Study on Austenitizing Process in Hot Stamping of 2000 MPa Grade Ultra-High Strength Steel

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Abstract. With the rapid development of the automobile industry and the increasing requirement of the environmental protection, ultra-high strength hot stamping steel is widely used in body parts of the car. In this paper, the precipitation changes of the second phase particles and CCT curves of 2000 MPa ultra-high strength steel under different austenitizing conditions are studied by the thermodynamic calculations and simulations. The effects of austenitizing temperature, holding time and cooling rate on the quenching transformation behaviors of the steel in the hot stamping process are explored. The microstructure differences on the surface and internal positions of the steel in the austenitizing quenching process are compared and analyzed. The austenitizing process parameters suitable for 2000 MPa ultra-high strength hot stamping steel are formulated, which provides a theoretical basis for the formulation of 2000 MPa ultra-high strength steel in the hot stamping process.

Keywords: Hot stamping · Steel · Microstructures · Phase transition

1 Introduction

With the rapid development of automobile industry at home and abroad, the development and application of ultra-high strength hot stamping steel has gradually become an important way to improve the body strength and reduce the body weight. At present, 22MnB5 steel, which is still 1500 MPa grade, is still widely used in car bodies, and has gradually failed to meet the requirements of car enterprises for the use of higher strength automotive steel. It is of great significance to study and develop the composition and phase transformation behavior of hot stamping steel with higher strength to improve the performance of automotive body and reduce exhaust emissions.

Many scholars at home and abroad have studied the composition development and transformation behavior of ultra-high strength steel for automobile. Naderi et al. [1] studied the deformation behaviors of 22MnB5 steel under non-isothermal conditions, and found that the higher initial deformation temperature resulted in a higher proportion of martensite in the microstructures, and the change of martensite initial temperature

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could be ignored. Not only the starting temperature of martensite, but also the amount of martensite decreased by applying higher strain and higher force level. Guo et al. [2] studied some basic properties and applications of hot stamping steel for vehicles, and obtained basic mechanical properties such as tensile strength, bending strength and stress-strain relationships of 22MnB5, and obtained key process parameters in the hot stamping process. Hou et al. [3] studied the effects of heating temperature on the microstructures and austenite grains of 22MnB5, and found that with the increase of heating temperature, the width of martensite lath bundle and austenite grain size of sheet microstructure increase. At 900 °C, the grain size was moderate and evenly distributed, and the grain size shown by oxidation method was smaller than that shown by grain boundary corrosion method. At present, there are still lack of systematic research on the composition designs and hot stamping behaviors of 2000 MPa ultra-high strength hot stamping steel. The development of 2000 MPa ultra-high strength hot stamping steel, the formulation of a reasonable process, and the exploration of its phase transformation behaviors in the hot stamping process are of great significance to the development of the automotive industry.

In this paper, the precipitation behaviors of the second phase particles, CCT curves and phase transformation behaviors of a 2000 MPa ultra-high strength steel were studied by means of thermodynamics and numerical simulations. The effects of austenitizing temperature, holding time and cooling rate on the quenching transformation behaviors of the steel during hot stamping were discussed.

2 Research Methods

The compositions of 2000 MPa hot stamping steel used in this paper are shown in Table 1. Firstly, the precipitation behaviors of the second phase particles and CCT curves of 2000 MPa ultra-high strength hot stamping steel were calculated and studied by using JMatPro software. During the calculations of quenching transformations, the austenitizing temperatures ware 810 °C, 870 °C and 930 °C, and the austenitizing time was 5 min, and the cooling rates ware 10 °C/s, 20 °C/s and 30 °C/s, respectively. The die temperature was 100 °C. This calculations ware completed in the quench properties in the general steel module. Then, in order to deeply study the changes of the temperature fields and phase transformation processes of 2000 MPa hot stamping steel, a thermal phase transformation coupling model of 2000 MPa steel [4] was established by using DEFORM software to predict and analyze the temperature fields and phase transformation behaviors of the steel under different composition conditions. Therefore, during the simulation calculations, the austenitizing temperature was 930 °C, and the holding time was 5 min, and the cooling rate was 40 °C/s. During the calculation, the initial phase microstructure of the sample was austenite, and the volume fraction was set as 1.0.

Table 1. Compositions of 2000 MPa ultra-high strength hot stamping steel.

C	Si	Mn	Al	Cr	B	Ti	Nb
0.38	0.6	2.3	0.05	1.1	0.005	0.05	0.05

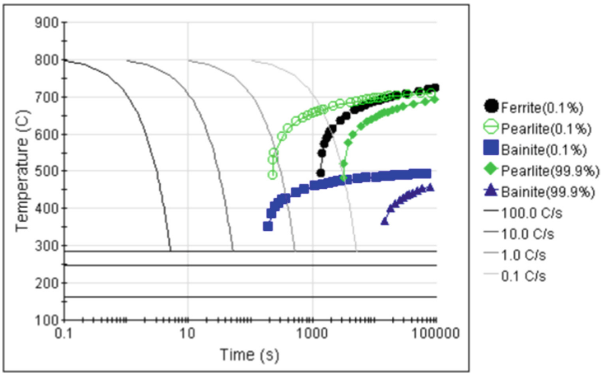

Fig. 1. CCT curve.

3 Results and Discussion

Figure 1 shows the CCT curve of 2000 MPa hot stamping steel. The results show that with the increase of the cooling rate, the microstructures after quenching gradually change from ferrite, pearlite, bainite and other mixed microstructures to full martensite. The initial transformation temperature of martensite is 284.5 °C, and the temperature when the martensite content reaches 90% is 162.5 °C. Therefore, controlling the die temperature at 100 °C can better ensure that the microstructures after quenching are full martensite.

Figure 2 shows the changes of Nb, Ti, C in M (C, N) phase of the steel during equilibrium cooling. When the temperature is high, the M (C, N) phase is dominated by Nb (C, N). When the temperature is low, the M (C, N) phase is mainly Ti (C, N). For the 2000 MPa ultra-high strength hot stamping steel, the quenched second phase particles contain Nb (C, N), Ti (C, N) at the same time.

Figure 3 shows the effects of holding temperature on quenching microstructures. During the calculations, the temperatures are 810 °C, 870 °C and 930 °C, respectively. The holding time is 5 min, and the quenching rate is 30 °C/s. When the holding temperature is 810 °C, the quenched microstructures contain a small amount of bainite; with the increase of the temperature, the bainite disappeared after quenching at 870 °C and 930 °C. Therefore, for this steel, the temperature is recommended to be 870 °C. The same method was used to study the effect of cooling rates. When the cooling rate is 10 °C/s, the steel still contains certain bainite. With the increase of the cooling rate, when the cooling rate reaches 20 °C/s and 30 °C/s, the bainite in the steel gradually disappears. Therefore, when the cooling rate is 20 °C/s, the requirement that the quenching microstructures in the steel is the coexistence of full martensite and retained austenite can be achieved.

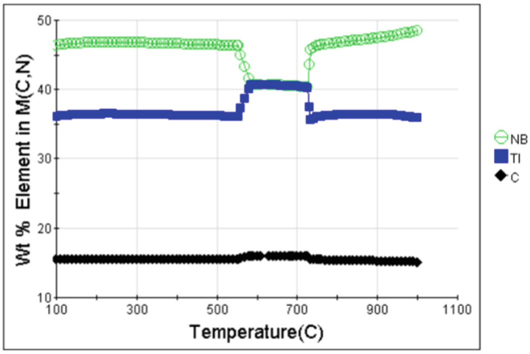

Fig. 2. Variations of element contents in M (C, N) phase with temperature.

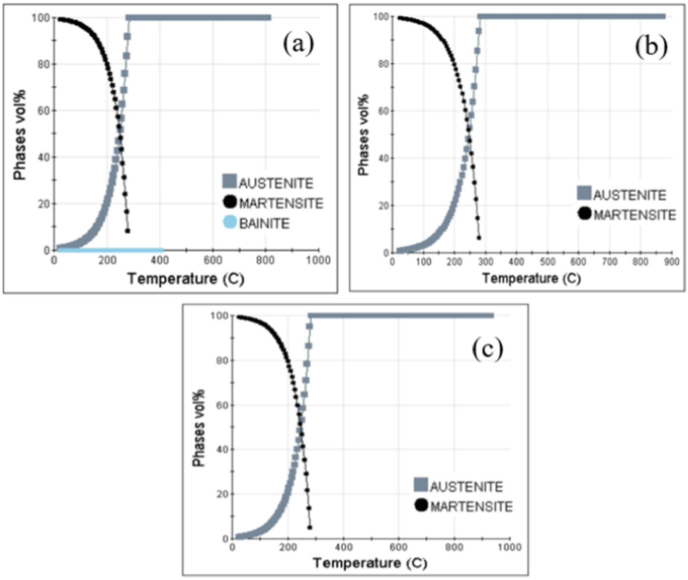

Fig. 3. Effects of holding temperature on quenching microstructures: (a) 810 °C, (b) 870 °C, (c) 930 °C.

Figure 4 shows the martensite change of the steel plate section during quenching. With the increase of the quenching time, the microstructures of the steel gradually change to full martensite and the distributions tend to be uniform. When the quenching time reaches 20 s, the average martensite content of the steel is 0.952. With the increase of quenching time, the average martensite content in the steel will continue to increase. The existence of a large amount of martensite can better ensure the strength of the hot stamping steel after quenching.

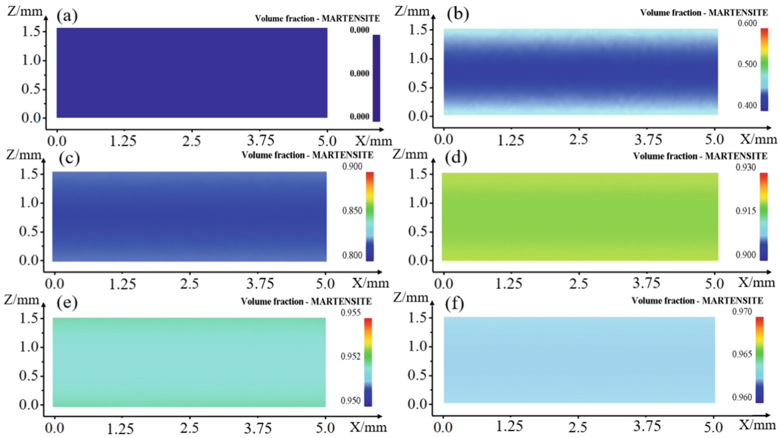

Fig. 4. Martensite change of the steel section during quenching: (a) 0 s, (b) 4 s, (c) 8 s, (d) 12 s, (e) 16 s, (f) 20 s.

4 Conclusions

(1) When the holding temperature is 870 °C and the cooling rate is 20 °C/s, the formation of bainite can be avoided after quenching, and the coexistence microstructures of martensite and retained austenite can be obtained.

(2) With the increase of quenching time, the martensite in the quenched steel gradually increases and tends to be uniform. When the quenching time reaches 20 s, the average martensite content in the steel is 0.952.

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