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ИССЛЕДОВАНИЯ ФИЗИКО-ХИМИЧЕСКИХ ПРОЦЕССОВ В СИСТЕМЕ «ЦЕМЕНТНЫЙ БЕТОН – ЖИДКАЯ АГРЕССИВНАЯ СРЕДА»

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Работа посвящена актуальной теме – изучению физико-химических процессов при эксплуатации железобетонных конструкций в агрессивных средах. Представлена высокая значимость для стабильного существования минералов цементного камня наличия насыщенного раствора гидроксида кальция в порах бетона. В статье рассмотрены основные методы математического моделирования, которые используются для описания физико-химических процессов массопереноса целевого компонента (гидроксида кальция). Показана возможность использования математических моделей при описании жидкостной коррозии цементных бетонов, осложненной химическими превращениями, для определения параметров массоперноса и расчета скорости коррозии бетона до защитного слоя арматуры. Получена математическая модель массопереноса целевого компонента в безразмерных переменных. Предложено применить комбинированный метод микропроцессов для получения численно-аналитического решения краевой задачи нестационарного массопереноса, осложненного химическими превращениями. Получено численно-аналитическое решение нелинейной краевой задачи с начальными и граничными условиями нестационарного массопереноса, позволяющее рассчитать концентрации целевого компонента в толще строительной конструкции из бетона или

железобетона на цементном вяжущем, а также позволяет определить значение градиента концентраций на границе раздела фаз гетерогенной системы «Бетон - жидкая агрессивная среда». Представленное решение задачи позволяет определить распределение концентрации целевого компонента в любой интересующий момент эксплуатации строительной конструкции, временные процессы достижения опасного содержания гидроксида кальция, находящегося в порах цементного бетона, до начала разложения компонентов высокоосновных соединений (алита, белита, трехкальциевого алюмината, четырехкальциевого алюмината) и, следовательно, перейти к дальнейшим этапам изучения и моделирования коррозионных процессов. Чтобы продемонстрировать возможности полученного решения, проведен численный эксперимент: показано изменение полей безразмерных концентраций при разных значениях массообменного критерия подобия Фурье, который в соответствии с теорией подобия является показателем времени процесса.

Ключевые слова: долговечность, массоперенос с химическими превращениями, агрессивная среда, защитный слой, бетон, арматура, поля концентраций

RESEARCH OF PHYSICAL AND CHEMICAL PROCESSES IN THE SYSTEM "CEMENT CONCRETE - LIQUID AGGRESSIVE ENVIRONMENT"

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This article is devoted to an urgent topic - the study of physico-chemical processes during the operation of reinforced concrete structures in aggressive environments. The high importance of calcium hydroxide in the solution of concrete pores is presented, since it is necessary to maintain the stable existence of cement stone minerals. The paper consideres the basic methods of mathematical modeling that are used to describe the physico-chemical processes of the mass transfer of target component (calcium hydroxide). The possibility of using mathematical models in describing the corrosion of the second stage of cement concretes to determine the mass transfer indicators and calculate the corrosion rate of reinforcing steel and concrete is shown. The mathematical model of mass transfer of target component in dimensionless variabl s was obtained. To obtain a numerical

analytic solution of the boundary value problem of non-stationary mass transfer, it is proposed to apply a combined method microprocess. The numerical-analytical solution of the nonlinear initial-boundary value problem of non-stationary mass transfer is obtained, which allows to calculate concentrations of target component in the thickness of a building structure made of concrete or reinforced concrete of cementitious binder but also makes it possible to determine the value of the gradient concentrations of at the interface of phases heterogeneous system «concrete - liquid aggressive environment». The obtained solution allows determining concentration distribution of the target component at any moment of interest in the operation of the building structure, the time processes of reaching the dangerous content of calcium hydroxide located in the preparation pores of to the beginning of decomposition of highly basic compound components (alite, belite, tricalcium aluminate, four-calcium aluminate), and hence moving on to the further stages of study and modeling of corrosion processes. To demonstrate the possibilities of the obtained solution, we will carry out a numerical experiment. It was shown how the field of dimensionless concentrations changes at different values of the Fourier similarity criterion, which in accordance with the theory of similarity is an indicator of the process time.

Key words: durability, mass transfer with chemical transformations, aggressive environment, protective layer, concrete, reinforcement, concentration fields

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INTRODUCTION

Concrete and reimposition concrete is the most significant common buildings material for the manufacture of structural elements of buildings and structures.

During operation, majority buildings structures is exposed to the aggressive environment, which promotes a variety of corrosion processes. Corrosion of concrete is a complex structural, mass transfer, physical and chemical processes, which leads change in identity, strength retrogression, to the destruction of the buildings structures. Corrosion and destruction of concrete can cause [1]:

- water (river, sea, industrial and domestic wastewater);
- periodically and repeatedly repeated temperature fluctuations (annual and daily), alternating freezing and thawing, heating and cooling;
- humidification and drying processes (fluctuations in atmospheric humidity, specific service conditions);
- mechanical effects - wave impacts, weathering, abrasion;
- biologically harmful effects of bacteria.

Very important to define and organize the causes of corrosion of building materials, to identify the factors that affect this diversiform process, to differentiate the physicochemical phenomena of mass transfer in concrete and reinforced concrete under the attack of different aggressive environments, determine the parameters necessary for the development of physical and mathematical models, determine the effectiveness of the prescribed corrosion protection.

RELEVANCE

All minerals in concrete of cementitious binder maintain stable existence only in solutions of calcium hydroxide of a not less certain concentration, close to the concentration of the saturated solution [2]. The concentrations of calcium hydroxide capable of maintaining the stable existence of cement stone minerals on a binder made of simple Portland cement are shown in Table.

In this case, the following processes occur simultaneously and mutually affect each other:

- diffusion (from a high-content zone to a lower-content zone) of calcium hydroxide molecules contained in the pores of cement stone through the through pores of concrete to the constructions surface in contact with a liquid aggressive environment;
- the transition of calcium hydroxide molecules across the phase interface, with their further flow in the liquid environment of operation and chemical reactions in the same environment;
- molecules of other compounds dissolved in water

penetrate through the phase interface into the concrete body;

- there is a diffusion of molecules of aggressive substances from the phase interface through the through pores of concrete into the depth of the structure;
- in the pores of concrete, the chemical interaction of calcium hydroxide with aggressive substances that have penetrated into the body of the structure from the external environment occurs, while the content of substances entering into chemical reactions decreases, and the reaction products increase.

Table

Chemical mineralogical composition of concrete on a cement binder and the equilibrium concentrations of calcium hydroxide at which this compounds exists

Таблица. **Химико-минералогический состав бетона на цементном вяжущем и равновесные концентрации гидроксида кальция**

Highly basic compounds of concrete	Chemical formula	The percentage of this compound in concrete	Calcium hydroxide content required in stable existence, g/l (in terms of calcium oxide)
Alite (tricalcium silicate)	$3CaO\cdot SiO_2\cdot 3H_2O$	37…60	1.10
Belite (dicalcium silicate)	$2CaO\cdot SiO_2\cdot 2H_2O$	15…37	1.29
Monocalcium silicate	$CaO\cdot 2SiO_2\cdot H_2O$	2…5	0.05
Tetracalcium Aluminate	$4CaO\cdot Al_2O_3\cdot 12H_2O$	0,1…4	1.08
Tricalcium Aluminate	$3CaO\cdot Al_2O_3\cdot 6H_2O$	7…15	0.56
Dicalcium aluminate	$2CaO\cdot Al_2O_3\cdot 7H_2O$	0.1…4	0.36
Hydrated tetracalcium ferrite	$4CaO\cdot Fe_2O_3$	1…8	1.06
Hydroferrites	$CaO\cdot Fe_2O_3\cdot H_2O$	0.5…6	0.64

The listed physico-chemical processes, the content of calcium hydroxide in the solution of concrete pores changes, which violates the chemical equilibrium between the pore fluid and the components of cement stone (highly basic compounds). After that, highly basic compounds undergo stepwise decomposition, which leads to a loss of strength and, as a consequence, to the destruction of building structure [2, 3]. Professor Moskvin V.M. conducted many experiments and established some relationship between the strength of concrete on a cement binder and the decrease in the number of "free calcium hydroxide" in the solution of pores concrete [2]. A decrease in the concentration of "free calcium hydroxide" 30% of the original located in the pores of concrete from cement binder causes a decrease in strength by 60...70%.

In the case of corrosion of reinforced concrete structures, the reinforcement of reinforced concrete is kept for a long time under the protection of a rust preventative protective coating of concrete. Over time, particles of aggressive environmental conditions diffuse to the surface of reinforcing bars through the pores of concrete, and due to structural defects, that are formed when concrete is destroyed during corrosion. Reinforcement corrosion is enhanced by the formation of microcracks in concrete or its partial collapse [3].

PROBLEM STATEMENT

Scientists have accumulated a large amount of scientific data on destructive processes occurring in reinforced concrete structures under the influence of the environment of a particular composition: the basic schemes of chemical reactions, their physico-chemical parameters are established and described; empirical, rheological and phenomenological dependences of some types of corrosion are given; a system of regulatory documents on corrosion control is created and actively modified.

The accumulated results of experimental and field studies allow us to generalize this information into a general methodology for predicting the life cycle of building structures in the form of mathematical models that will help to calculate changes in the design characteristics of concrete and reinforced concrete structures with a certain accuracy.

Mathematical modeling methods for calculations of corrosive mass transfer processes during the operation of building structures have not yet been widely implemented in real engineering calculations, although their advantages over class methods for determining the durability of structures are obvious [4-7]. In addition, the use of mathematical models determines the effectiveness of primary and secondary corrosion protection of building materials and structures.

The diversification of mathematical models will allow only a broad understanding of the physical and chemical mechanisms of corrosion processes in the material of the structural element. To ensure reproducibility of the implemented mathematical dependencies, a large amount of experimental data is needed showing the actual influence of various factors on the statics, dynamics and kinetics of processes, as well as verification of the reliability of the forecasting methodology on real construction sites.

The biased view of statics, kinetics and dynamics of mass transfer processes during concrete and reinforced concrete corrosion allows: to determine critical operating conditions for provoking mass exchange processes in the body of a building structure; to evaluate the effectiveness of methods for slowing down (accelerating) destructive processes; to develop physical and mathematical models of corrosion processes of reinforced concrete structures of buildings and structures in various environments; to calculate the durability of concrete and reinforced concrete building structures.

The question of the durability of concrete, metal, reinforced concrete, stone and wooden structures subject to corrosion should be considered not only from the point of view of the aggressive effects of a substance, but depending on the qualitative cumulative and quantitative effects of all those factors that can cause the destruction of the system.

It is possible to predict changes in the structure, physical, mechanical and chemical properties of materials of building structures, especially those made of concrete and reinforced concrete, using the theory of heat and mass transfer. Heat and mass transfer processes are one of the most important branches of modern science and are of great practical importance in [15, 16].

The current level of development of the theory of heat and mass transfer and computer technology allows us to solve complex physical and mathematical problems modeling the transfer processes occurring in building structures during their construction and operation. These processes determine the life cycle of the design.

The theoretical hypothesis for the diversification of mathematical models in this direction is the theory of heat and mass transfer and its expressions in the form of a system of partial differential equations analytically characterizing describing non-stationary interrelated phenomena of heat, mass and inflation transfer in solid capillary-porous bodies characterizing the transfer of substance at the boundaries of bodies with their surrounding gas (liquid) medium, obtained by academician A.V. Lykov [8, 9].

RESULTS OF THEORETICAL RESEARCH

According to the theory of mass transfer of academician Lykov A.V. [8, 9], in general, for corrosion heterogeneous system of the, diffusion of various substances (calcium hydroxide, aggressive substances) in the porous structure of concrete, which is a capillary-porous solid, is described by a nonlinear differential equation of mass conductivity of the second order:

$$\frac{\partial C(x,\tau)}{\partial \tau} = div[k(x,\tau) gradC(x,\tau)] + \frac{q_v(x,\tau)}{\rho_{con}}, \quad (1)$$

where: $k(x,\tau)$ is mass conductivity (diffusion) coefficient the test substance in the capillary-porous solid, m^2/s; $C(x,\tau)$ is the concentration of portable component ("free calcium hydroxide" located in the pores in concrete of cementitious binder) at the time τ at any point with the coordinate x, kg portable component /kg concrete; $q_v(x,\tau)$ is the power of additional volumetric release (collection) of mass because of chemical reactions or phase transformations, kg portable component /($m^3 \cdot s$); ρ_{con} – concrete true specific gravity, kg/m^3.

Many building structures, or their fragments, in general, can be represented in the form by an unlimited plate of thickness δ. The concrete of such structures will correspond to certain physical properties (humidity, true specific gravity ρ, porosity ε and mass conductivity coefficient k, other). The pores of concrete contain saturated calcium hydroxide solution, the concentration of which at the initial time of the operation of the structure is assumed to be steady, and then, in light of to the influence of the aggressive environment, it changes with time and takes an uneven appearance [10, 11].

Surrounding the building structure liquid aggressive environment with salts and acids , the concentration of which generally changes in time $C_{liq}(\tau)$ (kg of the agressive component/kg of the liquid) (Fig. 1). The intensity of the transfer of the substances (("free calcium hydroxide" located in the pores in concrete of cementitious binder or an aggressive component) is characterized by the mass current density of particles of this substances $q_f(\tau)$ (kg portable component/($m^2 \cdot s$)).

As soon as the liquid begins to come into contact with the concrete of the building structure, mass transfer processes will start, complicated by chemical reactions between calcium hydroxide dissolved in the liquid pores of concrete and aggressive components (solutions of salts and acids). The action of salts and acids is most often reduced to their reaction with calcium hydroxide, calcium hydrosilicates, etc. As a result, easily soluble salts are formed, which are washed out of the concrete body. Here are some examples of such reactions:

$$Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3\downarrow + 2H_2O, \quad (2)$$

$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O, \quad (3)$$

$$Ca(OH)_2 + MgCl_2 \rightarrow CaC1_2 + Mg(OH)_2\downarrow (4)$$

$$Ca(OH)_2 + MgSO_4 + 2H_2O \rightarrow$$
$$\rightarrow CaSO_4{\cdot}2H_2O + 2Mg(OH)_2\downarrow + 8H_2O \quad (5)$$

This process is accompanied by mutual diffusion through the through pores of concrete. Calcium hydroxide moves from the inner layers to the boundary of the interaction of concrete with a aggressive environment, and aggressive components from the liquid phase diffuses into the solid, while entering into a interacting with calcium hydroxide [12, 13]. After some time intervals τ_1 and τ_2 ($\tau_2 > \tau_1$), along the thickness of the structure, fields of concentrations of calcium hydroxide and an aggressive component are formed can be schematically illustrated by Fig. 1. Here: $C_{Ca(OH)_2}(x,\tau)$ is concentration recoverable substance from the capillary-porous body (calcium hydroxide of concrete), $C_{ag}(x,\tau)$ is concentration of absorbed (aggressive) substance in concrete [14].

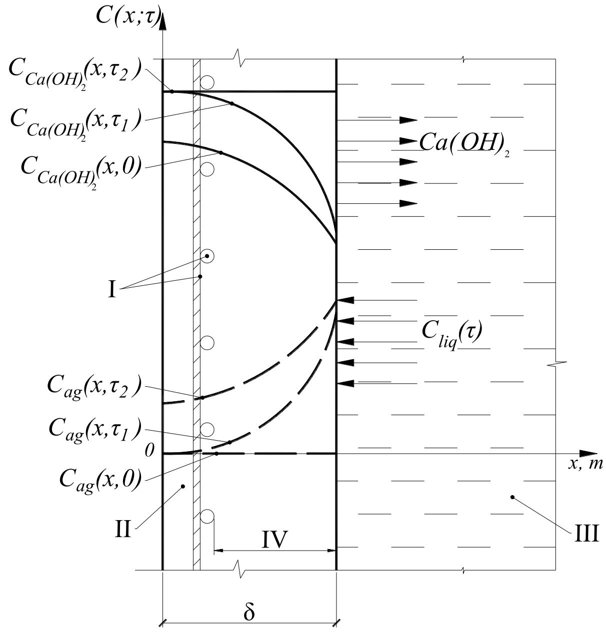

Fig. 1. System "steel reinforcement – concrete – aggressive environment". I – steel reinforcement; II – concrete; III – aggressive environment; IV - protective coating

Рис. 1. Система «арматура – бетон – агрессивная среда». I –арматура; II – бетон; III – агрессивная среда; IV – защитный слой

For the considered system "concrete – liquid aggressive environment" the mass transfer problem for calcium hydroxide, complicated by chemical and phase transformations, can be written as the following equations [2, 8, 12, 15]:

$$\frac{\partial C(x,\tau)}{\partial \tau} = k\frac{\partial^2 C(x,\tau)}{\partial x^2} + \frac{q_v(x,\tau)}{\rho_{con}}, \quad \tau > 0,\ 0 \le x \le \delta, \tag{6}$$

$$C(x,\tau)\big|_{\tau=0} = C_0(x), \tag{7}$$

$$\left.\frac{\partial C(x,\tau)}{\partial x}\right|_{x=0} = 0, \tag{8}$$

$$-k\cdot\rho_{con}\cdot\frac{\partial C(\delta,\tau)}{\partial x} = q_f(\tau) \tag{9}$$

Here: x is arbitrary coordinate, m; $C_0(x)$ is concentration of portable component ("free calcium hydroxide" located in the pores in concrete of cementitious binder) located in the pores in concrete of cementitious binder at the initial time in any point with coordinate x, in terms of calcium oxide, kg portable component/kg concrete; k is coefficient of mass conductivity calcium portable component in the concrete, m^2/s; τ is time, s; δ is wall thickness of the structure, m.

The formula (6) is the differential equation of non-stationary mass transfer in the body of a reinforced concrete structure. Equation (6) is a partial differential equation of parabolic type. In general, the additional volumetric release (collection) of mass is a quantity distributed along a coordinate according to an given by a mathematical function.

The equation (7) defines the initial condition of the process: the distribution of calcium hydroxide concentrations at the time instant taken as the initial one. The third and fourth expressions define the conditions at the interface.

The equation (8), also called the "non-penetration condition", determines the fact that calcium hydroxide does not diffuse into the liquid medium from the concrete mass.

The formula (9) is Newmann's boundary condition (a condition of the second type), shows that at the boundary of the heterogeneous System «concrete – liquid aggressive environment» there is a mass transfer between the solid and liquid phases.

For to reduce the number of arguments, the convenience of mathematical operations and analysis of statics, kinetics and dynamics of mass transfer processes, we give expressions (6)-(9) into a dimensionless form, introducing a dimensionless concentration and similaritys criterions of the form [2, 8]:

$$\theta(\bar{x},Fo_m) = \frac{C(x,\tau)-C_0}{C_0}, \quad Fo_m = \frac{k\tau}{\delta^2}$$

$$Po_m^* = \frac{q_v\cdot\delta^2}{k\cdot C_0\cdot\rho_{con}}, \quad Ki_m^* = \frac{q_f\cdot\delta}{k\cdot C_0\cdot\rho_{con}} \tag{10}$$

Here: $\theta(\bar{x},Fo_m)$ – dimensionless concentration of portable component located in the pores in concrete; Fo_m – Fourier mass transfer similarity criterion; Po^*_m – modified Pomerantsev mass transfer similarity criterion; Ki^*_m – modified Kirpichev mass transfer similarity criterion.

Finally, the boundary value problem of mass conductivity of portable component located in the pores in dimensionless variables has the form:

$$\frac{\partial\theta(\bar{x},Fo_m)}{\partial Fo_m} = \frac{\partial^2\theta(\bar{x},Fo_m)}{\partial\bar{x}^2} + Po_m^*(\bar{x}),\ Fo_m > 0,\ 0 \le \bar{x} \le 1 \tag{11}$$

$$\theta(\bar{x},Fo_m)\big|_{Fo_m=0} = \theta_0(\bar{x}) \tag{12}$$

$$\left.\frac{\partial\theta(\bar{x},Fo_m)}{\partial\bar{x}}\right|_{\bar{x}=0}=0 \tag{13}$$

$$-\left.\frac{\partial\theta(\bar{x},Fo_m)}{\partial\bar{x}}\right|_{\bar{x}=1}=Ki_m^* \tag{14}$$

Due to the rapid development of software development tools, numerical technique allowing to replace the original mathematical problem (the solution of partial differential equations) with another problem – a computational algorithm. The use of numerical simulations techniques often allows to reduce the difficult task nonlinear problem to a less expensive linear one. If we divide the sophisticated modeled process into n oversimplified microprocesses. Within microprocesses of which all parameters can be considered constant, then the nonlinear problem decomposes into many n linear problems [7]. To obtain a numerical analytic solution to the boundary value problem of nonstationary mass transfer, it is proposed to apply a combined method microprocess, which consists in the fact that the simulated process is divided into small time intervals (microprocesses), at the fo each microprocess athe concentration distribution is calculated analytically, and then the whole process is collaborate up to a general mathematical model of non-stationary mass transfer. It should be noted that the microprocessor method allows you to get good results if the integral Laplace transform is applied when solving a system of differential equations. In addition, in the field of Laplace images, it is often possible to obtain a solution in two forms: with small and large Fourier similarity criteria [4]. This is due to the fact that in the region of large Fourier similarity criterion, the results are quite accurate when using only the first few terms of the series [8].

The general solution of problem (11)-(14) when $Fo_m << 0,1$ has the form:

$$\begin{aligned}\theta(\bar{x},Fo_m) &= Ki_m^*(1\mp\bar{x}))erfc\left[\frac{(1\mp\bar{x})}{2\sqrt{Fo_m}}\right]-\\ &-2Ki_m^*\sqrt{\frac{Fo_m}{\pi}}\exp\left[-\frac{(1\mp\bar{x})^2}{4Fo_m}\right]+\\ &+\frac{1}{\sqrt{\pi Fo_m}}\int_0^1\theta_0(\xi)\exp\left[-\frac{(1\pm\bar{x}+\xi)^2}{4Fo_m}\right]d\xi+\\ &+2\sqrt{Fo_m}\int_0^1 Po_m^*(\xi)ierfc\left[\frac{(1\pm\bar{x}+\xi)}{2\sqrt{Fo_m}}\right]d\xi\end{aligned} \tag{15}$$

Expression (15) allows us to calculate the concentration field of both the target component and aggressive substances by the thickness of a concrete or reinforced concrete building structure at any time in the range of the Fourier mass transfer similarity criterion – exchange number 0...0.01. But also makes it possible to determine the value of the gradient target component ("free calcium hydroxide" this at the phases heterogeneous system «concrete – liquid aggressive environment» [2]. This decision is fair for the initial stage of corrosion, with a low-intensity mass transfer process, for example, either with small values of the mass conductivity coefficient, or with a large thickness of the calculated building structure.

RESULTS OF NUMERICAL EXPERIMENTS

Some results of calculations based on the obtained expression are shown in Fig. 2, 3 and 4.

The curves in Fig. 2 illustrate the influence of the power of additional volumetric release (collection) of mass because of chemical reactions or phase transformations on the profiles of dimensionless concentrations calcium hydroxide over the thickness of the structure, manufactured from cement concrete, depending on the modified Pomerantsev mass transfer similarity criterion. The greatest decrease in concentrations is recorded in the boundary layers interacting with the liquid aggressive environment.

As follows from Fig. 2, in the processes under study, it is necessary to study in more detail the kinetics of concentration changes in layers close to the liquid aggressive environment. For this purpose, kinetic curves of the dimensionless concentration change at the phase interface (Fig. 3) and at the boundary of the protective layer of steel reinforcement (Fig. 4) are additionally constructed. It is obvious that in the case of a positive additional volumetric release of mass, the concentration of the target component increases as it approaches the phase boundary, with a negative additional volumetric release of mass (calcium hydroxide loss due to chemical reaction), there is a more intensive mass transfer of the substance to the aggressive environment as a reaction product.

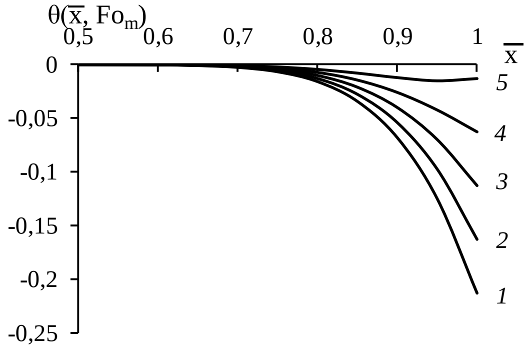

Fig. 2. Influence of the additional volumetric mass source (Po_m^*) on the profiles of dimensionless concentrations $Fo_m = 0.01$; $Ki_m^* = 1$; at $Po_m^* = 1 – (-10); 2 – (-5); 3 – 0; 4 – 5; 5 – 10$

Рис. 2. Влияние объемного источника массы (Po_m^*) на профили безразмерных концентраций $Fo_m = 0,01$; $Ki_m^* = 1$; при $Po_m^* = 1 – (-10); 2 – (-5); 3 – 0; 4 – 5; 5 – 10$

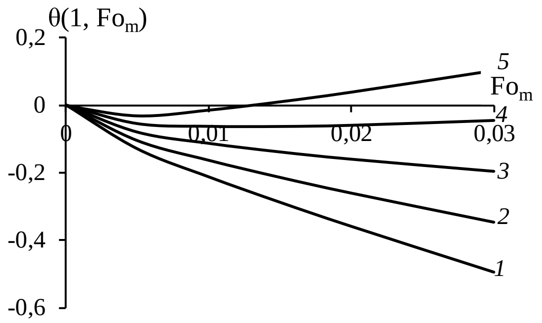

Fig. 3. Kinetic curves of changes in dimensionless concentrations on the concrete surface. $Fo_m = 0.01$; $Ki_m^* = 1$; at $Po_m^* = 1 – (-10)$; 2 – (-5); 3 – 0; 4 – 5; 5 – 10

Рис. 3. Кинетические кривые изменения безразмерных концентраций на поверхности бетона. $Fo_m = 0{,}01$; $Ki_m^* = 1$; при $Po_m^* = 1 – (-10)$; 2 – (-5); 3 – 0; 4 – 5; 5 – 10

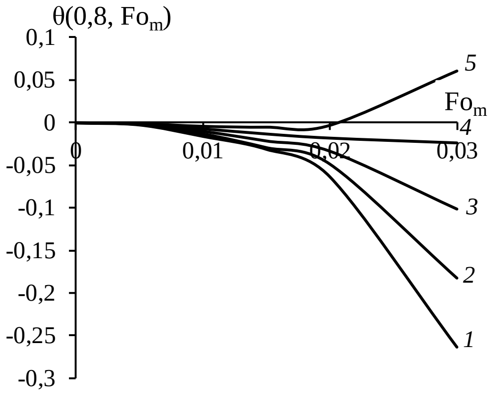

Fig. 4. Kinetic curves of changes in dimensionless concentrations at the boundary of the protective coating of steel reinforcement. $Fo_m = 0.01$; $Ki_m{}^* = 1$; at $Po_m^* = 1 – (-10)$; 2 – (-5); 3 – 0; 4 – 5; 5 – 10

Рис. 4. Кинетические кривые изменения безразмерных концентраций на границе защитного слоя арматуры. $Fo_m = 0{,}01$; $Ki_m{}^* = 1$; при $Po_m^* = 1 – (-10)$; 2 – (-5); 3 – 0; 4 – 5; 5 – 10

DISCUSSION

To solve the problem of protecting a reinforced concrete structure from the aggressive effects of the environment, it is necessary to use the obtained expression to solve the “inverse problem of non-stationary mass transfer” in order to find conditions under which the processes of mass transfer would be carried out with a minimum leaching rate. It is possible to control this process by influencing the structure of the concrete in the structure. Obviously, the time parameter is the Fourier mass transfer criterion. It is also obvious that the time τ is included in the exponential function, which is a factor in each term of the Fourier series.

Therefore, the solution of the “inverse mass transfer problem” is possible only with the use of the iteration method. Analysis of the solution also makes it possible to determine the duration of the service life of a reinforced concrete structure, which is determined by the processes occurring at the interface: in concrete – mass conductivity (k), and in the liquid phase – mass transfer (β). The first depends on the structural and mechanical characteristics of the reinforced concrete structure; the second – on the conditions of interaction at the phase boundary. All this determines the directions of scientific research of researchers. The main difficulty of applying solution (15) in engineering calculations is to determine the numerical value of the additional volumetric release (collection) mass source. The mathematical function of the the additional volumetric release (collection) mass source is mainly determined by the distribution of reagent concentrations and the laws of chemical kinetics, taking into account, among other things, the differences in intrapore pressure.

CONCLUSION

The developed algorithm for physical and mathematical modeling of mass transfer in the processes of liquid corrosion of concrete, taking into account the chemical effect of a liquid aggressive environment at the level of phenomenological equations, with non-uniform and non-stationary initial and boundary conditions, for small values of the similarity criterion will allow us to calculate the concentration of the transferred target component ("free calcium hydroxide" located in the pores) in the thickness of the structure. A mathematical model based on the theory of mass transfer, when using the combined method of microprocesses, makes it possible to determine the average one at the thickness and volume of the structure, and also allows to determine the time of reaching on the concrete structure surface critical content calcium hydroxide located in the pores leading to the beginning of decomposition of cement concrete highly basic compounds. This decision is fair for the initial stage of corrosion, with a low-intensity mass transfer process, for example, either with small values of the mass conductivity coefficient, or with a large thickness of the calculated building structure.

The authors declare the absence a conflict of interest warranting disclosure in this article.

Авторы заявляют об отсутствии конфликта интересов, требующего раскрытия в данной статье.

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