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Evaluation of On-site Conditions and Durability of Concrete Panels Exposed to Weather

Prévision de la durabilité de parois en béton exposées aux intempéries

Vorhersage der Dauerhaftigkeit bewitterter Betonbauten

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SUMMARY

A model for the prediction of durability of concrete panels exposed to weather is developed. This model combines a carbonation law derived on basis of the reaction process with on-site non-destructive measurements of the permeability of cover.

RÉSUMÉ

Un modèle pour la prévision de la durabilité de parois en béton exposées aux intempéries est dévoloppé. Ce modèle lie une loi de la carbonatation avec des mesures de la perméabilité du béton d'enrobage.

ZUSAMMENFASSUNG

Zur Vorhersage der Dauerhaftigkeit von Stahlbetonbauten wird ein Modell entwickelt, das einen physikochemisch begründeten Ansatz der Karbonatisierungstiefenberechnung mit Ergebnissen von Dichtigkeitsmessungen am Bauwerk verknüpft.

1. INTRODUCTION

Durability is generally defined as the characteristic property which ensures function, structural safety and adequate appearance of a r/c-member during service life with a minimum of maintenance. For a specific case, however, durability must be defined in terms of environment and potential type of damage. The most common damage is the corrosion of the reinforcement near the surface of the r/c-member. In this case, durability may be regarded as exhausted as soon as peaks of the carbonation front with pH 9 reach - with a certain probability - regions of the steel with a minimum cover. Thus, durability is defined as incubation time of corrosion as a function of depth and tightness of cover. In this report a prediction model is presented which combines a physicochemical law of carbonation with the results of non-destructive on-site permeability tests.

2. MODEL FOR THE PREDICTION OF DURABILITY

2.1 Range of validity of model

The prediction model is valid for r/c-members exposed to normal weather of Central Europe and for essentially vertical surfaces. Concrete with a quality of C 25 to C 35 made with portland cement and frost-resistant natural aggregate is considered; complete compaction is presupposed. The model is valid for any type of curing. The model describes the carbonation progress in uncracked concrete. It is, however, also applicable for cracked r/c-members as long as the 95 %-fractile of the actual, measured crack widths does not exceed 0,25 to 0,30 mm.

2.2 Schießl's carbonation law

The progress of carbonation can be described with Schießl's law [1]. The mean final depth of carbonation is given by

$$\bar{x}_\infty = \frac{D_{CO}}{\bar{b}} \Delta c \qquad (1)$$

with

Δc .... difference of CO_2-concentration of air between surface and carbonation front ($\approx$ 0,6 g/m^3 in urban and $\approx$ 0,8 - 1,0 g/m^3 in polluted industrial areas, 0,54 g/m^3 as average value).

D_{CO} ... coefficient of CO_2-diffusion through carbonated concrete at the member's surface at the age of about 90 d and for the mean annual moisture content of concrete cover.

$\bar{b}$ ..... coefficient taking into account the realkalization of carbonated concrete by $Ca(OH)_2$-diffusion and the dependence of D_{CO} on depth of carbonation, moisture of concrete, etc.

The progress of carbonation is described by:

$$t = -\frac{a}{\bar{b}}\left[x + x_\infty \ln\left(1 - \frac{x}{x_\infty}\right)\right] \qquad (2)$$

with a, content of all relevant alkaline hydration products which can be converted into carbonates.

The Equ.(1) and (2) were derived by idealization of the complex physicochemical reactions of carbonation. For prediction, representative values for the coefficient of Equ.(1) were proposed in [1]. Experiments show their wide range and considerable scatter. Thus, the prediction of durability of a specific structure solely on basis of representative values of D_{CO}, $\bar{b}$ and Δc is insecure. Uncertainty can be reduced if the carbonation depth and D_{CO} are measured. This, however, can only be performed in the laboratory, considerable core extraction becomes necessary. Because such procedure is usually impossible, the necessary information on the diffusivity for CO_2 must be acquired by substitutive on-site absorption tests such as ISA [2]. Such tests can be performed non-destructively and repeatedly.

2.3 Combination of carbonation law and ISA test results

By the ISA-test the absorption of water is measured as function of suction time t_s. The ISA-value is related to pore structure data of the first 10 to 20 mm of cover. These date incorporate the influence of compositional parameters of concrete, curing, carbonation, etc. Consequently, they also describe the diffusivity for CO_2 and water vapour. As explained and verified in [2], [3] the ISA-value can be expressed by:

$$ISA(t_s) = \frac{K_2 \sqrt{2r_h}\, \epsilon_{abs}}{2\rho_w a_{Tabs}} t_s^{-\frac{1}{2}} \tag{4}$$

Meaning of the parameters in Equ.(4) were defined in [2]. ϵ_{abs} is the effective porosity for absorption ($r \geq 100$ nm). The effective porosity for gas diffusion ϵ_{diff} exceeds ϵ_{abs} because pores with $r \geq 30$ nm become accessible. Tortuosity of diffusion consequently also increases. Acc. to [3], the following relations can be formulated:

$$\begin{aligned} \epsilon_{diff} &\approx 1{,}7\ \epsilon_{abs} \\ a_{Tdiff} &\approx 1{,}5\ a_{Tabs} \end{aligned} \tag{5}$$

The unknown coefficient D_c for CO_2-diffusion can be expressed by:

$$D_c = D_a \frac{\epsilon_{diff}}{a_{Tdiff}} \tag{6}$$

with D_a, the diffusivity of CO_2 through air (0,159 cm^2/s at 20 °C). By insertion of Equ.(4), (5), and (6) into Equ.(1), we obtain the prediction value of the mean, final carbonation depth based on the mean $ISA_{(10\,min.)}$-value:

$$\overline{x}_\infty \approx \frac{D_a \Delta c}{b\ K_3} \frac{\overline{ISA}_{10}}{\sqrt{2r_h}} \tag{7}$$

Progress function follows Equ.(2). Fig. 1 shows the evaluation of Equ.(7) for several mean values of ISA_{10} vs. age.

3. APPLICATION

3.1 Variability and durability criterion

The prediction model Equ.(7) contains essentially the same assumptions as Equ.(1). Though, by on-site measurement a realistic assessment of diffusivity becomes possible, the other coefficients must still be chosen within a reasonable range. Thereby, their scatter is taken into account. Furthermore, the ISA-value depends on the moisture and temperature of concrete at test. The effect of the difference between the temperature at test and the mean annual temperature ($\overline{T} \approx 12$ °C) can be taken into account. ISA-tests have to be performed a certain drying time after rainfall. It is assumed, that the moisture of concrete at this state corresponds to the mean annual value. The unknown scatter of the constituents of Equ.(7) is globally satisfied by a coefficient of variation of ≈ 40 % of carbonation depth [1]. Thus, we obtain for the 95 %-fractile of the carbonation depth at any age t:

$$x_{95}(t) \approx 1{,}7\ \overline{x}(t) \tag{8}$$

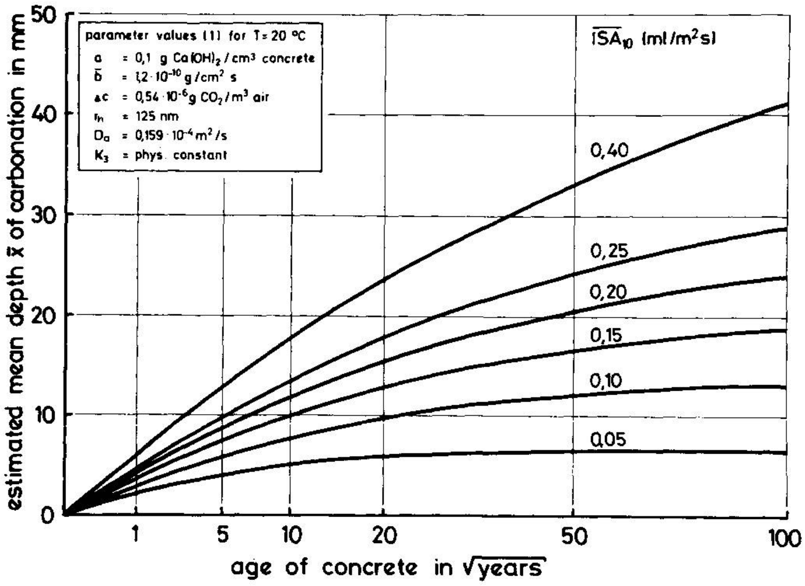

Fig. 1: Mean of carbonation depth dependent on age and ISA_{10}-value (Equ.(2) and (7))

The concrete cover also scatters [3]. Its 5 %-fractile may be expressed by

$$c_5 \approx 0,6\ \bar{c} \tag{9}$$

with $\bar{c}$, the nominal cover of bars to be ensured by spacers. Now, the durability criterion is expressed by:

$$x_{95}(t_l) \leq c_5 \tag{10}$$

with t_l, the service life.

This criterion is a rough simplification of reality because it stipulates a probability of 1 for the coincidence of peak values of carbonation depth occurring at the reinforcing bars placed with an unknown, distinct spacing.

3.2 Comparison with test results

Fig. 2 shows the dependence of test results of the mean carbonation depth on age for concrete walls exposed for about 25 years to weather. At the age of 25 years ISA-tests were performed on-site. With Equ.(7), (2) and with the mean experimental ISA-values the prediction curves x(t) and $x_{95}(t)$ can be calculated. For exposure to normal weather the minimum cover which corresponds to c_5 would have to be 25 mm acc. to DIN 1045. The example of Fig. 2 shows that peaks of carbonation would reach the steel's surface after ≈ 90 years.

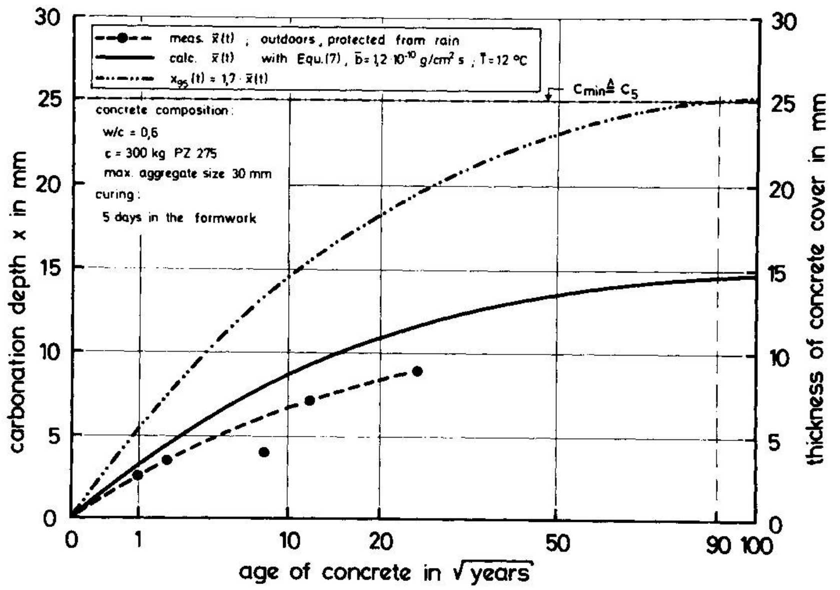

Fig. 2: Comparison of measured and calculated carbonation depth for a 25 years old concrete (calculation with measured ISA_{10}-value at 25 years)

3.3 Use of model in practice

The prediction model in combination with on-site ISA-tests can be used for: a) quality control in course of acceptance of the just completed structure and b) durability assessment of the older structure in course of maintenance. In any case reliable information on concrete cover is necessary.

For quality control certain mean ISA_{10}-values for acceptance must be stipulated which should not be transgressed by the on-site results.

In course of inspection of a structure, ISA-readings can be taken in suitable intervals. On their basis, carbonation can be estimated. By occasional measurement of the carbonation depth the model uncertainty can be reduced.

4. FINAL REMARK

The model presented is yet a tentative one. Several assumptions were necessary in course of its development. Thus, further evaluation is needed for its corroberation.

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