Universitat d'Alacant
Universidad de Alicante

Departament d'Enginyeria Civil
Departamento de Ingeniería Civil

REPORT OF A RESEARCH ON THE RESISTANCE TO CHLORIDE PENETRATION OF CEMENT MORTAR TREATED WITH THE PRODUCT KOMSOL CONTROLL INNERSEAL

Prof. Miguel A. Climent

(e-mail: ma.climent@ua.es)

Civil Engineering Department

University of Alicante, Spain

November 2014

Tel. 96 590 3707 - Fax 96 590 3678
Campus de Sant Vicent del Raspeig
Ap. 99 E-03080 Alacant
e-mail: dic@ua.es
web: http://dic.ua.es

1 OBJECTIVE OF THE RESEARCH

The objective of the research was to assess the relative increase of the initiation period of steel corrosion by chloride due to the use of the product Komsol Controll Inner Seal, in order to increase the service life of reinforced concrete in a chloride laden environment.

2 EXPERIMENTAL METHODOLOGY

The reference testing methods for resistance to chloride penetration are the non-steady state natural diffusion tests [1, 2]. Nevertheless, due the long time consuming nature of these diffusion tests [3], it was decided in this work to use accelerated methods based on chloride migration by application of an electric field, Nordic Standard NT Build 492 [4]. Also, due to tight schedule requirements, it was decided to work, in this preliminary investigation, with Portland cement mortar as a simplified material representative of the behavior of concrete. The composition of the tested cement mortar is that described in the following Table 1.

Composition of the cement mortar	
Portland cement (g) CEM I/42,5 R (according to European standard EN-197-1)	350
Standard siliceous sand (g)	1350
Water/cement ratio	0.5

Table 1. Composition of the mortar for the test specimens

The preparation of the test specimens was as follows:

- The mortar was cast in cylindrical moulds (10 cm diameter and 20 cm length), and compacted mechanically. The mortar cylinders were cured during 7 days in a humid curing chamber, temperature (*T*) 20ºC, relative humidity (*RH*) 95%.
- After curing, smaller test specimens (cylinders of 10 cm diameter and 5 cm length) were cut with a steel-diamond disc saw, using water as a cooler means. The top and bottom parts (1.5 cm at top and the same at bottom) of the larger

cylinders were discarded when cutting the test specimens. A total of eight specimens were used for the tests.

- The mortar specimens were dried in an oven at 105ºC until mass constancy. This step was introduced to allow a quick absorption after application of the product Komsol Controll Innerseal, due to the tight testing schedule.
- A part of the specimens was surface treated with the product Controll Innerseal on one of its bases, while the rest of specimens were kept untreated (to be used as reference samples for the relative comparative calculations). After treatment with the product, all test specimens (treated and non-treated) were kept under laboratory environmental conditions (approx. *T* 25ºC, and *RH* 50%-60%) until their corresponding testing times, which were at 7 days and 28 days after application of the product.
- Before testing, the specimens were water saturated under vacuum following the recommendation of the ASTM C-1202-97 standard [5]. The tests were conducted as per the Nordic standard NT Build 492 [4].

3 MATHEMATICAL MODEL FOR ASSESSING THE INCREASE OF SERVICE LIFE

Taking into account that the research is only aimed at a relative assessment of the durability properties, (treated mortar in relation to non-treated mortar), we will take the chloride migration coefficient as a first approach for the basic ionic transport parameter through concrete, which is the diffusion coefficient *D*.

Fick's second law for unidirectional semi-infinite diffusion in a homogeneous medium, in the absence of fixation of the diffusing substance, is the following expression [6]:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \qquad (1)$$

Where *C* is the concentration of the diffusing substance, *D* is the diffusion coefficient, *t* is time, and *x* is the distance from the diffusion focus (in the case of concrete exposed to a chloride laden environment it is depth from exposed surface).

The solution of differential equation (1) for the particular case of constant concentration of the diffusing substance at the concrete surface (C_S) and constant diffusion coefficient is the following:

$$C = C_S\left(1 - erf\frac{x}{\sqrt{Dt}}\right) \qquad (2)$$

Where *erf* is the mathematical function called as error function.

Steel corrosion by chlorides is initiated when a high enough critical chloride concentration (C_C), is reached in the zone in contact with the steel rebar, i.e. at a depth equal to the concrete cover on steel ($x = e$). So, the corrosion initiation time, which, in a first conservative approach can be taken as the useful life time, can be expressed as:

$$t = \frac{1}{D}\left(\frac{e}{inverf\left(1-\frac{C_C}{C_S}\right)}\right)^2 \quad (3)$$

Where *inverf* is the mathematical function called as inverse of the error function.

If the application of the product Controll Innerseal to mortar allow to reduce the magnitude of the diffusion coefficient from a value D_0 (reference mortar without product treatment), to a lower value D_{CI} (mortar treated with Controll Innerseal), then the relative increase of the service life, in relation with reinforcement corrosion by chloride, can be calculated through the following expression:

$$\frac{t_{CI}}{t_0} = \frac{D_0}{D_{CI}} \quad (4)$$

4 RESULTS AND DISCUSSION

Table 2 shows the results of the chloride migration tests, together with the calculated increases of the service life, Equation (4), in relation to reinforcement corrosion by chloride, achieved by the treatment with Komsol Controll Innerseal.

Time from product application (days)	Reference mortar (non-treated)		Mortar treated with Komsol Controll Innerseal		Relative increase of service life
	D_0 (x 10^{-12} m^2/s)	Mean value of D_0 (x 10^{-12} m^2/s)	D_{CI} (x 10^{-12} m^2/s)	Mean value of D_{CI} (x 10^{-12} m^2/s)	t_{CI}/t_0
7	155.6	163.0	61.0	62.5	2.6
	170.4		64.0		
28	122.6	122.2	40.4	40.9	3.0
	121.8		41.3		

Table 2. Results of the chloride migration tests and calculated values for the increase of service life (related to reinforcement corrosion by chloride) achieved by using Komsol Controll Innerseal

Table 2 shows rather high values for the diffusion coefficients, as compared to typical values found for commercial concretes used for building and infrastructure constructions [7]. Nevertheless, this fact is as expected since, due to schedule requirements, the mortar specimens had been dried before testing. It is known that this severe drying treatment (105ºC) may increase the porosity and change the pore size distribution of cementitious materials, and as a consequence modify considerably their mass transport properties [8].

The most important observation from Table 2 is that the application of the product, Komsol Controll Innerseal, leads to a considerable increase of the resistance to chloride penetration of the cementitious material, as shown by important decrease of the chloride migration coefficient values. In fact the calculated service life, in relation to initiation of steel reinforcement corrosion by chloride, is multiplied by a factor between 2.6 and 3.

5 CONCLUSION

The surface application of the product Komsol Controll Innerseal has increased considerably the resistance to chloride penetration of a cement mortar, as shown by important decrease of the chloride migration coefficient. On the basis of the reported data, the calculated service life, in relation to initiation of steel reinforcement corrosion by chloride, may be multiplied by a factor between 2.6 and 3.

6 REFERENCES

[1] CEN/TC 104 (2009). Testing hardened concrete—determination of the chloride resistance of concrete, unidirectional diffusion. Final draft prCEN/TS 12390-11. (European technical specification).

[2] ASTM (2004). Standard test method for determining the apparent chloride diffusion coefficient of cementitious mixtures by bulk diffusion, C1556-03. American Society for Testing and Materials, Pennsylvania, USA.

[3] M.A. Climent, G. de Vera, J.F. López, E. Viqueira, C. Andrade (2002). A test method for measuring chloride diffusion coefficients through nonsaturated concrete. Part I. The instantaneous plane source diffusion case. Cement and Concrete Research, 32(7):1113–1123.

[4] Nordtest (1999). NT Build 492. Concrete, mortar and cement-based repair materials: chloride migration coefficient from non-steady-state migration experiments. Espoo, Finland.

[5] ASTM (1997). Standard test method for electrical indication of concrete's ability to resist chloride ion penetration, C1202-97. American Society for Testing and Materials, Pennsylvania.

[6] J. Crank (1975). The Mathematics of Diffusion, 2nd edition. Oxford University Press, Oxford, UK.

[7] A. Boddy, E. Bentz, M.D.A. Thomas, R.D. Hooton (1999). An overview and sensitivity study of a multimechanistic chloride transport model, Cement and Concrete Research, 29 (6) (1999) 827–837.

[8] T.C. Powers, L.E. Copeland, J.C. Hayes, H.M. Mann (1955). Permeability of Portland cement paste. Portland Cement Association Bulletin 53, pp. 285-298, Chicago, USA.

Alicante, the 27th November 2014

DEPARTAMENTO DE INGENIERÍA CIVIL

Miguel-Ángel Climent

Full Professor of Chemistry and Concrete Durability