THE SURFACE LAYERS OF STEEL MACHINE PARTS AFTER ULTRASONIC FINISHING AND HARDENING TREATMENT

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The characteristic feature of ultrasonic finishing and hardening treatments is the alternating compression and shearing deformation of the surface (Fig. 1).

The hardening of steel machine parts by ultrasonic treatment was investigated in [1-3]. Here we give the results from an investigation of the physicomechanical condition of the surface of steel 45.

Figure 1 shows a diagram of the finishing and hardening treatment. Besides the conditions characteristic of ordinary burnishing with a ball or roller (initial height of irregularities Rz, diameter of the part D, rotation rate of the part v, feed rate of the tool s, diameter of the ball Db, number of passes i, and the lubricant), the physicomechanical properties of the surface (roughness, microhardness, residual stresses, etc.) are greatly affected by elements specific to this process – the static pressure of the ball against the machine part Pst, the amplitude of vibration A, the frequency of vibration f, etc.

The static pressure of the ball against the machine part and the amplitude and frequency of vibration of the tool determine the maximum deformation rate of the surface of the part \( v_d = 2\pi A \) and also the intensity of ultrasonic treatment \( I = 2\pi pc^2 A^2 \), where \( p \) is the density of the medium, \( c \) is the propagation rate of ultrasonic waves.

With \( A = 20 \mu \) and \( f = 2 \times 10^4 \) sec\(^{-1} \) the deformation rate amounts to \( v_d = 2.51 \) m/sec.

Of all the ultrasonic hardening parameters, the static pressure and amplitude of displacement have the principal effect on the roughness of the surface, the degree and depth of cold hardening, the magnitude of residual stresses in the surface, and other physicomechanical properties. The pressure and amplitude of displacement of the ball determine the rate of the treatment, and also the feed rate and rate of rotation and number of passes.

The less plastic the material of the part, the larger the original surface irregularities, the larger the diameter of the part and the ball, and the higher the feed rate and rate of rotation of the part, the higher the static pressure must be. Figure 2 shows the effect of the static pressure on the roughness of the surface with hardening parameters: \( 2A = 20 \mu, s = 0.07 \) mm/rev, \( v = 40 \) m/min, \( D_b = 10 \) mm. The variation of the microhardness of the hardened surface with the static pressure at \( 2A = 20 \mu, s = 0.07 \) mm/rev, \( v = 44 \) m/min, and \( D_b = 10 \) mm is shown in Fig. 3. It can be seen that the best ultrasonic finishing and hardening corresponds to the optimal static pressure.

Table 1

<table>
<thead>
<tr>
<th>Physicomechanical condition of the surface layer</th>
<th>Ultrasonic finishing and hardening treatment</th>
<th>Ball burnishing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness of surface, ( \mu ).................</td>
<td>9-10</td>
<td>8-9</td>
</tr>
<tr>
<td>Degree of cold hardening, %.................</td>
<td>1.2 (at ( P_{st} = 5 ) kg)</td>
<td>1.0 (at ( P = 200 ) kg)</td>
</tr>
<tr>
<td>Depth of cold hardening, mm.................</td>
<td>120</td>
<td>30-50</td>
</tr>
<tr>
<td>Residual compressive stresses, kg/mm(^2).....</td>
<td>110</td>
<td>35</td>
</tr>
</tbody>
</table>

However, the ultrasonic treatment conditions cannot be selected on the basis of microgeometry and depth and degree of cold hardening alone, since the wear resistance and strength of the part are affected by residual stresses and the character of their distribution.

The residual tangential stresses $\sigma_T$ were determined by the method given in [4]. Each curve was plotted from the results for 5-10 samples. Figure 4 shows the distribution of residual stresses in the depth of the surface layer at different pressures and hardening parameters: $v = 48$ m/min, $s = 0.07$ mm/rev, $2A = 20\mu$, $D_0 = 10$ mm, $i = 1$. The residual compressive stresses increase with the static pressure. The depth of the compressive stresses increases at the same time. At static pressures above the optimal, tensile stresses occur in the surface layer, leading to peeling and cracking. The static pressure during ultrasonic treatment is the main parameter of the process and has the greatest effect on the value and distribution of residual stresses.

The variation of the maximum residual tangential stresses $\sigma_T$, the depth at which they occur $h_T$, the surface hardness $H_{100}$, and the depth of cold hardening $h$ with the static pressure $P_{st}$, the amplitude of displacement of the ball $2A$, the feed rate $s$, and the rotation rate of the part $v$ is shown in Fig. 5. The experiments were made with the static pressure varied from 1 to 20 kg, the amplitude of vibration of the ball from 20 to 40 $\mu$, the feed rate from 0.07 to 0.34 mm/rev, the rotation rate from 2.5 to 150 m/min, at $i = 1$, $D_0 = 10$ mm, and $f = 20$ kHz. The samples were rings with an outside diameter of 40 mm and inside diameter of 32 mm, with a width of 10 mm.

The nature of the residual stresses and the increase of hardness in the surface are affected by the same processes of plastic deformation, and therefore one can assume that there is a direct relationship between the hardness of the cold hardened layer, the residual stresses, and the depth at which they occur. In fact, with an increase of the depth of residual compressive stresses $h_5$ one observes an increase of the depth of cold hardening $h$ (curves 1 and 2) and a reduction of the depth of residual compressive stresses with a corresponding reduction of the depth of cold hardening (curves 3 and 4). The same relationship is observed between the maximum residual tangential stresses $\sigma_T$ and the surface microhardness.