The durability of semifinished products at high operating temperatures is affected by the stability of the structure.

At the present time the stability of aluminum alloys is judged from the change in the strength and ductility in tension after prolonged holding at elevated temperatures, usually the operating temperature, without taking the effect of stress into account.

Here we present the results from an investigation of the effect of prolonged holding on the mechanical properties and structure of semifinished products of alloy AK4-1 at 135 and 150°C under tensile stress.

We investigated three sections from a slab 60 mm thick after quenching from 530°C (holding time 40 min) in water, which were subjected to considerable natural aging (6 months) and artificial aging at 195°C for 7 and 12 h, and also three small plates from a plate 1.8 mm thick after the same quenching and then aging at 190°C for 6, 9, and 12 h. The mechanical properties of these semifinished products at room temperature are given in Table 1.

At a testing temperature of 135°C the long-term strength of the plates aged at 190°C for 6 h is higher than that of the plates aged at the same temperature for 9 and 12 h (Fig. 1b).

The same variation of long-term strength was obtained for the slabs, tested at 150°C (Fig. 1b). After natural aging the slabs have the highest long-term strength, after aging at 195°C for 7 h the strength is lower, and after aging at 195°C for 12 h the strength is very low.

As can be seen in Fig. 1, the long-term strength curves for the different aging conditions tend to converge with increasing testing time, the difference in the values of the long-term strength decreasing.

The long-term ductility curves, plotted in coordinates of δ vs ln τ, also converge with increasing testing time.* At a testing temperature of 135°C the long-term ductility curves for the plates aged at 190°C for 6 h have a larger slope, intersecting the curves for the samples aged longer. This position of the curve indicates the higher rate of decrease of the ductility.

The high long-term strength and low long-term ductility of plates and slabs aged less at 190-195°C and of slabs aged naturally result from the additional aging under tensile stress at 135 and 150°C.

The effect of additional aging under stress on the variation of the mechanical properties in short-term tests is shown in Figs. 2 and 3.

We obtained interesting results from the tests of notched impact samples with started cracks 1.5 mm deep in plates 1.8 mm thick. For these tests some samples were prepared from the gage section of the smooth samples used in long-term strength tests, which were aged at 135°C under stress, and other samples were prepared from blanks held at 135°C but without stress.

As can be seen from Fig. 2, the work of fracture of samples with started cracks from the less aged plates (6 h at 190°C) and of plates aged naturally result from the additional aging under tensile stress at 135 and 150°C.

* The long-term strength and ductility curves were plotted by the method of least squares.
Fig. 1. Long-term strength and ductility of alloy AK4-1. a) Plates 1.8 mm thick after aging at 190°C for 6, 9, and 12 h; b) slabs 60 mm thick after natural aging and artificial aging at 195°C for 7 and 12 h. The plates were tested at 135°C, the slabs at 150°C.

Fig. 2. Effect of aging time on the work of fracture for plates of alloy AK4-1 1.8 mm thick with started cracks. O △ Aged without stress; ▲ ◼ Aged under stress; ◼ Aged 6 h at 190°C; ▲ A△ Aged 12 h at 190°C.

The highest values of \( \sigma_0 \) and \( \sigma_{0.2} \) for the slabs artificially aged were obtained after testing 10 h with \( \sigma = 24 \text{ kg/mm}^2 \). These values are approximately 1 kg/mm² higher than the original values. These characteristics

that were not subjected to stress was higher than the work of fracture of samples previously aged 12 h at 190°C. In both cases the work of fracture decreases somewhat with increasing time.

Aging under stress (see Fig. 2) causes a more substantial reduction of the work of fracture for samples with cracks, particularly for samples aged 6 h. After 700 h at 135°C without stress the work of fracture for these samples is \( \alpha_{ty} = 0.81 \text{ kg-m/cm}^2 \), while with a stress \( \sigma = 28 \text{ kg/mm}^2 \) it is \( \alpha_{ty} = 0.60 \text{ kg-m/cm}^2 \).

For samples aged 12 h \( \alpha_{ty} = 0.643 \text{ kg-m/cm}^2 \) after aging without stress and \( \alpha_{ty} = 0.54 \text{ kg-m/cm}^2 \) with \( \sigma = 26.5 \text{ kg/mm}^2 \). From the relative positions of the points and curves it can be seen that with increasing holding time the difference between the values for the work of fracture with and without stress becomes greater.

Additional aging under stress at 150°C increases the ultimate strength and yield strength and decreases the specific elongation and fracture toughness (Fig. 3). For these tests samples were prepared from slabs 60 mm thick after natural aging and aging at 195°C for 7 and 12 h. The stress amounted to 24 and 22.5 kg/mm². A stress of 24 kg/mm² is equal to the long-term strength after 500 h for the samples aged at 195°C for 12 h (Fig. 1b) and after 1000 h for the samples from slabs naturally aged. The testing times under stress were 10, 25, 250, 350, and 450 h for all aging conditions and 700 h for the slabs aged naturally. The stress of 22.5 kg/mm² is equal to the long-term strength after 1000 h for the slabs aged 12 h. The testing times were 700 and 900 h.