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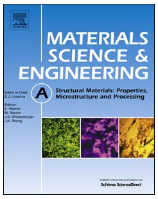

Comparison of the hot-stamped boron-alloyed steel and the warm-stamped medium-Mn steel on microstructure and mechanical properties

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ABSTRACT

The application of high strength steels (HSS) for automotive structural parts is an effective way to realize lightweight and enhance safety. Therefore, improvements in mechanical properties of HSS are needed. In the present study, the warm stamping process of the third generation automotive medium-Mn steel was discussed, the characteristics of martensitic transformation were investigated, as well as the microstructure and mechanical properties were analyzed, compared to the popular hot-stamped 22MnB5 steel in the automotive industry. The results are indicated as follows. Firstly, the quenching rate of the medium-Mn steel can be selected in a wide range based on its CCT curves, which is beneficial to the control of forming process. Secondly, the influence of stamping temperature and pressure on the M_s temperature of the medium-Mn steel is not obvious and can be neglected, which is favorable to the even distribution of martensitic microstructure and mechanical properties. Thirdly, the phenomenon of decarbonization is hardly found on the surface of the warm-stamped medium-Mn steel, and the ultra-fine-grained microstructure is found inside the medium-Mn steel after warm stamping. Besides, the warm-stamped medium-Mn steel holds the better comprehensive properties, such as a lower yield ratio, higher total elongation and higher tear toughness than the hot-stamped 22MnB5 steel. Furthermore, an actual warm-stamped B-pillar of medium-Mn steel is stamped and ultra-fine-grained martensitic microstructure is obtained. The mechanical properties are evenly distributed. As a result, this paper proves that the warm-stamped medium-Mn steel part can meet the requirements of lightweight and crash safety, and is promising for the industrial production of automotive structural parts.

1. Introduction

The application of high strength steels (HSS) for automotive structural parts is an effective way to realize lightweight and enhance safety [1,2]. Strength-ductility balance is the product of tensile strength (R_m, MPa) and total elongation (δ, %), and it is used to evaluate comprehensive performance of steels considering strength and ductility simultaneously. However, a conflict exists between the strength and the ductility during stamping processes [3–6]. The ductility is usually decreased with the increase of strength. Therefore, it is a key problem to find a suitable stamping technology to solve this conflict and improve the strength and ductility, as well as further improve the strength-ductility balance. Warm/hot stamping is favorable to manufacture HSS parts, especially the automotive structural parts with the yield strength ($R_{P0.2}$, MPa) of more than 1000 MPa, and thereby has become the first chosen technology for obtaining high strength [7–12]. During a hot stamping procedure, the steel is stamped following the complete austenization above 700 °C and then cooled quickly to room temperature to obtain martensitic microstructure. Compared to the hot stamping process, the warm stamping process with a stamping temperature under 500 °C has the advantages of energy-saving, high production efficiency, long die working life and low cost.

Currently, the studies of warm/hot stamped automotive steels are mainly focused on the popular boron steel in the automotive industry [13]. Many researchers studied the hot-stamping process of boron steels by experiments and numerical simulations [14–16]. Especially, Naderi et al. [12,17] proposed that the austenizing holding time, stamping temperature and applied force influenced considerably the martensitic transformation start (M_s) temperature of the 22MnB5 steel, described that the M_s temperature decreased from 410 °C to 360 °C at different applied forces, and drew a conclusion that the 22MnB5 steel was sensitive to the stamping process. Chang et al. [7] reported that the microstructure and mechanical properties were distributed unevenly after the 22MnB5 steel was hot-stamped to an

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automotive structural part. Meanwhile, several disadvantages exist in the hot-stamped boron steel, such as occurrence of oxidation and decarbonization (for non-coating steels) and low ductility (i.e., total elongation of less than 7%), which limits further improvement of automotive safety [17,18].

The third generation automotive medium-Mn steel was newly developed by Central Iron & Steel Research Institute (CISRI). Research on the stamping of this medium-Mn steel has just started. Chang et al. [19] have studied the effects of the process parameters on the mechanical properties of the medium-Mn steel and obtained the relatively optimal forming process. However, no reference was found to compare the medium-Mn steel and 22MnB5 steel on microstructure, martensitic transformation and mechanical properties after they were formed using their respective optimal processes. The characteristics of martensitic transformation of the medium-Mn steel at different stamping temperatures and loads hasn't also been reported.

This paper explored the characteristics of martensitic transformation of the warm-stamped medium-Mn steel, analyzed its surface decarbonization mechanism and investigated its mechanical properties. By contrast, the 22MnB5 steel has also been studied in these aspects. Furthermore, the medium-Mn steel was stamped to an actual automotive part in order to examine the distribution uniformity of microstructure and mechanical properties. As a result, the warm-stamped medium-Mn steel is promising for automotive structural parts replacing the hot-stamped 22MnB5 steel.

2. Materials and experimental

2.1. Materials

In this paper, the medium-Mn steel manufactured by Central Iron & Steel Research Institute (CISRI) was used in the experiment. For comparison, the 22MnB5 steel from BAOSTEEL GROUP was chosen. The thickness of tested steels is 1.5 mm. Their chemical compositions are listed in Table 1.

The Continuous Cooling Transformation (CCT) diagram of the medium-Mn steel was obtained by using dilatometry tests, metallographic investigations and hardness measurements. Fig. 1 presents the CCT curves of the tested medium-Mn steel. A wide austenitic stable region is observed and thereby the austenite is hardly transformed to other phases except martensite during quenching. The quenching rate can be chosen within a wide range and consequently water-cooling channels in dies for a high cooling rate are unnecessary in most cases. Thus, costs of channel design and die manufacturing are decreased. Moreover, it can be found that the influence of the quenching rate on hardness is not obvious, which is favorable to contribute to more uniform and steady distribution of hardness on the part. As shown in Fig. 1, the hardness is 425 HV when the cooling time is about 100 s and it is 390 HV when about 1000 s, which means only 35 HV decrease occurs when the quenching rate is decreased by 10 times.

2.2. Experimental

2.2.1. M_s temperature tests of the medium-Mn steel

The M_s temperature of the medium-Mn steel was tested on the thermomechanical simulator Gleeble-1500D. The sample size is presented as Fig. 2. The experimental process is as follows. (1) The medium-Mn steel is heated to 800 °C at a heating rate of 10 °C/s and kept for 5 mins for complete austenization; (2) quenched at a rate of 15 °C/s to a stamping temperature of 500 °C, 600 °C and 700 °C, respectively; (3) loaded at a certain axial pressure and meanwhile quenched at a rate of 5 °C/s till room temperature. The applied pressures are set up according to Table 2. An automatic recorder is used to collect the radial expansion during the whole process.

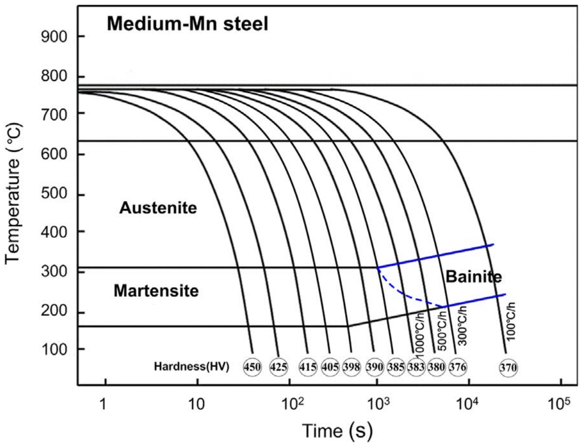

Fig. 1. CCT curves of the tested medium-Mn steel.

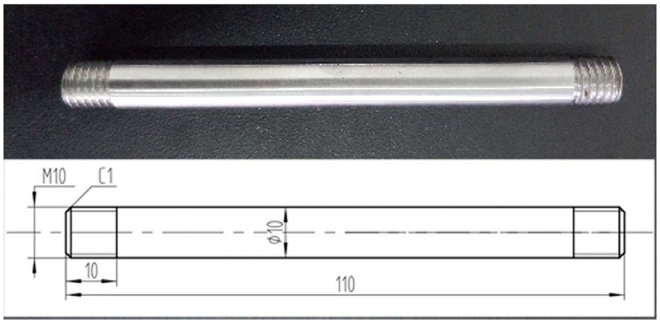

Fig. 2. Experimental sample and its dimension.

2.2.2. Warm/hot stamping tests

A 315 T high-speed hydraulic press was used for stamping tests. The medium-Mn steel and 22MnB5 steel were warm/hot stamped by their respective optimal stamping temperatures [19], as shown in Fig. 3. Fig. 3a demonstrates the experimental process of the medium-Mn steel as follows. (1) The medium-Mn steel is heated to 800 °C at a heating rate of 10 °C/s and kept for 5 min for complete austenization; (2) quenched at a rate of 15 °C/s to a stamping temperature of 500 °C; (3) stamped with a holding time of 10 s; (4) finally, quenched to room temperature. A similar experimental process is applied to the 22MnB5 steel, as shown in Fig. 3b. (1) The 22MnB5 steel is heated to 920 °C at a heating rate of 10 °C/s and kept for 5 mins for complete austenization; (2) quenched at a rate of more than 30 °C/s to a stamping temperature of 700 °C; (3) stamped with a holding time of 10 s; (4) finally, quenched to room temperature. The temperature was collected by a thermocouple and controlled by cooling channels in dies.

Mechanical properties were measured by uniaxial tensile tests and

Table 1
Chemical composition of experimental steels (wt%).

Steel	C	Si	Mn	P	S	Cr	Mo	Ti	Al
Medium-Mn steel	0.1	0.23	5.00	0.008	0.002	–	–	–	0.03
22MnB5 steel	0.22	0.28	1.35	0.012	0.004	0.21	0.04	0.03	0.04

Table 2
Loaded pressures at different stamping temperatures.

Stamping temperature (°C)	Stamping pressure (MPa)							
500	0	30	60	120	180	200	220	260
600	0	30	60	120	180	200	220	—
700	0	30	60	120	180	200	—	—