Study on High Tensile Heavy Plate with V-N Microalloying Technology

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Abstract: The contrast experiment of rolling heavy plate in Shougang is carried out between V-N microalloyed and V microalloyed steel. It is confirmed that not only the strengthening effect of V element is improved, but also the ferrite grain size becomes smaller with the increase of nitrogen content in the V-contained steel. The results have demonstrated that it has no disadvange to the performances of the steel. The heavy plates, 60 mm and 70 mm thickness, are manufactured with V–N microalloying combined with controlled rolling replacing the heat treatment processes. The performances of plate meet the requirements of Q390E steel.

Key words: V-N; microalloying; heavy plate; controlled rolling.

Introduction

With the quick development of economy, the tremendous requirement of high-strength heavy plates is rapidly increasing. The traditional manufacturing processes of high-strength heavy plate are microalloying combining with expensive heat treatment after rolling which increase manufacturing costs sharply. In this paper, through microalloying route and controlled rolling processes, high-strength heavy plates are achieved by eliminating expensive heat treatment procedures.

In the course of research, we found that both advantages and disadvantages are coexist with V microalloyed steel. One of the main drawbacks of V microalloying are that the actual strengthening effects of V microalloying element exhibit less than expectation, or the potential of V microalloying element can't be utilized fully. Based on the considerable experimental analyses, the main reason why V additions can not exhibit its actual strengthening effects is that almost all V prefer to solution rather than precipitation, so the effects of the precipitation strengthening of V(C,N) are weak. A technically very important findings and further studies show that the amount of precipitates of V(C,N) may considerably increase with the increase of the nitrogen content, so the precipitation strengthening of V increase on the while. So in order to demonstrate the strengthening effect of V and to meet the performance needs of plates, esp. heavy plate, we increase the additions of nitrogen by adopting V-N microalloying route in manufacturing heavy plate in Shougang.

1 Strengthening Effects of V-N microalloying and V Microalloying

In order to analyze the strengthening effects between high-N V-steels and low-N V-steels, V-N microalloying and V microalloying process routes are conducted, and respective strengthening characteristics are compared and analyzed carefully.

1.1 Chemical composition

The main chemical compositions of steels studied are given in Table 1. The carbon content of both steels, as shown from Table 1, is 0.13%, but the microalloying means of two steels are different, which are microalloyed with V and V-N respectively. Although the V-additions are almost equivalent, the N content varies sharply. The rests chemical compositions are consistent with GB/T 1591 standard.

Table 1 Main chemical composition of the steels studied (wt%)

Steel	C	V	N	Remark
Low-N	0.13	0.065	0.0030	V microalloying
High-N	0.13	0.064	0.0108	V-N microalloying

1.2 Experimental results

In this paper, plates of 18 mm are under experiment by adopting controlled rolling and controlled cooling processes. Experimental results are shown in Table 2 and Table 3 respectively. As seen from Table 2, although both mechanical properties of two microalloyed steels all meet the requirements, but the mechanical properties of V-N microalloyed steel exhibit differences. In the other hand, the impact energy of plates as shown from Table 3, demonstrates that the distinction are not obvious.

Table 2 The mechanical properties of plate studied

Microalloying	Thickness/mm	R_{el}/MPa	R_m/MPa	A_s/%
V-N	18	483	608	27.8
V	18	415	560	24.5

Table 3 The impact energy of plate studied

Process	Specimen direction	Regular impact energy/J				Strain-aging impact energy/J			
		20°C	0°C	-20°C	-40°C	20°C	0°C	-20°C	-40°C
V-N microalloying	longitudinal	250	220	183	159	198	182	132	99
	transverse	226	199	167	111	179	133	114	65
V microalloying	longitudinal	151	177	211	159	189	203	141	90
	transverse	98	77	59	45	82	50	31	23

1.3 Discussion and analysis

1.3.1 Strengthening capacity

As shown from experimental results, although all the chemical compositions apart from N content are equal, the mechanical properties varied clearly, in particular yield strength.

1.3.2 Grain size

As we known, grain refinement is unique in that it increases both strength and toughness to the steel whereas precipitation increases strength at the expense of some loss in toughness. As discussed earlier, the solubilities of the carbides and nitrides of V differ widely; the solubility product of VN is about two orders of magnitude lower than that of VC, so the role of N is of importance. Considerable experiments show that the ferrite grain size becomes much finer with increasing N-content. In this paper, the basic processing routes of two steels are complete uniform, so the strengthening effects of N content can be compared. Microstructures of two steels microalloyed with V-N and V are shown as Fig.1 and Fig.2. As demonstrated from Fig.1 and Fig.2, the grain size of V-N mocroalloyed steel is smaller than V microalloyed steel, which further confirms that the grain refinement effect of V-N microalloyed steel is larger than V steel.

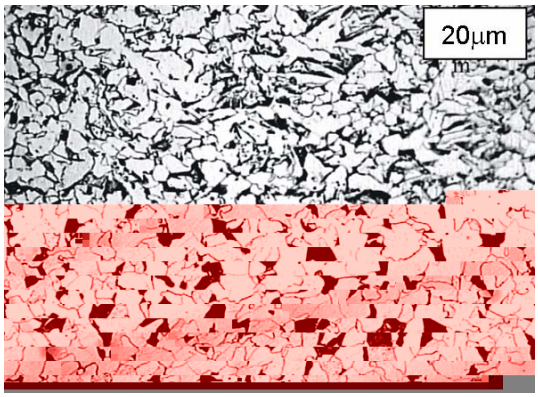

Fig.1 optical metallograph of steel microallyed with V-N

Fig.2 Optical metallograph of steel microallyed with V

1.3.3 Present forms of V in steel

In order to clarify the strengthening mechanism of two microalloying processes, electro-analysis and X-ray diffraction-analysis are carried out. Present form of V and N, together with precipitates of V, are analyzed and compared.

Analytical results show that the almost all N content combine with V to form V(C,N) then precipitate in the steel, and N content solutionized in the steel are very limited and almost equivalent in the two steels.

The main present forms of V in the steel are composed of V in solution and V(C,N) precipitated in austenite and ferrite, but the ratios of V in solution and V precipitated vary sharply. Sound determination results show the solution amount of V is 70.3% and the precipitation amount is 29.7 % in the V microalloyed steel whereas the amount is 58.5% and 41.5% respectively in the V-N microalloyed steel.

So the precipitation strengthening of V-N steel is more obvious than V steel. For V(C,N) precipitation particles, small angle X-ray diffraction technologies are adopted to measure the size. Determination results demonstrate that the average diameter of precipitation particle of V-steel is 81.1 nm, and for the V-N steel the average diameter is 69.5 nm.

V microalloying element is importantly strong element. Experimental results and analyses show clearly that the V(C,N)-precipitation becomes denser and the particles finer with increasing N-content.

1.3.4 Correlation between N and performance

Although V-N microalloying route is adopted, the sum N content is only 0.0108%(or 108 ppm). As shown from above comparisons of mechanical properties of strength、ballistic work and aging impact energy, high N content bring about no reverse effects, and on the other hand, improve the strengthening effect of V microalloying element. The free N in the steel is one of the important factors to decrease aging impact energy, but from measure results, the aging impact energy of V-N microalloyed steels is not lower than V microalloyed steels.

So in the steel added with V microalloying element, V can effectively inhibit the negative effect of free N, and bring about positive effects.

2 Manufacturing Practice of V-N Microalloyed Heavy Plate

In Shougang, the slab thickness applied to manufacture heavy plate is 220mm, and lack heat treatment furnace, so the product grades focus primarily on thickness below 50mm. In order to develop more thick products and expand the product scope, the experiments of 60mm and 70mm heavy plates with V-N microalloying processes are carried out. The sum compression ratios are 3.67 and 3.14 respectively.

2.1 Chemical composition

According to Chinese Standard GB/T 1591 and the existent actual conditions，the strict control steps of chemical compositions are taken. The chemical compositions of experimental steel are shown in Table 4.

2.2 Rolling technology

In the post, it is difficult to implement controlled rolling in the manufacturing heavy plate. So in order to guarantee the mechanical properties of heavy plate, strict controlled rolling steps are enforced in the whole experiment course, which include recrystallization rolling in high temperature range and rolling in low temperature zone. Water is more, the single pass reduction is improved and relative weak controlled cooling processes are applied after finish-rolling. Experimental processes are given in Table 5.

Table 4 The composition requirement for 60 & 70 mm heavy plate

Thickness/mm	C/%	Si/%	Mn/%	P/%	S/%	V/%
60	0.14	0.30	1.38	0.010	0.006	0.050
70	0.15	0.32	1.39	0.007	0.006	0.052

Table 5 The experimental processes

Reheat temperature/°C	Finish rolling temperature/°C		Cooling temperature/°C	
	Entry	Exit	Start	End
>1050	850-900	820-860	810-850	700-750

2.3 Mechanical properties

2.3.1 Regular property

The properties are determined on the standard sampling position for 60 mm and 70 mm heavy plates. Mechanical properties and a series of impact determination results are given in Table 6.As shown from Table 6, although the rolling passes are less than regular rolling for the heavy plates, the mechanical properties, such as yield strength, tensile strength and elongation percentage, all reach the quality specifications of Q390E grade.

2.3.2 Property of middle position

For the heavy plate studied the specimens (or the sampling position) are taken at a distance of 1/4 of the plate thickness, which can not represent the performance of the whole plate. One of the minimum position of performance focus primarily on core position, therefore the strength and impact energy values of core position is vital to test. The checking results are given in Table 6.

As demonstrated from Table 6, the strengths of core position are also minimum along the thickness direction, however no major differences are shown. Although the strengths of core position decrease more with increasing thickness, the properties all can meet the requirements of Q390.On the same, the variation rule of impact tests is almost same to the strength.

2.3.3 Metallurgical structure

Metallographic analyses are performed on the surface,1/4 and middle position. The microstructures of the whole plate are composed of ferrite and pearlite, and over-cooling microstructure and other microstructures are not seen due to controlled cooling. The average grain size reach N. 8 grade.

Table 6 The mechanical properties for 60mm and 70mm thickness

Location of thickness	Thickness	R_{eL}/MPa	R_m/MPa	A_s/%	Impact energy		
					0°C	-20°C	-40°C
Specification	>50-100	≥330	490-650	≥20			≥27
¼ t	60	382	553	30.5	193	171	145
	70	362	538	32.3	159	155	112
½ t	60	370	558	27.7	152	81	49
	70	337	523	22.2	167	122	82

2.3.4 Properties of Z-orientation

Z-orientation tests have shown that the reduction of area of Z-orientation is 50.5%～66.5% and 54.5%～58.0% for 60mm and 70mm grades, and the average value is 59.5% and 56.0 % respectively, which reach the standard demand to withstand layer-tiring

3 Conclusions

（1）By increasing N content, the strengthening effect of microalloying element can be displayed fully. Comparison experiments show that yield strength and tensile strength increase 68MPa and 48MPa respectively in cross direction with V-N microalloying processes.

（2）Grain refinement effect of V-N microalloying is clearly better than V microalloying. The grain grade of core position reach 8.5.

（3）Experimental results show, although the N content increase, the strain-aging impact energy does not fall down.

（4）In existent equipment conditions of Shougang, adopting V-N microalloying route & controlled rolling process may manufacture acceptable heavy plates below 70mm without heat treatment procedures. The properties reach quality requirements of Q390E and reduction of area Z- orientation reach anti-layer-tearing requirement.