The strength of a molybdenum single crystal under nonisothermal stressing has been investigated by using two different regimes of temperature and load variation.

In the first regime the load on the specimen was maintained constant while the temperature was varied periodically in accordance with a trapezoidal cycle. This regime corresponds with conditions of thermocyclic creep.

The second loading regime consisted of the simultaneous variation of temperature and alternating stress in accordance with a triangular cycle, i.e., the tests were carried out under conditions of nonisothermal low-cycle fatigue. In this case the amplitude of the total deformation of the specimen was maintained constant during the tests, and rigid loading took place.

The temperature limits of the cycle were the same for the two testing regimes, the maximum temperature being 1700°C and the minimum 350°C. In the low-cycle tests the specimen was heated to the maximum temperature in 15 sec, and it cooled in 75 sec. The corresponding figures for thermocyclic creep were 1 and 4 min. In addition, the specimens were held at 1700°C for 4 min.

In the low-cycle fatigue tests the specimens were heated by passing an electric current through them, and the specimens for thermocyclic creep testing were heated by a radiation method. The tests were carried out in vacuo at a pressure not exceeding 1.10⁻⁵ mm Hg.

The method of testing refractory alloys in accordance with the loading regimes given above has already been described in [1].

For the investigation we used single-crystal molybdenum of high purity with a (111) crystallographic orientation, produced by electron-beam melting in vacuo. Tubular specimens were prepared from the single crystal for the low-cycle fatigue tests, and solid cylindrical ones for the thermocyclic creep tests (Fig. 1).

At high temperatures (up to ~1200°C), the molybdenum single crystal is characterized by high ductility and low strength in comparison with commercial molybdenum and structural molybdenum-base alloys (Fig. 2 and [2]). At higher temperatures (above 1500°C) the short-term strength of single-crystal molybdenum is comparable with that of commercial molybdenum and the refractory alloys, while the ductility is considerably higher. Consequently, from the point of view of strength, single-crystal molybdenum can be used as a structural material for making components which are subjected when in use to elastoplastic deformation at high and superhigh temperatures.

Below we discuss the results of the investigation of the thermocyclic creep and low-cycle fatigue of a molybdenum single crystal, from which its potentialities as a structural material for use at high temperature can be assessed.

In the thermocycling of a molybdenum single crystal under constant load, the relationship between the number of stress cycles and the accumulated plastic deformation is represented by thermocyclic creep curves which are similar in character to isothermal creep curves (Fig. 3). The total plastic deformation accumulated in the specimen before failure by thermocycling is ~120%, which considerably exceeds the
Fig. 1. Specimens for thermocyclic creep tests (a) and for nonisothermal low-cycle fatigue tests (b).

Fig. 2. Temperature dependence of the short-term strength $\sigma_{ult}$ (continuous line) and percentage elongation $\delta$ (broken line) of single-crystal molybdenum (1), commercial powder molybdenum (2), and the alloy VM1 (3).

Figure obtained in short-term tests (60%), and it is practically constant irrespective of the number of cycles to failure in the endurance range investigated.

In the determination of the relative deformation of the specimens $\varepsilon$, the absolute deformation relates to a length of the zone of plastic flow of the material of 20 mm. In this zone deformation bands are clearly visible on the surface of the specimens (Fig. 4).

It should also be noted (see Fig. 4) that the area at the fracture section of the specimen is practically nil, and that the true plastic deformation, determined as $\varepsilon = \ln \left( \frac{\varepsilon}{1 - \varepsilon} \right)$, will accordingly tend to infinity.

Consequently, in high-temperature creep tests by thermocycling, single-crystal molybdenum possesses practically unlimited ductility, and in this respect it has definite advantages over structural refractory alloys [3].

The long-term strength of single-crystal molybdenum in thermocycling is comparable with that of the structural refractory molybdenum-base alloy under similar testing conditions in the endurance range up to 50 cycles and more [3] (Fig. 5).

Fig. 3. Creep curves for single-crystal molybdenum in thermocycling at $350 \approx 1700^\circ$C.

Fig. 4. Single-crystal molybdenum specimen fractured by thermocycling ($N_f = 24$ cycles, $\varepsilon = 118\%$, and $\sigma = 1.5$ kgf/mm$^2$).