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Study on time for corrosion initiation of reinforced concrete members subjected to chloride induced corrosion

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Abstract: Corrosion is the main problem faced by civil engineers all over the world. Hence numerous researches have been conducted in the field of civil engineering to mitigate this inevitable enemy. Rebar corrosion is a common problem seen in Reinforced Concrete structures which causes deposition of corrosion products on the rebar and that has higher volume compared to steel, causing internal stresses in concrete which ultimately results in cracking of concrete and thus affecting serviceability of the structure.

In this study it is mainly concentrated on corrosion caused due to chloride ingress. To determine the corrosion initiation time for Reinforced Concrete (RC) specimens accelerated corrosion test and Fick's second law of diffusion is used. Thus comparing the corrosion initiation time of test specimens with different composition of cementations material obtained experimentally and empirically.

Keywords: Corrosion, Rebar, Reinforced Concrete, Chloride

1. Introduction

Corrosion is usually caused by mechanism of chloride ingress, carbonation, freeze and thaw cycles, sulfate attack, or alkali aggregate reaction. This paper mainly concentrates on corrosion caused due to chloride ingress. A passive layer will protect reinforcement in the concrete from oxygen and water. This layer can only be maintained at a pH greater than 12.5. Chloride ingress and accumulation on the rebar decreases the pH at the rebar surface which destroys the passive layer thus making the rebar vulnerable for corrosion. Chloride ingress is usually caused by diffusion and absorption. Absorption occurs due to the repeated wetting and drying process of concrete surface up to the depth of 10-20 millimeter from the exposed concrete surface beyond which diffusion is predominant.

2. Objective

- Determination of time required for corrosion initiation of Reinforced Concrete (RC) specimens using accelerated corrosion test
- Prediction of corrosion initiation time based on law of diffusion given by Adolf Fick.
- Comparison of time for corrosion initiation of test specimens with a different composition of cementitious material obtained experimentally and empirically.

3. Methodology

Note:- The procedure mentioned below confines the experimental study alone however preparation of specimen , basic testing of materials, mix design and laboratory tests to be carried on according to engineering basics.

Accelerated Corrosion Test:- The test consists of passing a direct electric current through the reinforcement in the concrete specimen which is placed in a salt solution so that the current passing through the system aids the diffusion of chloride ions into the concrete. The present work consists of a constant DC supply of 12V constant potential difference. The concrete specimen acts as anode, the wire mesh as cathode and 5% Sodium Chloride (NaCl) solution is the electrolyte. The specimens were connected parallelly to the supply so that the current passing through it has constant potential difference of 12V.

Empirical approach to time for corrosion initiation:- As accepted by researchers all over the world, diffusion is the main phenomenon by which chloride ingress takes place in case of concrete. When the concrete is completely water saturated, chloride penetration by pure diffusion mechanism takes place in concrete with the concentration gradient between the reinforcement surface and the surrounding being gradient. This ingress of chloride reaches the threshold concentration around the rebar which causes corrosion. Diffusion is usually assumed as a steady state flow or non-steady state flow. This study assumes diffusion to be a non-steady state flow as it gives realistic results and it is usually solved based on Fick's second law of diffusion.

Chloride diffusion is usually described using a model based Diffusional law given by Adolf Fick assuming constant diffusion coefficient.

$$C(x,t) = C_o\left[1 - erf\left(\frac{x}{2\sqrt{D_c t}}\right)\right]$$

The above equation can be rearranged as follows to determine time t,

$$t = \frac{x^2}{4D_c}\left[erf^{-1}\left(\frac{C_o - C_{cr}}{C_o}\right)\right]^{-2} \text{ sec}$$

Where

t = time in seconds

C_{cr} = critical or threshold chloride concentration,

C_o = surface chloride concentration,

D_c = chloride diffusion coefficient (m^2/sec)

x = cover thickness(m)

erf^{-1} = inverse error function used for partial differential equations describing diffusion

Chloride diffusion coefficient represents or indicates the capacity of concrete to resist the penetration of chloride ions and is a very important aspect for service life prediction of a concrete structure. It mainly depends on water cement (w/c) ratio, temperature and composition of cementitious material.

$$D(t) = D_{ref}\left(\frac{t_{ref}}{t}\right)^m \text{ m}^2\text{/sec}$$

Where,

D(t) = chloride diffusion coefficient at time t

D_{ref} = chloride diffusion coefficient at time t_{ref}(usually 28 days)

m = diffusion decay coefficient depending on mix proportion

For concrete having only Ordinary Portland cement (OPC) as cementitious material with no special corrosion protection applied to the reinforcement the following relationship for the D at 28 days is assumed according to service life prediction model [10],

$$D_{28} = 1 \times 10^{-12.06 + 2.4 {w}/{c}} \text{ m}^2\text{/sec}$$

Where,

D_{28} = coefficient of diffusion at 28 days

w/c = water cement ratio of the concrete

For OPC concrete, according to life 365 model, diffusion decay coefficient is taken as, $m = 0.2$

Whereas, according to Jae-Im Park et.al, the diffusion decay coefficient is given by the following relationship [1],

$$m_{OPC} = \alpha({w}/{c})^a$$

Where,

α and a are coefficients of the empirical formula whose values are 0.06 and -1.66 respectively.

According to Life-365 model, it is assumed that neither GGBS nor Fly ash will affect the early age diffusion coefficient of concrete. Same assumption is used in this study for ease of calculation. Hence D_{28} is taken equal to that of OPC even though the experimental results obtained showed otherwise and the values for D_{56} and D_{91} are calculated.

According to Life- 365 model, the diffusion decay coefficient m for GGBS and Fly Ash concrete can be calculated based on the percentage replacements using the following relationship[10],

$$m = 0.2 + 0.4\left(\frac{\%FA}{50} + \frac{\%GGBS}{70}\right)$$

But according to Jae-Im Park et.al, the diffusion decay coefficient is given by the following relationship

$$m_{GGBS} = \alpha\left({w}/{b}\right)^a + \beta\left(\frac{\%GGBS}{70}\right)^b\left({w}/{b}\right)^c$$

$$m_{FA} = \alpha\left({w}/{b}\right)^a + \gamma\left(\frac{\%FA}{40}\right)^d\left({w}/{b}\right)^e$$

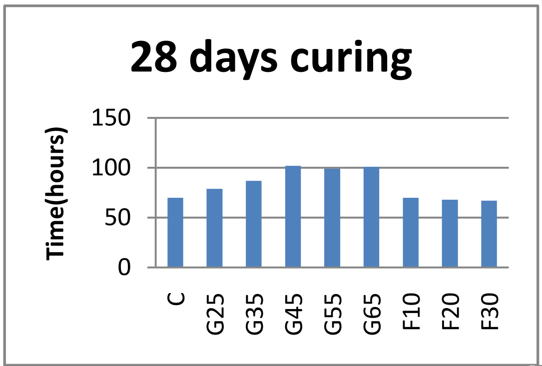
Where,

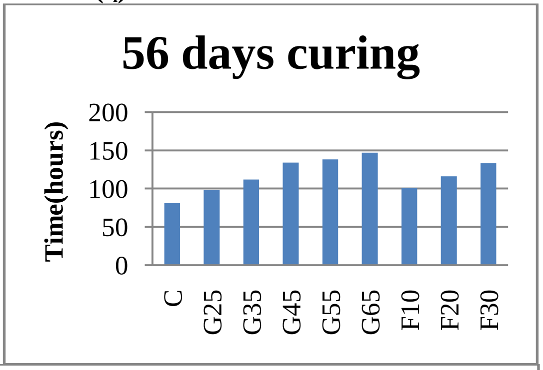
w/b is the water to binder ratio of the concrete.

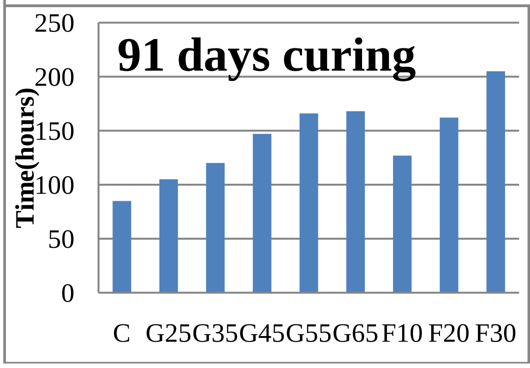
‘ β, γ, b, c, d and e are constants whose values are 4.24, 1.25, 1.12, 3.16, 0.75 and 0.33 respectively.

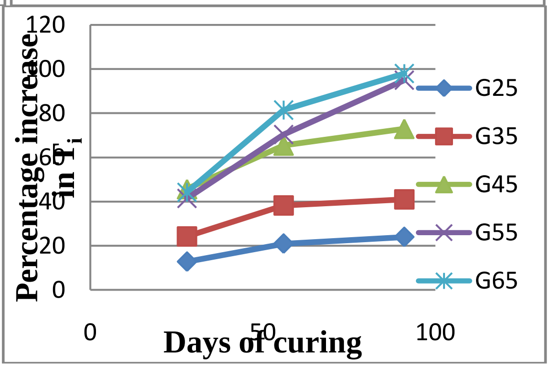
4. Outcome of analysis

Corrosion initiation time (t_i)

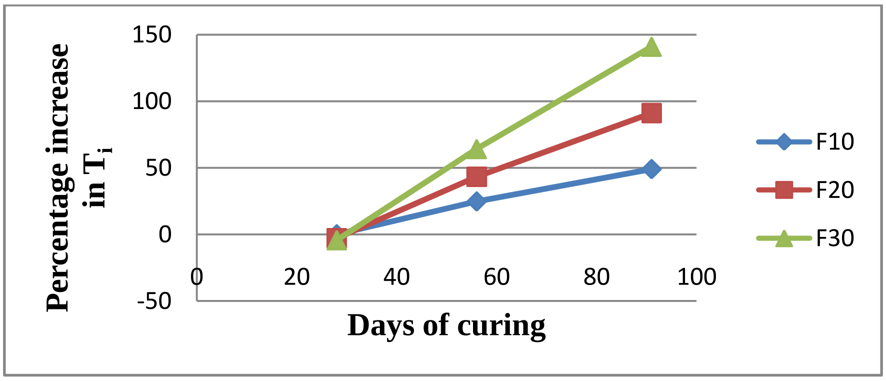








Percentage change in T_i for GGBS Specimens

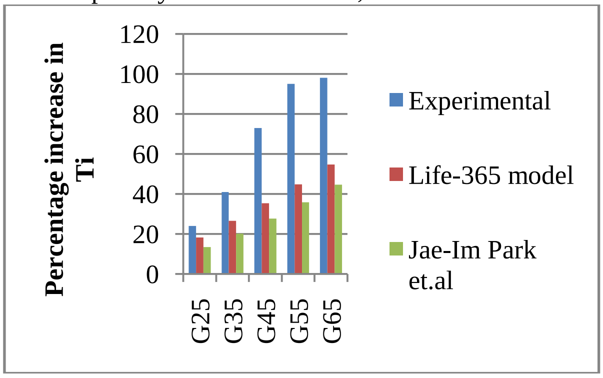


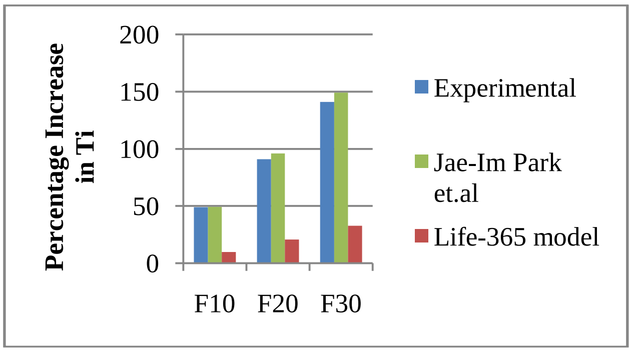
Percentage change in T_i for Fly Ash Specimens

Comparison of empirical and experimental results.

By comparing the empirical and experimental results some points are quite evident. It can be seen that the numerical techniques for calculation of time for corrosion initiation are quite conservative when compared to actual results obtained experimentally.

The time for corrosion initiations obtained by equations based on Life-365 service life prediction model are extremely conservative. The percentage increase seen at 91 days of curing, which is usually assumed as the age at which concrete completely matures, seen experimentally are much higher than the values obtained empirically. A maximum of 54.8 percent increase is seen in case of specimens made of GGBS empirically while experimentally an increase of 98 percent was seen, almost twice as much obtained experimentally. Same results are seen in case of the approach adopted by Jae-Im Park et.al, where an increase of only 44.6 percent is seen.





Percentage increase in Ti for GGBS concrete specimen Percentage increase in Ti for Fly Ash concrete specimens

5. Conclusions

In the present study, it deals with the behavior of corrosion of concrete with different replacements of Ordinary Portland Cement with Ground granulated blast furnace slag (GGBS) using accelerated corrosion test. The conclusions from the present study are as follows:

1. The test specimens made with blended cement had a higher corrosion resistance compared to ordinary cement.
2. The specimens made with replacements of OPC with GGBS had an increasing value for time for corrosion initiation when compared to ordinary cement upto 45% replacement at 28 days curing after which a slight decrease was seen.
3. All blended cement specimens showed high corrosion resistance at 56 days curing with the time for corrosion initiation increasing with increase in percentage of cement replacements.
4. .At 91 days Ground Granulated Blast Furnace Slag (GGBS) specimens having 55 and 65% replacements showed similar T_i value showing 55 being the highest Ground Granulated Blast Furnace Slag (GGBS) replacement percentage beyond which no increase in T_i is a possibility.
5. Empirical Approach based on Life-365 service life prediction model can be used to calculate time for corrosion initiation in case of the Ground Granulated Blast Furnace Slag (GGBS) concrete to obtain conservative results.
6. Empirical Approach based on the work of Jae-Im Park et.al, gives realistic results in case of Fly Ash concrete and can be used effectively for realistic service life predictions.

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