Influence of carbon potential ($C_p$) on microstructure and hardness of 20CrNi steel

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ABSTRACT

This article presents about effect of temperature on the $C_p$ potential of the carbonitriding medium. Using the sensor has determined the permeability potential with different modes is 0.66; 0.86 and 1.07. From the experimental results on the influence of gas flow (with different $C_p$ values), the hardness distribution from the surface to the core of the steel has been determined. By the results of the analysis of the microstructure, it has been shown that the permeable layer on the surface of 20CrNi steel. The microstructure obtained here is the carbide; nitride and residual austenite. The results also show the influence of $C_p$ on the microstructure of the research steel.

KEYWORDS

carbonitriding, microstructure, residual austenite, Xementie

INTRODUCTION

The carbonitriding is a method of simultaneously increasing both carbon and nitrogen elements on the surface of a part made of low carbon steel. The surface of steel will have a high hardness, but the matrix of steel will still retain the toughness. Carburizing and nitriding is accomplished by placing the part in medium with a much higher carbon and nitrogen content than in the steel [1]. The carbon and nitrogen atoms of the media diffuse into the surface of the part, along with iron and alloying elements to form carbide or nitride with high hardness on the surface, increasing wear resistance. The surface of the part has the highest quality when the total carbon and nitrogen content is in the range of 0.9 ÷ 1.3% [2-6]. The carbon potential of the medium is the carbon content of the medium. As mentioned above, the reactions in the medium are reversible.

Changing the concentrations of gaseous components all shift the equilibrium and affect the carbon potential. It is therefore possible to control the carbon potential through controlling components such as the water vapor content, via the $CO_2$ content or the partial pressure of oxygen. The control process is accompanied by the adjustment of the permeability potential [7-12]. One of the most important factors affecting the quality of the permeable layer is the composition and flow rate of the incoming gases. It is the composition of the gases put into the furnace that will determine the balance of chemical reactions, determine the content of carbon, nitrogen atoms and determine the formation of phases in the permeable layer.

If not adjusted so that the amount of carbon, nitrogen atoms is too small, it will not be enough to form a permeable layer, on the contrary, if the amount of carbon, nitrogen atoms is too large, it will form soot, creating defects that make the permeability layer’s hardness was low. The composition and flow of gas are calculated according to the retention time in the furnace [13-19]. The carbonitriding technology is implemented on the basis of creating a permeable media including permeable gases (source of carbon’s atomic, nitrogen’s atomic) and filler gases (to dilute permeable gas). At a certain temperature, the carbon’s atomic, nitrogen’s atomic diffuse into the surface of the part to form a permeable layer. When permeable in gaseous medium, the source of atomic carbon is usually
natural or industrial gas. The carbon’s atomic is formed on the basis of the decomposition reaction of those gases [4, 6, 20-22].

If the source of \( C_{\text{atom}} \) is methane, the following reaction occurs [2, 5, 23-25]:
\[
\text{CH}_4 \leftrightarrow \text{Fe}_x(\text{C}) + 2\text{H}_2
\]

If the source of \( C_{\text{atom}} \) is propan, the following reaction occurs [2, 5, 23, 24]:
\[
\text{C}_3\text{H}_6 \leftrightarrow \text{C}_2\text{H}_4 \leftrightarrow \text{CH}_4 \leftrightarrow \text{Fe}_x(\text{C}) + 2\text{H}_2
\]

If the source of \( N_{\text{atom}} \) is NH\(_3\), the following reaction occurs [2,5, 23, 24]:
\[
\text{NH}_3 \leftrightarrow \text{N}_2 + 3/2\text{H}_2
\]

At the permeation temperature, the above decomposition reaction occurs completely, creating \( C_{\text{atom}} \) and \( N_{\text{atom}} \) that diffuse into the surface steel, creating the necessary structure for the permeable layer. The advanced countries in the world (Russia, the US) often use the carbon source as natural gas CH4 along with filler gases [2, 5, 9, 26]. When increasing from the normal temperature to the permeation temperature (at 820 °C to 850°C), the activity of the medium increases gradually and the conversion capacity increases. The higher the temperature, the higher the activity of the medium. When the calcination reaches the austenite state, the first stage on the steel surface, the austenite dissolves the alloying elements and the elements present in the permeable medium, including: C, N. Then produces nitride-like compounds such as: (Fe,Mn)\(_x\)N or CrN (when the N content in steel is 0.1%). Next will appear nitride, carbide phases [5, 6, 21, 27]. This paper presents the research results on the influence of the gas permeable composition on the \( C_p \) potential, the microstructure and hardness of the permeable layer.

MATERIALS AND RESEARCH METHODS

The research steel used is 20CrNi which has the same composition as in the table:

Table 1. The chemical of 20CrNi steel

<table>
<thead>
<tr>
<th></th>
<th>% C</th>
<th>% Si</th>
<th>% Mn</th>
<th>% P</th>
<th>% S</th>
<th>% Cr</th>
<th>% Ni</th>
<th>% Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>20CrNi</td>
<td>0.20</td>
<td>0.22</td>
<td>0.78</td>
<td>0.01</td>
<td>0.01</td>
<td>1.18</td>
<td>1.04</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

The carbonitriding process is shown as follows: The carbonitriding temperature at \( T= 820°C \) and \( T=840°C \); time of carbonitriding process is 3h. At each carbonitriding temperature, there is a corresponding \( C_p \) value and the change in \( C_p \) will be accompanied by a change in the gas composition and flow rate. After carbonitriding process, the sample quenched in hot oil. After carbonitriding, the microstructure of steel was analyzed and evaluated using an Axiovert 25A optical microscope. The hardness is measured with a Duramin Struer equipment. Thickness of the permeable layer is performed by micro-hardness.

RESULTS AND DISCUSSIONS

The relationship between the permeable air flow component and \( C_p \).

The carbon potential (\( C_p \)) is determined by the sensor on the basis of adjusting the air flow component at 820°C and 840°C, which are commonly used temperatures for carbonitriding process. The results of the study on the relationship between the permeable mixture flow and \( C_p \) are presented in tables 2 and 3. On the basis of the results of previous studies, choose the ratio of CO\(_2\)/Gas from 1-1.7 with NH\(_3\) in the range of 10%. The \( C_p \) is determined by supplying permeable gas and holding for sufficient time for gas equilibrium to be established and the \( C_p \) value to stabilize (usually 30 to 45 minutes).

Table 2. The relationship between \( C_p \) and permeable air at 820°C.

<table>
<thead>
<tr>
<th></th>
<th>Gas</th>
<th>CO(_2)</th>
<th>NH(_3)</th>
<th>N(_2)</th>
<th>( T_{\text{sensor}} )</th>
<th>( C_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_{11} )</td>
<td>0.08</td>
<td>0.22</td>
<td>0.08</td>
<td>0.35</td>
<td>842</td>
<td>0.75</td>
</tr>
<tr>
<td>( Q_{12} )</td>
<td>0.085</td>
<td>0.22</td>
<td>0.08</td>
<td>0.30</td>
<td>841</td>
<td>0.83</td>
</tr>
<tr>
<td>( Q_{13} )</td>
<td>0.09</td>
<td>0.22</td>
<td>0.12</td>
<td>0.25</td>
<td>845</td>
<td>1.04</td>
</tr>
</tbody>
</table>
Table 3. The relationship between C_p and permeable air at 840°C.

<table>
<thead>
<tr>
<th>Q_21</th>
<th>Gas</th>
<th>CO_2</th>
<th>NH_3</th>
<th>N_2</th>
<th>T_{sensor}</th>
<th>C_p</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08</td>
<td>0.22</td>
<td>0.08</td>
<td>0.35</td>
<td>862</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>0.10</td>
<td>0.22</td>
<td>0.07</td>
<td>0.35</td>
<td>862</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>0.09</td>
<td>0.22</td>
<td>0.08</td>
<td>0.35</td>
<td>860</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>0.11</td>
<td>0.22</td>
<td>0.08</td>
<td>0.28</td>
<td>862</td>
<td>1.06</td>
<td></td>
</tr>
</tbody>
</table>

From the table of experimental results, changing the flow composition of the permeable gas as Gas, CO_2, NH_3 will lead to the change of C_p. The change in the CO_2/Gas ratio is the main, while the NH_3 flow changes little to ensure nitrogen for the permeable layer. Realized that C_p reached the maximum value when surveying at 1.06. Thus, increasing the rate of CO_2/Gas flow, C_p increases and the CO_2/Gas flow ratio is selected in the range of 1-1.7, it is reasonable if this ratio is exceeded, the permeability process will be less CO_2 because too much, and if it is lower, it is easy to create soot to prevent infiltration [5].

Influence of C_p on microstructure and hardness at T = 840°C

Table 4. Results of hardness

<table>
<thead>
<tr>
<th>Distance (μm)</th>
<th>20</th>
<th>70</th>
<th>120</th>
<th>170</th>
<th>220</th>
<th>270</th>
<th>320</th>
<th>370</th>
<th>470</th>
<th>570</th>
<th>670</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.66</td>
<td>64.8</td>
<td>67.1</td>
<td>64.9</td>
<td>62.8</td>
<td>61.8</td>
<td>56.7</td>
<td>55.4</td>
<td>53.2</td>
<td>51.7</td>
<td>48.5</td>
<td>48.4</td>
</tr>
<tr>
<td>0.86</td>
<td>58.8</td>
<td>59.3</td>
<td>61.8</td>
<td>61.2</td>
<td>60.5</td>
<td>60.4</td>
<td>58.1</td>
<td>56.7</td>
<td>53.7</td>
<td>51.1</td>
<td></td>
</tr>
<tr>
<td>1.07</td>
<td>62.6</td>
<td>63.8</td>
<td>63.1</td>
<td>62.9</td>
<td>63.5</td>
<td>61.1</td>
<td>60.2</td>
<td>55.7</td>
<td>54.1</td>
<td>50.7</td>
<td>50.1</td>
</tr>
</tbody>
</table>

Figure 1. Diagram of hardness on 20CrNi steel after carbonitriding
Influence of carbon potential (Cp) on microstructure and hardness of 20CrNi steel

Figure 2. Microstructure of 20CrNi after carbonitriding with \( \text{Cp} = 0.66 \)

Figure 3. Microstructure of 20CrNi after carbonitriding with \( \text{Cp} = 0.86 \)

Figure 4. Microstructure of 20CrNi after carbonitriding with \( \text{Cp} = 1.07 \)

As the carbon permeation potential increases (Cp), the depth of the permeable layer increases, the hardness increases, which can be seen in Figure 3.17, which is also reasonable with the theory. In the graph, we see that at the permeability potential \( \text{Cp} = 1.07 \), the depth of the permeable layer as well as the hardness should be the highest, but in reality it is smaller than with \( \text{Cp} = 0.86 \), because in the process Experimental process when permeation at
Cp=1.07 mode to avoid the possible formation of cementite during the experiment has reduced the permeation gas flow after 2h saturation time to maintain the diffusion process to create a permeable layer, has a harmonious distribution with the surface concentration is not too high, easy to form the cementite.

The carbon potential Cp = 0.86 has been maintained stably during the experimental period of 3 hours with the prediction that in this condition it is very difficult to form a cementite grid because the surface carbon concentration will not be too large. However, the obtained results have shown that the permeability layer increases quite a lot and the hardness distribution is also higher due to the higher carbon concentration distribution and deeper diffusion capacity when the carbon potential is maintained stably throughout the infiltration process. This comment is also demonstrated in the carbonitriding process with Cp = 0.66 also maintaining stability by not reducing the flow during the carbonitriding process, when we have a hardness distribution almost the same as when Cp = 1.07 is lower though. However, the results of the hardness decrease gradually from outside to inside unlike the samples in other process

CONCLUSIONS

The microstructure and hardness of the C-N permeable layer have been studied with sensor control at different carbon potentials (0.66; 0.86; 1.07) by changing the gas/CO₂ flow rate. The obtained structural and mechanical properties of the permeable layer are stable, in agreement with the best results obtained previously when the permeability was not controlled. The distribution of carbon in the permeable layer has been evaluated as well as the hardness distribution according to the layer sections. On that basis, the thermodynamic parameters of the permeation process have been preliminarily calculated such as: diffusion coefficient, diffusion activation energy for 20CrNi steel.

REFERENCES


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