The service life of rails can be increased by thermal hardening. However, heat treatment results not only in higher strength but also higher sensitivity to stress concentrators such as the thermomechanical damage [1] resulting from trains changing speeds [2] and slipping or sliding of the wheels during braking. Slipping or sliding of the wheels on the rail causes brief heating of the metal due to the heat of friction. Heating of the rail to high temperatures in a localized zone and subsequent rapid cooling lead to the formation of a white layer with a martensitic structure. The thickness of this hard and brittle layer varies, usually amounting to 0.1–1.0 mm, sometimes 2 mm. Fine transverse cracks occur in this layer, extending from the rolling surface into the depth of the layer with a martensitic structure. These lead to chipping of the layer (Fig. 1) or to a transverse fatigue crack in the railhead (Fig. 2).

A statistical analysis of the damage to bulk-quenched rails put out of commission showed that thermomechanical damage constitutes a large percentage of the total number of defects. The amount of thermomechanical damage may increase still more due to breaking in connection with higher speeds and weights of trains, which increase the load. This makes it necessary to study the susceptibility of rails to thermomechanical damage along with other parameters of the structural strength.

A study of the various factors that affect the susceptibility of rail steel to thermomechanical damage was conducted by means of laboratory tests of the cyclic strength and the strength when subjected to a single impact on samples with a stress concentrator in the form of thermomechanical damage [3].

The structure of high-strength rail steel consists of temper troostite ($\sigma_B = 170–180$ kg/mm$^2$, HB 450), and therefore after bulk quenching in oil the samples were tempered at a temperature inducing this structure and the strength indicated above.

We determined the effect of manganese, silicon, and chromium (from 0 to 2.2% each) on the properties of high-carbon rail steel (0.75% C) subjected to thermomechanical damage. We also tested alloy
Fig. 3. Effect of alloying with manganese (a), chromium (b), silicon (c), and titanium (d) on work of fracture of high-carbon steel with thermomechanical damage: 1) testing temperature +20°C; 2) -60°C.

The tests showed that alloying of steel with 0.75% C with manganese, chromium, silicon, or titanium has a negligible effect on the sensitivity of the steel to thermomechanical damage at +20°C. Tests at -60°C, where the reserve toughness decreases and the danger of unexpected brittle fracture increases, showed that the addition of 2.2% Cr doubles the work of fracture, while silicon and titanium have no effect on it.

It is known that carbon has a decisive effect on the structural strength of rail steel – the larger the carbon concentration, the higher the contact-fatigue strength, which is the basic factor in the service life of rails. The service life can be improved only by using alloy rail steels with a high carbon content [4], since no alloying within the permissible limits (up to 3% alloying elements) increases the contact-fatigue strength sufficiently for steel with about 0.6% C. However, some investigators consider [5] that raising the carbon content of rail steel may lead to a catastrophic reduction of the resistance to thermomechanical damage, particularly under conditions of impact loading at low temperatures.

To determine the danger of thermomechanical damage in relation to the amount of carbon in the steel, several alloy steels of the KhGS type were tested (1.0% Mn, 0.6% Si, 1.0% Cr) with a carbon content of 0.45-0.90% (Fig. 4). With increasing carbon concentrations from 0.45 to 0.6% the work of fracture decreases at room temperature (curve 1) and at -60°C (curve 2) for samples with a stress concentrator in the form of thermomechanical damage. This indicates that the high carbon content of alloy rail steel (over 0.70%) has a negligible effect on its susceptibility to thermomechanical damage. It should be kept in mind that the change in the work of fracture in impact tests of samples with thermomechanical damage in relation to the carbon content of the steel depends on the properties of the layer subjected to thermomechanical damage and the reserve toughness.

The susceptibility of the steel to thermomechanical damage was tested at 20°C with single and multiple impacts in the DSVO-150 impact testing machine. In the impact fatigue tests of samples 10 × 10 × 55 mm the samples were placed horizontally and fastened to two supports 40 mm apart so that the side of the sample with thermomechanical damage in the middle of the sample faced downward. The tests were made with a 6-kg hammer falling on the center of the sample at a frequency of 590 impacts per minute so that the zone of the sample with thermomechanical damage was subjected to cyclic tensile stresses. The number of cycles to failure was determined (transverse fracture) in relation to the height of the hammer.

Figure 5 shows (as an example) the impact fatigue resistance of complex alloy steels with a structure of temper troostite; the impact fatigue strength of standard bulk-quenched rail steel 75G with a structure of quench sorbite is shown for comparison. The nominal impact fatigue strength, determined at N = 2 · 10⁵, was somewhat higher for steel with 0.45% C than for steel with 0.75% C. The difference in the nominal values of the impact fatigue strength is relatively small.