**UDC 666.965:547.14:519.2** DOI: 10.31650/2786-6696-2025-14-70-77

# RESEARCH ON THE PROPERTIES OF SILICATE COMPOSITES FOR OPEN-ENVIRONMENT OBJECTS

[1]**Dotsenko Yu.,** PhD,
Julija0606@ukr.net, ORCID: 0000-0003-0382-9853
[1]**Sydorova N.,** PhD, Associate Professor,
sidorovanataliya@ukr.net, ORCID: 0000-0003-2772-5653
[1]*Odesa State Academy of Civil Engineering and Architecture*
4, Didrichson street, Odesa, 65029, Ukraine

**Abstract.** The article presents a comprehensive study of the properties of silicate composites and materials based on them, aimed at substantiating the feasibility and effectiveness of their application in the field of landscape architecture for open-air objects. In particular, attention is focused on the possibilities of integrating such materials into the processes of spatial organization of parks and recreational areas, which is an urgent task of modern urban planning. The study considers key aspects that determine the operational potential of silicate composites, including their structural and technological characteristics, indicators of durability, environmental safety and aesthetic appeal.

Special emphasis is placed on the analysis of the potential use of silicate composites in the creation of small architectural forms, decoration of open spaces, as well as in the formation of functional components of the urban environment. The presented advantages of these materials in the context of modern construction demonstrate their ability to provide not only architectural expressiveness and functionality of objects, but also to reduce financial costs for their construction, further operation and maintenance.

The article emphasizes the importance of using environmentally friendly raw materials in the production of silicate composites, which contributes to reducing the negative impact on the environment and complies with the principles of sustainable development in architectural practice. The study includes calculations and analysis of experimental and statistical models that demonstrate the relationship between the structural parameters of materials and their operational characteristics.

In particular, detailed studies of such physical and technical indicators as compressive strength, frost resistance, water resistance, density, crack resistance and carbonization resistance were carried out. A comprehensive analysis of these criteria allowed us to draw reasonable conclusions regarding the prospects for the use of silicate composites in the design of architectural elements of the environment, landscape design for open-air facilities and the rational organization of outdoor spaces in modern urban conditions.

**Keywords:** silicate composites, properties, landscape design, open environment, ecology, experiment.

**Introduction.** In modern landscape design, there is a growing need to use innovative materials that combine high performance characteristics with aesthetic and environmental requirements. One of the promising groups of such materials is silicate composites, which attract attention as a potentially effective alternative to traditional materials. Despite the diversity of silicate composites, their integration into landscape design practice is still not sufficiently structured and widely implemented. This necessitates a comprehensive study of the properties and performance of silicate composites to substantiate their potential for practical application.

**Analysis of recent research and publications.** In recent years, there has been an increase in scientific interest in the use of silicate composites in the fields of construction, architecture and outdoor space design. A significant part of the research is focused on the physicochemical characteristics of silicate composites, their durability, resistance to aggressive environments, frost resistance and ability to maintain operational properties under prolonged load conditions [1, 2].

Works by domestic and foreign researchers focus on the potential of using various building composites in landscape design, in particular as materials that combine decorative properties with high resistance to atmospheric influences, environmental safety and the ability to integrate into the natural and architectural environment [3-5]. Special attention is paid to the modification of composites with the addition of nanomaterials, which allows to increase their strength, water resistance and heat resistance [6-8].

At the same time, in the field of landscape architecture, publications dedicated to the use of silicate composites remain rare [9]. In the available works, the emphasis is mainly on the decorative qualities and properties of materials, the possibilities of their use for decoration, cladding and creation of small architectural forms [10, 11].

Considering that recently in the construction industry there has been a tendency to use "green" ecological technologies that do not harm the environment and health, the requirements for building materials are increasing every year [6]. The prospects for using silicate composites in landscape design are offered by their unique operational properties, environmentally friendly and high aesthetic potential, which allows for the effective integration of these materials into the formation of a harmonious external environment. Due to their mineral base and the number of environmentally harmful components, silicate composites meet modern requirements for environmental safety and sustainable development of urban areas [10]. Of particular interest is the use of silicate composites in the creation of small architectural forms – benches, park furniture, decorative steles, flower pots, flowerpots and other elements of landscape design. Due to their stable structure, resistance to atmospheric influences, as well as wide possibilities for varying texture, color and shape, these materials contribute to the formation of visually attractive and durable objects of the urban and natural environment. The mechanical strength, wear resistance and frost resistance of these materials ensure the preservation of the functional and aesthetic characteristics of the surface even under conditions of intensive use [11].

Despite the fact that information about the degree of environmental friendliness of certain materials is currently insufficient, currently in construction, conditionally ecological materials are widely used, which include natural resources, are safe for the environment, but have high technical and operational characteristics. An example of such a material today can be environmentally friendly silicates and blocks based on them [6, 12]. They are made from natural environmentally friendly materials, which are distinguished not only by their environmental friendliness and accessibility, but also by the relatively low cost of the finished product. In addition to the fact that this material corresponds to the so-called green construction, its use will allow to reduce the weight of structures, increase the factory readiness of silicate blocks while reducing their specific energy consumption, and improve thermal characteristics. Compared with the production technologies of other building materials, the production of ecological silicates is energy and resource-saving, since the casting technology is used in combination with complex activation [12]. Ecological silicates and products based on them, due to their cost-effectiveness and properties, will be relevant not only for individual construction, but also for the creation of small architectural forms and can even be recommended for decorative elements of garden and park architecture and interior design [13-15].

**Problem statement and research objective.** In modern conditions, there is a growing need for environmentally safe, durable and aesthetically attractive materials for the arrangement of open public spaces, in particular park and recreational areas, pedestrian zones and landscaping objects. At the same time, existing materials do not always provide the proper balance between operational characteristics, economic feasibility and architectural and artistic expression. In this context, research into new materials, in particular silicate composites, which have the potential to be used in the formation of small architectural forms and other elements of the external environment, is relevant. However, for the justified introduction of such materials into design practice, it is necessary to carry out a comprehensive study of their properties, including mechanical, weatherproof, environmental and aesthetic characteristics, as well as to identify the dependencies between the structural parameters of composites and their effectiveness in open environment conditions.

**Materials and methods of research.** To achieve the set goal, it is necessary to analyze the patterns of the influence of the composition of the mixture and additives on the properties of silicate composites and develop optimal compositions of complex-activated silicates of thermal-moisture hardening with improved properties for use in landscape design. Accordingly, the subject of the study is silicate composites of thermal-moisture hardening. Experiments and research, which were carried out with the aim of building experimental and statistical models, were performed in several scientific laboratories of the Odesa State Academy of Civil Engineering and Architecture: determination of basic properties – by standard methods, as well as determination of structural characteristics – at the departments of "Building Materials", "Production of Building Materials and Structures" and "Processes and Devices in the Technology of Building Materials" [4, 6, 12, 16]. The processing of experimental and statistical models was carried out by means of the COMPEX dialog system in combination with specially synthesized planning approaches, standard Microsoft Office applications, and the CorelDRAW software environment.

To address the stated problem, experimental studies were conducted using identical 6-factor, 24-point experimental designs of the "triangles on a cube" type (Fig. 1), developed by Professor T.V. Lyashenko [17, 18]. These designs allowed for the simultaneous consideration of three independent and three dependent compositional parameters. To facilitate data analysis, the six-factor space was transformed into a three-factor framework by fixing the dependent variables at discrete levels while varying the three independent variables. Specifically, the specific surface areas of slag and sand were maintained at three fixed levels of 400, 500, and 600 m²/kg. At each combination of dependent variable levels, the independent factors-dosages of alkaline additives (0.5–1%), liquid glass (1–5%), and gypsum (2–4%) – were systematically varied. Superplasticizer C-3 was applied at 1.0% of the binder mass to enhance sedimentation stability. Gypsum, as a key active component of the lime-silica mixture, played a dual role: it improved mixture mobility and contributed to the development of essential performance properties in the hardened composites. By adjusting the quantitative ratio of the initial components, it was possible to regulate the structure and properties of heat-moisture curing silicate composites, while controlling the influence of the fixed dependent parameters.

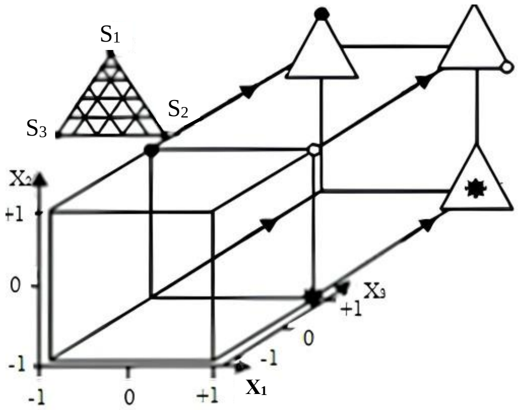


Fig. 1. Scheme of the plan "triangles on a cube"

**The results of the research.** In the experimental program, the assessment of silicate composites was carried out on the basis of a set of essential quality indicators established by current regulatory and technical documentation. These included compressive strength ($R_{st}$), frost resistance (F), water resistance ($k_s$), density (ρ), and the crack resistance coefficient ($k_{Ic}$). The analysis of the obtained results enabled a detailed evaluation of the material performance for each specified parameter.

The change in compressive strength under the influence of the studied factors, in particular the content of additives and the specific surface area of the silica-containing component, was described by a model, on the basis of which graphs of the dependence of compressive strength were constructed. Within the factor space, depending on the variation of all factors, the $R_{st}$ indicator changed from $R_{min}$ = 12.3 to $R_{max}$ = 18.1 MPa (Fig. 2). The highest strength value was obtained for compositions with the maximum content of all additives.


ISSN 2786-6696 Modern construction and architecture, 2025, no. 14, page 70-77

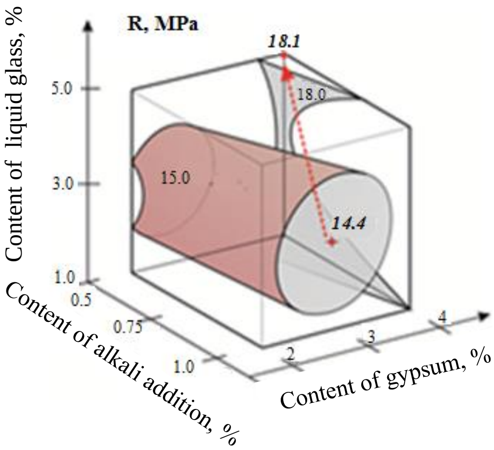


Fig. 2. Influence of all factors on compressive strength

Within the same area of the factor space (Fig. 3), the density value varies from 1340 to 1540 kg/m³, with the lowest density observed at minimum contents of gypsum and alkaline additives in the mixture. Such a density range is particularly suitable for landscape architectural elements, as it ensures a balance between mechanical strength and reduced self-weight. Lower-density composites allow for easier handling, transportation, and installation of items such as benches, decorative steles, planters, and park furniture, while still providing sufficient structural integrity and durability for landscape application.

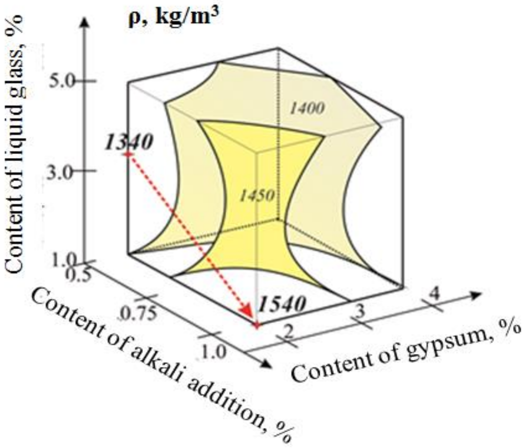


Fig. 3. Influence of all factors on density

In a similar way, diagrams of changes in properties were constructed according to frost resistance, which indirectly characterizes the durability of building materials (Fig. 4), and water resistance (Fig. 5).

Within the investigated factor space, the frost-resistance values (F) range from 26 to 33 cycles. It has been established that varying the specific surface area of the silica-containing component makes it possible to achieve standardized frost-resistance levels F25 and F35, which may be classified as sufficient for the operation of materials in environments with moderate freeze–thaw exposure, particularly in southern warm regions, where the number of natural freeze–thaw cycles is statistically low and the duration of periods with sub-zero temperatures is significantly reduced. The obtained indicators allow the use of the material in constructions that are not subjected to substantial mechanical loading and are characterized by limited water saturation. Examples of such applications include decorative garden and park elements (steles, sculptural forms, and other small architectural objects), components of park furniture located under partial shelter, planters and flowerpots with regulated drainage, as well as modular decorative blocks and inserts integrated into pavements in areas with minimal moisture exposure and without pedestrian or vehicular loading.

Water resistance was estimated by the softening coefficient, which in the studied factor space varied from 0.8 to 1.0. Due to the change in the studied factors, the softening coefficient can vary within 15–30%. All studied compositions provide water-resistant lime-silica composites. The highest water resistance, which is 0.9–1.0, is observed in compositions with a specific surface area of tripolite $S_2$ = 400 m²/kg.

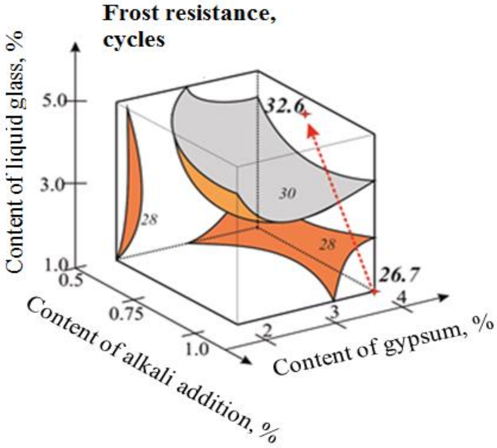


Fig. 4. The influence of all factors on the change in frost resistance

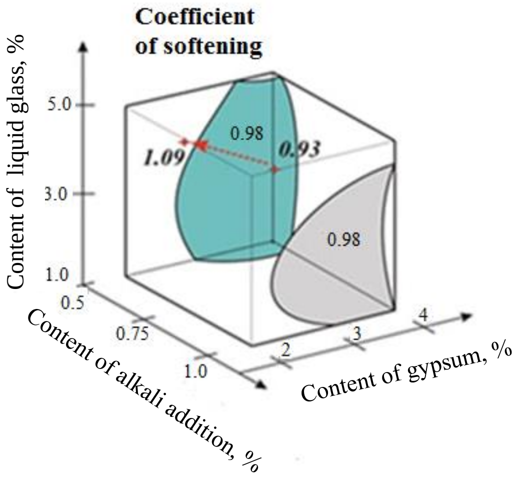


Fig. 5. The influence of all factors on the softening coefficient

In the experiment, the crack resistance of silicate composites was characterized by the critical stress intensity coefficient $k_{Ic}$, which, under the influence of all factors, changes by a factor of 1.8, from 0.91 to 1.64 MPa·m$^{-0.5}$ (Fig. 6). At the same time, the specific surface area of the silica-containing component has the greatest influence on the crack resistance.

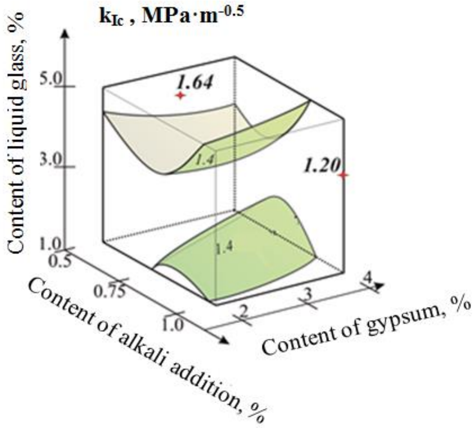


Fig. 6. The influence of all factors on the critical stress intensity coefficient


ISSN 2786-6696 Modern construction and architecture, 2025, no. 14, page 70-77

One of the key factors in ensuring the durability of structural elements in landscape design is the resistance of the materials used to carbonization. Silicate composites are exposed to prolonged exposure to atmospheric factors, in particular carbon dioxide. As a result of carbonization, the pH of the material decreases, which leads to the destruction of the microstructure, a decrease in mechanical strength and the appearance of defects on the surface of the products. In view of this, a study of the carbonization resistance of the used silicate composites was conducted, which is a necessary prerequisite for predicting the operational reliability of landscape architecture elements.

The carbonation resistance of silicate composites of thermal and moisture hardening significantly depends on the content of active additives, in particular, liquid glass, alkaline components and gypsum. An increase in the amount of liquid glass helps to compact the microstructure of the composites, reducing their gas permeability, which has a positive effect on carbonation resistance. A similar effect is observed with an increase in the concentration of alkaline additives, due to the stabilization of the high alkalinity of the pore environment, which slows down the processes of carbon dioxide corrosion. Gypsum plays a dual role: with rational dosages, it helps to optimize the structure of the material, but its excess can lead to the appearance of microcracks that reduce carbonation resistance. Thus, ensuring high resistance of silicate composites to carbonation is possible due to the balanced selection of the composition with the optimal content of liquid glass, alkali and gypsum. The use of materials with high resistance to carbonization allows you to minimize the risks of premature destruction, reduce the costs of maintenance of landscaping objects, and preserve their aesthetic properties throughout their entire service life.

Adjusting the properties of the silicate mixture ensures the production of silicate materials and products based on them using energy-saving technology with improved properties of standardized grades in terms of density, strength, frost resistance, crack resistance coefficient, taking into account carbonation resistance. The following intervals of property changes were obtained: concrete class B7.5–15, $\rho$ = 1150–1500 kg/m$^3$, $k_s$ = 0.9–1, F≥35, $k_{1c}$ = 0.91–1.64 MPa·m$^{-0.5}$, in connection with which silicate composites are recommended for use in landscape architecture (Fig. 7).

In the context of forming functional components of urban space, silicate composites can serve as an effective structural material for creating protective screens, urban barriers, lighting and landscaping elements that not only meet safety standards, but also harmoniously fit into the overall concept of spatial design. In the future, it is advisable to expand the research of these composites in order to increase their adaptability to different climatic zones, expand design possibilities and ensure maximum environmental neutrality.

Fig. 7. Examples of the use of silicate composites in landscape architecture

**Conclusions.** Based on the conducted research, it was established that silicate composites are promising materials for use in the field of landscape architecture, in particular in the formation of elements of park and recreational spaces, pedestrian infrastructure and small architectural forms. The experimental data obtained confirmed the high strength, resistance to atmospheric influences, wear resistance and environmental safety of these materials, which meets modern requirements for the organization of a comfortable and harmonious external environment.

A comprehensive analysis of physical and technical characteristics demonstrated that silicate composites are able not only to ensure the durability of structural elements, but also to contribute to aesthetic diversity in the design of urban space due to the wide possibilities of variation in shape, texture and color. Taking into account the results obtained, the use of silicate composites can be recommended for expanding the range of materials in landscape architecture design practice in order to improve the quality of the environment and reduce operating costs throughout the life cycle of objects.

The current tasks of further development of silicate composites for landscape architecture are to increase their strength, frost resistance, weather resistance and moisture resistance. Another important task is reducing the thermal conductivity of materials, as this helps regulate microclimatic conditions, prevents excessive surface heating, protects plants and soil, increases durability, and reduces the intensity of urban heat islands. Increasing the strength will allow creating landscaping elements that are more resistant to mechanical loads, in particular small architectural forms, garden and park structures, decorative fences and coatings. Improving frost resistance and moisture resistance will ensure the durability of products in various climatic conditions, including regions with difficult winter-spring operation. The color of the final product remains an important aspect for shaping the aesthetics of the landscape environment, therefore one of the areas of work is the study of additives that allow varying the color range of products without losing their basic physical and mechanical properties.

**References**

[1] M.M. Plemianykov and V.Yu. Tobilko, *Silikatne materialoznavstvo*. Kyiv: KPI im. Ihoria Sikorskoho, 2021.

[2] H. Shagwira, F.M. Mwema, and T.O. Mbuya, *Polymer-Silica Based Composites in Sustainable Construction*. Boca Raton: CRC Press, 2021.

[3] A. Zimmermann, *Constructing Landscape: Materials, Techniques, Structural Components*. Basel: Birkhäuser, 2015.

[4] E. Shinkevich and E. Lytskin, "Aerated complex activated composites on silicate matrix of thermal-moisture hardening", *in Proc. 14th Int. Congr. Chem. Cement*, Beijing, China, Oct. 13–16, 2015.

[5] R. Skane, F. Jones, A. van Riesse & et al *Optimisation of activator solutions for geopolymer synthesis: Thermochemical stability, sequencing, and standardisatio*, arXiv, 2025.

[6] Yu.V. Dotsenko, N.V. Sydorova, and A O. Perpery, "Analysis of the properties of ecological silicate composites for low-rise and cottage construction", *AIP Conf. Proc.*, vol. 2840, p. 040001, 2023. https://doi.org/10.1063/5.0167625.

[7] I. Amit-Cohen, "Silicatescape – Preserving building materials in the old urban center landscape: The case of the silicate brick and urban planning in Tel Aviv-Jaffa", *Journal of Cultural Heritage*, vol. 9, no. 4, pp. 494–502, 2008.

[8] Y.R. Hamed, M.M. Keshta, M.M.Y. Elshikh, A.A. Elshami, M.H.S. Matthana, and O. Youssf, "Performance of sustainable geopolymer concrete made of different alkaline activators", *Infrastructures*, vol. 10, no. 2, p. 41, 2025. https://doi.org/10.3390/infrastructures10020041.

[9] R. Khan, S. Iqbal, M. Soliyeva, A. Ali, and N. Elboughdiri, "Advanced clay-based geopolymer: Influence of structural and material parameters on its performance and applications", *RSC Advances*, vol. 15, pp. 12443–12471, 2025. https://doi.org/10.1039/D4RA07601J.

[10] J. Liversedge and R. Holden, *Construction for Landscape Architecture: Portfolio Skills*. London: Laurence King Publishing, 2011.

[11] C. Yglesias, *The Innovative Use of Materials in Architecture and Landscape Architecture: History, Theory and Performance*. Jefferson, NC: McFarland, 2014.

[12] O.S. Shinkevych, Ye.S. Luts'kin, N.V. Sydorova, O.O. Koichev, Yu.V. Dotsenko, H.H. Bondarenko, and S.S. Zakabluk, "Modyfikovana syrovynna sumish dlia oderzhannia sylikatnykh kompozytiv", Patent UA 124068, u201707878, filed Aug. 21, 2017, and issued Mar. 26, 2018.

[13] A. Dufresne and F.Villard, *Environmental Silicate Nano-biocomposites*. Cham: Springer, 2013.

[14] J. Zdarta and T. Jesionowski, "Silica and silica-based materials for biotechnology, polymer composites, and environmental protection", *Materials*, vol. 15, no. 21, art. no. 7703, 2022. https://doi.org/10.3390/ma15217703.

[15] Y. Xu, X. Wang, L. Yang, et al., "Geopolymer modified with insoluble calcite and various

silica fumes originated from different manufacturing processes", *Materials*, vol. 18, no. 12, p. 2795, 2025. https://doi.org/10.3390/ma18122795.

[16] O. Shinkevich, N. Rakhimova & et al., "Blended Alkali-Activated Cements Based on Blast-Furnace Slag and Calcined Clays: Statistical Modeling and Effect of Amount and Chemistry of Reactive Phase", *Journal of Materials in Civil Engineering*, 34(6), 2022. https://doi.org/10.1061/(ASCE)MT.1943-5533.0004248.

[17] T.V. Lyashenko, *Polya svoistv stroitel'nykh materialov: kontseptsiia, analiz, optymizatsiia: avtoreferat dys. dokt. tekhn. nauk*. Odesa: OGASA, 2003.

[18] T.V. Lyashenko, "Kontseptsiia polei svoistv: metodychna osnova vyvchennia informatsii z ES-modelei v kompiuternomu materialoznavstvi", *Visnyk ODABA*, no.12, pp. 171–179, 2003.

## ДОСЛІДЖЕННЯ ВЛАСТИВОСТЕЙ СИЛІКАТНИХ КОМПОЗИТІВ ДЛЯ ОБ'ЄКТІВ ВІДКРИТОГО СЕРЕДОВИЩА

[1]**Доценко Ю.В.,** к.т.н.,
Julija0606@ukr.net, ORCID: 0000-0003-0382-9853
[1]**Сидорова Н.В.,** к.т.н., доцент,
sidorovanataliya@ukr.net, ORCID: 0000-0003-2772-5653
[1]*Одеська державна академія будівництва та архітектури*
вул. Дідріхсона 4, м. Одеса, 65029, Україна

**Анотація.** У статті представлено комплексне дослідження властивостей силікатних композитів та матеріалів на їх основі, спрямоване на обґрунтування доцільності та ефективності їх застосування в галузі ландшафтної архітектури для об'єктів відкритого типу. Зокрема, увага зосереджена на можливостях інтеграції таких матеріалів у процеси просторової організації парків та рекреаційних зон, що є актуальним завданням сучасного містобудування. У дослідженні розглянуто ключові аспекти, що визначають експлуатаційний потенціал силікатних композитів, включаючи їх структурно-технологічні характеристики, показники довговічності, екологічної безпеки та естетичної привабливості.

Особливий акцент зроблено на аналізі потенційного використання силікатних композитів у створенні малих архітектурних форм, декоруванні відкритих просторів, а також у формуванні функціональних складових міського середовища. Представлені переваги цих матеріалів у контексті сучасного будівництва демонструють їх здатність забезпечувати не лише архітектурну виразність та функціональність об'єктів, але й знижувати фінансові витрати на їх будівництво, подальшу експлуатацію та обслуговування.

У статті зроблено акцент на важливості використання екологічно чистої сировини у виробництві силікатних композитів, що сприяє зменшенню негативного впливу на навколишнє середовище та відповідає принципам сталого розвитку в архітектурній практиці. Дослідження включає розрахунки та аналіз моделей, що демонструють зв'язок між структурними параметрами матеріалів та їх експлуатаційними характеристиками.

Зокрема, було проведено детальні дослідження таких фізико-технічних показників, як міцність на стиск, морозостійкість, водостійкість, щільність, тріщиностійкість та стійкість до карбонізації. Комплексний аналіз цих критеріїв дозволив зробити обґрунтовані висновки щодо перспектив використання силікатних композитів у проєктуванні архітектурних елементів навколишнього середовища, ландшафтному дизайні для об'єктів відкритого типу та раціональній організації зовнішніх просторів у сучасних міських умовах.

**Ключові слова:** силікатні композити, властивості, ландшафтний дизайн, відкрите середовище, екологія, експеримент.

Стаття надійшла до редакції 5.09.2025
Стаття прийнята до друку 28.11.2025
Дата публікації статті 25.12.2025