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RESEARCH INTO THE CHARGE COMPOSITIONS FOR THE SILICOALUMINIUM PRODUCTION

ДОСЛІДЖЕННЯ ШИХТОВИХ КОМПОЗИЦІЙ ДЛЯ ВИГОТОВЛЕННЯ СИЛІКОАЛЮМІНІЮ

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***Abstract**. The paper investigates the main aluminosilicate materials of Ukrainian deposits, which are developed industrially and are suitable as charge materials for smelting silicoaluminium by the electrothermal method. The calculation method is described, calculations of charge compositions from various components in different ratios are performed, which allow selecting the charge compositions from cheap raw materials to obtain silicoaluminium with a low content of impurity elements. The influence of the composition and ratio of charge materials on the qualitative and economic characteristics of the obtained silicoaluminium is investigated. The optimal charge composition for smelting silicoaluminium with the addition of return slag to the charge, which is formed at the alloy production, is determined. The proposed composition of the charge during ore-thermal smelting provides an 8 % higher yield of the primary alloy and an 13 % reduction in the cost of the finished alloy compared to the industrial charge, and allows for the disposal of waste from our own production.*

***Key words:** aluminosilicates, charge composition, primary aluminium-silicium alloy**,** return slag, silicoaluminium.*

Introduction.

Ukraine is a country with significant industrial potential, and even today, despite the challenging economic situation, industries such as aviation, engine manufacturing, shipbuilding and ship repair, agricultural machinery, chemical, ferrous and non-ferrous metallurgy are still active. Relatively low density, high electrical conductivity in combination with high plasticity, as well as significant raw materials contribute to the widespread introduction of aluminium and alloys based on it in various industries [1,2]. Therefore, it is no coincidence that the production of aluminium and its alloys is second only to the production of iron and cast iron [3]. All of this drives growing demand for aluminium and aluminium-silicium alloys and necessitates the development of aluminium-silicium alloy production using advanced technologies and developments in this non-ferrous metallurgy sector.

The main group of foundry aluminium alloys is silumins, containing 4–22 % silicium [1-3]. More than 90 % of all castings are made from silumins. The most important characteristics of silumins, which determine their manufacturability and areas of application, are high mechanical, corrosion and casting properties. All of them are determined by the chemical composition and structure of silumins. The structure, in turn, is formed depending on the conditions of melting, crystallization and subsequent heat treatment [3].

The existing traditional technology for producing aluminium-silicium alloys involves fusing of electrolytic aluminium with crystalline silicium and other alloying materials. However, the high consumption of electrolytic aluminium in this production process is required the search for and development of new technologies for producing aluminium-silicium alloys.

The rapid growth of light-based aluminium and alloys on its basis will cause significant problems in the next decade due to the problem of energy consumption and the number of natural resources for aluminium production. Rich and easily accessible bauxite deposits are being depleted, and the cost of mining and processing bauxite significantly affects the economics of aluminium production and its alloys.

The increase in the price of electrolytic aluminium on the market leads to an increase in the price of aluminium alloys, which entails an increase in the cost of many types of products. Based on this, it can be assumed that the importance of alternative raw material sources and technologies for obtaining aluminium and alloys based on it will increase sharply, one of which is the process of ore reduction of aluminosilicates with carbon (the electrothermal method).

Main text.

Over almost 90 years, the electrothermal method of producing aluminium and alloys based on it has come a long way in its development. To date, only the process of electrothermal production of primary aluminum-silicium alloy (silicoaluminium) is of industrial importance, on the basis of which about 20 grades of foundry aluminum-silicium alloys can be obtained [4]. Researchers A. I. Belyaev, M. B. Rapoport, L. A. Firsanova, R. I. Ragulina, B. I. Emlin, Yu. I. Brusakov and others have carried out extensive work on theoretical research of the process and practical improvement of the method [5].

Such advantages of the electrothermic method as high productivity of ore-reduction or mine furnaces and the ability to process low-modulus aluminum raw materials have recently attracted serious attention to the organization of the electrothermic process for production aluminium and its alloys with silicium [6-8]. The presence in the world of significant reserves of natural raw materials suitable for electrothermic processing (in Ukraine and China − numerous deposits of high-quality kaolin, in India − deposits of sillimanites etc.) encourage researchers to develop new options for organizing the process of reducing natural aluminosilicates with carbon.

The purpose of the work is to investigate aluminosilicate raw materials from deposits in Ukraine and to determine by calculation the optimal charge composition for silicoaluminium production by the electrothermal method.

Technological scheme of the process of obtaining structural aluminium alloys (casting aluminium-silicium alloys), which consists of three main stages [3]:

a) preparation of raw materials and charge production;

b) direct slag-free reduction of natural aluminosilicates in an ore-thermal electric furnace to obtain a (primary aluminum-silicium alloy) silicoaluminium;

c) the resulting silicoaluminium, containing 35-40 % silicium, is then diluted with electrolytic aluminium to a composition corresponding to different grades of structural casting aluminium alloys.

The process of reducing the charge takes place in powerful ore-thermal furnaces. The charge consists of natural aluminosilicates, a carbon reducing agent and a binder for the production of briquettes [3,5]. The requirements for raw materials vary depending on the purpose of the resulting alloy. The most important impurity to pay attention to is iron. The iron content should not exceed 1.5 % if the primary alloy is subsequently used for the preparation of structural cast aluminum alloys.

In thermal production, it is possible to use a wide range of raw materials (reducing agents, aluminosilicates). All of them are characterized by certain qualitative characteristics. Depending on the composition and ratio of these materials, it is possible to obtain a primary aluminium-silicium alloy with different qualitative and economic characteristics. In the industrial charge during the smelting of the primary aluminum-silicium alloy, kaolin and alumina are used.

To reduce the amount of formed mullite, it is proposed to granulate a portion (of up to 30 %) of the alumina-containing charge components.

During the production of the primary aluminium-silicium alloy, slag consisting of unreduced raw materials is formed. The slag amount reaches 15 % of the mass of the produced alloy. During refining, up to 15 % of the alloy is entangled in the slag which is separated from the alloy. Thus, the slag obtained during ore reduction contains quite a lot of metal. It is planned to return metallized slags and molding sand waste to briquettes after grinding. Adding quartz sand to the charge accelerates the formation of gaseous lower oxides of aluminium and silicium at the charge heating in furnaces. This increases the porosity and gas permeability of the agglomerated charge, and reduces its sintering on the furnace top.

Thus, to ensure the competitiveness of the electrothermal method of aluminium-silicium alloys production compared to the traditional technology of synthetic alloys obtaining by fusing aluminium, silicium and alloying elements, it is not enough to simply have a stable technology. It is necessary to continue researching the raw material base, searching for new raw materials, and also to analyze the available data more deeply.

The work investigates the main aluminium-containing materials that are available in significant quantities on the Ukraine territory, are developed industrially, and can be used in the existing scheme of charge preparation and ore-thermal smelting (Table 1).

The calculation of the charge determined the quantitative ratios of the main raw materials for obtaining a primary aluminum-silicon alloy containing 65 % aluminium. The smelting primary silicoaluminium is a process of electrothermal reduction of oxides of the ore part of the charge with carbon. The amount of reducing agent added to the charge must be strictly determined by the stoichiometric calculation of the reduction reaction.

Table 1 − Kaolin deposits in Ukraine

Kaolin deposit	Mass fraction, %			
	Al_2O_3	SiO_2	Fe_2O_3	TiO_2
1	2	3	4	5
Glukhovetske 1	22,1−26,22	65,3−69,6	0,22−0,52	0,22−1,1
Glukhovetske 2	37,1−39,26	46,1−47,8	0,32−0,95	0,30−0,97
Prosyanovske 1	21,7−26,40	65,0−69,7	0,84−1,0	< 0,40
Prosyanovske 2	37,7−39,80	46,7−46,8	0,30−0,73	0,10−0,35
Novoseletske	38,1−54,70	32,3−46,8	0,67−1,08	1,07−1,5
Pologovske	32,65−38,88	46,4−52,5	0,62−1,30	0,80−1,15

Table 1 continued

Kaolin deposit	Mass fraction, %				
	CaO	MgO	K_2O	Na_2O	Loss on ignition
1	6	7	8	9	10
Glukhovetske 1	0,13−0,45	Track	0,13−0,15	0,01−0,08	7,88−8,72
Glukhovetske 2	0,13−0,5	< 0,22	< 0,12	< 0,03	12,2−13,73
Prosyanovske 1	0,40−0,73	0,08−0,28	0,27	0,03	8,40
Prosyanovske 2	0,15−0,56	−	−	−	13,2−13,95
Novoseletske	0,07−0,28	Track	0,17−0,34	−	14,4−19,5
Pologovske	< 0,50	< 0,72	−	−	11,7−13,25

Compiled by authors based on data from sources: [9-11]

To calculate the charge, the following are specified:

- the calculated mass fraction of aluminium in the alloy from the charge;
- the ratio of kaolin and distensillimanite concentrate (DSC) in the charge;
- the mass fraction of non-volatile carbon as a percentage of the theoretically required amount for the reduction of the following oxides: Al_2O_3, SiO_2, Fe_2O_3, TiO_2, CaO and others, if present in significant quantities;
- the ratio of non-volatile carbon in the used carbon reducing agents;
- the mass fraction of dry binder over 100 % of the sum of the charge components;
- the chemical composition of the materials used for the charge.

The amount of solid carbon (reducing agent) introduced into the charge for smelting the silicoaluminium is taken according to the practical experience of one of the Ukrainian enterprises as 95 % of the theoretically required amount. The rest of the carbon required for the reduction process comes from self-sintering electrodes and volatile substances of reducing agents.

The calculation is carried out for 100 units of the charge mass. According to practical data, for each component included in the charge material, the amount of its extraction from the raw material into the smelting products is taken and the amount of each component of the charge material entering the alloy, slag and exhaust gases during the smelting is calculated.

In parallel, the amount of the corresponding metal reduced from each component of the charge material, the alloy total amount and it composition are calculated. Thus, in Table 2 shows the calculating results of kaolin components distribution during melting between the primary aluminium-silicium alloy, slag and exhaust gases. Similar calculations were also carried out for DSC, alumina, quartz sand, alumina dust.

Table 2 − Distribution of kaolin components

Component	Component amount in kaolin, kg	Component amount in smelting products, kg			Metal amount in alloy, kg	Alloy composition, %
		Alloy	Slag	Exhaust gases		
Al_2O_3	37,0	34,41	1,48	1,11	18,211	49,760
SiO_2	46,4	38,05	2,78	5,57	17,318	47,320
Fe_2O_3	0,6	0,60	–	–	0,420	1,148
CaO	0,8	0,32	0,32	0,16	0,229	0,626
TiO_2	0,7	0,70	–	–	0,420	1,148
Loss on ignition	14,5	–	–	14,50	–	–
Total	100,0	74,08	4,58	21,34	36,598	100,00

Author's development

The next stage of the calculation is to determine the characteristics of the alloy produced from the specified raw materials in the appropriate proportions. As a rule, the resulting calculated alloy does not contain a sufficient aluminium amount. To increase the aluminium content in the alloy to the specified amount, it is necessary to additionally add alumina to the charge, the amount of which is calculated.

Studies of the charges composition based on kaolin and DSC have shown that an increase in the DSC content in the charge by 10 % leads to a decrease in the required amount of alumina by 9 %. On the other hand, an increase in the DSC content by 10 % causes an increase in the iron content in the finished alloy by 3 %. The most expensive part of the charge materials is alumina. After reducing the value of the amount of iron in the alloy and the need for alumina addition to a fraction of the maximum value, a comparative analysis of charges of different compositions is carried out. Graphical analysis revealed the optimal ratio between kaolin and DSC, which is 75 : 25 (Figure 1). With this ratio, 100 kg of the calculated alloy contains 53.25 kg of Al, 43.33 kg of Si, 1.18 kg of Fe, 0.65 kg of Ca and 1.60 kg of Ti.

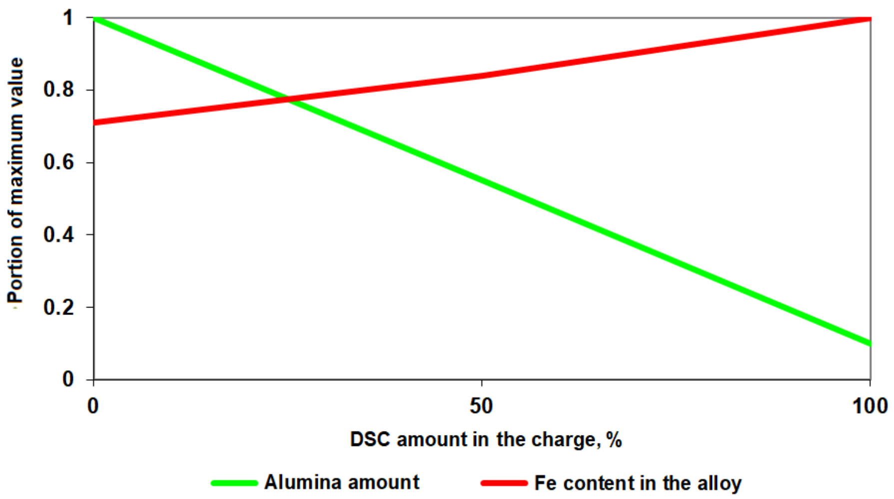

Figure 1 – Influence of amount DSC in the charge on iron content in the alloy

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At the production of the primary aluminium-silicium alloy, slag is formed, containing 46 % Al_2O_3, 40 % SiO_2 and up to 3 % Fe_2O_3. Such slag is advisable to use for undercharging to improve the quantitative characteristics of the production process. To reduce the cost of the charge based on kaolin and DSC, the addition of return slag formed during the alloy production was considered. The mass and composition of the primary alloy were calculated when adding return slag to the charge in the amount of 0 %, 10 %, 20 % 100 % of the charge mass. Calculations showed that with an increase in the slag amount, the iron content coming from the slag increases in the alloy. Graphical analysis showed that the slag addition of 28 % will not deteriorate the quality of the primary alloy (Figure 2).

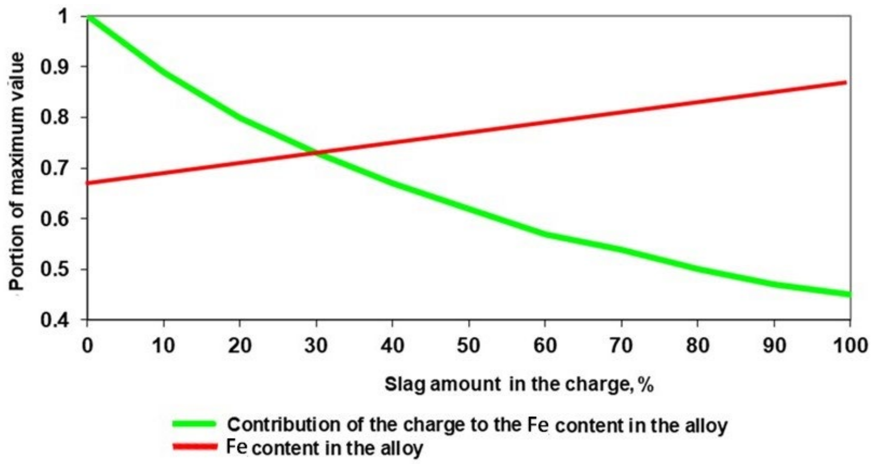

Figure 2 − Effect of adding slag to the charge on iron content in the alloy

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The characteristics of the charge and alloy were calculated when using different ratios of alumina and quartz sand in the charge. The calculation results are given on Figure 3 and Figure 4.

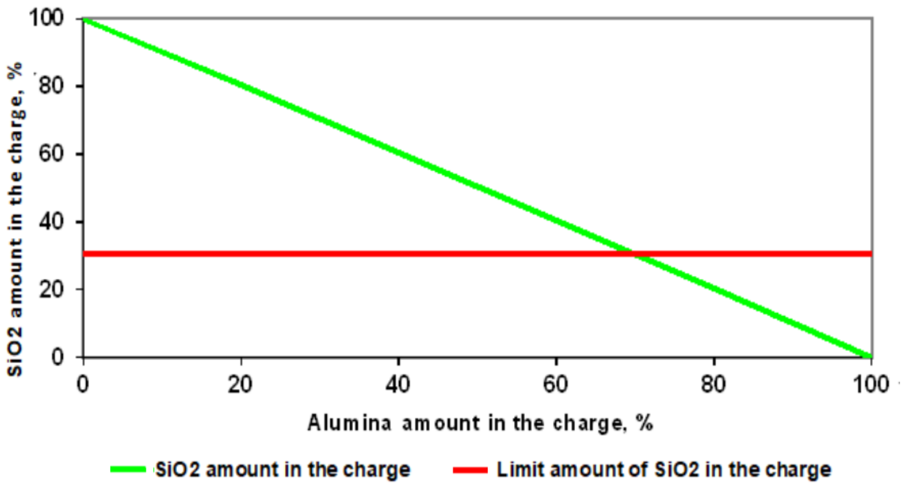

Figure 3 − Effect of the alumina amount on the SiO_2 amount in the charge

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For the joint reduction of Al_2O_3 and SiO_2 oxides and the destruction of the formed aluminium carbides, it is necessary to have a certain amount of silicium oxide in the charge. When the SiO_2 content in the charge is less than 30.5 %, the destruction of Al_4C_3 carbide becomes difficult. Graphical analysis revealed that it is possible to use charges with an alumina content in the charge of less than 70 %. That is, an alloy with a content of 65 % Al fully meets these requirements for providing the necessary amount of silicium oxide for the destruction of aluminum carbides.

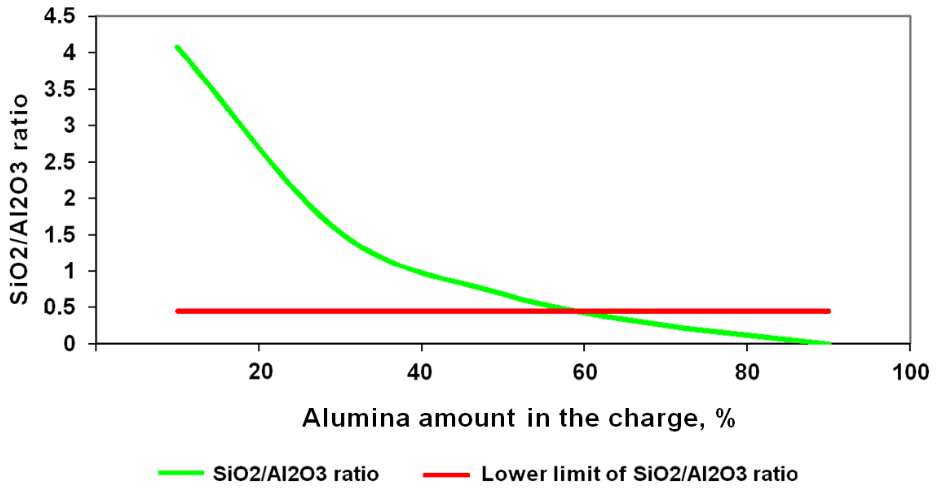

Figure 4 – Effect of alumina content on the SiO_2/Al_2O_3 ratio

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The study of charges based on alumina and quartz sand showed that their cost is quite high and increases with an increase in the alumina content in the charge (Table 3). However, according to calculations, a feature of these charges is the low iron content in the resulting alloy. The iron amount in the alloy containing 65 % aluminum reaches 0.17 % when a charge contains of 65 % alumina and 35 % quartz sand. Such an iron content in the alloy makes it possible not to use low-temperature filtration. Increasing the yield of the alloy results in a reduction in the cost of commercial products, which, due to the use of expensive alumina, is still quite high.

Table 3 − Comparative characteristics of different compositions charge

Charge composition	Charge amount, kg	Charge cost, conventional units	Yield of primary alloy, kg	Yield of finished products, %
Industrial charge	133,0	63,60	51,525	92
Kaolin + DSC	126,0	56,95	51,124	92
Kaolin + DSC + 25 % slag	157,5	60,27	56,127	92
Alumina + quartz sand	100,0	94,50	44,463	98
Alumina dust + quartz sand	100,0	67,20	42,324	98

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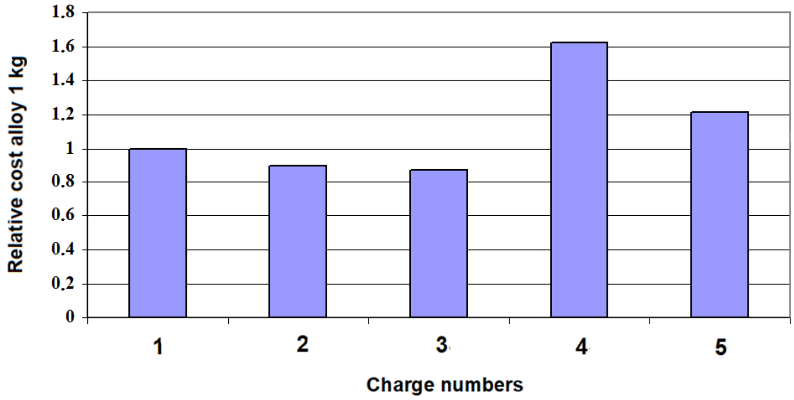

1 – industrial charge;
2 – kaolin + DSC;
3 – kaolin + DSC + 25 % slag;
4 – alumina + quartz sand;
5 – alumina dust + quartz sand

Figure 5 − Influence of the charge composition on the cost of the obtained alloy

Author's development

To reduce the cost of this type of charge, it is planned to replace expensive commercial alumina with alumina dust, despite the increased content of SiO_2 and Fe_2O_3 impurities. When studying different charge compositions for smelting silicoaluminum, the following main parameters were compared: alloys yield, charge cost, content of basic elements (Al, Si) and harmful impurities (Fe, Ti, Ca) in the alloy. The influence of the charge composition on the cost of the primary aluminum-silicon alloy is shown in Figure 5.

The studies allow us to conclude that the used industrial charge is not optimal for this production. Charges using aluminum-rich distensillimanite concentrate allow us to achieve better production performance.

Conclusions.

1. Aluminium-silicium alloys obtained by electrothermal method cannot currently compete with synthetic alloys in terms of production volumes due to their limited prevalence. Reducing the cost of structural aluminium alloys obtained by diluting silicoaluminium with primary aluminium can be achieved by developing new types of raw materials, in particular returns and waste from alloy production.

2. The base of potential raw aluminium-containing materials from Ukrainian deposits for obtaining silicoaluminium has been studied quite poorly. Kaolin and

alumina are mainly used in production. The study of charge compositions from a mixture of components in different ratios allows you to select charge compositions from cheap raw materials to produce alloys with a low content of impurity elements.

3. To reduce the charge cost based on kaolin and DSC, the addition of return slag formed during the alloy production was considered. Analytical studies have established that adding 28 % of slag to the kaolin-DSC-slag charge will not deteriorate the quality of the primary alloy.

4. The optimal charge is a composition of 75 % kaolin and 25 % DSC with the addition of alumina to obtain 65 % aluminium in the primary aluminum-silicium alloy and an additional addition of 25 % of the return slag from the charge mass. This composition of the charge during ore-thermal smelting provides an 8 % higher the primary alloy yield and a 13 % reduction in the cost of the finished alloy compared to the industrial charge, and allows the disposal of waste from our own production.

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Анотація. *У роботі досліджено основні алюмосилікатні матеріали українських родовищ, які розробляються промисловим способом і придатні як шихтові матеріали для виплавлення силікоалюмінію електротермічним способом. Описано методику розрахунку, виконано розрахунки шихтових композицій з різних компонентів у різних співвідношеннях, які дозволяють підібрати склади шихт з дешевої сировини для отримання силікоалюмінію з низьким вмістом домішкових елементів. Досліджено вплив складу і співвідношення шихтових матеріалів на якісні та економічні характеристики отриманого силікоалюмінію. Визначено оптимальний склад шихти для виплавлення силікоалюмінію з додаванням до шихти зворотного шлаку, що утворюється при отриманні сплаву. Запропонований склад шихти під час руднотермічної плавки забезпечує на 8 % вищий вихід первинного сплаву та зниження вартості товарного сплаву на 13 % порівняно з промисловою шихтою, дозволяє утилізовувати відходи власного виробництва.*

Ключові слова: *алюмосилікати**,** шихтова композиція, первинний алюмінієво-силіцієвий сплав, зворотний шлак, силікоалюміній.*

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