CHEMISTRY

1957

SovietRxiv

Abstract

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CHEMISTRY

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HIGH-TEMPERATURE STRENGTH OF ALLOYS OF CERTAIN BINARY, TERNARY, QUATERNARY, AND QUINARY NICKEL SYSTEMS AT 800°

(Presented by Academician I. P. Bardin, 21 VII 1956)

Investigations of a number of partial phase diagrams of binary, ternary, quaternary, and quinary nickel systems have shown that the elements chromium, tungsten, titanium, and aluminum form with nickel limited binary, ternary, quaternary, and quinary solid solutions of considerably higher concentration ([1-3]) than such elements as zirconium, beryllium, boron, carbon, nitrogen, and others.

The centrifugal method of testing alloys for high-temperature strength ([4,5]) made it possible to carry out numerous investigations comparatively rapidly, establishing regularities in the change of the high-temperature strength of alloys as a function of the composition and phase constitution of metallic systems. It was established that the above-mentioned elements strengthen nickel through the formation of limited solid solutions of considerable concentration. Maximum strengthening is achieved in the region of critically saturated and supersaturated solid solutions.

Nickel alloys with aluminum, titanium, tungsten, and chromium, representing critically saturated and supersaturated solid solutions, under certain conditions undergo additional strengthening owing to the formation and precipitation from the solid solutions of metallic compounds (Ni_3Al, Ni_3Ti, and Ni_4W) in a finely dispersed state. The precipitation of an excess second phase in alloys in the form of coagulated, isolated particles causes a decrease in the high-temperature strength of the alloys.

The more complex the chemical composition of the solid solution, the more the strength of the chemical bond between unlike atoms in it increases, and the more slowly proceed the processes of coagulation of the excess phase and of softening of the alloy at high temperatures. The rate of coagulation depends on the degree of supersaturation of the solid solution and on the difference in chemical composition between the solid solution and the second phase, since this determines the number of necessary atomic displacements for the formation and

Fig. 1. Increase in the limit of long-term strength (not less than 100 h to rupture) in limited solid solutions of nickel at 800°

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growth of crystals of the second phase.

A decrease in the rate of coagulation of the excess phase is one of the principal factors responsible for the experimentally confirmed regularity—an increase in high-temperature strength with an increase in the number of limited-solubility elements making up the alloy.

We have carried out a systematic investigation of the high-temperature strength of alloys:

a) of the binary system Ni—Ti with Ti content from 0 to 14%;

b) of the ternary system Ni—Cr—Ti at constant Cr contents of 10 and 20% and with a variable Ti content from 0 to 15% (2);

c) of the quaternary system Ni—Cr—Al—Nb with constant contents of Cr 10 and 15%, Al 6%, and variable Nb content from 0 to 12.5% (3);

d) of the quinary system Ni—Cr—W—Ti—Al with a constant Cr content of 20% and a variable Al content from 0 to 12% (6).

The compositions of these alloys encompass both solid solutions and compositions conjugate with them with precipitation of an excess phase. High-temperature strength

alloys of these systems was studied by the centrifugal method at 800° and at different stresses from 5 to 40 kg/mm^2.

As a result of these investigations it was established that in all cases the maximum strengthening is attained in the transition region from a homogeneous solid solution to alloys with a heterogeneous structure. The maximum strengthening of quinary nickel solid solutions is considerably higher than the maximum strengthening of quaternary ones, quaternary higher than ternary ones, and ternary higher than binary nickel solid solutions. And, finally, the latter are more heat-resistant than pure nickel.

The absolute values of the maxima of heat resistance of alloys on isothermal diagrams of composition—heat resistance for binary, ternary, and more complex nickel systems show a stepwise increase as the number of elements included in the solid solutions increases.

Fig. 1. Increase in the limit of long-term strength (not less than 100 h to rupture) in limited solid solutions of nickel at 800°.

Experimental data on establishing the maximum heat resistance of alloys for a number of binary, ternary, quaternary, and quinary systems at 800° make it possible to compare them in the form of a summary diagram showing the stepwise increase in the strength limit of alloys as a function of composition as the number of components in nickel systems increases.

In Fig. 1 are given experimental data on the change in heat resistance of alloys of the systems: Ni—Ti; Ni—Cr—Ti; Ni—Cr—Ti—W and Ni—Cr—W—Ti—Al as a function of the content of one of the elements while keeping the concentration of the other elements constant (at the expense of the nickel content).

The compositions of alloys of the binary Ni—Ti system with a Ti content of 8-10.8%, corresponding to the maximum heat resistance at 800°, withstand testing for 500 h without rupture at a stress not higher than 5 kg/mm^2.

In alloys of the ternary Ni—Cr—Ti system (section with 10% Cr), owing to the decrease in the limiting solubility of titanium, its optimum content is 6-7.5% Ti (as against 8-10% in the binary system). These alloy compositions at 800° do not rupture during 425 h at a higher stress, namely: 6.4-10 kg/mm^2 (2).

According to the data of I. I. Kornilov and N. V. Vyalya, who investigated the heat resistance of alloys of the Ni—Cr—Ti—W system with variable tungsten content at 800°, specimens do not rupture during 100 h at a stress of 15 kg/mm^2 (with 6% W).

The alloys investigated by us of the quaternary Ni—Cr—Al—Nb system (3), with Cr 10-15%, Al 6%, and Nb from 2.5 to 5.0%, also show higher heat resistance in comparison with alloys of ternary systems. At 800° and a stress of 24 kg/mm^2 the optimum alloy compositions of this quaternary system with Nb 2.5-5% do not rupture during 426 h (3).

The optimum compositions of the quinary Ni—Cr—W—Ti—Al system, with Cr 20% and Al 4-6%, possess the greatest heat resistance,

which at 800° do not fail in 100 hours or more under a stress of 35-40 kg/mm^2.

As is seen from Fig. 1, the limiting stress at which the optimum alloy compositions do not fail and only deform at a low rate is, for the binary Ni—Ti system, no more than 5 kg/mm^2 (for the Ni—Cr system it is 3.5 kg/mm^2 (1)). For alloys of the ternary Ni—Cr—Ti system this limiting stress increases to 6.4-10 kg/mm^2, and for the quaternary system—to 15 kg/mm^2 and higher.

The highest stress is withstood by alloy compositions of the quinary Ni—Cr—W—Ti—Al system, corresponding to the transition region from solid solutions to heterogeneous ones. For the optimum alloy compositions of this system, the long-time strength limit rises to 35-40 kg/mm^2.

As is seen from the data presented, the heat resistance of quinary alloys at one and the same temperature (800°) is almost 8-10 times greater than that of binary alloys, 3-5 times greater than that of ternary alloys, and twice as great as that of quaternary nickel alloys.

Thus, as the chemical composition of the alloy base becomes more complex, the special role of increasing the strength of the chemical bond between dissimilar atoms in the solid solution of nickel becomes apparent, as does its strengthening under conditions of limiting saturation and finely dispersed decomposition. These factors slow the process of structural weakening of the alloys and impart high heat resistance to them.

The high degree of strengthening of complex solid solutions of limiting saturation and supersaturation will be retained to the extent that their finely dispersed decomposition preserves this strengthened state in the first stage of decomposition and weakens it as the precipitated excess phase coagulates. Weakening as a result of coarsening and segregation of the excess phase can be explained by the fact that the initial concentration of the high-heat-resistant solid solution is thereby reduced through precipitation and segregation of the excess phase. The decrease in the concentration of elements occurs first of all along grain boundaries, where inclusions of the excess phase are concentrated mainly. Under such conditions, great possibilities are created for intergranular and other types of creep of the alloys, which undoubtedly leads to a reduction in heat resistance.

This is also observed in a number of cases verified in experimental investigations and in the service practice of heat-resistant alloys.

Received
21 VII 1956

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