Unstable stress-strain states in welds lead to the activation of significant plastic deformation during subsequent initial loading by external loads. The superposition of microstructural damage from cyclic loading during service on damage incurred as a result of thermomechanical loading during the welding operation accelerates attainment of the critical level of damage, where a microcrack is formed at the tip of a stress concentrator. The end result is a reduction in the overall life of the weld.

Several monographs [1, 2] have studied fracture under alternating loads. The strength of welded structures under such loads was examined in [3]. Here, while a very thorough investigation was made of the mechanism of the fatigue fracture of welds, not enough attention was given to the microscopic mechanism responsible for the initial stage of fracture.

The low strength indices of welds under alternating loads is usually associated with the magnitude of the residual stresses, without allowance for the plastic strains that develop during the thermo-deformational welding cycle (TDWC).

Active macroscopic and microscopic plastic strain develops in the weld and the heat-affected zone (HAZ). It increases significantly near stress concentrators: notches, abrupt changes in cross section, pores, cracks, nonmetallic inclusions. An example of such macroplastic strains are the Chernov—Lüders’ lines seen near welds and the tips of notches in HAZs (Fig. 1). Local plastic strain at the tip of a sharp notch may reach 4-6% [4, 5].

Microstresses characteristic of nonlinear strain-hardening are formed in microvolumes deformed beyond the elastic limit [6]. Such a microscopic stress-strain state has a definite effect on the properties of the metal of a weld during subsequent loading.

The most intensive plastic deformation (εres) occurs on sections adjacent to the boundaries of the region in which the base metal fuses with the weld: slip bands and grain-boundary slip, a sharp change in dislocation density to $10^{10}-10^{12} \text{cm}^{-2}$, vacancies and other structural defects [7]. The intensity of the microplastic strain decreases with increasing distance from the fusion boundaries. However, this strain increases considerably at grain boundaries, which are stress concentrators. Both intragranular and intergranular slip is seen (Fig. 2), and the intensity of this process determines dislocation density.

A stress-strain state is formed in the weld and the HAZ during cooling. Since "unloading" does not take place after welding, this state attains a certain equilibrium. The subsequent slight mechanical elongation that occurs with loading activates plastic deformation, which corresponds to the nonlinear strain-hardening curve. This curve will be determined by the strain-hardening modulus, which depends to a significant extent on loading rate and temperature [8]. The situation just described is illustrated by the results of tests of flat specimens of steel ST3 with a $110 \times 10 \text{mm}$ cross section. The length of the working part of the specimens was 220 mm. The specimens had a central axisymmetric transverse notch with a length of 20 mm ($r_{pol} = 0.1 \text{mm}$) and a weld located along the axis of the specimen. The tip of the notch was located in a region that was heated to 480-550°C.

According to the readings obtained with a water-cooled transducer (Fig. 3) during TDWC, a residual opening $\delta_{res} = 0.08$ occurred at the tip of the notch as a result of the thermo-deformation welding cycle. Here, plastic deformation was manifest in the form of Chernov—Lüders lines up to 10 mm long. To observe the repeated development of these bands from the notch tip during static loading, the existing bands were removed from the surface by grinding. We measured the opening of the notch $\delta_n$ and the nominal stresses $\sigma_n$. For comparison, we tested a similar specimen composed of the base metal (BM) that had been notched but not welded.
Fig. 1. General and local plastic deformation at the tip of notches on a specimen of steel St3 with a longitudinal weld.

Fig. 2. Heat-affected zone ($T_{\text{max}} = 1100^\circ\text{C}$) on a welded specimen of steel 15KhM ($\times 150$).

Fig. 3. Water-cooled transducer for measuring the opening of the edges of a notch.

Fig. 4. The $\sigma_n$–$\delta_n$ relation in the tension of wide specimens of steel St3:
1) BM specimen without a weld; 2) W specimen with a weld.

The $\delta_n$–$\sigma_n$ relations shown in Fig. 4 for the welded specimen (curve 2) are distinguished by the curvilinearity that exists during the initial stage of loading, which is due to the marked deviation from proportionality between $\sigma_n$ and $\delta_n$. Disturbance of the previously proportional relationship is accompanied by the formation of Chernov–Lüders lines. Even at 50 MPa, $\delta = 0.01$ mm, and $\sigma_n/\sigma_y = 0.15$, distinct lines 3-5 mm long are seen. These lines are oriented at 45-70°, and they become longer and more numerous with an increase in the load. The first lines were seen on the BM specimens at the notch tip when $\sigma_n = 170$ MPa, $\delta_n = 0.03$ mm, and $\sigma_n/\sigma_y = 0.65$ (curve 1).