The extent to which MC goes into solution as compared with M₆C varies much less with the austenitizing temperature in the range of 1100-1280°C. However, the solid solution is gradually saturated with carbon (and vanadium) during austenitizing, which leads to an increase of the red hardness. Under plant conditions the austenitizing temperature is selected in relation to the type and application of the tool, with these opposing parameters taken into account—the strength and red hardness. In the present case the optimal austenitizing temperature for steel R6M5 is 1230°C. The optimal temperature may vary within limits of ±10°C for other heats of steel R6M5.

LITERATURE CITED


USE OF MATHEMATICAL MODELING TO STUDY THE FORMATION PROCESSES OF THE SURFACE LAYER OF COMPONENTS FORMED FROM LOW-ALLOY LOW-CARBON STEELS SUBJECT TO FRICTION HARDENING

A. A. Levchenko

The method of surface friction hardening has yet to come into widespread use. This is associated to a significant degree with the complexity of processes that occur during rubbing, with the absence of information on the dependence of the quality of the hardened layers on the hardening conditions, etc.

The Higher School of Nautical Engineering in Odessa has, over a period of years, performed work, the objective of which has been to determine the feasibility of the use of friction to harden steel components in naval diesels.

Study of the characteristic features of the friction hardening of low-carbon low-alloy steels is of a significant practical interest, since many important components of low-rpm naval diesels, for example, piston heads, cylinder covers, rods, etc., are fabricated precisely from these steels.

In the present study, the objective of which is to develop a technological process for hardening the ring grooves of steel pistons of heavy-duty naval diesels, we investigated the possibility of the friction hardening of steel 20KhM specimens using methods of mathematical experiment planning.

The quality of the hardened surface was evaluated from its roughness Ra and the thickness δ of the hardened layer (optimization parameters). The parameter δ was set equal to the limiting thickness of the hardened layer with a microhardness H700, and the parameter Ra was determined as the average arithmetic value of the results of 10 measurements taken at various points on the component.

The speed of the disk v_d (m/sec), the speed of the specimen v_spec (m/sec), the depth of machining t (mm), and the feed s (mm/min) were adopted as independent variables. The limits of variation of the independent variables are given in Table 1. Logarithms of the independent variables are used in constructing the mathematical models.

During the investigations, we determined the components of the hardening force and the contact temperatures.

Fig. 1. Two-dimensional sections of model (1) in various coordinates (numbers near curves denote thickness of hardened layer in mm, cross-hatched rectangles define regions of variation of independent variables): a) $x_2-x_3$; b) $x_2-x_4$; c) $x_3-x_4$; d) $x_1-x_2$; e) $x_1-x_3$; f) $x_1-x_4$; a) $v_d = 54.00$ m/sec, $s = 26.750$ mm/min; b) $v_d = 54.00$ m/sec, $t = 0.30$ mm; c) $v_d = 54.00$ m/sec, $v_{spec} = 0.080$ m/sec; d) $t = 0.30$ mm; s = 26.750 mm/min; e) $v_{spec} = 0.080$ m/sec, $s = 26.750$ mm/min; f) $v_{spec} = 0.080$ m/sec, $t = 0.30$ mm.

To describe the hardening process, we used a second-order polynomial of the type

$$
\eta(x) = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ij} x_i^2 + \sum_{i<j} b_{ij} x_i x_j,
$$

The coefficients of the models were determined by the method of least squares using a central compositional rotating-table experiment plan.

As a result, we derived equations adequately describing the effect of the parameters of the hardening conditions on the thickness of the hardened layer $\delta(y_1)$ and surface roughness $R_a(y_2)$:

$$\begin{align*}
y_1 &= 1.529 + 0.172 X_1 - 0.068 X_2 + 0.081 X_3 + 0.001 X_4 - 0.011 X_1 X_3 - 0.006 X_1 X_4 + 0.032 X_2 X_3 - 0.018 X_2 X_4 - 0.025 X_3^2 + 0.019 X_3^2 - 0.042 X_4^2; \\
y_2 &= -0.373 - 0.088 X_1 - 0.055 X_2 + 0.053 X_3 - 0.002 X_4 + 0.072 X_1 X_3 - 0.070 X_1 X_4 - 0.009 X_2 X_3 - 0.009 X_2 X_4 + 0.001 X_3 X_4 + 0.006 X_1^2 - 0.049 X_2^2 + 0.012 X_3^2 + 0.042 X_4^2.
\end{align*}
$$

(1) (2)

A carburized steel disk (HRC 60) was used as the working tool.

**TABLE 1**

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Units of variation</th>
<th>Variation Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1$ (disk speed $v_d$, m/sec)</td>
<td>39–69</td>
<td>7,500</td>
</tr>
<tr>
<td>$X_2$ (specimen speed $v_{spec}$, m/sec)</td>
<td>0.03–0.13</td>
<td>0.025</td>
</tr>
<tr>
<td>$X_3$ (depth of machining $s$, mm/min)</td>
<td>0.10–0.50</td>
<td>0.100</td>
</tr>
<tr>
<td>$X_4$ (feed $s$, mm/min)</td>
<td>3.50–50.0</td>
<td>11.625</td>
</tr>
</tbody>
</table>

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