World Journal of Science and Technology Research
Vol. 1, No. 4, June 2013, PP: 67 - 74, ISSN: 2329 - 3837 (Online)
Available online at www.wjst.org

Research article

PREDICTIVE MODEL TO MONITOR THE RATE OF DIFFUSION CHLORIDE IONS TRANSPORT IN HOMOGENOUS CONCRETE STRUCTURE

Eluozo, S. N.

Subaka Nigeria Limited Port Harcourt Rivers State of Nigeria
Director and Principal Consultant Civil and Environmental Engineering, Research and Development
E-mail: Soloeluozo2013@hotmail.com
E-mail: solomoneluozo2000@yahoo.com

Abstract

Predictive model to monitor the rate of chloride ion under diffusion in concrete structure has been expressed. The concept was to monitor the concentration chloride ion in homogenous concrete structures, most materials applied in the formation of concrete passed through the uniformity of particle size, these materials micropores cannot be compared to heterogeneous materials, the study was to actually determine the rate of concentration ingress of chloride the model can be applied to determine the concentration from heterogeneous concrete formation, thus compare both parameters rate of concentration ingress, mathematical expression were derived to produce a model expression, the express model can be applied to generate different concentration from homogeneous and heterogeneous materials, this can be compared to determine the rate of diffusion chloride in concrete structures.

Keywords: predictive model rate diffusion chloride ion and concrete structure.

1. Introduction

The moving of chloride ions into concrete is a complex process which involves diffusion, capillary suction, penetration and convective flow through the pore system and microcracking network, accompanied by physical adsorption and chemical binding. With such a complex moving process, it is necessary to understand individual transport mechanisms and the predominant transport process in order to pinpoint the appropriate method for quantifying the chloride resistance of concrete.

Concrete provides physical and chemical protection to the reinforcing steel from penetrating chlorides which may cause steel depassivation leading to increased risk of steel corrosion. The chloride resistance depends on the permeability of the concrete and the thickness cover of the reinforcement. The integrity of the concrete cover under service load, in terms of cracking and crack width, also influences the resistance to penetrating chlorides. Corrosion of steel reinforcement is an electrochemical process. Hence electrochemical properties of concrete, such as resistivity, are important inherent properties affecting the corrosion rate of reinforcing steel. More so,

The physical and mechanical properties of pervious concretes are reported elsewhere (Onstenk et al. 1993, Yang and Jiang 2003, Neithalath 2004, Neithalath et al. 2005, 2006, Tennis et al. 2004). The use of larger aggregate sizes up to 20 mm maximum size has been recommended for pervious concrete since they result in large sized pores in the material as well as reduced clogging (Nelson and Phillips 1994). Recently, ACI Committee 522 has suggested that the aggregate sizes for pervious concrete should be between 9.5 mm and 19 mm, and that no fine aggregates should be used. The water permeation capacity or the drainage properties are closely related to the accessible porosity. For an accessible porosity of 20-29%, the coefficient of permeability is about 0.01 m/s (Belgian Road Research Center Report BE 3415, 1994). It has also been reported that the fine aggregate content determines the permeability. A drainage rate of 100 to 750 l/min/m2 has been reported for several pervious concretes (Tennis et al. 2004). Intrinsic permeability of 1 x 10-10 m2 to 5 x 10-10 m2 has been reported for pervious concretes with porosity ranging from 17% to 28% (Neithalath et al. 2006). The mixture proportions used in this study are given. This is adopted from a larger study directed towards ascertaining the influence of material structure of pervious concrete on hydraulic conductivity and acoustic absorption (Neithalath 2004, Marolf et al. 2004).

2. Theoretical Background

Concrete can infiltrate many aggressive ions; the main concrete with ionic diffusion is chloride ion migration into concrete, because of the extent of reinforced corrosion damage due to deicing and marine salts. However, sulfate ion can also be of relevance for ionic diffusion as well as other mechanism of ionic transport. When concrete is not saturated at the time ,definitely it will be subjected to ionic solution, then capillarity tension will rapidly draw the solution into the surface layer until the surface layer become saturated. This is very common mechanisms of chloride ingress. When concrete surface are exposed to wetting and drying cycles and is intermittently exposed to chloride,, concentrating them in building up an interior surface concentration at the depth of the convection zone. For the de-icing salt exposure, the chloride concentration in the outer convection zone will build up during the winter and reduce due to high rain intensities washout in warmer wealthier, [lindvall et al 2000, Joseph and James, 2006]. This is the scenario for bridge or parking deck subject to de-ice salt or for the tidal and splash zone in marine structures. When concrete are saturated, both surface are inundated and at least one surface is expose to a chloride solution, chloride concentration gradient exists between the surface and the pore solutions. And pure diffusion will result. The magnitude of the concentration gradient is the driving forces for diffusion as solution seek to come to an equilibrium concentration build up rapidly. In the case of deicing salts, the surface concentration will build up slowly over many years and only then will the surface concentration become constant. Wick action can occur where relative thin structural elements are exposed on one side to ionic solution and on the other to air a relative humidity less than hundred percent causing the ionic solutions to be drawn towards the air exposed surface and evaporated. This will result in an increased ionic concentration inside the concrete at the depth of evaporation; the effect of wick action will be to increase the rate of chloride ingress beyond that predicted by diffusion alone [wood et al 1989, Joseph and James, 2006].

3. Governing Equation

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

Equation [1] is the governing equation that express the rate of diffusion of chloride ionic transport in concrete structure, several attack has on examine on concrete structure, but the most commonest is the chloride that deform the concrete strength due to ionic transport, reinforced concrete structure are expose to harsh environment yet are often expected to last with little or no repairs or maintenance for long period of time. For reinforced concrete bridges, one of the major forms of environment attack is chloride ingress, which lead to corrosion of the reinforced steel and a subsequent reduction in the strength, the express equation will definitely monitor the rate of diffusion in concrete structure.

Substituting solution C = XT into (1), we have

$$XT^1 = DX^{11}T \qquad \ldots\ldots\ldots\ldots\ldots \qquad (2)$$

$$\phi \frac{T^1}{T} = -D \frac{X^{11}}{X} T \qquad \ldots\ldots\ldots\ldots\ldots \qquad (3)$$

$$\phi \frac{T^1}{T} \quad -D\left(\frac{X^{11}}{X}\right) \qquad \ldots\ldots\ldots\ldots\ldots \qquad (4)$$

$$\phi \frac{T^1}{T} \quad -\frac{X^1}{X} \qquad \ldots\ldots\ldots\ldots\ldots \qquad (5)$$

Considering when Ln x 0 $\rightarrow$

$$\phi T^1 = D\frac{X^1}{X} - T = \lambda^2 \qquad \ldots\ldots\ldots\ldots\ldots \qquad (6)$$

$$\phi \frac{T^1}{T} = \lambda^2 \qquad \ldots\ldots\ldots\ldots\ldots \qquad (7)$$

$$\frac{X^{11}}{X} = \lambda^2 \qquad \ldots\ldots\ldots\ldots\ldots \qquad (8)$$

$$D = \lambda^2 \qquad \ldots\ldots\ldots\ldots\ldots \qquad (9)$$

This implies that equation (10) can be expressed as:

$$D\frac{X^{11}}{X} = \lambda^2 \qquad \text{..................................} \qquad (10)$$

$$D\frac{X^{2}}{X} = \lambda^2 \qquad \text{..................................} \qquad (11)$$

$$\phi\frac{dy^{2}}{dx^2} = \lambda^2 \qquad \text{..................................} \qquad (12)$$

$$\frac{Ddy^{2}}{dx^2} = \lambda^2 \qquad \text{..................................} \qquad (13)$$

$$\phi\frac{d^2 y}{dx^2} = \lambda^2 \qquad \text{..................................} \qquad (14)$$

$$\frac{d^2 y}{dx^2} = \frac{\lambda^2}{\phi} \qquad \text{..................................} \qquad (15)$$

$$d^2 y = \left(\frac{\lambda^2}{\phi}\right) dx^2 \qquad \text{..................................} \qquad (16)$$

$$\int d^2 y = \int \frac{\lambda^2}{\phi}\, dx^2 \qquad \text{..................................} \qquad (17)$$

$$dy = \frac{\lambda^2}{\phi} x\, dx \qquad \text{..................................} \qquad (18)$$

$$\int dy = \int \frac{\lambda^2}{\phi} X\, dx + C_1 \qquad \text{..................................} \qquad (19)$$

$$y = \frac{\lambda^2}{\phi} X^2 + C_1 x + C_2 \qquad \text{..................................} \qquad (20)$$

$$y = \frac{\lambda^2}{\phi} + C_1 x + C_2 \qquad \text{..................................} \qquad (21)$$

$$y = 0$$

$$\Rightarrow \frac{\lambda^2}{\phi} X^2 + C_1 x + C_2 = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (22)$$

The expression from equation [2] to [22] is to descretized the variable in terms of the relating their function to where they are relevant to the system , the expression in this dimension streamline there various functions that influence are diffusion of chloride ion in homogenous concrete structure , various type of material use determine the rate of ingress of ionic content transport in concrete structure, the formation of concrete reflect the rate microstructural properties in the concrete constituent thus determine the rate of micropores in concrete formation.

Applying quadratic expression, we have

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (23)$$

Where a = $\frac{\lambda^2}{\phi}$, b = C_1 and c = C_2

$$X = \frac{-(C_1) \pm \sqrt{(C)^2 - 4\left(\frac{\lambda^2}{\phi}\right) C_2}}{2\frac{\lambda^2}{\phi}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (24)$$

$$= \frac{-C_1 \pm \sqrt{C_1{}^2 - 4C_2 \frac{\lambda^2}{\phi}}}{2\frac{\lambda^2}{\phi}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (25)$$

$$X = \frac{-C_1 + \sqrt{C_1{}^2 - 4C_2 \frac{\lambda^2}{\phi}}}{2\frac{\lambda^2}{\phi}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (26)$$

$$X = \frac{-C_1 + \sqrt{C_1{}^2 - 4C_2 \frac{\lambda^2}{\phi}}}{2C_1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (27)$$

$$X = \frac{-C - \sqrt{C_1^{\,2} - 4C_2 \frac{\lambda^2}{\phi}}}{2\frac{\lambda^2}{\phi}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

Substituting equation (20) to the following boundary conditions and initial values condition

$$t = 0 \quad C = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (29)$$

Therefore, $X_{(x)} = C_1 \ell^{-mx} + C_2 \ell^{m_2 x}$ .... (30)

$$C_1 \, Cos\, M_1 x + C_2 \, Sin\, M_2 x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (31)$$

$$y = \frac{\lambda^2}{\phi} + C_1 + C_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (32)$$

$$C(x,t) = \left(C_1 \, Cos\, M_1 \frac{\lambda^2}{\phi} x + C_2 \, Sin\, M_2 \frac{\lambda^2}{\phi} x \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (33)$$

The migration of diffusion is a serious threat to concrete structure; capillary absorption, hydrostatic pressure, and diffusion are the means by which chloride ion can penetrate concrete. The most familiar method is diffusion, the movement of chloride ions under a concentration gradient. For this to occur the concrete must have a continuous liquid phase and there must be chloride ion concentration. The other concept in the diffusion of concrete is the \ rate of permeation is driven through the pressure gradients. If there is an applied hydraulic head on the face of the concrete and chlorides are present they may permeate into the concrete. The rates of permeability in the concrete formation determine the rate of chloride ion ingress in the homogeneous concrete formation.

But if $x = \frac{v}{t}$

Therefore, equation (33) can be expressed as:

$$C(x,t) = \left(C_1 \, Cos\, M_1 \frac{\lambda^2}{\phi} \frac{v}{t} + C_2 \, Sin\, M_2 \frac{\lambda^2}{\phi} \frac{v}{t} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (34)$$

The hydraulic head rate of transport mechanism describe above can bring chloride into the concrete, the level of the rebar, the principal methods that of diffusion is rare for a significant hydraulic head to be exerted on the structure, and the effect of absorption is typically limited to a shallow cover region. In the bulk of the concrete, the pores saturated and chlorides ion movement is controlled by concentration gradient, the model at this stage expression the process of concrete engrossed by chloride depending on the pores of the structure of the concrete, this is affected by factors including materials, construction practice and age. The type of cement influences both the porosity of the concrete and its reaction with chlorides. The porosity of concrete is highly dependent on the water-cement and aggregate-cement ratios whereas the type and amount of cement affect the pore size distribution and chemical binding capacity of the concrete. The influences of cement type and water-cement ratio are reflected on the chloride resistance of concrete, measured in terms of effective diffusion coefficient. The developed mode considered several factors in ionic ingress on concrete formation, the expressed model will definitely predict the rate off chloride concentration in concrete formation.

4. Conclusion

Concrete is the mixture of fine and coarse aggregate water and cement, this construction material may be in insitu or precast through a formwork the concrete formation are found to pass through several state under the influence of cement paste hydration compaction and curing , this process are goal achieved through attaining an optimum compressive strength but several condition has been found to affect the compressive strength of concrete so that it withstand stress and any external attack these condition developed by several factors and has caused lots of different deformation of concrete strength and performance, one of the major factors in concrete deformation is the chloride ion ingress on concrete, this generates corrosion of reinforce steel in concrete formation ,. To monitor the rate of the ionic effect mathematical model were find suitable determine the cause and rate of this chloride concentration in concrete structure. External chlorides penetrate into the interconnecting pores in concrete as bulk liquid by convection, and chloride ions diffuse further into the saturated pore system. Diffusion is
Controlled by concentration gradients of the free chlorides; thus the capacity of the concrete to physically adsorb and to chemically react with chloride ions, this affects the free chloride ions concentration in the concrete. The chloride resistance of concrete is thus highly dependent on the porosity of concrete in terms of pore size thus pore distribution and interconnectivity of the pore system. An expression mathematically ere developed the denote the variables that will monitor the rate of chloride ion in homogeneous concrete structures, the model were develop through the governing equations, the derived mathematical expression generated the final model that will monitor the chloride ion in concrete structure.

References

[1] Lindvall, A, Anders, A, and Nilsson , L.O, 2000 chloride ingress data from Danish and Swedish road Bridges exposed to splash from deicing and Salt, second international RILEM, workshop on testing and modeling the chloride ingress into concrete, paris,11-12 September

[2] Wood J.G M, Wilson, R,f, and Leek. D. S. 1989 ,improved Testing for chloride ingress resistance of concrete and relation of results to calculation behaviour, proceeding, third international conference on deterioration and repair of reinforced concrete in the Arabian Gulf oct, pp 15

[3] Joseph F. L and James H. P 2006; significant of testing and properties of concrete marking materials ASTM international united sate of America 245

[4] Cement concrete Australia 2009 Cement Concrete & Aggregates Australia Chloride resistance of Concrete

[5] Neithalath, N. (2004) "Development and characterization of acoustically efficient cementitious materials", Ph.D Thesis, Purdue University, IN

[6] Neithalath, N., Weiss, J., and Olek, J. (2005). "Modeling the influence of pore structure on the acoustic absorption of enhanced porosity concrete", *Journal of Advanced Concrete Technology,* Japan Concrete Institute, 3(1), 29-40.

[7] Neithalath, N., Weiss, J., and Olek, J. (2006). "Characterizing enhanced porosity concrete using electrical impedance to predict acoustic and hydraulic performance", *Cement and Concrete Research,* in press.

[8] Nelson, P.M., and Phillips, S.M. (1994). "Quieter road surfaces", TRL Annual Review,Transportation Research Laboratories, UK.

[9] Onstenk, E., Aguado, A., Eickschen, E., and Josa, A. (1993). "Laboratory study of porous concrete for its use as top layer of concrete pavements", Proceedings of the Fifth International Conference on Concrete Pavement and Rehabilitation, Purdue University, Indiana, Vol.2, 125-139.

[10] Tennis, P,D., Leming, M.L., and Akers, D.J. (2004) *Pervious concrete pavements,* Portland Cement Association, Skokie, IL, 28 pp

[11] Yang, J., and Jiang, G. (2003). "Experimental study on properties of pervious concrete pavement materials", *Cement and Concrete Research,* 33, 381-386

[12] Marolf A., Neithalath N., Sell E., Weiss J., and Olek J. (2004). "Influence of aggregate size and gradation on the acoustic absorption of enhanced porosity concrete", *ACI Materials. Journal,* 101(1), 82-91.

[13] N. Neithalath1, J. Weiss and J. Olek 2006 Predicting the Permeability of Pervious Concrete (Enhanced Porosity Concrete) from Non-Destructive Electrical Measurements