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ON THE QUESTION OF STRENGTHENING NICKEL SOLID SOLUTIONS

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Metals capable of dissolving atoms of other elements in the solid state undergo considerable strengthening. This strengthening is due to distortion of the crystal lattice of the solvent metal, as a result of which its mechanical strength, specific electrical resistance, and other properties increase or change. A regularity in the increase of the high-temperature strength of nickel solid solutions with an increase in the number of elements of limited solubility constituting the alloy was previously established and then repeatedly confirmed experimentally ([1,2]); it was also established that the alloys possessing the greatest high-temperature strength are those located near the limit of ultimate solubility ([3–7]). It should be noted that these regularities were established for alloys of various systems, in which supersaturation of the solid solutions was produced by introducing different elements. It was therefore of interest to study the regularity of the change in high-temperature strength of binary and more complex nickel solid solutions by additional alloying with some one element, for example aluminum, which forms limited solid solutions and metallic compounds with nickel.

To create the base of the nickel solid solution, we selected the following elements: Cr, Ti, W, Mo, Nb, and Co. These elements form limited solid solutions with nickel, with the exception of cobalt, which forms a continuous series of solid solutions with nickel.

For the study, one section (with variable aluminum content) was chosen in each of the following nickel systems: Ni–Al, Ni–Cr–Al; Ni–Cr–Ti–Al; Ni–Cr–Ti–W–Al; Ni–Cr–Ti–W–Mo–Al; Ni–Cr–Ti–W–Mo–Nb–Al; Ni–Cr–Ti–W–Mo–Nb–Co–Al.

On the basis of data on the ultimate solubility of the above-mentioned elements in nickel ([8,9]) and of earlier investigations ([3–7]), the compositions of the nickel solid solutions selected for our study were established with the calculation that the introduction of all the elements, except aluminum, would lead to the formation only of unsaturated solid solutions. Proceeding from this, the following was introduced into the alloys: Cr 10, Ti 2, W 6, Mo 3, Nb 2, Co 5 wt. %. Supersaturation of the solid solutions was produced by means of one and the same element–aluminum, whose content was varied from 0 to 12 wt. %. At

Fig. 1

Figure 1: Fig. 1

low aluminum concentrations the alloys were solid solutions. Increasing the aluminum content in the alloys led to supersaturation of the solid solutions and to precipitation of one and the same excess γ'-phase for all the alloys studied, the basis of which is the compound Ni_3Al with a face-centered cubic lattice, slightly different from the lattice of nickel and its solid solutions.

On specimens melted along the above-mentioned sections of seven nickel systems, the following were studied: the melting temperature of the alloys, the phase

composition and physicochemical properties, including the parameters of the crystal lattices of the solid solutions, were determined, and heat-resistance testing was carried out by the centrifugal method. This method made it possible to conduct the investigation comparatively quickly and to establish the regularity of the change in heat resistance as a function of the composition and structure of the alloys. All alloys were tested under identical conditions: in the same furnace, at 900° and at one constant stress of 12 kg/mm^2.

In Fig. 1, on the basis of our experiments [10], the upper part shows the melting diagrams, the phase composition of the alloys, and the solubility curves of aluminum in the sections studied as a function of temperature.

Fig. 1

In the middle part are given the values of the crystal-lattice parameters of the nickel solid solutions at 1200°, and, finally, in the lower part, the composition–heat-resistance diagram for each section studied. The investigation showed that, as the aluminum content increases in each of the sections studied, strengthening of the solid solution takes place. This is indicated by the course of the curves in the composition–heat-resistance diagrams, as well as by the X-ray structural-analysis data, which showed that, as the aluminum content in the alloys increases, the period of the crystal lattice of the nickel solid solutions increases and, consequently, the degree of their distortion increases, which in turn causes strengthening of these solid solutions.

The greatest heat resistance in each section studied is possessed by alloys in which, as the aluminum content increases, supersaturation of the solid solution occurs and excess γ'-phase is precipitated in a finely dispersed state.

A comparison of the heat resistance of alloys of different sections with one and the same aluminum content shows that, as an additional element is introduced into the nickel solid solution, it becomes strengthened and the heat resistance of the alloys increases. Thus, for example, at 900° and a stress of 12 kg/mm^2, an alloy with 4 wt.% aluminum of the Ni—Al system deformed to the limiting value within several minutes, while an alloy with 4 wt.% aluminum of the Ni—Cr—Ti—W—Al system had a deflection of equal to

5 mm; after approximately 20 hours of testing, alloys with the same aluminum content in the systems Ni–Cr–Ti–W–Mo–Nb–Al and Ni–Cr–Ti–W–Mo–Nb–Co–Al had a deflection of 5 mm after 450 and 750 hours of testing, respectively.

X-ray structural investigation also showed that, with an increase in the number of components in the nickel solid solution, there is a stepwise increase in the magnitude of the period of its crystal lattice. The magnitude of the relative change in the lattice parameter Δa upon introduction into the solid solution of 1 at.% of an element increases in the order: Co, Cr, Ti, Mo, W, Nb. Consequently, a regularity is observed: as elements become more distant from nickel both by period and by group, the effect of their strengthening action on the nickel solid solution increases.

This agrees with the data obtained in work (11).

A comparison of the results for all systems (see Fig. 1) shows that the absolute values of the maxima of the heat resistance of the alloys, obtained by the centrifugal method, increase stepwise in going from the 2-component system to the 8-component system as the number of elements entering into the solid solutions increases. The alloys of the maximally alloyed 8-component system possess the greatest heat resistance.

Thus, the investigation carried out again confirms the previously established regularity: an increase in heat resistance with an increase in the number of elements of limited solubility entering into the solid solution.

As the chemical composition of the base of solid-solution alloys becomes more complex, the strength of the chemical bond between unlike atoms in the nickel solid solution increases. Under conditions of limiting saturation and finely dispersed decomposition of solid solutions, their additional strengthening occurs.

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