Microstructure and Properties Evolution of the Medium Manganese Steel During Inter-critical Annealing Heat Treatment and Its Influence by Vanadium Microalloying

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Abstract. The effect of V addition and inter-critical temperature quenching on the microstructure and properties of medium manganese steel were studied. As the quenching temperature of V-free medium manganese steel increased from 850 °C to 900 °C, the tensile strength of the steel increased from 980 MPa to 1220 MPa and the total elongation decreased from 30% to 15%. When the quenching temperature was increased to 950 °C, the tensile strength did not increase significantly, but the total elongation decreased to about 9.9%, which was due to the presence of coarse ferrite. The tensile strength of medium manganese steel quenched at 950 °C could reach 1500 MPa and the total elongation could reach 10.7% by V microalloying. Coarse banded ferrite in V-containing steel was greatly reduced and the morphology and distribution of ferrite between martensite in V-containing steel were optimized, which further improved the tensile strength of the medium-manganese steel without losing plasticity.

Keywords: Medium manganese steel · V Microalloying · Quenching temperature

1 Introduction

The low elongation greatly limits the use of 22MnB5, which is widely used in the automotive industry. Medium manganese steel has attracted widespread attention due to its excellent strength and plasticity [1, 2].

Medium manganese steel can often obtain higher products of ultimate tensile strength and total elongation (PSE) after inter-critically annealing [3]. The addition of Al can effectively expand the inter-critical temperature range. However, it will lead to the formation of coarse δ-ferrite during the solidification process, which limits the strength

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improvement of the steel [4]. Research showed that the addition of microalloying elements improves the strength of the steel without sacrificing plasticity [5].

In this study, the changes in microstructure and properties of 0.25C-5Mn-3Al steel quenched at different temperatures were observed and analyzed, and the effect of V addition on microstructure and mechanical properties was observed. This study has a certain reference value for further optimization of this series of medium manganese steels.

2 Materials and Experiments

The chemical compositions of the experimental steels are listed in Table 1. The thickness of the received hot-rolled sheets was 3.5 mm. The total thickness reduction imposed by cold rolling was 50%. Cold-rolled sheets shall be air-cooled to room temperature after annealing at 800 °C for 30 min. The ranges of Ae1-Ae3 for both V-free and V-containing steel are 604–986 °C and 579–1087 °C, respectively, which were calculated using the Thermo-Calc software with a TCFE12 database.

The V-free steel was kept at 850 °C, 900 °C, and 950 °C for 5 min, and then water-quenched to room temperature. To further improve the mechanical properties of the 950 °C quenched steel, 0.2%V was added. The microstructure was observed by optical st (OM; ZEISS Axioplan 2 imaging) and scanning electron microscope (SEM; Apreo S HiVac). Electron backscatter diffraction (EBSD; Oxford Symmetry), operated at 20 kV with a step size of 0.05 μm, was also employed to characterize different microstructural constituents. Samples for EBSD were electro-polished in a solution of 8% perchloric acid + 92% acetic acid at an operating voltage of 32 V. Phases present in the specimens were identified by X-ray diffraction (XRD; Cu-Kα radiation, scan rate 10°min^{-1}, scan step size 0.02°). Tensile test samples of width 6 mm and gauge of length of 25 mm were machined with their axis oriented parallel to the rolling direction. Tensile tests were conducted using an INSTRON 8801 machine at room temperature with a draw speed of 2 mm/min.

Table 1. The chemical composition of the tested steel (wt. %).

	C	Si	Mn	Al	V	Fe
V-free steel	0.25	0.2	5.0	3.0	—	Bal
V-containing steel	0.25	0.2	5.0	3.0	0.2	Bal

3 Result

3.1 Mechanical Property

Figure 1 shows engineering stress-strain curves of two kinds of steel after quenching. Continuous yielding occurred above 900 °C. With the increase in quenching temperature, the tensile strength of V-free steel increased, however, the total elongation decreased.

3.2 Microstructural Evolution

The microstructures of the two kinds of steel annealed at 800 °C were composed of martensite, fine elongated ferrite between martensite, and coarse banded ferrite, as shown in Fig. 2. With the increase in quenching temperature, the martensite content of V-free steel increased and the content of fine ferrite between martensite decreased, as shown in Fig. 3. Figure 4 shows the XRD results of the as-quenched samples. When the quenching temperature increased from 850 °C to above 900 °C, the volume fraction of retained austenite in the samples decreased from 9.64% to almost 0%. The ferrite in the V-free steel quenched at 950 °C was mostly block-shaped, while the ferrite in the V-containing steel was mostly strip-shaped and distributed between the martensitic laths, as shown in Fig. 5.

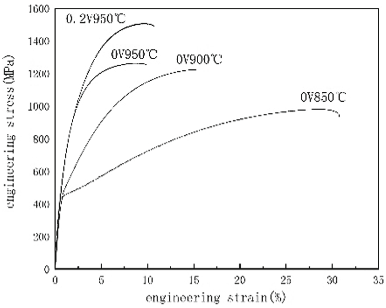

Fig. 1. Engineering stress-strain curves of V-free and V-containing steel.

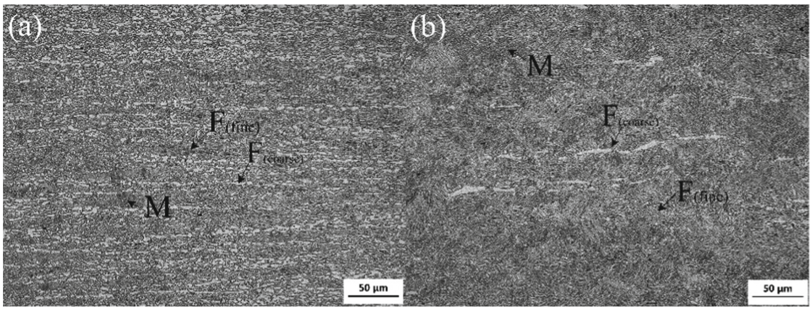

Fig. 2. Optical micrographs of (a) V-free (b) V-containing steel after annealing at 800 °C for 30 min.

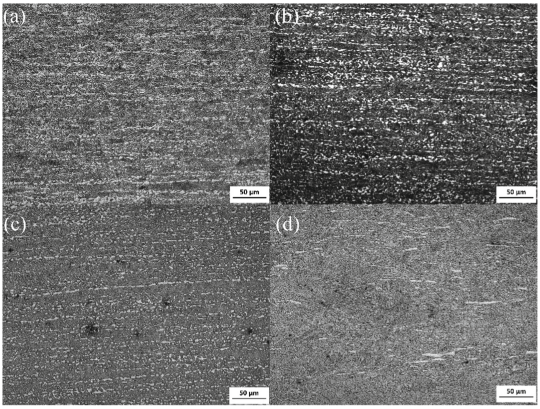

Fig. 3. Optical micrographs of V-free steel quenched at (a) 850 °C (b) 900 °C (c) 950 °C and V-containing steel quenched at (d) 950 °C.

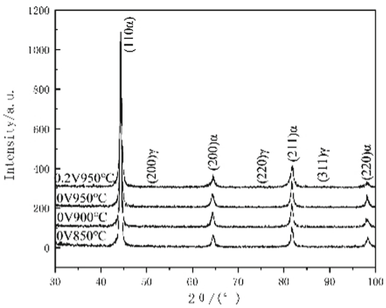

Fig. 4. XRD patterns of V-free and V-containing steel specimens after quenching.

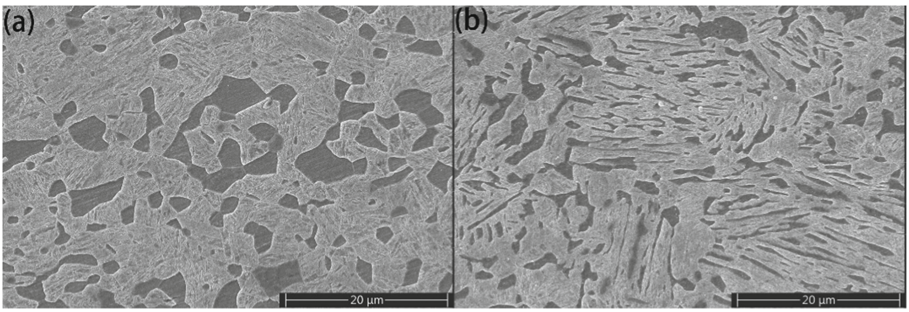

Fig. 5. SEM images of (a) 0 V (b) 0.2 V quenched at 950 °C.

Figure 6 shows the EBSD results of V-free steel quenched at 850 °C, 950 °C, and V-containing steel quenched at 950 °C. The grains colored in white, dark gray, and light gray correspond to ferrite, fresh martensite, and retained austenite, respectively. As the

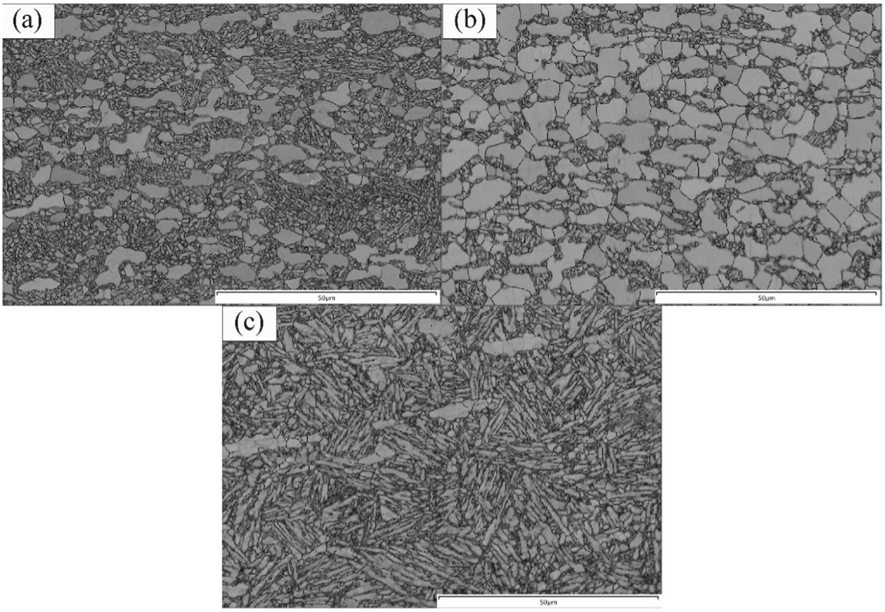

Fig. 6. Phase maps by EBSD (white: ferrite, light gray: austenite, dark gray: fresh martensite): quenched at (a) 850 °C (b) 950 °C (c) V-containing steel quenched at 950 °C.

quenching temperature increased from 850 °C to 950 °C, the fine-grained ferrite in V-free steel was transformed from strip to polygon.

4 Discussion

4.1 Influence of Quenching Temperature on Mechanical Properties

As the quenching temperature increased from 850 °C to 900 °C, the tensile strength of V-free steel increased from 980 MPa to 1220 MPa, the total elongation decreased from about 30.7% to 15.2%, and the martensite content in V-free steel increased from 51.2% to 65.4%. Although the increase in martensite content can improve the tensile strength of the steel, it also promotes crack propagation [6]. About 9.64% retained austenite was present in V-free steel quenched at 850 °C. The retained austenite transforms into martensite during the stretching process, resulting in stress relaxation and stress distribution, delaying the occurrence of necking and crack initiation, and improving the plasticity of the material [7].

Huang et al. reported that steel with higher martensite content exhibited lower tensile strength due to the larger ferrite grain size [8]. In this study, with the increase in quenching temperature, the content of coarse-grained banded ferrite was not significantly reduced, while the ferrite in the fine-grained region decreased greatly. This increases the average grain size of ferrite, resulting in that although the martensite content increased from 65.4% to 75.0%, the tensile strength after quenching at 950 °C was only 40 MPa higher than that at 900 °C.

4.2 The Effect of V on Mechanical Properties

After quenching at 950 °C, the tensile strength and total elongation of V-containing steel reached 1500 MPa and 10.7%, respectively, and that of V-free steel was 1260 MPa and 9.9%, respectively. The martensite content of V-containing steel increased from 75.0% to 83.4%, which improved the strength of V-containing steel. The microstructure of V-containing steel was mainly lath martensite and strip ferrite, as V delays the recovery and recrystallization of V-containing steel through the solute drag effect and grain boundary pinning [9]. The fine ferrite lamella structure in F/M dual-phase steel, according to Gao, can substantially improve the strength without affecting the plasticity of the steel [10]. The fine ferrite lamellae and lath martensite contribute positively to the strength and ductility of the V-containing steel after quenching in this study. VC, as the second phase, has a certain effect on the strength improvement of steel by precipitation strengthening. With the addition of V, the average grain size of the steel decreased slightly, from 1.28 μm to 1.23 μm, indicating that the addition of V has a limited effect on grain refinement at this quenching temperature.

5 Conclusion

(1) As the quenching temperature increased, the martensite content in the steel increased, the tensile strength increased, and the plasticity decreases.
(2) Coarse banded ferrite in V-free steel hindered the tensile strength increase with the increase of quenching temperature.
(3) Coarse banded ferrite in V-containing steel was greatly reduced. After quenching at 950 °C, the addition of V greatly increased the martensite content in the steel, and the morphology and distribution of ferrite between martensite were optimized, which further improved the tensile strength of the medium-manganese steel without losing plasticity.

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