INTRODUCTION

For the production of parts and pieces of equipment working at temperatures up to 1100–1150 °C, wide application has been made of disperse hardening nickel alloys in which high heat-resistance is achieved by complex alloying of a solid solution, above all by refractory elements like tantalum, wolfram, molybdenum, rhenium, and ruthenium, as well as by isolation from a supersaturated solid solution of small particles of strengthening phases with a size of from 0.1 to 0.3 μm coherently connecting with the matrix. At temperatures above 1100 °C, however, in aging alloys, intense disordering connected with coagulation and dissolving of disperse particles of strengthening phases occurs.

In connection with this, to secure maximum heat strength in a high-temperature area, disperse strengthening alloys in which the strengthening effect is achieved by complex alloying of a solid solution, above all by refractory elements like tantalum, wolfram, molybdenum, rhenium, and ruthenium, as well as by isolation from a supersaturated solid solution of small particles of strengthening phases with a size of from 0.1 to 0.3 μm coherently connecting with the matrix. At temperatures above 1100 °C, however, in aging alloys, intense disordering connected with coagulation and dissolving of disperse particles of strengthening phases occurs.

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EXPERIMENTAL

The results of the high-temperature oxidation of nickel alloy with nitride strengthening are considered in the present work. Experiments were carried out on samples with a size of 30 × 20 × 0.8 mm produced from an alloy containing (wt %): Ni (main), Cr 25.1, Co 26.3, W 10.3, Ti 1.9, and Mo 1.2 in the following states:

- without nitrides of alloying elements;
- with nitrides of alloying elements in an amount of no less than 50% (vol.); and
- with a protective cover obtained by slip aluminosiliconization at a temperature of 1000 °C for 2 h [3].

Testing of samples was performed in corundum crucibles in an SNOL laboratory oven (1.4, 2.5, 1.2/12.5) in isothermal conditions in air at temperatures of 1100 and 1150 °C. The results of testing were estimated from external appearance, changing masses of samples in crucibles, changing structure of the surface layer, and depth of corrosion damage, as well as based on X-ray structure analysis evidence of the surface-layer phase composition of oxidizing samples.

Samples with crucibles were weighed on analytic scales after 5, 10, 20, 35, 55, 75, and 100 h of testing. In addition, metallographic investigations of the sample surface-layer structure were conducted with the help of a JSM-5600 electron microscope.
EXPERIMENTAL RESULTS AND DISCUSSION

Alloy without Nitrides and without Cover

At a temperature of 1100°C, the alloy is easily oxidized, forming an oxide film that exfoliates as relatively large gray-green particles and powder falling onto the crucible bottom. The specific sample mass changes in accordance with a parabolic dependence (Fig. 1).

After 100 h of testing, the depth of corrosion damage of the surface-alloy layer ranges up to 150 μm (Fig. 2). X-ray structure analysis showed that, after 25 h of oxidation, Cr₂O₃ oxide predominates on sample surfaces in an amount that remains high after both 50 and 100 h of oxidation. As this takes place, commencing after 50 h, the amount of spinel (Ni, Co)Cr₂O₄ increases in scale composition. At the stage of steady oxidation, the corrosion rate is about 4.45 g²/(m⁴ h).

At a temperature of 1200°C, the formation of oxide film on the surface of samples occurs faster than at 1100°C (Fig. 3). The surface of samples beginning from 5 h oxidation becomes rough, scale exfoliates from the surface in the form of finely divided powder and granules. After 10 h of oxidation, the depth of the surface layer depleted by components of alloy and damaged by corrosion ranges up to 80–90 μm and increases up to 200–220 μm after 10 h (Fig. 4).

The main structural components of oxide film on the sample surface are the oxides Cr₂O₃, (Ni, Co)Cr₂O₄, and NiO. The phase composition and ratio of phase components of oxide film do not change over time. The smaller parameters of increasing specific sample mass with crucibles at a temperature of 1200°C as compared with 1100°C can be connected with the formation of volatile oxide fractions containing chromium and wolfram:

\[
\begin{align*}
\text{Cr}_2\text{O}_3 + 3/2\text{O}_2 & \rightarrow 2\text{CrO}_3 \quad (\text{g}) \\
\text{W} + 3/2\text{O}_2 & \rightarrow \text{WO}_3 \quad (\text{g})
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Alloy Containing No Less Than 50 vol % Nitride Particles of Alloving Elements, Mainly TiN

The presence of disperse nitride particles, mainly TiN, distributed in the bulk and on boundaries in the form of both small globules and thin plates is a distinctive feature of this alloy (Fig. 5).

The high thermal stability of nitride particles in alloy should be also noted. Thus, at temperatures of 1100 and 1200°C, after 100 h of testing the samples for heat stability, electron-microscopic investigation did not find sufficient interaction of nitride particles with matrix solid solution. The morphology of nitride particles is retained in the alloy without apparent changes (Figs. 6, 7).

Oxidation of samples at temperatures of 1100 and 1200°C occurs following a parabolic dependence. At 1100°C, the formation and increase of resistant oxide film occur even after 10–15 h of oxidation and at 1200°C after about 20–25 h of testing. At the subsequent high temperature, samples tested for surface oxidation heat tolerance have a stable nature.

The rate constant of oxidation of samples at a temperature of 1100°C is about 2.8 g²/(m⁴ h); at 1200°C, it is about 37.8 g²/(m⁴ h). Therewith, oxidation products fall onto the crucible bottom as small crystalline scales.

The depth of corrosion damage to the surface layer after 100 h of oxidation ranges up to 25 μm at a temperature of 1100°C and almost 130 μm at 1200°C. X-ray structure analysis found that the oxide film on sample surfaces tested at temperatures of 1100 and 1200°C contain mainly two oxide phases—Cr₂O₃ and (Ni, Co)Cr₂O₄.