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Effect of hot rolling temperature on the microstructure and mechanical properties of ultra-low carbon medium manganese steel

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ABSTRACT

The effect of hot rolling temperature on microstructural evolution and mechanical properties of 0.05C-5Mn (wt%) steel was investigated. With the decrease of hot rolling temperature from 1150 °C to 900 °C, the average size of prior austenite grain was decreased from ~ 40 µm to ~20 µm, and average width of martensite lath was refined from ~ 400 nm to ~ 250 nm. The morphology of reversed austenite was changed from film-like shape to block-like shape, and the volume fraction of reversed austenite was increased from 14.75% to 16.28% because of the stimulated nucleation in refined prior austenite grains by rolling at lower temperature. The yield strength, tensile strength and the total elongation were simultaneously increased from 673 MPa, 805 MPa, and 27.5% to 704 MPa, 846 MPa, and 31%, respectively. The low temperature impact toughness was significantly enhanced from 133 J to 222 J at − 40 °C. The significant improvement in mechanical properties by lower hot rolling temperature were attributed to both the refined tempered martensite lath with higher density of high misorientation grain boundaries and the active TRIP effect of reversed austenite with suitable mechanical stability.

1. Introduction

Light weight and safety is an important requirement of the industry [1–3]. Enhanced strength and toughness is usually obtained by addition of expensive alloying elements and adjustment of thermomechanical controlled processing, which unfortunately increases the cost and limits the development [4–7]. In comparison with conventional high strength steels, the medium manganese (5–8 wt%) steels have attracted significant attention because of excellent combination of high strength, excellent ductility and impact toughness, especially at low temperature. It has potential applications in automobiles, offshore platform, bridges and other structural component.

The superior mechanical properties of medium manganese steel are mainly attributed to the TRIP effect and the cooperative deformation of ferrite. For example, the Fe-0.2C-11Mn as-cold-rolled steel with a high volume fraction of austenite after intercritical annealing exhibited an excellent combination of TE of 43–70% and UTS of 900–1087 MPa [8]. It is recognized that stable retained austenite is beneficial to toughness by restricting brittle fracture without undergoing transformation [9–11]. For example, an excellent combination of ductility (total elongation of ~37.3%) and toughness (Charpy v-notch impact energy of ~ 158 J at −80 °C) was obtained by the design of fine ferrite-austenite microstructure [12]. Zou et al. [13] suggested that the metastable reversed austenite significantly improved the low-temperature toughness by relieving the local stress concentration and consuming the tip energy of the propagating crack. However, the mechanism of retained austenite in improving toughness and ductility is still unclear.

Although there have been extensive studies on medium manganese steel which focused on chemical composition and heat treatments, there are limited studies on hot rolling temperature. Therefore, the objective of this paper is to study the effect of hot rolling temperature on the microstructure and mechanical properties of ultra-low carbon medium manganese steel. Excellent properties and desired microstructure were obtained via low temperature rolling and annealing treatment.

2. Experimental procedure

The chemical composition of the steel was Fe-0.05C-0.2Si-5Mn-0.38Cr 0.28Cu-0.28Ni-0.22Mo (wt%). The experimental steel was melted in a high-frequency vacuum induction furnace and cast into ingot of thickness ~ 0 mm. The ingot was homogenized at 1200 °C for 2 h, and hot rolled to 12 mm thickness at 1150 °C and 900 °C (designated as HR1150 and LR900) via seven passes and cooled to room temperature in water. The two plates were intercritically annealed at

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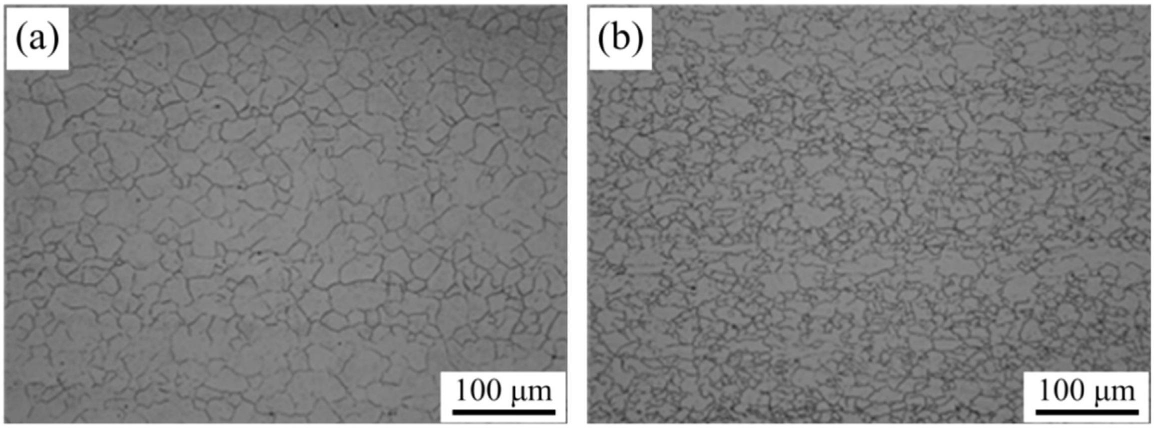

Fig. 1. Optical micrographs of prior austenite: (a) HR1150; (b) LR900.

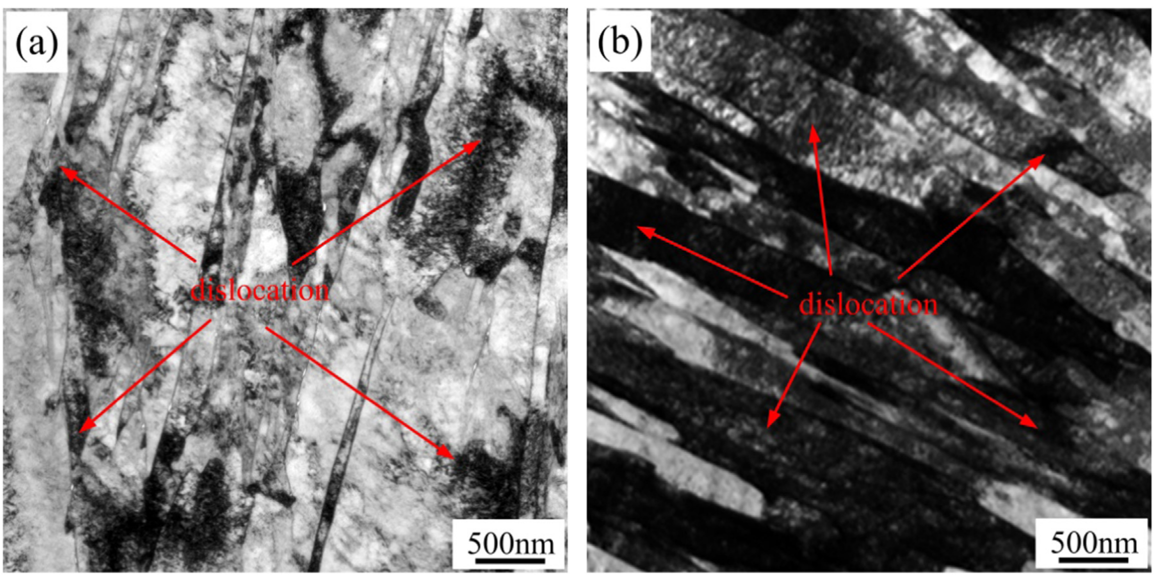

Fig. 2. Martensite lath microstructure: (a) HR1150; (b) LR900.

650 °C for 50 min, and air cooled to room temperature. The specimens were mechanically polished and etched by a mixed solution composed of 0.5% xylene, 3% dodecyl-benzene sulfonic acid, and 96.5% saturated picric acid at 65 °C to reveal the boundaries of prior austenite grains. The mean grain sizes of the specimens were determined by a linear intercept method. The specimens with dimensions of 6 mm diameter and 30 mm length were cut from the annealed plate along the rolling direction. The tensile tests were conducted on a Shimadzu AG-X universal testing machine at a speed of 3 mm/min. The impact test were performed in the temperature range of 20 to − 80 °C with standard Charpy impact specimens (dimensions: $10 \times 10 \times 55\ mm^3$) machined along the rolling direction using Instron Dynatup 9200 series instrumented drop weight impact tester, consistent with ASTME23 specification.

The specimens used for EBSD were electrolytically polished with a solution composed of 8% perchloric acid and 92% alcohol at room temperature, and EBSD analysis was carried out using a Zesis Ultra55 scanning electron microscope (SEM). For substructure observation, the 3 mm diameter disks were ground to thickness of 40 μm and then twin-jet electropolished using a solution consisting of 8% perchloric acid and 92% ethanol at − 30 °C, and their microstructures were examined by FEI Tecnai G² F20 transition electron microscope (TEM). The volume fraction of reversed austenite was determined by a D/max 2400 XRD using a Cu-Kα at room temperature and the integrated intensities of (200)γ, (220)γ, (311)γ, (200)α, and (211)α peaks were used to quantify the amount of reversed austenite using Eq. (1) [14]:

$$V_\gamma = 1.4 I_\gamma / (I_\alpha + 1.4\ I_\gamma) \quad (1)$$

where V_γ is the volume fraction of reversed austenite, I_γ is the integrated intensity of the austenite peaks, and I_α is the integrated intensity of the ferrite peaks.

3. Results and discussion

3.1. Microstructure

Fig. 1 provides prior austenite microstructure for the HR1150 and LR900 steels, showing the equiaxed prior austenite grains. Hence, it can be deduced that the recrystallization has occurred at both 1150 °C and 900 °C. The average prior austenite grain size is refined from ~ 40 μm to ~ 20 μm as the hot rolling temperature decreases from 1150 °C to 900 °C.

Fig. 2 exhibits the morphology of as-hot-rolled steel plate subjected to different rolling temperature. Both steels show fully martensite lathes, and the average values of lath width are ~ 400 nm and ~ 250 nm for the HR1150 and LR900 steels, respectively. Moreover, the dislocation density in the LR900 steel is pronouncedly higher than that in the HR1150 steel.