



# Difference in transformation behavior between ferrite and austenite formations in medium manganese steel

N. Nakada<sup>a,b,\*</sup>, K. Mizutani<sup>c,1</sup>, T. Tsuchiyama<sup>a,b</sup>, S. Takaki<sup>a,b</sup>

<sup>a</sup> Department of Materials Science and Engineering, Graduate School of Engineering, Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan

<sup>b</sup> International Institute for Carbon Neutral Energy Research (WPI-I2CNER), Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan

<sup>c</sup> Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan

Received 25 September 2013; received in revised form 25 October 2013; accepted 29 October 2013

Available online 23 November 2013

## Abstract

The difference in transformation behavior between the  $\gamma \rightarrow \alpha$  and  $\alpha' \rightarrow \gamma$  transformations at the transition temperature  $T_0$  was investigated in 0.1%C–5%Mn steel. The  $\gamma \rightarrow \alpha$  transformation was very slow, and so little ferrite phase formed at  $T_0$ , even after a lengthy annealing time of 50 h. However, the  $\alpha' \rightarrow \gamma$  transformation was relatively fast and rapidly proceeded at  $T_0$ . In the dual-phase structure formed by the  $\alpha' \rightarrow \gamma$  transformation, thin film-shaped reversed austenite grains with sufficient thermal stability formed along the lath boundaries of the tempered martensite matrix. The simulation using diffusion-controlled transformations (DICTRA) software confirmed that the rapid austenite formation in medium manganese steel is attributed to: (1) the high density of austenite nucleation sites derived from the hierarchical lath martensitic structure; (2) the negligible-partitioning local equilibrium growth controlled by very fast carbon diffusion at the initial stage; and (3) the relatively higher diffusivity of Mn within the martensite matrix under the partitioning local equilibrium growth that occurred at a subsequent stage.

© 2013 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.

**Keywords:** Medium Mn steel; Reversed austenite; Martensite; Local equilibrium; Growth kinetics

## 1. Introduction

High-manganese steel, in which the austenite phase is sufficiently stabilized by the addition of significant amounts of Mn and carbon, is usually referred to as Hadfield steel (e.g., Fe–(10–15)%Mn–(0.9–1.4)%C alloy, wt.%). These types of steel have been used as wear-resistant steels through the years because of their high strain hardenability [1–3]. The characteristic high strain hardenability of the austenite phase is essentially attributed to both low stacking fault energy [4,5] and dynamic strain aging [6,7]. For automotive steel sheets, a specialized high-Mn steel with a moderate

amount of Al and Si has been developed, in which the stacking fault energy is controlled so as to form deformation twinning during cold working (e.g., Fe–(15–30)%Mn–Al–Si–C alloy). This new class of high-Mn steel is called twinning-induced plasticity (TWIP) steel [8–10]. TWIP steel is characterized by an excellent strength–ductility balance compared with conventional high-strength automotive steel sheets, such as dual-phase steel and low-alloy TRIP steel. However, there is a serious problem in terms of mass production of this steel: adding a significant amount of Mn markedly raises the costs not only of the raw materials, but also of the production process. For this reason, the Mn content in these types of steel needs to be reduced to an industrially appropriate level. Indeed, medium-Mn steel containing 5–8% Mn has been getting much more attention lately [11–16]. Since the reduction in the Mn content leads to an increase in the martensite-start temperature  $M_s$ , a medium-Mn steel never exhibits an austenitic single-phase

\* Corresponding author at: Department of Materials Science and Engineering, Graduate School of Engineering, Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan.

E-mail address: [nakada@zaiko.kyushu-u.ac.jp](mailto:nakada@zaiko.kyushu-u.ac.jp) (N. Nakada).

<sup>1</sup> Current address: Maruichi Steel Tube Ltd.

structure at ambient temperature. Therefore, the microstructure of this steel is usually controlled to be a  $\alpha + \gamma$  dual-phase structure by heat treatment in order to concentrate Mn and carbon into the austenite phase. To achieve this, there are two approaches. One is ferrite formation during continuous or isothermal cooling after austenitization ( $\gamma \rightarrow \alpha$  transformation) and the other is austenite formation during partial reversion after quenching ( $\alpha' \rightarrow \gamma$  transformation). However, the difference in transformation behavior between both approaches, especially in terms of their kinetics, is unclear. In this study, the transformation behavior was compared between  $\gamma \rightarrow \alpha$  and  $\alpha' \rightarrow \gamma$  transformations at temperature  $T_0$  in a 0.1%C–5%Mn steel in order to determine an appropriate heat treatment for obtaining thermally stable austenite as a second phase in medium-Mn steel. The transformed microstructure and the transformation kinetics are then discussed, using a diffusion-controlled transformation (DICTRA) simulation.

## 2. Experimental procedure

The material used in this study was 0.1%C–5%Mn (wt.%) steel with the chemical composition listed in Table 1. This material was sufficiently homogenized at 1473 K for 20 h after hot rolling to diminish the segregation of Mn. It was then cold rolled to 10 mm in thickness. The specimen cut from the cold-rolled steel sheet was first austenitized at 1173 K for 1.8 ks, followed by water quenching to obtain an initial lath martensite. It was preliminarily confirmed by saturation–magnetization measurement that the lath martensite had no retained austenite. After that, the austenitized specimen was subjected to the heat-treatment routes illustrated in Fig. 1. One route was isothermal holding at 909 K, which is in the temperature range of an austenite–ferrite two-phase region without carbide for up to 50 h after re-austenitization to form ferrite within an austenite matrix ( $\gamma \rightarrow \alpha$ ). The other route was partial reversion, using so-called intercritical annealing at the same temperature to form austenite within a martensite matrix ( $\alpha' \rightarrow \gamma$ ). The temperature of 909 K corresponds to the transition temperature  $T_0$ , calculated with Thermo-Calc (TCFE6 database), at which the total driving force for the transformations was equal between the  $\gamma \rightarrow \alpha$  and  $\alpha' \rightarrow \gamma$  transformations using the two heat-treatment routes. The transformation rate during each heat treatment was measured by a thermal dilatation tester. The microstructure and crystallographic characteristics were analyzed by means of the electron back-scattering diffraction (EBSD) method, using a field-emission scanning electron microscope (JSM-6701F, JEOL Ltd.). Cs-corrected field-emission scanning transmission electron microscopy

(STEM; JEM-ARM200F, JEOL Ltd.) was also used for analyzing the distribution of Mn around the  $\alpha/\gamma$  interface. The  $\gamma \rightarrow \alpha$  and  $\alpha' \rightarrow \gamma$  transformations under local equilibrium conditions were simulated by DICTRA, using the TCFE6 and MOB2 databases.

## 3. Results

### 3.1. Difference in growth kinetics between ferrite and austenite formations at the transition temperature

Fig. 2 shows the changes in the austenite volume fraction during the holding at 909 K in each heat treatment route. The data of the  $\gamma \rightarrow \alpha$  and  $\alpha' \rightarrow \gamma$  transformations are drawn with broken and solid lines, respectively. In addition, the fractions of retained austenite measured at ambient temperature after the  $\alpha' \rightarrow \gamma$  transformation were also plotted in this figure using solid circles. It is worth noting that there is a significant difference in the transformation rate between the  $\gamma \rightarrow \alpha$  and  $\alpha' \rightarrow \gamma$  transformations, although the total driving force for the transformation is the same between them. The  $\gamma \rightarrow \alpha$  transformation was such a slow reaction that very little ferrite phase formed, even after a lengthy annealing time of 50 h. However, the  $\alpha' \rightarrow \gamma$  transformation was a relatively fast reaction, and thus the austenite fraction rapidly increased and eventually reached the equilibrium value calculated by Thermo-Calc. In addition, the austenite formed by the  $\alpha' \rightarrow \gamma$  transformation remained even after cooling to ambient temperature, which indicates that the austenite had sufficient thermal stability because of the Mn and/or carbon concentration. From the industrial point of view, the partial reversion process has an advantage in that it shortens the heat-treatment time.

### 3.2. Microstructural characteristics of reversed austenite formed by $\alpha' \rightarrow \gamma$ transformation

The orientation imaging map of the face-centered cubic (fcc) and body-centered cubic (bcc) microstructure after partial reversion treatment for 50 h is shown in Fig. 3. The orientations of both phases are shown in Fig. 3a and that of only the fcc phase is extracted in Fig. 3b. It was found that fine reversed austenite grains formed evenly within tempered martensite matrix during the partial reversion process, and the grains then remained stable at ambient temperature. The comparison between Fig. 3a and b reveals that the preferential nucleation sites of the reversed austenite grains are the lath and block boundaries of the martensite matrix. The TEM image in Fig. 4a shows the dual-phase structure within a martensite block in the same specimen, and Fig. 4b shows the corresponding dark-field image of the reversed austenite grains. Austenite grains in the shape of thin films several hundred nanometers thick seem to decorate the lath boundaries, and thus the dual-phase structure formed by the  $\alpha' \rightarrow \gamma$  transformation is characterized by a fine lamellar structure consisting of the film-shaped austenite grains and martensite lath with a

Table 1  
Chemical composition of steel used in the present study (wt.%).

C	Si	Mn	P	S	Al	N	Fe
0.092	0.004	4.96	<0.002	0.0024	0.034	0.0032	Bal.

Download English Version:

<https://daneshyari.com/en/article/1445938>

Download Persian Version:

<https://daneshyari.com/article/1445938>

[Daneshyari.com](https://daneshyari.com)