



Functionalization of one-component cement silicate paint

Yakovlev G.I.^{1*} , Pudov I.A.¹ , Saidova Z.S.¹ ,
Ginchitskaya Yu.N.¹ , Elrefaei A.E.M.M.² 

¹ Kalashnikov Izhevsk state technical university, Russia,

² Egyptian Russian University, Egypt

Abstract. The paper presents the results of a study devoted to expanding the functional properties of one-component cement-silicate paints based on white Portland cement, soluble sodium glass and a hardening retarder (sodium phosphate). Existing compositions, despite their exceptional performance qualities, are not able to provide the entire range of required functional characteristics. Therefore, in order to expand the areas of cement silicate paints application, additives based on aluminum powder and nano-sized titanium dioxide were introduced into the coating composition. This resulted in the increase in the electrical conductivity of the coating and made the paint self-cleaning due to photocatalysis.

The study showed that the introduction of nano-sized titanium dioxide particles into the paint composition provides the rapid degradation of organic pigments (within 2 days) due to the photocatalysis reaction occurring under the influence of ultraviolet solar radiation. The pigments are further removed due to precipitation. This helps to maintain the aesthetic properties of the paint even in high dust conditions, for example, in conditions of sandstorms, which are frequent in the African climate.

The introduction of aluminum powder into the paint composition reduces its electrical resistance (in a wet state) from 5.05 kOhm for the reference sample to 2.7 kOhm for the modified sample. The thickness of the applied paint was 350 microns. This can help the coating to absorb man-made electromagnetic radiation due to shielding, while preventing the accumulation of static electricity on the surface, which also contributes to less dust in the premises. In addition, the use of aluminum powder instead of traditional electrically conductive carbon-containing additives allows maintaining the aesthetically pleasant white color of the paint.

Keywords: one-component paint, white Portland cement, aluminum powder, titanium dioxide, microstructure, shielding, photocatalysis

Please cite this article as: Yakovlev G.I., Pudov I.A., Saidova Z.S., Ginchitskaya Yu.N., Elrefaei A.E.M.M. Functionalization of one-component cement silicate paint. Construction Materials and Products. 2024. 7 (5). 5. DOI: 10.58224/2618-7183-2024-7-5-5

*Corresponding author E-mail: gyakov@istu.ru

1. INTRODUCTION

Currently, different types of water-based emulsion paints are widely used for the in-situ finishing of building facades. Besides, some powder paints are applied to ceramic and sand-lime bricks during their production at brick factories in order to accelerate the rate of construction and obtain better cover qualities, provided by the paint application in factory conditions. The latter technology involves melting the paint powder by a slight heating in special ovens to create a thin polymer-based coating on the surface of the brick. However, despite its attractive appearance, the created coating has a dense structure that does not allow the transfer of vapor and moisture from the enclosing walls to the surface. As a consequence, this barrier for the passage of moisture between the brickwork and the layer of powder paint leads to the peeling of the paint (Fig. 1a - building parapets).

The situation is aggravated by efflorescence, which forms in the interfacial layer (at the boundary between the brick and the coating). When moisture migrates through the brickwork, the salts contained in the brick and masonry mortar dissolve and get carried to the surface of the masonry in the form of efflorescence. The recrystallization and significant increase in volume of efflorescence under the paint film also cause the peeling off the impenetrable layer of powder paint from the surface of the brickwork. (Fig. 1b).



Fig. 1. Destruction of powder paint on the parapet of a residential building (a), peeling of paint from the surface of ceramic bricks (b).

The crystal size of sodium sulfate, which prevails in efflorescence composition, can vary depending on the temperature and humidity of the environment by more than three times (Fig. 2) [1, 2]. Therefore, any slight change in temperature can lead to peeling of the paint layer from the surface bricks.

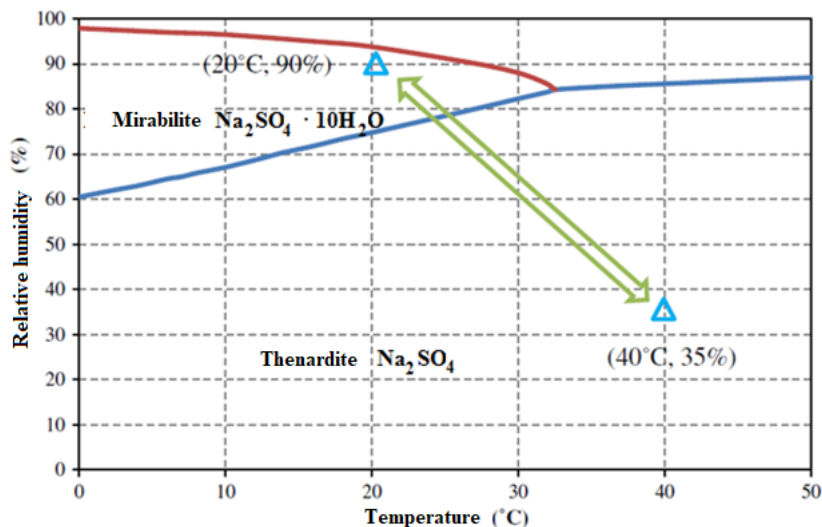


Fig. 2. Sodium sulfate state depending on the temperature and humidity of the environment.

The abovementioned problem of paint coatings destruction on the facades of painted buildings is not new and requires the development of compositions that can withstand the destruction and peeling during the operation of buildings.

To prevent peeling of paint coatings from the facades of brick buildings, it is necessary to use compositions that ensure normal mass transfer through the paint layer. The research team from Kalashnikov Izhevsk State Technical University developed a cement-silicate two-component paint for building facades finishing [3-5]. The advantages of the developed composition in comparison with known silicate paints based on liquid potassium glass and zinc oxide hardener are the increased durability of the composition and a lower price, provided by the use of cheaper liquid sodium glass and a hardener based on Portland cement. Pilot industrial use of this composition has shown a significant durability of the coating (over 25 years) without repainting. However, the application technology of a two-component paint limits its widespread use in construction site conditions.

To increase the manufacturability of a cement-silicate paint, a one-component composition is currently being developed, the production of which can be carried out in the form of a dry mixture.

The previous research [6] has shown that it is possible to replace the liquid potassium glass by the dry powder of soluble glass, namely, by sodium silicate hydrate powder. In this case, all components of the base mixture, including white Portland cement, sodium silicate hydrate, sodium phosphate (soluble glass coagulation retardant) and alkali-resistant pigment, are mixed at the construction site and kept for 15-20 minutes to ensure more complete dissolution of the sodium silicate hydrates. The resulting solution of cement-silicate paint hardens within 1.5 to 2 hours depending on the sodium phosphate content. The resulting coating becomes water resistant after 28 hours of curing.

The introduction of additional functional additives into the paint composition can significantly expand the areas of developed composition application. Therefore, the aim of this research is to study the properties of one-component cement-silicate paint modified with additives based on titanium dioxide and aluminum powder in order to impart new functional properties to the composition.

2. MATERIALS AND METHODS

The main components of the base composition are white Portland cement and soluble sodium glass.

In this research, hydrated sodium silicate powder produced by OOO Laysan in accordance with TU 20.13.62-060-00883732-2019 and meeting the requirements of TU 20.13.62-001-06051139-2020 (Fig. 3a) was used. The silicate modulus of the product varies from 2.8 to 3.4. The mass fraction of components, according to the quality certificate, is 24.13% for sodium oxide (Na_2O) and 70.83% for silicon dioxide (SiO_2). In accordance with the passport data, the time for complete dissolution of sodium silicate hydrate particles in water is 20 minutes at room temperature. If the holding time is not observed when dissolving a dry mixture of one-component cement-silicate paint, sodium silicate hydrate does not completely dissolve (Fig. 3b), which leads to a decrease in the adhesion of the paint to the surface being painted.

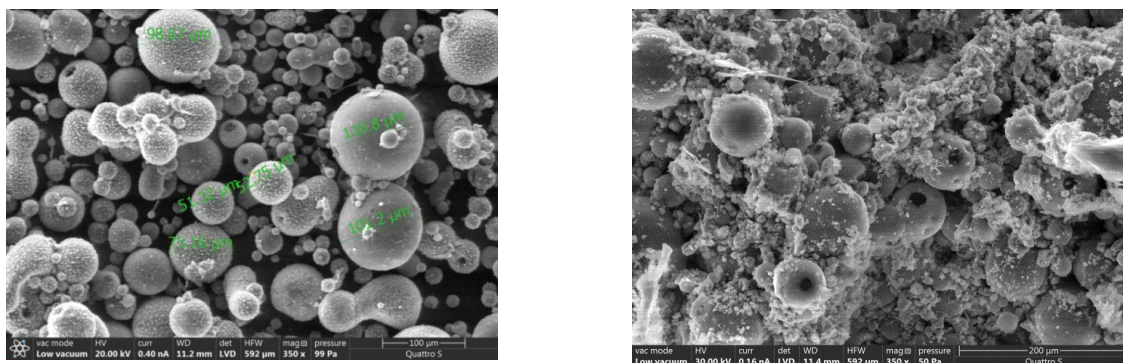


Fig. 3. Microstructure: sodium silicate hydrate powder (a), chipping of the base composition of cement-silicate paint with incomplete dissolution of sodium silicate hydrate (b).

To prevent instant hardening of the system, a retarder was introduced - sodium phosphate Na_3PO_4 according to GOST 201-76 in an amount of 3% by weight of Portland cement.

To expand the functional properties, nanotitanium dioxide with an average particle size of 26 nm was introduced into the composition of the cement-silicate paint. It ensured the creation of self-cleaning paint due to photocatalysis. Before use, the powder produced by ZAO PromKhimPerm was pre-fired at a temperature of 550°C and covered with paraffin to eliminate fire and explosion hazards.

To increase the electrical conductivity of the paint, a conductive component was added in the form of aluminum powder grade PAP-1 according to GOST 5494-2022.

3. RESULTS AND DISCUSSION

When a dry composition of cement-silicate paint is mixed with water, sodium phosphate interacts with calcium hydroxide, which is formed during the hydrolysis of the main mineral of Portland cement, tricalcium silicate [7]. The formed calcium hydroxide reacts with sodium phosphate. The product of the interaction in the form of calcium phosphate blocks the cement particles from the action of water and slows down the coagulation process.

Energy dispersive analysis of the cement-silicate paint confirmed the described hydration process for cement-silicate paint (Fig. 4).

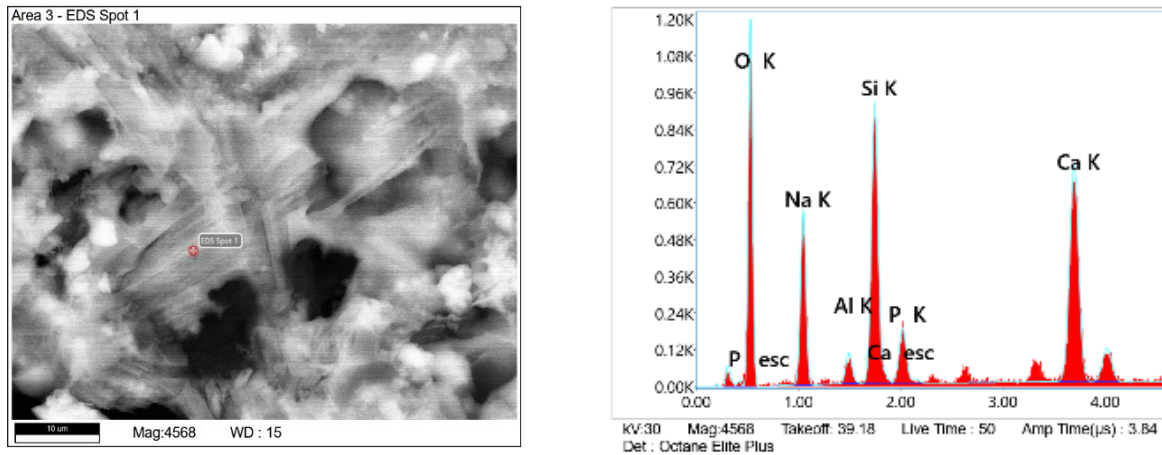


Fig. 4. Energy dispersive analysis of the crystalline hydrate phase in cement-silicate paint: (a) – microstructure of the crystalline hydrate phase in the area of analysis, (b) – chemical composition of hydration products in the structure of hardened paint.

When sodium phosphate is exhausted, cement hydration continues, providing further strengthening and increasing water resistance of hydration products, which are represented mainly by calcium silicate hydrates. Carbonization of liquid glass and calcium hydroxide also take place [8].

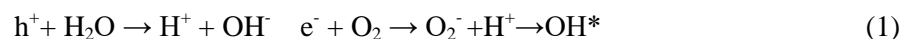
A photocatalyst in the form of nanotitanium dioxide, introduced into the paint, accelerates the slow processes of pollutants decomposition under exposure to sunlight in the ultraviolet range. The resulting products of decomposition are easily washed off by precipitation [9].

Along with the decomposition of organic pollutants, the process of photocatalysis, i.e. absorption of UV radiation by the TiO_2 photocatalyst, also leads to the formation of hydroxyl groups OH^\cdot , which increase the surface energy of the coating and contribute to its increased hydrophilicity [10]. Nanotitanium dioxide can also promote surface disinfection [11].

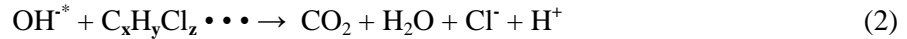
The photocatalytic reaction proceeds as follows (Fig. 6):

- Ultraviolet radiation excites (activates) the valence electron of a semiconductor TiO_2 ;
- The excited valence electron moves to an orbit with a higher energy level (photoexcitation);
- Pairs of electrons (e^-) and holes (h^+) are formed, creating conditions for reduction and oxidation.

Oxidation and reduction reactions:



Organics decompose:



where O_2^- – superoxide (hydrophobic).

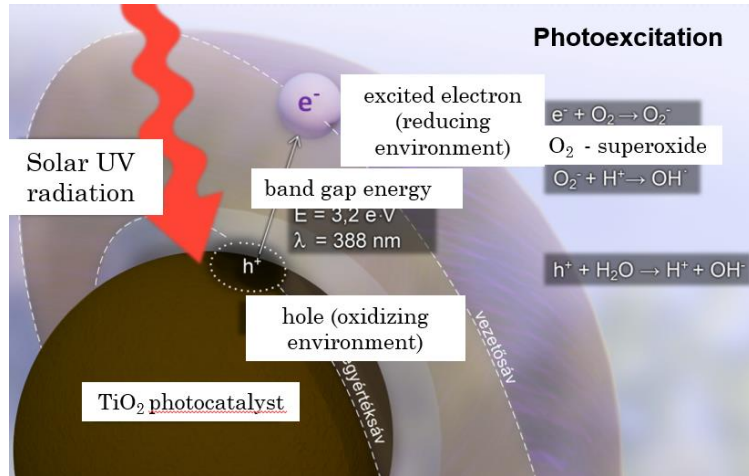


Fig. 6. Photocatalysis reaction.

The study on the possibility of photocatalysis in the developed cement-silicate paint with nanotitanium dioxide was carried out after applying paint with a thickness of 100 microns to glass plates and covering it with the organic pigment Rhodamine S, followed by exposure to the ultraviolet radiation in OBNP "GENERIS" irradiator. For the experiment, the compositions were modified with 5% and 10% of nanotitanium dioxide photocatalyst powder.

The experimental results confirming the degradation of Rhodamine S pigment are presented in Figures 6b and 6c. Visual assessment clearly indicates the degradation of the organic pigment "Rhodamine S" after exposure to the ultraviolet solar radiation in field conditions in the span of 2 days, followed by exposure to precipitation at a temperature of 14 °C (Fig. 7).

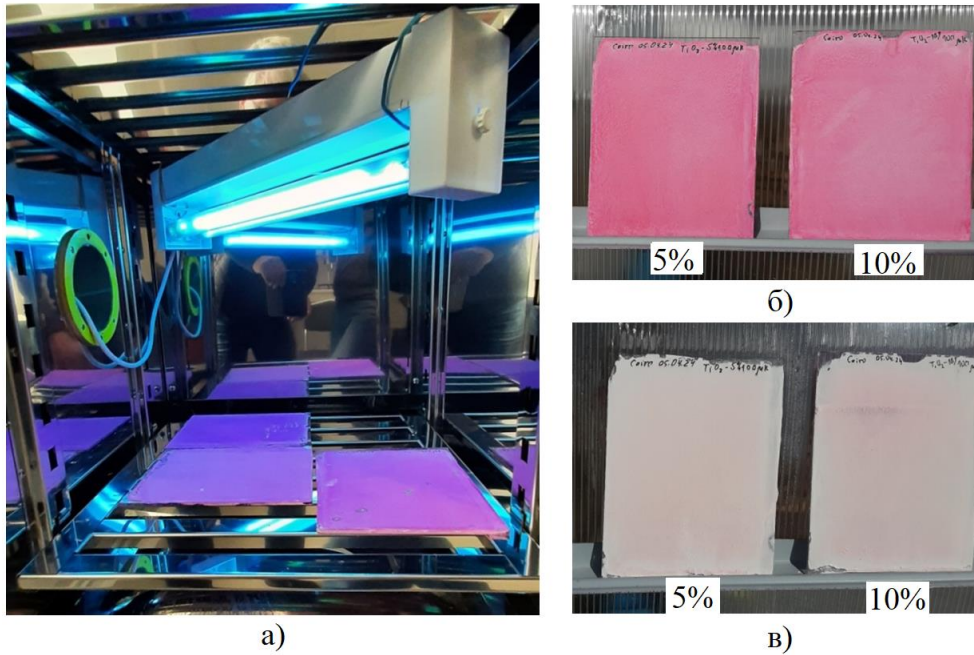


Fig. 7. Processing of paint samples coated with the organic dye "Rhodamin S" with an ultraviolet irradiator OBNP "GENERIS" (a), samples of cement-silicate paint before field testing (b), after exposure to ultraviolet radiation and subsequent precipitation (c)).

All these aspects of the self-cleaning effect result in reduced maintenance costs and longevity of color shades. Therefore, photocatalyzed nanoTiO₂ cement silicate paint has not only aesthetic, but also economical advantage. In addition, nanotitanium oxide can help accelerate the hydration of Portland cement and improve the durability of cement silicate paint [12].

Another factor that undermines the aesthetic properties of the finished surface is dispersed dust that accumulates on the finishing material due to static electricity. In a number of industries, especially in workshops for the production of microelectronics, the requirements for the prevention of dust accumulation on the walls are increased. Therefore, finishing materials, such as marble tiles, are used in order to prevent the accumulation of dust by reducing the level of static electricity. Obviously, this significantly increases the cost of buildings. Consequently, paint and varnish coatings are needed that can eliminate the accumulation of static electricity without increasing the final price. Some researches show [5, 13] that multiwalled carbon nanotubes (MWCNTs) introduced into the composition of cement-silicate paint, can increase its electrical conductivity by several times, which can lead to the “draining” of the electric charge, reducing the accumulation of dust on the surface of the façades or internal walls of buildings with high requirements for dust control. However, the complex technology of introducing MWCNT dispersion into cement-silicate paint and its high cost reduce the effectiveness of the composition [14, 15].

It is proposed to replace the conductive component in the mixture composition with a cheaper additive, namely, aluminum powder of grade PAP-1 in accordance with GOST 5494-2022.

To determine the electrical conductivity of cement-silicate paint with aluminum powder PAP-1, paint samples were prepared and applied to the surface of a glass plate with glued copper electrodes (Fig. 8a). After applying the paint, the samples were kept until setting and hardening for 24 hours in normal conditions and connected to the electrodes of the E7-20 immittance meter (Fig. 8b).

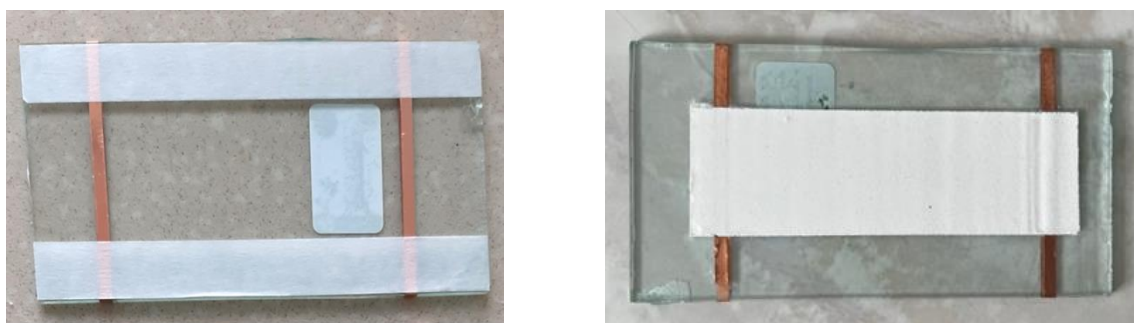


Fig. 8. Preparation of a base from a glass plate with glued copper electrodes (a), sample after applying paint with a conductive additive (b).

Analysis of the electrical conductivity of cement-silicate paint using an E7-20 immittance meter (Fig. 9) showed a decrease in the electrical resistance of the samples in a wet state from 5.05 kOhm for the reference sample to 2.7 kOhm for a sample modified with aluminum powder in an amount of 0.4% by weight of white Portland cement. The thickness of the applied paint was 350 microns.

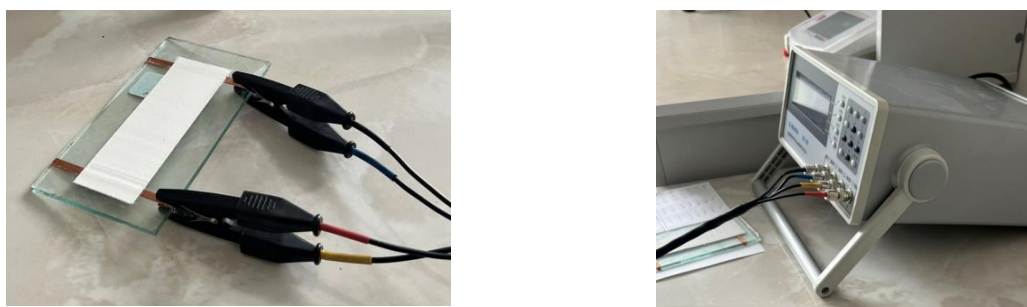


Fig. 9. Measuring the resistance of cement-silicate paint with a conductive additive using an E7-20 immittance meter: a) test sample, b) E7-20 immittance meter.

Therefore, the developed cement-silicate paint with conductive components has an increased electrical conductivity, which ensures the removal of static electricity and helps to absorb man-made electromagnetic radiation due to shielding [13]. Shielding leads to the weakening of electric and electromagnetic fields and prevents the penetration and impact of such fields on elements of premises and buildings. Besides, it suppresses electronic interference emanating from electrical and electronic industrial equipment and devices.

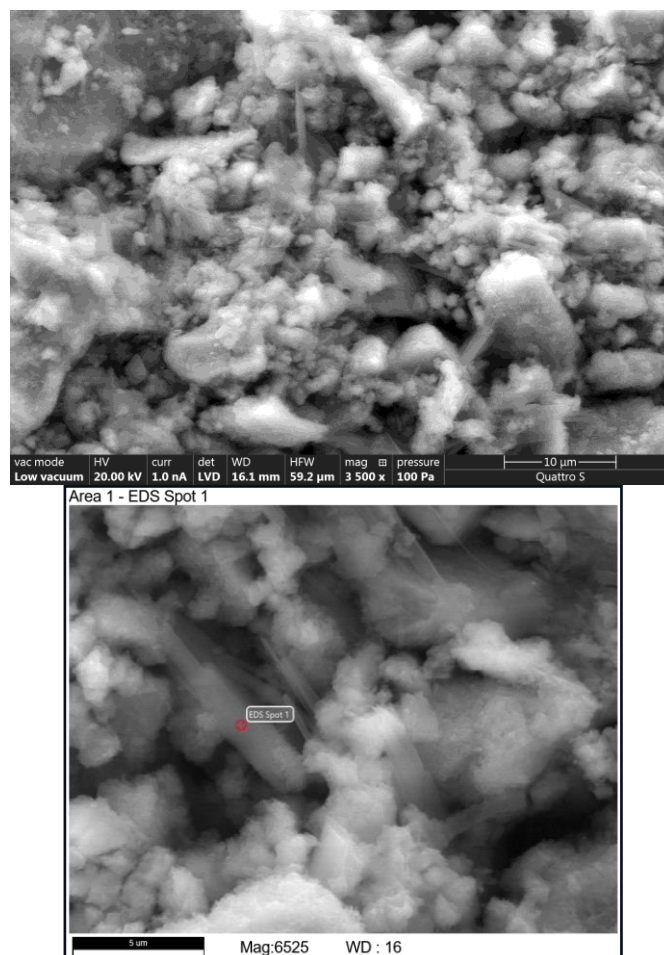
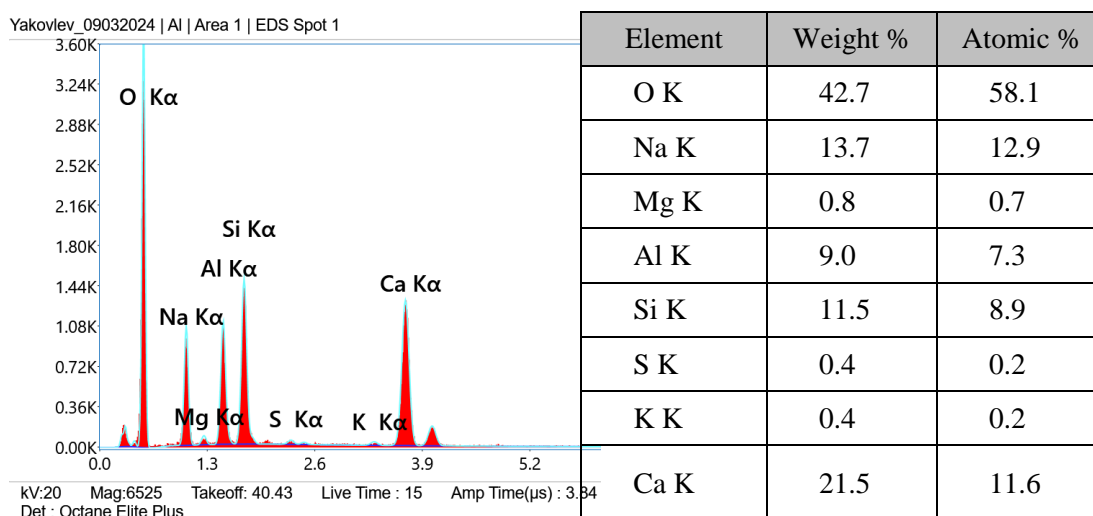


Fig. 10. Microstructure of a cement-silicate paint with the addition of aluminum powder in an amount of 0.4% of the weight of Portland cement: a) at 3500-fold magnification, b) at 6525-fold magnification (the marker is located on the surface of calcium aluminosilicate hydrate).

Analysis of the microstructure of a cement-silicate paint, modified with aluminum powder in an amount of 0.4% by the weight of Portland cement (Fig. 10) showed a significant change in hydration products with the formation of an amorphous structure in combination with crystal hydrates based on low-basic calcium aluminosilicate hydrates, which is confirmed by energy-dispersive analysis, presented in Table 1.

Table 1. Results of energy dispersive analysis.

Thus, aluminum powder particles not only contribute to an increase in the electrical conductivity of the a cement-silicate paint, but also affect the formation of hydration products as a result of exchange reactions, therefore, compacting the material structure.

4. CONCLUSIONS

Thus, a one-component silicate paint has been developed, in which Portland cement is used as a hardener, liquid sodium glass is replaced with powdered sodium silicate hydrate, and sodium phosphate is used to prevent early coagulation of the paint solution.

It has been established that one-component silicate paint, when modified with nanotitanium dioxide, exhibits surface self-cleaning properties during operation due to photocatalytic reactions.

The use of a conductive component based on aluminum powder as a modifying additive instead of expensive multi-walled carbon nanotubes reduces the cost of the finished dry mixture composition and prevents the accumulation of static electricity on the surface being finished.

The research was carried out in the Federal State Budgetary Educational Institution of Higher Education "Kalashnikov Izhevsk State Technical University" with funds from the Ministry of Education and Science grant No. 075-15-2023-590 (head – Yakovlev G.I.).

REFERENCES

- [1] Yakovlev G.I., Gailyus A. Salt corrosion of ceramic brick. *Glass and ceramics*. 2005. 10. P. 20 – 22.
- [2] Yakovlev G.I., Pervushin G.N., Kizievich O., Ginchitskaya Yu.N., Taibakhtina P.A. The influence of efflorescence in brickwork on the destruction of the finishing polymer coating. *Construction materials*. 2016. 4. P. 69 – 71.
- [3] Yakovlev G.I., Pislegina A.V., Kerene J., Buryanov A.F. Finishing composition based on liquid glass. *Construction materials, equipment, technologies of the 21st century*. 2009. 7. P. 42 – 44.
- [4] Shaibadullina A.V., Yakovlev G.I., Pervushin G.N., Polyanskikh I.S., Ognev A.M., Aliev E.V. Silicate coating of increased durability and method of its preparation. Patent for invention RU 2669642 C2, 10/12/2018. Application No. 2017115926 dated 05/04/2017
- [5] Yakovlev G.I., Shaibadullina A.V., Polyanskikh I.S., Gordina A.F., Pudov I.A., Grakhov V.P., Pervushin G.N., Buryanov A.F. Multifunctional decorative and finishing silicate compositions. Izhevsk: Information Resources Department of Kalashnikov Izhevsk State Technical University. 2021. 136 p.

- [6] Yakovlev G.I., Pervushin G.N., Saidova Z.S., Ginchitskaya Yu.N., Kuzmina N.V., Buryanov A.F., Trofimova D.A. Dry mixture for facade silicate paint. Construction materials. 2023. 3. P. 12–19.
- [7] Lidin R.A., Molochko V.A., Andreeva L.L. Reactions of inorganic substances: Handbook – M.; Bustard, 2007. 637 p.
- [8] Dongdong Jiang, Zuhua Zhang, Caijun Shi. Evolution of silicate species from waterglass in waterglass activated slag (WAS) pastes at early age. Cement and Concrete Research. 2024. 180. P. 107513.
- [9] Tryba B., Wrobel R.J., Homa P., Morawski A.W. Improvement of photocatalytic activity of silicate paints by removal of K₂SO₄. Atmospheric Environment. 2015. 115. P. 47 – 52. <https://doi.org/10.1016/j.atmosenv.2015.05.047>
- [10] Hela R., Bodnarova L. Study on the feasibility of testing the efficiency of TiO₂ photocatalyst. Construction materials. 2015. 3. P. 77 – 81.
- [11] Man C.C., Pei W.K., Vinoth K.P., Siew L.L., Titanium dioxide and other nanomaterials based antimicrobial additives in functional paints and coatings: Review, Progress in Organic Coatings. 2022. 163. P. 106660, <https://doi.org/10.1016/j.porgcoat.2021.106660>
- [12] Amor F., Baudys M., Racova Z., Scheinherrová L., Ingrisova L., Hajek P. Contribution of TiO₂ and ZnO nanoparticles to the hydration of Portland cement and photocatalytic properties of High Performance Concrete, Case Studies in Construction Materials. 2022. 16. P. e00965, <https://doi.org/10.1016/j.cscm.2022.e00965>
- [13] Shaibadullina A.V. Yakovlev G.I., Burdin V.S. Finishing facade composition modified with carbon nanotubes for protection against electromagnetic fields. Construction materials. 2013. 2. P. 41 – 43.
- [14] Lu D., Leng Zh., Lu G., Wang D., Huo Y. A critical review of carbon materials engineered electrically conductive cement concrete and its potential applications. International Journal of Smart and Nano Materials. 2023. 14. P. 1 – 27. [10.1080/19475411.2023.2199703](https://doi.org/10.1080/19475411.2023.2199703).
- [15] You I., Lee S-J, Zi G., Lim D. Influence of Carbon Fiber Incorporation on Electrical Conductivity of Cement Composites. Applied Sciences. 2020. 10 (24) P. 8993. <https://doi.org/10.3390/app10248993>

INFORMATION ABOUT THE AUTHORS

Yakovlev G.I., e-mail: gyakov@istu.ru, ORCID ID: <https://orcid.org/0000-0002-2754-3967>, SCOPUS: <https://www.scopus.com/authid/detail.uri?authorId=7006888927>, Kalashnikov Izhevsk State Technical University, Doctor of Engineering Sciences, Professor of Construction Materials, Mechanization and Geotechnics Department

Pudov I.A., e-mail: pudovia@yandex.ru, ORCID ID: <https://orcid.org/0000-0002-4256-6016>, SCOPUS: <https://www.scopus.com/authid/detail.uri?authorId=55986948600>, Kalashnikov Izhevsk State Technical University, Candidate of Engineering Sciences, Associate Professor of Construction Materials, Mechanization and Geotechnics Department

Saidova Z.S., e-mail: zarinasaidova@mail.ru, ORCID ID: <https://orcid.org/0000-0002-5905-0470>, SCOPUS: <https://www.scopus.com/authid/detail.uri?authorId=57202958717>, Kalashnikov Izhevsk State Technical University, Candidate of Engineering Sciences, Associate Professor of Civil and Industrial Engineering Department

Ginchitskaya Yu.N., e-mail: yula_yuka@mail.ru, ORCID ID: <https://orcid.org/0000-0002-7667-0209>, SCOPUS: <https://www.scopus.com/authid/detail.uri?authorId=57195740892>, Kalashnikov Izhevsk State Technical University, Candidate of Engineering Sciences, Associate Professor of Construction Materials, Mechanization and Geotechnics Department

Elrefaei A.E.M.M., email: ali-elrefaeu@eru.edu.eg, ORCID ID: <https://orcid.org/0000-0002-2272-7214>, SCOPUS: <https://www.scopus.com/authid/detail.uri?authorId=55988536300>, Egyptian Russian University, Phd of Engineering, Construction Department