

An Investigation of Deformation Effects on Phase Transformation in Hot Stamping Processes

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ABSTRACT

To reduce the fuel consumption as well as to improve the crash safety of vehicles, the usage of hot stamping parts is increasing dramatically in recent years. Aisin Takaoka has produced hot stamping parts since 2001 and has developed various technologies related to Hot Stamping. In an actual hot stamping process, parts with insufficient strength could be produced sometimes at a prototyping phase, even under the proper forming conditions. In order to understand these phenomena, in this paper, phase transformation in a boron steel 22MnB5 under various cooling rates were investigated and the effects of pre-strain conditions on the phase transformations were characterised. Uniaxial tensile specimens were stretched under isothermal conditions to different strain levels of 0-0.3, at strain rates of 0.1-5.0/s and deformation temperatures of 650-800°C. A dilatometer was used to measure the dimensional changes of the specimen to rationalize the phase transformation of the boron steel during rapid cooling after deformation. The results showed that the deformation at austenite phase causes the reduction in martensitic phase transformation. For a certain strain level, deformation applied at a lower temperature and a higher strain rate would result in less amount of martensitic phase transformation. In addition, the relations between hot stamping conditions and Vickers hardness, which are normally used as a daily quality check in the industry, are also presented in the paper.

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INTRODUCTION

Lightweight and high crash resistance are more and more important for the automotive industry. This has increased the usage of hot stamped parts rapidly over the last 5-10 years and will increase more in the future. In a hot stamping process, a fast cooling rate of the steel during forming and quenching in the cold dies is critical to obtain the ultrahigh strength and geometrical accuracy of the formed part. Continuous cooling transformation (CCT) diagram is normally used to determine the cooling rate for achieving full martensite phase in the formed parts. However the CCT diagram obtained from the full annealed material is not applicable for the hot stamping applications, since the phase transformation would be affected by the deformation of the material prior to quenching.

Studies on phase transformations during non-isothermal deformations have been conducted [1] [2]. Under the condition of hot non-isothermal deformation with a cooling rate of 50°C/s, a higher deformation temperature can reduce the effect of plastic strain on martensite phase transformation. Strain dependant CCT diagrams for FE analysis were also investigated by other researchers [3] [4], which enhanced the understanding of the effect of plastic deformation on

phase transformation during continuous cooling. However, in a real hot stamping process, the deformation temperature, strain level, and strain rate are not constant and the effects of strain at different deformation conditions on the phase transformation still have not been quantified. A process window needs to be created to ensure that full martensite in formed parts could be achieved.

In this paper, uniaxial tensile and heat treatment tests have been performed under different conditions which simulate the actual hot stamping mass production processes. It aims to investigate and analyse the relations of deformation conditions in terms of strain level, deformation temperatures and strain rates with cooling rates, and martensite phase transformation in terms of transformation temperatures and post hardness.

EXPERIMENT

Material and Equipment

The material used in this study was an uncoated 22MnB5. The dimensions of the tensile specimens are shown in Fig 1. All specimen used for the experiment were machined from the same batch of

as-delivered, 1.60 mm thick, boron steel sheet. The specimens were cut by using laser and cut-edges were polished. Gleeble 3800 which is shown in Fig 2 was used for the isothermal tensile and heat treatment tests. A pair of K-type thermocouples was attached onto the centre of the specimen, which was used to monitor and control the actual temperature of the specimen throughout the tests. C-shaped contact dilatometer was used to measure the dimensional changes of the steel by measuring the width of the middle of the specimen, so as to detect the phase transformation. Air cooling nozzles were employed to realise high cooling rates of specimens.

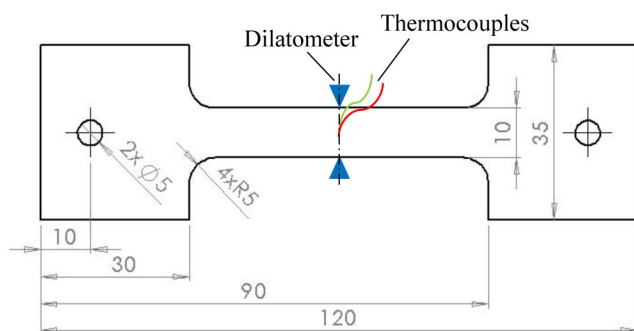


Figure 1. Specimen design (dimensions are in mm) with schematic dilatometer and a pair of K-type thermocouples attached.

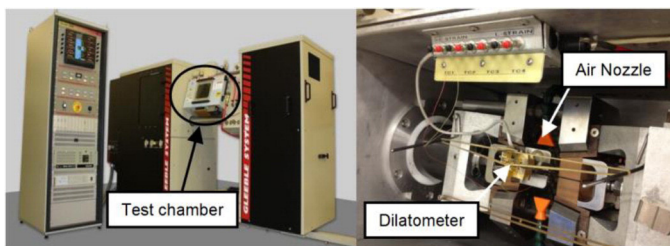


Figure 2. A Gleeble 3800 materials simulator and test set-up in the chamber

Test Conditions

Figure 3 shows the temperature-time profile for isothermal tensile testing and quenching of the specimen. An example of deformation at the temperature of 800°C is presented. The test specimen was heated up to 730°C with the heating rate of 8°C/s and then up to 900°C with 3°C/s. This was designed according to the heating condition of atmosphere furnace which is used in actual production processes. According to material supplier, the Ac3 temperature was about 820°C under the designed heating condition, thus the austenization in the boron steel was completed after heating. After that, there were two steps for cooling. The first step took 6 seconds which is the total time of cooling of a specimen from 900°C to the temperature for tensile testing and deformation of the tensile specimen. This cooling and tensile testing condition was also designed from actual production process that transferring a heated work piece from furnace to forming tools and forming the work piece. The second step was 10 seconds for quenching which is the time of work piece being quenched in forming tools. In addition, different deformation temperatures (650, 700, 750, and 800°C), strain rates (0.1, 1.0, and 5.0/s), strain levels (0, 0.1, 0.2, and 0.3), and cooling rate (25 - 80°C/s) were designed as test conditions.

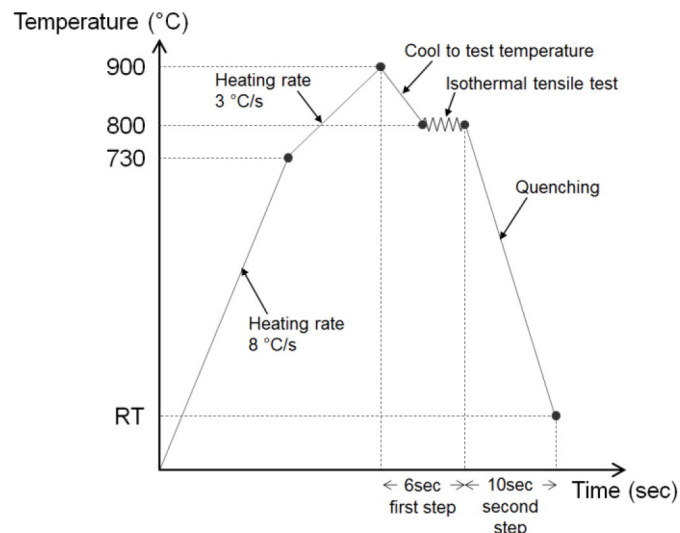


Figure 3. Temperature-time profile for isothermal tensile testing and quenching

RESULTS AND DISCUSSIONS

Measurement of the Amount of Martensite Phase Transformation

Fig.4 shows an example of strain changes of a boron steel specimen during quenching measured by a dilatometer. The thermal strain was calculated according to dilatometer reading. T_b represents the starting temperature of transformation from austenite to bainite T_{ms} and T_{mf} represent the starting temperature and finish temperature of martensite phase transformation, respectively. The difference between the minimum and maximum values of strain during martensite transformation, expressed by $\Delta\epsilon$ in Fig. 4, was used as a criterion to evaluate the amount of martensite phase transformation. A higher value of $\Delta\epsilon$ indicates a higher volume fraction of martensite obtained.

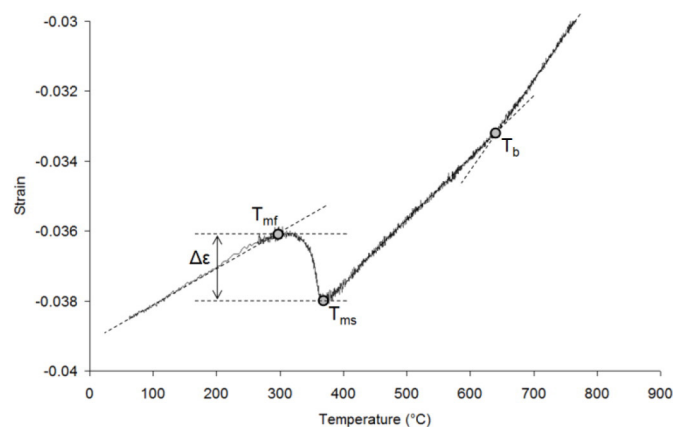


Figure 4. An example of strain changes of boron steel specimen, pre-deformed to the strain level of 0.1 at 800°C and a strain rate of 1/s, during quenching under the rate of 35°C/s.