CHEMICOTHERMAL TREATMENT

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KINETICS OF FORMATION OF A DIFFUSION LAYER ON STEEL 38Kh2MYuA IN GAS-CYCLIC NITRIDING

D. P. Shashkov and A. B. Goryachev

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INTRODUCTION

It is known that as compared with other methods of surface hardening nitriding provides the highest wear resistance of alloy steels but has one substantial drawback — the long duration of the process. As the nitriding time increases, the rate of growth of the diffusion layer diminishes due to the formation of a nitride layer on the surface, i.e., (ε + γ') phases having a low coefficient of nitrogen diffusion. This decelerates the diffusion of nitrogen from the surface of the part into the zone of internal nitriding. In addition, under a long-term saturation the brittleness of the ε-phase increases and substantially worsens the wear resistance of the steel [1].

In order to control the thickness of the nitride zone and increase the thickness of the zone of internal nitriding, we can use a gas-cyclic nitriding process with discontinuous feeding of ammonia [2, 3]. This process is simple technologically and does not require expensive and intricate equipment.

In the present work, we studied the kinetics of formation of nitrided layers on steel 38Kh2MYuA by means of gas-cyclic nitriding and determined the optimum nitriding regimes by experiment.

METHOD OF STUDY

The studied process of gas-cyclic nitriding consisted of repeated cycles, each of which included two half-cycles of different duration. The first half-cycle consisted of conventional nitriding in a flow of ammonia. The second half-cycle consisted of denitriding in an atmosphere of fully dissociated ammonia with closed inlet and outlet of the gas container of the device for conventional nitriding. Then the cycle was repeated. The total nitriding cycle lasted 6 h. The duration of each half-cycle (and hence the cycle) was different, i.e., 0.5, 1.0, 1.5, and 3.0 h, and the number of gas cycles was 6, 3.2, and 1, respectively. The final stage of the process was denitriding, which means that we could not expect a noticeable increase in the hardness and the wear resistance of the surface of the specimen. In this connection and independently of the duration of the half-cycles, we made a parallel study of specimens where the nitriding process ended with an additional saturation for 1 h. The total duration of the nitriding process in this case was 7 h.

The specimens were nitrided at 570°C. The degree of dissociation of ammonia in each first half-cycle, i.e., in the saturation stage, was 40-45%.

The thickness of the nitride zone and the effective thickness of the nitrided layer were determined under a PMT-3 microscope. For this purpose the nitrided specimens were cut for microscopic cross sections. The microstructure was studied after etching them in a 2% solution of nitric acid in alcohol under a Neophot microscope under a magnification of up to ×1000.

RESULTS AND THEIR DISCUSSION

The nitride zone always has a well-manifested interface with the zone of internal nitriding. The nitride zone consists of ε and γ' phases, i.e., solid solutions based on Fe₃N and Fe₄N nitrides respectively.

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1 Moscow State Automobile and Road Institute (Engineering University), Moscow, Russia.
TABLE 1

<table>
<thead>
<tr>
<th>Nitriding regime</th>
<th>Degree of dissociation of ammonia, ( % )</th>
<th>Thickness of nitride zone, ( \mu m ), after nitriding: gas-cyclic with half-cycles lasting for, h: 3/3</th>
<th>1.5/1.5</th>
<th>1/1</th>
<th>0.5/0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>570°C 6 h (1)</td>
<td>40 - 45</td>
<td>25</td>
<td>4</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>570°C 7 h (2)</td>
<td>40 - 45</td>
<td>26</td>
<td>10</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>570°C 7 h (3)</td>
<td>60 - 65</td>
<td>20</td>
<td>5</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

Notes. 1. The regimes are numbered in parentheses. 2. Gas-cyclic nitriding by regime 1 ends with a stage of denitriding; the process by regimes 2 and 3 ends with 1-h saturation at 570°C.

TABLE 2

<table>
<thead>
<tr>
<th>Nitriding regime</th>
<th>Degree of dissociation of ammonia, ( % )</th>
<th>Effective thickness of the layer, ( \mu m ), after nitriding: gas-cyclic with half-cycles lasting for, h: 3/3</th>
<th>1.5/1.5</th>
<th>1/1</th>
<th>0.5/0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>570°C 6 h (1)</td>
<td>40 - 45</td>
<td>90</td>
<td>20</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td>570°C 7 h (2)</td>
<td>40 - 45</td>
<td>100</td>
<td>80</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>570°C 7 h (3)</td>
<td>60 - 65</td>
<td>80</td>
<td>30</td>
<td>70</td>
<td>80</td>
</tr>
</tbody>
</table>

Note. See the notes to Table 1.

The thickness of the nitride zone obtained in gas cyclic nitriding is much less than after a conventional nitriding (Table 1). The most marked reduction in the thickness of the nitride zone occurs when the half-cycles last for 3 h. When their duration is decreased to 0.5 h the thickness of the nitride zone increases but still does not attain the value provided by conventional nitriding. This is connected with the fact that in denitriding, i.e., in the second stage of the cycle, the high-nitrogen nitride zone resorbs. The resorption occurs in two directions, namely, (1) into the gas medium represented by fully dissociated ammonia and (2) into the depth of the specimen.

It seems that the thickness of the nitride zone increases with reduction of the half-cycles for the following reasons. As the duration of denitriding is increased to 3 h, the nitride zone resorbs in the second stage of the nitriding process the most fully, i.e., denitriding dominates over nitriding. When the half-cycles are shortened, the denitriding in the second stage is less intense. As a result, the subsequent nitriding provides a greater saturation of the surface layers of the specimen with nitrogen, i.e., nitriding dominates over denitriding, which increases the thickness of the nitrided layer (Table 1).

The effective thickness of the nitrided layer, i.e., the thickness of the layer with a microhardness higher than 500 \( HH \), also depends on the duration of the half-cycles (Table 2). When a half-cycle lasts for 3 h, the effective thickness of the layer is the least due to the fullest denitriding process. With shortening of the half-cycles the effective thickness of the layer increases. This is explainable by the fact that the process of gas-cyclic nitriding in each second half-cycle is accompanied by periodic reduction of the thickness of the nitride zone, which hampers the diffusion of nitrogen from the surface of the specimen inside it.

The greatest effective thickness of the layer is provided by nitriding with half-cycles lasting for 1 h. For half-cycles lasting for 1.5 and 3 h, the resorption time is too great and the thickness of the nitrided layer begins to diminish. Nitriding with half-cycles lasting for 0.5 h is also less effective than that with 1-h half-cycles. This occurs because 0.5 h is not sufficient for the nitride zone to resorb well enough; in subsequent saturation it hampers the diffusion of nitrogen adsorbed by the surface into the depth of the metal. Thus, the optimum duration of a half-cycle is 1 h.

Figure 1 shows the distribution of the microhardness over the thickness of the surface layer after nitriding by different regimes. It can be seen that when the gas-cyclic nitriding ends with a stage of resorption, the microhardness of the surface of the steel is lower than in conventional nitriding. This is due to the more intense removal of nitrogen atoms from the surface into the depth of the specimens during the resorption of the layer in the stage of denitriding. The intense nitrogen diffusion is confirmed by the fact that the curve of the distribution of microhardness over the thickness of the nitrided layer lies higher than that in the case of conventional nitriding (curves 2 and 1 in the figure, respectively).

The deterioration of the hardness on the surface of the specimens can be eliminated if the gas-cyclic process is fi-