\[ P_z = -P_0 \left( 1 - \frac{\delta L}{a} \right) + \left( 1 + \frac{\delta F - \delta L}{4a} \right) \frac{\delta L}{a} \times \]
\[ \times \frac{E_L}{(1 - \nu_L^2)} \left\{ \left( S NV_L - 1 \right) \tilde{W} - \nu_L \left( \frac{a}{T} \right)^2 \left( S_2 + \right. \right. \]
\[ + \frac{\delta L}{a} \left( \frac{dW}{d\theta} \right) \left[ \nu_L \left( \frac{a}{T} \right)^2 \left( \frac{a}{T} \right) \left( \frac{dW}{d\theta} \right) \right] \right\}. \]

The numerical calculations were made for a shell with the parameters
\[ \left( \frac{a}{T} \right) = 15; \quad \left( \frac{a}{T} \right) = 15; \]
\[ \left( \frac{\delta L}{E_L} \right) = 1.5; \quad \left( \frac{\delta L}{E_F} \right) = 3.0; \quad E_F = 2E_L; \]
\[ E_F = 7E_L; \quad E_F = 1.5 \times 10^8 \text{ kgf/cm}^2 \]
\[ \nu_{xx}^F = 0.2; \quad \nu_{yy}^F = 0.09; \quad \nu_L = 0.36; \]
\[ \alpha_F = 2 \times 10^{-5} \text{ deg}^{-1}; \quad \alpha_L = 10^{-5} \text{ deg}^{-1}; \]
\[ \theta^F = -20^\circ \text{C}; \quad \theta^L = 60^\circ \text{C}; \quad P_0 = 105 \text{ kgf/cm}^2. \]

The results of calculation of the values of \( \tilde{W}, \sigma_x^L, \sigma_y^L, \sigma_x^F, \sigma_y^F, \) and \( \sigma_{\phi}^L \) and the forces of adhesion \( P_X \) and \( P_Z \) with \( z = 0 \) are shown in Fig. 4.

**LITERATURE CITED**


**EXPERIMENTAL INVESTIGATION OF THE EFFECT OF TEMPERATURE ON THE PARAMETERS OF THE LOADING SURFACE OF STEEL 45**

B. I. Koval’chuk, A. A. Lebedev, and I. V. Makovetskii

Utilization of the yield theory in calculations of the stress-strain state of structural elements operating at steady or variable temperatures requires knowledge of the law of strain-hardening of material which correlates the subsequent yield surface (loading surface) with the degree of plastic deformation and with the temperature.

At present a fairly large amount of works is known which deal with investigations of the laws governing the strain-hardening of materials at room temperature. However, the effect of the temperature, especially of low temperature, on the loading surface has not been sufficiently studied.

In [1] it was proved that the mutual disposition of the subsequent yield surfaces of chromium steel, previously deformed at room temperature, corresponds at room and low temperatures to the hypothesis of isotropic-kinematic hardening. The dependence of the radius of the loading surface on the magnitude of the plastic deformation is described by a linear function, and the displacement of the center by an exponential function.
TABLE 1. Parameters of the Loading Surface

<table>
<thead>
<tr>
<th>$\tau$, °C</th>
<th>$\varepsilon_z$, %</th>
<th>$\sigma_z$, kgf/mm$^2$</th>
<th>$\sigma_\theta$, kgf/mm$^2$</th>
<th>$\Delta\sigma_z$, kgf/mm$^2$</th>
<th>$\Delta\sigma_\theta$, %</th>
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</thead>
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</tbody>
</table>

Fig. 1. Loading surfaces of steel at different temperatures: 1) $\varepsilon_z = 0$; 2) $\varepsilon_z = 2\%$; 3) $\varepsilon_z = 6\%$.

The object of the present investigation is to verify the previously obtained relationships in other materials in a wider range of temperatures, and also to study the temperature dependences of the parameters determining the dimensions and position of the loading surface.

The investigations were carried out with thin-walled tubular specimens ($D_{ou} = 25$ mm, $d = 0.5$ mm) made of steel 45 GOST 1050-60. The material of the blanks for the specimens was heat-treated under the conditions: heating to 900°C, holding for 3 h, furnace-cooling.

The specimens were tested on an installation [2] provided with a system of automatic control and data processing, based on the Dnepr-1 computer. The plane stressed state with different ratios of the principal stresses was induced by loading the specimens with an axial force and internal pressure. The internal pressure in the specimen was produced at room and low temperatures by ethyl alcohol and isopentane, at high temperatures by overheated steam. The stipulated temperature regime for the investigations was established with the aid of a thermoelement situated in the internal hollow of the specimen (throughflow type cooler through which liquid nitrogen was passed in low-temperature tests, and a silite electric heater in high-temperature tests).

Axial strain $\varepsilon_z$ and tangential strain $\varepsilon_\theta$ were measured on the working part of the specimen with an electromechanical strain gauge containing elastic tensometric elements. The radial strain of the specimen was determined from the condition of elastic volumetric change.

The test program consisted in the following. The specimens were first deformed by an axial load at room temperature to two levels of plastic strain $\varepsilon_z = 2$ and $6\%$, and then held at room temperature for 30 days. After that the yield curves of the initial and the deformed material at $-100^\circ$, $20^\circ$, and $200^\circ$C were determined by loading the specimens along different beam trajectories in the plane of the principal stresses $\sigma_z - \sigma_\theta$. The following ratios between the principal stresses were effected: $K = \sigma_z/\sigma_\theta = \infty$; 2; 1; 0.5; 0; -1; $-\infty$. 

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