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Use of Vanadium for Low-alloy Steel Manufacturing at JSC “EVRAZ NTMK”

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Abstract

Joint Stock Company “EVRAZ Nizhniy Tagil Metallurgical Plant” (JSC “EVRAZ NTMK”) is the World’s largest processor of vanadium-rich titanium magnetite ores. This work describes the results of the research performed to test various combinations of vanadium and nitrogen microalloying targeted at repeatable quality and strength properties of the rolled steel products. In particular the benefits are described of using vanadium mass fractions in steel for manufacturing railway steel (rails, wheels, rings/tires), railcar body products (Z-beams, I-beams, etc.), API grades including large diameter X70 and X80 pipes. To optimize the analysis of different steel grades for the shaped sections manufacturing EVRAZ NTMK has taken efforts to identify the impact of the vanadium mass fraction in steel grade 09G2S on the mechanical properties of rolled steel with the elements of various thickness. During the effort, the mechanical tests were performed, the extent of vanadium reduction in the form of carbonitrides during the rolling and cooling process and its impact on the mechanical properties, the macrostructuring of rolled products was also studied. Recommendations were given on the chemical composition of steel 09G2S for manufacturing rolled steel of strength classes 375 and 390.

Keywords: EVRAZ NTMK, vanadium, I-beams, mechanical properties, impact strength

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1. Introduction

Being one of the most promising alloying elements, vanadium has acquired particular importance as a micro-alloying element capable of significantly increasing the performance of steel, as early as in the 60s of the last century.

The properties of vanadium, large mineable reserves of vanadium-containing ores in Russia determine the wide range of applications for vanadium-containing steels: railway rails, wheels and rings/tires, oil and gas pipes, and complex civil structures.

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The use of vanadium as a micro-alloying additive allows to obtain a consistently high level of mechanical properties and performance characteristics of railway steel, traditionally manufactured by JSC “EVRAZ NTMK”. Rails, wheels, rings/tires manufactured by the company, proved to be excellent among consumers both in Russia and abroad.

Table 1 shows the analysis of rail steel manufactured by EVRAZ NTMK, Table 2 shows the mechanical properties of the finished rails.

Table 1: The analysis of rail steel K76F.

		Main elements, %			
		C	Mn	Si	V
GOST R 51685-2013		0.71-0.82	0.75-1.25	0.25-0.60	0.03-0.15
Actual values	Mean	0.78	0.90	0.36	0.036
	Minimum	0.76	0.85	0.30	0.030
	Maximum	0.80	0.98	0.44	0.045

Table 2: Mechanical properties of rails type R65 of OT350 category.

		Impact strength, KCU, at +20°C, J/cm2	σ_T, N/mm^2	σ_B, N/mm^2	δ, %	φ, %	Hardness, HB: On the running surface	Hardness, HB: at depth 10 mm: Along the axis	Hardness, HB: at depth 10 mm: In The fillets	Hardness, HB: at depth 22 mm	Hardness, HB: in the web	Hardness, HB: in the base
GOST R 51685-2013		At least					352-405	At least			not to exceed	
		25	800	1180	8.0	25.0		341		321	388	
actual values	Mean	39	926	1305	14	33	360	364	366	337	351	359
	Minimum	25	855	1254	10	25	352	352	351	322	334	343
	Maximum	60	1012	1356	20	39	384	377	381	352	371	376

Growing rail freight turnover has tasked to develop a railcar of a new generation. For these purposes, the specialists of the company developed a technology and learned to manufacture the steel grade of strength class 390 micro-alloyed with vanadium, intended for rolled products for car building (Z-profile, I-beams, etc.), in substitution for the conventional steel grade 09G2S (09G2SD), which could offer maximum strength class 345.

Table 3 shows the analysis of steel grades 09G2S and 12G2FD manufactured by EVRAZ NTMK, and Table 4: the mechanical properties of the Z-section from steel grades 09G2S and 12G2FD.

In recent years, the company has learned to manufacture a wide range of pipe steel grades with vanadium, including those for large diameter pipes X70 and X80.

Table 3: The analysis of steel grades 09G2S and 12G2FD for car building.

	Reference	Main elements, %					
		C	Mn	Si	P	S	V
345 (09G2S)	GOST: 19281-2014	≤0.12	1.30-1.70	0.50-0.80	≤0.030	≤0.035	≤0.12
390 (12G2FD)	TU 14–1–5391–99	0.09-0.15	1.30-1.70	0.17-0.37	≤0.040	≤0.035	0.02-0.10

Table 4: Mechanical properties of Z-section from steel grades 09G2S and 12G2FD.

Section	Class Of strength (steel grade)	Indicator	σ, N/mm^2	σ_B, N/mm^2	δ_5, %, %	Impact strength, KCU, J/cm2, ˚C	
						+20, After mechanical aging	-60
Z section Z–310	390 (12G2FD)	Minimum	390	530	26	198	152
		Maximum	482	599	39	379	373
		Mean	419	543	31	297	278
	345 (09G2S)	Minimum	370	483	30	152	201
		Maximum	431	539	37	373	349
		Mean	399	514	33	279	284

Construction in different climatic zones requires the use of high-strength steels for the manufacture of structures. The required properties are achieved by introducing various alloying elements into the steel, however the microalloying of steel by carbon and nitride-forming elements, primarily vanadium, is a better tool to improve the quality of steel. In this context, the modern development of the construction industry, primarily in the direction of high-rise construction, involves the use of I-beams made of high-strength steels of classes 390, 440, 460, micro-alloyed with vanadium and nitrogen (Table 5).

Table 5: Analysis of steel for I-beam manufacturing.

Reference	Steel grade	Main elements, %								
		C	Mn	Si	P	S	N	Ni	V	Ceq
EN 10025	S450J0	≤0.20	≤1.70	≤0.55	≤0.035	≤0.035	≤0.025	–	≤0.13	≤0.47
ASTM A 572	Grade 65	≤0.23	0.50-1.65	≤0.40	≤0.030	≤0.030	0.003 - 0.015	–	≤0.06	–
JIS G 3101:3106	SM 570	≤0.18	≤1.70	≤0.55	≤0.035	≤0.035	–	–	–	≤0.44
GOST R 57837	S390B	≤0.16	1.30-1.70	0.15-0.50	≤0.020	≤0.010	≤0.020	≤0.50	≤0.12	≤0.46
	S440B	≤0.17			≤0.015				≤0.14	

In 2017 EVRAZ NTMK started to improve liquid steel and rolled steel manufacturing processes to obtain the properties of these strength classes. To obtain the properties of rolled products, the steel analysis variants were set, which offered varying amounts of alloying elements, including vanadium and nitrogen (Table 6).

Table 6: Chemical analysis of trial steel grades for testing of the I-beam process at EVRAZ NTMK.

Option	Main elements, %					
	Carbon (C)	Manganese (Mn)	Silicon (Si)	Vanadium (V)	Nitrogen (N)	Carbon equivalent:
1	0.10	1.45	0.46	**0.10**	**0.013**	0.41
2	0.11	1.55	0.30	**0.08**	**0.011**	0.42
3	0.11	1.57	0.39	**0.09**	**0.015**	0.44

The heats were intended for manufacturing of three I-beam section types: 40K2, 40K4, 40K5 with different flange thicknesses. They were rolled at the universal beam mill of the H-beam plant using the current process.Samples for mechanical tests were taken at the hot saws to measure the quality characteristics of the rolled steel. Tensile tests were performed on proportional flat specimens.Impact toughness was tested on Charpy V-notch specimens, KCV, at temperatures of minus 40°C, minus 60°C. See Table 7 for test results.

Microstructure of an 40K5 I-beam specimen (flange thickness is 35.5 mm) was studied, which was made from steel with the analysis of variant №3. Steel structure: pearlite and ferrite, grain size number seven through nine.

The test results showed:

1. The mechanical properties of I-beams made from steel grade of the variant two and three analyses comply with the requirements of GOST 27772–2015 for steel C390 and GOST R57837–2017 for steel S390B if the material thickness is up to 35.5 mm.

2. The mechanical properties of I-beams made from steel grade of the variant three analysis comply with the requirements of GOST R57837–2017 for steel C440B with a thickness of rolled products up to 35.5 mm.

3. The impact strength values in all variants significantly exceed the requirements of the standards. A high level of impact strength at test temperatures of minus 40°C and minus 60°C ensures proper I-beam performance in civil structures and in any climate zone.

Noteworthy that, having many years of experience in the production of steel grades with vanadium, specialists at JSC “EVRAZ NTMK” have developed several technological

Table 7: Mechanical test results of the I-beams manufactured from the trial heats.

Section	Flange thickness mm	Analysis variant	σ, N/mm^2	σ_B, N/mm^2	δ_5, %, %	Impact strength, KCV, J/cm2, °C	
						-40	-60
40K2	21.0	1	373	503	33	205	–
		2	413	560	31	265	–
		3	**473**	**600**	**26**	245	175
40K4	28.0	1	354	491	32	119	–
		2	437	572	25	208	–
		3	**471**	**585**	**25**	247	150
40K5	35.5	1	334	495	28	155	–
		2	429	569	27	143	–
		3	**454**	**582**	**29**	235	81
GOST 27772- 2015		C390	at least				
			370	490	20	34	–
GOST R 57837- 2017		S390B	at least				
			375	520	20	34	34
		S440B	at least				
			425	580	18	34	34

legend:
σ– tensile strength;
σ– ultimate resistance;
δ_5– percent elongation;
Note: The reference mechanical property values are shown for the rolled steel products over 20 through 40 mm thick.

methods for obtaining the required vanadium and, if necessary, that of nitrogen using different types of vanadium ferroalloys:

- lumpy (FeV80, FeV50, nitrided ferrovanadium quality FeV45N10, ferrovanadium nitride FV45N9);
- cored wire with fillers FeV80 and ferrovanadium nitride FV37N9.

Furthermore, various methods of nitrogen micro-alloying of steel are used to obtain target nitrogen both through the use of nitrogen ferroalloys and nitrogen gas as a purge gas during metal treatment at the ladle metallurgy furnaces or as a carrier gas during metal treatment at the RH vacuum degassers.

To date, the grade mix of JSC “EVRAZ NTMK” shows over 200 successfully manufactured vanadium micro-alloyed steel grades, which is over 20 percent of the total steel produced by the company.

2. Conclusions

The use of different combinations of micro-alloying of steel with vanadium and nitrogen enables obtaining of the target amounts of these elements in a preset range, which guarantees consistent quality and the required strength characteristics of the rolled steel products.