NATURE OF TEMPERATURE – TIME PARAMETERS USED IN PREDICTING LONG-TERM STRENGTH OF STEELS AND ALLOYS

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In the majority of methods for the extrapolation of long-term strength, use is made of temperature – time parameters determined by comparison of time until failure \( \tau \) at various temperatures \( T \) and a single level of stresses \( \sigma \) [1-5].

In many methods the value \( b \), proportional to the conditional failure activation energy \( Q \), is used as such a parameter. Both of the above values may be found from one of the modifications of the Arrhenius' equation used for construction of the generalized method of extrapolation of the Central Committee of Heavy Industry [1, 6]:

\[
\tau = A(\sigma) e^{\frac{Q(\sigma)}{R}};
\]

\[
b(\sigma) = \frac{Q(\sigma) \ln e}{R},
\]

where \( R \) is the universal gas constant and \( A(\sigma) \) is some function of stress.

For pure metals the creep and failure activation energy is equal to the self-diffusion activation energy.

In determining the value of \( Q(\sigma) \) for 12MKh, 12Kh1MF, 15Kh1M1F, and 1Kh18N12T steels with the use of the computer on the basis of the generalized method of the Central Committee of Heavy Industry by treatment of the data of many hundreds of long-term rupture tests [7-9] it was established (Fig. 1) that the value \( Q(\sigma) = 50-120 \text{ kcal/mole} \) differs markedly from the self-diffusion activation energy of iron (70 kcal/mole) and does not have a definite physical sense. This may be explained by the difference in structure, the occurrence of creep deformation, and the occurrence and development of damage in material under the action of constant stresses but at different temperatures. This article is devoted to a study of this phenomenon and its possible effect on the accuracy of extrapolation. Metal of steam pipes of the above steels (Table 1), for which the values of \( Q(\sigma) \) (Fig. 1) were determined, was used as the test material.

The metal was studied after standard heat treatment and after long-term service, for 12MKh after 95,000 h at 510°C, for 12Kh1MF after 60,000 h at 540°C, for 15Kh1M1F after 10,000 h at 565°C, and for 1Kh18N12T after 100,000 h at 550°C.

<table>
<thead>
<tr>
<th>Type of steel</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>Tl</th>
<th>Ni</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>12MKh</td>
<td>0.11</td>
<td>0.55</td>
<td>0.16</td>
<td>0.45</td>
<td>0.48</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.028</td>
<td>0.014</td>
</tr>
<tr>
<td>12Kh1MF</td>
<td>0.12</td>
<td>0.59</td>
<td>0.28</td>
<td>1.10</td>
<td>0.33</td>
<td>0.28</td>
<td>—</td>
<td>—</td>
<td>0.030</td>
<td>0.017</td>
</tr>
<tr>
<td>1Kh18N12T</td>
<td>0.10</td>
<td>1.50</td>
<td>0.66</td>
<td>17.7</td>
<td>—</td>
<td>—</td>
<td>0.38</td>
<td>12.3</td>
<td>0.011</td>
<td>0.020</td>
</tr>
<tr>
<td>15Kh1M1F</td>
<td>0.14</td>
<td>0.63</td>
<td>—</td>
<td>1.05</td>
<td>1.0</td>
<td>0.25</td>
<td>—</td>
<td>—</td>
<td>0.025</td>
<td>0.028</td>
</tr>
</tbody>
</table>

The method for preparing foil for electron microscopic investigation, determining their thickness, and rating the dislocation density, the dimensions and volumetric density of the special carbides, the absolute specific surface of the subgrains in the ferrite, the volumetric share of pearlite, and the absolute specific surface of the cementite have been described earlier [10]. To determine the above parameters tens of thousands of measurements have been made on optical and electron photomicrographs.

Long-term rupture tests of the investigated steels at one and the same level of stresses were made at two temperatures not differing by more than 30–50°C. Under these conditions the time until failure at one level of stresses differs by more than an order of magnitude, which corresponds to the difference in the length of laboratory tests (~10,000 h) and service life (100,000 h) on which extrapolation is done.

In order to establish the effect of creep deformation on the structural parameters of the steels metal in different cross sections of the failed samples was investigated. The amount of the true deformation was determined using the method of the Central Committee of Heavy Industry.

Figure 2 shows that for 12Kh1MF steel both in the original condition and after many years of service the relationship of the absolute specific surface of the subgrains, the dislocation density inside the subgrains \( \rho \), the size of the carbides \( d \), and their volumetric density \( N_v \) in the ferrite of 12Kh1MF steel in the original condition (a) and after service at 540°C for 60,000 h (b); 1) \( t = 540°C \); 2) \( t = 580°C \).

The values of the structural parameters presented above determine the level of (thermally nonactivated) stresses \( \sigma_1 \), which according to the model of creep of dispersion strengthened materials [10] as a first approximation are equal to the applied stress \( \sigma \). According to the data of [11], for 12MKh and 12Kh1MF steels the greatest effect of the structural parameters presented on the level of internal flow stresses is shown by the volumetric share of pearlite, the dislocation density \( \rho \), and the density \( N_v \) and size \( d \) of the special carbides in the ferrite. On the basis of these parameters it is possible to rate the components of the internal stresses corresponding to them and their total value \( \sigma_1 \) using the equations [11]

\[
\sigma(n) = \left( \frac{\mu b}{2k} \right)^{1/2};
\]

\[ \lambda = \frac{D}{2\pi}; \]

\[ \sigma(\rho) = 0.4\mu b^{1/2}; \]

\[ \sigma(N_v d) = k\sigma < 2\mu b (N_v d)^{1/2}; \]

\[ \sigma_1 = \sigma(n) + \sigma(\rho) + \sigma(N_v d). \]

where \( \mu \) is the shear modulus of the steel, \( \mu * \) is the shear modulus of the cementite, \( b \) is Burger's vector, \( c \) is a constant, \( \lambda \) is the average length on a straight line between the pearlite grains and the diameter \( D \), and \( k \) is a coefficient weakly related to \( N_v \) and \( d \) [11].

The value of the stress \( \sigma(N_v, d) \) in creep is always less than the stress calculated according to the Orovan model of bending of the particles by dislocations as a result of the possible overcoming of the