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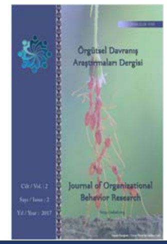

INCREASING THE DURABILITY OF CONSTRUCTION SITES THROUGH THEORETICAL AND EXPERIMENTAL STUDIES OF CORROSIVE MASS TRANSFER

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ABSTRACT

The laws of mass transfer, common to the whole variety of natural phenomena, make it possible to rationally design building structures in accordance with the modes of operation, optimal selection of material, and assessment of the state of structures. The study of mass transfer processes occurring during corrosion destruction is a problem of current interest, from a scientific and practical point of view. On the basis of a mathematical model, an engineering calculation method has been synthesized, and a computer program has been developed for determining the completion time of the initial stage of corrosion of cement concrete of type II.

Keywords: *Corrosion, Building Structures, Concrete, Mass Transfer, Mathematical Modeling Methods,*

INTRODUCTION

The experience of operating concrete structures, used since the late 80's of the 19th century, shows that concrete is comparable with natural stone materials, in terms of durability and reliability. But at the same time, there are cases of early destruction of concrete long before the end of the design life, due to the adverse effects of groundwater, river, sea, as well as waste and industrial waters. The reason for this lies in the corrosion processes, which cause severe damage to the construction complex (Fedosov, 2010).

Currently in the field of construction materials accumulated a large amount of scientific data about corrosion processes occurring in concrete under the influence of the environment of a particular composition: concepts of chemical reactions have been identified and investigated; Mathematical descriptions of some corrosion processes provided; and the system of regulatory documents against corrosion of concrete in construction created (Gusev and Fayvusovich, 2006). Numerous processes occurring during the corrosion process of concrete have been classified into three main types, by the founder of the science of concrete corrosion, Professor V.M. Moskvin, and the main ways to increase the corrosion resistance of concrete indicated. The first group (type I corrosion) integrates corrosion processes, which occur in concrete under the effect of water, when the constituent parts of the cement stone are dissolved and washed out by liquid. The second group (type II corrosion) includes the processes of corrosion that progress in concrete under the action of water containing chemicals, entering into

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interactive reactions with components of cement stone. The reaction products are either easily dissolved and washed away with water, or are deposited in the pores and capillaries of the cement stone in the form of an amorphous mass, acting as an inhibitor of corrosion destruction at the initial stage. The third group (type III corrosion) includes the processes of corrosion, which during the progress of them in the micro cavities of concrete, an accumulation of slightly soluble salts occurs, crystallization of which causes the occurrence of significant tensile stresses and final destruction. In concrete corrosion processes, the rate of destruction is determined by mass transfer processes. The processes of mass transfer are one of the most important sections of modern science and are of great practical importance in the construction materials (Rumyantsev, 2009; Fedosov, Rumyantseva and Kasyanenko, 2010).

The study of the kinetics and dynamics of the development of concrete corrosion processes allows:

- to determine the conditions for the occurrence of destructive processes, the causes of their acceleration or weakening;
- to develop mathematical models of the processes of concrete corrosion I-type and methods for determining the durability of concrete and reinforced concrete building structures.

Methods of mathematical modeling in the study of the processes of corrosion of concrete are not widely used in practice yet, although their advantages are obvious. Therefore, the study of the processes of corrosion of concrete is an urgent task from a scientific and practical points of view.

Solving the problems of durability of concrete and reinforced concrete objects is impossible without a clear understanding of the mechanism of the processes, and experimental data characterizing the influence of various factors on the kinetics and dynamics of corrosive mass transfer. The laws of mass transfer –common to all variety of natural phenomena, provide an opportunity for rational design of building structures in accordance with the modes of operation, optimal selection of material, assessment of the state of structures (Rumyantseva et al., 2010; Fedosov et al., 2010).

Methods of mathematical modeling in the study of concrete corrosion processes are not yet widely used in practice, although their advantages are obvious.

Based on the theoretical and experimental studies, we developed a mathematical model of mass transfer for the corrosion processes of the I-type of cement concrete in an enclosed "liquid-reservoir" system, and analyzed at the level of phenomenological equations, which allows to calculate the concentration of the transferred component ("free calcium hydroxide") according to the thickness of the structure at any given time, its content in the liquid phase and average thickness and volume of the structure, and ultimately, determine the time for completion of the initial stage of corrosion of cement concrete I of the form (Fedosov ety al., 2011; Fedosov, 1995).

Mathematically, in dimensionless coordinates, this problem can be represented as follows:

$$\frac{\partial Z(\bar{x}, Fo_m)}{\partial Fo_m} = \frac{\partial^2 Z(\bar{x}, Fo_m)}{\partial \bar{x}^2}, \; Fo_m > 0, \; 0 \le \bar{x} \le 1. \qquad (1)$$

Initial condition:

$$Z(\bar{x},0)=0. \tag{2}$$

Boundary condition:

$$\frac{\partial Z(0,Fo_m)}{\partial \bar{x}}=0, \tag{3}$$

$$\frac{1}{Bi_m}\cdot\frac{\partial Z(1,Fo_m)}{\partial \bar{x}}=\left[Z_p(Fo_m)-Z(1,Fo_m)\right]. \tag{4}$$

where: $Z(\bar{x},Fo_m)=\dfrac{C_0-C(x,\tau)}{C_0}$ – dimensionless concentration of the transferred component according to the concrete thickness at an arbitrary point in time;

C(x,τ) – the concentration of "free calcium hydroxide" in concrete at time τ at an arbitrary point with x coordinate, in terms of CaO, kg CaO/kg of concrete;

C_o – the initial concentration of "free calcium hydroxide", in terms of CaO, kg CaO / kg of concrete;

$\bar{x}=x/\delta$ – relative coordinate;

Fo_m – Fourier mass transfer criterion;

Bi_m – Biot mass transfer criterion.

The final solution of the boundary value problem for the region of large Fourier values is:

$$Z\left(\bar{x},Fo_m\right)=\frac{Z_{ж}(0)}{1+K_m}-2Bi_m Z_{ж}(0)\sum_{n=1}^{\infty}\frac{\cos\left(\mu_n\bar{x}\right)}{\psi'(\mu_n)}\exp\left(-\mu_n^{2}Fo_m\right), \tag{5}$$

where: $Z_{ж}(Fo_m)=\dfrac{C_0-m\cdot C_{ж}(\tau)}{C_0}$ – dimensionless concentration of the transfered component in the liquid;

$C_{ж}(\tau)$ – concentration of the transferred component in the liquid phase, kg / m3;

$Z_{ж}(0)$ – the initial concentration of the transferred component in the liquid;

$K_m=m\cdot G_Б/G_{ж}$ – coefficient, which takes into account the characteristics of the phases;

$G_Б, G_{ж}$ – the mass of the concrete reservoir and the liquid in the reservoir, respectively, kg;

m – equilibrium constant (Henry), determining the equilibrium conditions of the component between the liquid and solid phases;

Corrosion of the second type is noticeably more complicated, it can be divided into six successively interrelated stages of corrosion destruction: chemical interaction of an aggressive substance with “free calcium hydroxide” dissolved in concrete pores on the concrete surface; diffusion of "free calcium hydroxide" through the porous structure of concrete to the surface of the reaction until the moment of reaching to the concentration required for the beginning of decomposition of highly basic compounds; progression of the front zone of reaction of "Free calcium hydroxide" inside the concrete with the emergence of the reaction product;

penetration of the aggressive component from the solution into the porous structure of the concrete, through the layer of the reaction product; chemical reactions of decomposition of highly basic cement stone compounds with the formation of soluble or amorphous products; diffusion of soluble reaction products to the interface of "Liquid - concrete" and mass transfer to a liquid medium.

The boundary problem of mass conductivity in dimensionless coordinates is:

$$\frac{\partial\theta(\overline{x}, Fo_m)}{\partial Fo_m} = \frac{\partial^2\theta(\overline{x}, Fo_m)}{\partial\overline{x}^2} + Po^*(\overline{x}),\ Fo_m > 0,\ \ 0 \le \overline{x} \le 1. \quad (6)$$

Initial condition:

$$\theta(\overline{x}, Fo_m)\big|_{Fo_m=0} = \theta_0(\overline{x}). \quad (7)$$

Boundary condition:

$$\left.\frac{\partial\theta(\overline{x}, Fo_m)}{\partial\overline{x}}\right|_{\overline{x}=0} = 0, \quad (8)$$

$$-\left.\frac{\partial\theta(\overline{x}, Fo_m)}{\partial\overline{x}}\right|_{\overline{x}=1} = Ki^*. \quad (9)$$

where: Ki^*, Po^* – mass exchange criteria Kirpicheva, Pomerantseva, respectively;
$\theta(\overline{x}, Fo_m) = \frac{C(x,\tau) - C_0}{C_0}$ – dimensionless concentration of the transferred component according to the concrete thickness at an arbitrary point in time.
At a certain stage of corrosion development, there comes a time when the concentration of the transferred component at the interface with an aggressive environment becomes zero. In this case, the problem of mass transfer from diffusion-kinetic, controlled by external, internal diffusion and chemical kinetics, goes into the problem of mass transfer, controlled only by internal diffusion and chemical kinetics.
For this case, the boundary problem of mass conductivity in dimensionless coordinates is written as problem (6) - (9), with distinction in the boundary condition of the second kind (9):

$$\theta(\overline{x}, Fo_m)\big|_{\overline{x}=1} = 0. \quad (14)$$

The general solution to the problem of mass conductivity, controlled by intradiffusion resistance and chemical kinetics, obtained by the Laplace transform method, has the form of:

$$\theta(\overline{x}, Fo_m) = 2\int_0^1 \theta_0(\xi)d\xi - 2\int_0^1 \theta_0(\xi)\xi d\xi + \int_0^1 Po^*(\xi)d\xi - \int_0^1 Po^*(\xi)\xi d\xi +$$

$$+2\sum_{n=1}^{\infty}\cos\left[\frac{\pi}{2}(2n-1)\overline{x}\right]\exp\left[-\frac{\pi^2}{4}(2n-1)^2 Fo_m\right]\times\int_0^1\theta_0(\xi)\cos\left[\frac{\pi}{2}(2n-1)\xi\right]d\xi-$$

$$-4\sum_{n=1}^{\infty}\frac{\cos\left[\frac{\pi}{2}(2n-1)\overline{x}\right]}{\pi(2n-1)}\times\exp\left[-\frac{\pi^2}{4}(2n-1)^2 Fo_m\right]\int_0^1 Po^*(\xi)\cos\left(\frac{\pi}{2}(2n-1)\xi\right)d\xi. \qquad (15)$$

FINDINGS:

On the basis of a mathematical model, an engineering calculation method has been synthesized, and a computer program has been developed for determining the completion time of the initial stage of corrosion of cement concrete type II. It was experimentally and theoretically shown that for cement concrete the duration of the initial period of corrosion of the second type when exposed to a 2% aqueous solution of $MgCl_2$ may be about 2.8 years,and when exposed to 0.001% aqueous HCl solution, about 2.4 years from the moment of putting the structure into operation until reaching the saturation concentration of “free calcium hydroxide”, which is 1.1 kg / m3 (calculated as CaO) in the pores of the concrete, at which the decomposition of highly basic cement stone compounds begins.
Providing the durability of buildings and structures without high costs is possible if we consider the problem of durability as one of the key issues in the design, calculation, manufacturing and operation of concrete and reinforced concrete structures. All this will reduce costs in the construction industry, and the unreasonable costs of eliminating corrosion losses direct to the development of the construction industry of science and its equipping with modern equipment.

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