



A Novel High Strength Low Temperature Hot Forming Steel

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Abstract. The current trend of hot forming steel is mainly focused on improving the ductility, meanwhile, the new steel was also designed to overcome the surface oxidation and avoid the complexity of cooling system of the stamping dies. This new steel and corresponding forming technology were called low temperature hot forming or warm stamping technology, which overcomes the disadvantages of the conventional hot forming steel. This present work focused on the microstructure characteristics and mechanical behavior of a 0.1C-5Mn-0.02Ti-Fe balance steel warm stamped after different batch annealing temperature. It can be concluded that the microstructure and mechanical characteristics strongly depended on the annealing temperature. These results suggest that when the batch annealing temperature is between 570–630 °C, the steel exhibits over 1400 MPa tensile strength and 9% total elongation. A distinctly decrease in the tensile strength and total elongation was observed above 690 °C. These worsen mechanical properties can be attributed to the increased prior austenite grain sizes and fraction of lath martensitic.

Keywords: Low temperature hot forming · Medium-Mn · Microstructure · Mechanical characteristics

1 Introduction

The current demand for weight reduction and improved passive safety in vehicles' body has driven the automotive industry to develop new materials and manufacturing processes. Hot stamping is an innovative and effective method to produce ultra-high-strength components, such as A and B pillars, roof rails, and bumpers, which combines forming and quenching in one step [1, 2]. In the hot stamping process, the boron steels are austenitized at 900–950 °C in a furnace for 3–10 min, and then rapidly transferred to a die where the forming and subsequent quenching take place simultaneously. Finally, the formed components achieved full martensitic microstructure with an ultra-high tensile strength [3, 4].

However, a high austenitized temperature and cooling rates need to be used in order to obtain the prescribed microstructure, and that increases the cost of the process. The

conventional hot-stamped steel 22MnB5 has a tensile strength of 1400 MPa, nevertheless, its total elongation is not over 7% and it is formidable to improve it. Thus, in order to obtain an excellent combination of strength and ductility, recent research mainly focused on overcome the surface oxidation formed during high austenitizing temperature and avoid the complexity of cooling system of the stamping dies. Recently, a novel low temperature hot forming steel with tensile strength exceeding 1400 MPa has been developed to replace the conventional counterpart [5, 6].

2 Material and Test Process

The chemical composition (in wt.%) of the tested steel is as follows: C 0.1–0.13; Si 0.25; Mn 4.50–5.50; Cr 0.15–0.55; S 0.0017; P 0.006; B 0.0010–0.0040; and Fe, balance. The thickness of the cold-rolled sheet was 1.5mm. The equilibrium phase diagram of the steel was calculated by software and shown in Fig. 1. The temperatures Ae1 and Ae3 of the 451 °C and 737 °C, respectively.

The Ac1 and Ac3 temperatures of the steel, measured at a heating rate of 10 °C/s, were 652 °C and 781 °C, respectively. Therefore, the austenitizing temperatures 800 °C and dwell times 8 min were used for the low temperature hot stamping tests. The steel were bath annealed in the range of 570–720 °C prior to hot forming. Three tensile samples were cut vertical to the rolling direction for each annealing parameter. The mechanical properties were measured on an INSTRON 5985 tensile testing machine with a crosshead displacement of 2 mm/min with specimens of gage length of 50 mm and gage width of 12.5 mm at room temperature. Microstructural analysis was performed on the cross section by electron back scatter diffraction (EBSD) after electrolytic polishing parallel to rolling direction. The EBSD observation was conducted in a JSM 7001F FE-SEM. The EBSD samples were mechanically polished firstly and then electronically polished in a mixture solution of 10% perchloric acid and 85% alcohol at room temperature with an applied potential of 25 V.

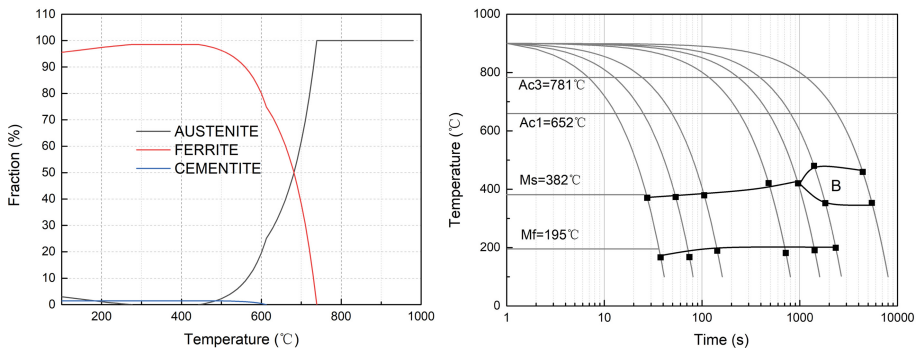


Fig. 1. Thermodynamics calculations of equilibrium phase fractions of ferrite and austenite and CCT curves.

3 Results and Discussion

3.1 Mechanical Properties Before and After Low Temperature Hot Forming

Figure 2 describes the mechanical properties of different bath annealing temperature and followed low temperature hot forming. These results suggest that when the bath annealing temperature is between 570–630 °C and the annealing time is 8 h, the tensile strength of the annealed steel is about 800 MPa. But it exceeds 1100 MPa when the heating temperature exceeds 690 °C. The results also showed that a slightly decrement of mechanical properties in the low temperature hot forming state. When the bath annealing temperature is between 570–630 °C, the tensile strength of the annealed steel exceed 1400 MPa after low temperature hot forming. However, when the bath annealing temperature exceeds 690 °C, the tensile strength and yield strength of the ow temperature hot forming steel decreased to about 1300 MPa.

3.2 Microstructure Evolution

Figure 3 shows the microstructure of the steel after bath annealing. The microstructure of the steel in the soft annealed condition consisted of ferrite and carbides below 630 °C. In addition, due to excellent quenching hardenability, martensite can be formed during simulated bath annealing furnace cooling. The martensite fraction increases gradually with the bath annealing temperature. An almost completely martensitic structure is formed after annealed at 720 °C.

The influence of bath annealing parameters on the microstructure of the test steel are shown in Fig. 4. The steel was austenitized at 800 °C and held isothermally for 8 min prior to die-quenching. It can be observed that the microstructures consist of lath martensite and massive martensite after full austenitization.

For a detailed analysis on the change of microstructure with different annealing conditions, an EBSD analysis was performed. Figure 5 shows EBSD inverse pole figure (IPF) and reconstructed grain-boundary maps of the half-sectioned area of the steels with the increase of bath annealing temperature, the fraction of lath martensite and prior austenite grain sizes increased. The average grain size of prior austenite increased from

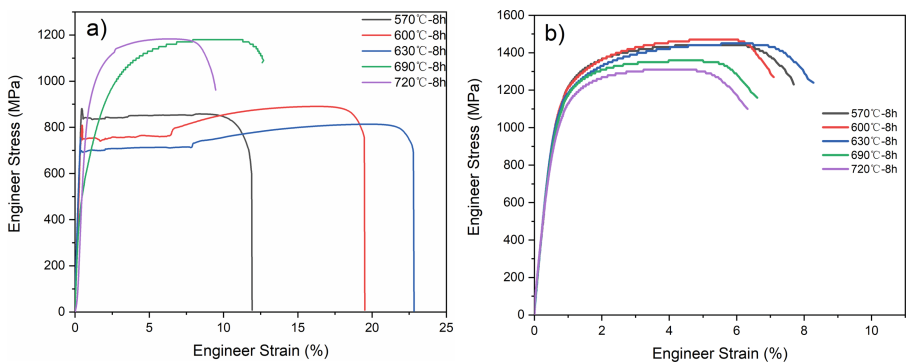


Fig. 2. Mechanical properties of the steel before and after hot stamping.

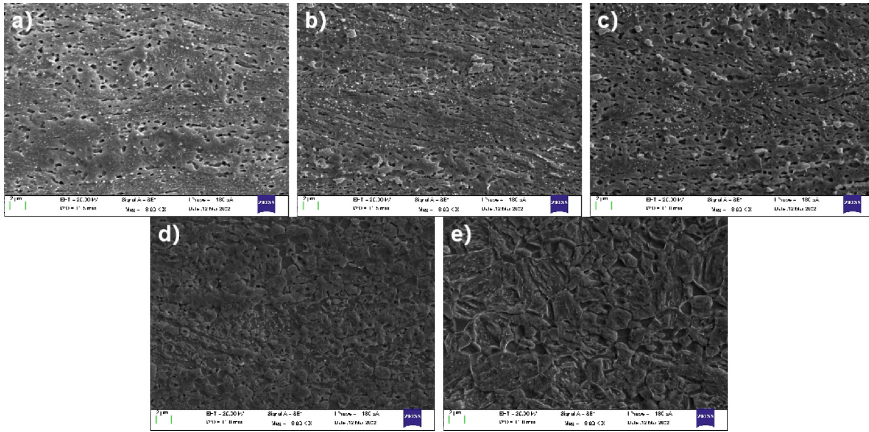


Fig. 3. Micrographs of the tested steel annealed at different temperatures: a) 570 °C; b) 600 °C; c) 630 °C; d) 690 °C; e) 720 °C.

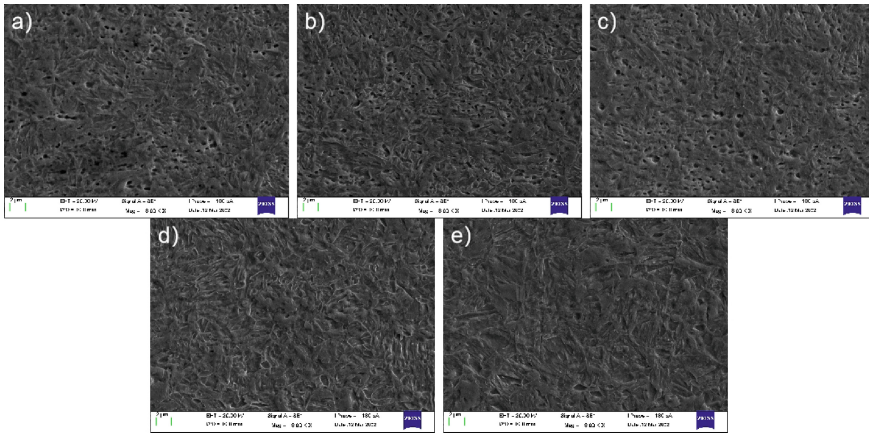


Fig. 4. Influence of bath annealing parameters on the low temperature hot formed microstructure: a) 570 °C; b) 600 °C; c) 630 °C; d) 690 °C; e) 720 °C.

5.9 μm to 9.6 μm . The lath of martensite annealed at 720 °C were larger in length and width than at 600 °C. The undissolved carbide and fine ferrite structure provide a large number of nucleation points, so the austenite grain size is smaller than the sample whose initial structure is coarse martensite. For martensitic steel, the strength is determined by the size of the three substructures within the original austenite grains. Thus, annealing temperature is a key factor that is related to the hot stamping application of a material. It can be summarized in the curves that the higher annealing temperatures samples seem to encounter a drop of strength.

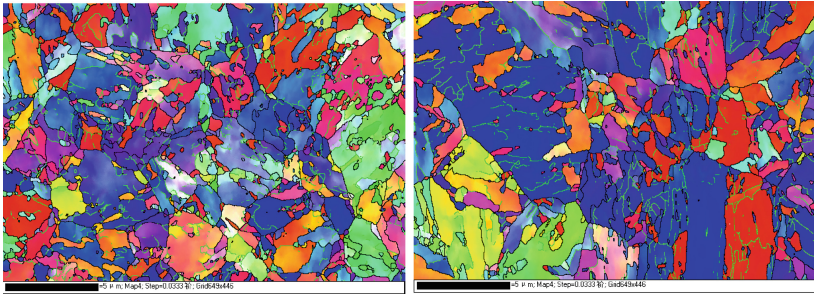


Fig. 5. Inverse pole figure (IPF) maps + reconstructed grain-boundary maps after hot formed of different bath annealing parameters a) 600 °C; b) 720 °C.

4 Conclusions

The main conclusions drawn from this paper are as follows:

- (1) When the bath annealing temperature is between 570–630 °C, the tensile strength of the annealed steel exceeds 1400 MPa after low temperature hot forming. However, when the bath annealing temperature exceeds 690 °C, the tensile strength and yield strength of the low temperature hot forming steel decreased to about 1300 MPa.
- (2) With the increase of bath annealing temperature, the fraction of lath martensite and prior austenite grain sizes increased. The average grain size of prior austenite increased from 5.9 μm to 9.6 μm . The higher annealing temperatures samples seem to encounter a drop of strength.

References

1. Z. Q. Zhang, C. H. Liu, S. F. Meng, X. J. Li and X. H. Zhao, Investigation of heat transfer in hot stamping of boron steel, *Metallurgical and Materials Transactions B* **47**, 824 (2016).
2. S. Q. Zhang, D. Feng, Y. H. Huang, S. Z. Wei, H. Mohrbacher and Y. Zhang, Constitutive Modeling of High-Temperature Flow Behavior of a Nb Micro-alloyed Hot Stamping Steel, *Journal of Materials Engineering and Performance* **25**, 948 (2016).
3. Z. X. Gui, W. K. Liang and Y. S. Zhang, Enhancing ductility of the Al-Si coating on hot stamping steel by controlling the Fe-Al phase transformation during austenitization, *Sciences China Technological Sciences* **57**, 1785 (2014).
4. P. F. Bariani, S. Bruschi, A. Ghiotti and A. Turetta, Testing formability in the hot stamping of HSS, *CIRP Annals* **57**, 265 (2008).

5. S. S. Li and H. W. Luo, Medium-Mn steels for hot forming application in the automotive industry, *International Journal of Minerals, Metallurgy and Materials* **28**, 741 (2021).
6. C. Y. Wang, X. D. Li, S. Han, L. Zhang, Y. Chang, W. Q. Cao and H. Dong, Warm stamping technology of the medium manganese steel, *Steel Research International* **89**, 1700360 (2018).

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