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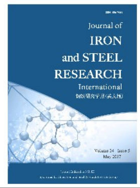

Effects of micro-alloying and production process on precipitation behaviors and mechanical properties of HRB600

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ABSTRACT

Effects of micro-alloying elements and production process on microstructure, mechanical properties and precipitates of 600 MPa grade rebars were studied by using pilot test, metallographic observation, tensile test, thermodynamic calculation and transmission electron microscopy. The results show that the tested steels are composed of ferrite and pearlite, in which the content range of pearlite is 33%－45%. For vanadium micro-alloyed steel, interphase precipitation strengthening effect of V can be promoted and the yield strength of tested steels can be increased with increasing V content and decreasing finishing rolling temperature. The temperature of terminated cooling should be more than 700 ℃ when the water cooling is used. When niobium is added to the steel, more coarse (Nb,V)C,N precipitates are generated at high temperature, so that the solid solubility of precipitated phases of vanadium is reduced and the precipitation strengthening effect of vanadium is weakened.

1. Introduction

In recent years, the production and consumption of hot-rolled steel rebar in China have been greatly increased with the rapid development of urbanization and construction industry. In accordance with the research data of Chinese industrial information, the total steel rebar production in 2013 has reached about 2.06×10^{6} t[1]. Although the production of steel rebar in China has achieved rapid growth, their structures and varieties are in a relatively low level, wherein the amount of 400 MPa grade (grade III) steel rebars accounts for about 90% and the amount of above 500 MPa grade (grade IV) steel rebars accounts for less than 5%. On the contrary, 500 MPa grade steel rebars are widely used in developed countries, and the amount of 500－600 MPa grade steel rebars accounts for more than 95%. The United States, Britain, Germany, Australia, France and other major industrialized countries have developed 600 MPa grade high strength steel rebars and 700 MPa grade steel rebars are under active development. The ultra-high strength steel rebars whose yield strength is between 685 and 1275 MPa have been developed in Japan, to improve the seismic resistance of buildings and have already been applied in high-rise buildings[2]. Russia added 600 MPa grade steel rebars into steel product standard in 1993 and South Korea added 600－700 MPa high strength steel rebars into steel product standard in 2007[3]. However, for the construction of engineering projects with a huge building size, complex function and large infrastructure, such as high-rise and super high-rise buildings, long-span bridges, and undersea tunnel construction, the normal strength steel rebars used as the main materials of building structure are unable to meet the demand of weight-reduction and durability of the building, so that better performance and higher strength rebars are in urgent need. The use of high strength steel rebars can not only solve the problem of fat beams and columns of building structure, but also increase the usable construction area

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and make the structure design more flexible. Besides, compared with the mainly used 400 and 500 MPa grade steel rebars, 600 MPa grade high strength steel rebars can save steel consumption of 33.3% and 19.2% respectively, and have a practical significance for energy saving and emission reduction[3].

At present, the main production processes of high strength steel rebars are Tempcore treatment (TMT process) and micro-alloying. The TMT process has been commonly used to improve the strength of steel rebars in Europe, Russia, Australia and South Korea since the majority of them use steel binding rebars to connect[2,4]. India has also carried out a lot of researches and applications in TMT process[5,6]. Because of the common use of welding and sleeve connection in China, the main production process is micro-alloying with addition of Nb or V which can refine the grain and control the precipitation process to improve the strength and performance of steel rebars. In this study, trial test and transmission electron microscopy (TEM) were conducted to analyze the effect of micro-alloying and production process on the precipitation behaviors and mechanical properties of 600 MPa grade high strength rebars, which can provide theoretical support for the optimal design of the composition, process and industrial stable production.

2. Experimental Materials and Procedures

Three kinds of steels with different chemical compositions were designed to study the effects of Nb, V, and N contents on the strength and precipitation behaviors, and were then smelted by a 150 kg medium frequency induction melting furnace. The chemical compositions are listed in Table 1. The casting ingots were heated to 1200 ℃ and then forged into 180 mm×200 mm×80 mm (length×width×height) slab. Different finishing rolling temperatures and cooling modes were used, and the ingots were finally rolled to the target thickness of 10 mm (reduction ratio is 8) by a pilot two-high hot rolling mill and the specific process scheme was as follows: the ingots were heated to 1230 ℃, rolled with finishing rolling temperatures of 900 and 1000 ℃, and then cooled by air and water. Air cooling was carried out again after the ingot was cooled to the target temperature for simulating cooling bed. Actual processing parameters of tested steels are shown in Table 2.

Table 1
Chemical composition of tested steels (wt.%)

Steel grade	C	Si	Mn	P	S	Al_s	N	V	Nb	Fe
1	0.254	0.71	1.53	0.021	0.017	0.028	0.014	0.14	—	Balance
2	0.263	0.59	1.49	0.024	0.014	0.046	0.018	0.17	—	Balance
3	0.230	0.58	1.44	0.022	0.013	0.027	0.014	0.14	0.043	Balance

Table 2
Actual processing parameters of tested steels

Number	Finishing rolling temperature/℃	Cooling mode	Water cooling terminal temperature/℃
1-1	960−980	Air cooling	
1-2	930−950	Water cooling	690−760
1-3	900	Water cooling	680−740
2-1	980−1020	Air cooling	
2-2	1000	Water cooling	690−780
2-3	900	Water cooling	620−670
3-1	976	Air cooling	
3-2	960−980	Air cooling	
3-3	900	Air cooling	

Metallographic specimens were cut and embedded, then mechanically ground and polished. The microstructure was observed by using an OLYMPUS-BX51 optical microscope after etched with 4 vol.% nital. The ferrite grain size and pearlite content were quantitatively analyzed by Image-pro plus software while A_{80} non scale standard tensile specimens were cut from the rolled samples along the rolling direction and were performed in a Zwick/Roell Z020 tensile testing machine at room temperature according to Chinese standard GB/T 228.1-2010. The TEM observation samples were cut by wire-electrode, then mechanically ground to thin films of about 50 μm in thickness, and finally punched to prepare round disks of 3 mm in diameter. The disks were electropolished in a solution of 95 vol.% ethanol and 5 vol.% perchloric acid at −30 ℃ by using a twin-jet polisher with the operating voltage of 50 V. The precipitates were observed by a Philips TECNAI F30 field emission transmission electron microscope with an accelerating voltage of 300 kV.

The phase transition temperatures based on thermal expansion principle were measured with Gleeble 3500 thermal-mechanical simulation testing machine. The samples were cylinders with diameter of 6 mm and length of 90 mm, and were heated to 1000 ℃ at a heating rate of 0.1 ℃/s.

3. Results and Discussion

3.1. Mechanical properties

Mechanical properties of tested steels are shown in Table 3, where the values are the average results of