Long-term durability of concrete structures

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Abstract. The issue of long-term strength of concrete in construction structures is considered, taking into account the features of concrete structure and the impact on the durability of concrete and force resistance to deformation and destruction. An approach to assessing the long-term strength of concrete as a thermodynamic system has been proposed. The effect of the growth of concrete strength at an early age when firming it in different temperature and humid conditions is shown to change the initial module of concrete deformations in time due to the physical and chemical reaction of hardening. The article proposes an approach to building the functions of aging concrete based on the kinetics of the physical and chemical reaction of cement hydration in a concrete mixture using its stehometry. The form of aging functions is presented using the analysis of the chemical reactions of cement hydration in concrete.

1. Introduction

Along with the increase in the cost of energy resources, the requirements for thermal and technical and economic indicators of fencing structures are increasing, which has led to the development of various methods of calculating multi-layered elements.

Based on the ratios of strength or deformatic characteristics of the layers, the most common method was to bring a heterogeneous section to the double-taurus.

As you know, to calculate the strength of reinforced concrete structures, the hypothesis of flat sections is used, when it is accepted that cross sections remain flat in the process of deformation and perpendicular to the axis of the element, as well as it is assumed that there is no shift in the thickness of the section [1, 2].

In the calculation of multi-layered structures with a low layer shift module, in most cases the theory of composite rods is used, when the work of each individual rod is considered on the basis of the law of flat sections and according to the theory resistance materials.

Here it is meant that at the beginning of the pressure the materials of rods and connections are deformed linearly at certain stress before the occurrence of plastic deformations.

Replacing the multi-layered section given homogeneous allows calculations to perform according to the methodology adopted in the current design rules as for conventional reinforced concrete structures [3-5].

Concrete is a composite material and is subject to the patterns of solid-phase interactions, which are quite diverse and differ in many ways.

A common sign is that they occur in several stages, including the delivery of reacting components to the reaction zone - chemical interaction, and the withdrawal of reaction products, which occurs usually on the diffusion mechanism.

It is known that all chemical reactions occur with the change of entalpies.
In each reversible reaction one of its directions (direct or reverse reaction) corresponds to the exothermal process, and the other - endothermic.

The effect of temperature change on the position of the chemical equilibrium is subject to the following rules: when the temperature rises, the chemical equilibrium shifts in the direction of endothermic reaction; when the temperature drops, in the direction of an exothermal reaction [6].

2. Method

It is known that the state of destruction is determined by the fixed value of the potentials of the S, S, U, i, etc.

Considering the process of increasing the initial module of concrete deformations in time as a consequence of some physical and chemical firming reaction, it was taken for the case of constant reaction temperature expression of the function of aging

\[ \Omega(\tau) = 1 - e^{-\alpha \tau} , \]

where \( \alpha \) - the constant of the rate of chemical reaction. It is accepted that the rate of chemical firming reaction is proportional to the concentration of reacting substances

\[ \frac{d(A_0 - A)}{d\tau} = \alpha (A_0 - A) . \]

Here \( A_0 \) - full concentration of reacting substances \( A \) - the concentration of reacted substances at the moment of time \( t \). The constant rate of chemical reaction \( \alpha \) does not depend on concentration, but depends on temperature.

This dependence is expressed by the Arrenius equation

\[ \alpha = \alpha_0 \sqrt{T} \exp(-\frac{E_A}{RT}) . \]

Here \( \alpha_0 \) some constant, \( T \) - absolute reaction temperature, \( R \) - universal gas constant, \( E_A \) - energy activation.

By substituting the last expression in the previous and dividing the variables, we will get

\[ \frac{d(A_0 - A)/(A_0 - A)}{d\tau} = \alpha_0 \sqrt{T} \exp(-\frac{E_A}{RT})d\tau . \]

Once integrated, we get

\[ \ln(A_0 - A) = \int_{t_0}^{t} \alpha d\tau + C . \]

When \( \tau = t_0 \) \( A = 0 \) and then \( C = \ln A_0 \), from where \( \ln((A_0 - A)/A_0) = -\int_{t_0}^{t} \alpha d\tau \) and, finally,

\[ \Omega(\tau) = A/A_0 = 1 - \exp(-\int_{t_0}^{t} \alpha d\tau) . \]

Here \( \alpha \) calculated by (5).

If we assume that the characteristic of the reaction rate depends on the temperature-time factor, then
Then the function of the age of concrete when the modes of temperature changes during the hardening period will have a view

\[ F_M(t) = 1 - e^{-\int_0^{\tau_2} \alpha(T(\tau))d\tau}. \]  

The difference of entropy for the two states of the system is equal (the second law of thermodynamics):

\[ S_2 - S_1 \geq \int_1^2 \frac{\delta Q}{T} \]  

for irreversible processes, as the processes of material deformation (especially concrete) are thermodynamically irreversible.

The concepts of temperature and tension tensor (etc.) in the case of stationary non-equilibrium processes receive a natural phenomenological definition, as these parameters can be measured by conventional instruments.

Process parameters that cannot be determined by the state of the system, i.e. the values used in thermodynamics equations depend on the path that brought the system into a given state. For example, the parameters included in the equation of the first law of thermodynamics - work \( A \) and heat \( Q \) for slow-moving processes have a form of

\[ U_2 - U_1 = A + Q \]  

and are not state functions, but there are process functions.

With the properties of non-linearity and non-balance, concrete deforms along an irreversible path, so that the \( \sigma \) and \( \varepsilon \) cannot simultaneously serve as the parameters of the state, because they are functional rather than function, and are highly dependent on the path of deformation. The variability of the properties of concrete, which change not only from their age, but also from external loads, as can be seen from this consideration, directly affects the behavior of reinforced concrete structures in real-world operating conditions.

3. Results

The experiments of S.V. Alexandrovsky and V.V. Solomonov [7] found that the deformation of creep \( S(t, \tau) = \frac{\varepsilon_c(t, \tau)}{\beta(\tau)} \) are specific in relation to the initial relative level of stress \( \beta(\tau) = \frac{\sigma(\tau)}{R_b(\tau)} \) and practically do not depend on the age of the concrete, i.e. invariant regarding the beginning of the heating. Mechanical characteristics of concrete: measures of strength \( \frac{1}{R_b(\tau)} \), - elastic-instant deformations \( \frac{1}{E_b(\tau)} \) and - creep \( C(t, \tau) \) are proportional to the value of one common function of aging, expressing changes in the considered indicators for any age of concrete \( \tau \) relative to the reference Age day. \( \tau_1 = 28 \) nights.
This fact is consistent with the physical meaning, if to remember that the process of changing these values is the consequence of one reason: the hardening of concrete.

Obviously, this reasoning can be transferred to other mechanical indicators of concrete, depending on its aging. Considering the process of increasing the initial module of deformations of concrete in time V.M. Bondarenko [8] received for the event of a constant temperature of reaction expression of the function of aging

$$\Omega(\tau)^{-1} = 1 - e^{-k\tau},$$

where $k$ constant of the speed of the chemical reaction. It is accepted that the rate of chemical firming reaction is proportional to the concentration of reacting substances $-d(A_0 - A_i)/d\tau = k(A_0 - A_i)$. Here - the $A_0$ full concentration of reacting substances, $A_i$ - the concentration of reacted substances at a time $t$.

The constant speed of the chemical reaction $k$ does not depend on concentration, but depends on the temperature.

To make it easier to select the right expression for reaction speed, we use Oswald's method of selection out. It is based on an approximation of a slight change in the concentration of the reacting substance during the reaction, if it is present in a significant excess.

Waterless clinker minerals when reacted with water as a result of hydration turn into hydrosilicates, hydroalluminates and calcium hydroferrates.

$$3\text{CaO}\cdot\text{SiO}_2 + \text{H}_2\text{O} \rightarrow 3\text{Ca}_2\text{SiO}_4\cdot\text{H}_2\text{O} + \text{Ca(OH)}_2 + 502 \text{J/g}$$

$$\text{Ca}_2\text{SiO}_4 + \text{H}_2\text{O} \rightarrow \text{Ca}_2\text{SiO}_4\cdot\text{H}_2\text{O} + 206 \text{J/g}$$

$$3\text{CaO}\cdot\text{Al}_2\text{O}_3 + 26\text{H}_2\text{O} \rightarrow 3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot6\text{H}_2\text{O} + 867 \text{J/g}$$

The formed Ca (OH)$_2$ under the influence of CO$_2$ air gradually turns into CaCO$_3$, calcium hydroalloilluminates with plaster in the presence of water give double basic sulfates, such as Ca$_6$Al$_2$(OH)$_{12}$2(SO$_4$)$_3$26H$_2$O and Ca$_4$Al$_2$(OH)$_{12}$SO$_4$6H$_2$O.

When concrete is obtained, Ca(OH)$_2$ from CO$_2$ air and SiO$_2$ turns into a very strong mass consisting of calcium carbonates and silicates.

They determine the physical and mechanical properties of concrete.

The latter obviously depend directly on the amount of pro-hydrated substance, which in turn depends on the speed and time of hydration.

The main data of chemical kinetics are the dependence of concentrations of reacting substances and reaction products in turn depends on the speed and time of hydration.

Reaction rate can be expressed as the rate of change in the concentration of any of these substances. Often the reaction rate is proportional to concentration to some extent, which can be determined by the reaction stehiometry. The above hydration reactions have the following stehiometry:

$$a)3\text{A}+\text{B} \rightarrow 3\text{C}+\text{D}; \quad b)\text{A}+\text{B} \rightarrow \text{C}; \quad c)\text{A}+2\text{B} \rightarrow \text{C}, \quad (11)$$

where A is the reacting agent CaO*SiO$_2$ in the first, Ca$_2$SiO$_4$ in the second and CaO*Al$_2$O$_3$ in the third reaction, B - water, C and D - hydration products.

For the case (a) reaction rate can be expressed by equations:

$$-d[A]/dt = k_1[A]^*\cdot[B]$$

$$-d[A]/dt = k_2[A]^3\cdot[B] \quad (12)$$

$$-d[A]/dt = k_3[A]^*\cdot[B]^{1/3}$$

For the case (b):

$$-d[A]/dt = k_4[A]$$

$$-d[A]/dt = k_5[A]^3$$

$$-d[A]/dt = k_6[A]^2$$
\[-d[A] / dt = k_1 [A]^* [B]\]

For the case (c):

\[-d[A] / dt = k_2 [A]^* [B]^2\]

\[-d[A] / dt = k_3 [A]^{1/2} [B]\]  \hspace{1cm} (14)

Values in brackets indicate the concentration rates of substances.

Water is such a substance in the hydration response. Its in the concrete mixture is always more needed for the reaction of quantity because of the need to provide sufficient digestibility. If the speed is expressed by law \(-d[A] / dt = k_1 [A]^* [B]\) and B is present in a significant excess, the concentration of [B] will be almost constant and can be included in the constant of speed \(k_1 = k_1^* [B]\).

Then the law of speed is simplified to \(-d[A] / dt = k_1 [A]\).

Taking that the properties of concrete are proportional to the amount of the retracted clinker, we get the function of changing its properties as the ratio of this quantity to its original concentration and call it, as is customary in the theory of creep, a function of aging:

\[
\Omega(t)^{-1} = ([A_0] - [A_t]) / [A_0] = 1 - \exp(-k_1 t). \hspace{1cm} (15)
\]

The resulting function of aging is based on the stehiometry of the above hydration reactions.

4. Discussion

The solution to the problem of long-term concrete strength in constructions has been made possible by the use of a solid criterion of the energy barrier.

Using the strength criterion of the energy barrier deformations, you can calculate long-term strength depending on the mode of loading [9].

The decrease in long-term strength is associated not only with the non-linearity of deformation, i.e. with the development of micro-destruction in time, but also with the processes of deformation development, in particular, with the overcoming of some energy barrier in time [10].

The process of deformation of all types of concrete is a typical thermodynamic process, but in most cases, the task of predicting the tense-deformed state of constructions is considered at a mechanical level.

References

[1] Bazhenov Y, Korol E, Yerofeyev V, Mitina E 2008 *Fechtkonstruktionen mit wärmearmem Beton* (Wissenschaftliche Ausgabe: Grundtheorie, Berechnungsmethoden und technologisches Design)

[2] Korol E, Berlinova 2018 *MATEC Web of Conferences* 03020

[3] Korol E 2019 *Entwicklung von Methoden zur Berechnung mehrschichtiger Zaulstrukturen mit monolithischer Schichtverbindung* (M.: MISI – MSU)

[4] Korol E, Berlinov M, Berlinova M 2017 *MATEC Web of Conference* 106

[5] Nazarenko V, Tvorogov A, Lukantsov P 2010 *Concrete and reinforced concrete* 1 6

[6] Zveryaev E, Berlinov M, Berlinova M 2016 *International Journal of Applied Engineering Research* 11(8) 5811

[7] Alexandrovsky S, Solomonov V 1972 *Domestic experience. Reference collection* 6

[8] Bondarenko V 2009 *V Intercollegiate Conference* (Moscow: MGAKHIS)

[9] Korol E, Berlinov M, Berlinova M 2016 *Procedia Engineering* 292
[10] Berlinov M, Berlinova M 2016 *MATEC Web of Conferences* 04014