Then, in accordance with the diagram (see Fig. 1) the times of heating and holding in hardening and tempering are calculated in the subsequent blocks and subprograms. After that the type of heat treatment equipment is chosen with a view to the length of the treated semi-product, the size of the working space, and the productivity of the equipment. We calculate the necessary number of furnaces, machines for grinding the surface, instruments for measuring hardness, work benches for straightening the semiproducts, and the floor space taken up by them. Then the disposition of the selected equipment is arranged, and the total floor space of the heat treatment sector is calculated. The results of the planning are then printed.

That way we worked out and obtained a program for the automated planning of the sector of preliminary heat treatment of tubular semiproducts obtained by hydraulic pressing. This program can be used in series and mass production for planning the sector of preliminary heat treatment of axisymmetric semiproducts obtained by methods of cold plastic deformation.

LITERATURE CITED


MECHANICAL CHARACTERISTICS OF HARDENED STEEL 16KhSN

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The main characteristics of steel for parts such as bolts, made by the method of cold plastic deformation, are the mechanical properties, the strain-hardening coefficient, sensitivity to the state of stress, and endurance.

The present work is a continuation of previous research [1]. We determined the mechanical characteristics of steel 16KhSN after preliminary heat treatment in different regimes and strengthening heat treatment with the object of determining the optimal structural state.

For the investigations we made cylindrical specimens, some smooth and some with an annular notch with different radii \( R_0 \), mm: 0.2, 0.6; 1.2; 2.5; 6.0 (Fig. 1). The specimens were subjected to static tests at a strain rate of \( 3.3 \times 10^{-5} \) m/sec (2 mm/min) on a tensile testing machine designed at TsNIITMASH, model IM-12A with recording of diagrams on the scale of strain 100:1. Dynamic extension of the specimens was effected at the strain rate of 5
Fig. 2. Microstructure of steel 16KhSN after treatment in regime 2 (a) and 3 (b). \( \times 1350 \).

**TABLE 1**

<table>
<thead>
<tr>
<th>Regime of treatment</th>
<th>( \varepsilon, % )</th>
<th>( \sigma_y, \text{N/mm}^2 )</th>
<th>( \sigma_u, \text{N/mm}^2 )</th>
<th>( \delta, % )</th>
<th>( \psi, % )</th>
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<td>Drawing, making specimens, heat treatment (1)</td>
<td>0</td>
<td>1115</td>
<td>1280</td>
<td>10.7</td>
<td>62.6</td>
</tr>
<tr>
<td></td>
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<td>1130</td>
<td>1290</td>
<td>10.6</td>
<td>62.7</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1170</td>
<td>1320</td>
<td>10.2</td>
<td>65.1</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>1140</td>
<td>1280</td>
<td>9.8</td>
<td>58.3</td>
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<tr>
<td>Drawing, making specimens, heat treatment (2)</td>
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<td>1195</td>
<td>1365</td>
<td>10.5</td>
<td>57.5</td>
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<tr>
<td>Drawing, heat treatment, drawing, making specimens (3)</td>
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<td>1470</td>
<td>1520</td>
<td>7.8</td>
<td>53.0</td>
</tr>
</tbody>
</table>

*Reduction drawing.*

Remarks. 1) Heat treatment consists of hardening in water from 930°C + tempering at 350°C. 2) In parentheses is the number of the regime.

The mechanical properties of the investigated steel 16KhSN after deformation and heat treatment in different regimes are presented in Table 1.

In comparison with the mechanical properties of annealed or previously formed steel presented in [1], hardening heat treatment improves the strength characteristics \( \sigma_{0.2} \) and \( \sigma_u \) 2-3 times while maintaining the indices of ductility \( \delta \) and \( \psi \) fairly high (see Table 1). At the same time heat treatment eliminates almost completely the effect of previous deformation on the mechanical properties. Only after treatment in regime 1 with reduction \( \varepsilon = 35\% \) the strength as well as the ductile properties are somewhat better than after heat treatment of undeformed steel \( (\varepsilon = 0) \) or steel deformed with \( \varepsilon = 15 \) or \( 60\% \). Plastic deformation with \( \varepsilon = 22\% \) of hardened steel (regime 3) greatly increases \( \sigma_{0.2} \) and \( \sigma_u \) but noticeably impairs \( \delta \) and slightly \( \psi \). The structure of the steel, which is temper troostite (Fig. 2a), assumes some directivity (Fig. 2b). On the whole, all the alternatives of treatment presented in Table 1 ensure good strength and ductility of steel 16KhSN.

It is known that the reliability of parts under operating conditions is determined not only by the level of the mechanical properties but also by the proneness of the steel to strain-hardening and its sensitivity to the state of stress.

The strain-hardening coefficients were determined from the tangent of the slope of the hardening curves plotted in accordance with the linear dependence [2] in the form

\[
\sigma = \sigma_y + B\sqrt{\varepsilon},
\]

where \( \sigma \) is the true flow stress; \( \varepsilon \) is the true (logarithmic) strain; \( \sigma_y \) is the yield point; \( B \) is the strain-hardening coefficient.