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Unique impact of ferrite in influencing austenite stability and deformation behavior in a hot-rolled Fe–Mn–Al–C steel

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A B S T R A C T

The unique impact of two types of ferrite, intercritical ferrite and δ-ferrite on austenite stability and deformation behavior of hot-rolled Fe–11Mn–4Al–0.2C transformation-induced plasticity (TRIP) steel were studied. Each of the two ferrites exhibited their respective role in enhancing the stability of austenite, contributing to superior ductility. An optimized quenching at 800 °C and tempering at 200 °C adopted on the as-hot-rolled steel led to a ferrite–austenite mixed microstructure that was characterized by excellent combination of tensile strength of 1082 MPa and elongation of 35%, and a three-stage work hardening behavior.

1. Introduction

Transformation induced plasticity (TRIP) steels exhibiting an excellent combination of high strength, superior ductility, and good crashworthiness are potential candidates for automotive components. Essentially, enhanced energy absorption behavior and work hardening rate are attributed to the TRIP effect that involves transformation of retained austenite to martensite [1,2].

The microstructure of conventional TRIP steels consists of ferrite as the dominant phase (55–65%), retained austenite (< 20%), bainite (25–35%), and occasionally a small amount of martensite [3–5]. A delta (δ) TRIP steel has the major constituent of δ-ferrite and the remaining constituents consist of bainitic ferrite and austenite. The austenite behaves in a manner similar to conventional TRIP assisted steels, and enhances the ductility of the alloy [6,7].

Recent researches [8–13] focused on medium Mn content (5–10%) TRIP steels. It was suggested that superior mechanical properties can be obtained with increase in Mn content, which increased the volume fraction of retained austenite. austenite reverted transformation (ART) annealing [9,13] was adopted, and the resulting microstructure of this type of steel was ferrite and austenite duplex structure with austenite fraction of about 30–40%. In the context of obtaining high strength–high ductility combination in TRIP steels, we underscore the practical significance of controlling the stability of austenite during deformation. In the present work, we describe the unique and significant contribution of co-existence of intercritical ferrite [14] and δ-ferrite in enhancing the stability of austenite with consequent enhancement in ductility.

2. Experimental

The chemical composition of the experimental TRIP steel is presented in Table 1. The identified composition is based on the roles of alloying elements and an equilibrium thermodynamic analysis that was discussed in our previous work [15]. A 40 kg experimental steel cast ingot was manufactured using a vacuum furnace. The ingot was heated at 1200 °C for 2 h, hot forged to rods with a section size of 100 mm × 30 mm, and then air cooled to room temperature (RT). Subsequently, the rods were soaked at 1200 °C for 2 h, and then hot rolled to 4 mm thickness in the temperature range of 1150–850 °C, and finally air cooled to RT.

In order to establish appropriate heat treatment schedules, the critical temperatures of Ac_1 and Ac_3 of the designed steel were obtained by dilatometry and are listed in Table 1. A two-stage heat treatment was adopted: (1) *Quenching*: The as-hot-rolled sheets were soaked in a high temperature furnace at the temperature of

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700, 750, 800, 850, and 900 °C for 1 h, and then immediately quenched in the water. (2) *Tempering*: The quenched samples were tempered at 200 °C for 20 min, followed by air cooling to RT.

Table 1
Chemical composition (wt%) of steel and critical temperatures (°C).

Mn	Al	C	Fe	Ac_1	Ac_3
11.02	3.81	0.18	Bal.	570	830

Table 2
Microhardness of constituent phases in heat treated and as-hot-rolled microstructure.

Phases	Vickers hardness, HV
δ-Ferrite	253 ± 6
Intercritical ferrite (IF)	336 ± 15
Austenite	212 ± 10
Martensite	452 ± 10
Matrix of as-hot-rolled	340 ± 6

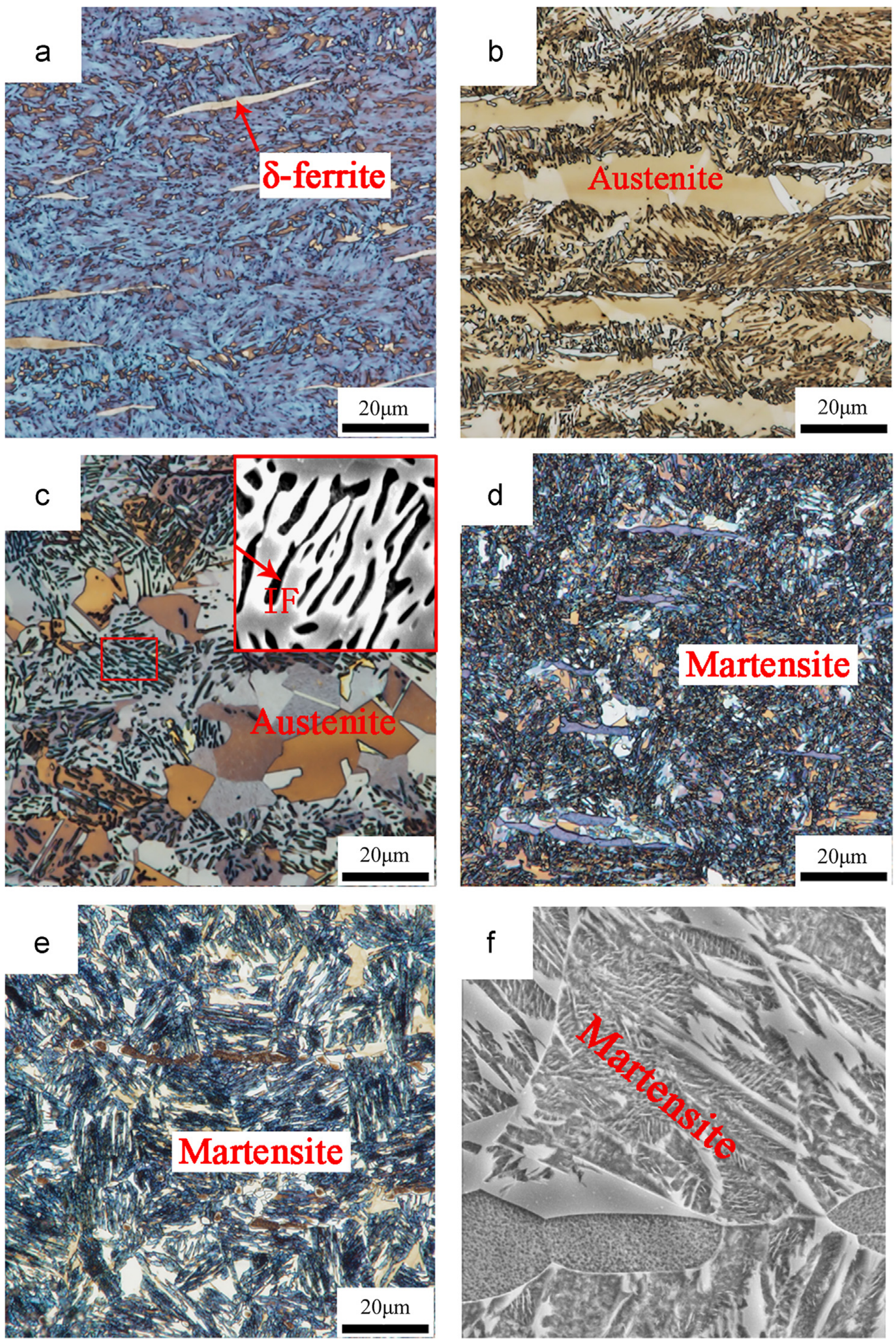

Fig. 1. Optical micrographs of (a) as-hot-rolled and quenched at (b) 750 °C, (c) 800 °C, (d) 850 °C (e) 900 °C and then tempered (200 °C, 20 min) TRIP steels, and (f) magnification of the region of martensite.