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DETERMINATION OF THE INFLUENCE OF TECHNOLOGICAL DAMAGE TO CONCRETE ON ITS PRISM STRENGTH

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Abstract: Despite almost two hundred years of experience in use and significant volumes of use, which no composite material can match, reinforced concrete is still far from being fully studied. It is necessary to clarify the calculation of structures in order to fully take into account the factors that affect their operation under load.

Due to the peculiarities of its structure, concrete is a multicomponent and multiphase polycrystalline formation that has a developed system of macro- and microdefects that arise in the structure during molding.

Since concrete as a structural material is formed directly in the structure or product itself, it is practically possible to control its quantitative and qualitative parameters only after receiving the finished product or structure.

Since the composition of concrete affects the structure, strength characteristics and deformation properties of reinforced concrete structures operating under the influence of external influences, there is a need for a more thorough study of it and the determination of optimal components in order to ensure the operational reliability of structures.

During the technological processing of concrete, technological cracks appear in products at all levels of structural inhomogeneities in the material, which, being structural parameters of concrete, determine damage to structures, and thereby their operational reliability.

A directed change in technological damage allows you to change the nature of crack formation and structural failure. The use of mineral filler in certain quantities and a certain dispersion allows you to control the processes of organizing the structure of concrete and regulate its initial volumetric changes, and therefore, technological damage in order to obtain building structures with the necessary properties.

The results of the research revealed the influence of fillers on the initial damage of concrete and on its prismatic strength. Since technological damage significantly affects the strength properties of concrete, this allows you to assign concrete compositions with specified characteristics.

Keywords: reinforced concrete, cracks, technological damage, prismatic strength.

ВИЗНАЧЕННЯ ВПЛИВУ ТЕХНОЛОГІЧНИХ ПОШКОДЖЕНЬ БЕТОНУ НА ЙОГО ПРИЗМАТИЧНУ МІЦНІСТЬ

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Анотація: Незважаючи на майже двохсотрічний досвід застосування та значні обсяги використання, з якими не може зрівнятися жоден інший композиційний матеріал, залізобетон і досі залишається недостатньо вивченим. Необхідно уточнювати методи розрахунку конструкцій з метою повного врахування факторів, що впливають на їхню роботу під навантаженням.

Через особливості своєї структури бетон є багатокомпонентним і багатофазним полікристалічним утворенням, що має розвинену систему макро- та мікродефектів, які виникають у процесі формування.

Оскільки бетон як конструкційний матеріал формується безпосередньо в самій конструкції або виробі, практично можливим є контроль його кількісних і якісних параметрів лише після отримання готового виробу чи конструкції.

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Оскільки склад бетону впливає на структуру, міцнісні характеристики та деформаційні властивості залізобетонних конструкцій, що працюють під дією зовнішніх впливів, виникає необхідність його більш ґрунтовного дослідження та визначення оптимальних компонентів з метою забезпечення експлуатаційної надійності конструкцій.

Під час технологічної обробки бетону у виробах виникають технологічні тріщини на всіх рівнях структурних неоднорідностей матеріалу, які, будучи структурними параметрами бетону, визначають пошкоджуваність конструкцій, а отже — їхню експлуатаційну надійність.

Спрямована зміна технологічної пошкодженості дозволяє змінювати характер тріщиноутворення та руйнування структури. Використання мінерального наповнювача у певній кількості та з визначеною дисперсністю дає змогу керувати процесами формування структури бетону та регулювати його початкові об’ємні зміни, а отже — технологічну пошкодженість, з метою отримання будівельних конструкцій із заданими властивостями.

Результати дослідження виявили вплив наповнювачів на початкову пошкодженість бетону та на його призматичну міцність. Оскільки технологічна пошкодженість суттєво впливає на міцнісні властивості бетону, це дозволяє призначати склади бетону із заданими характеристиками.

Ключові слова: залізобетон, тріщини, технологічна пошкодженість, призматична міцність.

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1 INTRODUCTION

The quality and operational reliability of a structure largely depend on the materials from which it is made. The load-bearing capacity of a structure is determined by the ability of the material to continue performing its functions under new conditions. Therefore, the task of obtaining construction materials and equipment with specified quality parameters while reducing material consumption remains relevant. One of the ways to reduce the material consumption of structural building materials is the use of fillers.

Fillers are defined as particles of arbitrary shape and surface activity, the size of which does not allow them to create fields of deformation and stress in the surrounding binder, but instead causes their participation in the processes of organizing the structure of the elementary structural elements of the binder.

2 ANALYSIS OF LITERARY DATA AND RESOLVING THE PROBLEM

The properties of a structure are determined both by the individual properties of all its subsystems (concrete, reinforcement) and by changes in these properties during internal structural interactions. In turn, the material of the structure (concrete) is itself a subsystem consisting of characteristic structural inhomogeneities. Therefore, when considering composite building materials (CBMs), it is advisable to represent them as complex organized systems arranged according to the principle of “structure within a structure” or “composite within a composite.” This makes it possible to view CBMs as complex self-organizing systems with a hierarchical subordination of different levels of structural inhomogeneities and qualitatively different mechanisms of structure formation.

Operational loads acting on a structure cause deformations and stresses, which the material perceives and redistributes among its structural elements. The load-bearing capacity of a structure is determined by the ability of the material to continue performing its functions under new conditions.

Thus, the structure of a construction can be represented by various models, the type of which depends on the purpose of the analysis and the study of its behavior under operational loads. Describing the structure of a construction makes it possible to identify the most important elements that determine the load-bearing capacity of its individual parts and of the entire structure within similar systems, to reveal the role of the material in its performance, and to determine ways for the targeted design of materials for a specific structure.

In composite materials and structures, in the general case, several characteristic types of damage can be distinguished, differing in their mechanisms of formation [1–2]:

– damage of individual components introduced with them into the material and the structure (initial);

– damage arising during the technological processing of the initial components into the material and its incorporation into the structure (technological);

– damage occurring under the action of operational loads on the structural material (operational).

3 PURPOSE AND TASKS OF THE STADY

Since the composition of concrete affects the structure, strength characteristics, and deformation properties of reinforced concrete structures operating under external influences, there is a need for more in-depth study and determination of optimal components in order to ensure the operational reliability of structures. During the technological processing of concrete into products, technological cracks arise at all levels of structural inhomogeneities in the material. Being structural parameters of concrete, these cracks determine the damage level of structures and, consequently, their operational reliability. The use of fillers optimized in type, quantity, and dispersion makes it possible to control technological damage in concrete and reinforced concrete structures, thereby improving their physical and technical characteristics.

Operational loads acting on a structure cause deformations and stresses, which the material perceives and redistributes among its structural elements. The load-bearing capacity of a structure is determined by the ability of the material to continue performing its functions under new conditions. The failure of concrete is always associated with the accumulation of damage in its initial structure at different levels and with the absorption of deformation energy, followed by its release on the surfaces of newly formed failure cracks [1, 2].

The object of analysis is defects that arise during the technological processing involved in the production of construction materials and structures. Such defects are classified as technological, initial, or inherent (hereditary) defects. According to [1, 2], technological (inherent) defects include pores, capillaries, cracks of various types, etc., which appear during material and structure formation and are present before the application of operational loads. Since the mechanical characteristics of composite materials, including construction materials, are largely determined by cracks, in what follows technological defects are understood as cracks that arise in the material of building structures during structure formation and exist prior to the application of external loads. It is assumed that cracks formed in the material automatically become cracks of the structure, thereby determining its crack resistance, deformability, and load-bearing capacity. For example, in precast reinforced concrete elements, the share of technologically induced cracks among all defects reaches about 60% [1].

Experimental studies have confirmed that operational cracks develop from technological ones. Since concrete is a material of the “structure within a structure” type, where each larger block consists of a combination of smaller ones, it can be assumed that volumetric deformations of each such block may lead to its fragmentation into sub-blocks. In this case, the crack pattern within a block reproduces the crack pattern at a higher scale level. Such fragmentation of structural blocks leads to the intensive development of operational cracks. Since the mechanical characteristics of composite materials are largely determined by cracks, it is assumed that cracks define the level of damage in the material and, consequently, in the structure.

A directed change in technological damage makes it possible to alter the nature of crack formation and structural failure. The use of mineral fillers in specific amounts and with a certain dispersion allows control over the processes of concrete structure formation and regulation of its initial volumetric changes, and thus technological damage, in order to obtain building structures with the required properties.

Mineral fillers, influencing the physical and mechanical properties of cement paste, determine its material consumption, which depends on the efficiency of using the clinker component of cement. Fillers are particles of arbitrary shape and surface activity, whose size does not allow them to create deformation and stress fields in the surrounding viscous medium but ensures their participation in the processes of structuring a material with specified properties. Fillers that do not contain chemically active components (low-activity mineral fillers) do not enter into chemical reactions with other components of the cement binder and mixing water. However, by influencing the physical and mechanical properties of cement paste, they determine its material consumption, which depends on how efficiently the clinker component is utilized. The more fully the potential properties of the most expensive and energy-intensive component of cement composites are used, the lower the material consumption. It has been proven that material consumption can be reduced by 15–21% through the use of fillers optimized in type and qualitative composition.

4 BASIC RESULTS

To obtain experimental data for the study of bending reinforced concrete elements and concrete specimens, an experiment consisting of nine tests was conducted. Portland cement with a specific surface area close to 300 m^2/kg, produced by co-grinding clinker and dihydrate gypsum, was used as the binder. Fine quartz sand with specific surface areas of Sy = 100, 200, and 300 m^2/kg, previously ground in a ball mill, was used as the filler. The sand was added to the binder in amounts of 8, 10, and 12% by mass. The specific surface area and quantity of the filler, depending on the concrete composition, are presented in Table 1. The filler was introduced directly into the concrete mix during its preparation.

The concrete composition per 1 m^3 was as follows: crushed stone – 1100 kg, sand – 171 kg, water – 140 kg, cement – 350 kg. Experimental studies were carried out on prism specimens with dimensions of 10 × 10 × 40 cm.

To study the initial (technological) damage of concrete prisms, attention was focused on the network of surface cracks. For a more accurate assessment of the technological damage of the specimens, crack manifestation was observed after the specimens had reached an age of 200–220 days, following carbonation—that is, the development of physical and chemical processes under the influence of atmospheric CO_2 in the presence of moisture, during which the concrete surface became covered with a network of fine cracks. Surface cracks were revealed by immersing the specimens in tannin solutions for 30–40 minutes and then dried in the laboratory for two days. Changes in the alkalinity of the concrete around the cracks altered the color of the tannin, thereby revealing and recording the cracks.

As a result of the studies on the lateral faces of the prisms, the crack lengths (T_0, cm) and the following average characteristics were obtained: the coefficient of technological damage by area, and the coefficients of technological damage in characteristic sections of the prisms (longitudinal and transverse), which are presented in Table 1.

Table 1

Coefficients of technological damage (K_pL, K_nS) and lengths of technological cracks (T_0) determined for the prisms

№ composition	H, %	Sy , m^2/кg	Longitudinal section (L_L = 40 sm)		Transverse section ($L_л$ = 10 sm)		Виділена площа (S = 100 sm^2)	
			T_o , sm	Kn_L , sm/cm	T_o , см	Kp_L , cm/cm	T_o , см	Kn_S , cm/cm
1	8	100	100,3	0,399	27,3	0,367	136	1,36
2		200	113	0,354	29,3	0,341	125	1,25
3		300	135,7	0,295	35,3	0,283	78	0,78
4	10	100	127	0,315	32,2	0,311	88	0,88
5		200	120,6	0,332	32,5	0,308	99	0,99
6		300	142	0,282	38,5	0,260	65	0,65
7	12	100	112	0,357	30,8	0,325	116	1,16
8		200	110,3	0,363	31,4	0,318	106	1,06
9		300	129,8	0,308	33,5	0,299	73	0,73

Analyzing the influence of the amount and dispersion of the filler on the technological damage of concrete prisms, it was found that the maximum value of the technological damage coefficient of concrete, determined from the transverse section of prism specimens, is achieved at a filler content of *H* = *8%* by mass of the binder and a dispersion of $Sy = 100\ m^2/kg$ (0.367), while the minimum value is observed at a filler content of *H* = *10%* and a dispersion of $Sy = 300\ m^2/kg$ (0.26).

The maximum value of the technological damage coefficient of concrete, determined from the longitudinal section of prism specimens, is achieved at a filler content of H = 8% by mass of the binder and a dispersion of $Sy = 100\ m^2/kg$ (0.399), while the minimum value is observed at a filler content of *H* = *10%* and a dispersion of $Sy = 300\ m^2/kg$ (0.282).

The maximum value of the technological damage coefficient of concrete, determined over the area of prism specimens, is achieved at a filler content of H = 8% by mass of the binder and a dispersion of $Sy = 100\ m^2/kg$ (1.36), while the minimum value is observed at a filler content of *H* = *10%* and a dispersion of $Sy = 300\ m^2/kg$ (0.65).

To assess the influence of technological damage in concrete, nine series of concrete prisms with different compositions were tested, and the prismatic strength of concrete (R_b), presented in Table 2, was determined. The value of the prismatic strength of concrete, depending on the quantity and quality of the filler, varies within the range from 27.14 to 34.35 MPa (by 26.6%).

Table 2

Values of prismatic strength

№ composition	*H*, %	S_y , м^2/кg	R_b , MPa
1	8	100	27,14
2		200	29,12
3		300	33,58
4	10	100	31,95
5		200	32,07
6		300	34,34
7	12	100	29,58
8		200	31,00
9		300	32,67

The influence of filler content on the prismatic strength of concrete is shown in Fig. 1a. The maximum change in prismatic strength (17.7%) is achieved when increasing H from 8% to 10% at $Sy = 100\ m^2/kg$. The minimum change in $R_{(b)}$ is observed when varying H from 8% to 10% at $Sy = 300\ m^2/kg$.

The influence of filler dispersion on the prismatic strength of concrete is shown in Fig. 1b.

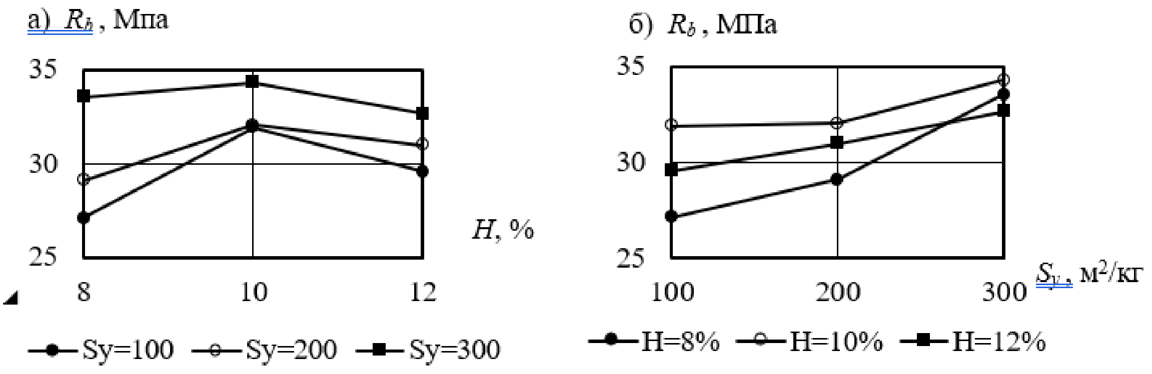

Fig. 1. Influence on the prismatic strength of concrete of the following factors:
(a) filler content; (b) filler dispersion

The maximum value of the prismatic strength of concrete is observed at a filler content of *H = 10%* by mass of the binder and a dispersion of *Sy = 300 m²/kg* (34.35 MPa), while the minimum value of $R_{(b)}$ is recorded at a filler content of *H = 8%* and a dispersion of *Sy = 100 m²/kg* (27.14 MPa).

Analyzing the values of prismatic strength (Table 1) and the coefficients of technological damage of prism specimens (Table 2), it can be noted that the minimum strength value of 27.14 MPa *(H = 8%; Sy = 100 m²/kg*) corresponds to the maximum value of the coefficient $K_nS = 1.36$ *cm/cm²* over the selected area. Similarly, for K_pL along both directions, the values are 0.399 in the transverse section and 0.367 in the longitudinal section.

Conversely, the maximum strength value of 34.34 MPa (*H = 10%; Sy = 300 m²/kg*) corresponds to the minimum value of the coefficient $K_nS = 0.65$ *cm/cm².* The values of K_pL for both considered directions are also minimal (0.282 and 0.260, respectively) in the same sections of the prisms. This relationship is clearly illustrated in Figs. 2 and 3.

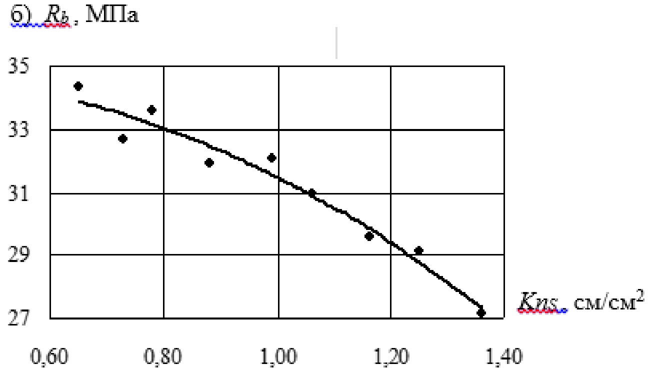

Fig. 2. Influence of technological damage, determined over the selected area of prism specimens, on prismatic strength

The influence of technological damage on the prismatic strength of concrete has been established. For R_b, the minimum value of 27.14 MPa (*H = 8%; Sy = 100 m²/kg*) corresponds to the maximum value of the coefficient $K_nS = 1.36\, sm/sm^2$ over the selected area. Conversely, the maximum value of 34.34 MPa (*H = 10%; Sy = 300 m²/kg*) corresponds to the minimum value of the coefficient $K_nS = 0,65\, sm/sm^2$.

Figure 4a presents the relationship between the prismatic strength of concrete and technological damage determined from the transverse section of the prism and expressed through the technological damage coefficient K_nL in the form

$$R_b = -225.35\, K_nL^2 + 69.24\, K_nL + 31.833.$$

As can be seen from the graph, with an increase in K_nL, the strength decreases from 34.7 to 27.05 MPa (by 28.28%). The largest deviation from the graph (1.49%) is observed at a filler content of *H = 12%* and a dispersion of *Sy = 100 m²/kg;* the smallest deviation (0.06%) is observed in other cases. In general, the deviations range from 1.6% to 0.08%.

Figure 3b shows the relationship between the prismatic strength of concrete and technological damage determined from the longitudinal section of the prism and expressed through the technological damage coefficient K_nL in the form

$$R_b = -57.727\, K_nL^2 - 19.449\, K_nL + 44.274.$$

As follows from the graph, with an increase in K_nL, the strength decreases from 34.25 to 27.39 MPa (by 25.05%). The maximum deviation from the graph (2.89%) is observed at a filler content of *H = 12%* and a dispersion of *Sy = 200 m²/kg*; the minimum deviation (0.05%)

is observed at *H* = *10%* and H = 12% with *Sy* = *300 m²/kg*. In other cases, the deviations range from 0.12% to 1.39%.

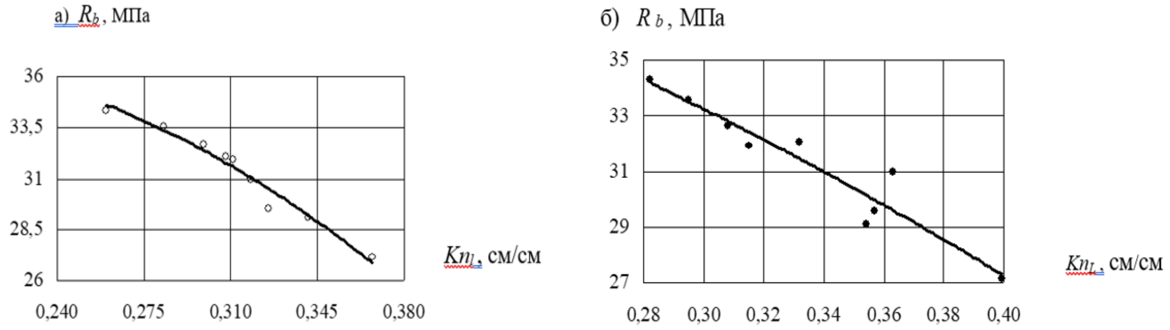

Fig. 3. Influence of technological damage on prismatic strength, determined from: (a) the transverse section of prism specimens; (b) the longitudinal section of prism specimens.

5 DISCUSSION OF THE RESULTS OF THE STUDY

The study confirmed that the composition of concrete significantly affects its structure, strength, and deformation properties of reinforced concrete structures. During the technological processing of concrete into products, technological cracks form at all levels of structural heterogeneity, determining the initial damage of the material and, consequently, the operational reliability of the structures. Experimental data showed that most service cracks develop from technological ones, highlighting the role of initial defects in the behavior of structures under load.

The analysis indicated that technological cracks forming in the concrete before the application of service loads automatically become structural defects of the construction, influencing its crack resistance, deformability, and load-bearing capacity. In precast reinforced concrete elements, the proportion of technological cracks reaches approximately 60% of the total defects. Due to the “structure-in-structure” nature of concrete, volumetric deformations of large blocks can lead to their fragmentation into sub-blocks, reproducing the crack pattern at a larger scale and contributing to the intensive development of service cracks.

The use of mineral fillers with optimal type, quantity, and dispersion allows control over the concrete structure formation, regulation of its initial volumetric changes, and technological damage, thereby enhancing the physical and mechanical properties of concrete and reinforced concrete structures. Mineral fillers, affecting the properties of the cement stone, determine the material consumption of the concrete mix, which depends on the efficiency of clinker utilization. Experimental results confirmed the possibility of reducing material consumption by 15–21% through the optimal selection of fillers by type and dispersion, simultaneously improving the operational reliability of structures.

Thus, the results emphasize the critical role of technological cracks in determining the strength and durability of concrete structures and demonstrate the effectiveness of using optimized fillers to control technological damage.

6 CONCLUSIONS

The conducted studies allow us to conclude that as the damage of concrete increases, its strength decreases, whereas a reduction in damage leads to an increase in strength. The mechanical characteristics of composite materials are largely determined by cracks; therefore, cracks define the damage of the material and, consequently, of the structure.

Such an influence of fillers on the initial damage allows for the design of concrete mixes with specified properties and highlights the need for further research, particularly regarding the deformation properties of concrete.

7 ETHICS DECLARATIONS

The author has no relevant financial or non-financial interests to disclose

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