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Effect of cooling path on phase transformation of boron steel 22MnB5

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Abstract

The properties of hot formed parts using boron steel are controlled by the microstructure evolved in hot working process. In order to obtain the required mechanical properties, the relationship among temperature history, phase transformation and final microstructure needs to be investigated and established. The dilatometric experiments with different cooling rates and dwell temperatures of boron steel 22MnB5 in different heat treatment processes were conducted to explore the effect of cooling path on the phase transformation of steel from austenite to ferrite, bainite and martensite. Metallographic analysis was then done to verify the existence of the corresponded microstructure of the heat treated specimen. The information about cooling parameters and phase transformation can thus help the design of hot forming process and the control of mechanical property of the parts formed.

1. Introduction

With the increasing requirements of vehicle safety and lightweight in automotive industry, the conventional hot stamped components with a full martensite state cannot meet the application requirements in terms of undergoing

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impact loading. Taking B-pillar as an instance, the ideal structure should have high strength in its upper region in order to resist intrusion, and low strength in the lower region to absorb crash energy (Bardelcik et al., 2012). Therefore, a new kind of hot stamped components with tailored mechanical properties need to be developed (Karbasian and Tekkaya, 2010), which can combine the capacities of anti-intrusion and energy absorption in one single part while minimizing additional manufacturing cost.

For the conventional hot stamped components, the major microstructure is martensite, but for the component with tailored mechanical properties, especially for its low strength region, the microstructure may consist of martensite, bainite and ferrite (George et al., 2012). Preparation of suitable microstructures requires the knowledge of phase transformation. Min et al. (2012) found that the incubation period of ferrite transformation of 22MnB5 is significantly shortened by isothermal deformation, and the isothermal deformation below start temperature of bainite transformation promotes bainite transformation obviously. Similarly, Barcellona et al. (2009) revealed that the large hot deformation in hot stamping process requires a strict control of cooling process such that the cooling rate facilitates the component with full martensite. The prior researches mainly focus on the effect of deformation on microstructure, thus, the effect of cooling path also needs to be explored in quenching process.

In this research, the relationship among cooling path, phase transformation, and the corresponded microstructure was explored. The dilatometric experiments with different cooling rates and dwell temperatures were conducted to determine the start and finish temperatures of different phase transformations with various temperature histories. Furthermore, the microstructures were also verified by the metallography results. The research can thus help design the cooling path of hot formed components with required tailored mechanical properties.

2. Dilatometric experiment

The obtained microstructure may consist of martensite, bainite and ferrite. The control and prediction of microstructure of steels is thus critical for ensuring the tailed-designed mechanical properties of 22MnB5 components. The detailed composition of boron steel 22MnB5 is shown in Table 1. The dilatometric tests were conducted on the DIL805 quench-deformation dilatometer. The specimen dimensions of boron steel are $1.4 \times 5 \times 10$ mm^3, in which the blank thickness is 1.4 mm and the length in rolling direction is 10 mm. The specimens were wire-electrode cut and then polished by abrasive paper. Thermocouple with a diameter of 0.2 mm was spot welded on the middle position of surface with the dimension of 5×10 mm^2 to record the temperature of specimen.

Table 1. Detailed composition of boron steel 22MnB5.

Elements	C	Mn	P	S	Si	Al	Ti	B	Cr
wt%	0.200	1.250	0.017	0.003	0.230	0.036	0.039	0.0037	0.190

In the testing, the specimen was heated to 900 °C with a constant heating rate of 15 °C /s, and kept for 5 minutes to obtain uniform austenite. The specimen was then quenched to room temperature with the cooling rate of 2, 10 and 50 °C /s directly and respectively, the cooling rates were chosen as indicated by the continuous cooling transformation diagram (Turetta, 2008). To determine the influence of dwell temperature over phase transformation, different dwell temperatures were applied. When the cooling rate is 2 °C /s, the dwell temperature is 750, 700, 650 and 500 °C; when the cooling rate is 10 °C /s, the dwell temperature is 700, 550, 500, 450, 400, 350 and 300 °C; and when the cooling rate is 50 °C /s, the dwell temperature is 700, 600, 500, 450, 400, 350 and 300 °C, respectively. The dwell time for all the conditions is 5 minutes.

3. Results and discussion

3.1. Start and finish temperatures of phase transformation

The specific volume of austenite is smallest compared to other phases with the same temperature condition (Kop et al., 2001). If there is no phase transformation occurred in an austenite state specimen, the specimen shrinks

according to the thermal expansion coefficient when it cools down directly. Therefore, when austenite is transformed to other phase, a variation appears in the dilatometric curve, which can be used to determine the start and finish temperatures of phase transformation.

For the cooling path with the cooling rate of 2 °C /s, as shown in Fig. 1, when the specimen was cooled down from 900 °C to room temperature directly, the phase transformations started at about 720 °C, and finished about 619 °C. According to the temperature range of phase transformation (Turetta, 2008), ferrite transformation thus can be confirmed. When the specimen dwelled at 700 °C and lower temperature, the transformation started at 716, 697, and 702 °C, respectively, but all finished at their dwell temperature. The transformation is thus easier to occur at the elevated temperature due to the better diffusion ability of atoms and a relatively small driving force needed for transformation (Offerman et al., 2002), the phase transformation thus occurred at 750 °C when the specimen dwelled at this temperature.
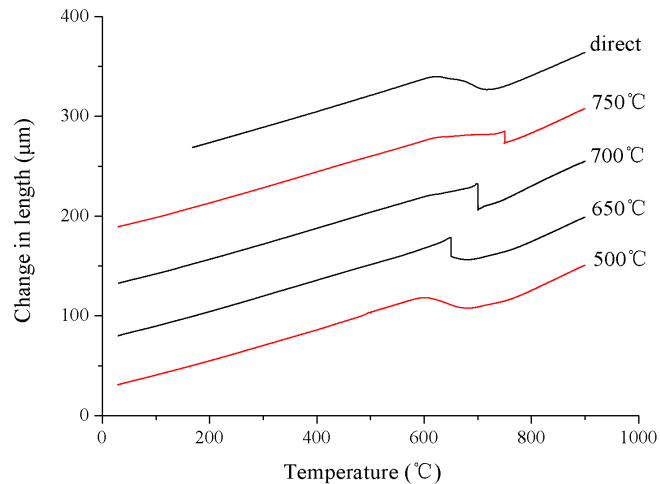

Fig. 1. Change in specimen length with the cooling rate of 2 °C /s.

As shown in Fig. 2, the specimen was quenched with the cooling rate of 50 °C/s. For the specimen cooled to room temperature directly, the martensite transformation started at 391 °C, finished at 315 °C. When the specimen was dwelled at 700 °C, the phase transformation started at the isothermal stage and ended at about 671 °C, therefore, ferrite transformation occurred. When the specimen dwelled at 600, 500 or 450 °C, which are located in the temperature range of bainite transformation, bainite should be the domain phase in the final microstructure. However, when the specimen was dwelled at 400 °C, the martensite transformation was completed at the dwell stage because of the temperature difference between surface and interior part of specimen. For the specimen dwelled at 350 °C or below, the martensite transformation started at about 390 °C and ended at about 315 °C.

With the cooling rate of 10 °C/s, as shown in Fig. 3, bainite transformation occurred when the specimen was cooled down directly with the start and finish temperatures of 660 and 513 °C, respectively. When the specimen dwelled at 700 °C which is located in the ferrite temperature range, ferrite transformation occurred during the isothermal stage. But the specimen dwelled at 550, 500 and 450 °C, the transformation started at about 710 °C and finished at the isothermal temperature, respectively. As they went through the temperature range of ferrite and bainite transformations, the finial microstructure should be a mixture of the two phases. But for the specimen dwelled at 400 °C and below, the start temperature is about 710 °C that ferrite transformation occurred. The transformation ended at its isothermal period, which is located at the temperature range of matensite transformation. The final microstructure should be consisting of ferrite, bainite and martensite.

Therefore, it can be found that ferrite transformation is easiest to occur as the cooling rate ensured, or the specimen dwelled in or near the temperature range of ferrite transformation without the consideration of cooling rate. Similarly, for bainite transformation, the specimen dwelled in or near the temperature range of bainite

transformation with the cooling rate equal or larger than critical cooling rate to produce bainite in boron steel specimen. From the viewpoint of manufacture, the low tensile strength region with ferrite and bainite in hot formed component with tailored mechanical properties is relatively simple to manufacture and control.
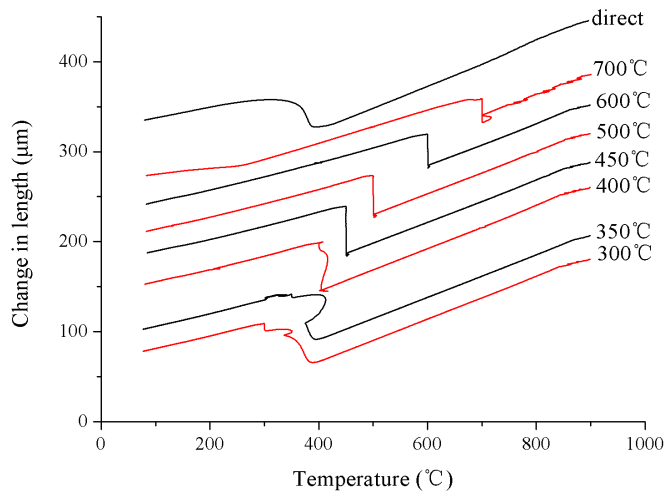
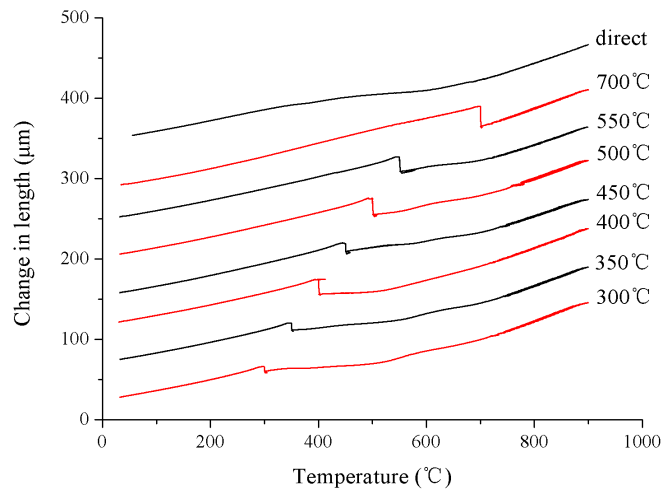Fig. 2. Change in specimen length with the cooling rate of 50 oC /s.

Fig. 3. Change in specimen length with the cooling rate of 10 ºC /s.

Compared to the ferrite and bainite transformations, martensite transformation is easily susceptible for the hot forming process, and the demand of cooling rate is more critical. So in order to obtain the high tensile strength region mainly consisting of martensite, the cooling rate for martensite transformation and the continuous cooling condition must be ensured.

3.2. Metallography

After dilatometric experiment, the specimens were studied by using the metallographic analysis. The specimens were mounted in epoxy resin, ground and polished to a mirror finish using 500, 1200 and 2000 grit SiC paper; followed by 3 and 1 μm diamond paste. A 4% nitric acid alcohol solution was used to reveal the microstructure.

Some typical microstructures with the cooling rate of 2, 50 and 10 °C/s are shown in Figs. 4-6, respectively. Through the observation of metallography, the microstructures with various cooling paths are found to be consistent with the analysis of dilatometric curves.
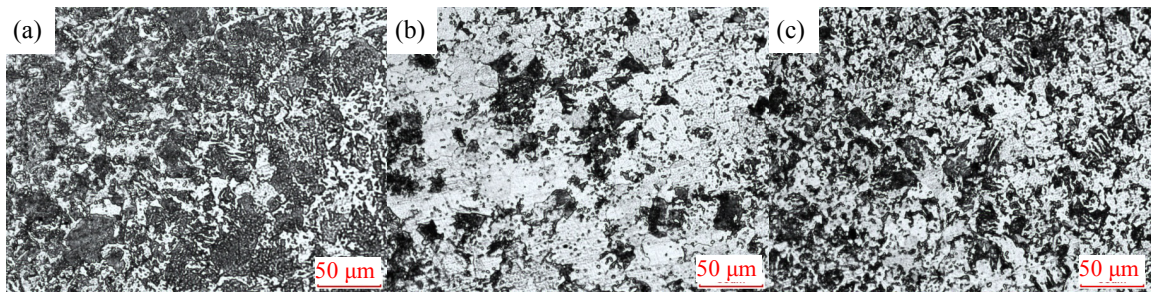

Fig. 4. Microstructures of specimen: (a) quenched to room temperature directly, or dwelled at (b) 750 and (c) 500 °C with the cooling rate of 2 °C/s.
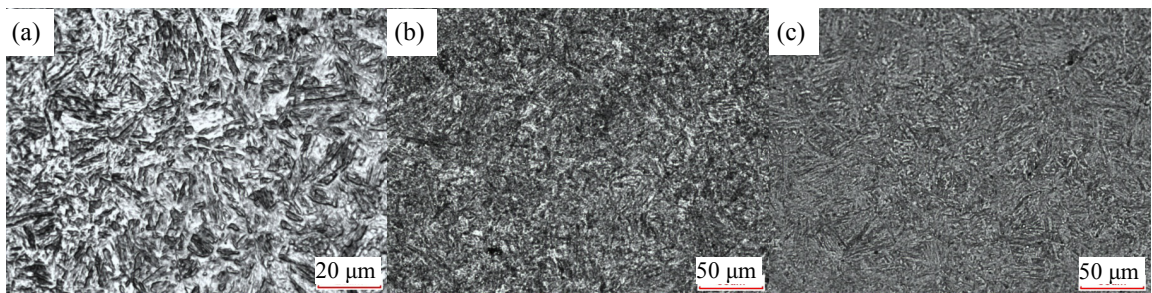

Fig. 5. Microstructures of specimen: (a) quenched to room temperature directly, or dwelled at (b) 450, and (c) 400 °C with the cooling rate of 50 °C/s.
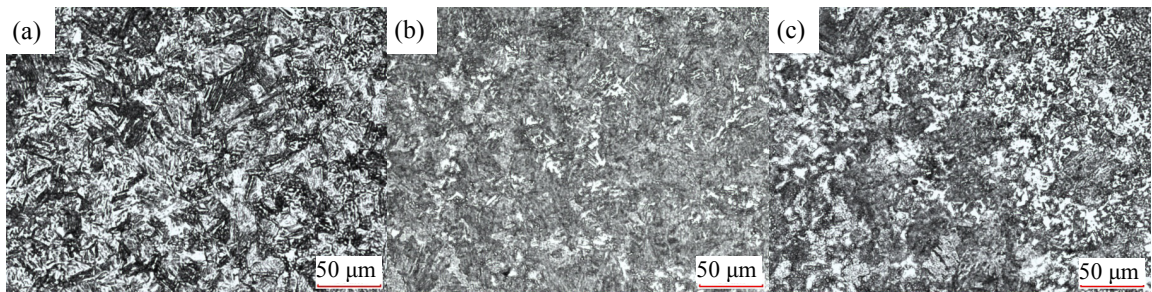

Fig. 6. Microstructures of specimen: (a) quenched to room temperature directly, or dwelled at (b) 700, and (c) 500 °C with the cooling rate of 10 °C/s.

For the cooling rate of 2 °C/s, the final microstructure is ferrite regardless the cooling path. For the specimen quenched directly to room temperature with the cooling rate of 50 °C/s, the final microstructure should be martensite. As the influence of dwell temperature, when specimen is dwelled at 450 and 400 °C, the microstructure is martensite and bainite, respectively. For the specimen quenched with the cooling rate of 10 °C/s, the specimen consists of bainite when it is cooled down without the isothermal period. However, when the specimen is dwelled at 700 °C, the microstructure mainly consist of ferrite and little bainite as the phase transformation mainly occurred in the temperature range of ferrite transformation. However, when the specimen is dwelled at 500 °C, bainite becomes the domain phase instead of ferrite. Therefore, the microstructure of the heat treated boron steel 22MnB5

is influenced by cooling rate significantly. And for the same cooling rate, the dwell temperature also affects the microstructure distribution in the temperature range of the related phase transformation, especially for the specimen with the cooling rate of 10 °C/s.

According to the analyze results of dilatometric experiment with the cooling rate of 10 °C/s, dwell at different temperatures can obtain various microstructure. That is to say, the mechanical properties can be customized based on the application demands by determine the cooling rate and dwell temperature of the hot forming process.

4. Conclusions

Based on the dilatometric results, the start and end temperatures of phase transformation from austenite to ferrite, bainite and martensite with different temperature histories were determined, and the influence of dwell temperature oover the phase transformations and final microstructures of boron steel after heat treatment was also analyzed.

(1) Microstructure of ferrite, bainite and martensite can be obtained by quenching the boron steel specimen to room temperature directly with the cooling rate of 2, 10 and 50 °C/s.

(2) Ferrite and bainite are the phases which are easier to appear during the cooling stage when the specimen is quenched with a small cooling rate, or dwells at the temperature in or near the temperature range of each transformation. For the hot forming process with tailored mechanical properties, low tensile strength region with ferrite and bainite is more controllable and easier to obtain. In order to obtain the high strength region which mainly consists of martensite, large cooling rate and continuous cooling condition should be ensured.

(3) In order to obtain a complex microstructure consisting of ferrite, bainite and martensite, or their combinations, suitable cooling rate and dwell temperature can be used in hot forming process. To study the phase transformation and the corresponded microstructure more comprehensively, the deformation at the elevated temperature must be considered in the next stage.

Acknowledgements

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