The present tendency toward an increase in the capacities and service life of power-generating equipment creates a need for comprehensive study and development of associated materials and for an improvement in methods of design and construction.

Heat-resistant, high-alloy nickel-base alloys have found wide use in power engineering [1]. In this connection, it is useful to further investigate and analyze the strength properties of these materials in order to determine their durability.

The present work presents the results of studies of the fatigue strength of alloys EI607A and EI929VD at different test temperatures.

The above alloys are members of a class of nickel-base alloys used in portable and stationary gas turbines, mainly in the manufacture of the rotors. These alloys are strengthened by the formation during heat treatment of an Ni3(Ti, Al)-type intermetallic γ'-phase, the amount of which determines the level of heat resistance of the given alloy. Figure 1 shows the microstructure of the alloys.

The content of the γ'-phase in alloy EI607A is 12-15% and is 45% in alloy EI929VD, indicating that the latter has a higher resistance to heat. For example, at 700°C, the long-term strength of alloys EI929VD, and EI607A over 10,000 h is 49 and 19 kgf/mm², respectively [2].

Short-term static tests of standard specimens of alloys EI607A and EI929VD at temperatures of 450, 600, 700, and 800°C showed that their strength decreases with increasing temperature: for alloy EI607A, from 79.0 kgf/mm² at 450°C to 63.0 kgf/mm² at 700°C; for alloy EI929VD from 103.0 kgf/mm² at 600°C to 81.0 kgf/mm² at 800°C.

The character of the change in the proof stress of alloy EI607A is more complex with an increase in temperature within the range from 450 to 700°C: at first, it increases from 42 kgf/mm² at 450°C to 50 kgf/mm² at 600°C, and then decreases to 40 kgf/mm² at 700°C. The ductility characteristics of the above alloy decrease with increasing temperature: elongation δ decreases from 48 to 39%, and reduction in area ψ decreases from 49 to 36%.

The proof stress of alloy EI929VD within the range 600-800°C remains practically constant (δ₀₁₀ ≈ 60 kgf/mm²); with an increase in temperature to 700°C, elongation δ and reduction in area ψ decrease somewhat, while they increase with a further increase in temperature to 800°C.

Fatigue tests of specimens of alloy EI607A were conducted at 500, 600, and 700°C, and were conducted at 600, 700, and 800°C for alloy EI929VD. We tested smooth cylindrical specimens with a working diameter...
Fig. 1. Microstructure of heat-resistant nickel alloys EI607A (a) and EI929VD (b) after the standard heat treatment.

of 7.5 mm in pure bending with rotation in a symmetrical load cycle. Frequency of load change was 50 Hz and the test base was 20 million cycles (~120 h). The finish of the specimen surfaces in the working section corresponded to class 9-10. The chemical composition of the alloys and the method of their heat treatment conformed to technical specifications.

We obtained a fatigue curve by testing 8 to 15 specimens at 4-5 levels of stress. Test results were analyzed on a computer by means of the least-squares method. Based on the computations, we obtained empirical regression lines representing equations of the fatigue curve of the type \( \log N = A + m \log \sigma \) with a probability of failure \( P = 50\% \).

Figure 2 shows in the coordinates \( \log \sigma - \log N \) the fatigue curves of specimens of alloys EI607A and EI929VD at different test temperatures. As a rule, the curves are approximated by two branches: either inclined to the N axis and horizontal, or two sloping curves with different intensities of fatigue-damage accumulation over time. An exception is the fatigue curve of alloy EI607A at 700°C, for which only a sloping branch was obtained within the investigated range of endurances. The slope of the branch of the fatigue curve is determined by the change in endurance during tests at high temperatures (500-800°C). As is apparent, an increase in temperature has a greater effect on the slope of the left branches of the fatigue curves of alloy EI607A specimens than on those of specimens of alloy EI929VD. For the first alloy, an increase in temperature is accompanied by the following pattern of change in coefficient \( m \) in the fatigue curve equation: it is 7.4 at 500°C, 15.4 at 600°C, and 21.5 at 700°C. For the second alloy, an increase in temperature from 600 to 800°C is not associated with any significant change in coefficient \( m \) (\( m = 7.5, 8.8, \) and \( 8.6 \)). Consequently, the left branches of the fatigue curves of alloy EI929VD are practically parallel.

Table 1 shows endurance limit values for the investigated materials. An analysis of the tabular data shows that an increase in temperature from 500 to 700°C (on a base of \( 2 \times 10^7 \) cycles) is not associated with any appreciable change in the finite endurance limit of specimens of alloy EI607A (\( \sigma_{-1} = 36.0-37.0 \) kgf/mm²). At 600°C the investigated alloy has a true endurance limit equal to 36.0 kgf/mm². For specimens of alloy EI929VD, with an increase in temperature from 600 to 700°C, resistance to fatigue increases by about 10%. A further increase in temperature to 800°C reduces fatigue resistance. Here, the fatigue curve does not have a horizontal section, but has a discontinuity in the direction of a less intensive accumulation of fatigue damages. Consequently, within the temperature range from 600 to 800°C, the alloy exhibits maximum resistance to fatigue at 700°C (\( \sigma_{-1} \approx 39.5 \) kgf/mm²).

Such a character of change in fatigue strength with increasing test temperature within a certain range is typical of most nickel-base heat-resistant alloys [3, 4]; there is a temperature region for these alloys in which they have maximum fatigue strength. Structural changes occurring during fatigue tests at high temperatures should be considered one of the possible causes of this phenomenon.

To explain the above effects, we studied the change in a structure-sensitive characteristic — hardness — on failed specimens of alloy EI929VD after fatigue tests at 600, 700, and 800°C. We measured hardness by the