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Abstract

Full Text

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THE INFLUENCE OF THE TIME FACTOR ON THE CHARACTER OF THE COMPOSITION–HIGH-TEMPERATURE STRENGTH DIAGRAM OF ALLOYS OF THE FIVE-COMPONENT SYSTEM Ni–Cr–W–Ti–Al

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Nickel is capable of forming solid solutions and intermetallic compounds with many elements. Crystallochemical reactions in nickel alloys, owing to the absence of polymorphism, are reduced only to the processes of formation of Kurnakov compounds from solid solutions and transformations of supersaturated solid solutions. With many metals (Cr, Mo, W, V, Nb, Ti, Al, Be, etc.) nickel forms limited solid solutions with temperature-dependent solubility. Usually, when the temperature is lowered, the solubility of components in nickel decreases. This creates favorable conditions for obtaining nickel solid solutions of both simple and complex composition in the supersaturated state and for subsequent processes of formation of excess phases and dispersion strengthening.

Fig. 1. Phase diagram and composition—high-temperature strength of alloys of one section of the five-component system Ni—Cr—W—Ti—Al at 900°C

The study of questions concerning the influence of the duration of crystallochemical reactions on the high-temperature strength of nickel alloys has been the subject of work by many investigators ([1]-[8]).

Most authors have considered questions of the influence of the duration of crystallochemical reactions on the change in high-temperature strength of a single alloy composition. Of interest is an investigation of the simultaneous influence of composition and prolonged transformation time on the high-temperature strength of alloys of metallic systems. To solve this problem, we studied the creep of alloys of one of the sections of the five-component system Ni—Cr—W—Ti—Al with a variable Al content from 0 to 7.9% (at the expense of the Ni content) and with constant Cr, W, and Ti contents.

Fig. 2. Creep curves of alloys of the Ni—Cr—W—Ti—Al system for 2000 hours.

Figure 2: Fig. 2. Creep curves of alloys of the Ni—Cr—W—Ti—Al system for 2000 hours.

The phase diagram of the section studied is shown in Fig. 1.

Before creep testing, the specimens were subjected to the following heat treatment: heating to 1150°C, holding for 7 hr, and cooling in air. After such homogenization, alloys containing up to 5.1% aluminum show the structure of five-component solid solutions with a small amount of excess phase γ', precipitated as a result of cooling in air. Above this aluminum content, a eutectic appears, consisting of solid solution γ and phase γ'.

Creep testing of the alloys of this section was carried out by the centrifugal method on 3-4 parallel specimens. The temperature chosen was 900° and the initial stress was 6 kg/mm^2.

The selected stress, as the study showed, for a number of compositions made it possible to study the deformation of the alloy over a long time, up to 10,000 hours and more. At present the tests have been carried to 10,000 hours and will be continued to 25,000 hours and more.

Fig. 2. Creep curves of alloys of the Ni—Cr—W—Ti—Al system for 2000 hours.

As the characteristic of creep, the magnitude of the deflection of the specimens during deformation was taken.

For a more detailed analysis of the creep curves as a function of deformation time and composition, we shall present them in diagrams, one of which (Fig. 2) characterizes in greater detail the creep process of different alloy compositions up to 2000 hours of deformation, while the second (on a smaller time scale) (Fig. 3) extends to 10,000 hours.

Examination of the curves shown in Fig. 2 indicates that alloys with a high aluminum content (6.5 and 7.9%), whose compositions lie in the region of joint crystallization of the γ-solid solution and the eutectic, proved to be not heat-resistant. Under these conditions they deform rapidly: the alloy with 7.9% Al (curve , Figs. 2, 3) was removed from the test after 500 hours and after reaching a deflection of 60 mm, while the alloy with 6.5% Al was removed after 2500 hours with a deflection of 59 mm (curve , Figs. 2, 3). The alloy with 0.5% Al, corresponding to a diluted solid solution, has a high rate of deformation and was removed after 750 hours with a deflection of 60 mm (curve , Figs. 2, 3). The creep curves of these three alloys are characterized by a rapid increase in deflection with time. Alloys located in the region of concentrated and supersaturated solid solutions (from 1.8 to 5.1% Al) differ sharply, in their high heat resistance, from the first two compositions of heterogeneous alloys with a eutectic constituent and from the third composition, a diluted solid solution.

Fig. 3. Creep curves of alloys of the Ni—Cr—W—Ti—Al system over 10,000 h.

Figure 3: Fig. 3. Creep curves of alloys of the Ni—Cr—W—Ti—Al system over 10,000 h.

It is very significant that the alloy with 5.1% Al (maximally supersaturated) in the initial stage (up to 300-400 hours) is almost not deformed (curve , Fig. 2). During the indicated test period, the alloy of this composition evidently only has time to undergo the first stage of dispersion decomposition of the supersaturated solid solution, with maximum strengthening of the latter. Beginning at 300-400 hours, this alloy undergoes accelerated creep, which apparently corresponds to the onset of the coagulation process in the decomposition reaction of the solid solution.

During the period from 400 to 1000 hours, the greatest creep rate is observed, and during this time the deflection increases from an almost zero value to 3.5 mm. Alloys with aluminum contents of 1.8 ( ), 2.8 ( ), and 3.4% ( ) under these ...

under the conditions deform at an accelerated rate in the initial stage, during the first 100-200 h, and thereafter at a uniform and low rate up to 2000 h.

Thus, from these curves it may be considered that for a short deformation time (up to 300-400 h) the most heat-resistant alloy is the one with maximum supersaturation (5.1% Al), whereas as the time increases beyond 700-800 h, the most heat-resistant become alloys with a lower degree of supersaturation (3.4, 2.8, and 1.8% Al), located near the limit of aluminum solubility. Of these last three compositions, the alloy with 1.8% Al is characterized, in its microstructure, by a purely polyhedral structure and is distinguished by the lowest creep rate.

Fig. 3. Creep curves of alloys of the Ni—Cr—W—Ti—Al system over 10,000 h.

Further increasing the creep-test time to 10,000 h does not change the general character of the change in the creep curves for different alloy compositions, with the exception of two compositions with 2.8 and 3.4% Al.

The alloy with 5.1% Al (curve *d*) is also distinguished in this case (see Fig. 3) by the greatest deflection, and the alloy with 1.8% Al (curve *b*) by the smallest. What is most interesting is that the alloys containing 2.8% Al (curve *v*) and 3.4% Al (*g*) in terms of deflection throughout the entire test time lie in the intervals between the alloy compositions with 5.1% and 1.8% Al; however, after 5000 h the deflection of the alloy with 3.4% Al becomes greater than that of the alloy with 2.8% Al. The alloy with 2.8% Al represents a less supersaturated solid solution than the alloy with 3.4% Al. In this case also, owing to the greater supersaturation in the alloy with 3.4% Al, coagulation of the excess phase proceeds more rapidly, causing an acceleration of creep.

On the basis of the deflection (equal to 2.5 mm) of alloy specimens during deformation for 10,000 h, a composition-heat-resistance diagram was constructed at 900° and a stress of 6 kg/mm^2 (see Fig. 1, curve *a*).

It shows that the maximum time to reach this deflection (or maximum heat resistance) is possessed by alloys containing 1.8–2.8% Al, located near the limit of saturation, with an almost homogeneous solid-solution structure or with a slight degree of their heterogenization. As the degree of supersaturation of the solid solution increases (alloys with 3.4 and 5.1% Al)—with strong heterogenization of the structure and formation of eutectic mixtures—the heat resistance of the alloys decreases successively and markedly. Dilute solid solutions (alloy with 0.5% Al) also show low values of heat resistance. If this is compared with the

the composition–high-temperature strength diagram obtained by us earlier for alloys of this system for a comparatively short test time (up to 200–300 h), but at a higher stress, then a substantial difference is revealed. It consists in a considerable shift to the right of the position of the maximum high-temperature strength on the composition–high-temperature strength diagram obtained as a result of short-term high-temperature-strength testing. In Fig. 1b the diagram is given for a deformation time of 250 h at 900° and a stress of 8 kg/mm^2. Fig. 1b shows that the region of maximum high-temperature strength corresponds to alloy compositions containing 4.5–5.5% Al, i.e., to alloy compositions with the maximum degree of supersaturation of the solid solution.

Lower values of high-temperature strength are obtained here both in the region of diluted, less saturated solid solutions and in alloys with a solid-solution structure containing a eutectic.

The explanation for this kind of displacement of the region of maximum high-temperature strength of alloys on the composition–high-temperature strength diagram under short-term (on the order of hundreds of hours) and long-term (up to 10,000 h) tests should be sought in the influence of the time factor on the processes of physicochemical transformation and structural change in the alloys during testing.

Under conditions of short-term high-temperature-strength testing, alloys with maximum supersaturation have the greatest strength, owing to large internal stresses in the solid-solution lattice. The first stage of decomposition of such supersaturated solid solutions, causing only the formation of atomic groupings enriched in components and the precipitation of an excess phase in a finely dispersed state, ensures preservation of the strengthened state of the alloy for this comparatively short time. This strengthening effect becomes smaller in the region of less supersaturated solutions and in the region of formation of eutectic mixtures during crystallization. It is absent in compositions of diluted solid solutions. Because of the different influence of the time factor, associated with the different character of the crystallochemical reaction, during prolonged creep-testing processes the strengthening factor changes into its opposite. The strengthening process is replaced by softening of the alloys. This softening proceeds with time the more intensively, the greater the degree of supersaturation of the solid solution and the longer the test time. In the latter case diffusion processes play a significant role. The formation of an excess phase with its subsequent coagulation leads to a decrease in high-temperature strength. Thus, under prolonged test conditions the maxima of high-temperature strength shift into the region of less supersaturated solid solutions, possessing greater thermal stability and a lesser tendency toward decomposition and coagulation of the excess phase during the prolonged action of stress.

The present investigation has shown that the maxima of high-temperature strength on isothermal composition–high-temperature strength diagrams are mobile not only as a function of the temperature factor, as was established earlier ([9]), but also as a function of the time factor.

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