

Structural Investigations of Dump Ferromanganese Silicon Slag and their Recycling Possibilities to Raise Throughout Recovery of Manganese and Silicon

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The microstructure of dump ferromanganese silicon slag is investigated by EMPA method. The slag is silica - enriched. The microstructure is represented by bustamite $(\text{Mn, Ca})_3[\text{Si}_3\text{O}_9]$ and probably johannsenite $\text{Ca, Mn}[\text{Si}_2\text{O}_6]$ as well as $\alpha\text{-MnS}$ alabandine precipitations and alloy prills; intergranular compounds contain Al_2O_3 , SiO_2 , Na_2O и K_2O . The results of laboratory and experimental-industrial tests of slag-coal pellet production and standard ferrosilicomanganese smelting are analyzed.

Keywords: FERROMANGANESE SILICON, DUMP SLAG, MICROSTRUCTURE, RESEARCH METHODS, QUARTZ, BUSTAMITE, JOHANNSENITE, ISOMORPHISM, SLAG-COAL PELLETS, ARC-FURNACE MELTING

Introduction

Furnace slag chemical composition and technological characteristics

According to DSTU (State Standard in Ukraine) 3548-97 (GOST 4755-80) ferromanganese silicon can be produced of four grades MnC12 (10-15 % Si), MnC17 (15-20 % Si), MnC22 (20-25 % Si) and MnC25 (from 25 to 35 % Si). MnC17 alloy production is the largest production. The electric furnace capacities of three ferroalloy plants of Ukraine (Nikopol Ferroalloy Plant, Zaporizhzhya Ferroalloy Plant and Stakhanov Ferroalloy Plant) exceed ferromanganese silicon production in terms of MnC17 alloy in more than 1 million tons per year. If slag multiplication factor is 1.2-1.4, then approximately 100 thousand tons of manganese is lost (in terms of metal) each year.

Ferromanganese silicon is smelted in high-powered ore-reducing closed electric arc furnaces of 63 MB·A unit size with rectangular baths and furnaces of 75 MB·A unit size with round baths [1, 2]. The original charge materials for ferromanganese silicon production are manganese sinter, quartzite and coke fines.

Ferromanganese silicon smelting is performed

by continuous charge loading process with repeating tapping of alloy and slag through the same notch. Ferromanganese silicon is tapped in the installed lined ladle; slag is repoured into non-lined steel bowls. There is always slag in the ladle with alloy. During ferromanganese silicon pouring slag is thickened by sand for excluding the possibility of its transfer into alloy ingots.

In general, both ferromanganese silicon and other ferroalloys are produced in Ukraine for export, while the amount of slag gradually increases. The average chemical composition of slag (%mass.) is presented in **Table 1**. The presence of elements in the slag is established by spectrographic analysis (in terms of metal, % wt.) **Table 2**.

It follows from shown data that the properties of dump slag according to basic oxide content can be examined based on analysis of system MnO-CaO-SiO_2 , though oxides of Al, O, Na_2O , K_2O , BaO and sulphides can considerably affect viscosity and electric conductivity.

Both electric conductivity and viscosity are one of the most important technological metallurgical properties of ferromanganese silicon furnace slag. Electric conductivity σ and dynamic viscosity η of ore-reducing process slags are

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usually connected by the following correlation:

$$\eta \cdot \sigma = \alpha T^2, \quad (\text{Eq. 1})$$

where α - constant depending on slag metallurgical nature. In our works we determined that $\eta \cdot \sigma$ product dependence on temperature as applied to manganese ferroalloy slag should be represented by the following formula [1]:

$$\eta \cdot \sigma = (\alpha + \beta T) T^2 \quad (\text{Eq. 2})$$

The dependence $\eta \cdot \sigma$ for pattern slag with ferromanganese silicon composition, %: 10-20 MnO; 30-50 SiO₂; 10-25 CaO; 1-2 MgO; 25-26 Al₂O₃ is as follows:

$$\eta \cdot \sigma = (4.98 - 0.0024T) \cdot 10^{-5} T^2 \quad (1573-1923 \text{ K}) \quad (\text{Eq. 3})$$

The best technical and economic indices of ferromanganese silicon smelting are reached under certain rational values of viscosity and electric conductivity parameters. As far as $\eta \cdot \sigma$ products are constant, then under constant temperature the increase of viscosity reduces electric conductivity, and vice versa.

To achieve higher furnace facility $\cos \varphi$ coefficient values it is necessary to carry out reduction smelting on the highest possible stress with electrode tip sunk into burden stock. This mode is possible under high charge electrical resistance, molten slag, i.e. low electric conductivity. Due to high slag viscosity, gravitation impaction of reduced manganese and silicon particles through slag layer to metal layer on the furnace bottom becomes more complicated. When tapping, liquid alloy fractions can be captured by slag.

Table 1. The average chemical composition of slag (% mass.)

MnO	SiO ₂	CaO	MgO	Al ₂ O ₃	P
15.80	47.40	19.60	5.83	6.98	0.004

Table 2. The presence of elements in the slag (in terms of metal, % wt.)

K	Na	Ba	Ti	Zr	Cr	S
1.70	6.5	0.8	0.1	0.01	0.02	1.10

Many year's experience of ferromanganese silicon industrial smelting and data analysis of experimental investigation under industrial conditions on the different unit size furnaces enabled to define and state the important rule for continuous manganese ferroalloy smelting processes: the rate of reduction processes of metal phase formation (ferromanganese silicon, carbon ferromanganese) should correspond with the rate of oxide compound (manganese sinter, ore quartzite) melting. If the rate of charge components melting is higher than manganese-silicon reduction rate, the molten alloy with insufficiently reduced manganese and silicon is accumulated in the furnace.

Charge composition consisting of manganese sinter (rather fusible component) and quartz (melting point 1700 °C) provides rather stable electrical regime in relation to specific power consumption indices as well as manganese and silicon recovery in ferromanganese silicon. However, in such a case 15 % of manganese in the oxide form and in form of alloy prills is lost with the slag.

Numerous industrial experiments focused on recycling dump slag containing ~ 50 % SiO₂, 15-

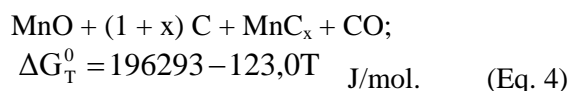
18 % MnO did not succeed. The reason of unsuccessful experiments results was scientifically baseless approach to solution of the important problem, i.e. dump slag recycling oriented on manganese and silicon recovery increase in the ferromanganese silicon end-to-end production.

Thus, fusibility and high electric conductivity of dump slag are the factors which do not favour the dump slag recycling without its special preparation with reducing agent as compared to conventional charge of heterostructural composition (manganese quartzite, quartzite and coke fines).

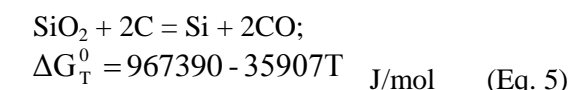
Research works and experimental-industrial tests on ferromanganese silicon melting using bricks consisting of manganese concentrate and carbonaceous reducing agent are carried out in the retrospection. Sulphide distillery stillage is used as binding agent. Herein, the developers of brick composition proceeded from the possibility of using low quality manganese concentrate (i.e. with great amount of silica).

Industrial tests of burdened bricks showed that the stable electric mode of furnace operation was not achieved because of fusible manganese silicates appearance in the brick structure and their

decomposition into components of low electric resistance. Shown regulations correlate with data of MnO-SiO₂ system fusibility diagram analysis. As follows from **Figure 1**, the melting temperatures of MnO and SiO₂ are 1850 and 1720 °C, respectively. While SiO₂ content in silicate compositions of this system increases, the liquidus temperature reduces essentially and reaches 1345 °C (first eutectic), and then 1250 °C (second eutectic). Theoretic temperature of the beginning of manganese oxide reduction is 1597 K (1324 °C). [4]



The temperature of SiO₂ reduction by carbon according to the reaction



is 1942 K (1669 °C).

Reducible silicon is dissolved in manganese followed by silicon α_{Si} activity lowering in manganese and vice versa under conditions of ferromanganese silicon smelting. Generally, this has a positive effect on temperature drop of ferromanganese silicon production process.

Nonslag process of ferromanganese silicon production similar to ferrosilicon smelting is the most favourable process in view of thermochemistry and thermokinetics. However, carbonaceous manganese (metal component of the charge) should be smelted first for this process. On the next stage the charge should consist of carbonaceous manganese, quartzite and fine coke. However because of low cost-performance indices, this nonslag process of silicomanganese production was successively substituted by more profit-proved one-stage slag method.

Thus, the brief analysis of the main thermochemistry indicators and thermokinetic features of manganese and silicon reduction during ferromanganese silicon smelting brought in this work shows that additional recovery of manganese and silicon from the dump slag can be accomplished by carbon-reducing process. However, the complicated problem is the increase of infusibility and electric resistance of charge containing ferromanganese silicon dump slag as well as creation of the most applicable thermal-kinetic conditions for total reduction process behaviour of ferromanganese silicon production. Technical-and-economic indices of new technological process with account of specific charge of material and electric power by actual market price can be the criteria of industrial applicability of dump slag recycling process.

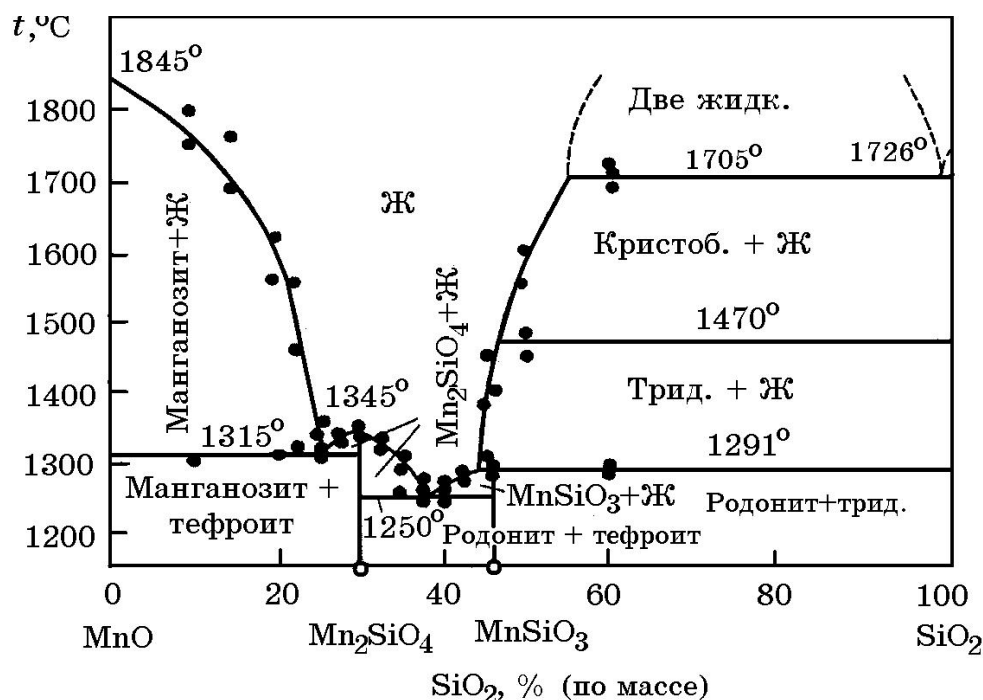


Figure 1. Equilibrium diagram in system MnO-SiO₂

Results and Discussion

Electron diffraction analysis and EMPA of ferromanganese silicon dump slag microstructure

Slag microstructure is examined on 40 mm fraction samples which did not revealed their “magnetic” properties during the extraction of ferromanganese silicon on dump slag separation unit at JSC “Nikopol Ferroalloy Plant” [5]. The experiments are held using electron-scan microscope JSM 6360 LA by Japanese Company “JEOL” equipped by electron microprobe analysis accomplishing (EMPA) system with automated calculation of chemical composition data of each investigated polished section by radiation intensity treatment of individual element with delivery of data about chemical composition in atomic fraction in elements and oxide content in mass %.

Slag microstructure is illustrated in **Figure 2** at amplification x3500. The polished section was prepared by slag sample polishing. It follows from

Figure 2 that the microstructure of polished section area is represented by elongated mineral compounds with unknown mineral compounds along their borders. White roundish and blob-like precipitations represent separate compounds. The chemical composition of these compounds is also an object of investigation using EMPA. The results of “gross” chemical composition of the marked area of polished section are presented in **Table 3** (in atomic %) and in terms of oxide content (in mass fractions, %) **Table 4**.

Shown chemical composition is received by radiation intensity spectrogram processing system of all elements which concentration in the analyzed area exceeded EMP detection limits (**Figure 3**).

The investigation of polished section in colour mapping mode of each element (**Figure 4**) helped find out that white blob-like precipitations represent manganese sulphide MnS (63 % Mn, 37 % S).

Table 3. Chemical composition of the marked area of polished section (in atomic %)

O	Na	Mg	Al	Si	S	K	Ca	Mn	Σ
20.72	1.26	3.99	4.22	26.80	1.77	3.97	15.28	22.0	100

Table 4. Chemical composition of the marked area in terms of oxide content (in mass fractions, %)

Na ₂ O	MgO	Al ₂ O	SiO ₂	SO ₃	K ₂ O	CaO	MnO	BaO
0.86	5.85	5.83	43.68	1.99	3.58	16.72	19.73	1.80



x3500

Figure 2. Microstructure of polished section rectangular area of ferromanganese silicon dump slag; blob-like white phase is manganese sulphide α -MnS

Polished section microstructure took in reflected secondary electrons is shown in **Figure 5**, upper left side. Eutectic buildups are represented by boundary intergranular precipitations. Comparing the data of each element colour scanning (**Figure 5**) we can draw a conclusion that these precipitations are represented predominately by oxides of Na, K, Al and Si. On the map of each element there is put the radiation intensity line of certain element during scanning of the same polished section area. Intensity peaks of Na, K, Al and Si correspond to eutectic phase formation when there is almost no Mg, Mn, Ca. The intensity line of silicon radiation is represented in narrow intensity borders because of high SiO_2 concentration, and that is why peak values of its distribution between main mineral phases and eutectic buildups are observed obscurely.

Element distribution between basic mineral buildups of complex composition manganese silicates ($\text{SiO}_2\text{-MnO-CaO}$) and eutectic buildups of system $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-K}_2\text{O-Na}_2\text{O}$ have been determined in this work for the first time and need scientific interpretation.

The necessity to explain established features of basic mineral and intergranular buildup formation is caused by incorrect identification of structural compounds in ferromanganese silicon dump slag in

retrospective investigations. According to data of ferromanganese silicon dump slag EMPA it is accepted that the microstructure is represented by two absolutely different phases: one is silicon-based including manganese and calcium oxides, and the second phase is mixed with high aluminium oxide content including silicon and calcium oxides. It is noted that structural component sizes in which Al_2O_3 serves as complexing compound are extremely small – about 2-6 μm , which makes interpretation by EMPA method almost impossible.

The works dealing with inclusion of aluminium impurity into silica mineral structure can be useful in the decoding the data about the formation composition without oxides, MnO and CaO, which were obtained in this work with the usage of scanning electron microscope JSM 6360LA.

V.P. Lyutov [7] notes that aluminium centres in silica lattice may be in different structural states, which makes the system of these defects sensitive to the conditions of mineral formation and transformation. With the use of electron spin resonance (ESR), the author [6] studied the content and structural state of impurity aluminium in natural varieties of silica (opal, pegmatite quartz etc.).

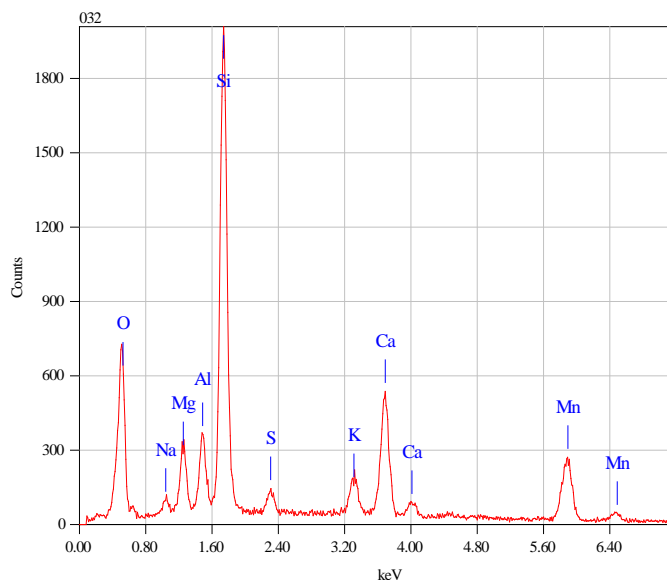
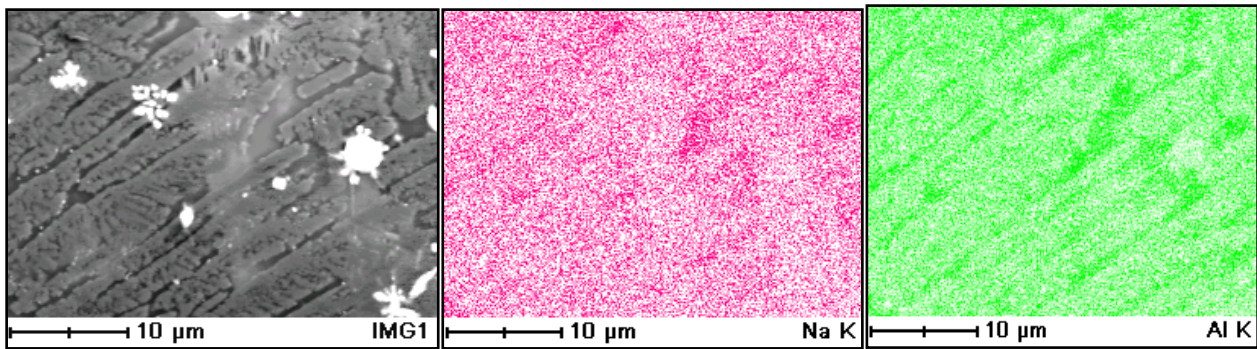


Figure 3. Spectrogram of polished section rectangular area of ferromanganese silicon dump slag with $\alpha\text{-MnS}$ manganese sulphide white phase



x 3500

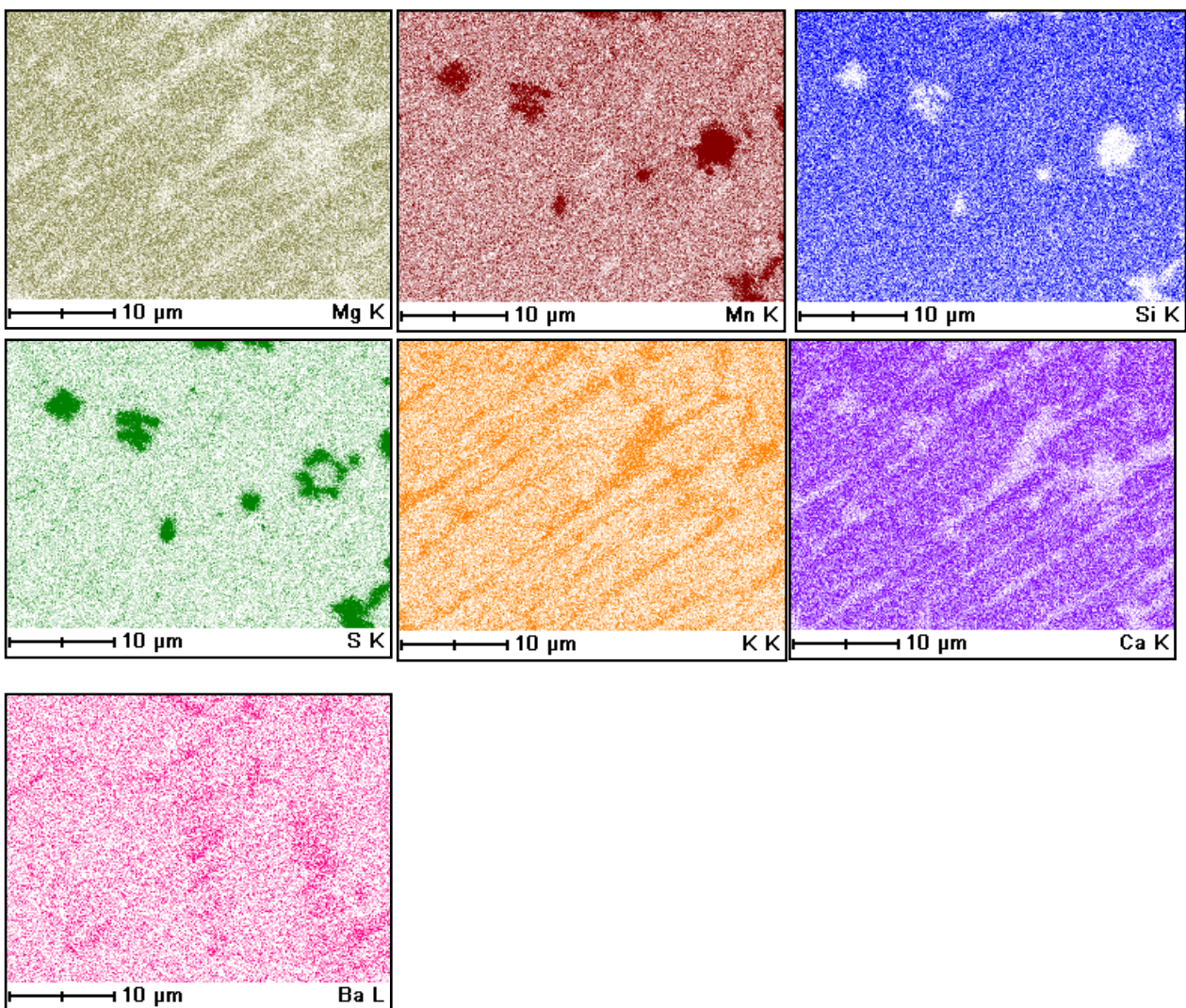
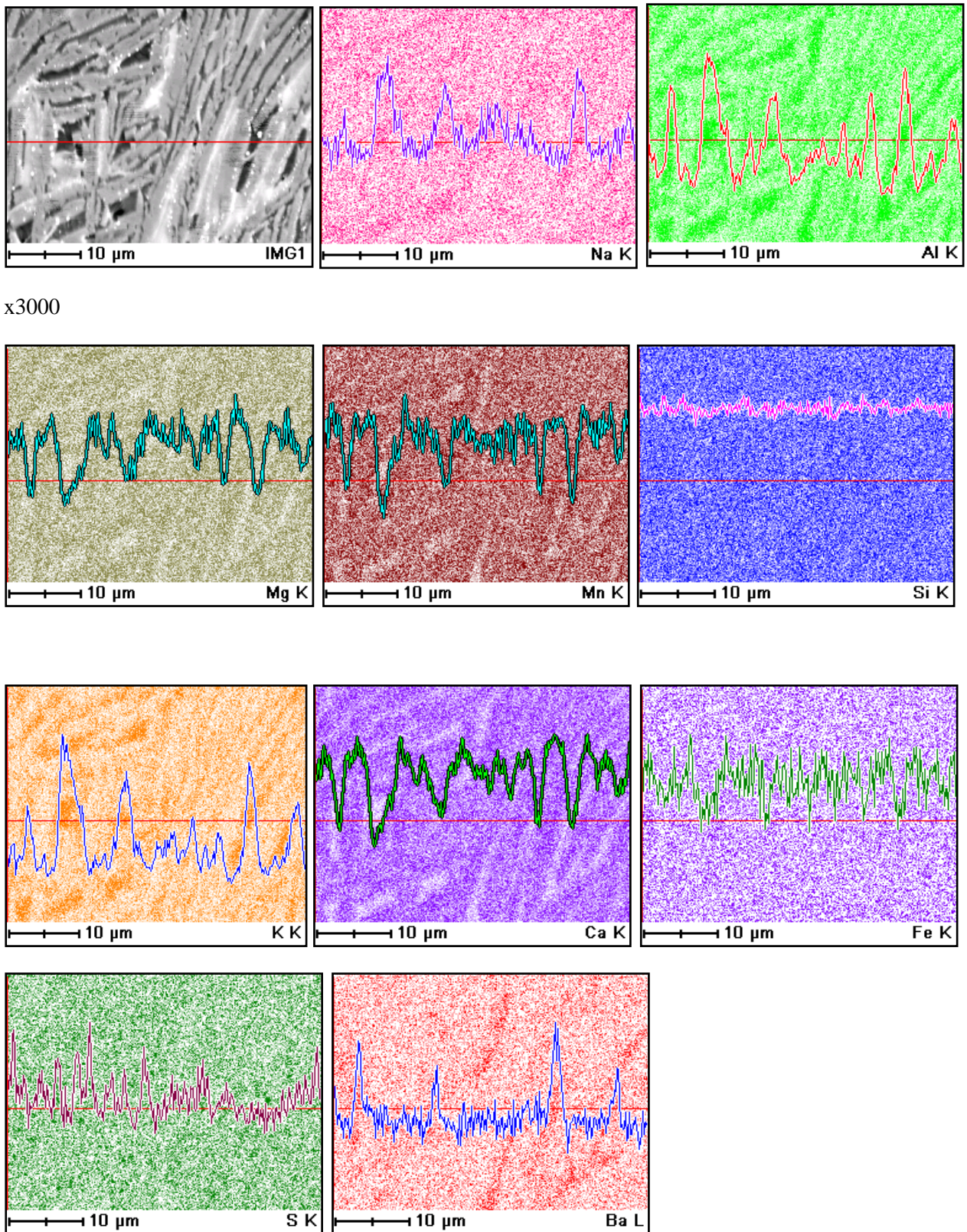


Figure 4. Microstructure of polished section rectangular area of ferromanganese silicon dump slag received by EMPA method in colour mapping mode; more intensive colouring corresponds to higher element content



x3000

Figure 5. Microstructure of polished section rectangular area of ferromanganese silicon dump slag, received by EMPA method in colour mapping mode with overlay of radiation spectra of each element on each map along the scanning line; microstructure obtained in secondary electrons – BEI – in the upper left side

It is found out that *heterovalent isomorphism* of $\text{Al}^{3+} \rightarrow \text{Si}^{4+}$ with compensation of excess negative charge by *alkali ion* ($[\text{AlO}_4\text{M}^+]^0$) or *proton* ($[\text{AlO}_4\text{H}^+]^0$) is implemented in the crystal lattice of quartz. Based on this, we can assume that fusible (eutectic) mineral buildups having heterovalent isomorphism $\text{Si}^{4+} \rightarrow \text{Al}^{3+}$ with compensation for the excess charge of Na^+ and K^+ ions crystallize in the intergranular layers.

From presented data about the "gross" chemical composition of polished section area, we can assume that 5.83 % Al_2O_3 , 0.86 % Na_2O , 3.58 % K_2O and some part of the total silica (43.68%) containing in the slag form fusible intergranular mineral buildup. Also, their electric conductivity is likely to increase while they are modifying into a liquid state. The term "eutectic buildups" accepted in this work for intergranular buildup characteristics may be conditional, since there is a group of natural minerals known as "feldspars", among which there is one potassium-enriched feldspar KAlSi_3O_8 (sadinite).

In this aspect a brief analysis of phase equilibria in the system $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-K}_2\text{O}$ [8] is of theoretical and technological interest. Among the triple combinations in this system there are known calcium aluminosilicates, such as $\text{K}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$ (kaliophilite), $\text{K}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 4\text{SiO}_2$ (leucite), $\text{K}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 6\text{SiO}_2$ (potassium feldspar (orthoclase)). In SiO_2 (tridymite) – $\text{K}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 6\text{SiO}_2$ system there is a eutectic ($t_{\text{eu}} = 990^\circ\text{C}$, 58 % SiO_2). Aluminosilicate $\text{K}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 6\text{SiO}_2$ has the following composition, %: 64.75 SiO_2 ; 18.35 Al_2O_3 ; 16.90 K_2O . Thus, the melting temperatures of intergranular formations depending on SiO_2 , Al_2O_3 content and alkaline metal oxides can differ essentially from the eutectic temperature – from 990 to 1800 °C for (kaliophilite). In the system $\text{Na}_2\text{O}\text{-Al}_2\text{O}_3\text{-SiO}_2$ the highest melting temperature of triple composition equals 1528 °C, the mutual effect of K_2O and Na_2O reduces melting temperatures of intergranular formations in quadruple system $\text{K}_2\text{O}\text{-Na}_2\text{O}\text{-Al}_2\text{O}_3\text{-SiO}_2$. According to the data, the ratio $\text{K}_2\text{O}:\text{Na}_2\text{O}$ in the intergranular formations equals 4.16 that is why the main effect on melting temperature is caused by K_2O .

In our work [9] we run a computer investigation of oxide phase thermodynamic stability under the heating of multicomponent alkaline-silicate phases of system $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-K}_2\text{O}\text{-Na}_2\text{O}\text{-B}_2\text{O}_3$ as ceramic binding agents in production

of abrasive instruments out of regular alumina.

The calculations of phase composition change are made for temperature range of 800-1250 °C. KAlSi_3O_8 , KAlSi_2O_6 and $\text{K}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 4\text{SiO}_2$ are ascertained to be the most stable mineral phases. The most stable sodium-containing phase under 1250 °C is only $\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$.

Thus, the revealed alkaline-silicate phases have complex composition and represent the object for further thorough investigation of their metallurgical nature. It is absolutely obvious that the beginning of dump slag melting during the heating is connected with low melting temperatures of exactly alkaline-silicate mineral formations.

The brief calculation of intergranular formations' mineral formula is given below for specifying the chemistry in aspect of SiO_2 content in them. Basing on "gross" chemistry, according to the EMPA data of polished section area MnO and CaO are included into bustamite content, which can be shown in the formula $(\text{Mn}_{1-x}\text{Ca}_x)\text{O}\cdot\text{SiO}_2$. The content of SiO_2 in bustamite and intergranular extractions equals 43.68 %. 18.34 g of SiO_2 is enough to bind MnO (19.73 %) and CaO (16.72 %), the rest quantity – 25.34 g moved into formation minerals with participation of Al_2O_3 (5.83 %), K_2O (3.58 %) and Na_2O (0.86%). The calculations show that intergranular formations have "gross" chemistry (% mass): 71.16 of SiO_2 , 16.37 of Al_2O_3 and 12.47 of K_2O (Na_2O).

The given chemical composition of intergranular formation is situated on the diagram of phase (melting) equilibria in the range of the isotherms 1300-1400 °C. The determination of presence of ferromanganese silicon inclusion prills in dump slag is of theoretical and practical interest. In contrast to the phase of $\alpha\text{-MnS}$, which is formed during the cooling, and then during the crystallization of molten slag, alloy prills represent alloy, caught in the slag as in the furnace bath, with the release of ferromanganese silicon and slag from the furnace through one tap hole, and at the "thickening" of fine coke by sand additives. **Figure 6** shows the microstructure of the slag polished section with the inclusion of spherically shaped alloy. Microstructure was obtained by EMPA method in colour scanning mode; the data showed in **Figure 6** confirm that the prill is represented by Mn, Fe and Si. At the same polished section area accumulation of spherical inclusions is revealed (**Figure 7**).

According to EMPA data, inclusion prills marked by frames on microstructure photo have

the following chemistry (**Table 5**) (% wt.). Thus, the shown data confirm, that the slag samples having overgone the reextraction of slagged alloy and non-sorted out into metal concentrate still contain different particles including ferromanganese silicon.

Laboratory and experimental-industrial mastering of recycling technology of dump slag ferromanganese silicon

In the retrospective investigations many industrial-experimental tests were held aimed on reduction of manganese and silicon losses with dump slag of ferromanganese silicon production. The investigators of State Enterprise «UkrNIIspestal» (Ukrainian Scientific-Research Institute of Special Steels, Alloys and Ferroalloys) suggested manganese postreduction by carbon, which was produced in separate furnace in liquid condition by periodic process. There was studied an opportunity of smelting silico-manganese ferroalloy using only slag-coal bricks. Among many variants of dump slag recycling the Department of Electrometallurgy of National Metallurgical Academy of Ukraine studied in their works mainly the technical plan and processes of obtaining thermally resistant slag-coal bricks and their additional charging in traditional charge for ferromanganese silicon smelting instead of manganese sinter part, quartzite and deficient coke. This easy-planned and extensive work was carried out under the general direction of JSC “Nikopol Ferroalloy Plant” and JSC “Zaporizhzhia Ferroalloy Plant”, with scientific leadership and active participation of the Department of Electrometallurgy of National Metallurgical

Academy of Ukraine.

The rational technological parameters of briquetting are defined in laboratory and semi-industrial conditions: the fractional composition of dump slag and coal is minus 2 mm, 8% of sulphite-spirit grains (density – 1.24 g/cm³) served as binding agents; compacting pressure was equal to 180-200kg/cm²; humidity of initial charge was 2 %, the quantity of coal in brick was 18-20%, the drying temperature of bricks was 130-140 °C, the mechanical durability of briquettes was 116-128 kg/cm². Bricks withstood thermal shock under 1600-1650 °C and did not destroy being immersed in the liquid slag and endurance in the melt under 1500-1550 °C.

The technology of bricking in experimental-industrial conditions is worked out basing on laboratory investigation data. The bricks obtained of the two parties had the chemistry shown in **Table 6** (% wt.).

Industrial heats of MnS17 ferromanganese silicon were carried out in the ferroalloy furnace PK3-23.

Charge burdens were constituted on the basis of ferromanganese silicon obtaining with increasing share of the quartzite replacement by slag-coal bricks and reduction of consumption of fine coal, A MH3 sinter and II grade Nikopol concentrate in the charge. The results of closed furnace operation for the best period (extraction of 70.4% of manganese, 35.6% silicon) were adopted as a basis variant for comparison with the experimental results. The 2-nd and the 3-rd variants with 50% replacement of quartzite and 4-th variant with 100% replacement of the quartzite were tested.

Table 5. Chemistry of inclusion prills

Frame	Mn	Si	Fe	P
020	76.15	13.65	9.93	0.27
021	78.01	12.91	8.75	0.32
022	77.66	13.20	9.15	absent

Table 6. Chemistry of bricks

Party	Mn	Fe ₂ O ₃	FeO	SiO ₂	Al ₂ O ₃	CaO	MgO	P ₂ O ₅	C _{TR}	C ₀₆	K ₂ O+ Na ₂ O
I	8.5	1.40	0.45	28.8	4.0	11.2	3.8	0.07	18.0	25	2.7
II	8.7	1.42	0.40	33.6	4.5	11.9	5.7	0.07	13.5	20	3.5

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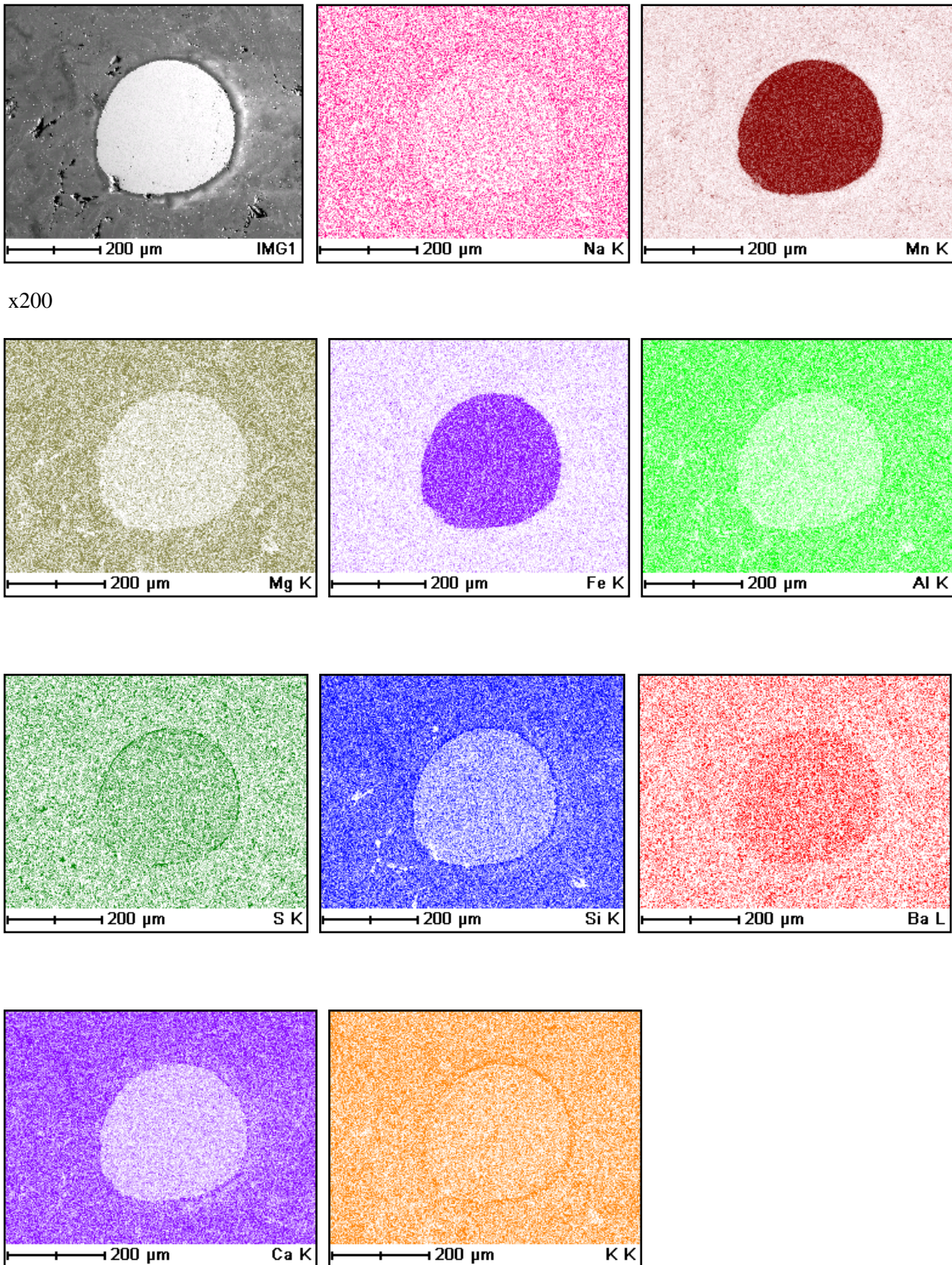
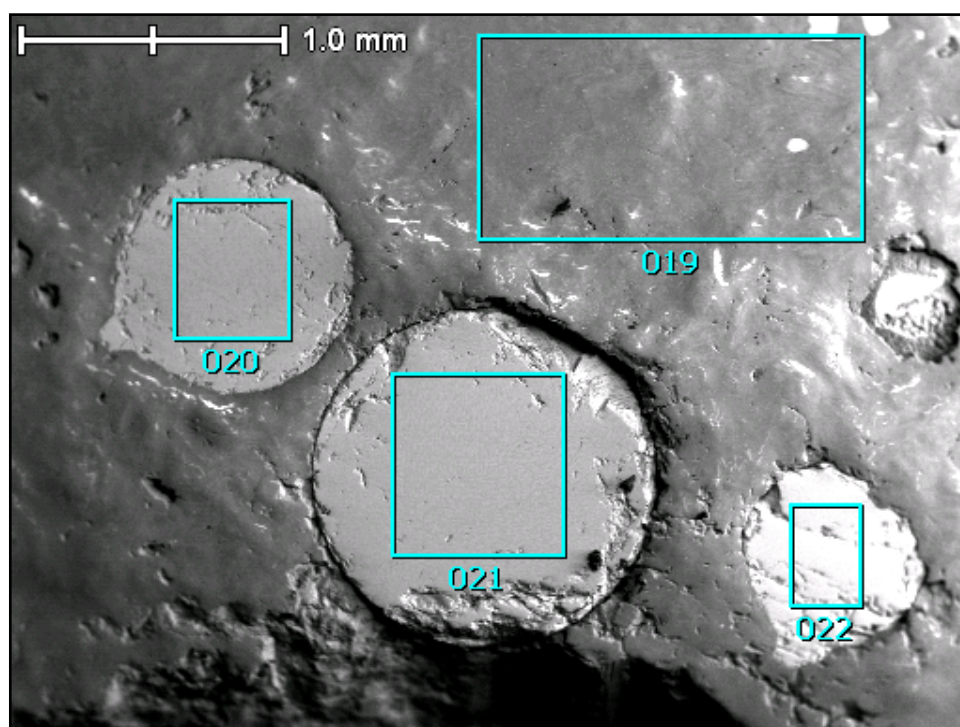


Figure 6. Microstructure of dump slag polished section area with ferromanganese silicon spherical prills inclusion with overlay of radiation intensity spectra for each element along the scanning line

It was established that in experiments of 2-nd and 3-rd variants the extraction of manganese increased by 4.8-8.6% and extraction of silicon increased by 5.2-1.2%. At the same time the multiplicity of slag decreased from 1.31 to 1.10-1.15, manganese content in the slag reduced from 18.4% to 13.3-12.9% and, in some slag it reduced to 10.7%. The average daily PK3-23 furnace productivity in actual time of the furnace operation presented 86.8-91.1 base tons (2-nd-4-th variants) and 90.9 base tons (1-st variant). The average daily PK3-23 furnace productivity in actual time of the

furnace operation presented 86.8-91.1 base tons (2-nd-4-th variants) and 90.9 base tons (1-st variant). There was noted the increase in the time of hot furnace outages at 6.2-8% and the increase in power consumption for the 250-300 kW·h of ferromanganese associated with it, reduction of productivity by 4-5%. However, the possibility of manganese ore mixture (sinter and concentrate) economy at 208-320 kg, the saving of quartzite at 161-292 kg and fine coke at 13-62 kg to 1 t of ferromanganese silicon was confirmed in a short period of experimental-industrial tests.



x35

Figure 7. Microstructure of dump slag polished section area with accumulation of ferromanganese silicon inclusions

Conclusions

The basic postulates of active ferromanganese silicon smelting technology are analysed and the reasons regarding high multiplicity of dump slag containing up to 15-18 % of MnO and 46-48 % SiO₂ are discussed. Also viscosities and electric conductivities of slag liquid-alloy are interrelated.

Dump slag microstructure is investigated by EMPA method. It is ascertained that the microstructure is represented by bustamite (Mn·Ca)₃[Si₃O₉] and probably by johannsenite of Ca, Mn [Si₂O₆], and also by alabandine (α - MnS), eutectics in oxide composition of system Al₂O₃-

SiO₂-K₂O-Na₂O. The probable heterovalent isomorphism of Al³⁺ → Si⁴⁺ is discussed.

The results of laboratory and experimental-industrial tests of slag-coal bricks obtaining and ferromanganese silicon smelting with the usage in their using them in the traditional charge composition are analyzed. The reasonability of continuing the theoretical and experimental studies on the recycling of ferromanganese silicon dump slag considering new scientific approaches to their bricking and usage in charge compositions for the production of traditional and new compositions of manganese-silica ferroalloys is confirmed.

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Структурные исследования отвальных шлаков ферросиликомарганца и возможности их рециклинга с целью повышения сквозного извлечения марганца и кремния

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Методом РСМА исследована микроструктура отвального шлака ферросиликомарганца. Установлено, что шлак насыщен кремнеземом. Микроструктура представлена бустамитом $(\text{Mn}, \text{Ca})_3 [\text{Si}_3\text{O}_9]$ и вероятно йохансенитом $\text{Ca}, \text{Mn} [\text{Si}_2\text{O}_6]$, а также выделениями алабандина $\alpha\text{-MnS}$ и корольки сплава; межзеренные образования содержат Al_2O_3 , SiO_2 , Na_2O и K_2O ; проанализированы результаты лабораторных и опытно-промышленных экспериментов по получению шлакоугольных брикетов и выплавки с их использованием стандартного ферросиликомарганца.