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Martensitic microstructural transformations from the hot stamping, quenching and partitioning process

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ABSTRACT

Hot stamping, which combines forming and quenching in one process, produces high strength steels with limited ductility because the quenching is uncontrolled. A new processing technique has been proposed in which the hot stamping step is followed by a controlled quenching and partitioning process, producing a microstructure containing retained austenite and martensite. To investigate this microstructure, specimens were heated at a rate of 10 °C/s to the austenitizing temperature of 900 °C, held for 5 min to eliminate thermal gradients, and cooled at a rate of 50 °C/s to a quenching temperature of 300 °C, which is between the martensite start temperature and the martensite finish temperatures. The resulting microstructure was examined using optical microscope, scanning electron microscopy and transmission electron microscopy. The material produced contains irregular, fragmented martensite plates, a result of the improved strength of the austenite phase and the constraints imposed by a high dislocation density.

1. Introduction

Hot stamping has received much attention recently as a method of producing automotive parts from high strength steel. Hot stamping is a nonisothermal sheet metal forming technique where the blank is formed in a single process that combines hot forming followed by press hardening between cooled dies [1–3]. In this process, the steel sheet is heated to a temperature in the austenite range and held there long enough to produce a homogenous austenitic microstructure. Then the austenitized steel sheet is transferred from the furnace to a pressing machine, formed into a prescribed shape using dies maintained at room temperature, and simultaneously quenched. At the end of the cycle, the part has a fully martensitic microstructure, with strength exceeding 1500 MPa [4–7]. Thanks to the formability that high strength steels exhibit at elevated temperatures, the final martensitic microstructure, and the reduced springback, thinner and more complex sheet metal parts can be produced with a high strength-to-mass ratio and high geometrical accuracy [8–11]. Thus, hot stamping is a useful technique to produce ultra high strength steel components such as side impact and bumper beams using boron steels. However, because the final microstructure of ultra high strength steel is fully martensitic after hot stamping, the ductility tends to be compromised. An effective method of improving the toughness of the material produced has long been needed.

Recently, Speer et al. [12–17] proposed a novel heat treatment in which the quenching is controlled during a quenching and partitioning process in order to produce a retained austenite and martensite microstructure. The quenched and partitioned steels generally consist of carbon-

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enriched stabilized austenite and carbon-depleted martensite, which together give it increased strength without compromising ductility. The quenching and partitioning process includes [18–21]: (1) a partial or full austenitizing heat treatment, (2) fast quenching to a temperature below the martensite start temperature (M_s) but above the martensite finish temperature (M_F), to produce a controlled volume fraction of supersaturated martensite and untransformed austenite, (3) subsequent partitioning during quenching (one-step treatment) or above the M_s temperature (two-step treatment), to produce the complete diffusion of carbon from martensite to residual austenite (carbide precipitation is prevented by alloying with Si or Al), and (4) quenching to room temperature. Consequently, the final microstructure contains ferrite (in the case of partial austenitization), martensite and retained austenite.

The combination of the austenite grain refinement produced by hot stamping and the subsequent quenching and partitioning process greatly improves the properties of high strength steels. The objective of this work is to investigate the martensite microstructure produced by this process.

2. Materials and Experimental Procedures

The chemical composition (wt.%) of the investigated material is shown in Table 1. The microstructure of as-delivered plates consists of 78 vol.% (±5%) ferrite and 22 vol.% (±5%) pearlite. The ingot was in a completely annealed state before being used in the experiments.

The specimens were heated to the austenitizing temperature of 900 °C at a rate of 10 °C/s, then held for 5 min to eliminate thermal gradients. This was immediately followed by deformation at a strain rate of 1 s^{-1} to a 50% strain. After deformation, the specimens were immediately quenched at 50 °C/s to a quenching temperature between the martensite start and finish temperatures, partitioned for a few seconds at 300 °C, then quenched to room temperature. A schematic of the applied thermal regime is shown in Fig. 1.

The deformed specimens were sectioned parallel to the compression axis for microstructural analysis. The microstructural examination of the sample was conducted using a Nikon EPIPHOT 300 optical microscope (OM) and a JSM-6460 scanning electron microscope (SEM) after conventional nital etching. Transmission electron microscope (TEM) specimens were thinned to 0.06 mm by abrasion with SiC papers. The 3 mm punched disk was twin-jet electropolished using 4% perchloric acid solution in the temperature of −20 °C at 45 V etching potential, then finally thinned by using a Gatanion-beam milling machine at low angle of 4° so as to achieve large thin areas for the observation of microstructure. A JEOL JEM-2010 high-resolution analytical TEM was used for microstructure examination.

Table 1 – The designed chemical compositions of the investigated material (wt.%).

C	Mn	Si	Ti	P	S	B
0.22	1.58	0.81	0.022	0.0064	0.0014	0.0024

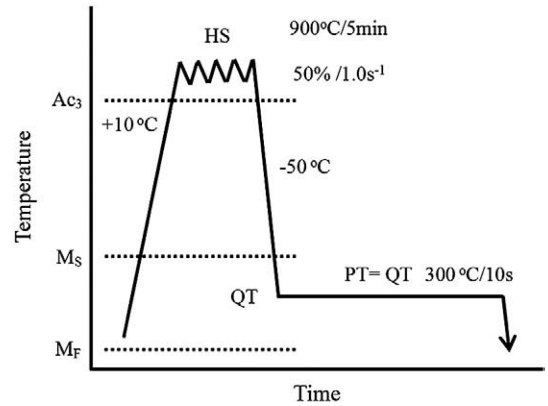

Fig. 1 – A scheme of the thermal schedules applied to the sample, hot stamping (HS) is followed by the application of 50% strain, then quenching treatment (QT) and partitioning treatment (PT).

3. Results and Discussions

An optical micrograph showing the morphology of the hot stamped, quenched and partitioned steel is shown in Fig. 2. Lath martensite is surrounded by retained austenite. Although the martensite has a lath morphology, its plates are not integral and are serrated at their edges. This is even more apparent in SEM secondary electron images such as the one shown in Fig. 3. The fragmented nature of the martensite plates into smaller segments is attributed to the heat treating, quenching and partitioning process. This microstructure was further examined using the TEM.

The typical TEM micrograph and corresponding selected area diffraction pattern are shown in Fig. 4. It is seen that the microstructure subjected to hot stamping plus the quenching and partitioning process consists of retained austenite and martensite with a mean lath thickness of about 200 nm. There are high-density dislocations accommodated around the grain boundaries. It appears that fine grains with crystal lattice distortions have been produced by hot deformation.

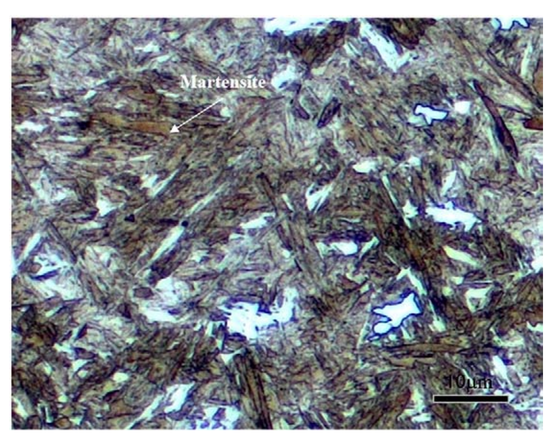

Fig. 2 – Optical micrograph showing the martensite morphology from the hot stamped, quenched and partitioned steel.