fig. 3. Projection of the tetrahedron of the quasi-quaternary system γ_4-Ni_3Ti-Ni_3Al-Ni_3Nb. Point 1 (γ_4), Ni–81.0, Cr–10.0, W–6.0, Mo–3.0 wt.%

the presence was established of a γ' phase–a solid solution based on the compound Ni_3Al, with a face-centered cubic lattice.

Since the compositions of alloys Nos. 6, 12, and 20 are not the same, the amount of dissolved metals (Cr, W, Mo, Nb, and Ti) in the γ' phase separated from these alloys was different. Depending on the composition, the lattice parameter of the γ' phase also changed.

Chemical and X-ray structural analyses of the precipitates separated from alloys Nos. 8 and 21 established that the η phase is a solid solution based on the compound Ni_3Nb and has an orthorhombic structure ([7]). The parameters of the crystal lattice of the β phase separated from alloys Nos. 8 and 21 differed somewhat from one another, which is explained by a slight difference in the chemical composition of the separated phases and by the different positions of these alloys in the phase diagram (see Fig. 3).

During anodic dissolution of alloys Nos. 7 and 21, precipitates were separated; analysis of them showed that they consist of the η phase (Ni_3Ti) and have a hexagonal close-packed lattice.

Microchemical analysis of the β phase established that, in addition to Ni and Ti, it contains small amounts of Cr, W, Mo, and Al, which proves the presence of a solid solution based on Ni_3Ti. Apparently, during formation of the Ni_3Ti phase in complex alloys, a solid solution based on this compound may form, although in the binary Ni–Ti system ([8]) this compound does not have a homogeneity region.

parts of the homogeneity region. Alloys from the three-phase regions of the diagram have been prepared and are being studied, but these investigations have not yet been completed.

On the basis of the results of the present investigation, the following conclusions may be drawn. By carrying out certain successive sections in multicomponent systems, it is possible to study partial phase diagrams of these systems, in which the components may be not only individual elements, but also their solid solutions, as well as intermetallic compounds. The ability of metals to form solid solutions with one another, and also the possibility of the formation of solid solutions between intermetallic compounds and between metals and intermetallic compounds, leads to a reduction in the total number of solid phases in equilibrium in multicomponent systems. In six-component alloys of the system Ni—Cr—W—Mo—Nb—Ti—Al, no more than 3 phases have been established. By methods of microstructural, X-ray structural, and intermetallic analyses, the chemical compositions of the phases in equilibrium (in the solid state) in several six-component alloys of the system under study have been established.

The type of crystal lattice of these phases and the lattice parameter have been determined. The possibility has been shown of the formation in multicomponent alloys of solid solutions not only on the basis of the compound Ni_3Al, but also of solid solutions based on the compounds Ni_3Nb and Ni_3Ti.

Since in most cases alloys with special properties (for new fields of technology) are either solid solutions based on some metal or intermetallic compound, or are heterophase alloys (in which the solid solutions are additionally strengthened by finely dispersed precipitation of intermetallic phases), the study of phase diagrams of multicomponent systems may be reduced to the study of partial diagrams and individual sections in these diagrams, as we have shown by the example of studying nickel-based systems.

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

Received
9 II 1961

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