Research and Application of Hot Stamping Process for High Strength Steel Zinc-Based Coated Sheet

Q. Wang[1](✉), X. Q. Zhang[2], B. Zhu[3], Y. L. Wang[3], and Y. S. Zhang[3]

[1] Anhui HST Automotive Parts Co., Ltd., HeFei 237005, China
huakewq@126.com
[2] Wuhan Zhongyu Dingli Intelligent Technology Co., Ltd., Wuhan 430061, China
[3] School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China

Abstract. High-strength steel hot-formed parts are widely used as safety protection parts for automobiles due to their ultra-high strength (1500–2000 MPa). In order to prevent the oxidation and decarburization of traditional high-strength steel sheets during the heating process of hot forming, and at the same time enhance the corrosion resistance of hot-formed parts, galvanized high-strength steel sheets have been applied. The hot forming process of galvanized high-strength steel plate is studied, the mechanism of LMIE crack generation is analyzed, and the hot-forming process route suitable for galvanized high-strength steel plate is formulated. The key process parameters in the hot stamping process of zinc-based plated sheets, namely heating temperature, holding time, effective range and effect of forming temperature, are studied. Short-term heating, pre-cooling forming, shortening the holding time of the sheet, and then reducing the temperature of the sheet to a certain extent by a specific method before forming, the results show that when the forming temperature is low (700 °C), the matrix basically has no cracks. The reduction of the forming temperature is beneficial to the elimination of liquid zinc in the coating, thereby preventing the occurrence of LMIE phenomenon. In addition, when the forming temperature is low, the matrix phase transition temperature range becomes narrow, and the rate of forming cooling is required to be higher. The new generation of zinc-based coated sheets can improve the low temperature hardenability, which is beneficial to the pre-cooling low temperature forming process, which can be regarded as the future direction.

Keywords: Hot stamping · Zinc-based coated sheet · Pre-cooling forming · LMIE crack

1 Introduction

In order to prevent the oxidation and decarburization of traditional high-strength steel sheets during the heating process of hot forming, and at the same time enhance the corrosion resistance of hot-formed parts, galvanized high-strength steel sheets have been applied. The hot forming process of galvanized high-strength steel plate is studied, the

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mechanism of LMIE crack generation is analyzed, and the hot-forming process route suitable for galvanized high-strength steel plate is formulated.

1.1 Oxidation and Decarburization

These problems in the hot forming process of uncoated high-strength steel plate seriously restrict the development and application of traditional high-strength steel. Therefore, it is necessary to add a surface protection method to the bare board, and the high-strength steel coating technology came into being, in which surface galvanizing was adopted as a long-standing method. Commonly coated high-strength steel surface coatings include Al-Si coating and Zn coating. Among them, Al-Si coating appeared earlier, and the related technology is relatively mature. As a new coating method, Zn-based coating has little related research and has a wide range of applications. Development prospects [1].

1.2 Zinc-Based Coated Sheet

Galvanized high-strength steels used for hot forming mainly include two types of pure zinc coating (GI) and alloyed zinc-based coating (GA). The GI coating is obtained by immersing the bare board in a zinc solution with a temperature of 445–455 °C for a period of time, and then taking it out for cooling to solidify the surface liquid zinc. The GA coating is obtained by thermally treating the pure zinc coating in the temperature range of 480–520 °C to promote the formation of a certain amount of Fe-Zn alloy phase in the coating and then cooling. Therefore, the coating in the GI coating is basically pure zinc, while the GA coating will contain Fe with a mass fraction of about 10%. It is worth mentioning that during the preparation of the GI coating, about 0.2% Al by mass will be added to the zinc liquid, so that a continuous Fe_2Al_5 inhibitory layer is formed at the liquid Zn/Fe interface, thereby preventing the interaction between iron and zinc. In the preparation process of GA coating, the mass fraction of Al added in the zinc solution is usually less than 0.15%, so that a continuous Fe_2Al_5 inhibitory layer cannot be formed, so that the Fe-Zn alloy phase can be formed smoothly [2].

After hot forming, the inside of the coating is mainly divided into three layers, namely the oxide layer on the surface, which is generally 1–2 μm, and the main components are ZnO and a small amount of Al_2O_3; the alloy layer in the middle includes various phases, and the phases contained in different process conditions. The composition and content are also different; the α-Fe layer, because it is close to the matrix, has a relatively high Fe content and is basically transformed into the α-Fe phase.

1.3 Hot Stamping Process of Galvanized Steel Sheet

The hot stamping state of the galvanized sheet has a strong sensitivity to the process parameters, and the traditional hot stamping process of the uncoated sheet cannot be fully applied to the hot stamping of the galvanized sheet. The cause of premature cracking of the matrix is Liquid metal induced embrittlement (LMIE) [3]. That is, when the liquid metal is in contact with another flexible metal, it will induce cracks in the flexible metal, and the cracks will be accompanied by stress expansion, which will eventually lead to premature cracking of the flexible metal. For hot forming of galvanized sheet, there is a relatively high risk of the LMIE phenomenon, because after heating to the austenitizing temperature, the coating surface exists in liquid form, and during the subsequent forming process, the coating is under tensile stress. When cracking occurs, the liquid Zn on the surface will penetrate into the matrix through the cracked coating, inducing cracks in the matrix and spreading along the grain boundaries, eventually leading to premature cracking of the matrix [4].

The difference between galvanized sheet and bare sheet in hot forming process is mainly that LMIE phenomenon may occur during hot forming process of galvanized sheet, and LMIE phenomenon is caused by the combination of applied stress and liquid zinc. The core of the hot forming process is to eliminate the existence of liquid zinc during forming by changing the process conditions.

2 Research on Hot Stamping Process Parameters

In order to roughly determine the effective working range of different process parameters, in order to lay the foundation for the next high temperature tensile experiment. The flat die experimental process is a typical hot stamping experimental process, that is, the sheet is first heated in a heating furnace to austenitize, and then quickly transferred to the cold die, and then the press is pressed down to complete the quenching on the die. The K-type thermocouple on the sheet collects the temperature of the sheet and reflects it on the computer in real time through the data acquisition system. The press used in the experiment is a 2000 KN electric servo press.

2.1 Influence of Heating Temperature

In order to study the effect of heating temperature on the heating process of the sheet and the performance of the parts, a 22MnB5 zinc-based coated plate was used, and six different heating temperatures of 850 °C, 860 °C, 870 °C, 880 °C, 890 °C, and 900 °C were set. The holding time is 5 min in total, and the sheet is transferred at the fastest speed for stamping.

After the hot stamping process of the sheet metal, take 5 points on the sheet at different heating temperatures to measure the Vickers hardness and take the average value. Elongation, and calculate the PSE (Product of Strength and Elongation), and the specific results are shown in Fig. 1.

To sum up, for the galvanized sheet, in order to ensure the surface quality of the coating and the mechanical properties of the substrate, the heating temperature should not be too high or too low, and the more suitable heating temperature range is 860–880 °C.

2.2 Influence of Holding Time

The average hardness of the punched sheet was measured at points and the mechanical properties were measured by making tensile samples. The specific results are shown in Fig. 2. From Fig. 2(a), it can be seen that except for the heating time of 6 min, the

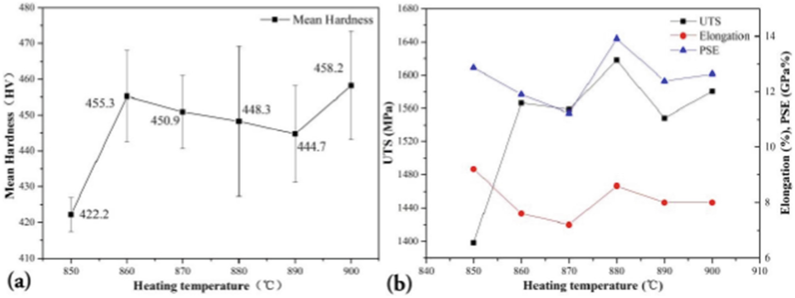

Fig. 1. Average hardness and mechanical properties at different heating temperatures: (a) average hardness; (b) mechanical properties.

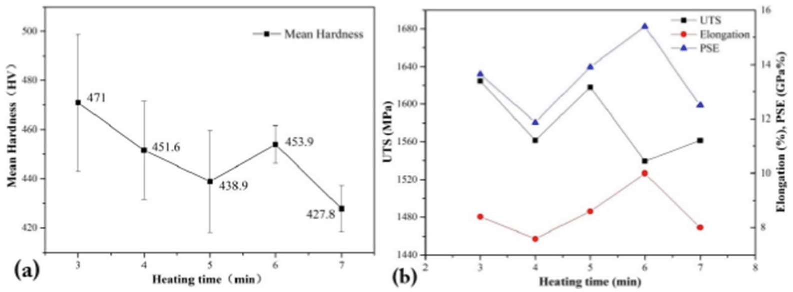

Fig. 2. Average hardness and mechanical properties under different holding times: (a) average hardness; (b) mechanical properties.

average hardness of the sheet decreases with the increase of the holding time as a whole. From the point of view of mechanical properties, the law is also similar. The longer the heating time, the lower the tensile strength, but the overall value is above 1500 MPa.

This is because the longer the holding time, the greater the growth of austenite grains, resulting in a certain reduction in the hardness and strength of the matrix. Overall, the change of holding time has little effect on the mechanical properties of the matrix.

3 Stamping Experiment of Zinc-Based Plated Auto Parts

The mold used in the experiment is a hot stamping mold used in the production of automobile anti-collision beams. The three-dimensional model of the part is shown in Fig. 3(a). During the experiment, the sheet metal first completed the heating and heat preservation process in the box-type heating furnace, and then the sheet metal was taken out from the heating furnace and transferred to the mold by the manipulator, and then the in-mold forming and quenching were completed under the pressure of the servo press, the whole process is basically automated.

Scheme I, the heating temperature is set to 880 °C, and four sets of different heating times are set, which are 2 min, 3 min, 5 min, and 6 min respectively, and then the sheet is quickly transferred to the mold and formed at a temperature of 800 °C. The formed parts with different heating times are shown in Fig. 3(b).

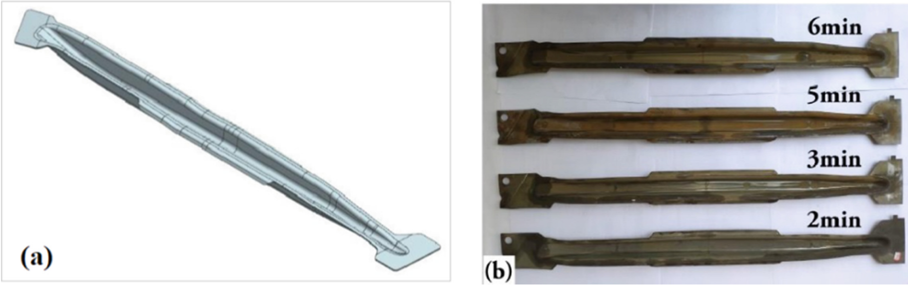

Fig. 3. A 3D model of the part and the actual picture of forming: (a) 3D picture of the part; (b) actual photo of the hot stamping part.

Fig. 4. Parts formed by pre-cooling and hot stamping of the A-pillar of the zinc-based plated sheet.

Scheme II, the heating temperature is set to 880 °C, and the heating time is set to 3 min. After the sheet is taken out of the heating furnace, it is allowed to stand in the air for 10 s, and then placed on the mold to form at a temperature of 700 °C.

4 Results and Discussion

Trial-produced a certain type of car door inner anti-collision beam, carried out experiments under different heating times and different forming temperatures, and analyzed the surface state of the parts, the occurrence of micro-cracks and the mechanical properties of the parts to verify the feasibility of the process plan and determine the final and reasonable process route. The specific conclusions are as follows:

(1) Long-term heating and direct forming, that is, the sheet material can be directly and quickly transferred to the mold for forming after a certain period of heat preservation. The results show that when the heating temperature is 880 °C and the heating time exceeds 3 min, the sheet metal is directly transferred to form, the parts will not have defects caused by the LMIE phenomenon, and the mechanical properties of the matrix can meet the requirements of thermoforming parts; when the heating time is less than when it is equal to 3 min, the coating is seriously damaged at the place where the deformation is large, and the substrate also has deep cracks. The above results are produced because the prolongation of the holding time is conducive to the elimination of liquid zinc, thereby preventing the occurrence of LMIE

phenomenon. Therefore, when the heating temperature is 880 °C, the heating time exceeds 3 min to directly transfer the sheet metal forming, which also proves that "long-term heating", "direct forming" process scheme is feasible.

(2) Short-term heating and pre-cooling forming, that is, using a short holding time, and then quickly reducing the temperature of the sheet to a certain degree by a specific method before forming. The results show that when the heating temperature is 880 °C, the heating time is 3 min, and the forming temperature is low (about 700 °C), there is basically no cracks in the matrix, and when the forming temperature is high (800 °C), microcracks appear in the matrix. Because the reduction of the forming temperature is beneficial to the elimination of liquid zinc in the coating, thereby preventing the occurrence of LMIE phenomenon. In addition, when the forming temperature is 700 °C, the tensile strength of the matrix is low, and the mechanical properties are not up to the standard, see Fig. 4. This is because the cooling rate in the pre-cooling stage is too slow, resulting in insufficient martensite transformation after quenching. For the feasibility of the "cold forming" process plan, it is necessary to increase the cooling rate in the pre-cooling stage as much as possible.

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