Effect of prior austenite grain size on bainitic transformation above and below Ms in medium Mn steel

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Abstract. The effect of prior austenite grain (PAG) size on bainitic transformation kinetics below Ms in 0.2C-3.92Mn-1.6Si steel has been investigated using a dilatometer. The samples were austenitized at two different temperature to achieve the average PAG size of ~10.9 μm and ~17.3 μm. The results show that above Ms the austenite grain size plays a significant role in bainitic transformation kinetics. However, the influence of austenite grain size on bainitic transformation kinetics below Ms becomes weaker which is ascribed to the acceleration of prior martensite on bainitic transformation below Ms.

1. Introduction

The 3rd generation advanced high strength steels (3G-AHSSs) due to its adequate strength and ductility have aroused wide public concern and well developed in the automobile industry for meeting the requirement of energy saving and emission reduction. The key design of most 3G-AHSSs relies on the control of the stability of retained austenite for transformation induced plasticity (TRIP) effect [1] and multi-phase are usually obtained including retained austenite [2]. Medium Mn steels containing 3–10 wt% Mn are being actively investigated as a good candidate of the 3G-AHSSs due to the combination of strength and plasticity [3]. Traditional medium Mn steels obtain lath ferrite and retained austenite by intercritical annealing process to achieve high strength plastic product.

The traditional medium-manganese steel developed by the intercritical annealing process is produced based on the continuous cold-rolling annealing process. The intercritical annealing process is not suitable for the hot-rolling process as automotive structural parts. However, ferrite and retained austenite have lower yield strength than martensite and bainite. He B. B. et al. [4] reported that the dislocations introduced using by warm-rolling increase the yield strength while maintaining an excellent uniform elongation. For increasing the yield strength the bainite is a potential choice of microstructure in medium Mn steel and the isothermal process is a easy heat treatment. Therefore, in the medium Mn steel the isothermal bainitic transformation is worth studying to develop the hot-rolling product. Some studies have been made on the effect of prior austenite grain (PAG) size on bainite transformation [5] in steels. However, little research has been reported about the effect of PAG size on bainitic transformation in medium Mn steel. Clarifying the relationship between PAG size and bainitic transformation could provide theoretical basis for tailor the microstructure in medium Mn steel.

This work is aimed to investigate the effect of PAG size on the bainitic transformation above and below Ms in 0.2C-3.92Mn-1.6Si steel. The bainitic transformation kinetics was separated into
incubation time, transformation velocity and transformed volume fraction. The bainitic transformation below Ms

2. Experimental procedure
The chemical composition of the steel used in this study was 0.2C-3.92Mn-1.6Si (wt.%). Silicon was added to suppress the precipitation of carbides and promote the diffusion of C from martensite to austenite during partitioning. A 50kg ingot was cast using a vacuum induction furnace and forged to 60 mm thickness and then cut to blocks. After solution treatment at 1200°C for 2 h, the blocks was hot rolled to about 6 mm through seven passes with a finish rolling temperature at around 870 °C. After hot rolling the steel plates were cooled to room temperature by water.

Fig. 1. Schematic of heat treatment processes

Dilatometry specimens (φ4×10 mm) were prepared along the rolling direction, and dilatometry experiments were performed with a TA Instruments DIL805A/D dilatometer with the heat treatment profiles shown in Figure 1. The Ms temperatures are 317 ℃ and 302 ℃ after austenitizing at 1000 ℃ and 850 ℃ for 3 min. The temperature of bainitic transformation above Ms is 350 ℃. The volume fraction of bainite and prior martensite was estimated by level rule. The temperature of bainitic transformation below Ms was determined at 280 ℃.

3. Results and discussion

3.1. Effect of austenitization temperature on PAG size
The dilatometry samples were austenitized at two different temperature in order to vary the PAG size. Fig. 2(a) and (b) show the optical micrographs of the samples which show that the PAG size. The average PAG size measured using the linear intercept method was observed to be 10.91±4.24 μm and 17.28±6.76 μm, respectively. The average PAG size increased when the austenitizing temperature increased from 850 ℃ to 1000 ℃.

Fig. 2 Effect of austenitization temperature on PAG size (a) 850 ℃ (b) 1000 ℃; distribution of PAG size (c) 850 ℃ and (d) 1000 ℃
3.2. Effect of PAG size on bainitic transformation above Ms

Fig. 3 Effect of PAG size on subsequent transformation kinetics (a) change in length as a function of temperature, (b) bainite volume fraction during isothermal stage

Fig. 3(a) and (b) show the dilatational curves of bainitic transformation at 350 °C (above Ms) after austenitizing temperature of 1000 °C and 850 °C. Fig. 3(a) shows that the Ms temperature is lower in final quenching when the amount of bainite is more. As shown in Fig. 3(b) the bainitic transformation kinetics follows an S-shape curve. When the PAG size decreases the incubation time was increased. The transformation velocity is defined as the maximum slope in the volume fraction curve. As shown in Fig. 3(b) the transformation velocity become quick when the average PAG size is 17.28μm. The transformed volume fraction of bainite increases up to 57% when the average PAG size is 17.28μm.

Above Ms the transformation velocity of bainite increase in sample with larger PAG size. Because the growth of a bainite plate is resisted by the matrix, a smaller PAG size must retard growth. The nucleation rate of bainite usually depend on the number density of potential nucleation sites [6]. The potential nucleation sites of grain boundary increase with grain refinement. However, the intragranular potential nucleation sites might decrease in smaller grain size. And the growth of a bainite plate is resisted by the matrix in a smaller austenite grain. The bainitic transformation rate is determined by the nucleation rate and growth of bainite. Therefore, it is reasonable that the bainitic transformation slowed down in the sample with a smaller PAG size.

3.3. Effect of PAG size on bainitic transformation below Ms

Fig. 4(a) and (b) show the dilatational curves of bainitic transformation at 280 °C (below Ms) after austenitizing temperature of 1000 °C and 850 °C. The presence of prior martensite strongly accelerated the subsequent isothermal transformation kinetics[7]. Obviously, the incubation time disappeared nearly in Fig. 4(b). Therefore, the incubation time shortened due to the presence of prior martensite. Below Ms the α/γ interface and dislocation appeared due to the presence of prior martensite. Below Ms the density of potential nucleation sites for bainitic ferrite increased which led to nucleate rapidly. Although the transformation rate was increased, the volume fraction of bainite at 280 °C was lower than ~30% within 1800 s which was lower than the amount of bainite at 350 °C in Fig.3(b). It is reason that the amount of available austenite that transformed into bainite becomes less due to the presence of prior martensite.
Fig. 4(a) shows that the Ms temperatures in final quenching are lower than those in Fig. 3(a). The result indicates that the retained austenite became more stable after isothermal bainitic transformation below Ms. The volume fraction of prior martensite was ~43% and ~32% at 280 °C after austenitizing temperature of 1000 °C and 850 °C. Above Ms and below Ms the untransformed austenite was almost same after isothermal bainitic transformation. Therefore, the contribution of bainitic transformation to the stability of austenite is weaker than the contribution of carbon partitioning from prior martensite.

3.4. Microstructure

Fig. 5 SEM morphology of samples treated at 350 °C; (a) and (c) austenitizing at 1000 °C, (b) and (d) austenitizing at 850 °C

The microstructure of samples after bainitic transformation at 350 °C (above Ms) are shown in Fig.5. The bainite (B) can be easily distinguished from the fresh martensite (FM) formed in the final quenching. As shown in Fig.5(a) and Fig.5(b) the volume fraction of bainite becomes less in sample with the smaller PAG size, which is in agreement with the results in Fig.3. As shown in Fig.5(c) the retained austenite (RA) is present in these microstructures in the form of films between bainitic ferrite units, and/or as coarser particles. Fig.5(d) shows that the microstructure contains irregular bainitic ferrite and retained austenite in the form of thin films or martensite-austenite (MA) islands.

Fig. 6 SEM morphology of samples treated at 280 °C after austenitizing at 1000 °C

The prior martensite would be tempered at lower than Ms temperature during isothermal process. Therefore, the microstructure below Ms contained tempered martensite (TM) as shown in Fig.6. Below Ms the bainitic ferrite appears in the form of acicular units as shown by the yellow arrow of Fig.6(a) and Fig.6(b). The acicular bainitic ferrite below Ms may be caused by the large driving force of transformation based on displacive mechanism. Different from Fig.5, the MA islands is not almost observed in Fig.6.
4. Conclusion
In summary, the average PAG size is from 10.91±4.24 μm and 17.28±6.76 μm when the austenitizing temperature increase from 850 °C to 1000 °C. Bainitic transformation above Ms is retarded in sample with the average smaller PAG size in 0.2C-3.92Mn-1.6Si steel. The bainitic transformation kinetics below Ms has little difference in different PAG size due to the presence of prior martensite. The bainite above Ms contains mainly irregular bainitic ferrite, yet there is acicular bainitic ferrite below Ms.

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