Analysis on Vanadium's Impact on Metallographic Transitions of HSLA Steel

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Abstract: HSLA vanadium steel is a kind of steel with rapid development due to its comprehensive good properties. P510L is taken as an example in this paper to discuss the impact on metallographic transitions in over-cooled austenite of vanadium steel under different cooling speeds. The lower temperature of austenite receives higher austenite changing temperature and bigger ferrite phase area while higher temperature for austenite receives lower changing temperature and smaller ferrite area. Through SEM experiment, the existence of vanadium precipitation and precipitation strengthening as well has been proved.

Key words: vanadium; metallographic transition; temperature for austenite.

1 Introduction

Low alloy steel is one of the most rapidly developed and most featuring steel grades in recent years. It has become the most produced, applied and economic steel. The stipulated minimum yield strength is 275MPa with maximum value of 1035MPa. Such category of steel is made by adding a small portion of alloy element in carbon steel, which can make the steel having high strength, good toughness, high weldability and strong formality and erosion resistance under hot rolling or heat treatment.

Normal elements for alloyment are those strong carbide combination element as Ti, Nb and V. Nb is most widely applied and enjoys most researches due to the fact that it can effectively condition various physical metallurgy factors and have the biggest refinement and precipitation strengthening in traditional controlled rolling process. However, there has never been a termination to research and development of Ti-alloyed and V-alloyed microstructural steels, whatever the steel is either made by singular Ti or V addition or addition of both Ti and V , even with Nb. There have different functions and impacts on steel structures since the physical metallurgical characteristic of Ti, V and Nb are not the same. Please see table 1.

Compared with Nb and Ti, the main features of V are:

(1) Big V(C,N) solubility , more apparent at high temperature. This means a lower V(C,N) soluble temperature or most V can be soluble at a giving temperature.

(2) There is big difference in solubility between V carbide and V nitride, which is opposite to Nb and close to Ti. The fact that the solubility of VN is smaller in two magnitude order than VC, which shows N plays a decisive role in V microalloyed steel, in particular for promotion of precipitation strengthening.

It has been referred as follows in table 2 the formation temperatures of typical carbonitrides at the beginning stage.

Table 1 The function and impact of microalloyed elements

Microalloyed element	Precipitation strengthening after hot rolling	Precipitation strengthening after normalizing	Impact om recrystallization during hot rolling	Refining the grain after normalizing	Refining high temperature austenite austenite grain	Impact on changing feature after HR	Atom With fixed space
V	VC, VN	VC					V
Nb	NbCN		Nb, NbCN	NbCN		Nb	Nb
Ti	TiC			TiC	TiN		Ti

Table 2 The formation temperatures of typical carbonitrides at the beginning stage. °C

TiN	NbN	TiC	NbC	VN	VC
1527	1272	1140	1137	1088	719

There have been more and more widespread researches and applications of V steel due many advantages of V microalloyed steel. P510L is taken as an example in this paper to discuss the impact on metallographic transitions in over-cooled austenite of vanadium steel under different cooling speeds. The lower temperature for austenite receives higher austenite changing temperature and wider ferrite phase area while higher temperature for austenite receives lower changing temperature and narrower ferrite area. Through SEM experiment, the existence of vanadium precipitation and precipitation strengthening as well has been proved.

2 Material and Method for Experiment

Fabricating P510L into Φ2×13 mm test pieces with chemicals of C 0.08%, Si 0.61%, Mn1.0 %, P0.018%, S0.012%, V0.08%. Overcooled austenite phase transition curves experiment has been undertaken on DT—1000 expansioner. The data are: to heat the test piece to austenite temperature of 930°C with speed of 10°C/s, then holding for 10min. After that, it is cooled to ambient temperature at speeds of 0.05, 0.1, 0.2, 2, 5, 10, 15, 21, 30, 35, 50, 80°C/s respectively.

Cut the test piece, in direction perpendicular to axis, into metallographic observation chips, then leached in 4% nitric acid, flushed and air-dried, observed its structure by optical microscope and bainite appearance , V precipitation by S-360 scanner, test its hardness by Vickers Hardometer. Finally some typical metallographic photos can be selected.

3 Results and Discussions

3.1 CCT diagram

From the CCT curves (Fig.1), we can find out that the critic transition curve in the experiment A_{c1}=759°C, A_{c3}=900°C, slight higher than theoretical value A_{c1}=700°C, A_{c3}=879°C. The temperature for transition from austenite to ferrite is also higher with 832°C at 0.05°C/s of cooling speed.

3.2 Microscopic structure

The transition structure of P510L, at

cooling speed of 0.2°C/s, is ferrite lump and a few pearlite on ferrite grain boundary, as in Fig.2(a). the structure is ferrite and pearlite combination when cooling speed is 5°C/s、10°C/s, the higher the cooling speed, the more pearlite. see Fig.2(b)、2(c). A small fraction of Vs structural chips can be seen in Fig.2(c). Fig. 2(d) shows the ferrite, pearlite and a few bainite combinations at cooling speed of 21°C/s,and Fig.2(e)、2(f) show the ferrite and bainite plate structures when cooled to ambient temperature at cooling speed of 35°C/s、80°C/s.

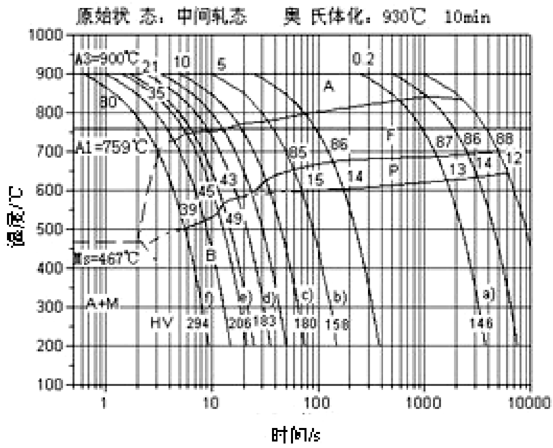
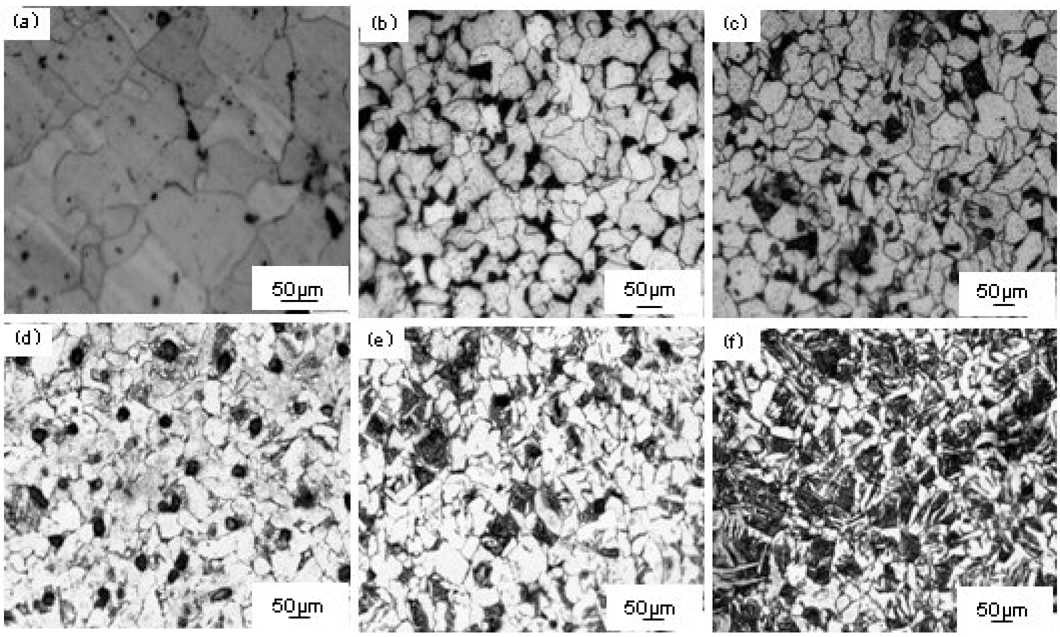
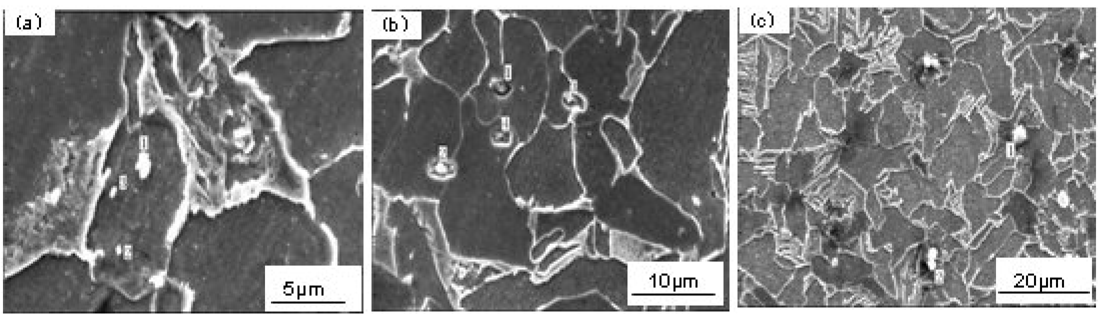


Fig. 1 CCT curves of P510L steel



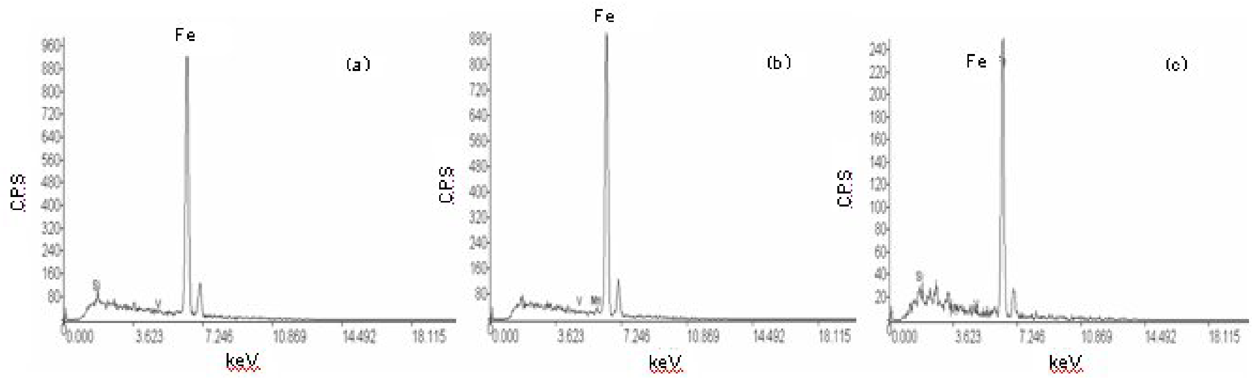
Cooling speed:（a）0.2 °C/s; （b）5°C/s; （c）10°C/s; （d）21°C/s; （e）35°C/s; （f）80°C/s

Fig. 2 Microscopic structures at different cooling speeds.



Cooling speed：(a) 10°C/s; (b) 21°C/s; (c) 35°C/s

Fig. 3 V precipitation at different temperatures.



Cooling speed: (a)10°C/s（mark 1）； (b) 21°C/s（mark 1）； (c) 35°C/s（mark no.2）

Fig. 4 Energy spectrums of V precipitation at different cooling speed.

3.3 SEM observations of V precipitation

A number of V precipitations have been observed during scanning the photos, most of them are precipitation along grain boundaries. The precipitated V(CN) appears to be rectangular or ball-like with sizes between 10～30 nm. They are typical V(CN) precipitations.

4 Discussions

V is one of the super ferrite forming elements. It reduces the γ phase area and increases temperatures of A 1 and A3. Steel with high V content has an outstanding medium temperature transitional area. In medium and low carbon steel, bainite structures are easily shown in normalization as a result of increasing V additions.

The impact of V on phase transitions depends upon its status. When solute in solid soluble, it needs time to diffuse since it reduces the diffusion speed of carbon. Hence, the phase transition becomes slow. On the other hand, when existing as fine carbonitride grain, it speeds up the phase transition since it refines the steel grains and can be nuclear of the new phase and can fix part of carbon contained in steel not to participate in the phase transition, which reduces the real contents of both carbon and V.

Based on a number of published solubilities, the calculated soluble temperature for 0.08%V ranges from 1150°C to 1054°C. Most formula calculations are around 1100°C. In our experiment, the temperature for austenite forming is 930°C, which means V has not yet become fully soluble in austenite. On the other hand it increases the transition temperature and expands the ferrite area.

In reference to some published CCT curves of 20MnV, it can be found that CCT curves are greatly different on condition that only austenite temperature is different while others remain the same. In comparison of 900°C and 1300°C, it can be seen, when austenite temperature is at 900°C, overcooled austenite begins transition to ferrite at 20～30°C higher than that at 1300°C and a larger percentage of transition rate is also shown. However, when austenite temperature is at 1300°C, the ferrite area becomes evidently smaller and bigger bainite area can be achieved.

5 Conclusions

（1）For the experimental P510L, low austenite temperature receives higher austenite transitional temperature and bigger ferrite area, while high austenite temperature receives lower austenite transitional temperature and smaller ferrite area.

（2）V is one of the super ferrite forming elements. It reduces the γ phase area and increases temperatures of A_1 and A_3. Steel with high V content has an outstanding medium temperature transitional area. In medium and low carbon steel, bainite structures are easily shown in normalization as a result of increasing V additions.

（3）V(C,N) has a good solubility, particularly at high temperature. There is big difference in solubility between V carbide and V nitride, which is opposite to Nb and close to Ti. the fact that the solubility of VN is smaller in two magnitude order than VC, which shows N plays a decisive role in V microalloyed steel, in particular for promotion of precipitation strengthening.

References:

［1］Wang Zubin,Dong Tao.Low Alloy High Strength Steel.

［2］E. R. Paul. Laboratory and Production Experience with Co - Ti Steels for HSLA Hot Rolled Sheet, in HSLA Steels 1984, ed. By Korchynsky, Philadelphia , USA. 1984, 203-208.

［3］Y. Shan, et al. Microstructure of Nb - V Microalloyed HSLA Steel ,in HSLA Steels’95 , ed. by G. Liu , Beijing , China. 1995, 138-142.

［4］Cai Qingwu .The Impact of CRC On Structural Properties and Precipitation of Nb-V Steel .

［5］Feng Guanghong .Impact of Accelerated Colling On Low Carbon Steel With Mn, Nb and Ti .

［6］Z. Yao, B. K. Zuidema. Hot Strip Mill Process Control to Improve Yield Strength Uniformity in a 550MPa Yield Strength Hot Rolled Steel Sheet, in HSLA Steels, p95, ed. by G. Liu, Beijing , China. 1995, 397-402.

［7］W. B. Morrison. Past and Future Development of HSLA Steels, in HSLA Steels 2000, ed. by G. Liu , Beijing , China. 2000, 11-19.

［8］A. M Saigi. The Properties and Applications of Modern Steel- Microalloyed Low Carbon High Strength Steel .

［9］Lin Huiguo, Fu Daizhi.The Theory, Test and Application of Austenite Transition Curves .

［10］Sun Zhenbao , Zhu Pufan. Manual for Alloyed Steel .

［11］No.1 Steel Works of Benxi Steel .The Overcooled Austenite Transitional Curves .