Effect of Annealing Process on Flanging Formability of 590MPa Grade Galvannealing Dual Phase Steel

LI Huiyuan1, DAI Jietao2, a, CHEN Yuanjun1, CHEN Jiangfeng1, LI Liejun3

1Guangzhou JFE Steel Sheet Company Ltd. Guangzhou 511462, China;  
2Guangzhou University School of Mechanic and Electric Engineering, Guangzhou 510006, China;  
3South China University of Technology School of Mechanical & Automotive Engineering, Guangzhou 510641, China

lihy@gjss.com.cn  a djt66008@163.com

Abstract: The DP590GA were widely used in automobile structural parts, which are mainly press-forming by stretch-flange. However, the hole expansion ratio (HE%) of dual phase steel is relatively low, which is not good for stretch-flange of automobile parts. In order to improve this situation, the effect of annealing process on flanging formability of C-Mn series 590MPa grade galvannealing dual phase steel was studied. In this study, the hole expanding test and microstructure of the test steel were investigated under different annealing temperature and rapid cooling temperature. The results of this investigation revealed following conclusions. The hole expansion ratio of the test steel increases with the increases of annealing temperature, and decreases with the increase of rapid cooling temperature. During hole expanding, the volume fractions of phases influence the flanging formability. When the proportion difference between ferrite phase and martensite phase is obvious, the hole expansion ratio is poor. And the proportion difference between ferrite phase and martensite phase is decreases, or the bainite phase was small amount appeared, the hole expansion ratio was increased.

1. Introduction

With the gradual promotion of automobile lightweight, the proportion of advanced high strength steel is increasing. Dual phase steel is a typical advanced high strength steel. Its microstructure is mainly composed of ferrite and martensite. It has the characteristics of low yield ratio, high initial work hardening rate, good strength and plasticity matching. It has become a new type of stamping steel with high strength and good formability. It is one of the main products of automobile steel at present [1, 2]. With the improvement of automobile corrosion resistance requirements, a large number of galvanized steel sheets are used in automobile body, and the average consumption of galvanized steel sheets accounts for more than 80% of the total steel plates for medium and high-grade cars [3, 4, 5]. At present, the galvannealing dual phase steel DP590GA has been widely used in Japanese car to replace the lower strength steel. The high strength steel is mainly used to manufacture structural components by bending forming and flanging forming. For ferritic/martensitic dual-phase steel, the flanging cracking is easy to occur in stamping production, which affects the use of dual phase steel. Therefore, it is necessary to study and improve the hole expansion ratio of dual phase steel to reduce flanging cracking.
Based on the problems of the G company in the production and application of galvannealing dual phase steel DP590GA, in this study, the hole expansion ratio was investigated under the phase transformation of the steel and the influence of annealing process. On the premise of not changing the steel composition, the annealing process during continuous hot dip galvanizing is optimized to improve the hole expansion performance of dual phase steel, so as to improve the flanging formability of the DP590GA in stamping production.

2. Experimental Procedures
The DP590GA sheets were investigated in this study. The test steel is galvannealing dual phase steel produced by G company. The chemical composition is shown in Table 1. The test steel sheets were smelted, continuously cast and hot rolled to 3.2mm thick hot rolled coil in J company. Then the test steel sheets were rolled into 1.6mm thickness in PLTCM of G company. The cold rolling reduction ratio is 50%. The test steel sheets were annealed and galvannealed in CGL of G company. There are two kinds of conditions in this test. The first condition is annealing at 770°C and then is cooling to different temperatures. The second condition is annealing at different temperatures in the two-phase region and then is cooling to 525°C and then is cooling to room temperature. The detailed test conditions are shown in Table 2.

| Sample No. | Anneal Temperature (°C) | Rapid Cooling Temperature (°C) | HE (%) |
|------------|-------------------------|-------------------------------|--------|
| 1#         | 770                     | 505                           | 46     |
| 2#         | 770                     | 515                           | 39     |
| 3#         | 770                     | 525                           | 24     |
| 4#         | 770                     | 535                           | 21     |
| 5#         | 790                     | 525                           | 31     |
| 6#         | 810                     | 525                           | 38     |
| 7#         | 830                     | 525                           | 47     |
| 8#         | 850                     | 525                           | 52     |

3. Results
3.1 Hole Expansion Properties
The test steel is produced by different annealing processes in the CGL. Stretch-flange-formability was evaluated by the hole-expanding test standardized by ISO 16630. The 150mm square samples with punched hole of 10 mm diameter at the center were used. The hole-expanding tests were evaluated with SAS 200dt-01 forming testing machine. The hole expansion ratio under different annealing processes are shown in Table 2.

The relationship between hole expansion properties and annealing temperature or rapid cooling temperature is shown in Figure 1. It can be found that the HE (%) is increases gradually with the increase of annealing temperature. And the HE (%) is decreases gradually with the increase of rapid cooling temperature.
3.2 Microstructures at Different Annealing Temperature
Samples were taken from different annealing temperatures and the microstructure were analyzed. The specimens were taken along the rolling direction at square of the width direction of the steel plate, etched with 1% nitric acid alcohol, and then the microstructure of RD was observed by SEM at Hitachi su-1500. The results are shown in Figure 2.

3.3 Microstructures at Different Rapid Cooling Temperature
Samples were taken from different rapid cooling temperatures and the microstructure were analyzed. The specimens were taken along the rolling direction at square of the width direction of the steel plate, etched with 1% nitric acid alcohol, and then the microstructure of RD was observed by SEM at Hitachi su-1500. The results are shown in Figure 3.
Fig. 2 Microstructure of the tested steel under different annealing temperatures
(a) 790°C; (b) 790°C; (c) 810°C; (d) 830°C;
Fig. 3 Microstructure of the tested steel under different rapid cooling temperatures
(a) 505°C; (b) 515°C; (c) 525°C; (d) 535°C;

4. Discussion

4.1 Effect of Annealing Temperature on Hole Expansion Ratio
As shown in Figure 1, there was significant effect on the hole expansion ratio and annealing temperature. Through the analysis of the microstructure of the test steel, it can be found that the proportion of ferrite and martensite changes at different annealing temperatures. With the increase of austenitization temperature, the proportion of martensite in the steel increases and the proportion of ferrite decreases. The volume ratio of martensite to ferrite is the main factor affecting the hole expansion ratio of dual phase steel. Due to the great difference of properties between ferrite and martensite in dual phase steel, the bonding force between grain boundaries is weakened, and the deformation resistance of the two phases is different. In the process of hole expanding, the edge of the hole is subject to the tangential tensile stress. Under the external load, the ferrite first has a great plastic deformation, while the martensite can’t completely produce the corresponding deformation. The additional stress produced by different degrees leads to cracks, which often occur at the interface of two phases \([2, 6, 7, 8]\). In addition, ferrite and martensite two-phase cross-sections have poor resistance to crack propagation, and once cracks are generated, they are easy to propagate along the two-phase cross-section \([9, 10, 11]\).

The austenitizing temperature in the two-phase region directly affects the amount of austenite formed. With the increase of soaking temperature in the two-phase region, the amount of austenite formation increases. When the soaking temperature is too high, the amount of final martensite will increase significantly and become the dominant phase, resulting in a significant increase in yield strength \([1]\). When the test steel were annealed at 760°C, due to the low austenitizing temperature and incomplete austenization, the part without austenization exists in the form of recrystallized ferrite,
while the incomplete austenization makes less martensite produced by transformation, and the microstructure inhomogeneity in dual phase steel is relatively serious, which shows that the hole expansion ratio is low. When the annealing temperature increases to 790 °C, the distribution of martensite is relatively uniform, but the grain size of ferrite is still uneven; when the annealing temperature is increased to 820 °C, the uniformity of ferrite grain size is greatly improved, and the deformation of the material is more uniform during plastic deformation, and there is no obvious stress concentration phenomenon. However, when the annealing temperature continues to increase to 850 °C, the degree of austenization is relatively high, the proportion of ferrite produced by transformation decreases, the proportion of martensite increases, and the proportion difference of two phases increases compared with that of low temperature annealing, which shows that the hole expansion ratio increases with the increase of annealing temperature.

4.2 Effect of Rapid Cooling Temperature on Hole Expansion Ratio
Because the main factor affecting the mechanical properties of dual phase steel is the content of martensite. And the martensite is obtained by transformation in the cooling process. Therefore, the Ms point of test steel is calculated by empirical formula. Whether using Andrew's formula (1965) of formula (1) or other formula (2) \[12, 13\], the Ms point of test steel is estimated to be about 447 °C.

\[
\begin{align*}
Ms(\degree C) &= 599 - 423C - 30.4Mn - 12.1Cr - 17.7Ni - 7.5Mn \\
Ms(\degree C) &= 550 - 316C - 35Mn - 35V - 20Cr - 17Ni - 10Cu - 5Mo + 30A
\end{align*}
\]

According the calculated, when the rapid cooling temperature is above 500 °C, the martensitic transformation does not occur in the steel. The contents of austenite in the steel is affected by the rapid cooling temperature, which affects the content of martensite in the test steel. When the rapid cooling temperature is low, a small amount of bainite transformation occurs, and the remaining austenite transforms into martensite in the final cooling stage. However, when the rapid cooling temperature is higher, the small amount of bainite transformation were occurs, and the more amount of austenite were retained in the final cooling stage. Thus, the more amount of martensite was transformed in the test steel. However, for the steel containing bainite, the difference in properties between bainite and ferrite is not as great as that between martensite and ferrite, which makes bainite and ferrite show a certain compatibility in the plastic deformation stage, and the deformation is more harmonious. When the large plastic deformation of the ferrite were produced, the bainite was yield. The probability of voids or microcracks at the interface of dual-phases were reduced. \[6,7,8\]. By comparing the metallographic structures at different rapid cooling temperatures in Figure 4, it can also be found that when the rapid cooling temperature was 505°C, the amount of martensite produced by transformation was the least, thus the hole expansion ratio of the test steel is the highest. However, when the rapid cooling temperature is increased to 535°C, the proportion of martensite in the steel increases obviously, which leads to the decrease of the hole expansion ratio.

5. Conclusions
1) The hole expansion ratio of hot-dip galvanized steel sheet increases with the increase of annealing temperature. The reason is that the proportion of martensite in steel increases with the increase of annealing temperature. And the inhomogeneity of ferrite and martensite phases were decreased. As a result, the hole expansion ratio of the test steel was increased.

2) The effect of the rapid cooling temperature on the hole expansion ratio of the test steel were obviously. When the rapid cooling temperature is low, a small amount of bainite were appeared in the steel. The inhomogeneity of ferrite and martensite phases in test steel were reduced. As a result, the hole expansion ratio of the test steel was improved.
Acknowledgements
The authors gratefully acknowledge the financial support of Guangzhou Science and Technology Plan Project [grant number: 201804010168]; And Guangzhou Key Area R&D Program Project [grant number: 202007020007].

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