

Effect of cooling process after rolling on microstructure and property of Nb-Ti micro-alloyed low-carbon bainite steel

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Abstract. The influence of cooling process on microstructure, second phase precipitation and mechanical property of Nb-Ti Micro-alloyed Low-Carbon Bainitic Steel has been examined by metalloscope and TEM. The results lustrate that accelerated cooling after air-cooling (relaxation) to a certain temperature could obtain ferrite / bainite dual phase structure. The reduction of relaxation stop temperature results in increases of the volume of ferrite phase and grain size, and second phase size has trendy of grow up, the shape of bainite has change, while the bainite lath boundaries and the orientation become less obvious, dislocation density decreases, and the shape of M/A island changes, which leads to lower strength but improve yield ratio and ductility.

Introduction

The great amount of low alloy high strength steel plate required low cost and high performance. Most of researches on high strength steel focus on heat treatment condition and effect of alloy element on microstructure and properties of steel plate at present^[1]. Although the method meets the demands of properties, the disadvantage of high energy consumption, high cost, and long production period becomes obvious. Therefore, the research on rolling technology attractive more attention recently. The main focus through solution strengthening, fine grained strengthening and precipitation strengthening to gain high strength^[2], but as the intensity of the increase, the ductility of the steel is reduced and cold forming process variation. The appearance of bainite steel has solved the problem, which contains some relatively soft matrix phase. It has a low yield strength and good formability, and the same time, because of the existence of hard phase, it has high tensile strength^[3-6]. There is not much more report about the study on cooling process after rolling on microstructure and property, but also for the mechanism of action research is not thorough. This paper study on the Nb-Ti micro-alloyed steel, on the basis of the more mature controlled rolling process, study the effort of cooling process after rolling on microstructure and properties of bainite steel, and provide some experimental and theoretical basis for industrial applications^[7].

Experimental

Table1 Tested steel chemical compositions (wt%)

C	Mn	Si	P	S	Mo+Cr	Nb	Ti
0.08	1.65	0.35	0.015	0.010	0.5	0.045	0.012

The tested steel chemical compositions are listed in Table1. The raw materials are billets with the section size of 250 mm×1800 mm. By the use of JMatPro software, base the tested steel chemical composition, and simulate the static curve of CCT. All of this test results will supply the basic

method of rolling and cooling technology of bainite. The simulate cooling rate from 0.1°C/s to 100°C/s, the temperature of phase transformation about the tested steel fall down while the cooling rate increase. When the cooling rate less than 10°C/s, the temperature of Ar₃ will be 805°C. As the result, the finish rolling temperature should more than 805°C and we can avoid rolling at two-phase area. The reduction of relaxation stop temperature should greater than 670°C which is the max pearlite start transformation temperature. When the cooling rate greater than 10°C/s, the bainite transformation temperature will less than 605°C, and reach at upward of the martensite point (about 405°C), the complete bainite transformation will be happened in theory, and we can obtain bainite structure in tested steel plate.

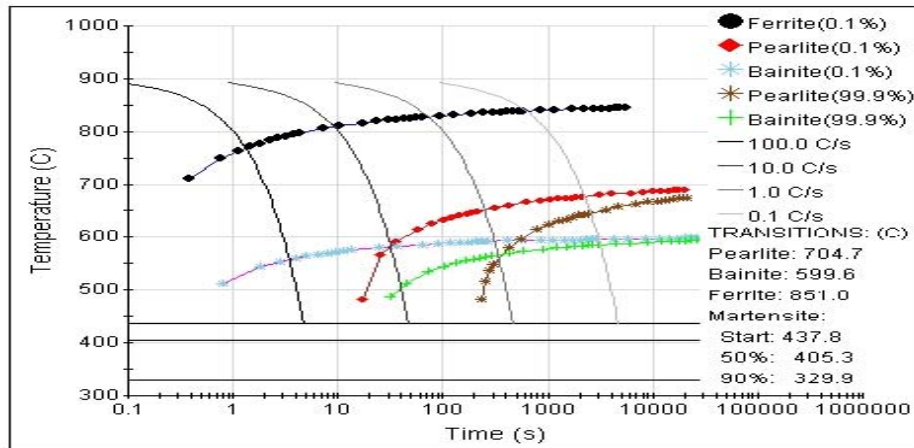


Fig.1 Static state CCT curve of tested steel plate

The slabs were heated to 1220°C and kept at temperature for more than 30min, and rolled at four-high reversing mills with two steps control. The technological parameters of control rolling and cooling shown as Table 2.

Table 2 Main technological parameters of control rolling and cooling

Plate	Recrystallization Zone		Non-Recrystallization Zone		Plate thick/mm	Finish air cooling Tem./°C	Accelerated Cooling	
	SRT/°C	First waiting point/mm	SRT/°C	FRT/°C			Cooling rate/°C/s	FCT/°C
No.1	1050	90	920	840	30	790	16	420
No.2						740		
No.3						690		

Results and discussion

Effect of cooling process after rolling on mechanical property. The yield strength (YS), TS, yield ratio (YR), elongation (EI) and Charpy impact absorbed energy at -40°C for Plates 1~3 are listed in Table 3. The TS of Plates 1~3 is within 600~750 MPa. It is noticed that Plate 1 is characterized by its extremely high strength, but EI and YR are not ideal. On the contrary, the strengths of Plates 2~3 not too bad, especially combination property of plate 2 reaches the need for the use of Q690 with GB/T 1591.

Table 3 Mechanical properties of tested steel plates

Plate	YS/Mpa	TS/Mpa	E/%	vE ₂₀ /J	YR
No.1	740	810	8.5	140	0.91
No.2	685	790	15.5	160	0.86
No.3	600	760	16.5	180	0.80

Effect of cooling process after rolling on microstructure. Fig.2 shows the microstructure of different cooling process, a, b, c are corresponding to No.1, No.2, No.3. The microstructures of tested steel were ferrite and bainite. It shows that as the finish air-cooling temperature reduce, the grain size and content of ferrite increase. This is because the finish air-cooling temperature was lower than the phase transition temperature of Ar₃ and part of supercooled austenite has been

occurred pre-eutectoid ferrite change before accelerated cooling. When the termination temperature is 690 °C, the microstructure mainly consists of bainite but also had massive ferrite or even some pre-eutectoid ferrite nucleus. This suggests that the pre-eutectoid ferrite begin to transform and bainite region is divided by the massive ferrite. Steel No.1 is dominated by slender bainites while granular bainites in No.2. this indicates the termination temperature fall down lead to increase of granular bainites, but slender bainites decrease. In original austenite grain, the structures of granular bainites are thick and also have some ferrite in boundaries.

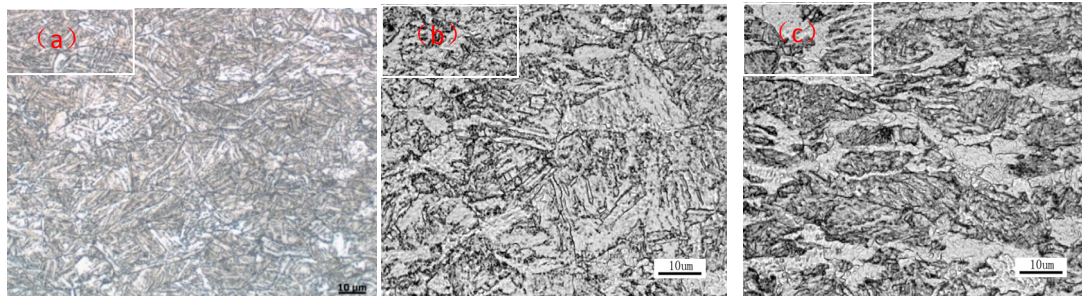


Fig.2 Effect of cooling process after rolling on microstructure of the testing steels

(a) 790°C (b) 740°C (c) 690°C

Effect of cooling process after rolling on bainite and precipitate. Fig.3 shows the bainite and precipitate of the tested steel at different finish air-cooling temperature. The bainite of No.1 is consist of parallel and long laths, and the misorientation of each bainite lath is tiny, higher proportion of small angle grain boundary. More important, the lath bainitic contains a high density of dislocations, and fine lamelliform M/A island exist in each lath, and less precipitate evenly distributed in lath bainite, approximately 10~30 nm in size. As finish air-cooling temperature after rolling fall down, bainitic lath broadening, granular bainites are mainly controlled by diffusion increased gradually, definition of boundary reduced, large angle grain boundary ratio increased significantly, density of dislocations reduce, precipitation will grow up and increased in amount, the M/A island structure refinement with irregular size, and in the shape of film (fig.3b).

When the termination temperature is 690 °C, bainite-ferrite laths are composed of thin retained austenite films within or between the bainitic ferrite laths, as show in fig.3c. Thickness of these bainite-ferrite laths are 200-400 nm. The deformed austenite recoved long time and through the mutual entanglement formed sub-grain boundary partition lath, along the length direction of the slats, retained austenitic films or dislocation wall divided bainite-ferrite laths into different sections, and in the shape of block and large granular. Precipitation has been fully aggregation and growth of spherical and irregular long distributed in bainite lath boundaries and ferrite bainite phase interface, about the size of 50-100nm. To analyze the precipitate of tested steel, it was found that the precipitates are Nb, Ti carbonitride and have similar energy spectrum with different cooling process.

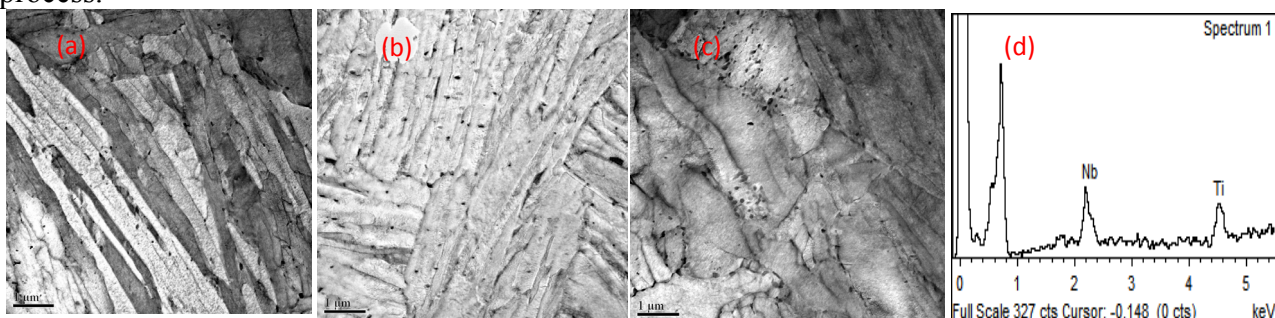


Fig.3 Effect of cooling process on bainite and precipitate of the tested steel

(a) 790°C (b) 740°C (c) 690°C (d) energy spectrum

From the tested steels precipitation TEM analysis, the size and distribution of precipitation mainly depends on finish air-cooling temperature after rolling, and that is the only variable factor. The termination temperature lower, the precipitation is more sufficient, and precipitates gathering grew up constantly. The No.2 test steel precipitate size and distribution helped the property most. Because

the tested steel No.1 has the largest hard phase volume fraction and high dislocation density, thus showing the highest tensile strength. With the air-cooling after finish rolling relaxation time increased, ferrite content increased gradually, the hard phase in the organization's ratio decreased gradually and dislocation density reduced, as a result, the tensile strength of No.2, No.3 decreased in the order. Hard and soft phase ratio also impact on the yield ratio and toughness plasticity. With the hard phase ratio decreased, yield ratio and the toughness and ductility can be improved.

Conclusions

- (1) The finish air-cooling temperature after rolling is key factor in effecting ferrite / bainite ferrite grain size and `ratio, as well as determining the second-phase precipitation morphology and size and on the bainite morphology.
- (2)Cooling process after rolling mainly though change the tested steel microstructure and second phase precipitation impact on mechanic property.
- (3)When the terminate temperature for relaxation ranges from 725 to 740°C, then reaches 440°C with 15°C/s cooling rate. The combination property reaches the need for the use of Q690 with GB/T 1591.

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