Application of VN in 400MPa Cu-P-Cr-Ni Weather and Erosion Resistant Steels

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Abstract: In time of domestic utilization of new generation rail-oriented steels, Pangang has developed 400MPa up V series weather and erosion resistant steels, the properties and applications of which have been described in this paper. Some test samples for industrial production have been used to show the function of VN in steels.

Key words: high strength; weather and erosion resistant steel; hot-rolled sheet; VN alloyment.

1 Introduction

Weather and erosion resistant steels are mainly used in rail vehicle industry. Some grades of 550MPa up are already available in America, etc. For a long term, however, domestic utilization in rail vehicles have been primarily oriented on 09CuPTiRe of 295MPa yield strength and 09CuPCrNi of 345MPa and in middle beams of cargo carriers on 09V of 295MPa (Z310 beams), which have a low carrying capacity and fail to meet the needs of speedy development of rail transportation by national economy. Hence, there is pressing demand for change and new generation steels.

The weather and erosion resistant steels of 400MPa up, both at home and abroad, mainly adopts a microalloy process using Nb、V or Nb+V. From July of 2002, with respect to its own characteristics, Pangang has set out to study and develop V-series weather and erosion resistant steels of 400MPa by way of VN microalloying process to improve V efficiency. From the results of both production and application of 400MPa Cu-P-Cr-Ni, VN microalloying can improve the comprehensive properties of steel sheets to satisfy the needs of new rail vehicles.

2 Research Aim

With reference to requirements of GB4171 and technical spec for cargo carriers in the document ［2000］137# by Ministry of Rails, in combination of requirements for new rail vehicle, the experiment aims were set as tables 1～3.

Table 1 Non - metallic inclusions and grain size.

Grain size	Non - metallic inclusions	
	Oxides	Sulphates
≥7	≥2.0	≥2.5

Table 2 Properties Index

R_{eL}/MPa	R_m/MPa	A/%	y-s ratio	A_{KV}/J(-40°C)	Cold bending	
					b = 20mm, 180°	
≥400	≥500	≥24	≤0.85	≥30 (full size)	D = a (thick≤6mm)	D = 2a (thick>6mm)

Note：when thickness is smaller than 12 mm, specimen of 5 mm×10 mm×55 mm or 7.5 mm×10 mm×55 mm can also be used for impact test, the results should not be less than 50% or 75% of specified values. No impact tests when thickness is smaller than 6 mm.

Table 3 Weather resistance

Grade	Relative erosion/%
Q235A	100
Specimen	≤60

3 Production Results

3.1 Process flow

Process flow for specimen:

Molten iron desulphuration → 120 tons LD converter → slag block and steel tapping m → predeoxidation、alloying、slag adjusting → bottom argon blow、temperature measuring、oxygen testing → LF bottom argon blow、temperature adjusting → RH treatment、fine analysis adjusting、VN microalloying (adopting special technology to improve N yield) → 1350mm slab casting（real-earth wires fed for mould → reheating furnace → rough rolling → 6-stand finishing rolling → laminar cooling → coiling → finishing and cutting .

Nearly 3000 tons of 400MPa Cu-P-Cr-Ni weather and erosion resistant hot strips have been produced.

3.2 Metallographic structure、non-metallic inclusion and grain size

The test results of specimens are shown in table 4. The structure is F+P. No martensite or bainite has been found. Grain size is bigger than 7.0.

Table 4 Metallographic structure, non-metallic inclusion and grain size

Thickness/mm	Structure	Grain size	Non-metallic inclusion			
			A	B	C	D
4.0~12.0	F+P little	10.5~12.0	0.5~1.0	0.5~1.5	0~1.0	0.5~1.0

Table 5 Properties of sheet

Thickness/mm	R_{eL}/MPa	R_m/MPa	A/%	y-s ratio	A_{KV}/J(-40°C)	Cold bending B = 20mm, 180°
4.0~12.0	$\frac{415\sim480}{445}$	$\frac{520\sim585}{555}$	$\frac{27\sim35}{31}$	$\frac{0.77\sim0.84}{0.80}$	$\frac{415\sim480}{445}$ (half size)	d=2a or d =a qualified
					$\frac{415\sim480}{445}$ (half size)	
					$\frac{415\sim480}{445}$ (half size)	

3.3 Properties of sheet

The tested properties of the specimen are shown in table 5. All cold bending are qualified. Other properties fluctuate in a range but meet the goals. Yeild-strength ratio is smaller than 0.85.

3.4 Weldablity

The welder is a CO_2/MAG protective type, model PANA-AUTO KRⅡ350. The protective gas is Ar 80%+$CO_2$20% mixture. The thickness of specimen is 10mm.

（1）Welding crack test

With reference to GB 4675.1，the specimen is tested under 0°C and 26°C respectively，2 pieces of each group are welded, and no surface crack and section crack are found when inspected 48 h after welding.

（2）Weld joint test

Sampling and inspection refers to GB

2649、GB 2651、GB 2651 and GB 2650，the results are shown in table 6. The minimum impact work value appears in the heat influence area.

3.5 Erosion resistant property

（1）Electro-chemical test

In laboratory the potential polarized curves of Q345 and specimen are tested and measured in 1.0% NaHSO3 solution shown in figure 1. The erosion resistance property of specimen is much better than that of Q345.

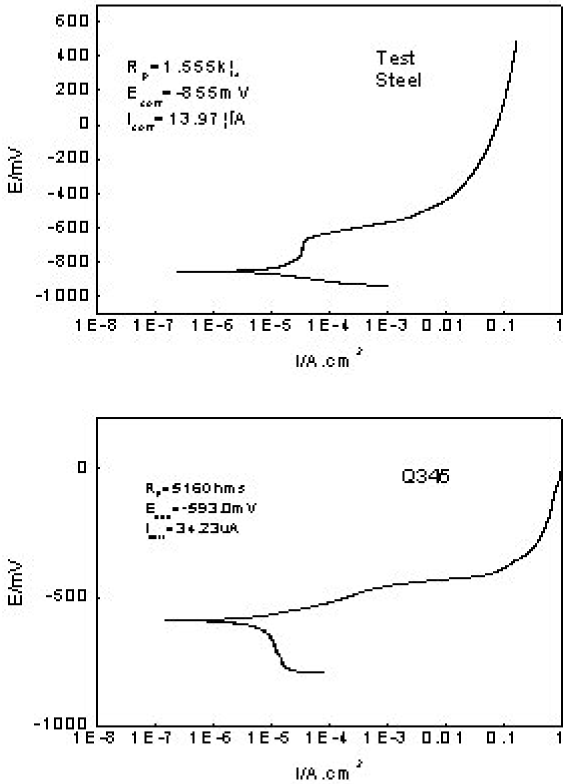

Fig. 1 The potential polarized curves of Q345 and specimen tested and measured in 1.0% NaHSO3 solution

（2）Cyclic leaching test

The test is made at the Metal and Chemical Research Institute of Rail Academy. Temperature: 45±1°C; Relative humidity: 70%±5°C；Solution:10–2mol/l $NaHSO_3$; Time duration: 72h, Leaching: 12min/60min; Maximum surface temperature:70°C, Test results are shown in Fig.2.

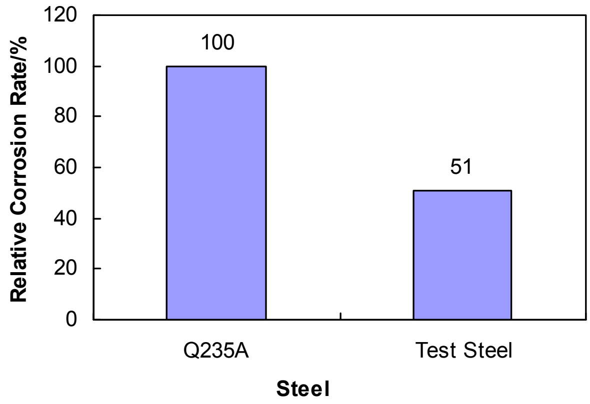

Fig. 2 Cyclic leaching test results.

3.6 Application cases

Y-type slope crack test and welding joint test were made by Zhuzhou Rail Vehicles, using the Solid Core type weld wires (brand no. H08MnSiCuCrNiⅡ), fabricated by Zhuzhou Weld Rod Fabrication for protective welding on the specimen of 10mm thick. The gas is of Ar 80%+CO2 20% mixture. Then the specimen was applied on vehicles.

The test and application results showed VN microalloyed 400 MPa Cu-P-Cr-Ni made by Pangang has very good weldability. There are no cracks for normal welding under ambient temperature. The sheet and welding joint are able to meet the requirements of new rail vehicle manufacturing.

4 The Funtion of VN in Steel

The specimens of V-Ti-N steel (1#～3#) and V-Ti steel (4#～6#) shown in table 7 are all taken from industrial coils with a thickness of 6.0～12.0mm. The content of unlisted chemical elements are similar for both cases, $Mn_2–Mn_1$=0.20%，V_1-V_2=0.01%，The final rolling temperature and coiling temperature are controlled within the required range. The microstructures of V-Ti-N (1#～3#) and V-Ti (4#～6#) are much multilateral figured ferrite+ little pearlite. Due to different coiling temperature and thickness, the size of ferrite grain is between 2.5～7.1μm，and that of pearlite between 14%～19%，the strip-like structure is 0～1.0. There is no big difference in Y-S ratio and elongation but big difference seen in strength. No apparent relation with grain size has shown.

Table 7 Test results of 1#-6# specimen steels

No.	Mn/%	V/%	N/PPm	N*/PPm	Precipitated Ti/%	Precipitated V ratio/%	Grain Size/μm	P content/%	R_{eL}/MPa	Y-S Ratio	A/%
1			94	44	0.017	25.0	3.5	18	470	0.82	30.5
2	Mn_1	V_1	83	45	0.013	28.3	4.2	17	465	0.84	30.5
3			98	48	0.017	31.3	7.1	15	455	0.81	29.0
4			20		0.017	10.8	2.5	19	470	0.82	29.5
5	Mn_2	V_2	20		0.017	13.9	3.5	14	445	0.82	31.0
6			20		0.017	11.4	5.0	17	450	0.81	28.0

In order to describe directly the VN's contribution to strength, we have calculated by using LINEST FUNCTION in Microsoft Excel 2000 the impact on yield strength by each factor with the following equation, where d is grain size, P is pearlite content，V is precipitated V content：

Yield Strength[MPa] = 297 + 53Mn[%] + $59.72d^{-1/2}$[μm] +2590.53V[%] + 4.29P[%] (1)

Justifying ratio: 100% (to demonstrate a much relevant specimen)；

Freedom: (4,1)；

$F_{calculated}$：155＞$F_{critical}$：55.8（α=0.10）

V contributes to strengthen mainly by precipitation. The result in (1) explains qualitatively sthength increases with rise in precipitated V content.

［N］ in steel contributes to strength by increasing precipitated V content on the one hand, and make V precipitations finer and more diffusive on the other hand. Electroscopic observations show that main precipitations in 1#～6# are square-like precipitations of less than 40 nm ，but more precipitates, and more diffusive and finer, in （1#～3#）than in V-Ti（4#～6#）.Figure 3 shows the appearances of precipitates in 2# and 5#.

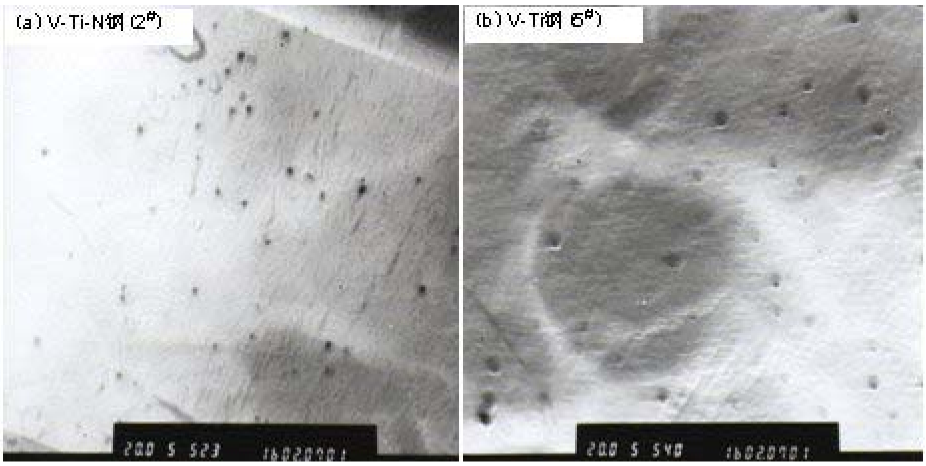

Fig. 3 Appearances of precipitates in V-Ti-N steel（2#，left）and V-Ti（5#，right)（20000 folds ）

Due to the following advantages of V [1,2]: ①smaller tend of longitudinal cracks and good surface quality when casting; ②lower hot rolling load and suitable for large scale production; ③easier in process control for hot rolling; ④good weldability, the specimen steels use V microalloyed steel to improve the strength. The tested results above-mentioned has demonstrated VN microalloy improves the positive function of V, and that the specimen steel can be ensured at a lower transforming temperature and hence neglected its aging effect since adding N increases V precipitation and keep a low level of free N in steel.

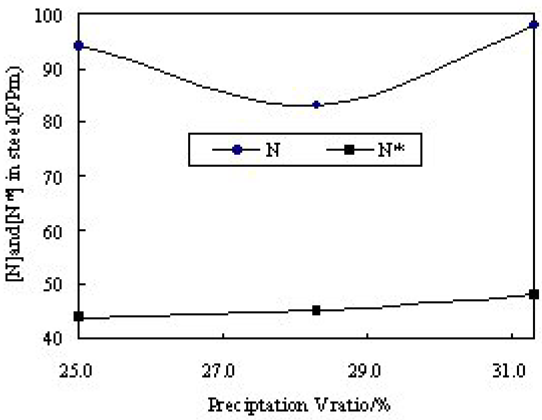

Fig. 4 The impact of [N] and [N] in steel on V precipitation.*

Through micro-treatment, V steel has following advantages: ① increasing grain 7coarsing temperature of reheated austenite [3]; ② lowing the temperature of austenite recrastallization [4]; ③ depressing grain coarsement between rolling passes [5]. That is to say, compared to V steel, V-Ti steel is easier to achieve finer austenite grains to refining ferrite grains. But in the same time adding micro Ti has positive effect, the TiV(N) grains formed at high temperature weakens V precipitation strengthening, as shown in figure 4. V precipitates increases singularly with rise of [N*] in steel. Therefore, for V-Ti-N steel, fairly decreasing and steadily controlling [Ti] in steel is vital for improving and keeping steel strength.

5 Conclusion

(1) The 400 MPa Cu-P-Cr-Ni hot strip series weather and erosion resistant steels produced by Pangang by way of VN microalloyment are good in terms of chemical analysis and process design and properties improvement as well.

(2) The welding test assessment and application results from Zhuzhou Rail Vehicles Factory has demonstrated that the 400 MPa Cu-P-Cr-Ni hot strip series weather and erosion resistant steels produced by Pangang by way of VN microalloyment are able to meet the demands of Brazilian rail vehicles manufacturing.

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