Effects of Different Baking Temperature on Three-Point Bending Properties of 1800 MPa Al-Si Coating Hot Stamping Steel

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Abstract. To study the effects of baking temperature on the three-point bending properties of 1800 MPa hot stamping steel, cold-rolled 1800 MPa hot stamping steel with Al-Si coating was used. The heating condition was 930 °C for 300 s, after hot stamping, the samples were baking under 140 °C, 170 °C, 200 °C, 230 °C and 260°C respectively. SEM were used to analysis the microstructure of the samples. The bending tests were carried out according to VDA 238-100. The results show that baking process can effectively improve the bending properties of 1800 MPa hot stamping steel. After baking under 260 °C, the bending angle increased by 43%. After baking, the microstructure is martensite, tempered martensite and carbides. In conclusion, baking process can improve the three-point bending properties of 1800 MPa hot stamping steel.

Keywords: 1800 MPa hot stamping steel · Three-point properties · Microstructure

1 Introduction

With the vigorous development of China's new energy vehicle industry, the design requirements for BIW are becoming more and more strict. BIW is now developing towards high safety and lightweight. This puts forward higher requirements for materials of BIW, so high-strength automobile steel have been widely concerned at present. Among the currently used high-strength steels, hot stamping steel has the highest strength grade, so it is usually used in some structural safety parts such as: A pillar, B pillar and door impact beam. The hot stamping process can avoid the serious phenomena of stamping cracking and spring back in the traditional cold forming process, so the hot stamping technology has been developed rapidly. With the higher requirements for automobile crash safety, hot stamping steel is also developing towards a higher strength level. At present, 1800 MPa and 2000 MPa hot stamping steels have been developed and have been used in car bodies [1, 2]. In order to avoid the generation of iron oxide scale during material heating, hot stamping steel with coating is usually used for hot forming production. The commonly used coating for hot stamping steel is aluminum-silicon (Al-Si) coating. Al-Si coating has excellent high temperature resistance and can protect the

Y. Zhang and M. Ma (Eds.): ICHSU 2022, AHMST 2, pp. 53–58, 2023.
https://doi.org/10.2991/978-94-6463-114-2_8

surface of materials under high temperature heating conditions [3]. Furthermore, the production technology of Al-Si coating is the most mature among all the coatings of hot stamping steels.

In the process of using ultra-high strength steel, not only the strength but also the toughness of the material should be considered. If the toughness of the material is insufficient, the brittle fracture of the material will occur during the collision, which will harm the safety of passengers. At present, VDA 238-100 standard is usually used to measure the ultimate cold bending angle of high-strength steel to evaluate the toughness of materials [4, 5]. However, the Fe-Al-Si ternary phase can be formed in the Al-Si coating after heating, which will reduce the plasticity of the coating, resulting in the reduction of mechanical properties of the material [6]. Therefore, it is necessary to study the three-point bending properties of 1800 MPa hot stamping steel with Al-Si coating.

2 Experiments

2.1 Experiments Materials

The base material used in the paper was 1800 MPa hot stamping steel with Al-Si coating. The chemical composition (wt.%) of the steel was 0.34 C, 0.25 Si, 1.4 Mn, 0.2 Cr, 0.05 Al and 0.003 B, the others were Fe and inevitable impurities. The bath composition (wt.%) was 90 Al and 10 Si.

2.2 Experiments Methods

Samples were cut by wire cutting and the size were 350 mm $\times$ 300 mm $\times$ 1.6 mm. The samples were heated in box furnace and the austenitizing temperature was 930 °C, the dwell time was 300 s. After heating, samples were quickly transferred to 3000 KN hydraulic press for plate die cooling and the press holding time was 12 s. Then the samples were baking under 140 °C, 170 °C, 200 °C, 230 °C and 260 °C respectively for 20 min. After cooling, metallographic specimens were cut to 15 mm $\times$ 15 mm $\times$ 1.6 mm by wire cutting on each sample. 150#, 600#, 800#, 1500# and 2000# sandpapers were used to polish specimen step by step. The microstructures of prepared specimens were analyzed and observed by SEM (Hitachi S-3400 N).

The materials after hot forming were processed into the tensile samples as shown in Fig. 1 by wire cutting. Tensile tests were carried by Zwick Z1200 Tensile testing machine with 0.0025 s^{-1} constant tensile rate and the experimental temperature was room temperature. Three times of repeated experiments were carried out under each hot stamping process condition. The average value was taken as the result, but the tensile curves were drawn by using only one of data.

The three-point bending experiment was carried out on the electronic universal material testing machine (Instron-5985). The ultimate cold bending angle was measured according to VDA238-100, and the sample size is 60 $\times$ 60 mm. The experimental temperature was room temperature and the experimental sample direction was rolling direction. Five groups of experiments were carried out at each baking temperature, and the average value was recorded. The experiment was carried out according to the schematic diagram shown in Fig. 2.

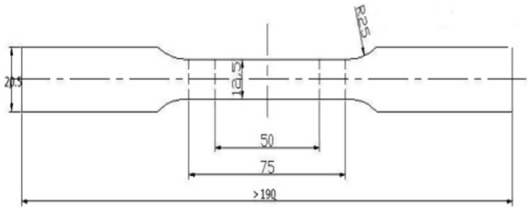

Fig. 1. The picture of tensile specimens used in the experiments.

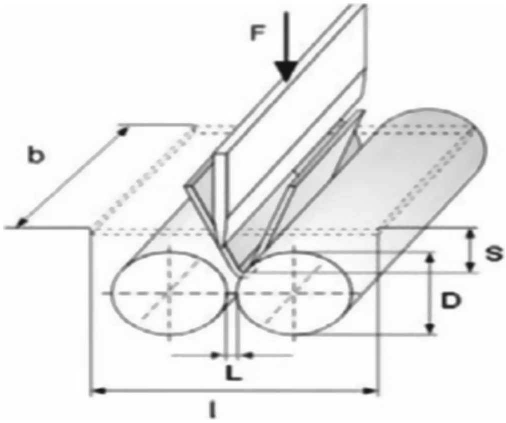

Fig. 2. Schematic diagram of the three-point bending angle experiment.

3 Results and Discussions

3.1 Microstructures Under Different Baking Temperature

According to Fig. 3(a), the microstructure of the material after hot stamping is martensite. When baking under 140 °C, there is no significant change in the microstructure of base steel. When the baking temperature rises to 200 °C, carbides begin to form in the microstructure. With the increase of baking temperature, the recovery degree of the material increases and the amount of tempered martensite increases at the same time [7].

3.2 Mechanical Properties Under Different Baking Temperature

It can be seen from Fig. 4 that with the increase of baking temperature, the tensile strength of the material decreases and the elongation increases. As the baking temperature increases, the content of tempered martensite in the material increases, resulting in the reduction of the tensile strength of the material. Due to the formation of carbides in the baking process, the yield strength of the material is slightly improved. When the baking temperature increases, the dislocation density and residual stress in the material decrease, so the elongation of the material increases.

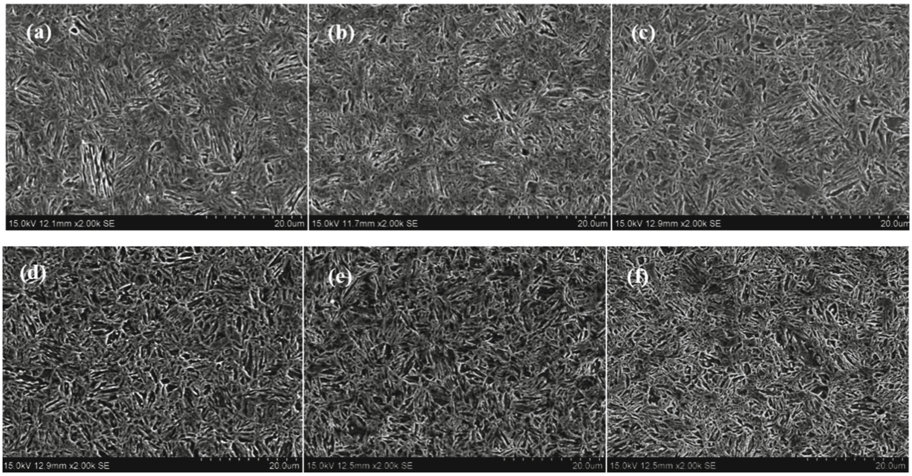

Fig. 3. Microstructures under different baking temperature for 20 min: (a) no baking, (b) 140 °C, (c) 170 °C, (d) 200 °C, (e) 230 °C, (f) 260 °C.

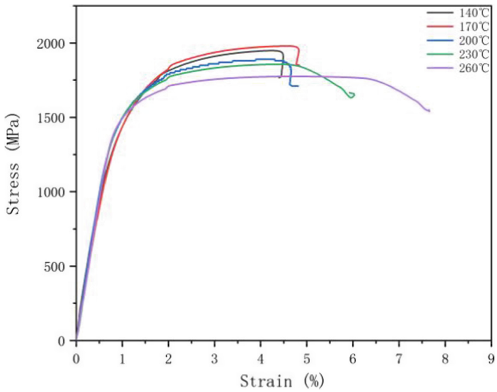

Fig. 4. Tensile curves of materials at different baking temperatures.

3.3 The Ultimate Bending Angle

The average ultimate bending angles under different baking temperature were: 33.12 (no baking), 40.50 (140 °C), 41.70 (170 °C), 44.79 (200 °C), 45.63 (230 °C) and 47.43 (260 °C). It can be seen from Fig. 5 that the ultimate cold bending angle of the material increases with the increase of baking temperature. After baking at 260 °C, the ultimate cold bending angle increased by 43%. As the tensile strength of the material after baking decreases, the maximum load during bending angle measurement also decreases.

It can be seen from Fig. 6. That, under all the condition, the crack propagation direction and stress direction form an intersection angle of 45°, so the material teared under the condition of plane stress. All the fracture mode is transgranular fracture and cracks penetrated across austenite grain boundaries, packet boundaries and block boundaries.

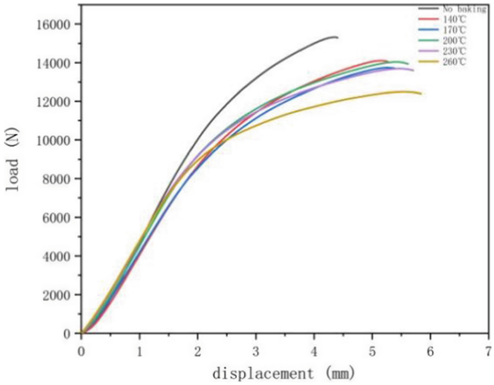

Fig. 5. Curve of force versus displacement in experiment of ultimate cold bending angle.

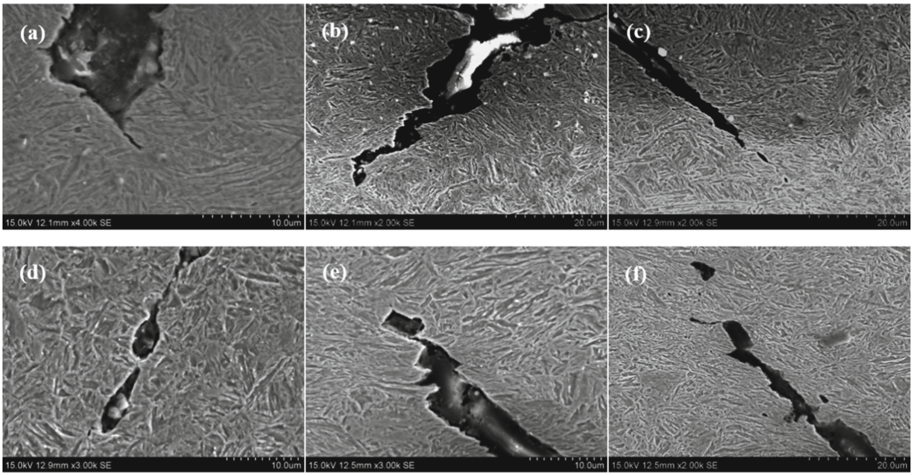

Fig. 6. Fracture section morphology at different baking temperatures: (a) no baking, (b) 140 °C, (c) 170 °C, (d) 200 °C, (e) 230 °C, (f) 260 °C.

In addition, the cracks end at the martensite lath and the crack direction is perpendicular to the martensite lath direction which indicating that martensite laths play a role in preventing crack propagation. When the baking temperature is 260 °C, there are holes around the cracks, which indicates that the plasticity of the material is good and dimples are formed during bending.

4 Conclusion

By analyzing the microstructure, mechanical properties and three-point bending properties of 1800 MPa Al-Si coating hot stamping steel under different baking temperatures, the following conclusions can be obtained.

(1) With the increase of baking temperature, the content of tempered martensite increases and the dislocation density decreases. When baking above 200 °C, carbides is formed inside the material.
(2) With the increase of baking temperature, the tensile strength of the material decreases, and the yield strength and elongation increase.
(3) Baking process can significantly improve the three-point bending performance of the material and increase the ultimate cold bending angle. With the increase of baking temperature, the three-point bending performance of the material is improved.

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