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A potential hot stamping process for microstructure optimization of 22MnB5 steels characterized by asymmetric pre-rolling and one- or two-step pre-heating

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ABSTRACT

In this paper, a study on the innovative hot stamping process and the typical microstructures is presented, aiming to clarify insights into the influence of processing variables (asymmetric rolling temperature, rolling reduction, pre-heating method, and so on) on the evolution of microstructure, in order to evaluate the feasibility of the new process to improve properties of 22MnB5 steels. TEM investigations of asymmetrically rolled samples indicate different morphologies of dislocation density and pearlite with altering the rolling reduction, velocity ratio (VR) and rolling temperature. And the study demonstrates that asymmetric rolling before hot stamping process greatly promotes the austenite transformation during the pre-heating stage, especially when the rolling temperature is lowered to liquid nitrogen temperature (LNT) and the velocity ratio is higher than 1.5. And two-step pre-heating with induction heater and roller hearth furnace contributes positively to the austenite grain refinement in pre-deformed 22MnB5 steel. Another relevant conclusion is that the cooling microstructures can also be adjusted by changing the pre-deformed temperature of the samples.

1. Introduction

The requirement for lightweight vehicle body and lower emissions, improving safety and crashworthiness qualities motivates the application of advanced high/ultra-high strength steels in automobile industry. The hot stamping of quenchable steel was one of the most popular products due to its ultra-high strength and good forming precision. Generally, the hot stamping process could enhance the tensile strength to approximately 1.5 GPa, lower the forming load remarkably, prevent the springback and improve the formability of those ultra-high strength steels Mori et al. (2005a,b). Experiments by Neugebauer et al. (2006) demonstrated that elevated increasing temperature could firstly improve the ductility and hence the forming capability of the steels and benefit to reduce the yield point of the materials and therefore the critical force and pressure of the forming as well. Karbasian and Tekkaya (2010) also emphasized high shape accuracy of the hot stamped parts could be achieved with minimal springback within an optimized process window of conventional hot stamping.

In recent years, higher strength steels are required in manufacturing of body in white (BIW). The tensile strength of some quenchable steel sheets can reach 1800 MPa or even higher. However, the cost of these raw materials is always increased because of high concentration of alloying elements like Cr or C (Cheng et al., 2014). Bian et al. (2014) also developed a steel with improved crash performance and strength by alloying of Nb. However, the hot stamping process is still unchangeable, which sequentially includes the long-time pre-heating with the roller hearth furnace, blank transfer, press hardening and unloading stamping part. As is well-known, the roller hearth furnace is now being modified in term of its lower thermal efficiency and higher construction and maintenance costs (Barthel et al., 2016). For example, for the Al-Si coated sheets, the length of the furnace is estimated to be 24 m under the condition of 3 rpm cycle speed and 5 min heating time and 1.6 m in the distance of two parts per shot. Furthermore, the length of these furnaces increases with productivity of the hot stamping operations (Mori et al., 2017). Therefore, some alternative heating approaches, such as infrared heating (Lee et al., 2014), induction heating (Bok et al., 2014), resistance heating (Mori et al., 2005a,b) and contact heating (Rasera et al., 2016), are verified for fast heating rate and high energy efficiency.

Aiming for the industrial applications, a new hot stamping process characterized by combination of induction heating and short length of roller-hearth furnace was proposed. During induction heating, steels

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Table 1
Chemical compositions of 22MnB5 (wt.%).

C	Si	Mn	P	S	Cr	Ti	B	Al	Fe
0.22	0.28	1.25	0.01	0.005	0.23	0.02	0.003	0.03	Bal.

can be easily heated to the Curie temperature with less energy consumption, and then, further pre-heating for homogeneous austenitization is implemented in roller-heath furnace as quickly as possible. Besides, grain refinement is always considered as one of the most important approaches for improvement of the strength and toughness with low cost. Because of fully martensitic crystal structure in hot stamping parts, austenite refinement is definitely a factor determining the final property of steels. Generally, size of the austenite grain is around 10–15 μm for conventional roller-hearth furnace in 22MnB5, although it can be refined to about 5 μm with addition of 0.05 wt.% niobium by Bian et al. (2013). Here, we tried to prepare ultrafine grained austenite by using this assorted heating method in asymmetrically pre-rolled 22MnB5 without any change of chemical compositions in the present study. It could be a new promising hot stamping process for manufacturing higher strength parts in 22MnB5.

2. Materials and method

2.1. Materials

A commercial 22MnB5 with chemical composition listed in Table 1 was used as the experimental sample. The initial size of the experimental boron alloy blank sheets in rolling was 100 × 20 × 1.2 mm^3 with a typical ferrite plus pearlite microstructure.

2.2. Asymmetric rolling procedure

Before the hot stamping process, the 1.2 mm thick sheets were predeformed by asymmetric rolling in a non-reverse mill with a pair of ladder roller at ambient and liquid nitrogen temperatures, respectively. The ratio of velocities was changed by alternating the difference of diameters between the two work rolls. Four ladders with different diameters along the axial direction of upper roller were successively machined to 246, 295, 328 and 268 mm, respectively. And the corresponding diameters of the four ladders along bottom roller were 246, 197, 164 and 224 mm, respectively. Consequently, the velocity ratio could be chosen as 1.0, 1.2, 1.5 and 2.0 in one pair of rollers. Especially, the asymmetric rolling approach was performed a plural number of times, and the plural number of times should include at least once that rolling material was simultaneously rolled by turning the rolling material upside down and by changing directions of the rolling material. Fig. 1 illustrates the asymmetric rolling process in details.

The total reduction was selected as 30%, 50% and 70% resulting the final thickness of sheets was 0.84 mm, 0.60 mm and 0.36 mm, respectively. In cryogenic rolling, the samples were always kept in liquid nitrogen for 3 min before each rolling pass to assure the samples were cooled sufficiently, and the temperature was uniform across the thickness.

2.3. Flash hot stamping process and equipment

Fig. 2 presents the experimental heating line, which includes both induction heating device and roller-hearth furnace. The high-frequency induction heating installation had a maximum input power of 80 kW, and was equipped with induction coil for rapid heating. The roller-hearth furnace with maximum power of 10 kW was heated by resistive heaters and the temperature in furnace was measured by thermocouple and controlled in error range of ± 5 K. The temperatures during induction heating were measured by infrared thermometer, and the heating process in furnace was detected by K-type thermocouples and temperature recorder. For the sheets implemented with asymmetric rolling, they were proceeded with two different hot stamping processes as illustrated in Fig. 3. In process I, the sheet was solely pre-heated in roller-hearth furnace at temperature 1183 K of for 30 s. In process II, the sheet was firstly pre-heated by induction heating method to Curie point (973 ± 10 K for 22MnB5) in a very short time about 2 s, and then it was subsequently transited to roller-hearth furnace at temperature 1183 K for 10 s as the second-stage pre-heating.

The thin hot sheets were cooled in air for simulating the cooling rate of thick sheets that were press hardened in dies. Meanwhile, the hot sheets were directly water-quenched for the observation of austenite grains.

2.4. Microstructure characterization

The microstructural characterization was performed by optical microscope (OM, OLYMPUS GX51) and scanning electron microscope (SEM, TESCAN VEGAII) operated at 20 kV. Samples for OM and SEM observations were sectioned along the transverse direction, normal direction and rolling surface of the specimens, respectively, followed by standard mechanical grinding procedures and etching in 4% nital solution and in oversaturated picric acid aqueous solution at temperature 333 ~ 343 K for the erosion of austenite grain boundaries. The sizes of austenite grains were determined by the image analysis software, Image-Pro Plus.

The samples for transmission electronic microscope (TEM, JEM-2100, accelerated voltage = 200 kV) were prepared by twin-jet electropolishing with 8% perchlorate alcohol solution at 244 K (voltage = 32.5 V, current value = 30 mA) after mechanical grinding. For the microstructure observation near rolling surface, the samples were continuously mechanical grinded to about 50 μm from one side, and then slightly grinded to less than 30 μm from the other side. Otherwise, the samples were symmetrically mechanical grinded from both sides until the thickness reached to less than 30 μm, in order to assure the final samples were located in half-thickness.

3. Results and discussion

3.1. Microstructure of pre-rolled samples

In Fig. 4(a), small rolling reduction can induce a relatively high

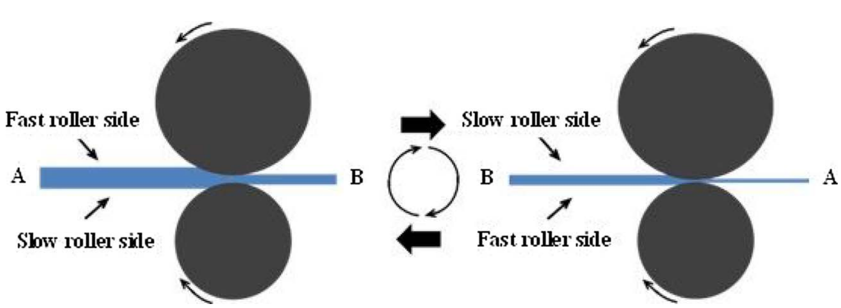

Fig. 1. Schematic diagram of asymmetric rolling process.