The development of machine construction demands that the fatigue strength of structural steels be increased. Surface plastic deformation (SPD) is widely used to increase the fatigue strength of high-strength structural steels. SPD is especially effective for steels in the martensitic condition [1]. The effect of the metastability of martensite and strain aging on the fatigue strength of low-alloy structural steels after SPD has been studied little [2, 3]. It was reported in [4] that the effect of SPD can be increased by additional aging, although the structural condition before strain hardening has an equal or almost equal effect (sorbite, temper troostite). Therefore strain aging occurs in the ferritic matrix of the alloy [5]. It is known that the effect of strain aging is largest due to plastic deformation of martensite, i.e., with the steel in the equilibrium condition [6].

The fatigue strength of steels with a martensitic structure will vary with the residual compressive stresses resulting from SPD and subsequent hardening of the surface layer during tempering. SPD of steels with a martensitic structure produces the highest residual compressive stresses in the surface [2, 7]. Under identical heating conditions after SPD the structural transformation in the deformed surface layer correspond to the process of strain aging, and the core to the ordinary thermal process — tempering or aging — if the heating temperature is below the recrystallization temperature.

We investigated the effect of strain aging of martensite on the fatigue strength of steel 40KhNMA subjected to SPD. The samples were quenched in oil from 850°C after holding for 30 min.

The sensitivity of the steel to strain hardening and strain aging was determined from the hardness by Sauveur's method [8]. The hardness measurements were made in the spherical indentation from a ball 10 mm in diameter in the TSh apparatus under a load of 2500 kg.

After SPD the samples were tempered at 100-550°C for 2 h. The hardness was highest after the following treatment: quenching + strain hardening + tempering in the range of 100-200°C (Fig. 1). With this sequence of tempering and strain hardening the plastic deformation of "fresh" untempered martensite induces a larger increase in hardness during subsequent tempering (more precisely, strain aging during tempering) than mechanical strain hardening of the tempered steel. Consequently, during tempering of strain hardened steel the hardening is greatest due to hardening of martensite from mechanical strain hardening and to additional hardening of martensite during precipitation hardening resulting from the precipitation of finely dispersed carbides [6]. At higher tempering temperatures the effect of hardening is not so large due to decomposition of martensite, and therefore the hardenability is almost independent of the sequence of operations with strain hardening and tempering at 350-450°C, while above 450°C the hardenability is higher after the sequence of tempering + strain hardening.

The strain aging temperature for tempered martensite was selected by the same method. After quenching and tempering at 200°C for 2 h, the steel was subjected to strain hardening and subsequent aging at 100 and 200°C for 10 min to 4 h (20 min intervals). It was found that the hardness of HRC 58-60, obtainable by...
Fig. 1. Effect of tempering temperature on hardness of steel 40KhNMA. 1) Quenching + tempering; 2) quenching + tempering + strain hardening; 3) quenching + strain hardening + tempering for 2 h. quenching + strain hardening + tempering at 200° for 2 h, can also be obtained by quenching + tempering at 200° for 2 h + strain hardening + aging at 200° for 20-30 min or aging at 100° for 2.5-3 h. In the given case the aging of strain hardened temper martensite also induced an additional increase in hardness.

It would be expected that with the same final hardness after quenching + strain hardening + tempering and quenching + tempering + strain hardening + aging the residual compressive stresses in the surface layer would differ.

To determine the change in the residual compressive stresses in the surface layer and the hardenability with SPD we conducted the following experiment. The change in the first-order residual stresses and the microhardness through the section was determined on samples 10 mm in diameter and 60 mm long. The distribution of axial residual stresses was investigated on the samples after tempering at 200° for 2 h and aging at 200° for 30 min. For comparison we determined the residual stresses in quenched (not tempered) samples, with subsequent roller burnishing.

The criterion of the transition from strain hardening with a ball to strain hardening by means of roller burnishing was the equality of the degree of deformation in both methods of strain hardening, for which the method described in [9] was used. The roller required a force of 350 kg to obtain a degree of deformation in roller burnishing equivalent to the degree of deformation in strain hardening with a ball under a load of 2500 kg. The diameter of the roller was 20 mm, with a profile 6 mm in diameter.

The microhardness* was measured on transverse microsections cut from the roller burnished samples. The samples were cut with a cutting wheel under water.

The residual stresses were determined by measuring the deformation (elongation) after anodic etching of the roller burnished surface.

The face of the samples with marks for measurements of the length was carefully protected during etching. The reagent consisted of 75 g KCl + 5 g dry citric acid in 1 liter H₂O. The current density was 0.5 A/cm²; the cathode was stainless steel.

*H₁₀₀ measured in the PMT-3 apparatus.