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Resource-Saving Technologies in Production Cold-Resistant Steels

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Abstract. The possibility of application for steel alloying with vanadium of the technology based on restoration of vanadium from oxides of converter vanadic slag with use of the reducers (carbon of a koksik and silicon of ferrosilicium) having low cost and a purge gaseous nitrogen with high coefficient of extraction of the alloying element is shown.

Introduction

In the conditions of the Arctic to the used materials, first of steel, higher requirements, especially on cold resistance are placed. For receiving metal with high office properties now the most demanded microalloying element is vanadium. It is caused by high efficiency of alloying. Researches showed that microalloying reinforcing manganiferous steels vanadium and nitrogen allows to receive a unique complex of properties after rolling and cooling: high level of mechanical characteristics, high resistance to fragile destruction and high crack resistance; low sensitivity to corrosive attack; the high cyclic viscosity providing seismic stability; resistance to mechanical aging; the guaranteed ability to welding [1]. On the level of a complex of properties containing vanadium reinforcing steel can work in extreme conditions of a frigid climate and seismic zones. In work [2] the results of researches which showed that in machine-building medium-carbon steels introduction of vanadium provides uniform distribution of hardness and mechanical properties on detail section are presented. These became have high resistance of the overcooled austenite and a deep ability to calcination. Chromomolybdenic steel with vanadium are cold-resistant, and impact strength with fall of temperature changes smoothly, and the threshold of cold resistance is at a temperature below – 353 K. According to authors [3] use of vanadium as the alloying element in production of rail steel increases strength characteristics of products. Steel are characterized by the disperse structure increased by the resilience to contact fatigue damages, the minimum roughnesses on the surface of driving. Formation of cracks on a working surface of rails decreases. Steels, alloyed by vanadium, can be operated both in usual climatic conditions, and at low temperatures, for example, for production of rails of low-temperature reliability.

Influence of vanadium amplifies in the presence of nitrogen, turning the last from harmful impurity into the alloying element. The last is especially important for steels, melted in arc furnaces. Positive influence of nitrogen is connected with formation of the karbonitrid of vanadium, which are the strengthening phases allowing to combine high durability threw with sufficient plasticity. The nitrogen dissolved in metal interacts on a nanolevel with the restored vanadium, vanadium carbide, forming nitrides and karbonitride of vanadium.

Now by production of steel apply the next main ways of alloying with vanadium:
- receiving the nature alloying steel from vanadic cast iron;
- use of vanadium-bearing alloys;
- alloying with use of vanadic cast iron
- alloying with vanadium at restoration it from oxidic materials.

The most perspective direction in development of technology of alloying became vanadium application of intermediate products of vanadic repartition (vanadic cast iron, vanadium pentoxide, vanadic slag, undergone metallization vanadium-bearing pellets, a vanadium-bearing product of metal), in particular vanadic slag is.

The main methods of input of nitrogen in metal are connected with use of materials with the high content of the dissolved nitrogen, the compounds of nitrogen, which are easily decaying at temperatures of metallurgical processes with activation of molecular nitrogen and its dissolution in liquid metal [4, 5].

Shortcomings of the first two methods is need of production of special ferroalloys or chemical compounds, instability of digestion of nitrogen from them in the course of alloying and quite high heterogeneity of content of nitrogen in ready metal.

Obviously, ecologically and economically expedient to use gaseous nitrogen for metal alloying. However, the difficulties arising because of energy costs of activation of intermolecular communications of gaseous nitrogen interfere with wide circulation of alloying with nitrogen from a gas phase. Works on development of ways of alloying of metal with nitrogen from a gas phase are actively conducted not one decade as at us in the country, and abroad.

Relevant task is development of technology of processing now became converter vanadic slag with application as reducers of silicon and carbon and also use for microalloying of gaseous nitrogen. Due to the low cost of initial materials and high extent of extraction of vanadium and digestion of nitrogen use of such technology will allow to increase significantly quality and to reduce prime cost of steel products.

Authors conducted the researches [6-10] including thermodynamic modeling of restoration of vanadium as from vanadium pentoxide and from converter vanadic slag, digestion of nitrogen at a steel purge with use of the program Terra complex, laboratory experiments and industrial tests, the technologies of alloying which allowed to offer option became vanadium from vanadium-bearing vanadic slag with use as reducers of silicon of ferrosilicium and carbon of small coke and a purge gaseous nitrogen.

The conducted researches of influence of temperature and expenses of reducers on process of restoration of vanadium of vanadium-bearing oxidic systems showed that at a temperature from 1673 to 2073K this process depends only on a consumption of reducers. Temperature change of influence does not render. Restoration of vanadium from vanadium pentoxide carbon, silicon and in common carbon and silicon happens to primary formation of compounds of vanadium: carbide of vanadium and silicides of vanadium. The mass of vanadium metal is insignificant. The received results allowed to draw a conclusion that at carbon and silicon restoration of vanadium carbon is the main reducer.

The carried-out thermodynamic modeling of process of restoration of vanadium of converter vanadic slag metal carbon on release showed that we realize process of alloying with vanadium of converter vanadic slag in the wide range of the required concentration of vanadium in metal, and the best indicators of process turn out at joint restoration of oxides of vanadium silicon and carbon, especially it belongs to smelting of low-carbon grades of steel. Restoration of manganese and titanium and their transition to metal on release and in the conditions of formation of ladle slag are limited.

For the purpose of confirmation of results of thermodynamic modeling pilot studies of processes of restoration of vanadium of oxidic materials (pentoxide of vanadium and converter vanadic slag) which showed that there is a complete recovery of vanadium from vanadium-bearing oxidic materials to primary formation of carbide of vanadium were conducted.

The estimated structure and results of the X-ray phase analysis are given in tables 1 and 2.

Table 1 - Estimated structure and results of the X-ray phase analysis of system V_2O_5– C – Si

Experience	Estimated structure	Results of the analysis
1	C – 1.1; VC – 94.0	prevails V_8C_7.
2	SiO_2 – 43.4; VO-43.9; V_5Si_3 – 12.7	V_5Si_3, a little Si
3	SiO_2 – 42.5; VO – 0.17; V_5Si_3 – 7,88; VSi_2 -49.44	Si, VSi_2
4	SiO_2 – 38.3; VO – 0.4; VC – 48.7; SiC – 4.9; V_5Si_3 – 7.7	V_8C_7, β - SiC, VC_xO_y, Si_3V_5
5	SiO_2 – 39.6; VO – 0.3; SiC – 11.8; V_5Si_3 – 48.2	β-SiC, V_5Si_3, VC_xO_y, V_8C_7,
6	SiO_2 – 30.8; VO – 69.0	prevails VC_xO_y

Table 2 - Results of the X-ray phase analysis of products of restoration of vanadic slag

Experience	Phase structure
1	X-ray amorphous substance, V_8C_7, α- Al_2O_3, α- Fe, Fe_3C,
2	α- Fe, VC
3	α- Fe, is present VC
4	X-ray amorphous substance, V_8C_7, α- Fe
5	α- Fe, is present VC, a little impurity (possibly V_8C_7)
6	V_8C_7, α- Fe, X-ray amorphous substance
7	VC, α- Fe, X-ray amorphous substance
8	X-ray amorphous substance, α- Fe, VC
9	α- Fe, is present VC, V_8C_7.

For the purpose of confirmation of data thermodynamic calculation on steel alloying with vanadium of converter vanadic slag a series of melting on the laboratory furnace at a temperature of 1873K was carried out. Were a part of initial materials carbon steel of the following structure of 0.27%, 0.49% of Mn, 0.02% of Si, 0.02%V, converter vanadic slag, reducers, lime. As reducers crystal silicon and graphite was used.

Results of the spectral analysis of the received metal are given in table 3.

Table 3 - Results of the spectral analysis

Melting No.	Composition of metal, wt. %							
	C	Ni	Mn	Ti	Mo	Si	W	V
1	0.412	0.098	0.456	it is not	0.014	0.353	0.004	0.126
2	0.166	0.072	0.461	0.054	0.013	1.051	0.004	0.108
3	0.309	0.094	0.515	0.06	0.015	1.938	0.006	0.1
4	0.254	0.078	0.388	it is not	0.013	0.333	0.005	0.114
5	0.337	0.086	0.424	it is not	0.013	0.332	0.004	0.111
6	0.242	0.092	0.421	it is not	0.014	0.508	0.005	0.118

As a result of carrying out a series of smelting on alloying of carbon steel with use of converter vanadic slag it was revealed that the greatest coefficient of extraction of vanadium when processing became converter vanadic slag it is received at joint restoration by carbon and silicon.

Thermodynamic assessment of process of interaction of the fusion processed by converter vanadic slag with the nitrogen blown through a ground furma allowed to define conditions of formation of nitrides and karbonitrid of vanadium. In particular, for steel 20GFL temperature of the beginning of formation of karbonitride is 1150 K at the minimum concentration of nitrogen of 0.003% and vanadium of 0.04%.

Gain of content of nitrogen in steel at its purge in a ladle nitrogen depends on a way of a purge: at introduction more than 20 m^3 of nitrogen within 20 min. through ground furma gain of content of nitrogen averages 0.005% and does not exceed 0.015%, and at a purge through the top immersed furma within 15 min. – about 0.003% also do not exceed 0.012%.

Pilot studies on a purge became gaseous nitrogen and gaseous nitrogen through ground furma on the unit of complex processing of steel (UCPS) showed to preliminary estimate of digestion of nitrogen when smelting steel of the brands St3sp, 09G2S, NE76F with a purge that at increase in time of a purge from 30 to 60 min. digestion of nitrogen steel increases from 20 to 37%. At increase in a consumption of gaseous nitrogen its content in steel increases and during a purge can change from 0.002% at an expense of 10 m^3 of gaseous nitrogen up to 0.005% – at an expense of 20 - 22 m^3.

Results of theoretical and pilot studies and industrial tests were used for development and optimization of schemes of smelting and processing of steel and alloys with use of the nanotechnologies allowing to receive optimum low residual oxygen concentrations, nitrogen and optimum structure of metal for the purpose of ensuring the maximum consumer properties and also became, alloyed by nitrogen, with a high durability, plasticity and cold resistance.

The received results allowed to offer the following technological scheme of processing became converter vanadic slag (figure 1). At the first stage on release in a ladle move converter vanadic slag and slag-forming, there is a fusion of slag and restoration of vanadium metal carbon on release, on the second - restoration carbon of small coke and silicon of ferrosilicium on installation the unit of complex processing of steel and a purge nitrogen.

The developed technology was tested in electrosteel-smelting factory JSC EVRAZ of ZSMK.

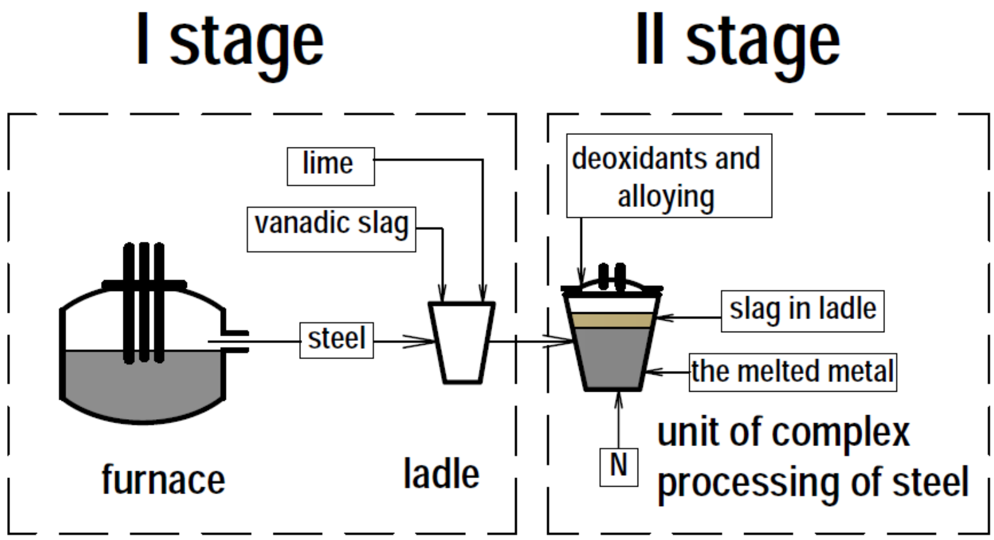

Fig. 1 - The technological scheme of process of alloying became vanadium

In 100 - t arc steel-smelting furnaces melted metal, carried out dephosphorization, decarbonization, heated metal to the set temperature. After that metal was produced in a ladle for pouring of steel with a cut-off of oven slag. During release in a ladle added deoxidants and the slag-forming mix consisting of lime and fluorspar with estimated amount of vanadium-bearing slag. Materials gave from the scoop suspended on the crane after filling of a ladle with metal on 1/4 - 1/3. Further the ladle with metal was directed to processing on the unit of complex processing of steel and spilled on the car of continuous casting of preparations in preparation by section 300×330.

On the unit of complex processing of steel carried out a purge by nitrogen, selected tests of metal and slag. After obtaining analyses carried out final alloying of metal. On the processing course slag was periodically deoxidated additives by 75% of ferrosilicium and coke powder. If necessary metal was carbonized inflation of coke dust. Duration of extra oven processing averaged 40 min. For microalloying used vanadic slag of ShIVd-1 brand (TU 14-11-178-86) with the content of pentoxide of vanadium of 17.6%. The metal purge nitrogen was carried out through a porous stopper.

Results of industrial approbation confirmed that restoration of vanadium comes from vanadium-bearing slag in two stages:

- first stage – restoration during release in a ladle when forming slag from slag-forming mix;
- second stage – restoration of vanadium during extra oven processing of steel on installation a ladle furnace.

Comparison of these stages indicates that the main share of vanadium passes into metal during release – 70 – 90%.

Metal working in the unit of complex processing of steel provides full extraction of vanadium. The through coefficient of extraction of vanadium average on all swimming trunks is close to 100%. The received indicators are close to data of the carried-out thermodynamic calculations (figure 2).

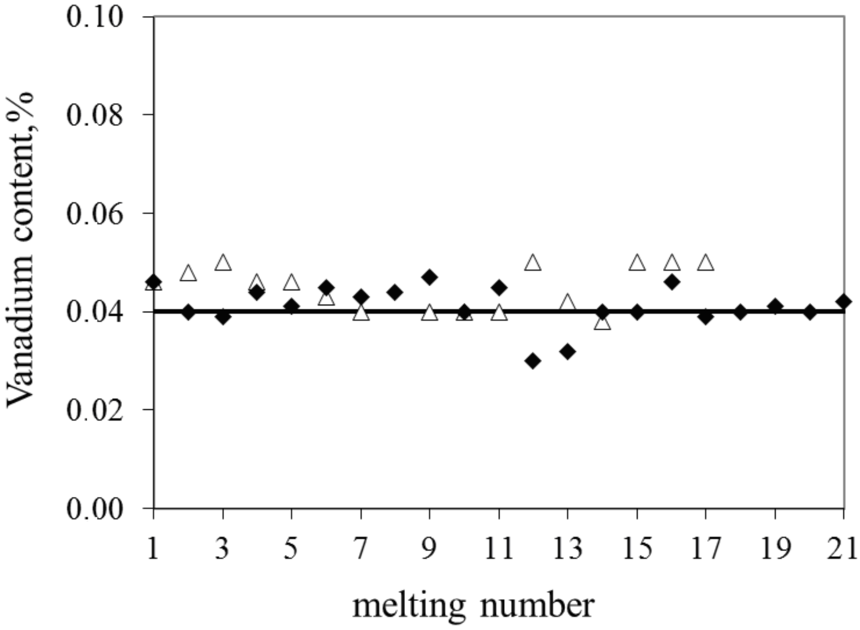

Fig. 2 - Vanadium content in metal according to calculation and to results of the chemical analysis

Conclusions

The analysis of results of researches showed that nitrogen content in ready metal fluctuates from 0.009 to 0.012%. Gain of content of nitrogen averages 0.005%.

It is possible to realize stable process of extraction of vanadium of converter vanadic slag in the range of change of process parameters, which exist by production of steel in actual practice for each separate brand.

The conducted complex of researches showed a possibility of application for steel alloying with vanadium of the technology based on restoration of vanadium from oxides of converter vanadic slag with use of the reducers (carbon of small coke and silicon of ferrosilicium) having low cost with high coefficient of extraction of the alloying element.

The analysis of quality of the steel melted on the developed technology, executed on the basis of researches macro and microstructures became also impurity of metal nonmetallic inclusions, showed full compliance to requirements of the standard.

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