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RESISTANCE OF COMPOSITE BUILDING MATERIALS UNDER THE INFLUENCE OF THE ENVIRONMENT

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Abstract. The article provides a detailed analysis of the impact of climatic conditions on the physical and mechanical properties of building materials, particularly concrete, which is a key material for construction structures. The study examines the complex effects of temperature and humidity fluctuations, freeze-thaw cycles, and wetting-drying processes, which cause irreversible structural changes in the material. These factors are identified as the main reasons for the reduction in durability and stability of composite building materials under operating conditions.

The analysis revealed that the climatic conditions of southern Ukraine, characterized by significant daily and seasonal temperature variations, high precipitation levels during the autumn-winter period, and elevated summer temperatures, exert a complex impact on concrete. These climatic factors contribute to the development of internal defects, such as microcracks, degradation of the porous structure, and a decrease in adhesion between the material's components. The role of not only freeze-thaw cycles, which cause stress in the structure of concrete, but also wetting-drying processes and the overall complex influence of climatic factors, is emphasized.

The article substantiates the importance of considering climatic impacts during the design stage of concrete composition. Based on experimental research, it has been established that cyclical climatic influences cause changes in characteristics such as compressive strength, flexural strength, ultrasonic wave velocity, water absorption, and carbonation depth.

The findings highlight the necessity of developing compositional and technological solutions to enhance the resistance of building materials to climatic factors. The article proposes recommendations for the development of concretes with improved operational characteristics, which will extend the service life of structures and ensure their safety.

Keywords: climatic influences, durability, stability of structures, freezing-thawing, moistening-drying, structural changes, physical and mechanical characteristics, adaptation of concrete.

Introduction. The safe operation of structural elements, buildings, and facilities must be ensured throughout their entire lifecycle. Experts distinguish between external and internal safety for any objects considered as systems of a certain type [1]. External safety refers to the system's ability, during interaction with the environment, to prevent alterations in its primary parameters. The main purpose of a structure as a subsystem is to interact harmoniously with similar subsystems, which collectively ensure the integrity and fulfillment of the functional purpose of the building volume as a complexly organized open system. External safety is critical because, if stability is compromised, the system could pose a threat to neighboring structural elements, potentially lowering the system's overall safety level.

Internal safety characterizes the system's capacity to retain its integrity and essential functional properties under internal and external impacts. Here, it is emphasized that internal safety is defined by the system's homeostasis indicator [2].

Comprehensive safety is understood as a system state in which a certain balance of external and internal safety is maintained through spontaneous structural parameter adjustments within limits that ensure necessary property manifestations (adaptation).

Adaptation properties are particularly characteristic of concrete as a complexly organized material, which determines the entire range of properties in construction structures. The operation of structural elements, buildings, and facilities a priori implies the permanent impact of the surrounding environment. Concrete responds to changes in temperature, humidity, as well as static and dynamic loads, leading to irreversible structural changes that may alter its properties and thereby affect safe operational conditions. When assessing the durability and stability of concrete, the number of freeze-thaw cycles is typically standardized. Certain studies highlight the impact of alternating temperature and humidity changes on the durability of construction materials [1]. However, there is a lack of information on the behavior of building materials, including all types of concrete, under all types of climate impacts (integrated climatic effects).

In Ukraine, the average July temperature varies from +18°C in the northern regions to +21°C in the south. Daytime temperatures in July usually reach +22 to +26°C, while nighttime temperatures range from +11 to +15°C. The average January temperature ranges from -7°C in the northeast, -5°C in the central regions, to -2°C in the south. Nighttime temperatures vary from -11 to -9°C in the northeast and from -5 to -3°C in the south, with daytime temperatures from -6 to -3°C to 0 to +2°C, respectively.

The frost-free period in southern Ukraine lasts 260–270 days per year, while in the north, it is around 170–180 days. The highest annual precipitation occurs in the Carpathians, typically reaching 1400–1600 mm. The lowest precipitation is in the southern regions, with 250–350 mm annually in southeastern Ukraine, and 150–200 mm along the Black and Azov Sea coasts. Elsewhere in Ukraine, annual precipitation ranges from 600 to 800 mm. Thus, construction structures, buildings, and facilities in southern Ukraine are exposed to the integrated climate effects of the environment.

Analysis of Climate Conditions in Southern Ukraine. Table 1 presents average data on climatic conditions, with analysis of autumn-winter and spring-summer periods for construction sites in southern Ukraine during the 2014-2015 period.

Table 1 – Climatic conditions during the autumn-winter period

Phenomenon	Autumn-winter period
Clear	38 days
Fog	60 days
Rain (rain with snow)	52 days
Snow	24 days
Tmax of air	+10...+18°C
Tmin of air	-15 °C
Humidification-freezing thawing	46 cycles

In this case, the focus should not be on temperature gradients but rather on the fact of temperature transitions from negative to positive values. In the Odessa region, during the autumn-winter period, the temperature crossed the 0°C mark 46 times (cycles). Emphasis on temperature transitions across 0°C is related to the change in the aggregate state of water. When water transforms into ice, its volume increases by up to 9%, which, according to experts, is one of the key reasons for the adverse physical impact on the capillary-porous structure of building materials.

An analysis of climate conditions during the autumn-winter period revealed that precipitation during this time takes the form of rain, sleet, and snow [3]. Fog, sometimes dense, also occurs periodically, which leads to the wetting of building structures. Additionally, during the daytime, when temperatures rise above zero, structures can become damp due to the melting of ice and snow. At night, when temperatures fall below zero, water that has penetrated the porous spaces of building materials and structures freezes. Thus, within a single year, a series of wetting and drying, freezing and thawing cycles can occur in various types of construction structures.

The variety of factors that contribute to reduced durability prevents a unified criterion from being established for external influences that cause irreversible internal structural changes. Studies have highlighted [4, 5] the adaptability of concrete, as a complex system, to operational conditions. Special attention is given to the alternating cycles of heating-cooling and wetting-drying, which can lead to premature reductions in the safety and functionality of structures.

Table 2 provides data on the climatic conditions in southern Ukraine during the spring-summer period.

Table 2 – Climatic conditions during the spring-summer period

Spring-summer phenomenon	Spring-summer phenomenon
Clear (clear-cloudy)	90 days
Cloudy	49 days
Rain	37 days
Tmax of air	+34.7°C
Tmin of air	+14°C
Surface temperature	62 °C
Wetting-drying	26 cycles

The data on the operational conditions for construction structures of various types show that the moisture levels of most structures are influenced by fluctuating water levels and moisture resulting from changes in humidity due to irrigation (fog, rain). Drying of these wet structures generally occurs when the temperature rises and humidity decreases. Temperature changes are associated with shifts in weather conditions and daily fluctuations. When materials dry at elevated temperatures, temperature-related deformations occur in addition to moisture-induced deformations. The combined impact of moisture and temperature deformations is expected to lead to significant structural changes in the material, potentially affecting its resistance to repeated wetting and drying cycles.

Typically, temperature and moisture do not act in isolation but are inherently interconnected. Even in dry periods, temperature gradients on the surface and in peripheral zones of an object cause the migration of pore liquid within the concrete, a capillary-porous material. Additionally, temperature and moisture effects are unevenly distributed throughout the object, creating gradients in moisture and thermal deformations across the structure’s cross-section. Because temperature and moisture fluctuations follow certain cycles (daily, seasonal), deformation "waves" are assumed to continually pass through the structures (Fig. 1.)

The material in construction structures responds to the cumulative effects of external climatic impacts by repeatedly changing volume, which leads to structural changes that may result in a decline in properties below standard levels. Repetitive external impacts associated with temperature and humidity fluctuations are classified as low-cycle impacts that contribute to material fatigue.

The main climatic impacts on construction structures are recurring (daily, seasonal) thermal, moisture, and combined thermal-moisture effects, along with gradients of moisture and temperature across the object's cross-section. These impacts may lead to structural changes in the material that can cause premature failure. Therefore, during the concrete mix design phase, measures should be taken to ensure that required properties are maintained for the intended lifespan of the structure, considering technological deformations and stresses that could either strengthen or weaken the structure’s resistance to external influences [6].

Analysis of recent research. The analysis of the weather conditions in southern Ukraine showed that most concrete and reinforced concrete products and structures are operated under conditions of periodic changes in humidity and temperature. Such fluctuations lead to reversible and irreversible deformations that gradually alter the structure of concrete and contribute to the premature deterioration of their functional state.

According to established practice, the primary parameter determining the durability of building materials is their frost resistance – the ability to maintain strength and operational characteristics under cyclic freezing and thawing in a water-saturated state. Frost resistance is directly related to the porosity of the material, and it can be improved by controlling the distribution of pores and capillaries. Particular attention is paid to the formation of reserve porosity, which creates conditions for the accumulation of free water during freezing, as noted by Powers [7].

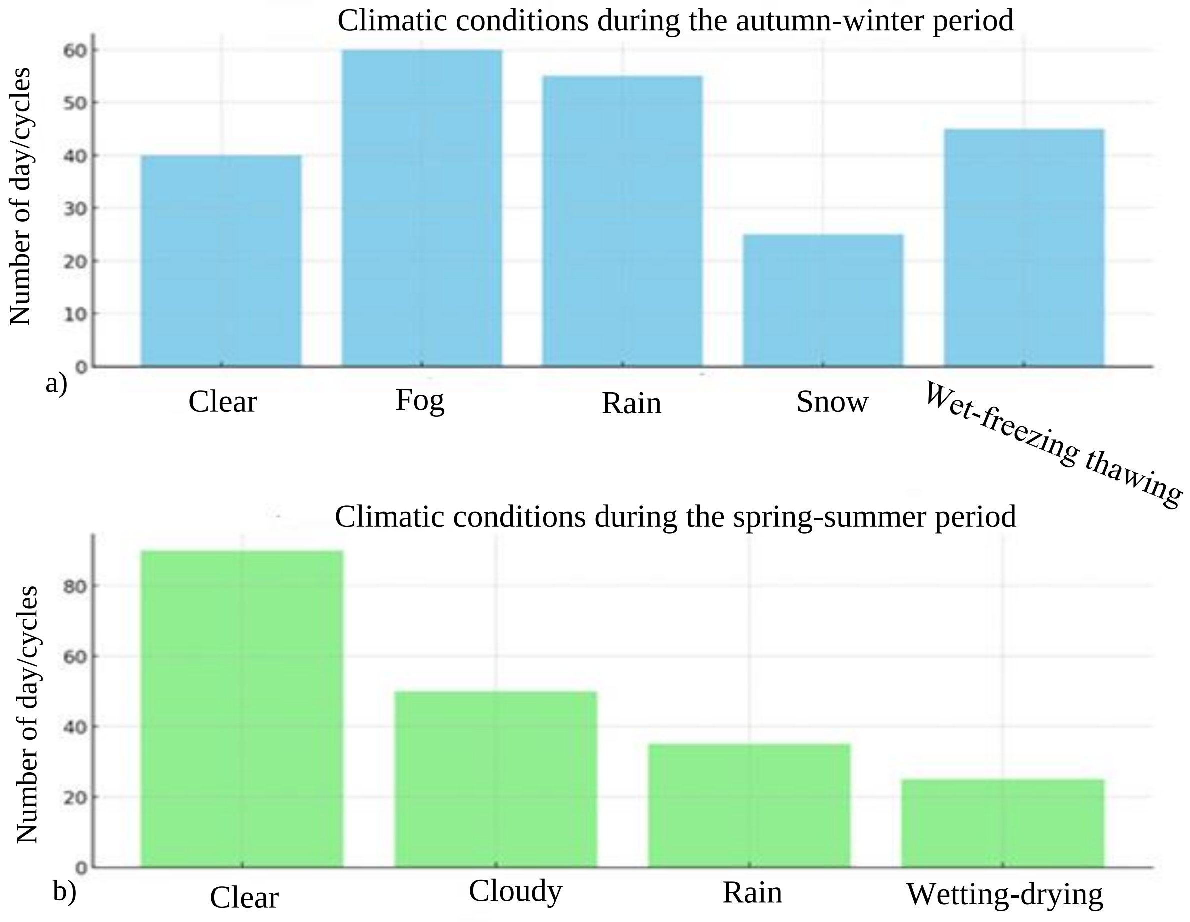

Fig. 1. Climatic conditions during: a – the autumn-winter period b – the spring-summer period

To enhance the frost resistance of building materials, air-entraining surfactants (SAS) are currently used. Studies by L. Y. Dvorkin, M. A. Sanitsky, V. R. Serdyuk, A. E. Sheikin, and other researchers have shown that modern surfactants contribute to optimizing the porous structure of concrete, positively affecting its frost resistance [8, 9]. Additionally, as noted by K.K. Pushkarova, E.O. Shinkevich, V.M. Derevyanko, the use of mineral nanoparticles allows adjusting the composite structure, changing porosity, and reducing deformation [10, 11].

The type of mineral binders significantly affects the frost resistance and water resistance of concrete, as confirmed by studies by M.Sh. Fominera, M.A. Sanitsky, S.M. Tolmachov, and other researchers [12, 13]. In particular, A.V. Mishutin, S.O. Krovjakov, A.A. Khomenko emphasize that local moisture or heating changes thermal deformations, impacting the weather resistance of materials [14, 15].

It has also been established that the crack resistance of concrete directly affects its durability, as highlighted in the works of I.M. Hrushko, S.Y. Solodky, Y.Y. Luchko, and other researchers.

Most scientific studies focus on the resistance of materials to individual weather impacts, such as heating-cooling or freezing-thawing. However, this approach may lead to an incomplete understanding of the actual operating conditions of structures. To more objectively assess the durability of materials, it is necessary to consider the complex impact of weather factors, including their cyclicity and changes in material characteristics under real conditions.

Taking into account the complex impact will allow for a more accurate assessment of the effectiveness of solutions to ensure the standard service life of construction objects. In particular, attention should be paid to rhythmic temperature, humidity, and temperature-humidity changes, which can cause structural changes in the material and, consequently, its premature wear. Thus, at the stage of designing concrete compositions, measures should be provided to maintain the necessary properties throughout the entire operational period of the structure, considering possible deformations and stresses [16].

Research Aim and Objectives. The objective of the study is to analyze and consider adverse operating conditions related to individual and combined weather effects on the physical and mechanical properties and stability of concretes based on dense and porous aggregates.

To achieve the research goal, a series of tasks have been identified, including experimental studies to determine the impact of both individual environmental factors (related to humidity and temperature changes) and the integrated interrelated impact characterized by a model of periodic changes in weather loads (e.g., heating – cooling – moistening – freezing – thawing – drying).

The analysis of the obtained results will provide a more objective assessment of the entire spectrum of weather impacts on the properties and stability of concretes with various aggregates. This will allow for the proposal of adequate formulation and technological solutions to ensure the safe functioning of construction products, structures, buildings, and facilities.

Methodology. Experimental studies were conducted on prismatic samples measuring 10×10×40 cm and 10×10×10 cm, made of heavy concrete and expanded clay concrete.

After curing under normal conditions, identical samples were subjected to individual and combined climatic effects, including:

- Heating for 6 hours at T = +105°C ±5°C until moisture content W = 20%, followed by cooling for 4 hours to T = +30°C (+t, t) (Fig. 2, a).
- Water saturation for 3 hours to W = 80%, followed by drying for 12 hours to W = 20% (W, +t) (Fig. 2, b).
- Water saturation for 3 hours to W = 80%, followed by freezing for 3 hours at T = -18°C ±2°C, then thawing for 3 hours at T = +20°C ±2°C (F, +W) (Fig. 2, c).

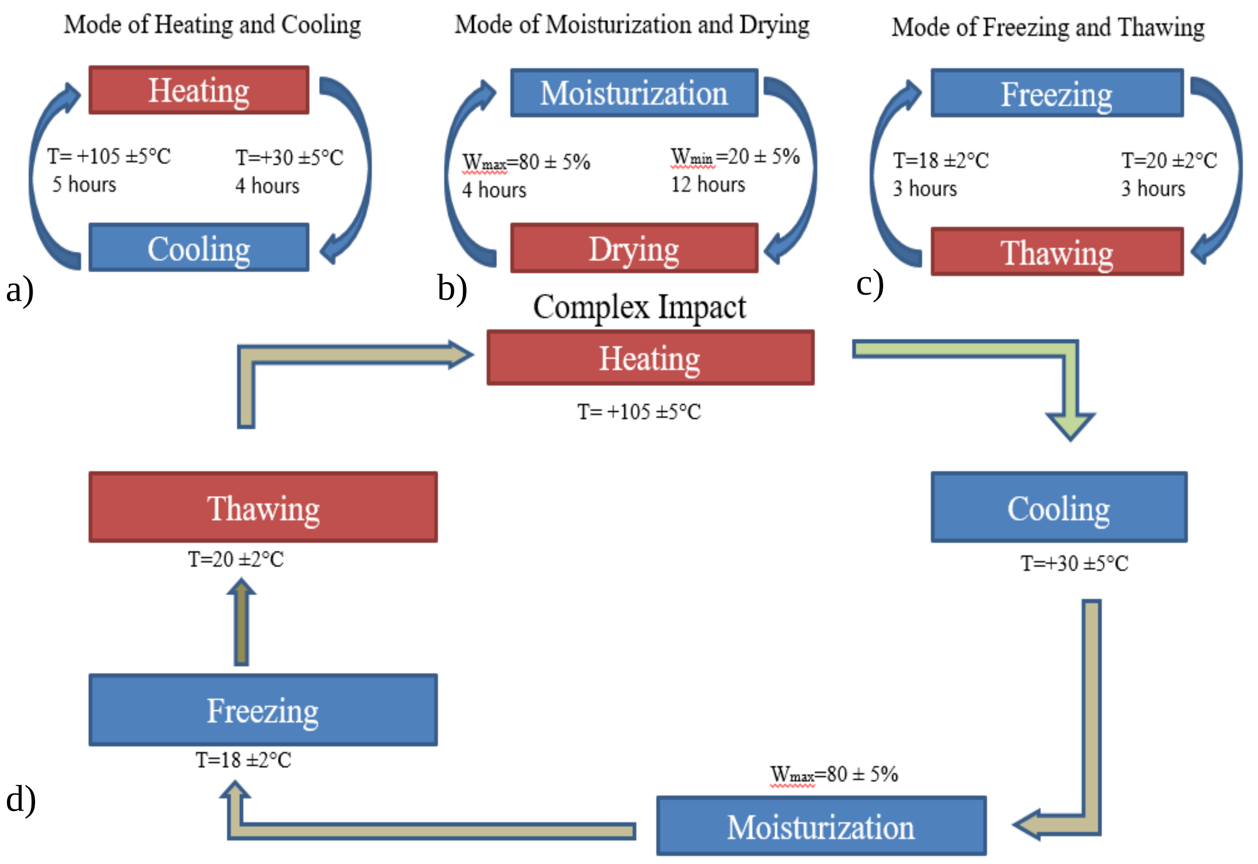

Fig. 2. Experimental Procedure:
a – Heating and cooling; b – Water saturation and drying; c – Freezing and thawing; d – Combined exposure

- Drying for 12 hours at T = +105°C ±5°C until W = 20%, then cooling for 4 hours to T = +30°C, followed by water saturation for 3 hours to W = 80%, freezing for 3 hours at T = -18°C ±2°C, and thawing for 3 hours at T = +20°C ±2°C (Fig. 2, d).

The results of the research. After 15 cycles of heating and cooling, the ultrasonic wave velocity decreased by 11.6%, which may indicate the development of internal inhomogeneities, leading to reduced ultrasonic speed.

Flexural strength decreased by 33.3% compared to control samples (from f_{ctk} = 13.8 MPa to f_{ctk} = 9.2 MPa), and compressive strength dropped by 10.3% (from f_{ck}=55.1 MPa, до f_{ck} = 49.4 MPa). The stability coefficient was Ks=0.9.

After 15 cycles of wetting and drying, the ultrasonic wave velocity decreased by 2.5%. Flexural strength declined by 37.7% compared to control samples (from f_{ctk} = 13.8 MPa до f_{ctk} = 8.6 MPa), and compressive strength fell by 14.5% (from f_{ck}=55.1 MPa, до f_{ck} = 47.1 MPa). The stability coefficient was Ks=0.85. Over 15 full wetting and drying cycles, compressive strength was reduced by 15%.

After 15 cycles of freezing and thawing, the ultrasonic wave velocity dropped by 17.1%.

Flexural strength decreased by 50% (from f_{ctk} = 13.8 MPa до f_{ctk} = 6.9 MPa), while compressive strength reduced by 20.7% (from f_{ck}=55.1 MPa, до f_{ck} = 43.7 MPa). The stability coefficient was Ks=0.8.

After 15 cycles of combined impacts**,** ultrasonic wave velocity decreased by 16.8%. Flexural strength declined by 44.9% (from f_{ctk} = 13.8 MPa до f_{ctk} = 7.6 MPa), and compressive strength fell by 14.0% (from f_{ctk} = 13.8 MPa до f_{ctk} = 7.6 MPa). The stability coefficient was Ks=0.86.

Conclusions. The analysis of climate conditions in Ukraine and the Odessa region showed that within a single year, repeated temperature and humidity fluctuations occur, affecting all types of construction. Under these integral climate impacts, building materials may experience a reduction in key property indicators, potentially compromising the safe operation of structures.

The analysis of experimental results demonstrated that with an increasing number of thermal and moisture cycles on concrete samples, structural changes occur depending on the conditions of heating, cooling, water saturation, freezing, and thawing. The study provided valuable insights into the effect of climatic conditions on changes in the physical and mechanical characteristics of construction materials.

The analysis revealed that freezing and thawing have the most detrimental effect on concrete strength compared to combined loading. These experimental results indicate that exposure to sub-zero temperatures plays a significant role in the resistance of materials and structures to environmental conditions. Further research programs have been developed to investigate the causes of this observed phenomenon.

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СТІЙКІСТЬ КОМПОЗИЦІЙНИХ БУДІВЕЛЬНИХ МАТЕРІАЛІВ ПРИ ВПЛИВІ НАВКОЛИШНЬОГО СЕРЕДОВИЩА

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Анотація. У статті здійснено детальний аналіз впливу погодних умов на фізико-механічні характеристики будівельних матеріалів, зокрема бетону, який є основним матеріалом для будівельних конструкцій. Розглянуто комплексний вплив температурних і вологісних коливань, циклів заморожування-відтавання та зволоження-висихання, які спричиняють незворотні структурні зміни в матеріалі. Саме ці фактори є ключовими причинами зниження довговічності і стійкості будівельних композиційних матеріалів в умовах експлуатації.

Аналіз показав, що кліматичні умови півдня України, які характеризуються значними добовими та сезонними перепадами температур, високим рівнем опадів в осінньо-зимовий період і підвищеними температурами влітку, створюють комплексний вплив на бетон. Ці кліматичні фактори сприяють розвитку дефектів, таких як мікротріщини, деградація порової структури та зниження адгезії між компонентами матеріалу. Важливу роль у цьому відіграють не тільки цикли заморожування-відтавання, які призводять до змін у структури бетону, а і зволоження-висушування та періодична зміна температури.

У статті обґрунтовані важливість погодних навантажень при проєктуванні складу бетону. На основі експериментальних досліджень встановлено, що комплексні циклічні впливи викликають зміну таких характеристик, як міцність при стисканні, міцність на згин, швидкість проходження ультразвукових хвиль, водопоглинання та глибина карбонізації.

Отримані результати підкреслюють важливість враховувати комплексні погодні навантаження при прийняті технологічних рішень для підвищення стійкості будівельних матеріалів, виробів та конструкцій. У статті запропоновано рекомендації для розробки бетонів із підвищеними експлуатаційними характеристиками, що дозволить продовжити термін служби конструкцій та забезпечити їхню безпеку.

Ключові слова: погодні впливи, бетон, довговічність, стійкість, заморожування-відтавання, зволоження-висушування, структурні зміни, адаптація бетону.

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