Journal of Iron and Steel Research, International 24 (2017) 508－512

Contents lists available at ScienceDirect

Journal of Iron and Steel Research, International

journal homepage: www.chinamet.cn

# Tailored properties of a novelly-designed press-hardened 22MnMoB steel

Ming-bo Zhou[1], Jing-lin Tang[1,*], Jie Yang[2], Cun-yu Wang[3]

[1] Key Laboratory of Advanced Forging & Stamping Technology and Science (Yanshan University), Ministry of Education of China, Qinhuangdao 066004, Hebei, China

[2] Lightweight Research Department, Society of Automotive Engineers of China, Beijing 100055, China

[3] Central Iron & Steel Research Institute, Beijing 100081, China

ARTICLE INFO

*Key words*:
Hot stamping
Bainite
Tailored property
Mechanical property
Microstructure

ABSTRACT

A novel 22MnMoB hot stamping steel was designed. The continuous cooling transformation (CCT) measurement of the 22MnMoB steel showed that the ferrite-bainite microstructure could be obtained at cooling rates lower than 25 ℃/s, and the complete martensite structure required the cooling rate higher than 30 ℃/s. The experiments with non-uniform die temperatures were carried out to obtain tailored properties. The results showed that strength of 1411 MPa and elongation of 6% could be obtained in the hard zone, and strength of 916 MPa and elongation of 9% could be obtained in the soft zone, which can be realized by controlling the die temperature at 400 ℃. The transition zone was found smooth and could be beneficial to reduce the stress concentration and therefore improve the performance of components.

## 1. Introduction

Hot stamping components have been widely used in automobile as structural and safety parts, due to their ultra-high tensile strength. As the most popular hot stamping steel, the 22MnB5 steel has been deeply studied theoretically and pratically[1-8]. High tensile strength of about 1500 MPa and Vickers hardness of about 425 HV are generally desired for hot stamping components[9], and a cooling rate of over 30 ℃/s is needed during the hot stamping process to obtain complete martensite microstructure[10,11].

Hot stamped 22MnB5 component is favorable for the anti-intrusion vehicle structure during a traffic accident. However, its energy management capability is limited due to its poor ductility[12]. To satisfy more strict safety and light-weighting requirements, tailored hot stamping has been developed. Tailored properties, namely high strength at hard zone and high ductility at soft zone in a press-hardened part, were obtained to satisfy the requirements of both anti-intrusion and energy absorption[13]. Generally, the tailored properties can be realized by three techniques: tailored cooling, tailored welding, or multi-stage heating[14-16]. Among them, the tailored cooling technique is the most popular one; in this way, the hot-stamped part was cooled in die by controlling different cooling rates at different die locations, to obtain the hard zone with high strength and soft zone with high ductility (i. e., total elongation of about 10%) simultaneously[17]. For the 22MnB5 steel, long holding time is necessary in order to form soft zone with microstructure consisting of ferrite and bainite and tensile strength of 714 MPa[18,19], which reduces the efficiency and consequently increases the cost compared to the conventional hot stamping process.

In this paper, a novel low alloy steel was designed and proposed to realize the tailored properties with reduced holding time.

## 2. Material and Experimental Procedures

### 2.1. Alloy design

In order to improve the ductility of soft zone in tailored component, the transformation from austenite into ferrite or bainite during hot stamping is necessary. In the present paper, the transformation from austenite into complete bainite microstructure was realized instead of the transformation from austenite to ferrite in conventional 22MnB5 steel. The reasons are given as follows: (1) occurrence of ferrite is harmful to the ultimate tensile strength (UTS) of

* Corresponding author. Prof., Ph.D.
*E-mail address*: *jltang@ysu.edu.cn* (*J.L. Tang*).

Received 3 January 2017; Received in revised form 22 February 2017; Accepted 23 February 2017
Available online 15 May 2017

martensitic steel; (2) the transformation from austenite into ferrite consumes more time because of its diffusive transformation nature, while the transformation from austenite into bainite is mainly displacive transformation, which can be finished quickly; (3) carbide precipitation is not necessary in lower bainite.

From above ideas, the designed alloy should be flexibly controlled to form martensite or bainite during the hot stamping process. Molybdenum is the most effective alloying element to suppress the nucleation and growth of ferrite and pearlite, but the molybdenum addition of 0.4 wt.% could hardly influence the bainitic transformation start temperature ($B_s$) of the Fe-0.22C-0.2Si-0.3Mn-0.2Cr-0/0.4Mo alloy[6]. Moreover, manganese addition of 0.9 wt.% led to a 41 ℃ dropping in $B_s$ of the Fe-0.22C-0.2Si-0.2Cr-0.3/1.2Mn alloy, which means that the manganese element inhibits the bainitic transformation seriously. Thus, the Mo-added (replacing a part of Mn) alloy has sufficient hardenability against the formation of ferrite and contributes to a wide selectable range of cooling rate to control the formation of complete martensite or complete bainite microstructure. Dropping in $B_s$ of the Fe-0.22C-0.2Si-0.2Cr-0.3/1.2Mn alloy, which means that the manganese element inhibits the bainitic transformation seriously.

A novel hot stamping steel of 22MnMoB was then designed, and a 30 kg ingot was melted in a vacuum induction furnace. The ingot was reheated to 1200 ℃ and held for 120 min, and then forged into a billet with dimensions of 60 mm×60 mm×1000 mm. After being reheated to 1200 ℃ for about 2 h, the billet was hot rolled into a plate with the section dimension of 4 mm×150 mm in a temperature range from 1100 to 900 ℃, and air cooled to room temperature, finally cold rolled to the thickness of 1.8 mm after acid pickling. The chemical compositions of experimental 22MnMoB steel and the traditional 22MnB5 steel are given in Table 1.

**Table 1**
Chemical compositions of experimental steels (wt.%)

| Alloy | C | Si | Mn | Mo | Cr | Ti | B | Fe |
|---|---|---|---|---|---|---|---|---|
| 22MnMoB | 0.22 | 0.21 | 0.29 | 0.39 | 0.2 | 0.03 | 0.0022 | Balance |
| 22MnB5 | 0.22 | 0.20 | 1.20 | — | 0.2 | 0.03 | 0.0020 | Balance |

## 2.2. *Experimental procedures*

The continuous cooling transformation (CCT) curves of the 22MnMoB steel were measured using a dilatometer (Formastor-FII). The cylinder specimens with size of $\phi$3 mm×10 mm were machined from the hot-rolled plate. The specimens were heated to 900 ℃ and held for 3 min for complete austenization and then continuously cooled down to ambient temperature at a series of cooling rates ranging from 5 to 50 ℃/s for CCT measurement.

Hot stamping experiments were carried out in a trial line with pressure of 50 MPa and flat dies. The blanks with size of 130.0 mm×210.0 mm×1.8 mm were cut from the cold-rolled sheet for hot stamping. The blanks were austenitized by soaking at 910 ℃ for 3 min in a muffle furnace protected by argon atmosphere, transferred into dies and finally quenched in dies to ambient temperature. The cooling rate is determined by controlling die temperatures under the pressure of 10 MPa. To evaluate the effect of die temperature on the microstructure and mechanical properties, five die temperatures, such as ambient temperature ($T_1$), 360 ℃ ($T_2$), 380 ℃ ($T_3$), 400 ℃ ($T_4$) and 420 ℃ ($T_5$), were applied in the hot stamping experiment, respectively.

For the microstructure observation by scanning electron microscopy (SEM), samples were ground and polished mechanically, and then etched by 2 vol.% nital for 30 s. The Vickers hardness was measured under 200 N with a loading time of 20 s. Tensile tests were carried out at a strain rate of $2\times10^{-3}$ $s^{-1}$, and the dog-bone-shaped tensile blanks with a gauge length of 50 mm and gauge width of 12.5 mm were machined according to ASTM 370 standard. The tensile test of each experiment was repeated twice for reliability.

# 3. Results and Discussion

## 3.1. *CCT diagram and microstructure at different cooling rates*

The CCT curves of 22MnMoB and 22MnB5 steels are shown in Fig. 1. The 22MnMoB steel exhibits a different CCT curve (Fig. 1(a)) compared to 22MnB5 steel (Fig. 1(b)[15-17]). When the cooling rate is higher than 30 ℃/s, both steels can obtain complete martensite microstructure. When the cooling rate ranges from 25 to 5 ℃/s, the 22MnMoB steel obtains mixture microstructure of ferrite and bainite. While for the 22MnB5 steel, when the cooling rate ranges from 25 to 10 ℃/s, it obtains mixture microstructure of bainite and martensite, or that of ferrite, bainite and martensite. When the cooling rate is 5 ℃/s, the microstructure of ferrite and pearlite is obtained. The microstructures of 22MnMoB and 22MnB5 steels at different cooling rates are shown in Fig. 2 and Vickers hardness values are shown in Table 2.

## 3.2. *Hot stamping of 22MnMoB steel at different die temperatures*

### 3.2.1. *Cooling procedure analysis*

Hot stamping tests were conducted at die temperatures of 100 and 400 ℃ respectively, and the temperature-time curves of blank and dies are presented