Phase structures of hot stamping zinc coating treated by multi-step rapid heating procedure

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In this study, a multi-step rapid heating procedure composed of two holding stages is developed to achieve fast alloying as well as less zinc loss of the zinc coating. The oxidation behavior during the first holding stage and the microstructure evolution during the final holding stage of the zinc coating are investigated. The results suggest that a continuous surface oxidation layer can be formed during the first dwell stage. In addition, the phase structures of the zinc-based coating treated by multi-step rapid heating show dramatic difference compared with that of the coating subjected to direct rapid heating. Furthermore, the zinc loss due to evaporation could be reduced by the multi-step rapid heating procedure.

Keywords: Hot stamping; Zinc coating; Multi-step rapid heating; Phase structures.

1. Introduction

The application of hot stamping parts has shown dramatic potential in weight reduction and anticollision performance improvement of car bodies in recent years [1, 2]. In hot stamping process of boron steel, coating systems are commonly adopted to prevent the steel substrate from surface oxidation. The zinc coating has drawn significant attention due to its remarkable cathodic protection for boron steel [3-5].

Nevertheless, the widespread application of zinc coating in hot stamping is limited by its metal induced embrittlement (MIE) risk to steel substrate [6, 7]. Rapid heating of zinc coated boron steel is one of the solutions to avoid MIE by facilitating coating alloying during austenization treatment [8]. However, the zinc coating might suffer from zinc loss due to zinc evaporation during direct rapid heating procedure. In this study, a multi-step rapid heating procedure is proposed to achieve fast alloying and less zinc loss of the zinc coating. The surface oxidation behavior and phase structures evolution of the coating are investigated.

2. Experimental Procedures

The material used is hot stamping boron steel sheet with hot-dip galvannealed zinc coating which is dominated by δ phase in as-delivered condition. A Gleeble thermo-mechanical simulator was adopted to conduct the heat treatment of zinc coated steel specimens. The

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heating rate during rapid heating was set as 100 °C/s. After holding at the heating temperature, the specimens were cooled to room temperature by compressed air.

According to the heat treatment conditions, the specimens were divided into three groups as shown in Table 1. The specimens in Group 1 were used to analyze the surface oxidation behavior of zinc coating during the first holding stage (Step 1) of the multi-step rapid heating procedure. The specimens in Group 2 were used to investigate the phase structures evolution of zinc coating during the final holding stage (Step 2) of the multi-step rapid heating procedure. As for Group 3, the specimens were treated by direct rapid heating (DRH) procedure. After rapid heating treatment, a scanning electron microscopy (SEM) was used to characterize the surface and cross-sectional morphologies of zinc coating.

Table 1. Heat treatment conditions of the zinc coated specimens.

Group	Heating temperature (°C)	Holding time (s)
1	Step 1: 820	30, 60
2	Step 1: 820 Step 2: 885	Step 1: 40 Step 2: 5, 20, 50, 100
3 (DRH)	885	45, 60, 90

3. Results and Discussion

3.1. *Surface oxidation behavior of zinc coating during the first holding stage*

The surface oxidation morphologies of the zinc coating after the first holding stage are shown in Fig. 1. When the specimen was heat treated at 820 °C for 30 s, almost the entire coating surface was covered by the oxide layer with few amounts of oxide particles (Fig. 1a). As the holding time was prolonged to 60 s, the ravined size of the oxide layer became larger (Fig. 1b). The formation of the continuous compact oxide layer on coating surface indicated effective suppression of zinc evaporation during subsequent heating procedure. Therefore, the holding time during holding stage Step 1 for the specimens in Group 2 were set as 40 s.

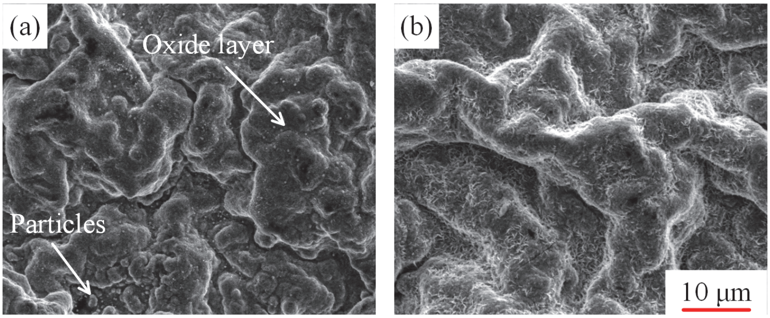

Fig. 1. Coating surface SEM morphologies of the Group 1 specimens holding for different time at 820 °C: (a) 30s; (b) 60s.

3.2. *Phase structures evolution of zinc coating during the final holding stage*

Figure 2 shows the SEM cross-sectional morphologies of the zinc coating after the final holding stage. When the holding time was 5 s, the coating is mainly composed of Γ phase and α-Fe(Zn) phase, with minor δ phase in the surface region (Fig. 2a). With the holding time increasing to 20 s, the δ phase disappeared, while the continuous α-Fe(Zn) layer became thicker with decreasing proportion of the Γ phase (Fig. 2b). As the holding time reached 50 s, the coating was dominated by the α-Fe(Zn) phase (Fig. 2c). The coating transformed into a complete α-Fe(Zn) layer with the holding time prolonged to 100 s (Fig. 2d). Under this condition, the sufficient alloying of zinc coating was achieved.

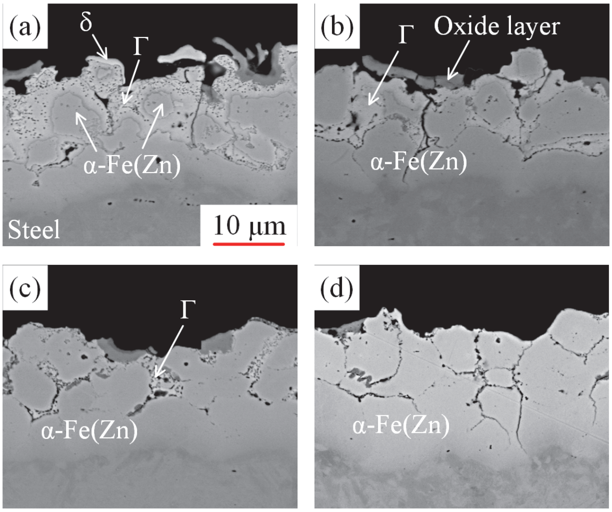

Fig. 2. Coating cross-sectional SEM morphologies of the Group 2 specimens subjected to different holding time during the final holding stage: (a) 5 s; (b) 20 s; (c) 50 s; (d) 100 s.

The SEM cross-sectional morphologies of the zinc coating treated by direct rapid heating procedure are illustrated in Fig. 3. It should be noted that the total heating times of the specimens in Fig. 3a and Fig. 3b were almost the same with that of the specimens in Fig. 2a and Fig. 2b respectively.

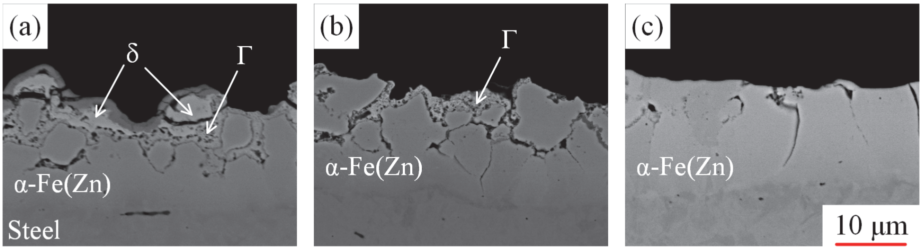

Fig. 3. Coating cross-sectional SEM morphologies of the Group 3 specimens subjected to different holding time during the direct rapid heating procedure: (a) 45 s; (b) 60 s; (c) 90 s.

It could be found that the phase structures of the zinc coating treated by multi-step rapid heating procedure showed dramatic difference with that of the zinc coating treated by direct rapid heating procedure. At a total holding time of 45 s, the δ phase almost disappeared in the coating subjected to multi-step rapid heating procedure, as shown in Fig. 2a. As a contrast, the zinc coating treated by direct rapid heating procedure demonstrated a three-layer phase structures (Fig. 3a). With the holding time increasing to 60 s, the δ phase disappeared and the coating was dominated by the α-Fe(Zn) phase (Fig. 3b). At a holding time of 90 s, the zinc coating transformed into a complete α-Fe(Zn) layer (Fig. 3c). However, the thickness of the α-Fe(Zn) coating treated by DRH procedure was significantly smaller than that of the α-Fe(Zn) coating shown in Fig. 2d. This suggests that the zinc loss due to evaporation could be reduced by the multi-step rapid heating procedure.

4. Conclusions

During the first holding stage of the multi-step rapid heating procedure, a continuous oxidation layer could be formed as the holding time reached 30 s. The phase structures of the zinc coating treated by multi-step rapid heating was dramatically different from that of the zinc coating treated by direct rapid heating. With the holding time increasing from 5 s to 100 s during the final holding stage, the zinc coating dominated by Γ phase and α-Fe(Zn) phase gradually transformed into a complete α-Fe(Zn) layer. Furthermore, the zinc loss due to evaporation was reduced by the multi-step rapid heating procedure.

Acknowledgments

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References

1. J. Q. Li, C. P. Tong, R. Q. Zhang, Z. S. Shi and J. G. Lin, A data-informed review of scientific and technological developments and future trends in hot stamping, *Int. J. Lightweight Mater. Manuf.* **7**, 327 (2024).
2. Y. S. Zhang, Z. J. Wang and L. Wang, Progress in hot stamping process and equipment for high strength steel sheet, *J. Plast. Eng.* **25**, 11 (2018).
3. A. Ghiotti, S. Bruschi, F. Sgarabotto and P. F. Bariani, Tribological performances of Zn-based coating in direct hot stamping, *Tribol. Int.* **78**, 142 (2014).
4. T. Taylor and A. Clough, Critical review of automotive hot-stamped sheet steel from an industrial perspective, *Mater. Sci. Technol.* **34**, 809 (2018).
5. K. Wang, B. Zhu, Z. J. Wang, Y. Liu, L. Wang, Y. S. Zhang and S. Q. Li, Successive phase and morphology evolution of galvannealed coating in hot stamping and diffusion modeling of α-Fe(Zn)/steel system considering the effect of Zn concentration, *Surf. Coat. Tech.* **380**, 125036 (2019).
6. M. Arndt, P. Kürnsteiner, T. Truglas, J. Duchoslav, K. Hingerl, D. Stifter, C. Commenda, J. Haslmayr, S. Kolnberger, J. Faderl and H. Groiss, Multiscale

Investigation of Microcracks and Grain Boundary Wetting in Press-Hardened Galvanized 20MnB8 Steel, *Metals* **14**, 46 (2024).

7. W. J. Peng, G. X. Wu and J. Y. Zhang, In-situ observation of liquid zinc-induced erosion behavior diffusion mechanism in zinc-coated 22MnB5 steel, *J. Mater. Res. Technol.* **9**, 4399 (2020).
8. K. Wang, D. Y. Fang, B. Zhu, Y. L. Wang, Y. S. Zhang, Z. Z. Wang, W. Z. Dong and Q. Q. Lin, The influence of heating rate on phase transformation of ZnFe coating in hot stamping, in *Proceedings of the 6th International Conference on Advanced High Strength Steel and Press Hardening (ICHSU2022)*, (Wuhan, China, 2022).