The development and introduction of resource saving technology of non-standard manganese ferroalloy fines recycling

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ABSTRACT

The particle composition and thermophysical properties of manganese ferroalloys fractionation screenings have been presented. The existing technology of non-standard fines recycling in the high-power electric furnaces and advanced operation schedules at PJSC Nikopol Ferroalloy Plant has been analyzed. It has been proposed to re-melt screenings in the ore-smelting furnace of type RKZ-22.5. The industrial tests have been carried out; efficient composition of charging materials has been determined and resource saving technology of non-standard fines recycling has been developed. The electrical parameters of screenings re-melting process have been analyzed. The technical-and-economic parameters of the process have been presented. The developed technology has been introduced in the industrial scale.

1. INTRODUCTION

The issues of competitiveness improvement of the manufactured products are of primary concern when enhancing the manganese ferroalloys melting technology at PJSC Nikopol Ferroalloy Plant. The world market imposes strict requirements for chemical and particle compositions of ferroalloys. The manganese ferroalloys sold by the plant are shipped strictly to the grain size category established by the order; however, the elements composition in the ferroalloys complies with requirements outlined in the international standards.

The portion of fractionated metal in the ferroalloys shipped by the plant has been increased to 90% in recent years. During the ferroalloys fractioning process a lot of screenings (non-standard fines), which are generally represented by 0-10 mm fraction, are generated. The yield of non-standard fines during ferrosilicon manganese fractionation is within the range of 10-18%, of high-carbon ferromanganese is within the range of 12-20%. Currently, the issue concerning development of efficient technology of ferroalloys fractionation screenings recycling is of great importance, the solution of which will make it possible to increase significantly technical-and-economic parameters of the process and introduce resource-saving operation schedule of multipurpose use of mineral raw materials [1].

2. EXPERIMENT

The screenings of manganese ferroalloys fractionation represent fine material containing both metallic phase (in terms of its chemical composition it complies with metal being fractionated) and great number (4-10%) of non-metallic inclusions represented by particles of dump slag and lime (ingot mold dressing). The particle composition and thermophysical properties of non-standard ferroalloys fines are represented in Tables 2.1 and 2.2 respectively.

Table 2.1 Particle composition of ferroalloys screenings, % wt

No.	Alloy	Fraction, mm					
1		5-10	2.8-5	1.6-2.8	0.63-1.6	0.25-0.63	0-9.25
2	MnS17	16-20	20-24	7-11	18-23	14-18	15-19
3	FMn78	20-24	18-22	9-13	16-21	12-16	13-17

The data, as shown in Table 2.1, demonstrate that main part of non-standard manganese ferroalloys fines is represented by fine fractions with dimensions of less than 2.8 mm; however, the portion of fine dust particles in screenings (fraction of < 0.63 mm) is about 33 and 29% respectively.

Table 2.2 Thermophysical properties of ferroalloys screenings

No.	Properties	MnS17	FMn78
1	Melting temperature, K	1380-1580	1480-1600
2	Thermal capacity, J/kg × K	720-780	750-800
3	Melting heat, kJ/kg	480-530	250-300
4	Thermal conductivity, W/m × K	17-21	25-28

In general, thermophysical properties of screenings and commercial metal are close enough; however, non-standard fines are characterized by low thermal conductivity [2].

Earlier on, the non-standard ferroalloys fines were recycled at the plant by melting of screenings being a part of charging materials in the high-power ore-smelting furnaces of type RPZ-63 and RKG-75. In such a case, the extraction of metallic phase from screenings did not exceed 65-70%; metal losses were 30-35%. The analysis of screenings distribution between melt products showed that fine and dust fractions of non-standard fines are almost completely lost with gas cleaning sludge and dump slag. Considering the volumes of screenings production (10-12 thousand tons/month), the metal losses were 3-4 thousand tons resulting in dramatic deterioration of technical-and-economic parameters of the production.

The analysis of known operational schedules of metal waste recovery at the foreign ferroalloy companies demonstrated that there had been no chances yet to achieve high level of metal extraction from screenings in the industrial scale. The laboratory and semi-industrial tests of technology of non-standard fines re-melting in the induction and direct current electric arc furnaces showed relatively high level of metallic phase transformation (up to 90%) in the alloy; however, the introduction of the above described technology requires significant capital expenditures, time for its follow on development and introduction.

The challenging issue of increase in the level of metallic phase recovery from non-standard fines was solved by the plant specialists through the development and introduction of technology dedicated to the screenings re-melting in the existing electric furnace of type RKZ-22.5. Previously, the high-carbon ferromanganese was melted in the furnace using flux-free method, and then it was reconstructed to produce ferrosilicon and high-silicon ferrosilicon manganese. During the reconstruction, the furnace bath diameter and depth were reduced (which allowed increasing significantly the specific power density) and electrical isolation of furnace roof water-cooled elements, as well as charge charging system were improved.

The geometrical parameters of the revamped electric furnace RKZ-22.5 are as follows:

- bath diameter, mm: 7210;
- bath depth, mm: 3000;
- electrode diameter, mm: 1200;
- electrode pitch circle diameter, mm: 3100.

The charging materials are conventionally fed into the furnace by the charging pipes in the central part, under electrodes and by the bath periphery.

The furnace is equipped with three single-phase transformers of type EOTsN 8200/10 (low voltage side is 137-204 V, current strength is 79.6-64.9 kA, 17 voltage levels).

The crushed stone of ferrosilicon manganese dump slag and slag-and-metallic waste of alloy in the ratio of 0.05 and 0.12 is added to the screenings weighted portion in order to increase the electrical resistance in the furnace bath and provide for satisfactory electric mode of technological process.

As a result of high electrical conductivity of metal screenings during the industrial tests in order to reduce the furnace top caking capacity, avoid short circuit in the charging system and provide for acceptable electric and gas conditions of the operation, it was concluded that it is necessary to ensure differential charging of the materials by the furnace zones with preferential supply of less conductive materials in the central part of the furnace bath.

3. RESULTS

During the researches, it was established that optimal value of electric power take-off between tapping is about 15-25 thousand kW/h. In case of complete melt tapping, the electrodes are fixed till the level of 100-200 mm, the resistance between them is at the level of 1.0-1.5 Mohm (if the electrodes are shortened, the resistance increases to 2-3 Mohm), the current strength is 45-55 kA, the furnace operates with the capacity of 10-12 MW and 12-16 voltage levels. After taking-off 10-15 thousand kW/h, the resistance under electrodes gradually begins to decline, the current strength grows, and the electrode seating is increased. Before tapping (electric power take-off is about 20 thousand kW/h), the technological conditions begin to deteriorate – the resistance under electrode is reduced to 0.6-0.9 Mohm, the current strength is increased to 60-75 kA, and the capacity is reduced to 7-9 MW.

The tapping lasts within 20-30 minutes. The melt weight is 25-35 t of metal and 7-15 t of slag. The chemical composition of metal in terms of manganese and phosphorus composition complies with their composition in metallic phase of screenings; the concentration of silicon in the alloy is within the stable range of 16-17%. The dump slag contains 9-15% of Mn, 50-52% of SiO_2, 16-19.5% of CaO, 5-6% of MgO, and 7-8% of Al_2O_3.

During the technology commercial development, it was found that screenings re-melting process is characterized by relatively low melting temperature of the melt products tapping caused by its reduction in the furnace reaction zone. The melt temperature during tapping is reduced to 1550-1800 K (in case of ferrosilicon manganese melting in the ore-smelting furnace, it is at the level of 1800-1900 K). However, when the furnace is transferred to the screenings re-melting, the melt temperature is very high within the first 8-12 hours and achieves 1750-1800 K; during further operation, it is gradually reduced and on 2-3 day of screenings re-melting does not exceed 1550-1600 K, which results in the increase of metal losses during casting as waste and scull in the ladles. The reduction in the process temperature in the furnace reaction zone is also leads to the disruption of the melt electrical mode. In order to minimize the metal losses, the developed technology provides for gradual re-melting of screenings over a month – implementation of the screenings re-melting process within 2-3 days (optimal number of the utilized screenings is 800-1000 t), the furnace transfer to the ore-smelting melting with the duration of 4-5 days, further furnace transfer to the fractionation screenings re-melting. Furthermore, in order to reduce the quantity of generated waste the alloy is to be cast without metal holding in the ladles.

4. DISCUSSIONS

When developing the technology, the electrical operation mode of the furnace as compared to the technology of ferrosilicon manganese melting using ore charge was analyzed in details. The automated process electrical mode control system (APEMCS) providing for melting electrical parameters monitoring was equipped at the furnace RKZ-22.5. The furnace electrical mode control was based on the determination method of electrical parameters of equivalent circuit of near-electrode space of wavepacket propagation using the results of the current (i_{EL}) and voltage (u_{EL}) instantaneous values measurement. The electric arc available in the near-electrode zone defines the non-linear character of equivalent resistance ($r_{EQ}(t)$). The nonlinearity degree depends on the furnace operation conditions. The APEMCS mathematic model, as detailed in the papers [3-5], is based on the measurement of current and voltage instantaneous values and their conversion using Fourier transformations as follows:

$$i_{EL}(t) = I_{m1}\sin(\acute{\omega}t + \varphi_1) + \ldots + I_{mn}\sin(\acute{\omega}t + \varphi_1) \qquad (4.1)$$

$$u_{EL}(t) = U_{m1}\sin(\acute{\omega}t + \varphi_{u1}) + \ldots + U_{mn}\sin(\acute{\omega}t_n + \varphi_{un}) \qquad (4.2)$$

and presence of linear resistance of the melt, shunt and non-linear resistance of the arc, averaged for the current changes period. The above mentioned algorithm allows evaluating the energy distribution in the furnace reaction zone on a real-time basis (Fig. 4.1 and 4.2).

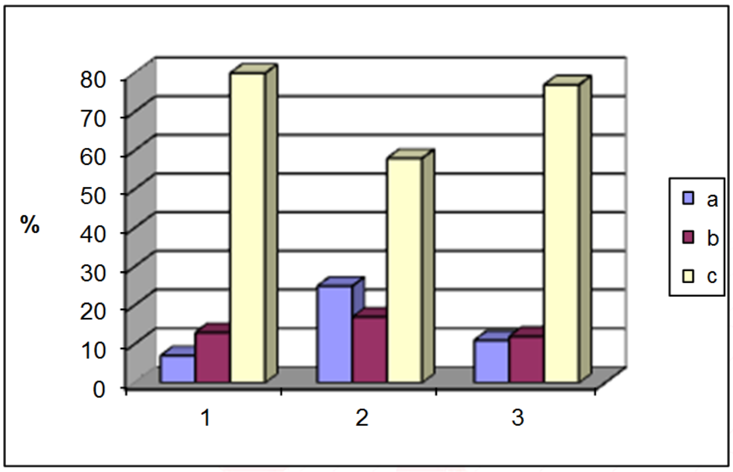

Figure 4.1: Active power distribution: 1 – before tapping, 2 – after tapping, 3 – during melting of при ferrosilicon manganese using ore charge. Diagram legend: a – credit of power generated in the arc, b – shunt power, c – power generated in the melt.

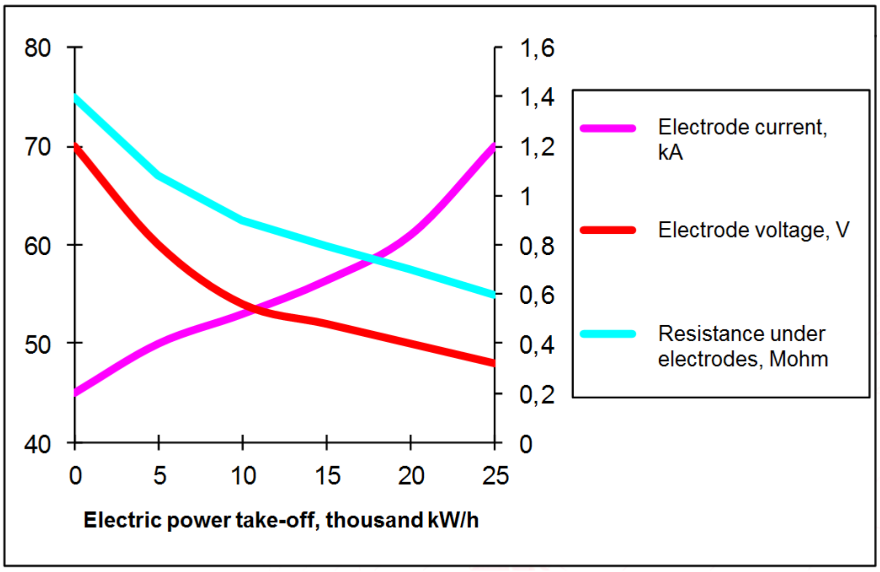

Figure 4.2: Variation of electric parameters during melting

After the melt tapping, a lot of charge characterized by low electric resistance enters the reaction zone; however, the credits of power generated in the voltage arc and shunt are sharply increased. The value of active resistance under electrodes is increased, whereas the current strength is reduced. The electrode voltage is increased to keep the installed power. As far as the electric power is taken off and the charge is melted, the melt begins to be collected in the reaction zone, the charge descent speed is reduced, the resistance under electrodes is decreased and the current strength grows gradually. Before tapping, the power generated in the arc and shunt is decreased, the electrical parameters of the process more or less comply with electrical mode of alloy melting using ore charge.

The material balance of the screenings re-melting and achieved technical-and-economic parameters of ferrosilicon manganese production at the furnace RKZ-22.5 according to the developed technology are represented in Tables 4.1 and 4.2 respectively.

Table 4.1 Material balance of screenings re-melting process (data as of September 2014)

No.	**Charged**			**Produced**		
1	Charge designation	t	%	Melt products designation	t	%
2	screenings	4357.8	86.2	metal	3703.5	73.31
3	crushed stone	185.6	3.7	slag	511.3	10.1
4	slag-and-metallic waste (in mixture, by type of generation)	510.4	10.1	slag-and-metallic waste during tapping	472.6	9.35
5	Total	5053.8	100.0	slag-and-metallic waste in the ladles	150.1	2.97
6				slag-and-metallic waste during casting	101.2	2.0
7				escape and other losses (in terms of difference)	115.1	2.27
8				Total	5053.8	100.0

The data, as shown in Table 4.1, demonstrate that metal is the main melting product (73.31%); 10.1% of the charged material weight accounts for the portion of dump slag. During the re-melting, slag-and-metallic waste of different types is generated in large quantities (in total 14.32%).

Table 4.2 Technical-and-economic parameters of non-standard ferrosilicon manganese fines re-melting according to the mastered technology

No.	Parameter designation	Value
1	Specific consumption, kg/t:	
2	- of screenings	1176.7
3	- of crushed stone	50.1
4	- of slag-and-metallic waste	137.8
5	Metal extraction from screenings during re-melting, %	85.0
6	Extraction of metallic phase from screenings,%	89.5
7	Slag ratio	0.14
8	Specific power consumption, kWh/t of alloy	767
9	Specific power consumption, kWh/t of charge	554

As can be seen from the obtained results on the developed technology shown in Table 4.2, the metal yield during screenings re-melting is 85%, however, the extraction of metallic phase from screenings is 89.5% (if the fractionation screenings contain 5% of non-metallic inclusions), the specific power consumption is 767 kWh/t of the produced alloy and 554 kWh/t of the re-melted charge.

The industrial researches made it possible to develop and introduce in the industrial scale the technology of non-standard manganese ferroalloy fines recycling by means of their re-melting in the ore-smelting furnace of type RKZ-22.5 with relatively high technical-and-economic parameters.

SUMMARY

The technology of ferroalloys screenings re-melting in the ore-smelting furnace of type RKZ-22.5 has been developed. During the industrial researches, the optimal technological and electrical conditions of the screenings re-melting process have been determined. The electrical parameters of the technological process have been investigated. The required charge materials and their reasonable ratio in the charge, which enable to achieve the metal yield during the non-standard fines re-melting at the level of 85% and specific power consumption of 767 kWh/t of produced metal, have been established. The developed technology has been introduced in the industrial scale at PJSC Nikopol Ferroalloy Plant.

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