

To the question of improving steel processing technology by converter vanadium slag

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Abstract. The results of thermodynamic modeling and laboratory study of the process of steel microalloying by vanadium from converter vanadium slag using coke carbon and silicon ferrosilicon are presented. These experimental studies on a laboratory arc furnace confirmed the results of thermodynamic modeling.

1. Introduction

At present, the technology of steel, based on the introduction of oxide materials and the provision of conditions for the reduction of alloying elements from their oxides, becomes a promising one in connection with the need to reduce the energy- and material intensity of production, solution of environmental problems. One of the most effective and therefore demanded alloying elements for the production of steels with high performance properties is vanadium. The source of vanadium oxides can be vanadium-containing metallized pellets, technical pentoxide vanadium and converter vanadium slag. It is more economically efficient to use converter vanadium slag, which is an intermediate product of the vanadium conversion, because its cost is much lower than the cost of technical pentoxide vanadium, and the vanadium content is higher than in metallized pellets. The actual task is to develop a technology for processing steel with converter vanadium slag using silicon and carbon as reducing agents, since at the present time high-priced aluminum, silicon, and calcium are used as reducing agents.

2. Methods of research

To solve the above stated problem using the previously developed thermodynamic simulation methods [1, 2], on the basis of the finished software product – “Terra” software package [3], calculations were carried out to determine the optimal conditions for the reduction of vanadium from vanadium converter slag, the laboratory investigations were carried out modelling the process of vanadium reduction from converter vanadium slag during out-of-furnace processing of steel (alloying the steel in the ladle at the outlet and processing at the unit furnace-ladle).

Calculations were carried out at a temperature of 1873 K, the amount of furnace slag getting into the ladle is 1 kg/t of metal, the additives of lime and ferrosilicon FS 75 are taken equal to 2 kg/t, respectively. The consumption of converter vanadium slag was 4, 6, 8, 10 and 12 kg/t of metal with a change in the consumption of coke in the range from 0 to 2 kg/t of metal.

During the calculations the following compositions of the initial materials were adopted:

- converter vanadium slag: 16 % V_2O_5 , 25 % Fe_{tot} , 8 % MnO , 15 % SiO_2 , 4 % TiO_2 ;
- lime: 85% CaO , 2% SiO_2 , 1% Al_2O_3 , 2% MgO , 9% $CaCO_3$;
- electric furnace slag: 25% FeO , 8% MnO , 45% CaO , 15% SiO_2 , 2% MgO , 2% Al_2O_3 , 2% P_2O_5 ;
- metal released from the electric arc furnace: 0.2% Mn , 0.02% S , 0.02% P , 0.1% to 0.7% C .

In order to confirm the results of the thermodynamic modeling of steel alloying by vanadium from converter vanadium slag, a series of experimental meltings was carried out on a laboratory arc furnace with a capacity of 2 kg with magnesite lining at a temperature of 1873 K. The base materials included



carbon steel with the following composition 0.27% C, 0.49% Mn, 0.02% Si, 0.02% V, vanadium converter slag, reducing agents and lime. Crystalline silicon and graphite were used as reducing agents.

From pre-crushed and carefully mixed base materials, briquettes with different ratio of reducing agents were made. Liquid glass was used as a binder. The prepared briquettes were dried in the air. The composition and quantity of materials are given in table 1.

Table 1. The number of raw materials and additives, g.

No.	Mass of the briquette components			Briquette mass	Metal mass	Lime mass	Silicon mass (deoxidizer)
	slag	graphite	silicon				
1	100	17	0	25	1840	25	10
2	100	0	15	25	1695	25	10
3	100	15	3	15	1650	15	15
4	100	12	6	20	1675	20	10
5	100	7.6	9	25	1945	25	15
6	100	5	12	25	1845	25	25

The furnace was charged with carbon steel and slag-forming materials. After melting the materials and slag formation, the metal was deoxidized with silicon and briquettes were introduced. The effect of the steel processing with converter vanadium slag was achieved due to the mechanical mixing of the metal in the furnace.

The temperature of the experiments was controlled by a tungsten-rhenium thermocouple BP5/20. The time of the experiment after stabilizing the temperature was 10 minutes. After the end of the process, the metal was poured into a mold and cooled in the air.

3. Results and discussion

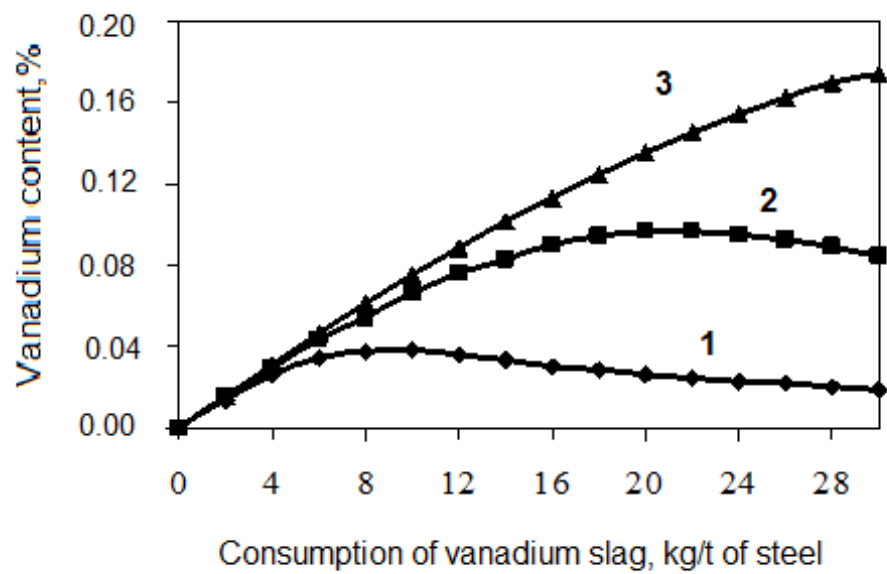
The obtained in the calculations dependences of vanadium content in the metal on the carbon content in the steel discharge and the consumption of the converter vanadium slag are shown in figure 1, and they have extrema. The calculation data showed that at a consumption of converter slag up to 8 kg/t of steel, the vanadium content in the metal is not less than 0.04% for both high carbon, medium and low carbon steels. For medium-carbon steel, it is possible to obtain a content of vanadium in the metal not more than 0.09% at a consumption of converter vanadium slag up to 20 kg/t of steel.

The completed thermodynamic calculations made it possible to determine the theoretical coefficient of vanadium extraction from the converter vanadium slag during the steel tapping and formation of ladle slag (figure 2).

From the results obtained, it follows that at the tapping time the coefficient of vanadium extraction is 0.5 with the consumption of converter vanadium slag 10 kg/t of steel, which makes it possible to obtain the vanadium content in the steel 0.04% (figure 2). For medium- and high-carbon steel with this slag consumption, the extraction coefficient is more than 0.9.

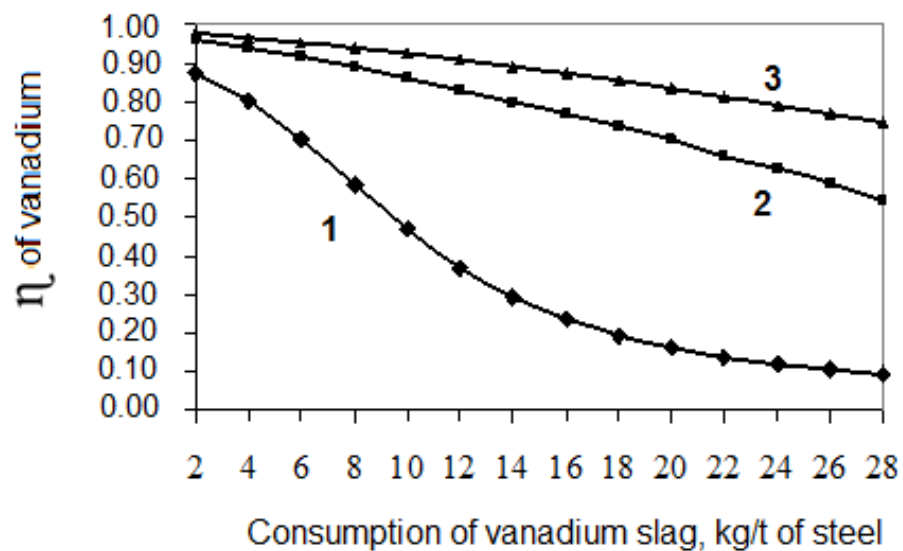
To evaluate the final result of the out-of-furnace treatment of steel, a thermodynamic simulation of the of vanadium reduction process from converter vanadium slag taking into account the introduced reducing agents (coke carbon and silicon ferrosilicon) was performed.

The calculations were carried out for the following additional conditions: medium-carbon steel, coke consumption – from 0 to 2 kg/t of steel, the consumption of vanadium slag from 4 to 16 kg/t of steel, the amount of furnace slag – 10 kg/t of steel. The results showed that in the indicated range of slag consumption with a coke consumption more than 0.6 kg/t of steel, the vanadium content in the metal does not change (figure 3) and the vanadium extraction coefficient exceeds 0.9 (figure 4) at any slag consumption.



1 – 0.1 % [C], 2 – 0.3 % [C], 3 – 0.7 % [C]

Figure 1. Dependence of the vanadium content in steel on the carbon content of in metal and the consumption of converter vanadium slag.



1 – 0.1 % [C], 2 – 0.3 % [C], 3 – 0.7 % [C]

Figure 2. Dependence of vanadium extraction coefficient on steel carbon and the amount of converter vanadium slag.

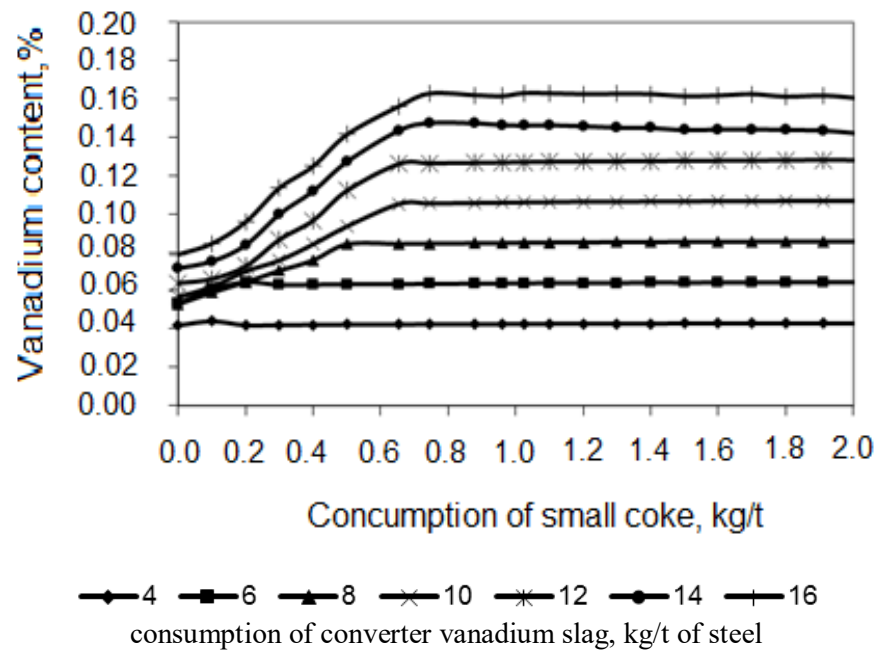


Figure 3. Dependence of the content of vanadium in steel on the costs of coke and converter vanadium slag.

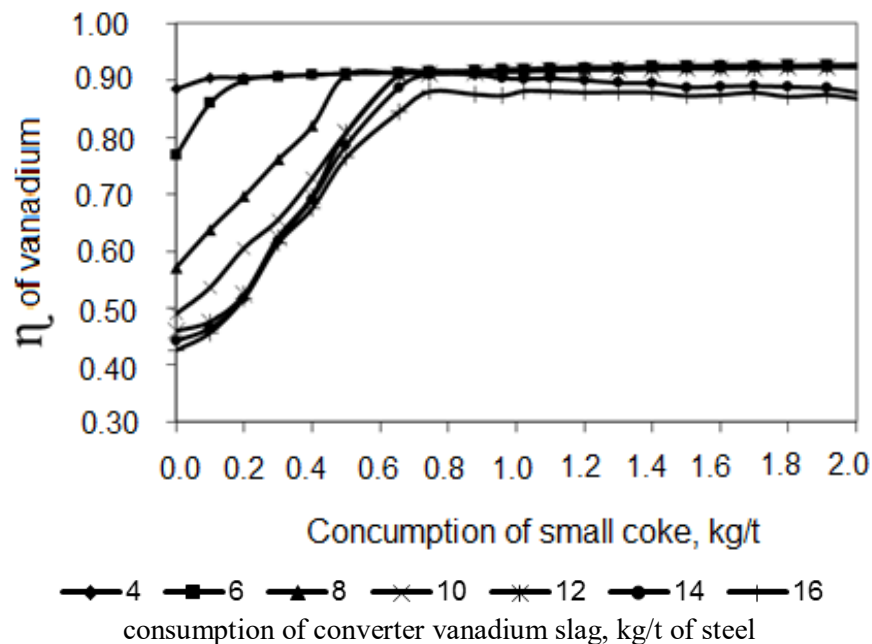


Figure 4. Dependence of vanadium extraction coefficient on coke consumption and converter vanadium slag.

The performed calculations also indicate that:

- vanadium oxides disappear at coke consumption from 0.5 to 0.6 kg/t of steel in the range of variation of the consumption of converter vanadium slag from 4 to 12 kg/t;
- the carbon content in the steel, depending on the consumption of coke, varies from 0.01 to 0.80% irrespective of the consumption of converter vanadium slag;

- manganese is reduced completely, its concentration in the metal increases in proportion to the consumption of slag;
- titanium is present in the metal insignificantly in the form of titanium carbides at high coke consumption and in the slag as CaTiO_3 ;
- slag is represented by oxides of calcium, magnesium, aluminum and silicon.

The metal, obtained after experiments, was subjected to spectral analysis, the results of which are given in table 2.

Table 2. Results of spectral analysis of the obtained metal.

No.	Mass fraction of the element, %								
	<i>C</i>	<i>Ni</i>	<i>Mn</i>	<i>Ti</i>	<i>Mo</i>	<i>Si</i>	<i>W</i>	<i>V</i>	<i>Al</i>
1	0.412	0.098	0.456	not det.	0.014	0.353	0.004	0.126	0.002
2	0.166	0.072	0.461	0.054	0.013	1.051	0.004	0.108	0.002
3	0.309	0.094	0.515	0.06	0.015	1.938	0.006	0.1	0.002
4	0.254	0.078	0.388	not det.	0.013	0.333	0.005	0.114	0.001
5	0.337	0.086	0.424	not det.	0.013	0.332	0.004	0.111	0.002
6	0.242	0.092	0.421	not det.	0.014	0.508	0.005	0.118	0.002

The error of the analysis results in accordance with GOST (State Standards) 18895 – 97, %

± 0.003

± 0.012

± 0.008

± 0.015

± 0.008

The analysis of the resulting metal showed a stable content of manganese and vanadium in the samples. Titanium was present only in two samples: when using silicon as a reducing agent (sample 2) and with a low consumption of lime (sample 3). Samples 2 and 3 also showed an increased silicon content in the metal, which is associated with a higher consumption of silicon in the charge materials.

According to the analysis, vanadium extraction coefficients η_V were determined taking into account the vanadium content in the base metal. The calculation results of the ratios are given in table 3.

Table 3. Ratio values of η_V .

No.	Briquette mass, g	Metal mass, g	Vanadium mass in the base metal, g	Vanadium mass in the briquette, g	Vanadium mass in the metal, g	η_V
1	25	1840	0.37	1.91	2.32	0.99
2	25	1695	0.34	1.91	1.83	0.96
3	15	1650	0.33	1.14	1.65	0.99
4	20	1675	0.34	1.51	1.91	0.99
5	25	1945	0.39	1.81	2.15	0.98
6	25	1845	0.37	1.91	2.17	0.95

4. Conclusion

The results of thermodynamic modeling show the possibility of steel microalloying by vanadium using converter vanadium slag in the ladle with coke and ferrosilicon.

The experimental studies on the laboratory arc furnace confirmed the results of thermodynamic modeling and showed the possibility of steel processing with converter vanadium slag using carbon and silicon as reducing agents.

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