X-RAY INVESTIGATION OF SURFACE LAYERS OF 9Kh STEEL STRENGTHENED BY THERMOMECHANICAL SURFACE TREATMENT

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It was shown in [1] that high-temperature thermomechanical surface treatment increases the resistance of 9Kh steel to contact fatigue by a factor of 2-2.5 and that of rollers used for cold rolling* by a factor of 3. The lack of correlation between the hardness and the increase in the contact fatigue resistance resulting from high-temperature thermomechanical surface treatment means that more refined methods are needed to measure the changes induced by the high-temperature thermomechanical treatment (HTTMT) in the structure and fine structure of the surface layer.

We made an x-ray investigation [1] of the surface layers of rollers used for cold rolling (38 mm in diameter) made of 9Kh steel and strengthened by HTTMT (the deformation temperature was 950°C; the rolling pressure was varied). The analysis of the width of the (110)α line at different distances from the surface as a function of the treatment conditions was undertaken in view of studying the change in the fine structure after HTTMT as compared to that resulting from high-frequency heating and quenching and also to determine indirectly the thickness of the hardened layer after different HTTMT conditions. Samples 15 × 15 mm were cut out of rollers. Successive layers were etched away electrolytically in concentrated nitric acid. The photographs were made with the URS-50I apparatus.

We determined the width of the (110)α line in successive layers after different conditions of HTTMT and high-frequency heating and quenching. The final tempering of the rollers was the same for all samples: 160-180°C for 90 min. One can see (Fig. 1) that HTTMT induces the greatest change in the width of the line. Only at a depth of about 1 mm does the width of the line begin to decrease. After HTTMT with a rolling pressure of 45 and 55 kg the width of the (110)α line of the hardened layer (taking into account the mean square error) is the same as after HTTMT with a rolling pressure of 65 kg, but the width of the line begins to decrease at a smaller distance from the surface. For examples subjected to HTTMT with a pressure of 75 kg the width of the (110)α line is close to that resulting from high-frequency heating and quenching followed by low-temperature tempering. This can be explained by the development of recrystallization processes during HTTMT with high rolling pressures [1].

The surfaces in contact during cold rolling reach temperatures up to 200-250°C. Therefore, we made a detailed investigation of the change in the width of the (110)α line after HTTMT and, for comparison, after high-frequency heating and quenching, after which the samples were tempered 1.5 h at 250°C. The analysis of the results obtained (Fig. 2) showed that the changes in the fine structure resulting from HTTMT are stable and remain even after tempering at 250°C. The (110)α line is wider after all the HTTMT conditions followed by tempering at 250°C than after high-frequency heating and quenching. Only beginning at a tempering temperature of 300°C does the width of the (110)α line resemble that of the samples after high-frequency heating and quenching followed by the same type of tempering (Fig. 3). These results allow us to explain the considerable increase in the resistance to contact fatigue if we take into account the increase in the temperature of the contact zone occurring under actual working conditions or during tests.

The x-ray analysis made it possible to determine precisely the thickness of the hardened layer, which is difficult to achieve by other methods. The thickness of the hardened layer resulting from HTTMT is the thickness

*The optimum HTTMT conditions for 9Kh steel are follows; high-frequency heating to 950-970°C, rolling with rollers on a three-roller device under a pressure of 65 kg, and immediate quenching in water and tempering at 160-180°C for 1.5 h. 257
Fig. 1. Variation of the width of the (110)α line with the depth of the layer as a function of the rolling pressure during HTTMT (tempering at 160-180°C). 1) High-frequency heating and quenching; 2) HTTMT, P = 65 kg; 3) HTTMT, P = 45 kg; 4) HTTMT, P = 55 kg; 5) HTTMT, P = 75 kg.

Fig. 2. Variation of the width of the (110)α line with the depth of the layer after tempering at 250°C. 1-5) Same as in Fig. 1.

Fig. 3. Influence of the tempering temperature on the width of the (110)α line after high-frequency heating and quenching and after HTTMT under optimum conditions. 1) High-frequency heating and quenching; 2) HTTMT, P = 65 kg.

Fig. 4. Distribution of the width of the (110)α line with the depth of the hardened layer (the curve is drawn by taking into account the mean square error). 1-5) Same as in Fig. 3.

The investigation of the dependence of the width of the (110)α line on the tempering temperature after optimum HTTMT conditions and after high-frequency heating and quenching showed that the width of the line after HTTMT but without tempering is narrower than after high-frequency heating and quenching (see Fig. 3). Similar

Table 1

<table>
<thead>
<tr>
<th>Treatment conditions</th>
<th>% C</th>
<th>Error ± % C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quenched</td>
<td>0.83</td>
<td>0.04</td>
</tr>
<tr>
<td>HTTMT, 25%</td>
<td>0.76</td>
<td>0.14</td>
</tr>
<tr>
<td>HTTMT, 50%</td>
<td>0.61</td>
<td>0.07</td>
</tr>
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where the mean square error in the values of the width of the line for samples after HTTMT under a specific rolling pressure and after high-frequency heating and quenching are superposed (Fig. 4). Fig. 5 shows the dependence of the thickness of the layer hardened by HTTMT on the rolling pressure after tempering at 160-180°C and 250°C.

We investigated the influence of HTTMT on the amount of residual austenite in the hardened layer. The amount of residual austenite distributed over different layers below the surface of samples after HTTMT and after high-frequency heating and quenching (final tempering at 160-180°C) was determined by the ratio of the intensities of the integral (111) and (110)α lines of the α-phase. The photographs were made with the URS-50I apparatus. The increase in the amount of residual austenite after HTTMT (Figs. 6 and 7) can be related to strong fragmentation of austenite during high-temperature deformation as the result of which the martensitic transformation is slowed down. This martensitic transformation is characterized by coherent growth of martensite needles. The dependence of the amount of residual austenite on the rolling pressure (Fig. 7) showed that the considerable increase in the amount of residual austenite occurs during HTTMT with a rolling pressure of 45 kg. With further increase in the rolling pressure the amount of residual austenite in the hardened layer remains practically constant. This is apparently due to the fact that a greatly fragmented structure is formed at rolling pressures as low as 45 kg, and an increase in the rolling pressure beyond 45 kg leads only to a change in the structure of the walls of the fragments without changing their size. This is characteristic of the cellular structure. An increase in the amount of residual austenite in the strengthened layer after HTTMT makes it possible to examine the apparent increase in the thickness of the hardened layer after tempering at 250°C (Fig. 5).