RELAXATION RESISTANCE OF ALLOYS BASED ON
IRON AND NICKEL AT HIGH TEMPERATURES

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The structural condition of heat resistant steels and alloys determines to a considerable extent the working capacity of apparatus in power plants [1]. Most heat resistant materials are heterophase, and therefore the effect of alloying on the solid solution and the hardening phase must be taken into account in studies of their relaxation resistance.

The resistance to small plastic deformation (about 0.2%) with brief loading was investigated on binary and more complex solid solutions based on iron and nickel and also the stress relaxation conditions at elevated temperatures. The solid solutions were alloyed with transition elements (Mo, W, Nb, V, and Cr), added separately and together in amounts not exceeding their solubility in iron or nickel. The investigations showed that the relaxation resistance is determined by the elastic characteristics of the solid solution. For determining atomic interactions, the x-ray method proved to be the most sensitive, and also the internal friction and modulus of elasticity determined at high temperatures, while the lattice constants were the least sensitive [2-5]. The change in the lattice constant of the α solid solution alloyed with different elements of the transition group is shown in Fig. 1. With increasing concentrations of Nb, Mo, W, and Cr up to saturation of the solid solution there is a continuous increase of the lattice constant, which decreases with the addition of vanadium. The modulus of elasticity at 565°C increases on alloying with niobium, tungsten, and molybdenum, but decreases with the addition of vanadium. It should be noted that when iron is alloyed with chromium the modulus of elasticity also increases, but not monotonically like the lattice constant: with 6% Cr the modulus of elasticity decreases, and with further increase of the chromium

![Fig. 1](image1)

![Fig. 2](image2)

Fig. 1. Variation of the lattice constant and modulus of elasticity at 565°C with the concentration of the alloying element in binary solutions of iron.

Fig. 2. Variation of lattice constant and modulus of elasticity at 700°C with the concentration of alloying elements in solid solutions of nickel. 1) Ni–Cr alloy; 2) Ni–W with 15% Cr and 5% Mo; 3) Ni–W with 15% Cr, 5% Mo, and 2% Nb.
content to 10% it increases again. Similar results were obtained for multicomponent solid solutions based on iron [3, 6].

The change in the elastic characteristics of the lattice of solid solutions based on nickel is shown in Fig. 2. For binary solid solutions of nickel with as much as 15% Cr, 5% Mo, and 2% Nb the lattice constant increases considerably, and with an increase of the tungsten content from 0 to 11% it increases continuously. The modulus of elasticity of the solid solutions based on nickel is affected most by additions of as much as 5% W, while with further increase of the tungsten content to 11% no increase of the elasticity modulus is observed, although the lattice constant increases. The data obtained agree with the results from other studies [2, 4, 7, 8].

Figure 3 shows the change in the yield strength at 550°C for binary solid solutions of iron in relation to the concentration of the alloying element. The strength is lowest for solid solutions with vanadium and highest for those with molybdenum. For solid solutions with chromium the yield strength first increases with as much as 1.5–2% Cr, decreases with 6% Cr, and again increases with 7% Cr.

A similar change in the relaxation resistance occurs at 565°C for solid solutions of iron. An increase of the residual stress after 500 h of testing is observed for solid solutions alloyed with niobium, molybdenum, tungsten, and chromium; with over 0.5% V the relaxation resistance decreases. A similar relationship was observed earlier for multicomponent solid solutions of iron [3]. Even with a large amount of chromium in the binary alloy it is impossible to attain the same degree of strengthening and resistance to stress relaxation observed in solid solutions of iron with molybdenum, niobium, and other elements.

The same results were obtained for solid solutions based on nickel (Fig. 4). The yield strength and residual stress after testing for 3000 h at 700°C are highest for the Ni–Cr solid solution alloyed with molybdenum, tungsten, and niobium together.

It is well known that the relaxation resistance of alloys is increased by alloying with elements that not only strengthen the solid solution but also induce the formation of dispersed excess phases. The structural condition of the alloy is of great importance, determining the type of hardening phase, the amount of it, the dispersity, and the thermal stability.

Heterophase relaxation resistant steels and alloys should be alloyed primarily with such elements as niobium, molybdenum, vanadium, and tungsten, which form thermally stable carbides of the NbC of $M_2C_3$ types, or intermetallic phases of the Laves type, and nickel alloys should be alloyed with titanium and aluminum, promoting the formation of $\gamma'$ phase. Figure 5 shows the relative relaxation resistance of various steels. The presence of hardening phases ($M_2C_3$ and NbC carbides) in the slightly hardened matrix of steel with 5% Cr, 1% Mo, and 0.2% Nb does not lead to a substantial increase of the resistance to small plastic