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THE SPECIFIC FEATURES OF MANUFACTURING CORROSION-RESISTANT FLUOROPHLOGOPITE PRODUCTS BY ELECTRIC ARC MELTING WITH THE USE OF CARBIDE POWDER MODIFIERS IN CONDITIONS OF SMALL-SCALE PRODUCTION

Introduction. *The reliability and efficiency of industrial metallurgical units such as chlorinators, electrolyzers, and others operating in aggressive acid and alkaline environments at high temperature are primarily determined by their service life.*

Problem Statement. *The corrosion-resistant protective layer of the inner surfaces of metallurgical units composed of relatively small individual protective elements has a drawback, namely, a joint made of mounting compounds that have a much lower resistance.*

Purpose. *The purpose is to create technologies for small-batch and periodic production of dense cast heat- and corrosion-resistant products in the form of massive shaped castings from fluorosilicate melt.*

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Material and Methods. Fluorine- and potassium-containing mineral compounds have been used as charge materials due to their availability and manufacturability. The melting and casting conditions have been evaluated based on the current-voltage characteristics of the power source of the electric arc furnace. The mineral composition and microstructure of the cast material have been studied by the crystal optical method in transparent sections and uncut sections.

Results. Optimization of the batch composition and melting conditions allows reducing the melting time of fluorophlogopite melt 2.3 times and the total energy consumption of melting by 38%. The use of carbide modifiers ensures a homogeneous structure in the outer skin and the main part of the casting, with the size of fluorophlogopite crystals ranging from 0.10 to 0.15 mm.

Conclusions. The choice of raw materials for fluorophlogopite casting significantly affects the conditions of melt formation and the structure of the cast material. To achieve the purpose of the research, the authors have proposed a technology for the manufacture of cast fluorophlogopite products, which combines the selection of charge mineral materials, the optimization of the electric arc melting conditions for obtaining fluorosilicate melt, and the castings structure control by means of modification with silicon and boron carbide powders.

Keywords: stone casting, artificial mica, fluorophlogopite, corrosion-resistant materials, carbides, and modification.

Improving the operational reliability and increasing the service life of the main units of metallurgical and chemical production are important tasks of Ukraine's industry. The upgrade of metallurgical and chemical enterprises is closely related to the use of cutting-edge corrosion-resistant materials to protect the operating surfaces of chemical and metallurgical units. Resistance to the prolonged action of melts, acid solutions, and alkali salts at high temperatures requires the use of corrosion-resistant materials without open porosity that leads to the impregnation of aggressive substances into the material and its further destruction. Only cast ceramic materials made by electric arc melting of aluminosilicates (alumina, fireclay) and stones (diabase, basalt) possess the required properties. There has been no serial production of such materials in Ukraine. Domestic metallurgical and chemical enterprises are completely dependent on the import of these materials from abroad. At the same time, the imported refractory products have standard shapes (bricks, blocks, tiles) and during the assembly, they form a plane of joints vulnerable to the impregnation by aggressive media, which reduces the total service life and efficiency of chemical and metallurgical units. The production of shaped massive castings for most ceramic materials is a complicated and costly process, primarily due to extremely low casting properties of these materials. The cast material obtained by the casting of oxyfluoride melts can be used as a refractory corrosion-resis-

tant material. Their casting properties are close to those of cast iron; upon crystallization, these melts form a composite polycrystalline structure of artificial mica (fluorophlogopite) and a glass phase with inclusions of impurities along the crystal grain boundaries [1].

Artificial mica fluorophlogopite is a complex oxide with a complex crystalline structure. Its high dielectric properties determine the main industrial application of fluorophlogopite, in the form of chipped single crystals that, having been machined, are used for the production of sheet mica, mica powder and mica products on polymer and vitreous binders [2]. The basis of melting and casting technology for this type of material has been developed by PTIMA of the NAS of Ukraine and IPM of the NAS of Ukraine [3]. In comparison with the standard corrosion-resistant lining, the refractory lining of large-sized monolithic stone fluorophlogopite products has the following indisputable advantages:

- ◆ lining without mounting joints;
- ◆ various lining shapes;
- ◆ installation manufacturability;
- ◆ lower labor costs of installation.

The main advantage of protective fluorophlogopite products is a unique set of physical, mechanical, and technological properties (corrosion resistance, heat resistance, thermal shock resistance, high-temperature strength, and durability of the products) as compared with other refractory materials. It is possible to obtain massive products

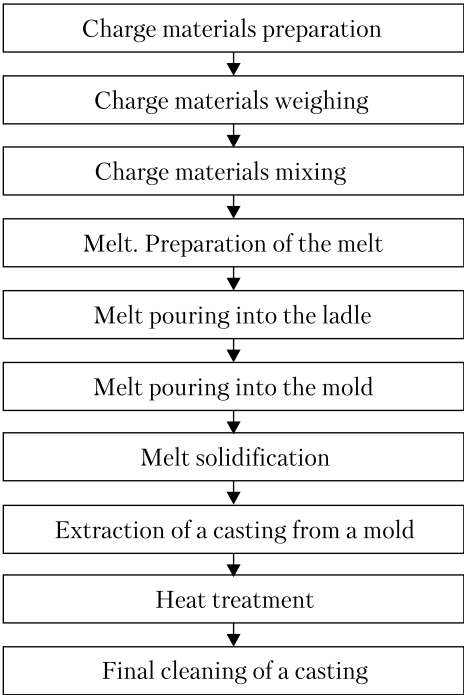


Fig. 1. Block diagram of the fluorophlogopite casting process

with closed porosity (4–6%) and sizes up to 1500–2000 mm by casting from fluorophlogopite melt. The cast fluorophlogopite products have passed industrial trials in real production conditions as a part of a diaphragm-free magnesium cell, at the Ust-Kamenogorsk Titanium and Magnesium combine (Kazakhstan). The trial lasted for 47 months and 20 days, i.e. the fluorophlogopite products worked out the whole service life and still remained in operating condition.

OBTAINING FLUOROPHLOGOPITE CASTINGS BY ARC MELTING

With this experience, the specialists of PTIMA of the NAS of Ukraine have developed a technology for casting massive shaped cast products from cast fluorophlogopite. The technology can be implemented for the manufacture of separate corrosion-resistant refractory products, as well as for the industrial production at metallurgical enterprises, with the use of die or sand mold casting (Fig. 1).

The research deals with the results of industrial trials of the developed production technology as an accompanying manufacture of corrosion-resistant cast fluorophlogopite products for own needs of metallurgical production. The technology has been implemented within the framework of R&D cooperation between Zaporizhzhia Titanium and Magnesium Works Ltd and PTIMA of the NAS of Ukraine.

Increasing the service life and the efficiency of the main metallurgical units of titanium-magnesium plants is impossible unless a high level of tightness and reliability is ensured. The only way to achieve this is to use massive monolithic corrosion-resistant refractories for chlorine accumulation and supply parts. Such corrosion-resistant parts shall reliably protect process equipment from aggressive melts of chloride salts, chlorine, and metallic magnesium, which have a high chemical activity in the molten state [4].

The stone fluorophlogopite products for the protection of the most vulnerable to corrosion structural parts of the main equipment of ZTMC Ltd (chlorinators and electrolyzer cells) include chlorine lances, electrode protection, tap hole, curtain stone, and others. In general, in terms of weight, the demand for such corrosion-resistant products per 1 cell is 8000–10000 kg. Mainly, they are large massive complex-shaped castings with a wall thickness of up to 200–250 mm and a weight of up to 350–400 kg. Practically, it is difficult to obtain such castings with a homogeneous fine-crystalline structure.

The manufacture and application of cast fluorophlogopite products have shown that the main crystalline phase of fluorophlogopite forms the basis of the product and does not interact with melts of chlorides, magnesium, and chlorine. As a result, the material preserves its structure and physical and mechanical properties. However, the developed experimental technology contains many shortcomings to be removed:

- ◆ charge materials;
- ◆ optimizing the melting conditions and melt attainment;

- ◆ ensuring a uniform fine crystal structure of castings.

Removing these shortcomings allows obtaining high-quality massive-shaped fluorophlogopite castings (for magnesium chlorinators) by means of the foundry workshop of ZTMC Ltd.

The experimental production site for stone-fluorophlogopite products at ZTMC was organized in the foundry workshop equipped with foundry and thermal equipment and other facilities for cast stone production. To obtain a fluorosilicate melt we have used an electric arc single-phase furnace with a graphite conductive hearth and a graphite lining of the original design (Fig. 2). It has been created on the basis of a flux-melting furnace developed by E.O. Paton Institute of Welding of the NAS of Ukraine. The melt is poured into sand-and-clay molds with a pouring ladle. The melting conditions have been optimized based on the volt-ampere characteristics of the process at different melting stages to reduce the total power consumption of the process. The melting and casting temperature is controlled by a non-contact pyrometer (*Bentech GM 1651*) and a type-k thermocouple (BP-5/20). The viscosity characteristics of the fluorophlogopite melt are measured by an electrorotational viscometer with a registration unit based on an analog-to-digital converter NI 6009 USB. The petrographic method is used to study the cast material structure properties and mineral composition. To study the material microstructure, samples of various thicknesses are carved from different parts of the casting. The polished planes of the metallographic samples are studied in the reflected light mode. The macrostructure of the samples is observed with an MBS-2 binocular microscope. The microstructure and mineral (phase) composition are studied by the crystalloptic method in transparent sections with polarization microscopes MIM-8 and MIM-10 with a dark-field illuminator, at a magnification of up to 200 times. The phase is determined by measuring individual optical characteristics of the phase [5]. The refractive indices of fluorophlogopite crystals and other minerals are determined in im-

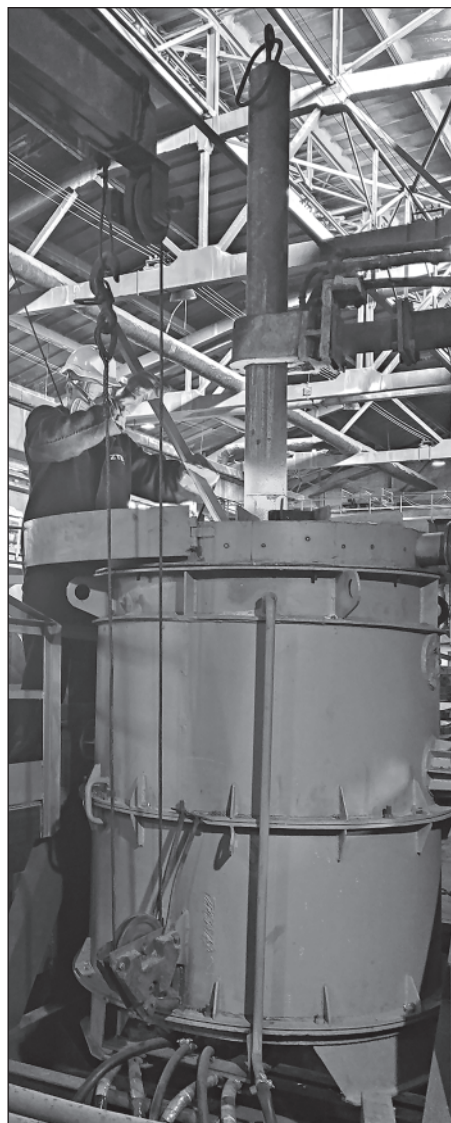


Fig. 2. Smelting of fluorosilicate melt in the arc furnace of ZTMC Ltd

mersion liquids. The volume of separated phases is measured by the comparative method of determining minerals in micro sections.

THE CHARGE MATERIALS OPTIMIZATION FOR FLUOROPHLOGOPITE CASTINGS

Based on the chemical composition of the fluorophlogopite molecule $[\text{KMg}_3(\text{Si}_3\text{Al})\text{O}_{10}\text{F}_2]$, we may use mineral raw materials containing oxides

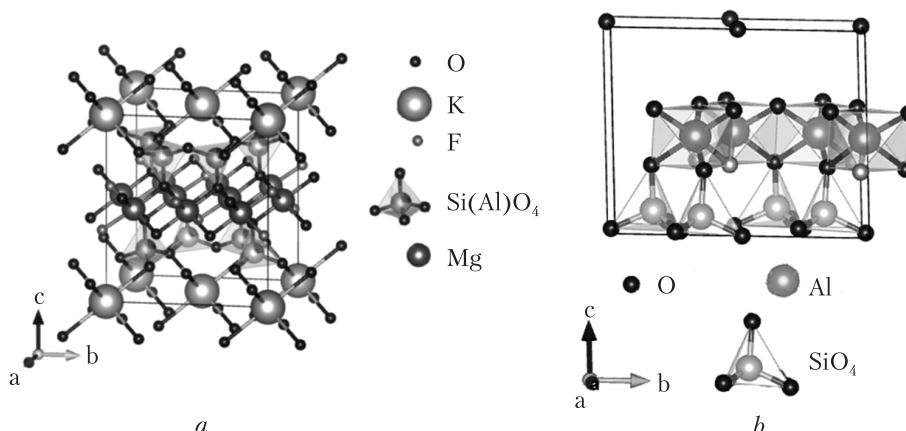


Fig. 3. The molecular structure of fluorophlogopite (a) and kaolinite (b) [6]

of magnesium, silicon, and aluminum as charge materials for obtaining fluorophlogopite melt. Fluorophlogopite casting may be made from a variety of charge materials and the choice depends on their cost and availability. In addition, as a result of experimental melting and energy consumption measurements, it has been found that the use of mineral raw materials with clay mineral kaolinite [$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$] allows reducing the total melting energy consumption (by 12–17 %) and the total melting time. This effect can be explained by the fact that the structure of kaolinite accelerates the synthesis of fluorophlogopite during the melting of charge materials, due to the fact that like fluorophlogopite, kaolinite has [SiO_4] tetrahedrons with total formula [Si_2O_5] ∞ in its structure (Fig. 3) [6]. In the presence of kaolinite, during the fluorophlogopite melt synthesis, the structural rearrangement of tetrahedrons does not require much time and energy, which leads to a decrease in the energy consumption of obtaining the melt in arc furnace.

The market analysis of the fluorine-containing materials has shown that potassium cryolite and magnesium fluoride used in the production of aluminum by electrolysis are the most suitable for use as fluorine-containing charge components in terms of availability and properties. When cryolite is added, together with fluorine, potassium and alumina are partially introduced into the composition

of the charge as well. The lack of potassium can be compensated with potash, while fireclay powder, is the most available and cheapest product to substitute the alumina. Silica is partially introduced into the charge together with alumina.

The fluorine- and potassium-containing minerals (potassium cryolite [KAlF_4], potassium hexafluorosilicate [K_2SiF_6], and potash [K_2CO_3]) have been chosen as sources of fluorine and potassium for the charge. The best mineral source of silica [SiO_2] is quartz sand, while that of magnesium oxide [MgO] is periclase.

In the case of combining potassium hexafluorosilicate (K_2SiF_6) and fireclay containing ~20 wt. % Al_2O_3 , the approximate composition of the charge is as follows: — 28 wt. % periclase metallurgical powder; 25 wt. % potassium hexafluorosilicate, and 47 % wt. fireclay.

OPTIMIZATION OF CONDITIONS FOR ARC MELTING OF FLUROSILICATE MELTS

The general scheme of fluorosilicates melting in an arc furnace includes the three stages: obtaining of a mineral melt (the furnace operates in the “arc” mode), bulk melting (the furnace operates in the “resistance” mode), heating and pouring of melt. During the melting a part of the fluorine evaporates, especially at the first stage of

melting, when the furnace operates in the “arc” mode, there is a risk of local overheating of the melt. Therefore, the amount of fluorine in the melt depends on the melting temperature and time parameters, which significantly impact the structure and properties of the material of castings. To reduce local overheating at the first stage, we make pre-arc heating of the furnace volume, which is followed by loading the recycled fluorosilicate as raw material in the amount that provides a 20–30 cm level of melt in the furnace. This allows loading the mineral charge materials directly into the liquid melt when the furnace operates in the “resistance” mode. The second melting stage is performed in the forced mode, to reduce the melting time when fluorine can be released. At this stage, the charge is rapidly loaded into the furnace, at a rate that does not allow the formation of a complete melt mirror. The mirror is formed as late as at the third stage. The proposed melting mode removes the melting power dip between the first and second stages and reduces the melting time (from 60 to 26 min) and the energy consumption (by 38%) (Fig. 4).

The casting formation consists of heterogeneous phenomena, but the structure of the casting and most of the properties are formed during the solidification of the melt in the mold.

CAST STRUCTURE CONTROL AND MODIFICATION

Casting process includes the formation of surface crust, bulk cast structure, and various defects that worsen casting's quality: in homogeneity of crystal structure, shrinkage hole, gas and shrinkage porosity, residual stress cracks, and others. As the thickness and mass of the casting increase, so do the size and the number of various crystallization defects. Removing these defects and flaws is the precondition for high-quality stone casting production.

The sample analysis of the fluorophlogopite material poured into sand molds has shown that the charge composition has the macro- and microstructure of a straight zonal structure (Fig. 5). The outer part of the casting has a layer of parallel columnar crystals having a size of up to 10 mm. Such structure is harmful to the corrosion-resistant cast products because of 5–10 vol. % of the glass phase that is vulnerable to the aggressive environment and is concentrated on the borders of fluorophlogopite crystals, which may lead to destruction of the casting.

The most difficult issue in the production of cast stone products is to control the crystallization of castings. The mineral (phase) composition

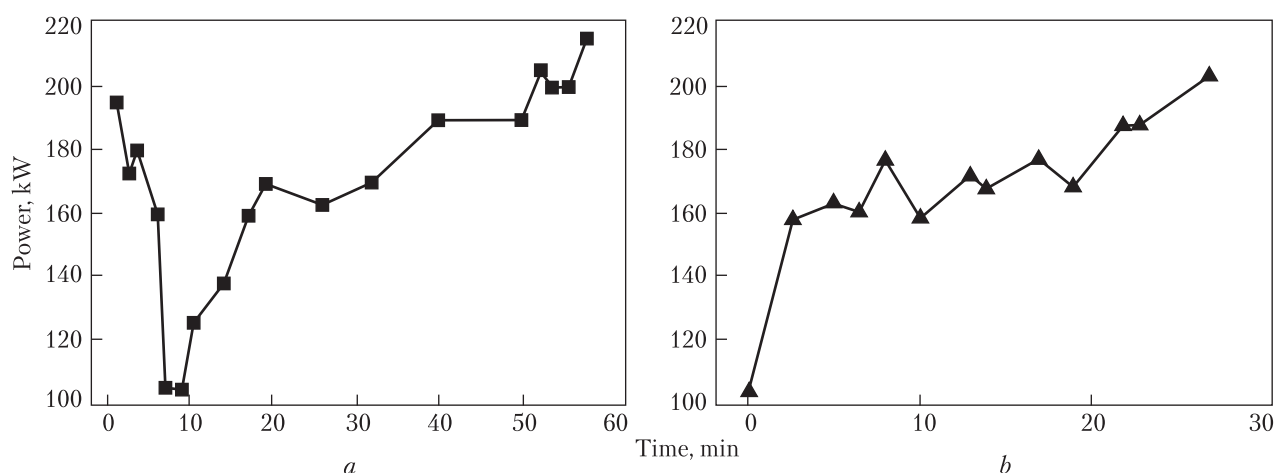


Fig. 4. Energy consumption during the obtainment of fluorosilicate melt: *a* – before optimization; *b* – with the used of optimized melting mode



Fig. 5. Cast structure of fluorophlogopite, $\times 50$

of the casting material should contain about 90 vol. % of the main phase, fluorophlogopite, and the minimum level (at most, 10 vol. %) of the glass phase and(or) impurity minerals. The purpose of controlling the fluorosilicate melt crystallization is to provide a monolithic growth of small-size crystals of fluorophlogopite in the form of a casting. Thus the size and morphology of the crystal phases should be adjustable to get a macro- and microstructure without changing the phase composition of the cast material. The fluorophlogopite melt poured into the mold starts getting solidified, because of super cooling, the crystallization process begins, and crystals grow. It is possible to control the cast structure by regulating the rate of crystallization center formation and crystal growth. For the fluorosilicate melts, it is possible to apply two approaches to manage the process of nucleation and growth of crystals; these are the modification and the adjustment of the melt density due to isomorphism of the fluor-

ophlogopite crystal structure. It is possible to reduce the growth rate of fluorophlogopite crystals by isomorphic replacement of Al^{3+} cation with Si^{4+} cation. In the fluorophlogopite melt, there are relatively isolated and structurally different regions (equal in equimolecular amount): the silicate clusters of complex structure, including Si^{4+} , Al^{3+} ions, and the fluoride liquid enriched in K^{1+} , Mg^{2+} ions. An increase in the number of Si^{4+} cation increases the viscosity of the fluorosilicate melt, thereby reducing the rate of the crystals' growth.

The ratio of the content of cations (Si^{4+} and Al^{3+}) that, as mentioned, form the tetrahedral grid as the main nucleus of the fluorophlogopite structure (50% of the whole material structure [7]), has a significant effect on the structure of the cast material and the size of the fluorophlogopite crystals. As Al^{3+} cation concentration in the melt increases and exceeds the stoichiometric one (12.1 wt. %), the melt viscosity decreases, the linear growth rate of fluorophlogopite crystals increases, the structure of the material becomes coarse crystalline and zonal, and the linear size of crystals in the central zone reaches 12 mm. This is explained by a low melt viscosity, as a result of an increase in the Al^{3+} cation content. At the pouring temperature (about 1400 °C), the viscosity ranges within 0.25–0.30 n · s/m², which for the stoichiometric content should reach 0.5–0.7 n · s/m². As the concentration of Si^{4+} cation ups (exceeds the stoichiometric one), the viscosity increases, the growth rate of fluorophlogopite crystals decreases, the cast structure becomes homogeneous, fine-crystalline, the linear size of fluorophlogopite crystals is 0.5–3 mm. The conclusion is boosting the fluorosilicate melt viscosity is a way to control the crystal growth and to provide a desirable fine-grained structure with small fluorophlogopite crystals. An example of cast structure control by the isomorphism effect is the mineral composition of charge materials developed for ZTMC Ltd, which has the following chemical composition: 6–8 wt.% Al_2O_3 , 40–38 wt. % SiO_2 , 28 wt. % MgO , and 26 wt. % K_2SiF_6 .

The periodic production of stone products for own consumption by metallurgical enterprises is

associated with numerous difficulties caused by the specifics of non-mass production. First of all, this is the charge material quality. The raw materials of technical purity (quartz sand, fireclay powder, periclase) usually do not pass periodic batch control of the chemical and mineral composition stability. The use of chemically pure reagent-grade oxide materials for industrial production as charge materials is economically unfeasible. Therefore, controlling the crystal formation process by the isomorphism mechanism is not sufficient for small-scale production. Moreover, additional impurities in a mineral mixture of technical purity (calcium oxides, sodium oxides, iron oxides, manganese oxides, titanium oxides, etc.) affect the amount of glass phase, which significantly deteriorates the properties of the cast material. Therefore, for the periodic production of cast stone products, it is necessary to use additional modifiers, especially those of the nucleation type (the second type modification). This gives an increase in the crystallization nuclei number without inhibiting the growth rate of crystals. The first type modification prolongs the crystallization time and increases the supercooling degree of the melt, it can result in the formation of additional glass phase.

The mechanism of the crystallization of fluorophlogopite melt, as well as other silicate systems, includes the two physical processes: the formation of crystallization centers and the crystal growth [8]. The centers of crystallization in the fluorophlogopite melt are as follows: gas bubbles (CO , CO_2 , H_2 , KF , SiF_4 , etc.), whiskers, graphite inclusions (the result of electrode and lining combus-

tion), fine iron particles (reduced from impurities of charge materials), as well as high-temperature minerals (percales, norbergite, forsterite, etc.) [9]. In addition to microliquefaction phenomena, the fluorophlogopite melt is characterized by macrostratification, especially in large volumes of melt [7]. Thus, controlling the fluorosilicate melt crystallization without periodic input control of the mineral charge materials can be done only by additional melt modification. It is obligatory for the production of quality castings with fine-grained crystal phase.

The modification technology has been finalized and tested in industrial conditions, with the use of silicon carbide (SiC) and boron carbide (B_4C) powders as modifiers.

The molar mass of silicon carbide is 40.096 g/mol, the density is 3.21 g/cm³, the melting point is 2730 °C. SiC is a hard refractory, thermally stable, inert substance that does not melt at any pressure, has a very low thermal coefficient (TCLE) of linear expansion ($4.0 \cdot 10^{-6}$ K) and has no phase transitions in a wide temperature range. The stiffness, high thermal conductivity, and low TCLE make SiC a thermo stable material in a wide range of temperature [10].

Silicon carbide powder (particles 20–50 μm) is added to the melt in the two ways: in the course of melting with the last portions of the charge and introduced to the melt stream in the course of the pouring process. The properties of the obtained cast materials are given in Table 1.

The stoichiometric composition fluorophlogopite casting (without modification) has a coarse

Table 1. The Properties of Fluorophlogopite Material Modified with Silicon Carbide Particles

Sample number	SiC amount, wt. %	The average size of fluorophlogopite crystals, mm		Phase composition, vol. %		
		Casting's skin zone	Casting's center	Fluorophlogopite	Enstatite	Glass phase
1	0	0.3÷0.5 –	8÷10	75	15	10
2	1	0.3÷0.5 –	1.5÷2	80	10	10
3	2	0.15 –	0.20	86	10	1–4
4	3	0.10 –	0.15	85	10	1–5

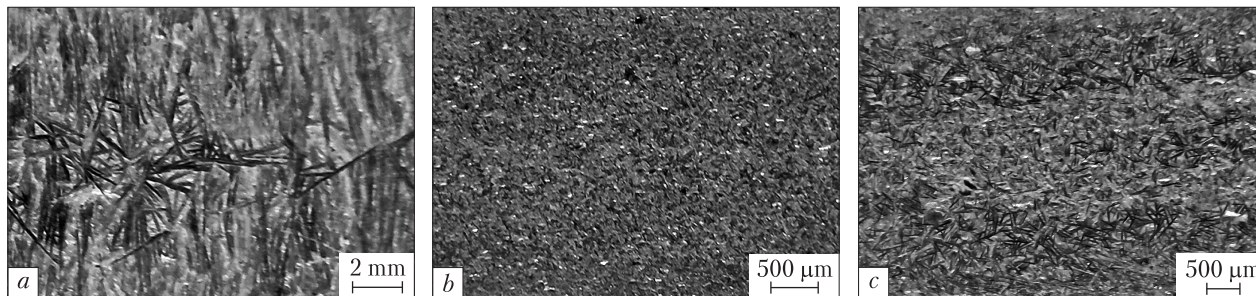


Fig. 6. The modified fluorophlogopite structure: *a* – modified by 1.0 wt. % SiC; *b* – modified by 3.0 wt. % SiC; *c* – modified by 0.3 wt. % B_4C

crystalline zonal structure with long- and narrow-plate crystals. The fluorophlogopite crystal size increases from 0.3–0.5 mm, in the skin zone, to 8–10 mm, in the center. The fluorophlogopite crystals have different optical orientation. Their characteristic optical properties are clear relief, relatively perfect cleavage, bright second-order interference colors, direct attenuation, positive elongation, angle 2V: 10–15°, optically negative; $n_g = 1.548–1.549$; $n_p = 1.519–1.52$ (Fig. 5).

The addition of silicon carbide fine particles changes the crystallization properties of the melt. SiC particles are distributed uniformly in the casting's body in both introducing methods. It is easier to add modification powder to the last portions of the charge, so this method is more convenient. The addition of 1 wt. % SiC particles leads to the formation of an almost homogeneous cast structure, with the fluorophlogopite crystal size in the casting's center decreasing to 1.5–2 mm. The modification of 2–3 wt. % SiC causes even more fine cast microstructure and provides a homogeneous morphology of fluorophlogopite grains in the skin and in the main part of the casting.

The microstructure analysis has shown that the silicon carbide particles are in the centers of crystal grains. It has proven their nuclei action for fluorophlogopite crystals. The material modified by SiC particles has a uniform and homogeneous structure over the whole cross-section of the casting.

The petrographic analysis has shown that the volume phase content of the cast material remains the same after modification with 1 wt. % SiC, un-

like the size and morphology of the phases (Fig. 6, *a*). In the cast structure, there is an impurity phase of enstatite mineral in the form of dendrites with a size of 0.02–0.3 mm. The glass phase is isolated in the area of fluorophlogopite crystal cleavage and in the interstitium. In SiC material modified with 3 wt. % the amount of glass phase decreases sharply to 1 vol. %, which testifies to a significant increase in the silicate melt crystallization ability. During the melting, the shape of silicon carbide particles in the fluorosilicate melt remains unchanged with acute angles morphology (Fig. 6, *b*). The mentioned above mass amount of silicon carbide modifier corresponds to the 10–50 μm particle size of the powder modifier. If we use a smaller SiC powder fraction, the modifier's efficiency increases proportionally to the specific surface area of the used powder, i.e. by parabolic law in terms of particle radius. The modification by 0.1 wt. % ultra-dispersed (up to 1 μm) silicon carbide particles gives an effect similar to that in the case of modification with 3–5 wt. % 50 μm powder modifier. The silicon carbide modifier fraction can be adjustable in terms of size and quantity for achieving the lowest modification cost possible.

Boron carbide particles having a size of 100–200 μm have been used as modifier with the last portions of the charge. Boron carbide B_4C is one of the most chemically stable compounds, it decomposes above 2450 °C, its density is 2.52 g / cm^3 , the temperature coefficient of linear expansion is $4.5 \cdot 10^{-6} K^{-1}$ (300–1100 K), and the micro hardness is 49.1 GPa [11].

B_4C boron carbide changes the crystallization properties of the melt and acts as a surfactant (the first type cast modifier). According to the petrographic analysis, B_4C boron carbide particles are located on the borders of fluorophlogopite crystals and thus inhibit their growth. As mentioned above, this type of modification is less desirable for fluorosilicate melts, because of the risk of increasing the glass phase, however, the effect from modification with 100–200 μm boron carbide powder is significant starting with a content of 0.3 wt. %, so the required amount to fine the microstructure and to ensure the uniform grain morphology of the casting should be 8–10 times less than that for the same fraction of silicon carbide powder. At the same time, boron carbide modification redistributes the amount of crystalline and glass phases and thickens the plates of the amorphous component (Fig. 6, c). Unlike silicon carbide, boron carbide is soluble in the fluorosilicate melt, so decreasing the particle size does not affect its efficiency.

During the industrial tests of the technology, the modified massive corrosion-resistant fluorophlogopite castings with a weight of up to 300 kg (Fig. 7) have been obtained at the foundry site of ZTMC Ltd.

In this research, the casting technology of massive shaped fluorophlogopite products has been improved in terms of optimizing the charge mineral material cost; reducing the energy consumption for obtaining fluorosilicate melt; and optimizing the melting conditions and casting processes. As a result, the melting time decreases 2.3 times, while energy consumption becomes lower by 38%. The modification and the isomorphism phenomenon ensure a guaranteed fine crystal structure of castings without the zone of columnar crystals.

The use of carbide modifiers may compensate for the absence of periodic chemical control of the mineral constituents of charge materials in small-scale or periodic production of fluorophlogopite castings. The modification has been shown to be a prerequisite for ensuring a stable structure of castings, and consequently, a high quality of cor-

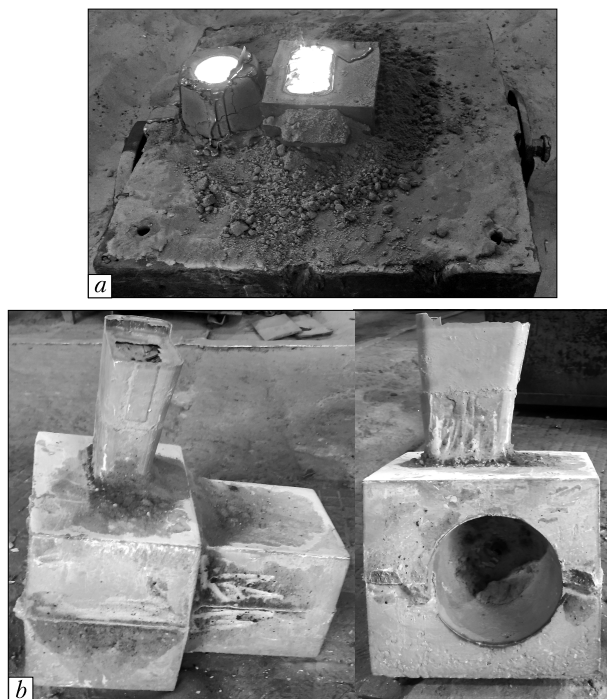


Fig. 7. Production of massive shaped fluorophlogopite castings: *a* – cast mold; *b* – fluorophlogopite casting, a chlorinator element “taphole stone”

rosion-resistant cast products characterized by a fine-grained microstructure and a stable content of the glass phase.

The modification with 3 wt. % SiC (powder particle size ranges within 20–50 μm) provides a homogeneous fine structure of the whole casting body; the size of the fluorophlogopite crystals is 0.10–0.15 mm. The efficiency of modification by silicon carbide powders depends on the powder fraction and can be enhanced by decreasing the modifier particle size. In the case of boron carbide powders used as a modifier its amount is 8–10 times less than in the case of silicon carbide (for a powder particle size of 100–200 μm) to achieve the same modification effect. However, as a first-type modifier, boron carbide increases the volume of a glass phase, the growth of which is not blocked unlike the crystalline one. The effect of silicon carbide is more predictable (in terms of the phase composition of the casting), so its use is more desirable.

The results of the research have become a basis for the industrial technology of fluorophlogopite castings production, which can be implemented for independent manufacture of corrosion-resistant cast products, as well as for manufacturing products for metallurgical enterprises' own needs.

The developed technology allows manufacturing of various-shaped cast corrosion-resistant products, such as channels for aluminum, magnesium, and copper alloy melt; high-energy insulation pro-

ducts as well as heat-resistant gas flow swirlers in plasma and hybrid plasma-laser processes [12].

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ОСОБЛИВОСТІ ОДЕРЖАННЯ КАМЕНЕЛИТИХ КОРОЗІЄСТІЙКИХ ФТОРФЛОГОПІТОВИХ ВИРОБІВ ЕЛЕКТРОДУГОВОЮ ПЛАВКОЮ З ЗАСТОСУВАННЯМ КАРБІДНИХ ПОРОШКОВИХ МОДИФІКАТОРІВ В УМОВАХ МАЛОСЕРІЙНОГО ВИРОБНИЦТВА

Вступ. Надійність та ефективність роботи промислових металургійних агрегатів, таких як хлоратори, електролізери та інші, що працюють в умовах агресивних кислотних і лужних середовищ при підвищених температурах, в першу чергу визначаються строком їх експлуатації.

Проблематика. Захисний шар корозієстійких внутрішніх поверхонь металургійних агрегатів, що складений з відносно невеликих за розміром окремих захисних елементів, має недолік — стик, сформований монтажними сумішами, стійкість яких значно поступається основному матеріалу.

Мета. Створення технологій малосерійного або періодичного виробництва щільних литих жаро- та корозієстійких виробів у вигляді масивних фасонних виливок з фторфосилікатного розплаву.

Матеріали й методи. За доступністю та технологічністю використання, в якості шихтових матеріалів використано фторвмісні та калієвмісні мінеральні сполуки. Оцінювання режимів плавки та лиття виконували шляхом зняття вольт-амперних характеристик джерела живлення електродугової печі. Мінеральний склад та мікроструктуру одержаного каменелитого матеріалу досліджували кристалооптичним методом на прозорих шліфах і аншліфах.

Результати. Оптимізація шихтового складу та режимів плавки й лиття дозволила скоротити час виплавки розплаву фторфлогопіту в 2,3 рази та знизити загальні енерговитрати плавки на 38%. Застосування карбідних модифікаторів показало, що їх використання забезпечує отримання однорідної структури виливка в корковій і основній частинах, розмір кристалів фторфлогопіту складає 0,10—0,15 мм.

Висновки. Вибір сировинних матеріалів для фторфлогопітового лиття значно впливає на умови формування розплаву та структуру литого матеріалу. Запропонована технологія виробництва литих фторфлогопітових виробів поєднує вибір шихтових мінеральних матеріалів, оптимізацію режиму електродугової плавки для одержання фторфосилікатного розплаву, керування структурою виливків, зокрема й завдяки модифікуванню порошками карбідів кремнію та бору.

Ключові слова: кам'яне литво, штучна слюда, фторфлогопіт, корозієстійкі матеріали, карбіди, модифікування.