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# STUDY ON A ROLLING PROCESS FOR OBTAINING FERRITE-MARTENSITIC (DP) MICROSTRUCTURES IN ER70S-6 STEEL

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**Abstract.** The rolling process parameters of ER70S-6 steel for obtaining a ferrite plus martensite dual phase (DP) microstructure for high strength fasteners graded 8.8 were investigated. Thermal simulating experiments were carried out using Gleeble3500 simulator. Referring to the simulating results, the productive experiment was conducted in a continuous no-twist mill, and the mechanical properties of the as-rolled materials were tested. The results showed that deformed at 845 °C, followed by cooling to 780 °C at 5 °C /s and holding for 30 s, then quenching in water led to DP microstructure consisting of fine grained ferrite matrix plus about 20% martensite particles(in volume fraction). The wire rod rolled in this process route had a heterogeneous DP microstructure. Tensile strengths of the hot rolled DP wire rod and the drawn wire rod with a 19% reduction in area were 675-720 MPa and 915-970 MPa, respectively. ER70S-6 steel with DP microstructure could meet the tensile strength specification for grade 8.8 components.

## 1. INTRODUCTION

Dual phase (DP) steel is characterized by a microstructure consisting of a dispersion of a hard matensite in a ferrite matrix. The steel exhibits continuous yielding behavior, a low yield/tensile strength ratio, a high rate of work hardening, and high levels of uniform and total elongation [1]. The automotive industry has provided the stimulus for a very high proportion of the developments in strip steel and the commercial application of DP steel has been almost within this sector. Examples of automotive components manufactured from DP steels include bumper reinforcement, jack posts, wheels, alternator fan blades, and inner and outer door panels [1,2]. In resent years the dual phase wire rod is intended to apply in the cold heading industry, such as fastener for classes 8.8 [3-5]. DP steels for fastener application can provide substantial cost savings and energy reducing through the elimination of processing stages including spheroidisation annealing, quenching and tempering, and post heat treatment descaling. Several hot rolled DP steels developed by others simply contain C, Mn, and Si additions [3-6]. Some steels have the composition similar to that of ER70S-6 steel [4,5], which is usually used as carbon steel electrode in ferrite plus pearlite microstructure. As a main product of Xingtai Iron and Steel Corporation Limited, if ER70S-6 steel obtained DP microstructure by hot rolling, its scope of applications will be extended from welding steel to cold heading steel. But the rolling processes for obtaining DP microstructure and the properties of the steel with DP microstructure have not been investigated as yet. The present work will firstly

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design and optimize the rolling process parameters by carrying out thermal simulating experiments on a Gleeble3500 thermal simulator, then conduct productive experiments on no-twist mill, and finally test the mechanical properties of the wire rod and drawn rod.

## 2. EXPERIMENTAL

### 2.1. Material and simulating experiments

The typical chemical composition of ER70S-6 steel produced by Xingtai Iron and Steel Company Limited consists of 0.07 wt.% C, 0.90 wt.% Mn, 1.50 wt.% Si, 0.025 wt.% P, 0.025 wt.% S. To identify the effects of rolling and the subsequent cooling process on the microstructure of the steel, simulations of the finishing rolling and post rolling cooling were conducted using Gleeble3500 simulator. The test schedules were shown in Table1. All the samples having the dimension of ∅10×16 mm were heated to 950 °C and held for 5 minutes (just being the status at exit of the pre-finishing mill), and then cooled to 845 °C at a cooling rate of 15 °C/s (just being the rate in water box before finishing mill). Deformations with the engineering stain of 80% and the strain rate of 1.54 $s^{-1}$ are preformed in this temperature. These parameters were worked out according to the finishing mill condition. The cooling from deformation temperature was composed of two stages: cooling to 780 °C at 1.5 °C/s (S5) or 5/s °C (other schedules) and holding at this temperature for 0 s (S1 and S4), 30 s (S2 and S5) or 90 s (S3), and then cooling form 780 °C to room temperature (R.T.) by water (S1 through S4) or cooling at a rate of 7 °C/s (S5), which approximated to the maximum cooling rate of the conveyor. The microstructures of the deformed samples were observed after cutting along the axes, ground and mechanical polished, and etching.

### 2.2. Productive experiment and microstructure and properties analysis for wire rod

Guided by the simulation results, a billet with dimension of 88×88×800 mm was cut from the continuous casting bloom and rolled from 1200 °C through 27 passes, with finishing rolling carried out in 8 passes in a continuous no-twist mill. The ∅7 mm rod emerged from the no-twist mill at the speed of 12 m/s and a temperature of 845 °C. After cooling to 780 °C and holding for 30 s, the wire coil was cooled in water immediately. Drawing operation was performed on a drawbench which pulled and drew part of the pickled and limed hot rolled wire rod. The drawing led to a 19% reduction in cross-section area.

The optical microstructure of the wire rod was analyzed. The mechanical properties of the wire rod and the drawn wire were measured in a tensile machine modeling WDW-1000 at R. T. and a crosshead rate of $2x10^{-2}$ mm/s.

## 3. RESULTS AND DISCUSSION

### 3.1. Microstructures of the samples after simulating experiments and optimization of rolling process parameters

Fig. 1 shows the microstructures of the samples deformed in the Gleeble3500 system. All the samples except S4 are composed of ferrite matrix

**Table1.** Cooling schedules and corresponding microstructures of thermal simulating experiments.

| Schedules | Cooling processing | Volume fraction [%] | | |
|---|---|---|---|---|
| | | Ferrite | Martensite | Pearlite |
| S1 | 845 °C(rolling) 5 °C/s 780 °C (0 s) *W.C.*, R.T. | 73.0 | 32.0 | 0 |
| S2 | 845 °C(rolling) 5 °C/s 780 °C (30 s) *W.C.*, R.T. | 80.6 | 19.4 | 0 |
| S3 | 845 °C(rolling) 5 °C/s 780 °C (90 s) *W.C.*, R.T. | 83.5 | 16.5 | 0 |
| S4 | 845 °C(rolling) 1.5 °C/s 780 °C(0 s) *W.C.*, R.T. | 81.5 | 26.5 | 0 |
| S5 | 845 °C(rolling) 5 °C/s 780 °C (30 s) 7 °C/s R.T. | 78.1 | 20.0 | 1.9 |

*W.C.* - water cooling, R.T. - room temperature.

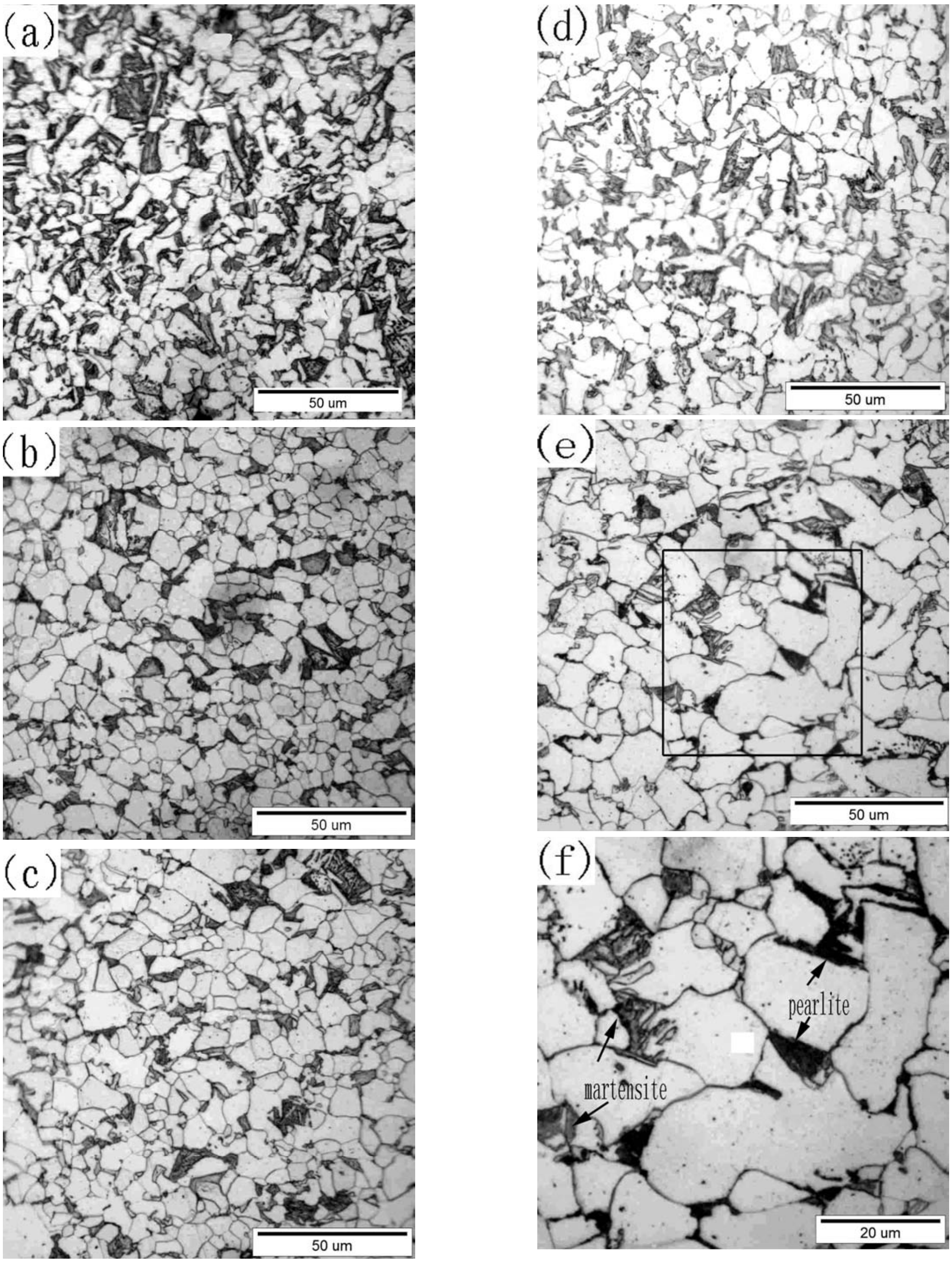


**Fig. 1.** Microstructures of the ∅10×16 mm samples deformed in the Gleeble3500 simulator: (a) S1; (b) S2; (c) S3; (d) S4; (e) S5; (f) boxed zone in e.

and discrete martensite grains. The formation of these microstructures is because the rolling and the holding temperatures are in the ferrite plus austenite phase field, and during the second step cooling a austenite to pearlite plus martensite transformation or a austenite to martensite transformation occurs. The sample cooling from 845 °C to 780 °C at the cooling rate of 5 °C/s followed by immediately cooling in water (S1 shown in Fig. 1a) contained 32.0% (hereinafter in volume fraction) martensite. This martensite volume is 6.5% more than that of the sample cooling from 845 °C to 780 °C at a cooling rate of 1.5 °C/s followed by immediate water cooling (S4 in Fig. 1d). It is inferred from the fact that the cooling rate from 845 °C to 780 °C has obvious effect on the martensite volume fraction of ER70S-6 steel. Thus, in the interval between emerging from the laying head and starting of holding, a suitable cooling rate should be chosen for obtaining desired microstructure. Under the same cooling condition, the samples holding at 780 °C for different times have various volume fractions of martensite, which decreases with the increase of holding time (Figs. 1a through 1c). Directly quenching the sample


**Fig. 2.** Wire rod rolled using the optimized parameters in continuous no-twist mill.

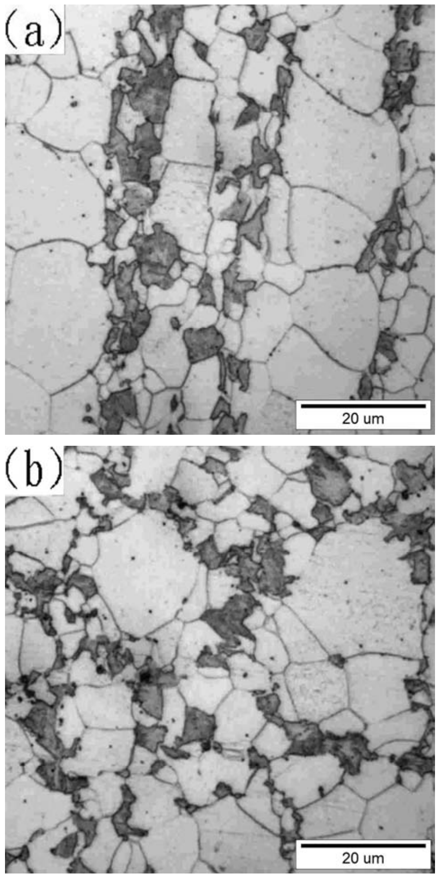


**Fig. 3.** Microstructures of the wire rod: (a) the longitudinal section; (b) the cross section.

from 780 °C leads to 32% martensite (S1 in Fig. 1a), holding the sample at 780 °C for 30 s and 90 s, followed by water cooling leads to 19.4% martensite (S2 in Fig. 1b) and 16.5% martensite (S3 in Fig. 1c), respectively. From these results, we know that martensitic volume fraction in DP steel can also be controlled by the holding time, which takes significant effect within the first 30 s. These also suggest that holding in ferrite plus austenite field hardly reduces the product efficiency. Cooling rate from 780 °C to R.T. affects the constituents of the microstructure and the grain size. The cooling rate simulating the maximum value of conveyor (the present conveyor can not be cooled by blowing air), which is about 7 °C/s, results in a microstructure containing 20.0% martensite and 1.9% pearlite (S5 shown in Figs. 1d and 1e). Thus, for obtaining strict DP microstructure in ER70S-6 steel fast cooling from the temperature of austenite plus ferrite to R. T. is necessary. Another distinct difference between S1 and S5 is the former has a finer mean grain size of 6.2 μm, yet the latter has a mean grain size of 8.6 μm. From Fig. 1, it is concluded that the grain size is more dependent on the second step cooling rate than on the first step cooling rate and holding time.

After analyzing the results of thermal simulating experiments, we know that for ER70S-6 steel two-step cooling process is reasonable for obtaining DP microstructure without decreasing the productive efficiency. We design the cooling process according to the following principles: controlling first step cooling rate and holding in ferrite plus austenite phase field for a time on the order of 10 seconds for controlling the volume fraction of martensite, sufficient cooling rate in second step for constrained pearlite formation and grain growth. Using above principles on the experimental mill, A rolling process is optimized as follows: billet is rolled from 1200 °C, through 27 passes, with finishing rolling at 845 °C; after emerging from the lying head, the wire is cooled to 780 °C at about 5 °C/s, and holding at this temperature for about 30 s in the coil-conveying system, followed by water cooling.

## 3.2. Microstructure and properties of the wire rod

Fig. 2 is the wire coil rolled using the above mentioned process. The coil has a good appearance as well as good surface quality and close dimensional tolerances. Though there is a red scale induced by water cooling on the surface, the descaling carried out before drawing eliminates it easily. Cooling by forced air is a favorite way avoiding red scale; this process can not conduct by the palletized coil-conveying system used in the present work.

The microstructures of the hot rolled wire rod are shown in Fig. 3. The wire rod has a heterogeneous DP microstructure, as is seen form both the cross section and the longitudinal section. The microstructure seen from the cross section

**Table 2.** Tensile properties of as-rolled rod and as-drawn rod.

| | YS [MPa] | UTD [MPa] | EL [%] | R of A [%] | YS/UTS |
|---|---|---|---|---|---|
| As-rolled | 370 | 715 | 17.5 | 49.5 | 0.52 |
| Wire rod | 395 | 720 | 14.5 | 46.5 | 0.55 |
| | 345 | 675 | 19.5 | 53.0 | 0.51 |
| drawing | - | 935 | 4.0 | 40.0 | - |
| Wire rod | 935 | 970 | 5.0 | 43.5 | 0.96 |
| | 905 | 915 | 6.5 | 50.0 | 0.99 |

consists of a ferrite matrix with a grain size of 7.0 μm and 21.8% martensite particles with a grain size of 2.6 μm. The grains are elongated along the axis of the rod, and the martensite exhibits banded morphology. The heterogeneous microstructure is attributed to compositional microsegregation formed during the solidification of the bloom. The interdendritic zone is rich in C, forming the pearlite in the bloom and martensite in the wire rod. The uneven distribution of martensite is detrimental to the mechanical properties of the rod [7]. The banded microstructure must be improved to ensure the superior properties, and this is likely to be solved by a diffusion annealing before rolling. This work is undertaken.

Table 2 is the tensile properties of the wire rod before and after drawing. The yield stress (YS) and the tensile strength (UTS) of the wire rod are 345-370 MPa and 675-715 MPa, respectively, and the elongation at failure (EL) and the cross sectional reduction of area at failure (R of A) are 14.5%-19.5% and 46.5%-53%, respectively. The rod has a low yield/tensile strength ratio, within 0.51-0.55. Compared with the ER70S-6 steel wire rod with a ferrite plus pearlite microstructure, which has the values of 340-358 MPa in YS, 505-515 MPa in UTS, 27%-34% in EL and 79%-85% in R of A [8], respectively, the DP wire rod has higher strength and the lower ductility. The steel with both microstructures has property fluctuation. This is owing to non-uniformity of the cooling rate from the overlapped parts to the non-touching parts of the rings on the conveyor. Scatter of the data for the DP microstructure is graver than that for ferrite plus pearlite microstructure, showing the DP microstructure is more sensitive to cooling rate.

It is worth to note that the tensile strength of the DP microstructure can not meet national standard GB/T-3098-2000. However, it is the final fastener properties and not the rod properties which must meet the specified properties requirements. The forming process from rod to component involves significant cold work, both in drawing the rod to correctly sized wire (to ensure correct die filling) and in the heading itself. Both these operations harden the steel and increase the strength. This possibility is confirmed by the properties of the drawn wire with a diameter of 6.3 mm, which has values of 915-970 MPa in UTS, 4.0%-6.0% in EL and 50.0%-40.0% in R of A (also in Table 2). The drawing operation increases the tensile strength and decrease the ductility significantly. This is attributed to the more martensite content of the present microstructure. The higher strength and lower ductility of the drawn rod impair the formability, increase the power requirement and decrease the life of the dies and tools for manufacturing fasteners. For solving all these problems, it is necessary to investigate the suitable finishing diameter of the wire rod, the amount of reduction in diameter during drawing and the process of the manufacturing fastener systematically and intensively. These works are underway.

## 4. CONCLUSIONS

1. Determined on physical simulator Gleeble3500, ER70S-6 steel deformed at 845 °C, followed by slow cooling to 780 °C and holding at this temperature for 30 s, then quenching in water has a DP microstructure consisting of fine grained ferrite matrix plus about 20% martensite particles(in volume fraction).
2. As an application of the simulation result, hot rolled wire rod is produced in a continuous no-twist mill. The wire rod had a heterogeneous DP microstructure. The heterogeneity is owing to the compositional microsegregation of the bloom.
3. Tensile strengths of the hot rolled DP wire rod and the drawn wire rod which is produced after a drawing with a 19% reduction in area were 675-715 MPa and 915-970 MPa, respectively. ER70S-6E steel with DP microstructure can meet the tensile strength specification for grade 8.8 components.

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