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Phase transformations in a simulated hot stamping process of the boron bearing steel

M. Nikravesh [a,*], M. Naderi [b], G.H. Akbari [a], W. Bleck [c]

[a] Department of Metallurgy and Materials Science, Shahid Bahonar University, Kerman, Iran
[b] Department of Mining and Metallurgical Engineering, Amirkabir University of Technology, Tehran, Iran
[c] Department of Ferrous Metallurgy, RWTH Aachen University, Aachen, Germany

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A B S T R A C T

A hot stamping process was experimentally simulated by a hot deformation dilatometer to investigate phase transformations and final properties of 22MnB5 boron\bearing steel. For this purpose, the phase fraction in the microstructure of boron bearing steel with and without hot deformation was evaluated. The results showed that mechanical stabilization of austenite during the deformation process led to decreased amount of military phases while bainite and reconstructive transformations, especially ferrite were promoted. But, when there was no martensite in the final microstructure, the effect of deformation on ferrite formation was negligible. Also, due to deformation, total hardness was decreased in cooling rates of higher than 6 °C/s. But, on the contrary, in cooling rates of lower than 6 °C/s, remarkably reverse results were achieved. Finally, the CCT and DCCT diagrams of elaborated steel were constructed.

1. Introduction

The hot deformation behavior and constitutive description of the boron steel 22MnB5 are of vital importance to the process design and numerical simulation of the steel during hot stamping [35] that lead to a solution for producing high strength structural components without the occurrence of spring back. From the review of Karbasian and Tekkaya [17], two kinds of hot stamping processes are known which are direct and in-direct. During the direct hot stamping process, the blank is initially austenized, then deformed and quenched simultaneously. The indirect hot stamping process is characterized by room-temperature deformation, which is followed by austenitization in the press tool and the subsequent quenching.

One of the most important points in thermo-mechanical treatment is prediction of the final microstructure. However, this agent is not an independent variable and depends on chemical composition, deformation temperature, cooling rate, etc. Even some authors have shown that type of deformation i.e. tensile, compression, torsion or hydrostatic [5,9], amount of strain [21], strain rate [25] and prior austenite grain size ([18, 15]) have a significant effect on thermo-mechanical processes. For example, Min et al. [20] investigated the effect of the thermo-mechanical process on the microstructure and secondary-deformation behavior of 22MnB5 steels and it was concluded that as the steel was deformed at 650 °C, deformation induced ferrite transformation occurred even when a small strain of 0.044 was applied, and the volume fraction of deformation induced ferrite increases with increasing applied strain level. When deformed at 420 °C, deformation induced bainite transformation was observed. In 22SiMn2TiB steel investigated by Shi et al. [28], promotion of diffusional transformation by non-isothermal deformation was reported. In Cu–P–Cr–Ni–Mo weathering steel which was investigated by Zhang et al. [33], after hot deformation, a decrease of the bainitic transformation area was observed.

But, Taherian et al. [29] reported that hot deformation in NiCrMoV steel shifted the bainite nose in the deformed CCT diagram to left and the bainite area has developed and Jin et al. [16] found no effect of prior plastic deformation in austenite on the following bainite formation, even main features such as acceleration or retardation.

The available investigation by Shi et al. [28] on steel 22SiMn2TiB, a kind of high strength steel like 22MnB5, has focused on the phase transformation of the steel in hot stamping processes with different parameters. They reported variation in the volume fraction of phases by changing the process parameters. For example the volume fraction of martensite is significantly reduced at deformation amounts higher than 30%, with a cooling rate of 50 °C/s.

It seems that hot deformation promotes diffusion processes by two mechanisms: on the one hand, because of the prohibition of military phases due to mechanical stabilization, diffusion process is promoted; and on the other hand, hot deformation leads to increased nucleation sites and diffusion rate. But, there is a relationship between transformations. It means that an increase in the volume fraction of one phase could result in a decrease of other phases. Systematic studies are needed to determine the final microstructure.

* Corresponding author.
E-mail address: nikravesh@yahoo.com (M. Nikravesh).

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22MnB5 boron steel is the most common steel which is used for hot stamping. This steel grade belongs to the product category of quenched and tempered steels and features outstanding forming properties in the soft delivery state and high strength after heat treatment. Material strength is propagated by adding a small fraction of boron to the carbon, manganese and chromium composition. Therefore, this steel grade is also called “boron steel” in colloquial terms [22,27].

To continue previous works on 22MnB5 boron steel ([19, 2, 1,7,17, 24]) the authors simulated the direct hot stamping process by a deformation dilatometer to investigate the effect of this process on hardness and all continuous cooling transformation microstructures, i.e. martensite, bainite, pearlite and ferrite, in order to provide a prediction of the final microstructure of boron steel in hot stamping.

2. Materials and experiments

10 mm sheet of 22MnB5 steel with a composition of Fe–0.23C–0.22Si–1.18Mn–0.16Cr–0.12Ni–0.03Al–0.04Ti–0.002B–0.1Mo (wt.%) was used in this study. The microstructure of as-received steel is 78% ferrite besides 22% pearlite with a hardness value of 170 Hv.

The aim of the present research was to investigate the phase transformations of boron steel during hot stamping by means of a Baehr 805 deformation dilatometer simulator. After inserting a cylindrical specimen with a length of 10 mm and diameter of 5 mm in a vacuum chamber of a deformation dilatometer, the samples were heated up to an austenitization temperature of 900 °C for 5 min and then compressed and quenched in different cooling rates from 0.01 to 100 °C/s. Non-isothermal deformations were established through several simultaneous forming and quenching tests starting from a deformation temperature of 850 °C by a strain rate of 7 s^{-1}. Due to the high strain rate, temperature rise during deformation was observed in the samples. Accordingly, we call this process quasi-isothermal instead of non-isothermal. Regarding the hot stamping process, the samples were deformed in compression mode up to the strain of 0.4 in a single step. The atmosphere was first protected by a 10^{-6} bar vacuum and then argon and helium shower was employed for controlled cooling.

The transformed phase fraction was determined by using Nital as etchant and light optical microscopic investigations. For this etchant, ferrite, bainite and martensite appeared in white, light gray and gray to black laths, respectively. Using the image analysis on optical microstructures, quantitative measurements of the phases were done (3 measurements per condition). The Vickers hardness of the specimens was measured by a hardness tester (HV_{10}) at room temperature (5 measurements per condition). Finally, the continuous cooling transformation (CCT) and deformed continuous cooling transformation (DCCT) curves of the steel were developed.

3. Results and discussion

3.1. Effect of deformation and cooling rate on volume fraction of martensite

Fig. 1 shows the volume percent of the martensite curve in different cooling rates obtained from image analysis of the microstructure. The horizontal axis is in logarithmic scale to distinctly show variation.

By deformation, the critical cooling rate to martensite transformation, (the cooling rate that leads to a fully martensitic microstructure) was increased from 30 °C/s to 60 °C/s as reported by Nikravesh et al. [24]. Wang et al. [31] have also shown an increase in the critical cooling rate due to deformation of austenite in Mn–Cr gear steel. But the amount of increase depends on the amount of deformation and other process parameters.

As shown in Fig. 1, by increasing the critical cooling rate, the deformed curve deviated from 100% martensite horizontal line in comparison with the non-deformed curve. Because of the mechanical stabilization of austenite (MSA), the volume fraction of martensite decreased due to hot deformation. Deformation of austenite postponed shear transformations, e.g. martensite, by increasing defects like dislocations that resulted in the strengthening of austenite and reduction of the volume fraction of martensite. Bhadeshia [5] has reported that martensite plates, which form by a displacive mechanism, cannot cross austenite grain boundaries. Smaller defects such as isolated dislocations hinder the progress of such transformations. However, severe deformation of austenite prior to its transformation hinders the growth of martensite, causing a reduction in the fraction of transformation in spite of an increase in the number of nucleation sites.

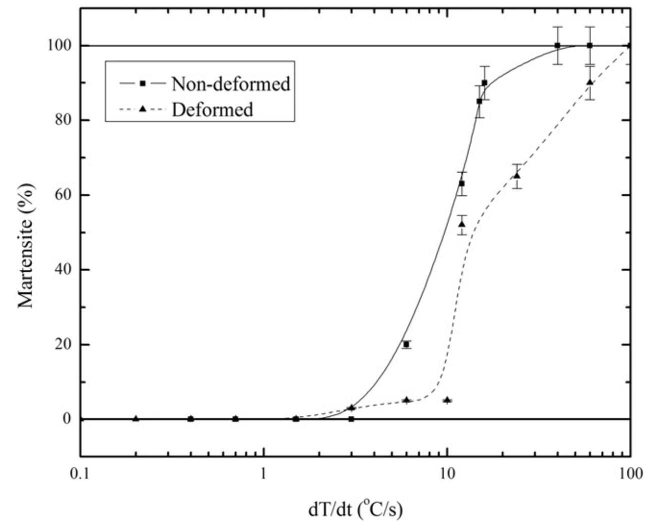

Fig. 1. Volume percent of martensite in deformed and non-deformed conditions.

Moreover, Naderi et al. [23] found that an increase of strain rate amplifies this occurrence, unlike increasing cooling rate. In the presence of deformation, with respect to strain rate, a higher cooling rate does not essentially result in a higher amount of martensite, which was due to the continuation of deformation at lower temperatures that enhanced the possibility of bainitic transformation. Therefore, it seems that, there is a critical cooling rate in each strain rate that leads to a maximum fraction of martensite in the final microstructure.

As shown in Fig. 1, with a decreasing cooling rate from 12 °C/s, drastic variation of martensite volume fraction was observed. Because of reduction of motivation energy due to decrement of cooling rate, transformations other than martensitic which had less shearing nature, e.g. bainite, or had diffusional characteristic, e.g. pearlite and ferrite, were encouraged. In other words, deformation led to increased diffusion rate and accelerated reconstructive transformations [24]. While, because of activation of recovery and recrystallization phenomena in a very short time, the difference of these two curves was negligible in a cooling rate of slower than 2 °C/s. If deformation was finished at higher temperatures, the effect of plastic deformation and mechanical stabilization would decrease. In other words, decreased cooling rate resulted in decreased martensite. Therefore, variation in the amount of this phase in the cooling rate of lower than 2 °C/s in comparison with the non-deformed condition was negligible.

3.2. Effect of deformation and cooling rate on volume fractions of ferrite and pearlite

The results indicated that the formation of diffusion phases increased by deformation (Fig. 2). It has been widely reported that deformation of austenite increases the density of ferrite nucleation sites due to the increase in austenite grain boundary [26]. Moreover, austenite deformation creates high density of dislocations, which raises austenite free energy, and leads to increased driving force of ferrite transformation. Because the defects introduced by deformation are destroyed as the new phase grows, rather as in recrystallization. The elimination of