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Effect of carbon at interface of austenite on manganese segregation of low carbon and manganese steel

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ABSTRACT

The effect of carbon at interface of austenite on manganese segregation was investigated. Carbon segregating at interface of retained austenite within ferrite grains can attract manganese atoms to form atomic couples C-Mn filling into vacancies. C and Mn segregation can make the interface of austenite more stabilization so that the interface cannot transform to twin martensite under 20% pre-straining. The interface can act as deformation buffer zones to make for plasticity accommodation between ferrite and twin martensite leading to improved ductility of the steel.

1. Introduction

There is much current interest in accelerating the development of the third generation of advanced high-strength steels (AHSS) with improved strength and ductility [1]. Quenching and partitioning (Q&P) steel is one of third generation AHSS with excellent mechanical properties [2,3].

B.B. Straumal [4,5] reported that carbon segregation at ferrite grain boundaries can strongly influence the microstructure and properties of nanograined steels, and lead to the decrease of amount of bulk carbides. In addition, Mn has also a high segregation at grain boundaries [6], which affects stacking fault energy, stabilization of retained austenite and deformation mechanism [7–11]. Therefore, this paper makes Mn act as an interesting element, and the effect of C at the interface of austenite on Mn segregation was investigated by three dimensional atom probe (3DAP), which is a characterization technique that provides three dimensional elemental mapping with nearly atomic resolution and local chemical gradients [12,13]. And the different response from the interface and interior of retained austenite to 20% pre-straining was investigated by transmission electron microscopy (TEM) and electron back scattered diffraction (EBSD).

2. Experimental

The chemical composition of the investigated steel is Fe-0.19C-1.42Si-2.02Mn (wt%). The cold-rolled steel was 2 mm thick. Q&P heat treatment started with intercritical annealing temperature, 800 °C for 150 s, at 10 °C/s, followed by cooling at 50 °C/s to quenching temperature 180 °C, after that specimens were re-heated to partitioning temperature 400 °C, isothermal holding for 300 s. Finally, they were quenched to ambient temperature. The ultimate tensile strength is 1080 MPa and the total elongation is 29.5%.

Samples for 3DAP measurements were prepared by two-step electrolytic polishing. 3DAP analyses were performed using a local electrode atom probe (LEAP 4000X HR, Cameca Instruments) in voltage mode at temperature of 50 K. The evaporation rate and the pulse rate were 1% and 250 kHz, respectively. Data analyses were performed using the IVAS 3.6.8 software. The acquired mass spectra revealed peaks corresponding to C^+, C^{2+}, C+2, C+3, C^2+3, C^2+4, Fe^{2+}, $Si^{2+}$and Mn^{2+}. The specimen under 20% pre-straining was investigated by TEM on a JEM-2100 (HR) operating at 200 kV and EBSD on a TESCAN MIRA 3 LMH field emission scanning electron microscope. The obtained EBSD data (step size: 0.01 μm) was analyzed using Channel 5 software provided by Oxford HKL.

3. Results and discussion

The microstructure of Q&P steel consists of ferrite, martensite

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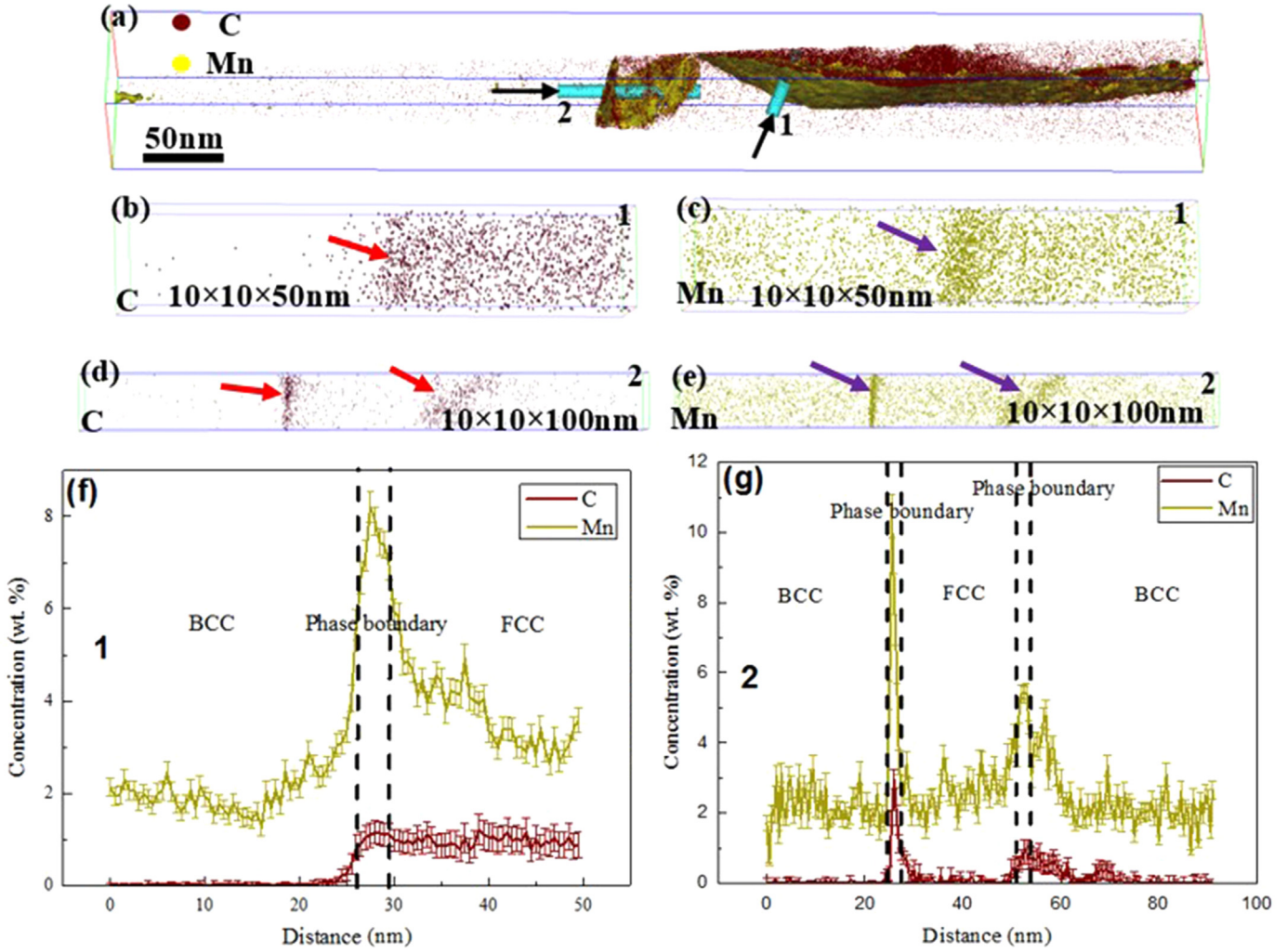

Fig. 1. (a) 3D elemental map showing the distribution of C ● and Mn ● with Mn also in terms of 4 at% Mn isoconcentration surfaces. (b) and (c) show carbon and manganese atoms distribution in the cylinder "1" of (a). (d) and (e) show carbon and manganese atoms distribution in the cylinder "2" of (a). (f) and (g) show carbon and manganese content along the cylinder "1" and "2" of (a) respectively.

and retained austenite. Fig. 1(a) shows 3D elements map of C and Mn of the specimen after Q&P heating treatment. Fig. 1. (f) and (g) show concentration profiles of carbon and manganese in the cylinder "1" and "2" as indicated in Fig. 1(a). Carbon partitioning is clearly seen in Fig. 1(a), and carbon-poor and carbon-enriched regions must be BCC phases and retained austenite, respectively in terms of their carbon content, morphology and scale. Carbon content at the interface of the two austenite can reach maximum 1.21 and 2.96 wt%, respectively, which indicates that carbon atoms can segregate at the interface, which are marked with red arrows in Fig. 1(b) and (d).

Mn segregating at the interfaces of austenite can also be observed and is marked with purple arrows in Fig. 1(c) and (e). The yellow envelopes are isoconcentration surfaces representing 4.0 at% manganese as shown in Fig. 1(a). The Mn content at the interfaces of strip shaped and granular austenite reach maximum 8.20 and 10.48 wt% respectively as shown in Fig. 1(f) and (g), and Mn content at the interface is about 4–5 times more than the bulk concentration of the steel. Mn segregation can occur after C segregation due to its slower diffusion coefficient [14]. And auger electron spectroscopy measurements showed N on the intergranular facets with no enhancement of Mn, however, on aging at 450 °C grain boundary segregation of Mn was observed [15], which indicates that Mn segregation can occur during aging. For the Q&P steel, Mn segregation can occur during partitioning. Maier [16] reported that manganese, influenced by nonequilibrium segregation, is independent of additional elements. However, for the low carbon and manganese steel, Mn and C segregating at interface of retained austenite can be both observed. Therefore, in the following, the effect of C at the interface of austenite on Mn segregation was investigated.

The kinetic behavior about C and Mn diffusion was simulated by DICTRA, and linear cell geometry was chosen. The spatial range of BCC and FCC phases was shown in Fig. 2(a), and atoms diffusive motion was vertical to the plane. The spaces can be discretized as geometrical grids as shown in Fig. 2(a). The compositions of C and Mn in BCC and FCC phases were assumed to the same with the bulk concentration. The simulation was performed at partitioning temperature of 400 °C. The shape of the curve showing carbon content distribution in austenite changes from slim to pyknic with time increasing as shown in Fig. 2(b). And carbon content at the interface of austenite reaches maximum. In Fig. 2(c) and (d), the horizontal and vertical axis represent square root of time and Mn content at the interface of austenite, respectively. And Mn content in the interface of austenite increases with time increasing as shown in Fig. 2(c). However, Mn content at the interface of austenite remains unchanged when carbon atoms indiffusion is defined during partitioning at 400 °C as shown in Fig. 2(d). It indicates that C segregating at interface of austenite leads to Mn segregation, and C atoms at the interface can attract Mn atoms