High Strength-Ductility Combination of a Medium-Mn Steel Through Pre-annealing and Fast Heating

H. F. Lan(✉), M. R. Wu, J. P. Li, and L. X. Du

State Key Laboratory of Rolling and Automation, Northeastern University, Shenyang 110819, China

Lanhf@mail.neu.edu.cn

Abstract. In this study, the effect of pre-annealing treatment on the microstructure and mechanical properties of a cold rolled medium-Mn steel was investigated. The C/Mn distribution in austenite during the following heating was simulated. The results showed that the inhomogeneous Mn distribution is fabricated during the pre-annealing process, which leads to enriched and poor Mn region in austenite in virtue of rapid heating. Consequently, varied transformation, i.e. martensite/retained austenite and bainite transformation occurs during the final cooling process. Accordingly, the combination of strength and ductility was improved significantly with the assistance of bainite and retained austenite.

Keywords: Medium-Mn steel · Pre-annealing · Cementite dissolution · Austenite transformation · Strength-ductility combination

1 Introduction

Transformation-induced plasticity (TRIP) plays a major role in improving the combination of strength and ductility of steels, which are widely used in the automobile industry [1–5]. The enhanced plasticity is determined by both the volume fraction and the stability of the retained austenite [6–8].

John et al. [9] performed a rapid heat treatment with AlSI8620 steel in which it revealed that fine austenite grains were obtained under the rapid heat treatment conditions Meanwhile, due to the rapid heating rate, there is element distribution concentration gradient in austenite. This leads to non-uniform chemical composition inside the austenite grains, so that different microstructure was obtained after cooling.

In this paper, numerical simulation was carried out using DICTRA software under the assumption of local equilibrium (instead of para-equilibrium assumption). On this basis, the effect of the pre-annealing on microstructural evolution, alloying partitioning and mechanical properties was investigated.

Y. Zhang and M. Ma (Eds.): ICHSU 2022, AHMST 2, pp. 124–128, 2023.
https://doi.org/10.2991/978-94-6463-114-2_17

Table 1. Chemical composition of the investigated steels (wt.%).

C	Mn	Si	Fe
0.10	4.53	0.25	Bal.

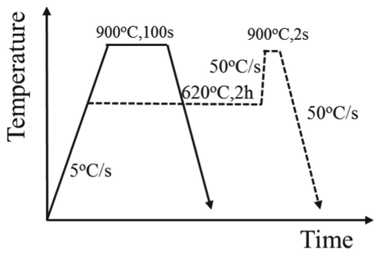

Fig. 1. Schematic annealing diagram.

2 Experimental

2.1 Experimental Procedures

The steel studied, was melted in an induction furnace under a vacuum and cast to a 50 kg ingot, which was then forged into a 140 mm × 140 mm thick billet. The chemical composition of the experimental steel is shown in Table 1. Then the billets are homogenized at 1250 °C for 2 h, and then hot rolled into 5 mm sheet using a Φ450 mm hot rolling mill with finish rolling temperature of 900 °C and air cooled to room temperature. The hot rolled plates were further cold rolled with a total reduction of 70% through 11 passes. The cold rolled plates were annealed at 620 °C for 2 h and heated with heating rate of 50 °C/s to 900 °C and soak for 2 s, which is named as processing 1#. Other ones were continuously heated to 900 °C and soaked for 100 s with a heating rate of 5 °C/s, which is named as processing 2# (shown in Fig. 1).

The microstructure was observed by electron probe microanalyzer (EPMA) and the components of different phases were analyzed. Samples for EPMA are normally ground, polished and etched with 4% alcohol nitrate. Tensile test was carried out with gauge length of 40 mm with a tensile speed of 3 mm/min.

2.2 Simulation Setups

The C and Mn distribution during annealig was modelled in the DICTRA module of the Thermo-Calc software package, using the TCFE9 thermodynamic database and the MOBFE4 mobility database. One-dimensional system (cell) including α and γ was used.

3 Results and Discussion

Figure 2 shows the microstructure and C and Mn distribution after annealing at 620 °C for 2 h. One can see that both C and Mn are enriched in some regions which is corresponding to austenite at 620 °C.

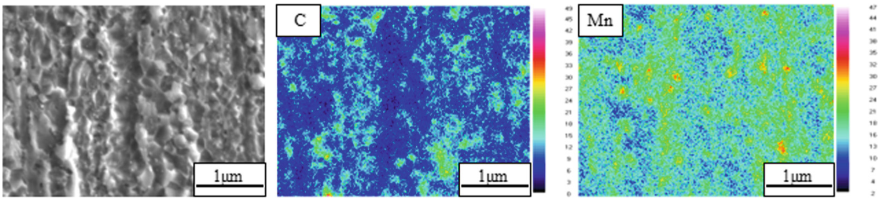

Fig. 2. Distribution of Mn and C after annealing at 620 °C for 2 h.

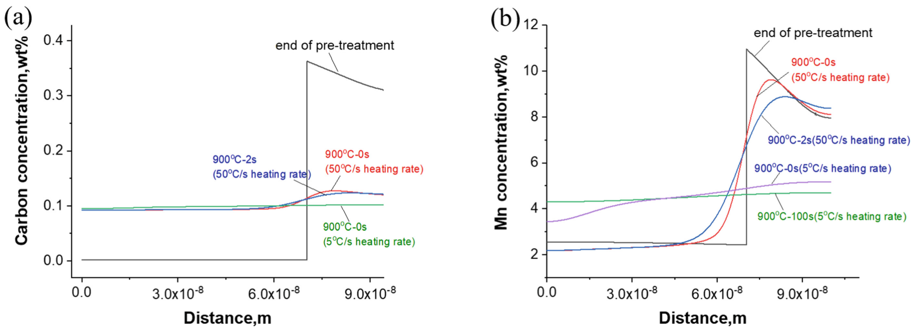

Fig. 3. C and Mn distribution at different heating rate: (a) C, (b) Mn.

Figure 3 shows the C and Mn distribution at different annealing stage and heating rate. One can see that at the end of the pre-treatment (620 °C annealing), both C and Mn are much higher in γ even though they are not uniform because of the slow diffusion coefficient in γ. While heating to 900 °C with heating rate of 50 °C/s, slight enrichment of C in γ is maintained for 0 s and 2 s soaking. Whereas, C concentration is uniform with heating rate of 5 °C/s. As for Mn, significant Mn enrichment in γ is observed under the heating rate of 50 °C/s, which is inherited from the original Mn-enriched γ at the end of pre-treatment. However, Mn tends to be uniform in γ under the heating rate of 5 °C/s. This indicates that with fast heating, the inhomogeneous Mn distribution in the original microstructure could be retained in the full austenite region, which is beneficial to the remaining of austenite during the cooling process.

Figure 4 shows the final microstructure of different annealing processes. One can see that the microstructure is obviously different for the two processings. In Fig. 4(a), bainite and martensite microstructure is found with a refined morphology. While in Fig. 4(b), microstructure is mainly consisted of martensite with a much coarser morphology. It is known from Fig. 4 that especially Mn distribution is inhomogeneous in austenite under high heating rate. It is considered that the poor Mn regions and those enriched Mn ones would be transformed into bainite and martensite, respectively due to the varied quenchability. Moreover, the high heating rate as well as the short soaking time contributes to refined microstructure. As for the heating rate of 5 °C/s (Fig. 4(b)), Mn distribution is much more uniform for the soaking time of 100 s, leading to the martensite transformation during the following cooling process.

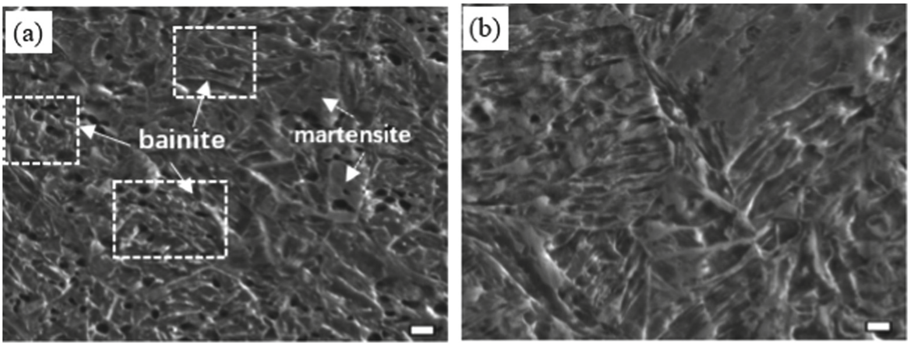

Fig. 4. The microstructure of different annealing processes of experimental steel: (a) Processing 1#, (b) Processing 2#.

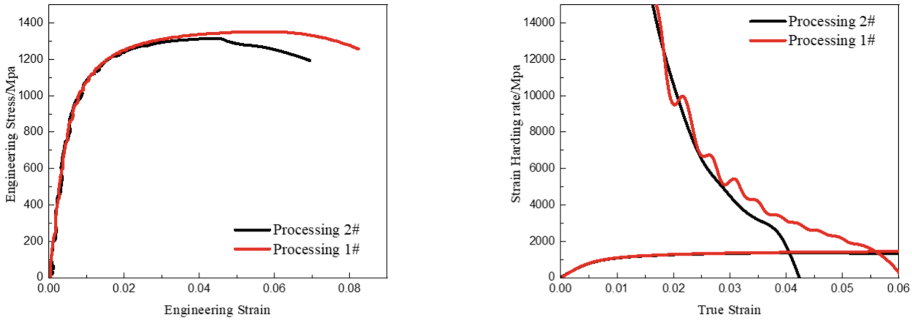

Fig. 5. The tensile curves and strain hardening rate curves of varied processing.

Figure 5 shows the tensile curves and strain hardening curves of varied processing. One can see that a high strength-ductility combination is achieved in Processing 1# with tensile strength of 1360 MPa and total elongation of 9.0%. This could be due to the contribution of combined effect of bainite and retained austenite. Whereas, the total elongation for Processing 2# is 7.0%, much lower than Processing 1#. In addition, the strain hardening rate of Processing 1# is higher than Processing 2#, leading to the higher uniform elongation.

4 Conclusions

In this study, the effect of pre-annealing treatment on the microstructure and mechanical properties of a cold rolled medium-Mn steel was investigated. The conclusions are as follows.

(1) The C/Mn distribution in austenite during the following heating was simulated. The results showed that the inhomogeneous Mn distribution is fabricated during the pre-annealing process, which leads to enriched and poor Mn region in austenite in virtue of rapid heating.

(2) Due to the inhomogeneous Mn distribution in austenite, varied transformation, i.e. martensite/retained austenite and bainite transformation occurs during the final cooling process.
(3) High combination of strength and ductility was achieved with the assistance of bainite and retained austenite contributed by pre-annealing treatment and fast heating.

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