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Isothermal versus non-isothermal hot compression process: A comparative study on phase transformations and structure–property relationships

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ABSTRACT

It is known that the direct hot stamping process in which the specimen is deformed and quenched simultaneously results in a high-strength product without the occurrence of springback. In the current work, the effects of isothermal and non-isothermal thermo-mechanical processes on the phase transformations and the resultant microstructure and mechanical properties of 22MnB5 steel are investigated. For the non-isothermal processing route which is similar to direct hot stamping, the specimens were simultaneously compressed and quenched, while in the isothermal route, the specimens were isothermally deformed and subsequently quenched. The results indicated that higher forming loads as well as M_s and M_f temperatures are the characteristics of the former process over the latter one. Additionally, following the isothermal compression process by quenching resulted in a fully martensitic microstructure.

1. Introduction

Reductions of weight and air pollution, increment of safety as well as improvement of fuel consumption are some goals of automobile industries [1]. Application of hot stamping process to produce high strength specimens without the occurrence of springback is a solution to meet these requirements [2]. Two kinds of hot stamping processes are known: direct and in-direct. During the popular direct hot stamping process, the blank is initially austenized, then deformed and quenched simultaneously. Indirect hot stamping process is characterized by a room-temperature deformation followed by austenitization in the press tool and the subsequent quenching and calibration [3].

Materials, process modification regarding tools and variables as well as simulation of hot stamping process have been the point of focus of many researchers. Schieβl et al. [4] studied the microstructure, corrosion behavior and mechanical properties of 22MnB5 steel and two non-boron alloyed steels, MS-W 1200 and CP-W 800, after being hot stamped and semi-hot stamped. The material 22MnB5 reached component strength levels over 1500 MPa at elongations of 5–8% while with MS-W 1200 strength value of at most 1200 MPa were obtained. Naderi et al. [5] analyzed the different characteristics of non-boron alloyed steels after being hot stamped. Ambrogio et al. [6] proposed a novel manufacturing process by supplying a continuous current in order to generate heat. Mori et al. [7] used a resistance heating to elevate the temperature of sheet during forming and studied the effects of warm stamping on the springback of ultra high tensile strength steel sheets. The springback in hat-shaped bending of the high tensile strength steel sheets was eliminated by heating the sheets. Mori and Ito [8] evaluated the effect of different oils for prevention of oxide scale formation occurs immediately when the steel is in contact with air. Xing et al. [9] set up a material model under hot stamping condition of quenchable steel, based on the experimental data of mechanical and physical properties. They also simulated the whole hot stamping process by ABAQUS software. Their simulation results were basically in agreement with experimental results.

Another kind of hot stamping process which can be assumed as a modification to direct hot stamping process is targeted in this research. This process consists of an isothermal deformation at high temperature together with a subsequent quenching process. Abbasi et al. [10] studied the effect of strain rate and deformation temperature on the properties resulted from 22MnB5 steel after being isothermally hot compressed and subsequently quenched. In the current work, different properties of a boron-alloyed steel, namely microstructure, hardness, forming load, work hardening rate as well as dilatation data, after being isothermally and non-isothermally compressed are compared.

2. Materials and methods

2.1. As-received material

The chemical composition of the studied steel which is known as 22MnB5 is represented in Table 1. CCT diagram of the studied

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Table 1
Chemical composition of the studied steel.

C	Si	Mn	P	S	Cr	Ti	B
0.24	0.27	1.14	0.015	0.001	0.17	0.036	0.003

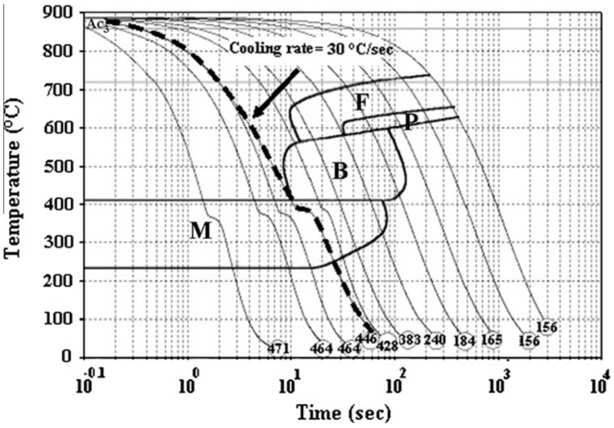

Fig. 1. The CCT diagram of the studied steel.

steel which was obtained by using dilatometry tests, metallographic investigations as well as hardness measurements is represented in Fig. 1. It should be paid attention that although CCT diagram is an effective tool to characterize phase transformations happen during thermo-mechanical processes, but movement of phase domains due to deformation processes is inevitable [11].

2.2. Thermo-mechanical processes

In Fig. 2, two studied processes are schematically illustrated. As thermo-mechanical processes vary differently and there are no standard test methods for applying, experimental condition of these processes varies based on researchers' goals. In the current research, cylindrical specimens were first austenized at 900 °C for 5 min, then compressed and quenched based on Fig. 2. The total strain and the applied strain rate for both processes were 0.5 and 0.1 s^{-1}, respectively.

All the experiments took place in a Baehr DIL 805 deformation dilatometer with the cylindrical samples of 5.0 ± 0.1 mm diameter and 10.0 ± 0.1 mm height. The specimens were heated up to the austenization temperature through resistance heating method. Additionally, the compression tests were carried out by SiN_2 anvils while argon and helium shower were employed for a controlled cooling with 50 °C/s rate. Molybdenum foils used to prevent the specimen sticking to the anvils and glass powder was added for lubrication.

2.3. Hardness

The hardness was evaluated by using Vickers hardness test ($HV_{0.8}$) method. Hardness tests were performed by using a programmable hardness test machine with uncertainty of about ±5 $HV_{0.8}$, and the step-size of 300 μm for the measured points. The polished samples, taken from the vertically cut cross section of the cylindrical samples, were utilized for the hardness measurements. More information about the machine used to assess the hardness is represented in Ref. [12].

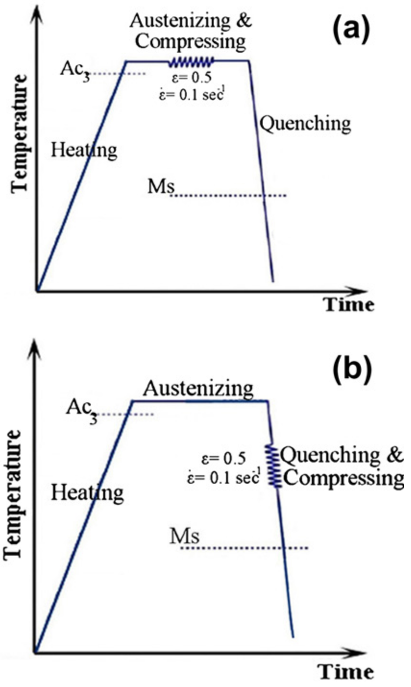

Fig. 2. Schematic illustration of procedures followed for isothermal (a) and non-isothermal (b) thermo-mechanical processes.

3. Results and discussion

3.1. Microstructure

The microstructures of specimens after the mentioned thermo-mechanical processes are represented in Fig. 3. While the pronounced martensitic transformation is the characteristic of isothermal route (Fig. 3a), presence of phases other than martensite is observable in microstructure of non-isothermally deformed sample (Fig. 3b).

3.2. Hardness

The hardness mapping technique was used to support the phase identification and characterization (Fig. 4). It is observed that hardness values of isothermally deformed and subsequently quenched specimen are higher than 400 $HV_{0.8}$, while hardness values of simultaneously deformed and quenched specimen are equal or more than 300 $HV_{0.8}$. Abbasi et al. [10] denoted that in the investigated steel, the hardness values more than 400–450 and 250–300 $HV_{0.8}$ were related to martensite and bainite phases, respectively, while the hardness values less than 250 $HV_{0.8}$ were attributed to ferrite phase.

Observed results in Figs. 3 and 4 can be related to the effect of forming process. During forming, different defects such as dislocations are produced [13]. While during isothermal compression process these defects annihilate due to high temperature, specimens which experience simultaneous forming and quenching processes do not get this opportunity [14]. It is well established that martensitic transformation involves the coordinated movement of atoms [15,16]. Additionally, it has been pointed out by different researchers [17–19] that such movements cannot be sustained against defects, such as grain boundaries and dislocations. As a result, presence of dislocations may mechanically stabilize austenite and retard or even impede the martensitic transformation [20].