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Preparation of Silumin through Arc-Plasmous Processing Mechanically Activated Minerals of the Sillimanite Group

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Abstract

Experiments on carbothermy of minerals of the sillimanite group (MSG, Al_2SiO_5 , composition (mass %): Al_2O_3 62.9, SiO_2 37.1) and quartzites containing them. The mixture melted after the mechanical activation under reducing conditions. Graphite, charcoal and sawdust were used as reducing agents. Graphite, charcoal and sawdust were used as reducing agents. The average statistical compositions of the products of melting were determined (mass %): aluminium-silicon – Al 93.62, Si 6.14, Fe 0.13, Ti 0.06; $n = 429$ (n is the number of determinations over which averaging was carried out), in 245 analyses the content of aluminium exceeds 98 mass %; silicon – Si 99.65, Al 0.22, Fe 0.12, Ti 0.02; $n = 122$. The results of the research show the fundamental possibility of the preparation of silumin, and along the way, silicon from MSG using plasma heating. Resources of the minerals of the group of sillimanite in Russia were evaluated. The program of specific activities on the transition of the production of silumin and aluminium to a new sort of raw materials and new technologies were proposed.

Key words: minerals of the group of sillimanite, plasma heating, reducing agents, mechanic activation, products of electrothermy, silumin, aluminium

INTRODUCTION

The detailed review of the formation and development of carbothermy in Russia and the world in general has been implemented in the work [1]. The All-Russian Aluminium-Magnesium Institute (OJSC “RUSAL VAMI”) has large experience in this field.

Minerals of the group of sillimanite (MSG: andalusite, sillimanite, kyanite) are described by the general formula Al_2SiO_5 (62.9 mass % of Al_2O_3 , 37.1 mass % of SiO_2). This sort of raw materials for our country is of the strategic im-

portance, since the industrial production of silumin, aluminium, refractories and other high-tech products can be produced on its base [11–18].

Silumin is an alloy of silicon and aluminium characterized by a low density (2.4–2.7 g/cm³) and high specific strength at the normal temperature and good casting properties. At the present time, it is obtained by alloying crystalline silicon and aluminium in electric or flame furnaces. This method requires the electrolytic production of aluminium; it is characterized by high costs for the production of alumina, anode mass, cryolite, aluminium fluoride, elec-

troenergy on the capital construction of large shops with electrolyzers and converter stations. The alternative of this technology is electrothermy that includes the direct carbothermal smelting of MGS in electric furnaces and getting an alloy with 32–35 % of silicon as an intermediate product. The latter may melt in to conditioned silumin and aluminium on a metallurgical limit.

Aluminum-silicon was obtained by the reduction of kaolin by charcoal at the Dnieper Aluminium Plant in 1934. The alloy, rich in aluminum (up to 70 %), was produced here as well in 1939. This technology was introduced to industry in 1964.

Aluminum-silicon was obtained from kyanite flotation concentrates of the Abramovo deposit under laboratory conditions at the Urals Aluminum Plant in 1948. In the early 1960s, at the Irkutsk aluminum plant, testing the two-stage method of the production of silumin from sillimanite concentrates of the Kyakhta deposit were conducted.

According to numerous expert evaluations of specialists, the electrothermal method for producing silumin from aluminosilicates has the following advantages.

1. Complex and expensive production of alumina, necessary for the electrolytic production of aluminum is excluded from the production cycle.

2. The power of the ore-thermal furnace is much higher than the electrolyzer power. For example, one furnace of the productivity of 10 thousand tons of aluminium a year may replace 30 electrolyzers.

3. There is no need to convert the AC to DC, and this reduces electroenergy losses.

4. There is no need to use fluorine compounds.

5. Aluminum-silicon is produced by relatively cheap and available reducing agents.

6. Electroenergy consumption per the unit of the resulting production reduces by almost 20 % and its prime cost by 30 %.

7. The capital cost of the construction of the shop with an ore-thermal furnace is 30–40 % lower than the capital costs of the construction of aluminous and electrolytic shops.

8. The production of silumin even with the use of electrolytic aluminum for dilution gives a significant economic effect.

For our country, electrothermy has another principal advantage: raw materials are local,

and therefore, the external raw materials dependence is completely eliminated and transport costs are minimized.

The technology of electrothermy provides the reduction of specific and capital costs, which depends directly on the single-unit power of the ore-thermal furnace. The use of plasma heating allows increasing significantly the power of ore-thermal furnaces and unlocks the following features:

- 1) to receive high temperatures at a high concentration of energy in the reaction space;

- 2) to stabilize the electric regime of the furnace work not depending on electric properties of the mixture;

- 3) to establish a high voltage on an arc plasma and due to this attract the plasmatrons of a higher power at a relatively low current strength;

- 4) to work in a broad temperature diapason in any medium, moreover argon, hydrogen, air, natural gas and their mixtures may be used as plasma-forming.

According to literature data, in case of the plasmatron use in the melting unit the approximate electroenergy consumption is 10–12 thousand kW/h per 1 t of silicon-aluminum alloy. For comparison: the electroenergy consumption in the electrolytic production of 1 t of aluminium exceeds 15 thousand kW/h.

ELECTROTHERMY OF MINERALS OF THE GROUP OF SILLIMANITE OF URAL AND SIBERIAN DEPOSITS

In the course of experimental studies on carbothermy we implemented plasma heating. To this end the furnace was constructed (Fig. 1). The metal sealed housing of the furnace 1 has the following internal dimensions: the width is 0.5 m, height is 0.6 m, and length 0.72 m, volume is 0.216 m³. The furnace is lined with fire-clay bricks 2, masonry is made dry, without a solution, bricks are lapped. The furnace cover 3 is metallic, it attached to the housing by bolts through the cover gasket 4. On the cover, the water-cooled of the body of the electrode holder 5, water-cooled peepers 6 and water-cooled branch pipe for the exit of exhaust gases 7 are sealed. A water-cooled muff 8 with a ring heat-resistant rubber seal and isolating beaker 9 creating the electric isolation between the

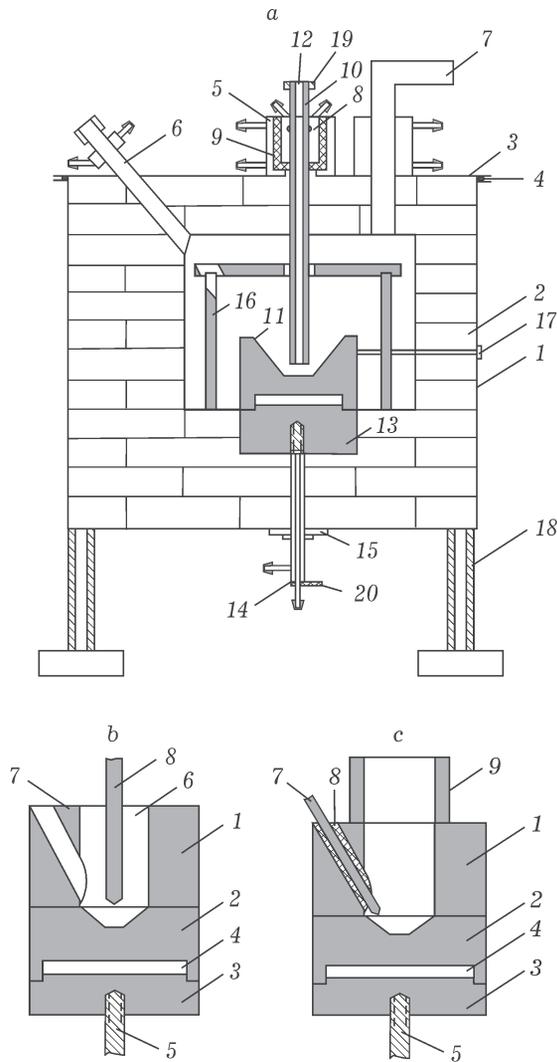


Fig. 1. Scheme of the plasma arc furnace: *a-c* – various variants of the geometrical shape of the graphite crucible with graphite electrode-cathode.

muff and housing of an electro-holder are located inside of the case of electro-holder. The furnace housing rests on the supports 18 with a height of 500 mm providing the access to a water-cooled current lead 14.

The source of the thermal energy of the furnace is an electric arc burning between the rod graphite electrode 10 (with the diameter up to 28 mm) and graphite crucible 11 (with the diameter of 150 mm). The electrode has an axial cylindrical channel 12 with the diameter 6.5 mm for the delivery of argon. The removable and replaceable graphite crucible is electrically connected with the contact graphite block 13. Working current on the contact block is supplied *via* a water-cooled current lead 14,

which is attached to the bottom of the furnace through the insulating spacer 15, providing isolation of the crucible from the furnace housing. The operating voltage from a power source is supplied to the terminals 19 and 20. Inside of the working space of the furnace of the size $0.24 \times 0.48 \times 0.48 \text{ m}^3$ a graphite screen 16 with internal dimensions $0.22 \times 0.175 \times 0.3 \text{ m}^3$ and a wall thickness of 15 mm, which reduces the heat sink through the lining is installed. It is closed by a graphite lid from the top with holes for peepers and a rod electrode.

Temperature measurements were carried out using a thermocouple TTR (tungsten-rhenium TR) 17. According to the data of the Obninsk Thermoelectric Company (Obninsk, Kaluga Region), its limits of the measured temperatures at the constant inclusion are $0\text{--}2200 \text{ }^\circ\text{C}$, during short-term inclusion they are $0\text{--}2500 \text{ }^\circ\text{C}$.

The argon flowing through the channel 12 in the zone of electric arc burning between the rod electrode and the graphite crucible hinders the penetration of air into the high temperature zone of the furnace from the furnace space. The working mode of the furnace: the consumption of argon 700 L/h; arc amperage 70–100 A; arc voltage 28–70 V; temperature in the plasma arc more than $3000 \text{ }^\circ\text{C}$; temperature at the base of the crucible $2500 \text{ }^\circ\text{C}$.

Experiments were performed on kyanite and sillimanite concentrates of the Andreev-Yuliyevsk placers (Pl1), Karabash (Kr1) and Kyakhta (Kh1) deposits (Table 1), and quartzites (Kr2 and Kh2) containing them.

The mixture with a reducing agent was subjected to mechanical activation in the mill of the centrifugal type [19] that has 42 disks with the thickness of 7 mm (the external radius is 40 mm, internal radius is 19 mm), the mass of each disk is 0.06 kg. The rotation frequency was 1000 min^{-1} , power consumption was 640 W, and power of the engine was 1.5 kW. From the original particles of the size of $300\text{--}500 \text{ }\mu\text{m}$ per one passing in this mill, particles with the size of less than $10\text{--}15 \text{ }\mu\text{m}$ are produced.

A total of 29 experiments were conducted, in which designs of crucibles, compositions of the initial mixtures and reducing agents were varied. The mixture contained from 100 to 500 g of the starting material (kyanite, sillimanite concentrates or quartzites, containing them).

TABLE 1

Chemical analysis of the starting products, mass %

SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	Total	Ky, Sil	Qu
<i>Theoretical composition of MSG</i>											
37.1	–	62.9	–	–	–	–	–	–	100.0	100.0	0
<i>Kyanitic concentrate (technogenic sands of the Plast District, Chelyabinsk Region) Pl1</i>											
40.06	0.55	57.07	0.61	0.10	0.01	–	0.40	0.06	98.86	90.7	6.4
<i>Kyanitic concentrate (Karabash deposit, Chelyabinsk Region) Kr1</i>											
36.78	0.35	62.64	0.00	0.10	0.00	0.03	0.00	0.06	99.96	99.6	0.1
<i>Kyanite-containing quartzite (Karabash deposit) Kr2</i>											
78.24	0.56	18.5	1.69	0.03	0.1	0.05	0.3	0.28	99.75	29.4	67.3
<i>Sillimanite concentrate (Kyakhta deposit, Buryatia) Kh1</i>											
48.33	2.0	46.34	1.03	–	0.67	0.18	0.02	0.09	98.66	73.7	21
<i>Sillimanite-containing quartzite (Kyakhta deposit) Kh2</i>											
75.04	1.11	18.80	1.49	<0.03	<0.01	0.26	<0.03	0.13	96.9	29.9	64.0

Notes. 1. Ky – kyanite, Sil – sillimanite, Qu – quartzites. The dash – absent.

Graphite, charcoal, and sawdust were used as reducing agents. The duration of the tests was 30–60 min.

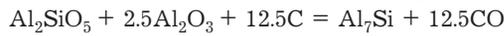
Visual observations of the process of reduction of Al₂O₃ and SiO₂ showed that when using powdery starting materials formed in the area of the discharge without granulating the gas flow of CO, passing through the layer of the mixture in the download section and gas combustion carries away the most lightweight powder of charcoal. As a result, the mixture is depleted of the reductant. In order to exclude the effect of dusting-out carbon, the mixture was preliminary granulated.

Three variants of the geometric shape of the graphite crucible with a graphite electrode (see Fig. 1, a–c) were used in the experiments. In the first variant (see Fig. 1, a), the thickness of the mixture on the initial stage of the experiment did not exceed 100 mm, and the graphite electrode 10 was located along the axis of the crucible 11 and had the axial channel for supplying argon. The electric-contact section 13 with water-cooled current lead was located under the crucible 11. The working regime: the consumption of argon is 700 L/h; the arc current strength is 70–100 A, the voltage on the arc is 28–70 V. The experiments showed that a significant loss of aluminum due to the evaporation of suboxide aluminum (Al₂O) and its entrainment along with carbon monoxide and argon, supplied through the electrode is observed.

In the second variant (see Fig. 1, b), the crucible consisted of three graphite sections: the download section 1 that had a cylindrical channel of the initial load 6 and channel of the subsequent periodic download 7 (this section is absent in the first variant), the bottom section 2 and section 3 of electric-contact with the current lead 5. The heat insulating gas chamber 4 was located between the sections 2 and 3. Aluminium losses are lower in this variant and the yield of aluminum-silicon is higher due to the increase of the mixture layer. However, when warming-up the electrode in the upper part of the mixture the silicon-aluminum alloy and gas cavities (gas is CO), through which vapours of Al and Al₂O broke through from the crucible to the furnace space, were formed along the red-hot electrode. The working mode: argon was not supplied (the arc discharge was steadily burned in the atmosphere of the gas CO and reagents vapours), the power of the arc current strength was 100 A, arc voltage was in the range of from 45 to 80 V; the experiments duration was 1 h. Herewith, the mixture contained approximately 500 g of the kyanite concentrate.

In the third variant (see Fig. 1, c), to increase the layer of the mixture, the additional section of the load 9 was introduced in the crucible, and the graphite electrode 7 was located *via* a heat-resistant insulator at an angle to the axis of the crucible. The download section 1,

bottom section 2, electric-contact section 3 and the current lead 5 were placed analogously to the second variant. Breakthroughs of gas fractions (“fistulas”) were not observed in this variant. Two series of experiments were carried out: in the first one, the correcting amount of Al_2O_3 calculated according to the below reaction was added to the kyanite Al_2SiO_5 :



Then single samples and those in the mixture with $\gamma\text{-Al}_2\text{O}_3$ were mixed, exposed to the mechanical activation, the powder was loaded into the crucible. It was discovered that in the work process dusting-out the mixture occurs, as a result of which its chemical composition deviates from stoichiometry. With this in mind, in this series of experiments, the mixture was

granulated by glueing with the glue KMT, then dried, crushed and sifted through a sieve with a cell of 2 mm.

When using a granular mixture in the section 9 a smooth burning of CO gas over the surface of the mixture is observed, particles of the reductant in a stream are absent. At the attenuation or termination of the process of the gas combustion either the arc was switched off, or a new portion of the mixture was added, which from top was pressed by a special high-temperature pusher and fell into the zone of the action of the arc discharge. The process of allocating CO and burning continued. The processing mode: the arc current strength is up to 100 A, arc voltage is up to 50 V, and processing time is up to 1 h.

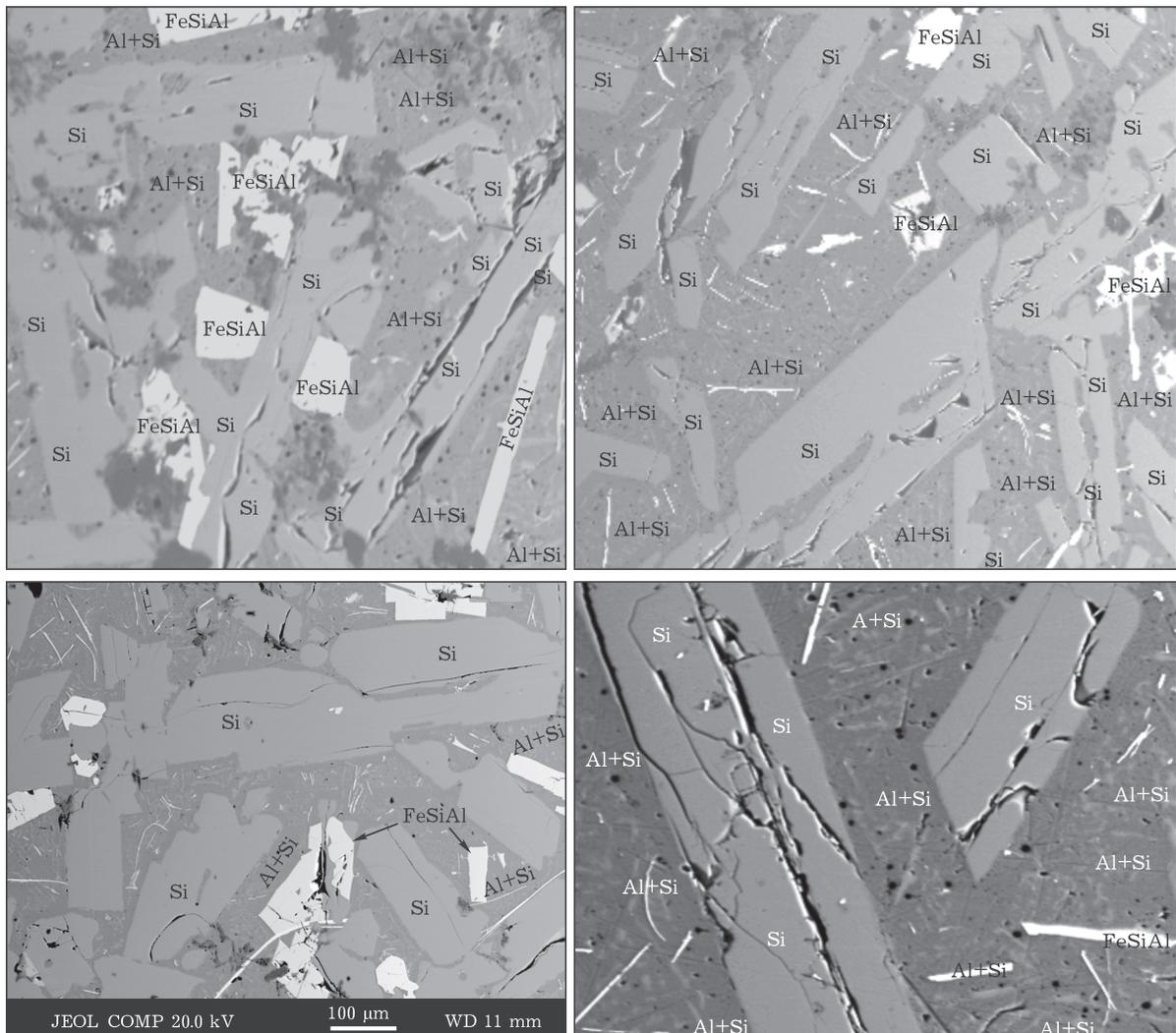


Fig. 2. Electrothermy products of MSG and quartzites containing them.

TABLE 2
X-ray spectral microanalysis of standards, mass %

Al	Ti	Fe	Si	Total
<i>Aluminium of KAP</i>				
99.32	0.06	0.38	0.25	100.0
<i>Aluminium of SAP</i>				
99.58	0.0	0.0	0.24	100.0
<i>Silicon of a high purity</i>				
0.0	0.0	0.0	100.0	100.0

Note. KAP is the Krasnoyarsk Aluminum Plant; SAP is the Sayanogorsk Aluminum Plant.

The best results were obtained in case of the use of the third variant of the crucible and preliminarily mechanically activated and granulated mixture.

Products of electrothermy are balls and hollow spheres. The relations of phases in them and their quantitative ratios are shown in Fig. 2. Free silicon prevails, next is the alloy Si-Al. The iron-containing phase (AlFeSi) is present in products of each experiment. Relicts of kyanite, newly formed corundum and silicon carbides are rarely met. Silicon-aluminium alloy

cements other phases; hence, it is formed during final stages of the process.

Aluminum-silicon, silicon and other phases were analysed using a Jeol JXA-8100 X-ray microanalyzer. Conditions of shooting: the accelerating voltage is 20 kV, current strength of the absorbed electrons is 40 nA, diameter of the probe is 2–4 μm , and count time is 10 s on each analytical line. Aluminium of the Krasnoyarsk and Sayanogorsk aluminum plants and silicon of high purity were used as standards (Table 2).

The average statistical compositions of products of electrothermy of MGS are presented in Table 3 and Fig. 3. It can be seen that they are located compactly, composition fields do not overlap.

Alloy Si-Al (silumin). Features of the distribution of aluminium in samples of silicon-aluminium alloy are shown in Fig. 4. The content of aluminium exceeds 98 mass % ($X = 99.12$) in 57 % cases ($n = 245$ in case of the total number of analyses $n = 429$). In this case, the total content of Si, Ti, Fe does not reach 2 %; actually, only the right part of Fig. 5 ($n = 184$) corresponds to silumin. The composition of the alloy on average (mass %): Al 93.36, Si 6.73, Fe 0.14, Ti 0.05 meets sorts (State Stan-

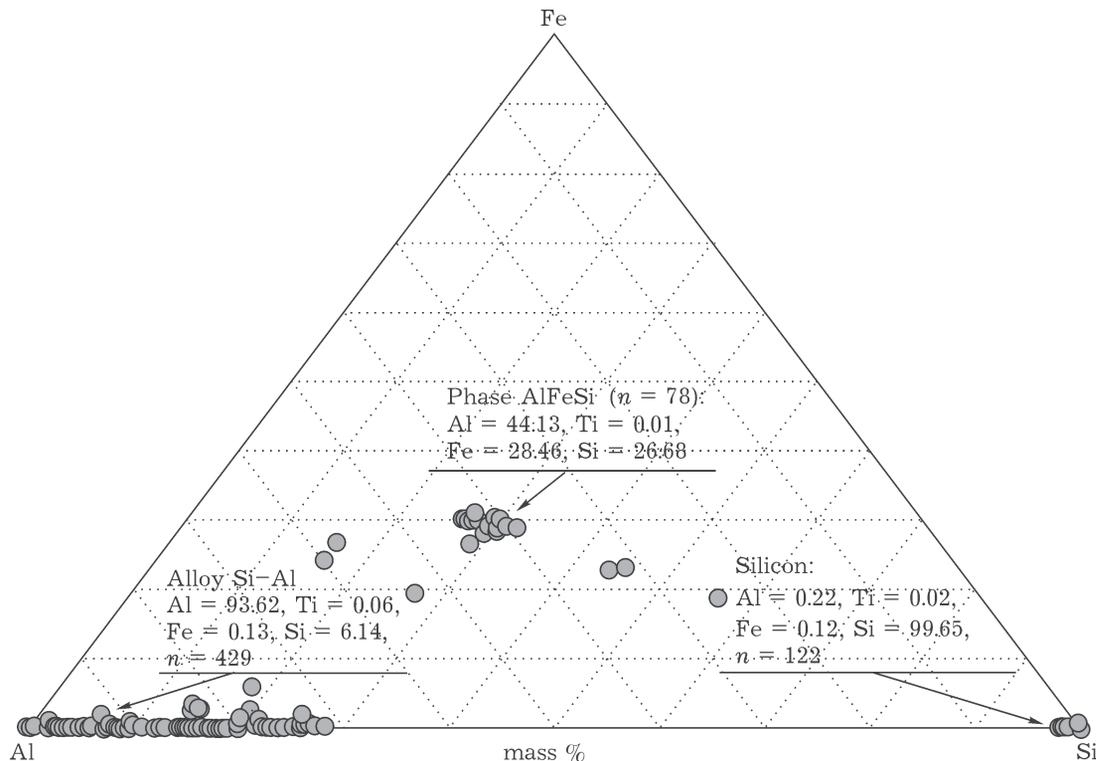


Fig. 3. Position of products of electrothermy in the coordinates of Al-Fe-Si.

TABLE 3

Average-statistic composition of the products of electrothermy, mass %

Statistical parameters	Al	Ti	Fe	Si
Silicon-aluminium alloy				
<i>Kyanite concentrate, n = 391</i>				
\bar{X}	94.01	0.05	0.12	5.78
S	8.06	0.04	0.13	6.33
<i>Sillimanite concentrate, n = 13</i>				
\bar{X}	90.74	0.01	0.11	9.10
S	6.26,	0.01	0.08	6.22
<i>Kyanite-containing quartzite, n = 13</i>				
\bar{X}	89.42	0.12	0.25	10.22
S	9.17	0.05	0.32	9.09
<i>Sillimanite-containing quartzite, n = 12</i>				
\bar{X}	88.64	0	0.25	10.15
S	9.03	0	0.32	9.03
<i>Array as a whole, n = 429</i>				
\bar{X}	93.62	0.06	0.13	6.14
S	7.51	0.06	0.16	7.41
Silicon				
<i>Kyanite concentrate, n = 100</i>				
\bar{X}	0.24	0.02	0.14	99.63
S	0.31	0.02	0.16	0.36
<i>Sillimanite concentrate, n = 12</i>				
\bar{X}	0.04	0.01	0.04	99.78
S	0.01	0.01	0.02	0.17
<i>Kyanite-containing quartzite, n = 4</i>				
\bar{X}	0.21	0	0.03	99.77
S	0.19	0	0.02	0.21
<i>Sillimanite-containing quartzite, n = 6</i>				
\bar{X}	0.21	0	0.03	99.57
S	0.22	0	0.02	0.30
<i>Array as a whole, n = 122</i>				
\bar{X}	0.22	0.02	0.12	99.65
S	0.29	0.07	0.14	0.33
Phase containing Fe, Si, Al (n = 78)				
\bar{X}	44.13	0.01	28.46	26.68
S	4.63	0.01	4.58	5.06
Gross composition of electrothermy products, n = 41				
\bar{X}	49.48	0.23	3.45	46.64
S	13.29	0.13	2.49	11.79

Note. \bar{X} is the average content, S is the standard deviation.

dard GOST 1583-93) AK12h (SIL-1), AK12ph (SIL-0) and AK12oh (SIL-00)

Silicon. It is present in three positions: in a eutectic mixture with aluminium, in iron-containing phase and in the form of separate elongated crystals (see Fig. 2). The X-ray spectral composi-

tion of the latter is presented in Table 3. The average content of Si in the sample (n = 122) is 99.65 mass %, its distribution in analyses is uniform (see Fig. 5). The total amount of trace substances (Al + Ti + Fe) is equal to 0.36 mass %. Silicon meets brands Kr2, Kr1, Kr00 (GOST 2169-69).

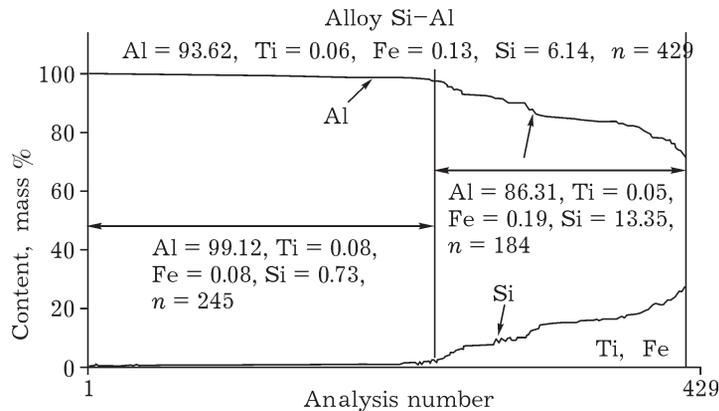


Fig. 4. Distribution of aluminium, silicon, titanium and iron in analyses of aluminium-silicon.

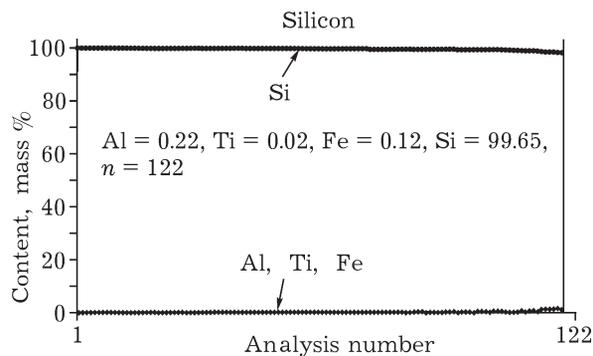


Fig. 5. Distribution of silicon, aluminium, titanium and iron in analyses of silicon.

Phase AlFeSi. It is met in products in all experiments even where the starting material was maximally pure kyanite. Apparently it appears as a result of the blockage of the mixture by iron when its crushing in a metal mill. The average statistic composition of the phase

(mass %): Al 44.13, Ti 0.01, Fe 28.46, Si 26.68 (Table 3, Fig. 6).

By averaging data obtained using an X-MET5100 XRF analyzer of the company Oxford Instruments the gross composition of the products of electrothermy (mass %): Al 49.48, Si 46.64, Fe 3.45, Ti 0.23, $\Sigma = 99.80$ (see Table 3). The distribution of components in analyses is uneven, the content of aluminium varies from 28 to 79 %, of silicon from 20 to 70 %, of iron from 0.2 to 20 %, of Ti from 0.10 to 0.5 mass % (Fig. 7).

Knowing the average statistical gross composition of products of electrothermy and average statistical compositions of individual phases, one may also calculate and their average statistical quantitative ratios: phase AlFeSi – 9.80 %, aluminum-silicon – 46.67 %, silicon – 41.56 %, $\Sigma = 98.03$ %. Iron in silicon-aluminum alloy, as well as iron and aluminium in silicon were not taken into account in the calculations.

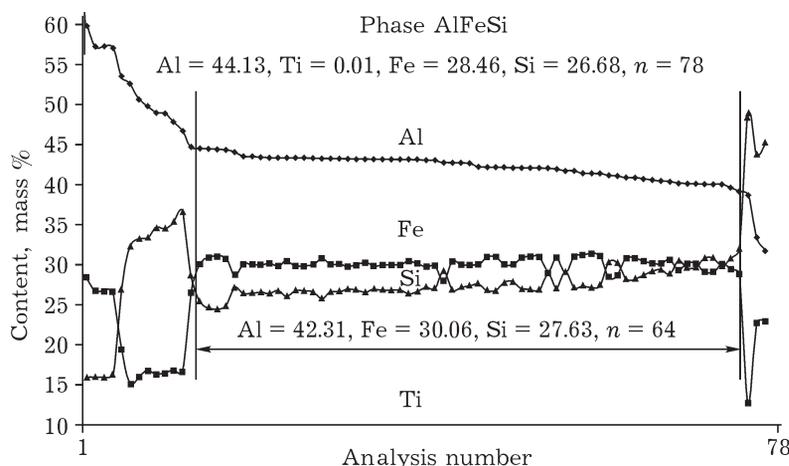


Fig. 6. Distribution of aluminium, silicon and iron in analyses of the phase AlFeSi.

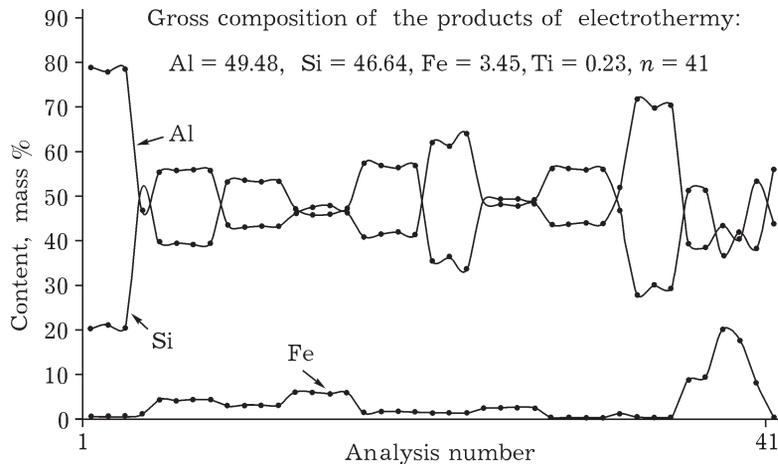


Fig. 7. Distribution of aluminium, silicon and iron in gross analyses.

Their contents here are maximally low, so, they cannot substantially influence the ratios calculated above.

The quantitative composition of phases can also be established by another way. The photomicrography of products of electrothermy of the sillimanite concentrate (a fragment of Fig. 2, the left bottom corner) is given in Fig. 8. In percentage ratio, these phases have the following squares: Si 55.4, alloy Al–Si (silumin) 36.5, phase AlSiFe 8.1, $\Sigma = 100$.

The content of aluminium and silicon in the minerals of the sillimanite group (subtracting oxygen) is 65.8 and 34.32 mass %, respectively. In case of the eutectic composition of silumin (Al 87.5 mass %, Si 12.5 mass %) 75.2 % of aluminum-silicon and 24.8 % of free silicon should

be obtained from MSG. In our case, the calculated amount of eutectic silumin in the products of electrothermy is 49.93 %, what is 28.5 % lower than the theoretically possible amount, and silicon is by 16.76 % greater. These differences may be explained by the fact that in experiments, simultaneously with high-quality concentrates (P11, Kr1), concentrates and quartzites containing them that are substantially different in composition from MGS (see Table 1) were used.

Therefore, experimental studies clearly indicate that it is principally possible to obtain aluminum-silicon along with silicon from the minerals of the group of sillimanite and ores containing them using plasma heating. Experiments have been implemented for the raw materials from specific deposits of Ural and Siberia. It is possible to distinguish the following most important and significant results.

1. Regardless the quality of the initial raw (kyanite concentrates Kr1, P11 with the content of Al_2O_3 of 57–62 %; sillimanite concentrates Kh1 with the content of Al_2O_3 of 46 %; kyanite and sillimanite quartzites Kr2, Kh2 with the content of Al_2O_3 of 18–19 %), the same products in different quantitative ratios: aluminum-silicon, free silicon and the phase AlSiFe (see Table 3) are obtained in the outcome. Naturally, the more silicon oxide is in the initial raw materials, the more silicon will be contained and in the resulting products. From the practical point of view, this fact deserves a special attention. The fact of the matter is costs of the manufacture of concentrates of MGS de-

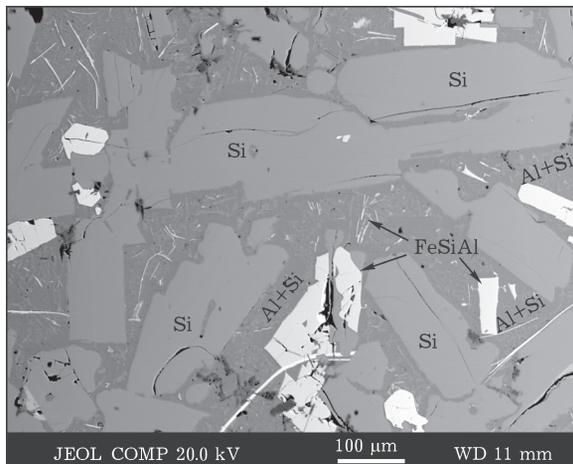


Fig. 8. Products of electrothermy of the sillimanite concentrate (Kh1).

pend directly on the enrichment technology. The most inexpensive and most environmentally safe way is gravitation that is especially efficient in case of kyanite quartzites, due to a significant difference in the specific weights of kyanite (3.5 g/cm^3) and quartz (2.5 g/cm^3). It was established experimentally that the gravitational method allowed obtaining concentrates with the content of alumina of up to 52–54 mass %. It is necessary to apply flotation for a further increase of the content of Al_2O_3 and this will inevitably result in the increase of their prime cost.

2. The average statistical composition of aluminum-silicon (Al 93.62 mass %, Si 6.14 mass %; $n = 429$) differ from the eutectic one (Al 87.5 mass %, Si 12.5 mass %). This fact can be given two likely explanations: 1) the composition of the eutectic is defined not entirely accurately: in fact, shifts toward the aluminum approximately by 6 mass %; 2) kinetic factors conditioned by high rates of the increase and lowering temperatures could influence the composition of silicon aluminum alloy.

3. From 429 analyses of silicon-aluminum alloy even in case of the maximal centering the electron-probe beam up to $2 \mu\text{m}$ pure silicon was not registered in it. This indicates that the size of its crystals in the eutectic alloy is lower this value. From the viewpoint of strength properties of products from silumin this may also be helpful.

EVALUATION OF THE EFFICIENCY OF THE ELECTROTHERMAL PREPARATION OF ALUMINUM-SILICON FROM MSG

The duration of experiments on electrothermy was 30–60 min; the continuance of the mechanical activation was 1 h. The energy cost counting on the experiment in the first case was 7–14 kW, in the second case 1.5 kW. It is obvious that the prime cost of the production of silumin by this technology will depend not only on the energy cost but also on many other factors. In addition to aluminum-silicon, silicon that can also be extracted is present in products of electrothermy. Kyanite concentrates derived from quartzites by the gravitational method are more profitable to use in the production of silumin. According to the calculations available, its prime cost in this case will be about 50 USD/t

and can be reduced through the use of by-products. Quartz sand for the glass industry and construction sand can be obtained from final tailings from the enrichment. The allocation of quartz of a higher purity is not excluded. One should pay attention to rutile also, that is concentrated in heavy non-electromagnetic fraction: its content here reaches 5 mass %.

The advantage of electrothermy was convincingly demonstrated in the work [1]. The authors conducted the comparative calculations of economic efficiency of the preparation of silicon-aluminum alloys of the brands of AK12M2MN and AK18 by the traditional method of alloying aluminium and crystalline silicon and by electrothermic method from kaolin and sillimanite. The following variants have been considered: 1) for enterprises having their own production of aluminum and silicon, the prime cost reduction of 1 t of alloys obtained by the electrothermal method, in comparison with the synthetics, will be 90 USD; 2) for enterprises having their own production of aluminium but purchasing silicon on the market, the analogous calculation gives the prime cost reduction by 150 USD; 3) for manufacturers of alloys not having their own production of aluminium and silicon, the electrothermal method is the most preferred one and it allows reducing the prime cost of 1 t of alloys, in comparison with the synthetics by 213 USD. These data indicate univalently economic advantages of the electrothermal method of the production of aluminum-silicon, in comparison with the current technology of the preparation of silumin by alloying electrolytic aluminum and silicon.

RAW MATERIALS BASE OF RUSSIA FOR THE CARBOTHERMAL PRODUCTION OF SILUMIN AND ALUMINIUM

The largest deposits of the minerals of the sillimanite group in our country are concentrated in the Kola Peninsula and Siberia [11–18]. Their explored reserves in the re-calculation of the final product that is aluminium exceed 400 million tons, and the resources are estimated at 2 billion tons (Table 4). At the current production volume of aluminium (4 million t/year) the explored reserves of ores will be enough for more than a hundred years.

TABLE 4

Explored reserves and prognostic resources of ores containing minerals of the sillimanite (Al_2SiO_5) group, alumina and aluminium in Russia, thousand tons (Lepezin, 2003–2005)

Regions	Ore	Al_2SiO_5	Al_2O_3	Al
<i>Explored reserves (categories C_2, C_1, B, A)</i>				
Kola Peninsula	3 400 000	1 186 879	676 518	358 556
Karelia	116 820	25 000	14 250	7553
Siberia	511 750	131 114	74 732	39 608
Ural	66 684	11 710	6 675	3537
<i>In total</i>	4 095 254	1 236 698	772 175	409 254
<i>Prognostic resources (categories P_2, P_3)</i>				
Kola Peninsula	11 000 000	3 840 000	2 188 230	1 159 762
Ural	109 890	30 000	17 100	9 063
Siberia	8 138 400	2 588 517	1 475 455	781 991
<i>In total</i>	19 248 290	6 458 517	3 680 785	1 950 816

The advantage of ores containing MSG is that they are easily enriched. The amount of alumina in the enrichment products reaches 62.64 mass % (Table 5). Of impurities, iron and titanium oxides are registered in them in small amounts. Except for high-quality bauxites which we almost do not have, no other types of raw materials cannot give such contents of alumina even at the most advanced enrichment technologies. All deposits can be developed in an open method.

TABLE 5

Chemical composition of MSG from Russian deposits and of their concentrates, mass %

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
<i>Theoretical composition of MSG Al_2SiO_5</i>								
37.1	—	62.9	—	—	—	—	—	—
<i>Average-statistical composition of MSG ($n = 186$)</i>								
37.01	—	62.72	0.29	0.01	0.03	0.01	0.00	0.00
<i>Selected chemical analyses of MSG concentrates</i>								
40.06	0.55	57.07	0.61	0.10	0.01	0.06	0.40	0.06
39.01	0.25	59.47	0.10	0.00	0.03	0.03	0.22	0.10
37.47	0.67	60.45	0.37	0.10	0.00	0.03	0.09	0.05
36.78	0.35	62.64	0.00	0.10	0.00	0.03	0.00	0.06
37.21	0.23	60.20	0.26	0.10	0.09	0.54	0.00	0.53
37.57	0.66	60.40	0.49	0.10	0.05	0.06	0.00	0.30

Note. The dash — absent.

PROGRAM OF MEASURES ON THE TRANSITION TO A NEW TYPE OF RAW MATERIALS AND NEW TECHNOLOGIES OF THE PRODUCTION OF SILUMIN AND ALUMINIUM

To organize large-scale production of silumin and aluminum in a short time is impossible, therefore, the following activities are proposed for the gradual transition from one type of the raw material to another and from one technology to another one.

1. On the initial stage, it is necessary to master the deposit of minerals of the sillimanite group with the productivity of 10–30 thousand tons of concentrate per year. It should be located in an area with the developed infrastructure, close to a railway. There are such deposits in Russia, and their development will require one to two years and relatively small capital costs.

2. To create the industrial production of concentrates of MSG. This matter is absolutely a win-win, as there is a demand for these products in refractory, ceramic and other industries.

3. To carry out pilot tests on carbothermy of minerals of the sillimanite group.

4. Upon receiving results of electrothermy one may proceed to mastering large deposits of MSG and establishing industrial productions of silumin and aluminum.

For Russia, this type of raw materials is of the strategic importance, all other ways of solving the problems of raw material base of the aluminum industry of the country are unpromising.

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