Study on microstructure and Properties control of 30MnSi steel bar for prestressed concrete

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Abstract: In this paper, the microstructure evolution of 30MnSi steel bar after drawing, quenching and tempering was studied by optical microscope and scanning electron microscope, and the mechanical properties at different stages were analyzed. The results show that when the quenching temperature is 925℃ and the tempering temperature is 465℃, the microstructure changes from the ferrite and pearlite before cold drawing to the martensite after quenching, and then to the tempered troostite after tempering. After quenching and tempering, the yield strength can reach more than 1250Mpa, the tensile strength can reach more than 1450Mpa, and the elongation after breaking is maintained at more than 7.5%.

1. Introduction
Prestressed concrete steel bar (referred to as PC steel bar), Western Europe called hi-bond WIRE, Japan commonly known as ULBON (ULBON). It is a kind of high strength and low alloy structural steel, which is generally made of medium and low carbon and low alloy steel hot rolled wire rod and tempered after cold drawing. It has the characteristics of high strength, low relaxation rate, continuous spiral groove, strong gripping force with concrete, good comprehensive mechanical properties, zigzag resistance and long service life. Because the low carbon steel has good weldability, it is very suitable for spot welding cage and forming pipe pile. It has been widely used in high-strength prestressed concrete centrifugal pipe pile, concrete pipe pile for high-rise building foundation, concrete pipe pile for elevated bridge pier, electric pole, railway sleeper and other prestressed components at home and abroad[1]. At present, PC steel bar still has quality problems, such as weak anti-delay fracture ability, unstable mechanical properties, high flexural strength ratio, poor flatness.[2]. This paper aims at the above problems and combines the actual production situation of PC steel bar in Zhongshan Yima Company, starting from the key heat treatment process of PC steel bar production, the microstructure changes of 30MnSi steel bar after drawing, induction heating quenching and tempering is studied to provide technical guidance for the industrial production of high performance 30MnSi steel bar.

2. Experimental materials and methods
The material selected in the test is the 30MnSi hot-rolled wire rod with a diameter of 12mm, which is the raw material of yima PC steel bar production line. Its chemical composition is shown in Table 1.

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Φ 12mm 30MnSi hot-rolled wire rod used in the test was cold drawn at the processing speed of 85m/min PC steel rod production line, and the Φ 10.7mm 30MnSi threaded steel rod was cold pulled out under the action of the mould, and the compression deformation in the process was about 10%.

After straightening and pulling, the cold-drawn 30MnSi steel bar enters the fast induction heating furnace, which successively passes through the 3.3m medium frequency preheating furnace at 770℃, the 2.1m high frequency heating furnace at 830℃ and the 4.4m uHF heating furnace at 900℃ or above. The speed of the whole production line is still 85m/min. After the heating is completed, the 30MnSi steel bar is quenched by spraying water in a 2m long quenching incubator. After quenching, it enters the 4.8m long tempering furnace at 465℃. After tempering, it enters the 2m long tempering incubator. After the tempering, it enters the cooling water tank for cooling. Infrared thermometer is used to measure the surface temperature of the sample between each heating furnace or incubator, and the temperature is recorded every 10 s.

The microstructure of 10mm long Φ 12mm 30MnSi hot-rolled wire rod raw material, 10mm long Φ 10.7mm 30MnSi steel rod quenched sample and 10mm long Φ 10.7mm 30MnSi steel rod tempered sample were observed. After polishing, the metallographic specimens were corroded for about 10s with 4% nitric acid alcohol solution. The metallographic structures in different areas were observed under an optical microscope, and the microstructures were photographed under a scanning electron microscope at different magnification rates.

| Table 1 Chemical composition of the 30MnSi hot rolled wire rod (wt.%). |
|----------------|-------|------|-----|-----|-----|-----|
| C              | Si    | Mn   | P       | S     | Cu   | Fe       |
| 0.27~0.34      | 0.60~0.90 | 1.00~1.40 | ≤0.030   | ≤0.025 | ≤0.25 | Bal.     |

3. Results and discussion

3.1 Setting of quenching and tempering temperature

The quenching temperature directly affects the austenitizing degree of steel, the size of austenitic grain and the microstructure after quenching, and then affects the mechanical properties of steel. In order to develop a reasonable austenitization process, Ac3 and Ac1 points of the test steel were measured at 840℃ and 720℃ on gleeble-3800 thermal simulation test machine[3]. The quenching temperature of hypoeutectoid steel is generally 30~50℃ above Ac3, and due to the rapid induction heating and considering the large diameter of 30MnSi steel bar, in order to ensure the internal full quenching, the quenching temperature is set to 925℃.

The determination of tempering temperature is especially important in this test. If the tempering temperature is low, the hardness of steel will be very high, brittleness will be very large, easy to produce brittle fracture. If the tempering temperature is too high, the strength may not meet the requirements[4]. In this test, the tempering temperature was set at 465℃ in order to avoid the moderate tempering brittleness existing in the temperature range of 350 ~ 370℃, and obtain the tempered sostenite or tempered troostite with both high strength and enough plasticity and toughness.

3.2. Microstructure changes under different heat treatment conditions

Fig. 1 shows the metallographic structure of the raw material of 30MnSi hot-rolled wire rod and its samples after different heat treatment, after sandpaper grinding and polishing under the microscope ×500. As can be seen from Fig. 1, a1 is the original structure of the hot-rolled wire rod, mainly composed of evenly distributed ferrite and pearlite. The white part is ferrite, and the black part is pearlite. The ferrite grain size is about 15μm, and the pearlite grain size is about 10μm. b1 is 925℃ quenching structure, the structure is mainly martensite, and a small amount of residual austenite and granular carbide; The microstructure of C1 after quenching at 925℃ and tempering at 465℃ is mainly tempered troostite. In the process of heating and cooling, with the change of temperature, the structure of the material is changed through solid phase transformation, so as to obtain different properties[5]. After quenching at 925℃, martensite, granular carbide and a small amount of residual austenite were formed.
by solid phase transformation of 30MnSi hot rolled wire rod. After 465°C tempering, the first martensite decomposition, tempered martensite, and then the residual austenite also changed into tempered martensite, after that the unsaturated carbon in martensite precipitated to form stable carbides, and finally the accumulation of carbide growth and α phase recovery recrystallization into tempered stovesite[6].

Fig. 1 Microstructure (500X) and SEM (10KX) of 30MnSi steel bar under different heat treatment

In Fig. 1, a2, b2, c2 are the electron microscope images of hot rolled wire rod raw materials, quenched microstructure at 925℃, quenched and tempered microstructure at 925℃+465℃ under 10KX scanning electron microscope. It can be seen that the material of hot rolled wire rod is characterized by lamellar pearlite structure, and the lamellar spacing of pearlite is about 0.2μm, as shown in a2. After quenching at 925℃, a large amount of acicular martensite was obtained. It can be seen that the acicular martensite extended inwardly along the austenite grain boundary, and a small amount of granular carbide could be observed on the matrix, as shown in b2. After quenching at 925℃ and tempering at 465℃, tempered troostite was obtained. Compared with the raw material of hot rolled wire rod, the microstructure changed significantly, and lamellar pearlite changed into spherical structure, as shown in c2.
3.3. Variation of properties under different heat treatment conditions

The tensile strength and elongation after breaking of all materials can be measured by a tension machine, and the data obtained are shown in Table 2. The yield strength of 30MnSi hot rolled wire rod is 550–600Mpa, the tensile strength is 650–700Mpa, the elongation after breaking is 20.0–25.0%, and the size of raw material is Φ 12mm. After drawing, due to the role of the mould, its size is reduced to Φ10.7mm. After quenching at 925℃ and tempering at 465℃, the tempered troostitic structure is obtained. The yield strength can reach more than 1250Mpa, the tensile strength can reach more than 1450Mpa, and the elongation after breaking is 7.5–8.0%. This is because the 30 MnSi hot-rolled wire rod material after cold drawing, quenching, tempering, structure by the original layer lamellar pearlite transformation for spheroidal pearlite, the equivalent of pearlite in the structure of the spacing is reduced, the fine-grain strengthening effect, at the same time, in the process of cold drawing and work hardening, the 30 MnSi steel bar intensity increases, plasticity reduces.

Table 2 Comparison of properties between raw material of hot rolled wire rod and quenched and tempered product

|                     | Yield strength (Mpa) | Tensile strength (Mpa) | Elongation after breaking (%) |
|---------------------|----------------------|------------------------|-------------------------------|
| Raw material of hot rolled wire rod | 550–600              | 650–700                | 20.0–25.0                     |
| Quenched and tempered product | 1250–1300            | 1450–1500              | 7.5–8.0                       |

4. Conclusions

1. The original structure of 30MnSi hot rolled wire rod raw material is ferrite and lamellar pearlite. After cold drawing and quenching at 925℃, a large number of martensite structure is obtained. After tempering at 465℃, the lamellar pearlite structure becomes spherical pearlite and forms tempered troostite.

2. The yield strength of 30MnSi hot rolled wire rod is 550–600Mpa, the tensile strength is 650–700Mpa and the elongation after breaking is 20.0–25.0%. After cold drawing, quenching at 925℃ and tempering at 465℃, the yield strength is 1250-1300Mpa, which increases by 121.7%. The tensile strength is 1450-1500Mpa, which increased by 134.6%; the elongation after breaking is 7.5–8.0%, which decreased by 65.6%.

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