NATURE OF THE EMBRITTLEMENT OF 12KhlMF STEEL

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12KhlMF steel is widely used for power plant equipment, although it is embrittled by tempering at 600-700°C. In this work we investigate the steel with the following composition: 0.11% C, 0.25% Si, 0.64% Mn, 0.018% S, 0.022% P, 0.20% Cu, 0.11% Ni, 1.08% Cr, 0.31% Mo, 0.29% V.

The mechanical properties and structure after normalization and tempering were determined on samples from pipes 273 x 40 mm. The microhardness was measured with the PMT-3 apparatus.

Normalization was conducted by the following methods: A) heating to 970°C, holding 30 min, and cooling at a rate of 15°C/min; B) heating to 970°C, holding 30 min, and cooling at the rate of 125°C/min; C) heating to 1200°C, holding 30 min, and cooling at the rate of 15°C/min; D) heating to 1200°C, holding 5 h, and cooling at the rate of 15°C/min. After normalization the structure of the steel consisted of ferrite, pearlite, intermediate transformation products, and carbides.

It is well known that the transformation of austenite in 12KhlMF steel during continuous cooling occurs at 820-650°C (ferrite and pearlite) and at 600-350°C (intermediate transformation products). At high cooling rates both transformations occur at the same time [1, 2].

For the purpose of investigating the transformation of austenite during continuous cooling we conducted the following heat treatment: heating to 970° and 1200°C, soaking 30 min, cooling at the rate of 15°C/min to temperatures between 640 and 300°C (at 20°C intervals), and quenching in an aqueous solution of NaCl. It was found that ferrite is formed in two temperature ranges, in the upper and intermediate ranges the transformation of austenite begins with the formation of excess ferrite.

The ferrite formed in the upper temperature range we have arbitrarily labeled ferrite I and that formed in the intermediate range (560-540°C) ferrite II. The difference in the temperature and mechanism of formation of the two ferrite structures determines many of their features.

Ferrite I is precipitated on the austenite grain boundaries. The grains of ferrite I are larger and stretched out in the direction of the austenite boundaries. The grains of ferrite II are equiaxial and finer. Ferrite II is more severely etched. After etching for longer than the normal time one observes a light network of ferrite I on the former boundaries of the austenite grains. On the grains of ferrite II there are etched lines in parallel bunches running from the boundaries to the center of the grains.

Ferrite II has a high microhardness. After normalization by method D the microhardness is $H_b$ 145 for ferrite I and $H_b$ 190 for ferrite II.

After normalization, we determined the total amount of ferrite in the structure. One set of

<table>
<thead>
<tr>
<th>Normalization method</th>
<th>Composition, %</th>
<th>Ferrite I</th>
<th>Ferrite II</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80.9</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>46.5</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>41.5</td>
<td>21.5</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Variation of the impact strength and hardness with the tempering temperature for steel previously normalized by different methods.
Fig. 2. Variation of the hardness and microhardness of the structural components with the tempering temperature. a) Normalization by method B, 15-g load; b) normalization by method D, 20-g load.

Fig. 3. Grains of ferrite II after normalization by method D and tempering (× 1000). a) Tempered at 300°C; b) 600°C; c) 650°C; d) 700°C.

samples was normalized by this same method but cooled from the temperature at which the first transformation had ended but the second had not yet begun (500°C) and then quenched in an aqueous solution of NaCl. We found martensite in the structure of these samples, and therefore it was possible to determine the quantity of ferrite I alone. The quantity of ferrite II was determined by the difference between the total quantity of ferrite and the quantity of ferrite I (Table 1).

After normalization at 970°C with low rates of cooling a small quantity of ferrite II was formed. With increasing cooling rates or normalization temperatures the quantity of ferrite II increased, although the total quantity of ferrite decreased.

Greater supercooling of austenite was attained with increasing cooling rates. The precipitation of excess ferrite in the upper range was depressed and the major part of the ferrite was formed in the intermediate range.

At 970°C vanadium carbides are completely undissolved [3]. With increasing normalization temperatures the solubility of the vanadium carbides increases and one obtains, as it were, a more highly alloyed steel with a great inclination to supercooling. The quantity of ferrite is also increased, being formed in the intermediate range.