INHERITANCE OF HOT ROLLED TMCP MICROSTRUCTURE AND TEXTURE DURING THE CONTINUOUS ANNEALING PROCESS OF HIGH-END Q&P STEELS*

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Abstract

Q&P steels undergo continuous multiple processes, including hot rolling, intermediate heat treatment, cold rolling and continuous annealing etc. The inheritant effect of initial microstructure could affect the final microstructure and mechanical properties of Q&P steels. In this work, effects of different hot rolled microstructure/texture on the final microstructure and properties subjected to Q&P process were investigated in Fe-0.38C-1.58Mn-1.6Si system. Different initial microstructures were generated combing different TMCP and cooling strategies. The microstructure and texture of hot rolled materials were characterized in detail. The hot rolled material was subsequently processed by intermediate annealing, cold rolling and continuous annealing. The comparison reveals great effects of the initial hot rolled microstructures, i.e. inheritance effect. The faster reverse transformation would lead to more sufficient austenitization and it would greatly weaken the inheritant effect of the initial microstructure. Although the difference of final phase fraction for different initial microstructures was not significant, the inheritance effect was mainly reflected in the effect on austenite morphology. For the mechanical properties, no obvious difference in strength was shown for the samples with different initial microstructures after Q&P heat treatment, but there was fluctuation in elongation.

Keywords: Inheritance; Initial microstructure; Q&P steel; Mechanical properties.

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1 INTRODUCTION

With the motivation of automobile lightweight, obtaining high strength and high plasticity steels, which can reduce weight and improve automobile safety for vehicles has been the mainstream direction in the field of automobile steels [1-3]. Since the concept of Q&P steel was put forward by Speer et al. [4] in 2003, its excellent properties for both strength and plasticity have been paid close attention by researches all around the world. Since that, more researches devoted to the development of higher-grade Q&P steel.

In summary, most researches of Q&P steel in domestic and abroad were still in the experimental stages. Previous researches mainly focused on the composition design combined with the modification of heat treatment [5-8] (austenitizing temperature, quenching temperature, partitioning conditions, etc.). The main idea of most modification was tailoring the volume fraction of each phase, carbon partition, austenite stability and morphology of retained austenite, etc., in order to improve the comprehensive mechanical properties. With the deepening of the research, in recent years, further improvement was made in the research of Q&P steel, which was in the direction of Q&P heat treatment process. For example, strip austenite was stabilized by one-stage annealing after Q&P heat treatment [9]. Also, the pre-quenching treatment was used before Q&P process to refine microstructure [10]. Dynamic partitioning was also analyzed to obtain more uniform microstructure, compared with traditional Q&P steel during deformation [11]. In addition, by rapid heating, the recrystallization process was postponed and more defects were introducd. The defects could provide more nucleation sites in the process of austenite transformation and help to refine the grains, which was good to obtain high-strength and high-plasticity steels [12-14].

Although great breakthroughs have been made in the innovation of Q&P process, most previous modification only focused on the heat treatment process without considering the inheritance effect of the initial microstructures formed by hot rolling. Inheritance effect was a long-standing topic in the field of steels. For example, for press hardened steel (PHS), 22MnB5 steel with different initial microstructures was treated by the same heat treatment process to obtain austenite with different grain sizes, and different morphologies of martensite. Also, the difference of strength and uniform elongation was further discussed to explain the inheritance effect of the initial microstructure [15]; For dual-phase (DP) steel, the effects of different initial microstructures on the morphology, size and distribution of final martensite and ferrite grain size were also studied[16-17]. For medium manganese steel, cold-rolled (CR) martensite and as-quenching (AQ) martensite were two different initial microstructures. Therefore, with the effect of initial microstructure, the tensile strength and yield strength of CR sample are about 80 MPa and 166 MPa higher than those of AQ sample, respectively [18].

Therefore, based on the above background and the basic theoretical research of Q&P steel, this paper focused on the analysis of inheritance effect in Q&P steels. In this paper, traditional chemical composition of Q&P steel was used as Fe-0.38C-1.6Si-1.58Mn. Three different cooling methods (water cooling, air cooling and coiling) were designed to obtain three different initial microstructures after hot rolling. Differences in final microstructure state and elements distribution could be obtained by different initial microstructures, the distinguish between different initial microstructures can be inherited after Q&P heat treatment by affecting the nucleation position, growth mode and kinetics of austenite, the evolution of initial microstructures and the difference of deformation behavior during Q&P heat treatment were discussed.

2 MATERIAL AND METHODS

In the present work, the investigated steel was smelted by vacuum induction furnace. The ingot is forged into a billet with the size of 200 mm ×140 mm ×70 mm and hot rolled in the laboratory. The billet was heated to 1200ºC for 2 hours as the homogenization treatment. Then the hot-rolled plate was rolled to the thickness of 3 mm by thermo-mechanical processing. Finally, the hot rolling plate was further cold rolled to the thickness of 1.5mm.
In order to study the hereditary behavior of different initial microstructures during Q&P heat treatment, the hot rolling-cold rolling-heat treatment trilogy was studied. The specific process is shown in Figure 1. In the first step, three different microstructures were obtained by adjusting the cooling methods during hot rolling. The cooling modes were as follows: 1) direct water-cooling to room temperature; 2) direct air-cooling to room temperature; 3) placing steel plate in heating preservation cotton to simulate coiling process in industry (slow cooling). The aim of using slow cooling method was to obtain mixed microstructure of ferrite and pearlite. To prevent the plate from cracking during cold rolling, the water-cooled plate was tempered at 600 ℃ for 5 hours after water-cooling. The second step was cold rolling for three different initial microstructures. The third step was to heat cold rolled sheet to 900 ℃ at rate of 10 ℃/s and held for 300s for austenitization, followed rapidly cooled to 230 ℃ to avobid pearlite and bainite transformation, then it was heated to 400 ℃ for 50 s, to obtain a certain amount of high-stability retained austenite by the partitioning of carbon, and finally quenched to room temperature.
Meanwhile, in order to accurately analyze the microstructure transformation and content change in Q&P heat treatment process, simulation experiments were carried out in a DIL 805A/D dilatometer on cold rolled samples with dimensions of 1.4 × 4 × 10 mm^3. The longest axis of the samples paralleled to the plate rolling direction.

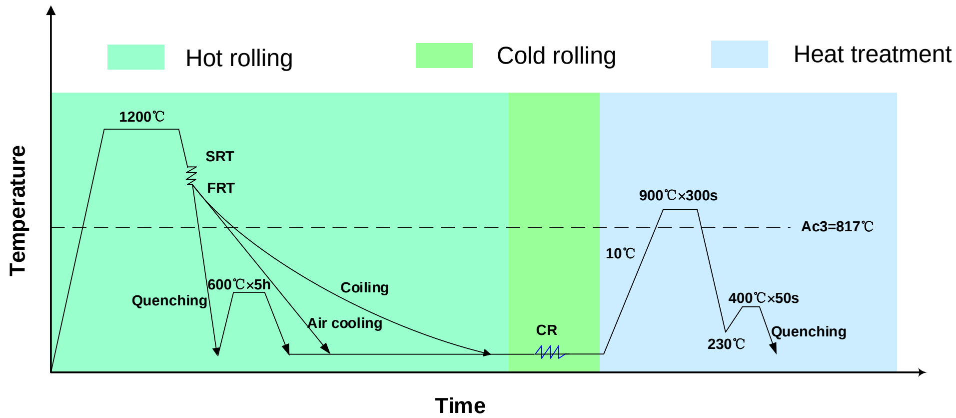

Figure 1. Schematic diagram of TMCP experimental steels for three different cooling procedures and Q&P heat treatment processing (SRT: Start rolling temperature; FRT: Finish rolling temperature).

The microstructure was characterized by JSM-7800F field emission scanning electron microscope (SEM) equipped with an electron backscattered diffraction (EBSD) system. EBSD samples were electropolished with a solution of perchloric acid and ethanol in the proportion ratio of 1:8 at room temperature. The integral intensities of (200) γ, (220) γ, (311) γ, (200) α and (211) α were obtained by X-ray diffraction (XRD) using Cu-Ka radiation with a scanning step of 5 degrees/min and a 2θ range from 40° to 110° to calculate the volume fraction and average carbon content of retained austenite. The mechanical properties were measured on

A25 (gauge length of 25 mm) tensile test samples by Shimadzu AG-X Plus 100KN tensile testing machine with a crosshead displacement of 2 mm/min at room temperature. Also, the length direction of the samples paralleled to rolling direction.

3 RESULTS AND DISCUSSION

3.1 Initial microstructure

Figure 2 shows different initial microstructures obtained by adjusting thermo mechanical control process (TMCP) on the basis of the same material. The initial microstructures after hot-rolling, quenching and tempering are presented in Figure. 2a, it was shown that carbides formed profusely at the lath boundary of martensite. With the decrease of the carbon concentration in tempered martensite, both the dislocation density and the strength could also decrease. Figure. 2b shows the microstructure for direct air cooling. Due to the insufficient cooling rate, some ferrite transformation appeared, therefore, the final microstructures for direct air cooling were ferrite + bainite. Figure.2c shows the ferrite and pearlite mixed microstructures obtained by simulated coiling in heating preservation cotton after hot rolling due to the relatively slower cooling rate.

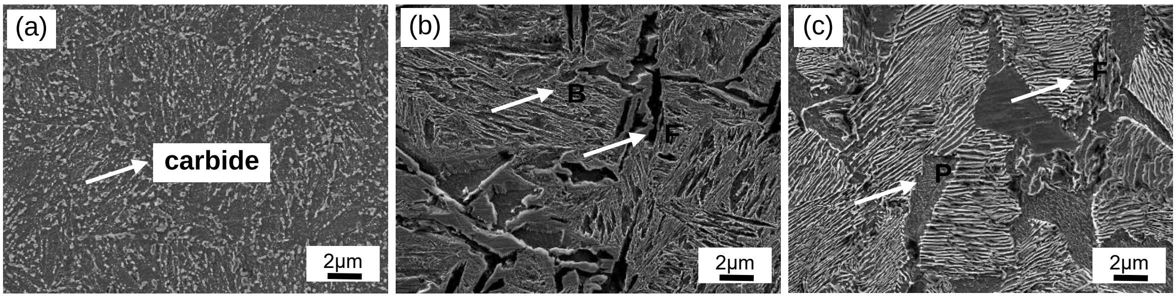

Figure 2. Initial microstructure of different hot rolling states (F: ferrite; B: bainite; P: pearlite), (a)—Quenching & Tempering (QT); (b)—Air Cooling (AC); (c)—Coiling.

3.2 Analysis of dilatometric curve

To make further understanding of phase transformation for the three different initial microstructures during Q&P heat treatment, dilatometer experiments were carried out, and the results are shown in Figure. 3. With the combination of figure. 4 and figure. 5, the XRD results of three different initial Q&P heat treatment and the leverage method were used to calculate the fraction of each phase, as shown in Table 1.

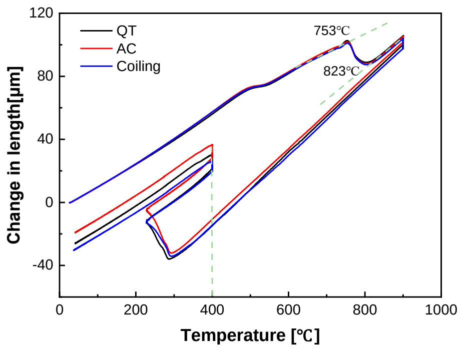

Figure. 3 Dilatometer curve of different initial microstructures after Q&P treatment

Table 1. Contents of each phase after Q&P heat treatment

Material	RA/%	B/%	TM/%	FM/%
QT sample	22.8	13.4±3.6	50.3±0.1	13.5
AC sample	22.9	13.6±3.3	52.4±5.6	11.1
Coiling sample	25.1	10.3±1.8	47.8±2.5	16.8

(RA: retained austenite; TM: tempering martensite; FM: fresh martensite.)

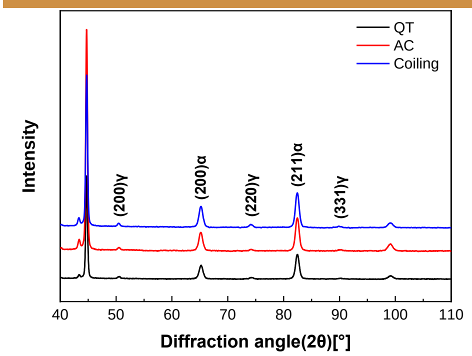

Figure.4 X-ray diffraction patterns after cold rolling sample subjected to Q&P heat treatment

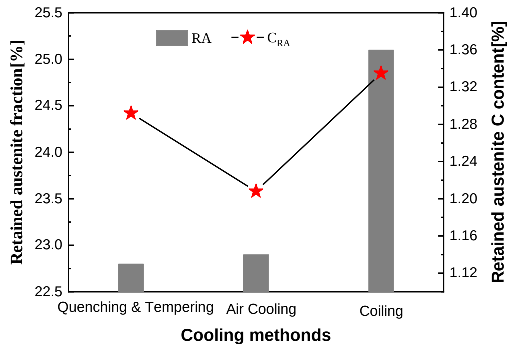

Figure.5 Volume fraction of RA and the average carbon content in RA after cold rolling sample subjected to Q&P heat treatment

It could be clearly seen from the dilatometer curve and the calculation of phase volume fraction that no significant difference was shown for the final fraction of the microstructure. It meant that the inheritance effect for the three different initial microstructures after Q&P heat treatment was not significant. The faster reverse transformation would lead to more sufficient austenitization and it would greatly weaken the inheritant effect of the initial microstructure. At about 753 ℃, the transformation of austenite begins almost simultaneously in three different initial microstructures and ended at about 823℃ After the temperature rised to 900℃ with the isothermal time of 300 s, the samples were rapidly cooled to 230 ℃. At this time, about 50% of austenite transforms into martensite. After heating to 400 ℃ and holding for 50 s, bainite transformation formed with the volume fraction of ~10%. Finally, the samples were quenched to room temperature and resulting in the formation of fresh martensite with the fraction of more than 10%. The retained austenite for all samples were nearly 22%. In general, there was no significant difference in phase content under austenitization parameters set in this experiment. Therefore, in order to further study the inheritance of the initial structure during Q&P heat treatment, the morphology of the structure was characterized.

3.3 Microstructure characteristics after Q&P heat treatment

Figure. 6 shows the morphology of the microstructure after Q&P heat treatment for three different initial microstructures. It was found that the final microstructures of different initial microstructures under the same Q&P treatment conditions were composed of bainite 、temper martensite 、fresh martensite and retained austenite, which was consistent with the analysis of phase fraction in section 3.2. Also, no significant distinguish was found in the width of bainite and martensite lath from the morphology. However, compared with the initial microstructure of tempered martensite, the initial microstructures of duplex bainite + ferrite and duplex ferrite + pearlite seemed to lead to blocky retained austenite, instead of thin films. However, the morphological differences of the retained austenite can't be well reflected only by SEM observation. Therefore, the morphology of the retained austenite was characterized by EBSD.

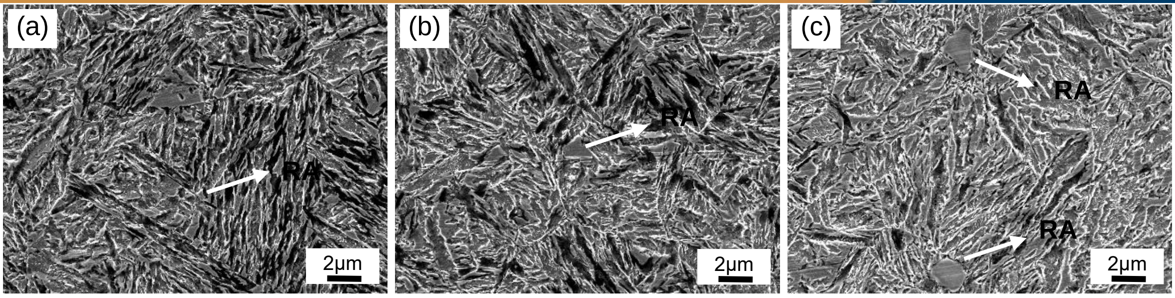

Figure. 6 SEM diagrams of different initial structures after Q&P heat treatment
(a)—Quenching & Tempering; (b)—Air Cooling; (c)—Coiling

3.4 Retained austenite characteristics after Q&P heat treatment

Figure 7 shows the morphology and distribution of retained austenite in the final microstructure under EBSD. It could be seen from the figure that there were three morphologies of retained austenite, thin film, strip and block, respectively. Also, different morphology of RA had different proportions in different initial microstructure, because the distribution of alloying elements and carbon element in the microstructure is not-uniform due to the different initial microstructures, and the distribution of elements in the grains after austenitization was also different [19]. Meanwhile, the nucleation sites and the effect of surrounding grains on austenite was also different [20,21].

In figure 7a, the size of retained austenite was relatively small, and the amount of film retained austenite was relatively larger. The initial microstructure for figure 7(a) was tempered martensite. When tempered at 600 ℃, the martensite lath boundary became blurred and larger carbides formed. During austenitizing progress, the austenite nucleates at the slab boundary, and the carbon-rich precipitates phase could provide a large number of carbon atoms for the surrounding grains, resulting in not uniform distribution of C and Mn elements in austenite. It could probably lead to the difference of stability for austenite, and the formation of thin-film retained austenite during quenching [22,23].

In Figure 7b, the initial microstructure is mixed ferrite and bainite. After heat treatment, the final microstructure had relatively more strip RA and film RA. As shown in Figure 7c. more block austenite was formed at the boundary of the prior austenite [26,27]. In summary, although the difference of final phase fraction for different initial microstructures was not significant, the inheritance effect was mainly reflected in the effect on austenite morphology.

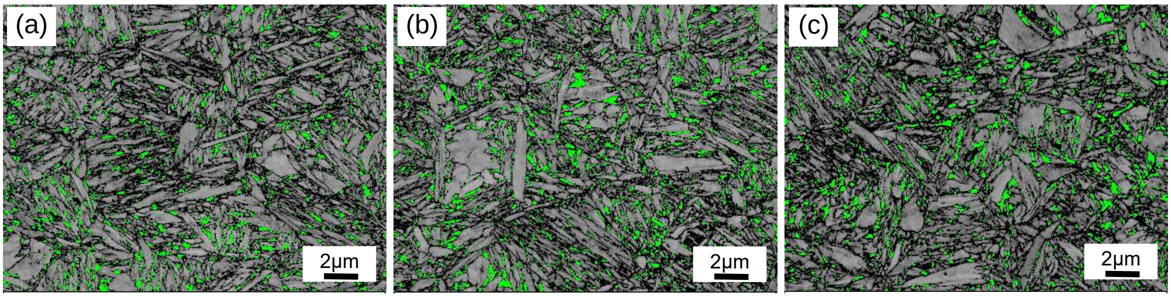

Figure. 7 Distribution of retained austenite obtained subject to Q&P heat treatment of austenization at 900 ℃ for 300s under various processing conditions. (a)—Quenching & Tempering; (b)—Air Cooling; (c)—Coiling.

3.5 Summary of mechanical properties

Figure. 8 shows the stress-strain curves and corresponding mechanical properties of the samples with three different initial microstructures and the same Q&P heat treatment. The results indicated that no significant difference of strength was shown among the three initial microstructures after Q&P treatment, the yield strength was about 1200 MPa and the tensile strength was about 1500 MPa. The main reason was that the final microstructures of all the samples were B, TM, FM and RA, and there was no significant difference in their phase fraction.

However, for plasticity, although the RA fraction differed slightly between the three initial microstructures, the difference of plasticity is relatively larger, compared with strength. For the sample with initial microstructure of martensite, although the fraction of retained austenite was the least (22.8%), the elongation was the highest (16.06%). Also, its strength-plastic was 24.14 GP·% and the comprehensive mechanical properties were the best. The difference of mechanical properties for the samples with different initial microstructures was probably because of the different morphology of RA as mentioned in section 3.4. It indicated that the mechanical properties of steels with the same composition and the same Q&P treatment could be different due to the hereditary effects.

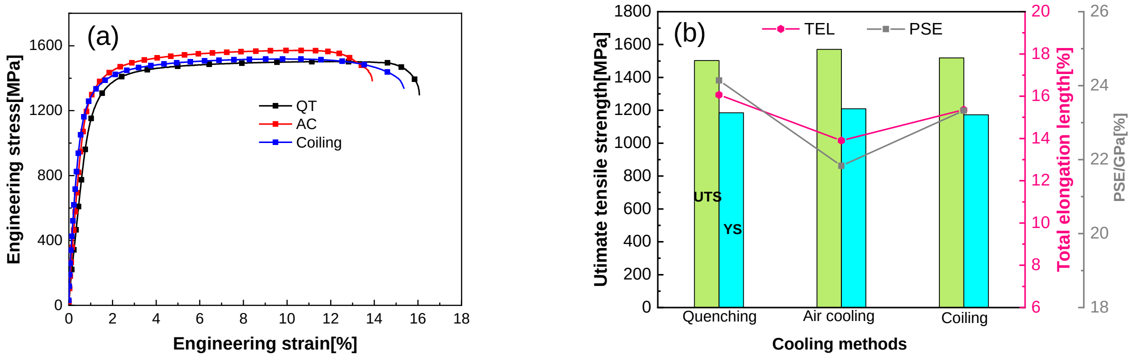

Figure. 8 Mechanical properties obtained subject to Q&P heat treatment of austenization at 900 ℃ for 300s under various processing conditions:(a) Engineering stress-strain curves, (b) The yield strength (YS), ultimate tensile strength (UTS), total elongation (TEL), and product of strength (PSE) for experiment steel.

4 CONCLUSION

In this paper, different initial microstructures were obtained by adjusting TMCP process. The inheritance behavior of different initial microstructures during Q&P heat treatment and their effects on microstructures and mechanical properties were analyzed. The following conclusions were drawn.

1. by QT, AC and Coiling, three different initial microstructures were obtained. Then, all the samples were heated to 900 ° C for 300 s and followed with quenching and partitioning. The types and fraction of final microstructures were not obvious affected by the differences of the initial microstructures. However, for the morphology of the microstructure, the morphology of RA had differences, which showed the effect of inheritance.

2. No obvious difference in strength was shown for the samples with different initial microstructures after Q&P heat treatment (YS: about 1200 MPa, UTS: about 1500 MPa), but there was fluctuation in elongation. For the sample with initial microstructure of martensite, although the fraction of retained austenite was the least (22.8%), the elongation was the highest (16.06%). Also, its strength-plastic was 24.14 GP·% and the comprehensive mechanical properties were the best. The difference of mechanical properties for the

samples with different initial microstructures was probably because of the different morphology of RA.

Acknowledgments

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