

PREDVIĐANJE DUGOTRAJNOSTI STUPOVA NA TEMELJU KRITERIJA KARBONIZACIJE BETONA I KOROZIJE ARMATURE

PREDICTING THE DURABILITY OF THE COLUMNS ON THE CRITERION OF CONCRETE CARBONATION AND CORROSION OF REINFORCEMENT

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Prethodno priopćenje

Sažetak: Članak opisuje ovisnost realne čvrstoće cementa o koeficijentu difuzije ugljik dioksida ovisno o temperaturi i vlažnosti okoliša. Izračuni su rađeni za vrijeme karbonizacije betona i koroziju zaštitnog sloja armature betonskih stupova. Predloženi odnosi mogu se povoljno koristiti u predviđanju dubine karbonizacije betona.

Ključne riječi: beton, betonski stupovi, koeficijent difuzije, ugljik dioksid, vrijeme karbonizacije

Preliminary communication

Abstract: This paper describes the dependence of the strength of the concrete in regards to the diffusion coefficient of carbon dioxide in dependence to the temperature and humidity of the environment. Calculations are designed for the time of carbonation of concrete and the corrosion of the reinforcement's protective layer in concrete columns. The proposed relationships can advantageously be used in predicting the depth of carbonation of concrete works.

Key words: diffusion coefficient, carbon dioxide, time carbonation, concrete, concrete columns

1. INTRODUCTION

The relevance of this article is to clarify the methods of predictions and development of technological ways to improve the durability of the columns on the criterion of carbonation of concrete and reinforcement corrosion.

One of the causes of the failure of the concrete columns of buildings and structures is the corrosion of reinforcement. It manifests itself most severely in structures subjected to constant exposure to atmospheric or technogenic water. However, as practice shows the exploitation of buildings and structures for various purposes, even in the absence of concrete moisture, shows with time that corrosion of reinforcement occurs.

The main reason for the beginning of the steel reinforcement corrosion is termination of the passive action of the protective layer of concrete.

Alkaline environment of fresh concrete (pH~12 ... 13) with time reduces the alkalinity (acidity) due to the passage of the carbonation process of concrete components with carbon dioxide. As a result of such exposure, the carbonation of concrete cover occurs and creates the initial conditions for the further development of corrosion processes on the surface of the steel reinforcement (Fig. 1).

A feature of the carbonization process is that at subzero temperatures it practically ceases the interaction of CO₂ with the active components that are dissolved in the pore liquid of the concrete.

This is due to the fact that the smallest pores, where the unfrozen capillary moisture is stored, are not available for the diffusion of CO₂ gas and limestone because the matrix goes into crystal hydrate even at -0.150°C.

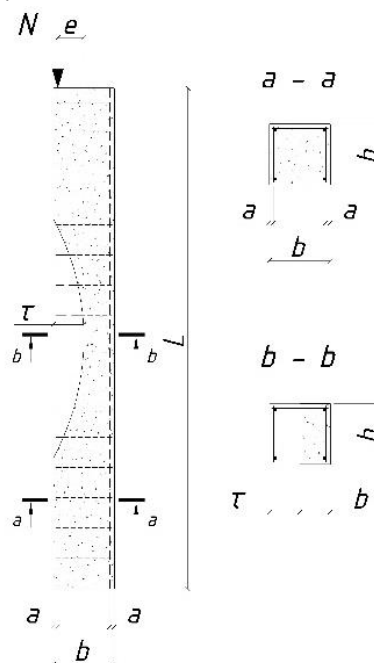


Fig. 1. Reinforced concrete column with damaged part in the middle section

During carbonization the carbon dioxide from air penetrates into concrete pores and capillaries, dissolves itself in the pore liquid and reacts with the limestone to form calcium carbonate. The process can continue until the consumption of limestone in the carbonized layer of concrete and the expansion of the calcium silicate and hydroaluminat is complete.

2. CALCULATION

In calculation of concrete carbonation time in natural environments, only the period of positive temperature is taken into consideration. The period with negative temperature is not considered.

On the basis of experimental data obtained according to the calculation the effective coefficient of diffusion as a function of the most important parameters - the relative humidity of the air and water-cement ratio, characterizing the structure of concrete and its permeability (the accessibility of the internal surface of the concrete):

$$\text{at } \varphi = 60\% \quad D_0 = 10^{-4} \cdot 10^{(WC - 0.4) / 0.27} \quad (1)$$

$$\text{at } \varphi = 90\% \quad D_0 = 10^{-4} \cdot 10^{(WC - 0.7) / 0.2} \quad (2)$$

where D_0 - the effective diffusion coefficient of carbon dioxide in concrete; WC - water-cement ratio of concrete.

Taking the linear interpolation for the influence of ambient air humidity and water-cement ratio of concrete to the value of effective diffusion coefficient at $W/C = 0.5$ for the effective diffusion coefficient of carbon dioxide in the range of relative humidity (60-90)% an expression is obtained:

$$D_\varphi(60 - 90) = 1 \times 10^{-5} + 0,333 \times 10^{-5}(90 - \varphi); \quad (3)$$

where $D_\varphi(60 - 90)$ - the effective diffusion coefficient of carbon dioxide in the concrete at a relative humidity in the range 60 - 90%; φ - relative humidity of ambient air, %.

The formula to calculate the time (year), carbonation of concrete reinforcement of the protective layer is given by:

$$\tau_{\text{carb}} = \frac{a}{\sum_{i=1}^n y_i} \quad (4)$$

where a - the value of the concrete protective layer; $\sum_{i=1}^n y_i$ - the depth of concrete protective layer carbonation for one calendar year; y_i - the depth of carbonation of concrete protective layer for the i -th month with positive temperature:

$$\delta_s = \sqrt{\frac{2D_i C_0 \tau_i}{m_0}}; \quad (5)$$

where D_i - the effective diffusion coefficient CO_2 in the concrete in the i -th month, depending on the temperature and humidity of outside air; C_0 - volume concentration of gas, %; τ_i - interaction time during the month under review; m_0 - the reactivity of the of concrete.

Influence of temperature on the value of the effective diffusion coefficient is possible to consider using the dependency ε_T :

$$D = D_0 \varepsilon_T; \quad (6)$$

$$\varepsilon_0 = \left(\frac{273+t}{273}\right)^{1.75}; \quad (7)$$

where D_0 - gas diffusion coefficient in concrete at $t=0$ $^\circ\text{C}$; t - ambient temperature, 0C° .

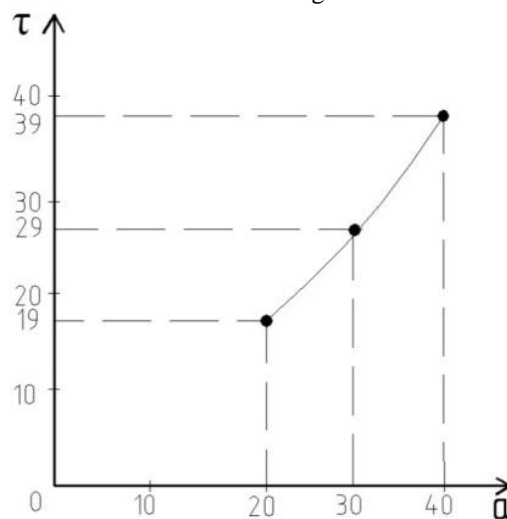
Using the obtained dependences we can estimate time of protective layer of concrete carbonation in columns. Nominal characteristics of the protective layer of concrete columns and the concentration of carbon dioxide, according to the adopted regulatory documents [1, 2] following - Consumption of cement 250 kg/m³, the protective layer - 30 mm, taking into account possible deviations in the nominal characteristics of the concrete protective layer from the designed concrete durability of the protective layer on the criterion of carbonization.

These calculations according to (5) indicate that the speed of carbonation of the concrete protective layer is 1.04 mm / year using the 250 kg / m³ of portland cement and 0.95 mm / year when the content of Portland cement is 300 kg / m³.

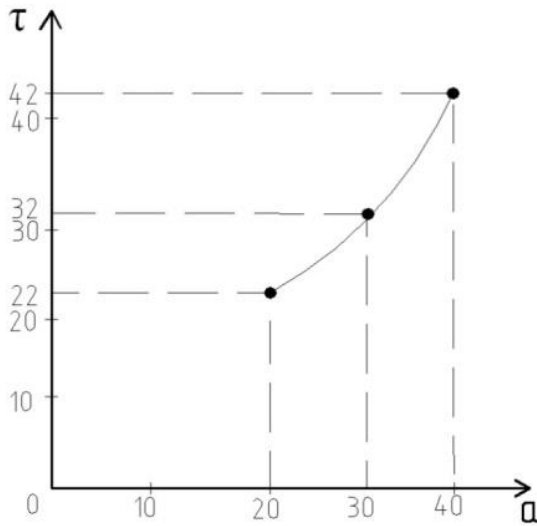
Consequently, according to relation (4) the carbonation time of concrete protective layer of 20 mm is 19 years, 30 mm - 29 years, 40 mm - 39 years at the Portland cement content of 250 kg / m³ and $WC = 0,5$.

When Portland cement content is 250 kg / m³ and $WC = 0,5$, the carbonation time of concrete protective layer of 20 mm is 22 years, 30 mm - 32 years and 40 mm - 42 years.

Graphs containing the carbonation of concrete protective layer of examined columns with portland cement content of 250 and 300 kg/m³ and water-cement ratio $W/C = 0.5$ are shown in Fig. 1.



a) 250 kg/m³



b) 300 kg/m³

Fig. 2. Time of concrete cover carbonation τ_1 with portland cement content of kg/m³

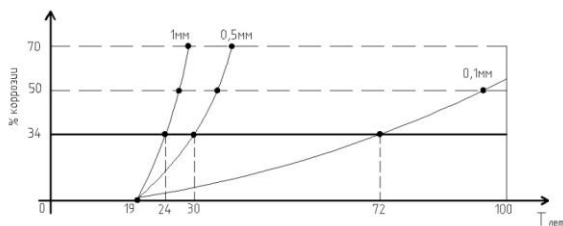
For buildings with service life of 50 years or more, according to the results of the calculation, it is possible to expect the full carbonation of concrete protective layer even when the deviation of nominal parameters of the concrete protective layer is a favorable (increases).

Therefore, there is a real danger of the beginning of reinforcing steel connections depassivation process and appearance of corrosion of the reinforcement.

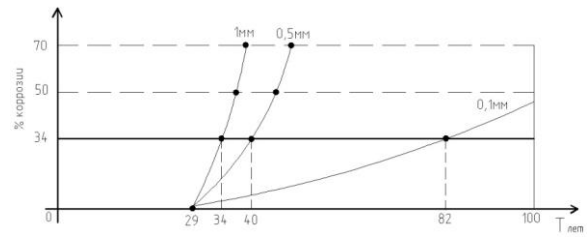
When depassivation reinforcement in concrete as a result of concrete neutralization of acidic gases and certain conditions (presence of oxygen and moisture), the reinforcement steel can intensively corrodate, with speed of corrosion of 0,1 – 1 mm/year.

Depassivation of the steel surface begins only by carbonation of concrete under the influence of carbon dioxide or neutralization of concrete when exposed to other acidic gases. Until the depassivation of steel reinforcement surface, its corrosion is excluded.

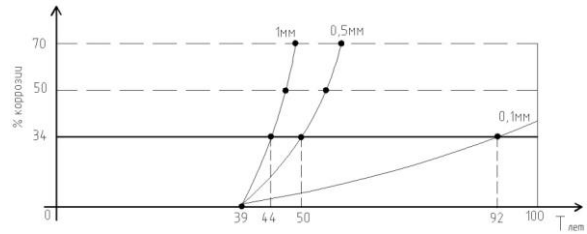
A study of the steel corrosion kinetics is carried out under the following variations of factors: the protective layer cover - 20, 30, 40 mm; Portland cement consumption - 250 to 300 kg/m³, speed of uniform surface corrosion of reinforcement - 0.1, 0.5, 1 mm/year Fig. 3, 4.



a) a = 20 mm

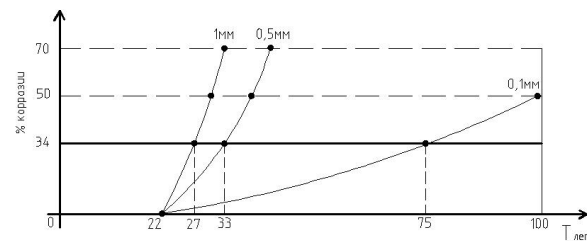


b) a = 30 mm

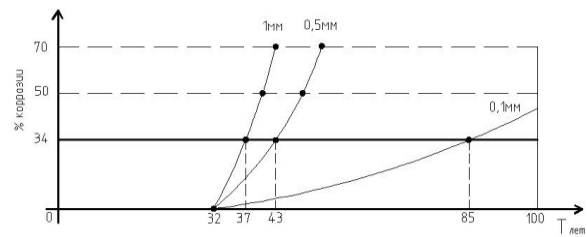


c) a = 40 mm

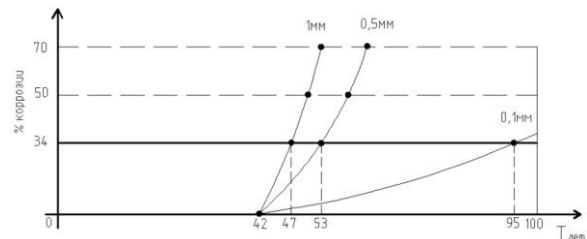
Fig. 3. The value of reinforcement corrosion, depending on the lifetime and corrosion rate of steel at Portland cement consumption of 250 kg/m³ and the thickness of concrete protective layer.



a) a = 20 mm



b) a = 30 mm



c) a = 40 mm

Fig. 4. The value of reinforcement corrosion, depending on the lifetime and corrosion rate of steel at Portland cement consumption of 300 kg/m³ and the thickness of concrete protective layer.

Table. 1 shows the average data from various literature sources for the carbonation depth of concrete cover for concrete of different compressive strength in last 50 years.

Table 1 Average data of carbonation protective layer depth for past 50 years

Source	The depth of carbonation [mm], at concrete strength [MPa]				
	Up to 25	30	37	45	60
Hamada M. [4]	24-85	20-70	16-57	13-47	10-35
Smolchik H.G. [5]	24,5-46	21,4-33,5	-	10,2-21,7	0-13,7
Kondo R. et.al. [6]	-	-	-	33	22
Schneider U. et.al. [7]	-	-	69,4	-	52
Nizh [8]	25-54	21-33	-	9-22	0-18

Data presented in Table 1 have considerable dispersion of values of carbonation depth in the range of strength of concrete which indicates considerable heterogeneity of concrete, different conditions of their production and experimenting.

3. CONCLUSION

1. On the basis of previously developed theoretical data on the mechanism of interaction of acid gases with active components of the cement stone, here is proposed an estimation method for the durability of concrete columns protective layer on the criterion of carbonization taking into account temperature and humidity obtained by the expression (3) for the effective diffusion coefficient of carbon dioxide, which allows to take into account the humidity of air.

There were also obtained relations (4), (5) to calculate the time of carbonation of the concrete protective layer of a certain thickness.

2. Calculations to predict the time of protective layer carbonization are formed (with thickness of 20, 30, 40 mm) with Portland cement consumption - 250 to 300 kg/m³ and water-cement ratio (W/C) of 0,5.

Results of the calculations indicate that the durability range of the concrete protective layer for these input data is 19 - 42 years. Taking into account the actual life of the building (about 50 years) there is a real danger of reinforcement depassivation and early corrosion of the reinforcement in columns.

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