HARDENING OF MACHINE PARTS BY SURFACE
DEFORMATION AND NITRIDING

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In most cases, nitriding is the final treatment of machine parts, and therefore the surface finish of nitrided parts must be V7-V9. This is achieved by grinding, polishing, and other finishing treatments. Surface plastic deformation (SPD) is widely used at the present time as a final treatment, including parts to be nitrided. However, there are few data concerning the effect of preliminary deformation on the quality of the nitrided layer.

We investigated the effect of SPD on the residual stresses and the depth and distribution of stresses, surface hardness, and fatigue strength of nitrided steel 18Kh2N4VA. Samples quenched and tempered at 560°C were subjected to gas nitriding at 490°C for 40 h, and one set of samples was nitrided for 12 h.

The residual stresses were determined* by the Davidenkov-Birger method [1]. Rings and bands 5 x 10 x 42 mm were cut from crankshafts and high-speed diesel springs. The residual stresses on the outer surfaces were determined on samples with an outside diameter of 95 mm, inside diameter 85 mm, height 12 mm, and outside diameter 34 mm, inside diameter 24 mm, and height 12 mm.

Diamond burnishing and roller burnishing were used before nitriding to produce different gradients of the original residual stresses and different depths of the stresses. Burnishing was conducted with a diamond tip with a sphere radius of 1.7 mm under a force of 10 kg (s = 0.035 mm/revolution, n = 100 rpm) in one pass. The surface finish was V10.

Roller burnishing was conducted with a three-roller device (roller diameter 60 mm, radius 15 mm, s = 0.074 mm/revolution, n = 630 rpm) with a force of 100-280 kg on each roller.

The compressive residual stresses (tangential and axial) that occur during preliminary diamond burnishing do not differ from the residual stresses that occur after nitriding with preparation of the surface by grinding and polishing. The depth of plastic deformation from diamond burnishing is approximately the depth of the nitrided case, and therefore the residual stresses remain unchanged.

With preliminary roller burnishing the character of the residual stresses changes sharply. The maximum compressive stresses $\sigma_T$ and $\sigma_Z$ increase by a factor of 1.5-2 as compared with standard nitriding with holding for 12 h (Fig. 1a and b, curves 1 and 4). The depth of the compressive stresses increases by a factor of 3-5 in this case. In comparing the residual stresses resulting from roller burnishing without nitriding and roller burnishing followed by nitriding one notes a substantial difference only in the nitrided case (curves 4 and 5). The residual stress curves seem to be superimposed with nitriding and roller burnishing. The residual stresses increase in a thin surface layer. The highest stress $\sigma_T$ max is observed at the surface, and the highest $\sigma_Z$ max at a certain depth. At the boundary of the nitrided case the residual compressive stresses are minimal; they increase slightly in the adjoining unnitrided layer.

It should be noted that almost no relaxation of the residual stresses resulting from roller burnishing is observed during nitriding of steel 18Kh2N4VA for 12 h.

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Nitriding of steel 18Kh2N4VA at 490° for 40 h leads to a greater increase of the residual stresses than nitriding for 12 h (Fig. 1c, curve 1). The shape of the curves changes (curves 2, 3) after nitriding of samples subjected to roller burnishing with a force of 100-200 kg. The residual stresses are highest on the surface and differ little from the stresses in unnitrided parts. Increasing the burnishing force to 280 kg leads to a great reduction of residual stresses on the surface and to a depth of 0.1-0.3 mm (curve 4).

With nitriding for 40 h (curve 4) the residual stresses resulting from roller burnishing change considerably (curve 5) due to stress relaxation during prolonged nitriding.

Diamond burnishing makes it possible to redistribute the residual stresses in the nitrided case and doubles the maximum value of $\sigma_y$ and $\sigma_z$. Nitriding for 40 h after diamond burnishing makes it possible to obtain tangential and axial compressive stresses of 74 and 79 kg/mm$^2$, respectively. Diamond burnishing after nitriding increases the stress to 140 and 160 kg/mm$^2$, respectively, with a slight increase (10-40%) in the depth of the layer with residual compressive stresses.

Thus, preliminary surface deformation under optimal conditions makes it possible to obtain residual stresses of 70-80 kg/mm$^2$ after nitriding, as in nitriding of polished samples.

The surface hardness of the layer is one of the most important characteristics determining the wear resistance, resistance to seizing, fatigue strength, and other operating characteristics of steels. The hardness of the nitrided layer was determined on sloping sections with angles of $2°28'$ and $3°20'$ in the TP-2 apparatus (Vickers). The spacing of the indents was 0.75 and 1 mm, which made it possible to obtain an interval of 0.03-0.06 mm along the depth of the hardened layer. The surface hardness of nitrided steel 18Kh2N4VA was HV$_{10}$ = 650-720. Preliminary roller burnishing increases the surface hardness only slightly (HV$_{10}$ = 700-740). The increase in hardness extends to a depth of 0.27-0.3 mm. Diamond burnishing of the nitried surface made it possible to increase the hardness 20%.

The effect of the finishing treatment before nitriding on the fatigue strength was investigated on samples 16 mm in diameter and 220 mm long with a pressed bushing (o.d. = 30 mm, i.d. = 16 mm, $l$ = 40 mm, pressed at 3.75 kg/mm$^2$). The tests were made with the U-20 machine (N = 10$^6$).

The fatigue curves are shown in Fig. 2. The fatigue limit of ground and polished samples (curve 1) was $\sigma_{-1} = 19.5$ kg/mm$^2$. The use of surface hardening by roller burnishing with a force of 280 kg increased the fatigue limit to 42 kg/mm$^2$, which is more than double that of unhardened samples (curve 2). Nitriding of polished samples raised the fatigue limit to 50 kg/mm$^2$ (curve 3).