Research and Development of Cold Rolled Hot-dip Galvanized DP590 Steel with Low Cost

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ABSTRACT: Two low-cost cold rolled hot-dip galvanizing DP590 steels with different alloy elements were designed and the effects of alloy elements and galvanizing process parameters on the microstructure and mechanical properties were investigated. The results show that both of the experimental steels exhibit typical dual phase microstructure. Compared to the steel with higher silicon, the ferrite phase of steel with higher chromium is more pure and martensite-austenite (MA) islands are more evenly distributed. Both of the steels satisfy the mechanical properties standard of cold rolled hot-dip galvanizing DP590 steel, while steel with higher chromium has better elongation.

1 INTRODUCTION

The energy conservation, emissions reduction and increasing the safety of the car body has become the development trend of automotive industry. Because of the low yield strength, high beginning hardening rate, high strength, good plasticity and high impact energy absorption, the cold rolled dual phase (DP) steel shows great superiority and good prospects in the vehicle weight reduction (Park, et al. 2007, Akbarpour & Ekrami, 2008, Liang, et al. 2008, and Kuang, et al. 2009). As for the cold rolled hot-dip galvanizing DP steel, many alloy elements should be added to enhance the hardenability so that the martensite can be formed during the cooling stage after the galvanizing process. Generally, Si and Mn elements should be partially replaced by Cr and Mo elements, since they are harmful to the galvanizing quality (Hasegawa, et al. 2004). However, the addition of the Mo elements increases the cost of steel which brings the steel company great challenges and pressures under the current economic situation. In this work, two cold rolled hot-dip galvanizing DP590 steels with different compositions without Mo element were designed and effects of alloy elements and galvanizing processes on the microstructure and mechanical properties were investigated.

2 EXPERIMENTAL SCHEME

The chemical compositions of the experimental steels are listed in Table 1. It can be seen that, 1# steel has higher chromium content while 2# steel has higher silicon content. Nevertheless, both of
them reduce the alloy cost because there has no expensive alloy element addition such as molybdenum.

Table 1. Chemical compositions of the designed steels (mass percent, %).

<table>
<thead>
<tr>
<th>Steels</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Al</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1# steel</td>
<td>0.12</td>
<td>0.20</td>
<td>1.60</td>
<td>0.55</td>
<td>0.03</td>
<td>&lt;0.02</td>
<td>&lt;0.007</td>
</tr>
<tr>
<td>2# steel</td>
<td>0.12</td>
<td>0.50</td>
<td>1.60</td>
<td>0.20</td>
<td>0.03</td>
<td>&lt;0.02</td>
<td>&lt;0.007</td>
</tr>
</tbody>
</table>

The experimental steel was fabricated by 50 kg vacuum induction furnace and casted into square ingots. The ingots were homogenized at 1200 °C for 1 hour and then rolled to 3mm thickness plate. The finished rolling temperature and simulating coiling temperature were 870 °C and 660 °C, respectively. The plates were then air cooled to the room temperature. After the hot rolling, the plates were cold rolled to 1.5mm thickness. The galvanizing cycle was simulated by a multi-purpose simulator in the laboratory and the galvanizing cycle parameters are listed in table 2.

Table 2. Parameters of galvanizing cycle.

<table>
<thead>
<tr>
<th>Process No.</th>
<th>Preheating temperature</th>
<th>Heating temperature</th>
<th>Soaking temperature</th>
<th>Slow cooling temperature</th>
<th>Galvanizing temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>220°C</td>
<td>760°C</td>
<td>760°C</td>
<td>680°C</td>
<td>460°C</td>
</tr>
<tr>
<td>2</td>
<td>220°C</td>
<td>780°C</td>
<td>780°C</td>
<td>690°C</td>
<td>460°C</td>
</tr>
<tr>
<td>3</td>
<td>220°C</td>
<td>800°C</td>
<td>800°C</td>
<td>700°C</td>
<td>460°C</td>
</tr>
</tbody>
</table>

The tensile samples were cut from the experimental steels and the tensile test was conducted on a universal materials tester at room temperature. The specimens were prepared by polishing and etching in lepera solution to observe their microstructures and MA Islands by optical microscopy (OM).

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Mechanical properties of experimental steels

Figure 1 shows the mechanical properties of two experimental steels experienced various galvanizing simulation processes listed in Table 2. It can be seen that as the temperature increases, both of the tensile strength and yield strength are enhanced for the two experimental steels. This may be attributed to the increment of austenite which could transform to martensite during the following cooling stage. However, both of the steels experienced 2# process has the best elongation. In addition, it can be found that 1# steel has higher tensile strength, higher elongation and lower yield strength compared to 2# steel. It implies that 1# steel with higher
elongation and lower yield ratio has better forming ability. From Fig.1, the best combined mechanical properties of 1# and 2# steel can be concluded as 618MPa (TS), 298MPa (YS), 29% (A50 EL) and 609MPa (TS), 310MPa (YS), 26% (A50 EL), respectively, all of which well satisfy the mechanical properties of DP590 steel.

![Figure 1. Mechanical properties of the experimental steels experienced various processes.](image)

3.2 Microstructures of experimental steels

The samples of experimental steels experienced process 2 were etched by Lepera solution for microstructure observation, as shown in Fig.2. Figs.2 (a) and 2(b) show the microstructure and MA island distribution of 1# and 2# steels, respectively. It can be seen that the experimental steels exhibit typical dual phase microstructure character which consists of grey ferrite, bright white MA island and little black bainite. The amount of the bainite and MA island in 2# steel is also less than that of 1# steel. Through a quantitative examination, the volume fraction of the MA islands in 1# steel and 2# steel is around 17.51% and 14.33%, respectively. It is obvious that 1# steel has more MA islands than 2# steel. Furthermore, MA islands in 1# steel is more evenly distributed than that in 2# steel, and no longer distributed in the form of banding which is harmful to the mechanical properties.

![Figure 2. Microstructure and MA island distribution of (a) 1# steel and (b) 2# steel.](image)
3.3 Thermodynamic analysis

In order to clarify the microstructure evolution, the Thermo-calc software was used to calculate the phase mass fraction and the result is shown in Figure 3. It shows the phase transformation and its mass fraction of the experimental steels at different temperature. It can be seen that, at the same temperature, 1# steel has larger fraction of ferrite phase and smaller fraction of austenite phase than 2# steel. It implies that higher chromium is more helpful to form the ferrite phase.

![Figure 3. Phase fraction of the experimental steels calculated by Thermo-calc.](image)

It should be noticed that Fig. 2 has shown that the volume fraction of the MA island in 1# steel is larger than that in 2# steel. So, austenite stability may play an important role during the phase transformation. For this, Fig. 4 shows the calculated mass fraction of various elements in ferrite and austenite phases by Thermo-calc software. Figs. 4(a)-(d) show the mass fraction of C, Cr, Mn, Si, respectively. It is found that the mass fraction of C and Mn elements in phases of two experimental steels nearly has no difference. However, the variation of Cr and Si mass fraction in phases of two experimental steels is obvious. From Fig. 4b, it can be seen that the mass fractions of Cr in phases of 1# steel are all higher than that in 2# steel, and Cr mass fraction in austenite is also larger than that in ferrite. In the two phase region, the largest mass fraction of Cr in austenite is above 0.8%. Then, as the temperature increases, the Cr mass fraction decreases because of the increment of austenite volume fraction. When the temperature reduces to the ferrite region, the Cr mass fraction in ferrite decreases monotonously. As for Si element shown in Fig. 4d, the situation is nearly inverse. The mass fractions of Si in phases of 2# steel are all higher than that in 1# steel, and Si mass fraction in ferrite is also larger than that in austenite in the two phase region. However, the disparity of the Si mass fraction between ferrite and austenite is not too much. Furthermore, the Si mass fractions in ferrite and austenite are equal to the Si content of the
experimental steel at other temperature. In a word, compared 1# steel with 2# steel, 1# steel has higher Cr content in austenite which is helpful to enhance the austenite stability and increase the mass fraction of MA islands, so that its tensile strength is higher than 2# steel. Meanwhile, 1# steel has lower Cr and Si content in ferrite which makes the ferrite more pure, so that it has lower yield strength and better elongation than 2# steel. Moreover, 2# steel has higher Si content in ferrite which is effective to strengthen the ferrite so that its yield strength is higher. In addition, increment of Cr content is also helpful to make the MA islands more evenly distributed which are also effective to improve the mechanical properties (Han, et al. 2014).

Figure 4. Mass fraction of various elements in ferrite and austenite phases calculated by Thermo-calc.

(a) C element; (b) Cr element; (c) Mn element; (d) Si element.

4 CONCLUSION

(1) Two experimental steels exhibit typical dual phase feature, while 1# steel with higher chromium has more MA islands which are also more uniformly distributed than 2# steel with higher silicon.
1# steel has higher tensile strength, higher elongation and lower yield strength compared to 2# steel. The best combined mechanical properties of 1# and 2# steel can be concluded as 618MPa (TS), 298MPa (YS), 29% (A50 EL) and 609MPa (TS), 310MPa (YS), 26% (A50 EL), respectively.

REFERENCES


