Influence of intercritical temperature on microstructure of cold rolled DP980

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Abstract: In this study, Gleeble 3800 thermal simulator was used to simulate the continuous annealing process of industrial production of dual phase steel with the tensile strength over 980 MPa. In the experiment, four different annealing temperatures of 700 ℃, 720 ℃, 740 ℃ and 760 ℃ were set in the intercritical region while keeping other process parameters unchanged. The experimental results showed that the martensite content increases with the rise of intercritical annealing temperature. However, this growth is not persistent, the obvious change of martensite content can be seen only when the temperature exceeds 20 ℃ in current study. In addition, with the increase of temperature, the elongated ferrite grains tend to become more equiaxed.

1. Introduction
The higher requirements of automotive industry for energy conservation, gas emission reduction and green environmental protection makes the automotive steels tend to be lightweight and highly strengthened. As the first generation of advanced high strength steel (AHSS), dual phase (DP) steel is mainly composed of soft ferrite and hard martensite¹⁻⁴. It has many advantages, such as excellent combination of strength and ductility, low yield ratio, high initial work hardening rate, low alloying cost, thus possessing broad application prospects⁵. It is the most widely used high strength steel in automotive bodies at present. Especially the cold-rolled dual phase steel with 980MPa tensile strength and above is favored by researchers. Continuous annealing process is generally the main way to produce dual phase steel in industry, but due to the complex interaction among many actual process parameters, there are differences in the conclusions of many studies on microstructure regulation of DP980⁶. Therefore, it is still the goal for metallurgical workers to study the influence of continuous annealing process parameters on the microstructure of cold rolled DP980 and further improve the microstructure regulation law of DP980.

In this paper, the cold rolled DP980 of an iron and steel company is used as raw material, the specific continuous annealing process parameters are set, and Gleeble3800 is used for thermal simulation. The effect of intercritical annealing temperature on microstructure of cold rolled DP980 is
studied while maintaining the annealing time, the end temperature of slow cooling, over-aging temperature and time, cooling speeds of slow cooling and fast cooling unchanged.

2. Materials and Methods

2.1 Materials
The experimental steels were supplied in the cold-rolled state, with a thickness of 1.5mm, whose chemical composition is shown in Table 1.

| C  | Si  | Mn  | Cr  | Mo  | W   | Ti  | Al  | P   | S   |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.13 | 0.14 | 2.24 | 0.29 | 0.15 | 0.02 | 0.19 | 0.014 | 0.002 |

2.2 Determination of $A_{c1}$ and $A_{c3}$
In order to set a reasonable annealing temperature range of intercritical zone, the $A_{c1}$ and $A_{c3}$ phase transformation points of cold-rolled DP980 were measured by thermal expansion method using Gleeble3800 thermal simulator. The sample was heated to 950 ℃ (complete austenization temperature) at a heating rate of 5 ℃/s (the same as the heating rate of actual heat treatment), and the $A_{c1}$ and $A_{c3}$ were judged by the thermal expansion curve during heating, about 670℃ and 840℃ respectively as shown in Figure 1.

![Figure 1. The thermal expansion-temperature curve of DP980](image)

2.3 Continuous annealing process
After the determination of phase transition points, the cold-rolled DP980 was annealed at different intercritical temperatures of 700℃, 720℃, 740℃ and 760℃ between $A_{c1}$ and $A_{c3}$ using Gleeble3800 thermal simulator. The specific heat treatment process parameters are shown in Fig 2.
2.4 Microstructure analysis
The microstructural observations were conducted using DMI5000 intelligent inverted metallographic microscope (Leica, Germany) and Sigma300 scanning electron microscopy (Gemini, ZEISS, the United Kingdom). The metallographic samples were sequentially ground with 180, 300, 600, 800, 1000, 1200, 1500, 2000 and 3000 grit sandpapers, polished using diamond polishing powder with particle diameters of 1.5 μm and 0.5 μm and etched in a 4% Nital solution. The estimation of martensite volume fraction was obtained by using Image-Pro Plus 6.0 software, combined with intercept method.

3. Results and Discussion

3.1 Metallographic microstructure
The metallographic microstructure of different intercritical annealing temperature are shown in Figure 3a, b, c, d. The white parts are ferrite and the black parts are martensite in the micrograph, this is because when nitric acid-alcohol solution is used for corrosion, martensite is more likely to be corroded than ferrite due to large structural stress, thus displayed in black under optical microscope. It can be seen from the figure that at low intercritical annealing temperature, there are obvious rolling traces in the microstructure, and the ferrite grains are elongated along the rolling direction. With the rise of annealing temperature, the proportion of black parts increases and the white parts decrease gradually. In other words, the content of martensite increases and the content of ferrite decreases. This is related to the degree of austenization, with the rise of temperature, more austenite are generated, which transform into martensite in the subsequent cooling process. Meanwhile, as temperature increases, the whole microstructure tends to be homogeneous, and the banded characteristic of ferrite is disappearing and becoming uniform equiaxed crystal distribution, as shown in Figure 3d.
Figure 3. Metallographic microstructure of different intercritical annealing temperature.
3.2 SEM microstructure evolution

The as received steel has an initial ferrite-pearlite microstructure as shown in Figure 4. After cold rolling, the ferrite and pearlite grains exhibit an elongated and flattened shape, both with a thickness of about 1μm, while grain lengths are varying. The cementite lamellae inside the pearlite islands were fragmented during large deformation, which make the cementite not perfectly lamellar but present a more rounded shape[7].

After continuous annealing, the microstructure is composed of ferrite and martensite, in which the martensite islands with bright edge are dispersed in ferrite matrix. This kind of brightness is caused by the rich manganese at the martensite edge, making the SEM microstructure of dual phase steel have an obvious convexity effect. At 700℃ and 720℃ (Figure 5a, 5b), the banded ferrite can still be clearly identified, which tells that the ferrite has not been fully recrystallized. The content of martensite is increasing on the whole but it is worth noting that with the increase of temperature from 700℃ to 720℃, the size as well as volume fraction of martensite islands has little change. In order to obtain a quantitative comparison, the volume fraction of martensite at 700℃ and 720℃ was estimated, accounting for 30% and 24% respectively. From 740℃ to 760℃ (Figure 5d), the content of martensite also decreases slightly as from 700℃ to 720℃, about 41% and 35% at 740℃ and 760℃ respectively. In fact, there are three types of ferrite in this study: the first is deformed “old” ferrite (as shown by the red arrows in Figure 5d); the second is recrystallized ferrite (as shown by the blue arrows in Figure 5d), and the third is newborn ferrite precipitated along the austenite grain boundaries during slow cooling, also known as oriented epigenic ferrite (as shown by the yellow arrows in Figure 5d). This kind of slight periodic decline of martensite content may be that the increase of temperature can not lead to the formation of more austenite (that is, the final martensite), but produce more oriented epigenic ferrite in the slow cooling process.

Figure 4. The initial SEM microstructure of cold rolled DP980

(a) 700℃
Figure 5. The SEM microstructure of different intercritical annealing temperatures

4. Conclusions

(1) The intercritical annealing temperature has a great influence on the microstructure obtained by continuous annealing process, especially on the martensite content and morphology in dual phase steel. With the increase of temperature, the martensite content generally increases, about 30%, 24%, 41% and 35% at 700℃, 720℃, 740℃ and 760℃ respectively. And due to the increase of martensite content, some martensite islands are connected into blocks.

(2) With the increase of intercritical annealing temperature, the strip ferrite in rolling state gradually tends to be equiaxed and the grains generally show a growth trend.
(3) High degree of austenitization is beneficial for the increase of martensite content, while the production of ferrite during slow cooling will reduce the martensite content. The two are in a trade-off relationship. The periodic decline of martensite content in this study may be that due to the increase of temperature, more oriented epigenic ferrite are generated when this increase is not enough to cause more austenite.

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