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Abstract

Full Text

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I. I. KORNILOV and N. T. DOMOTENKO

THE INFLUENCE OF THE ATOMIC CONCENTRATION OF CHROMIUM, MOLYBDENUM, AND TUNGSTEN ON THE PROPERTIES OF SOLID SOLUTIONS OF NICKEL

(Presented by Academician A. A. Blagonravov, 11 I 1958)

Chromium, molybdenum, and tungsten—elements of Group VI of D. I. Mendeleev' s periodic system—have a body-centered cubic lattice and form limited solid solutions with nickel.

The solubility of these elements in nickel decreases from chromium to molybdenum and tungsten. It is determined by the relative difference between the atomic diameters of nickel and these metals. The differences between the atomic diameters of these elements and the atomic diameter of nickel, and their limiting solubility in nickel, are as follows:

	Cr	Mo	W
Difference of atomic diameters from the atomic diameter of Ni (in %)	3	12.4	13.3
Limiting solubility (in at. %) at the eutectic temperature	50.0	23.0	18.1
Limiting solubility (in at. %) at 700°	40.0	14.9	13.0

The replacement of atoms of the solvent metal by atoms of the dissolved substance causes the appearance in the system of additional chemical bonds that

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strengthen the lattice of the solvent metal. Attention was drawn to this in a work on the physicochemical theory of the heat resistance of solid solutions of metals ([1]).

The different solubility of chromium, molybdenum, and tungsten in nickel, as well as the difference in their atomic structure, should have different effects on the properties of nickel solid solutions. Establishing the regularities in the variation of these properties as a function of the atomic concentration of Cr, Mo, and W by methods of physicochemical analysis is the aim of the present study. The results of measurements of the lattice period of nickel solid solution show that, at equal atomic concentrations of these elements, the degree of distortion of the crystalline lattice of nickel increases in going from Cr to Mo and W. This regularity corresponds to the successive arrangement of these elements in the periodic system of elements and follows from the degree of difference between their atomic diameters and the atomic diameter of nickel. This is confirmed by the different de-

Table 1

Lattice parameters of pure Ni and of its solid solutions with 4, 6, and 10 at. % Cr, Mo, and W

	Lattice parameter, Å		Lattice parameter, Å		Lattice parameter, Å
Ni	3.518	with Cr 6%	3.524	with Cr 10%	3.528
Solid solution Ni: with Cr 4%	3.522	with Mo 6%	3.542	with Mo 10%	3.558
with Mo 4%	3.533	with W 6%	3.543	with W 10%	3.560
with W 4%	3.535				

···of expansion of the nickel lattice parameter at equal atomic concentrations of Cr, Mo, and W (Table 1).

As is evident from these data, the greatest difference in the lattice parameters occurs in the cases of the nickel solid solution with tungsten (at W concentrations of 4, 6, and 10%) and the smallest in the solid solutions of nickel with chromium (at the same Cr concentrations). Molybdenum occupies an intermediate position.

Study of the specific electrical resistivity at the same atomic concentrations of Cr, Mo, and W showed a sequence of increase of this physical constant also in

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Figure 1

Figure 1: Figure 1

Figure 2

Figure 2: Figure 2

the transition from chromium to molybdenum and from the latter to tungsten. Further, we studied on alloys with 4, 6, and 10% Cr, Mo, and W the hardness of these alloys at room temperature, at 800 and 1000° (see Table 2), and the heat resistance at 800 and a stress of 4 kg/mm^2 and at 1000° and a stress of 2 kg/mm^2. The study of hot hardness was carried out on the apparatus described in work ([2]), and the heat-resistance tests were performed by the bending method on a centrifugal machine ([3]).

Table 2

Hardness of Ni alloys with 4, 6, and 10 at. % Cr, Mo, and W (in kg/mm^2)

T, °C	Cr 4%	Cr 6%	Cr 10%	Mo 4%	Mo 6%	Mo 10%	W 4%	W 6%	W 10%
20	96	102	124	124	144	166	106	120	142
800	40	46	60	82	98	122	72	84	110
1000	20	22	26	42	51	64	30	36	42

As is evident from the data of Table 2, the hardness values at equal atomic concentrations and at the investigated temperatures increase from chromium to tungsten and from tungsten to molybdenum. Molybdenum at all three temperature values gives the maximum increase in hardness of the nickel solid solutions. Thus, in the change in hardness, as one of the strength characteristics, the sequence of the influence of Cr, Mo, and W does not correspond to their position in the periodic system of elements. The same is observed in the change in heat resistance (determined by the bending method) depending on the concentration of these metals in their solid solutions with nickel. According to the results of measuring the bending deflection at different times

Fig. 1. Dependence of the time to reach a bending deflection of 5 mm on the content of Cr, Mo, and W in a nickel solid solution.
a –at $t = 800$°C, $\sigma = 4$ kg/mm^2; b –at $t = 1000$°C, $\sigma = 2$ kg/mm^2

Fig. 2. Effect of chromium, molybdenum, and tungsten on the strength of a nickel solid solution at $t = 800$°C and $\sigma = 4$ kg/mm^2.
a –$C = 4$ at. %, b –$C = 6$ at. %, c –$C = 10$ at. %

a diagram was constructed of the time required for the pointer to reach a deflection of 5 mm under stress, as a function of the content of Cr, Mo, and W in solid

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solutions of nickel. The corresponding curves for 800 and 1000° are presented in Fig. 1. From analysis of this graph it follows that increasing the concentration of Cr, Mo, and W in the nickel solid solution leads to strengthening of the alloys at both isotherms shown in the graph. At equal atomic concentrations of the interacting element, nickel alloys with molybdenum have higher values of heat resistance than solid solutions with chromium and tungsten. To reach a pointer deflection of 5 mm at a temperature of 800° and a stress of 4 kg/mm^2, a solid solution of Ni with 10 at.% Cr requires 200 h, with 10% W—500 h, and with 10% Mo—more than 900 h.

The results of these investigations have been summarized by us in a generalized diagram (Fig. 2), on which the interacting elements with nickel are plotted along the abscissa in the sequence in which they are located in group VI of the periodic system of the elements, and along the ordinate is plotted the time required for the pointer to reach a specified deflection (5 mm) in determining heat resistance at 800°C and a stress of 4 kg/mm^2. From this diagram it is evident that, at all three investigated concentrations of the element interacting with Ni, the heat resistance of solid solutions of Cr, Mo, and W changes in the same sequence as the hardness at the same temperature. As for hardness, these elements may also be arranged by magnitude of heat resistance in the series: Cr $\rightarrow$ W $\rightarrow$ Mo.

The different influence of molybdenum and tungsten on the electrical resistivity and on the change in the period of the crystal lattice of the solid solution, on the one hand, and on hardness and heat resistance, on the other, can be explained by the fact that the first two properties are decisively affected by the difference in atomic diameters, whereas the mechanical properties are affected by the forces of chemical bonding between the interacting atoms in the solid solutions of the metals. In the latter case, there is an individual influence of the elements on the chemical strengthening of the solid solutions of nickel.

The decrease in heat resistance of alloys when molybdenum in the nickel solid solution is replaced by tungsten is probably due to the fact that the chemical-bond forces between atoms of nickel and tungsten (because of the more complex structure of tungsten atoms) are smaller than those between nickel and molybdenum. These questions require further investigation.

Air Force Engineering Academy
named after N. E. Zhukovsky

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

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