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Influence of stress on martensitic transformation and mechanical properties of hot stamped AHSS parts

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ABSTRACT

Non-isothermal tension and compression tests of 22MnB5 boron steel were carried out in this study. How different stress state influences the martensitic transformation of advanced high strength steel (AHSS) parts was analyzed. The analysis reveals that the martensitic transformation starting temperature (M_s) changes with different stress states. Specifically, the M_s temperature rises with increasing tensile stress, however, it rises first and then drops with increasing compressive stress. Moreover, a higher initial forming temperature leads to a higher M_s temperature under the same stress. Simulation of an actual hot-formed AHSS B-pillar together with the microscopic metallography, hardness and martensitic content shows that in higher tensile stress dominated area, the martensitic content and hardness are usually higher than in other areas. Although the stress can promote the M_s temperature, a lower cooling rate may lead to less martensite fraction.

1. Introduction

Hot forming technology has received much attention as a method of producing automobile parts from AHSS. Direct hot forming is such a process that the heat-treated AHSS blank is transferred to the press and subsequently stamped and quenched in a closed die. Achieving very high strength as a result of martensitic microstructure and requiring lower forming tonnage are the advantages of the hot forming process. In the researches of the hot forming process, the characteristics of martensitic transformation, and the optimal process parameters and mechanical properties have become hot topics [1–7]. 22MnB5 boron steel is the most common steel used for hot forming, so most researchers focus their studies on it. Karbasian et al. [8] have demonstrated that full martensitic transformation during water-quenching causes an increase of the tensile strength to above 1500 MPa and the hardness to about 450 HV. Naderi et al. [9] have analyzed the influence of hot plastic deformation and cooling rate on the M_s and bainite start temperatures. Merklein et al. [10] have studied the flow stress curves of 22MnB5 at high temperature.

During hot forming of an automobile structure part, some areas of the part may be in tension, some areas in compression, and some areas in combined tension and compression. The non-uniform distribution of stress in a complex part leads to different microstructure and mechanical properties. However, most experimental work published in the literature is limited to simple uniaxial tension of sheet or uniaxial compression of cylindrical bar [11–21]. For example, Liu et al. [14] found out from their uniaxial compression test that the M_s temperature decreased as the compression proceeded, and Hu et al. [20] presented that the M_s temperature increased when the specimen was uniaxially stretched at a high temperature. These studies rarely involve the influence of different stress state and stress intensity on sheet steels.

In this paper, the effects of both tensile and compressive stress state on the M_s temperature of 22MnB5 sheet steel were experimentally studied and theoretically analyzed. An automobile B-pillar was selected as an example to simulate and explain the difference of martensite transformation and mechanical properties under tensile and compressive stresses. Future research work was also recommended.

2. Materials and experimental procedures

2.1. Materials

Within the scope of this paper, a 2-mm thick hot-rolled sheet of 22MnB5 steel produced by Baosteel was used. The chemical

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composition (wt%) of the investigated material is as follows: C, 0.225; Mn, 1.24; Cr, 0.163; Si, 0.256; B, 0.003; P, 0.013, S, 0.003; and Fe, balance. The boron/manganese micro-alloys steel exhibits a ferritic–pearlitic microstructure with a hardness of 170 HV_{10}, yield strength of 400 MPa and tensile strength of 600 MPa or so.

2.2. Test setup

The 22MnB5 steels under tension and compression were tested, respectively. The tension test was conducted on a Gleeble 1500-D thermomechanical simulator. The specimen for tension is the dog-bone type as shown in Fig. 1(a). The thickness of the specimen is 2 mm. This type of sheet metal specimen is prone to buckle when compressed longitudinally without being clamped from both sides. Therefore, the specimen for compression test was designed to be a 2-mm thick circular plate of 75-mm diameter as shown in Fig. 1(b). The specimen was compressed in thickness direction by a die in a 35T high-speed hydraulic press. Water cooling channels were built in the die to quench the specimen.

The non-isothermal forming experimental procedure is as follows: The specimen is heated up to around 900 °C at a heating rate faster than 10 °C/s. To achieve the required homogeneous austenitic microstructure before forming, a furnace dwell of at least 3 min for a 2 mm thick blank is essential. A cooling rate of more than 30 °C/s is set during forming and quenching to avoid bainitic transformation and to achieve a full martensitic microstructure. The final hardness is measured by macro Vickers HV_{10} and the final microstructure was observed by a Scanning Electron Microscope (SEM) Model S-4300. The volume fraction of martensite was measured by metallographic analysis.

The temperature in both tests was measured using a surface mounted thermocouple located at the middle/center of the specimen. Essentially, in the experiment for 22MnB5, the cooling curves under different pressures have a turning point at M_s temperature because of the released latent heat during martensite phase transformation, as proposed by Sjostrom [22]. Therefore, the M_s temperature of 22MnB5 sheet under different stresses could be obtained according to its cooling curve.

2.3. The forming process for a B-pillar

Fig. 2 shows the hot forming process for an automotive part B-pillar. The 22MnB5 blank is heated up in a furnace to 900 °C, kept at this temperature for 3 min, transferred to the high-speed hydraulic press, formed by a die with internal water cooling channels, and quenched at a cooling rate of 30 °C/s under certain holding pressure.

3. Results and discussion

3.1. Influence of stress and forming temperature on the M_s temperature

In 1959, Koistinen and Marburger presented the relationship between the martensite fraction and M_s temperature during non-isothermal martensite transformation, as shown in Eq. (1) [23]:

$$\xi = 1 - \exp\left[-\theta(M_s - T)\right] \tag{1}$$

where ξ is the martensite fraction, M_s is the martensite transformation start temperature, θ is the constant of martensite transforming rate, and T is a value of temperature below the M_s temperature. In Eq. (1), the temperature field is regarded as the only factor that affects the martensite fraction of steel during martensitic transformation.

In 1973, Eq. (1) was simplified as Eq. (2) by Guimaraes and Shyne [24].

$$\xi = 1 - \exp[-0.011(M_s - T)], \quad -80\ ^\circ\mathrm{C} < T < M_s \tag{2}$$

Both Eqs. (1) and (2) have been implemented in hot stamping simulation software such as LS-DYNA, by which the martensite fraction anywhere in the B-pillar can be calculated. However, the effect of stress on the M_s temperature and martensite transforming rate was not taken into consideration and often times the difference between the calculated and actual values of martensite fraction was obvious. According to the classic theory of martensite transformation, the stress has significant influence on the phase

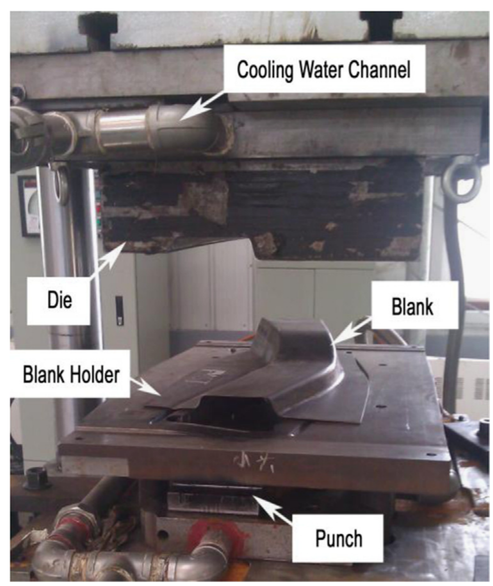

Fig. 2. Die setup for hot forming a B-pillar.

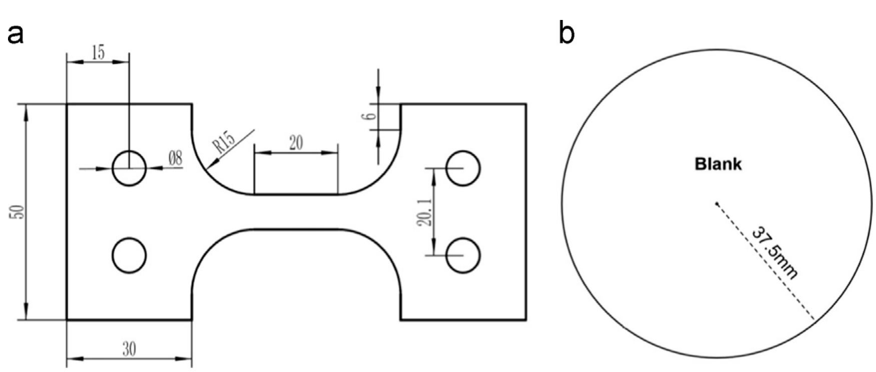

Fig. 1. Dimension of the specimen (a) in tension test and (b) in compression test.