EXPERIMENTAL TIME TO CORROSION INITIATION OF REINFORCED CONCRETE CONTAINING MINERAL ADMIXTURES

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Abstract
Corrosion is one of the most prominent problem faced by structures all over world. This inevitable phenomenon affects the service life and reliability of structures by causing deterioration in the reinforcement steel. The loss of reinforcement steel leads to loss of strength in the structural components and the corrosion products formed causes excess internal stresses in the concrete which leads to cracking of concrete. This work mainly concentrates on the experimental evaluation of time to corrosion initiation of Reinforced Concrete. The concrete specimens casted had varying percentage replacements of mineral admixtures, namely GGBS and Fly Ash. Accelerated corrosion test was used to determine the time to corrosion initiation of different specimens and the obtained results were compared. The results showed that increase in replacement of cement by with mineral admixture had a positive effect on the corrosion resistance of the specimen thus prolonging the time to corrosion initiation.
Index Terms: Accelerated Corrosion test, Corrosion, GGBS, Fly Ash, Reinforced Concrete.

I. INTRODUCTION

Concrete in severe conditions need special design consideration for extended service life. Exposure to high percentage of chloride in marine structures is one such severity concrete is exposed to. Chloride ingress seen in such environment causes the deterioration of reinforcing steel by corrosion. Once the percentage of chloride around the reinforcing steel goes beyond the threshold value corrosion of steel is seen [1]. The corrosion products thus formed fill the pores present in the concrete initially which reduces the pressure on the surrounding concrete but later on after the pores are filled, stress is developed in the concrete which results in cracking and spalling of concrete cover thus exposing the reinforcing steel [2].

Diffusion is the basic phenomenon seen in chloride ingress and the time taken for the chloride concentration around the reinforcing steel to reach the threshold value and thus initiate corrosion is denoted as Time to Corrosion Initiation (Ti). Concrete with low permeability and dense microstructure has been proved to resist corrosion initiation to a greater extend [1]. This can be achieved with the use of mineral admixtures like GGBS which provide better durability to concrete [3]. Determination of effect of such mineral admixture on time to corrosion initiation naturally is time consuming. Accelerated Corrosion test is a test widely accepted by researchers to induce corrosion in a very short time and the results of which can be used to compare resistivity of different concrete specimens to corrosion [1], [2], [4]. This investigation focuses on effects of mineral admixtures, namely GGBS and Fly Ash, on time to corrosion initiation as they provide better durability to concrete and decreases permeability [3],[5].

II. OBJECTIVE OF PAPER

The purpose of this paper is to find the different times to corrosion initiation of RC specimens made of blended cement using accelerated corrosion test. The mineral admixtures used were Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash. This work is of great interest to designers as it gives the variation of corrosion initiation with different composition of cementitious materials at different ages of curing.

III. MATERIALS USED

A. Cement

The cement used for the current work is Ordinary Portland Cement (OPC) of 53 grade adhering to IS 12269:2013. The properties of the cement used are given in table 1.

Table 1. Specification of OPC 53 grade.

Sl No	Property	Value
1	Specific Gravity	3.14
2	Normal Consistency	32%
3	Initial Setting time	60 mins
4	Final Setting time	320 mins

B. Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnace Slag (GGBS) used is as per British Standards EN15167-1:2006. The properties of the GGBS are given in table 2.

C. Fly Ash

Fly Ash is one of the most widely used pozzolana in the world. The Fly Ash used for this work is of Class F and its properties are given in table 3.

D. Aggregates

River sand passing through 4.75mm sieve was used as fine aggregate. Water absorption of fine aggregate was found to be 3 percentages by weight of fine aggregate taken. The fine aggregate used is of zone III as per IS 383: 2016 and has a specific gravity of 2.65.

Coarse Aggregate used was well graded crushed gravel passing through 10 mm sieve and retaining on 4.75 mm sieve. Water absorption was found to be 1 percent by weight and specific gravity was determined to be 2.69.

Table 2. Specification of GGBS.

Sl.No	Characteristics	Results
	Chemical Characteristics	
1	Magnesium Content	7.82%
2	Sulphide Sulphur	0.45%
3	Sulphite content	0.3%
4	Loss on ignition	0.21%
5	Chloride content	0.009%
6	Glass content	90%
7	Moisture content	0.13%
	Physical Charateristics	
1	Fineness	378 m^2/kg
2	Specific Gravity	2.88
3	45 Micron(Residue)	7.9%

E. Water

Ordinary portable water is used for mixing of concrete for all specimens prepared.

F. Reinforcement

The reinforcing bar element used for corrosion test in the RC specimen is a 20mm High Yield Strength deformed bar of 200mm length. The length of the bar is constant in all specimens prepared.

Table 3. Specification of Fly Ash.

Sl No	Characteristics	Results
	Chemical Characteristics	
1	Silicon Dioxide+ Aluminium Oxide	72.4%
2	Silicon Dioxide	41.8%
3	Magesium Oxide	1.06
4	Total Sulphur as Sulphur Trioxide	0.26%
5	Loss on ignition	1.65%
	Physical Characteristics	
1	Specific Gravity	2.16
2	Fineness	426 m^2/kg
3	45 Micron (Residue)	18.6%

IV. EXPERIMENTAL PROGRAM

A. Mix Proportion

The mix proportions for concrete specimens were done as per IS 10262:2009. Considering a very severe exposure condition, a mix design of M35 grade concrete with 0.45 water cement ratio was done as per IS 456:2000. Mineral admixtures, GGBS and Fly Ash, were used to prepare two types of blended cement concrete specimens. RC specimens with GGBS replacement percentages of 25, 35, 45, 55 and 65 and Fly Ash replacement percentages of 10, 20 and 30 were designed. The detailed Mix

Proportion for surface dry saturated condition of aggregates is given in table 4.

B. Casting and Curing

Concrete specimens of size 70X70X250 mm size were casted having a concrete cover of 25 mm on all four sides of the embedded steel of 20mm diameter and 200mm length [1]. Electrical connection to the steel rod was achieved by using an insulated copper wire. The cover required was maintained using concrete cover blocks. Super plasticizer was used at a dosage of 1% by weight of cement for better workability.

Table 4. Mix Proportions for Concrete specimens.

Specimen name	Cement (kg/m^3)	GGBS (kg/m^3)	Fly Ash (kg/m^3)	Water (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)
C	400	0	0	180	913	936
G25	300	100	0	180	909	932
G35	260	140	0	180	908	931
G45	220	180	0	180	906	929
G55	180	220	0	180	905	928
G65	140	260	0	180	903	926
F10	360	0	40	180	905	928
F20	320	0	80	180	898	921
F30	280	0	120	180	890	913

Table 5. Corrosion initiation time (Ti) at 28 and 56 days of curing.

Concrete specimen	Ti at 28 days of curing (hours)	Percentage increase	Ti at 56 days of curing (hours)	Percentage increase
C	70	0	81	0
G25	79	12.85	98	21
G35	87	24.28	112	38.27
G45	102	45.71	134	65.43
G55	99	41.43	138	70.37
G65	101	44.28	147	81.48
F10	70	0	101	24.69
F20	68	-2.86	116	43.21
F30	67	-4.29	133	64.20

Curing was done in a water bath at room temperature for 28 and 56 days and time to corrosion initiation (Ti) was determined for both curing ages.

C. Accelerated Corrosion Test

The setup for Accelerated corrosion test was done as per Fig 1. The concrete specimens were connected to a DC power supply of 12V in parallel so that a constant potential is maintained across all specimens. The positive terminal of the power supply was connected to the concrete specimens acting as anode and the negative terminal was connected to the wire mesh acting as cathode.

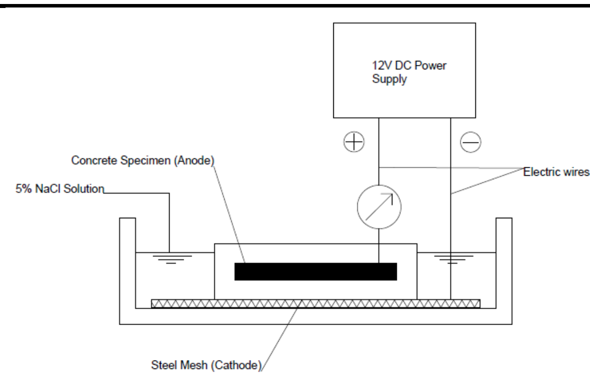

Fig 1. Schematic representation of test setup.

The specimens were submerged in a 5% NaCl solution which provides the chloride ions required for chloride ingress to cause corrosion [1]. The current passing through each concrete specimen was monitored by connecting a milliameter in series. For every mix proportion and curing age 2 specimens were tested and the average time to corrosion initiation (Ti) was taken.

V. RESULTS AND DISCUSSIONS

Accelerated corrosion testing was done two curing ages that is 28 days and 56 days. Electric current flowing through the specimens was monitored and current readings were recorded at every half hour intervals. The point at which current flowing through the specimen reaches the lowest value after which it goes on increasing is taken as the time to corrosion initiation (T_i) [1].

Fig 2 shows the change in current flow through specimen G25 at 56 days of curing. The value reaches a minimum of 32 mA and after which it increases. The time at which the current reaches the minimum value before the sudden increase is taken as time to corrosion initiation.

Table 5 shows the time to corrosion initiation (T_i) for different specimens at different ages of curing and also the percentage increase of T_i of blended concrete specimens when compared to control specimens (C) made of OPC.

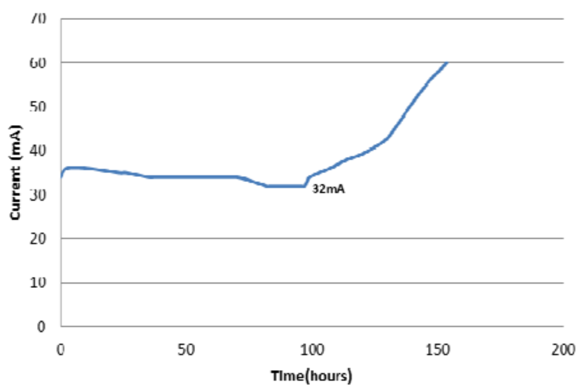

Fig 2. Change of current with time through Specimen G25 at 56 days of curing.

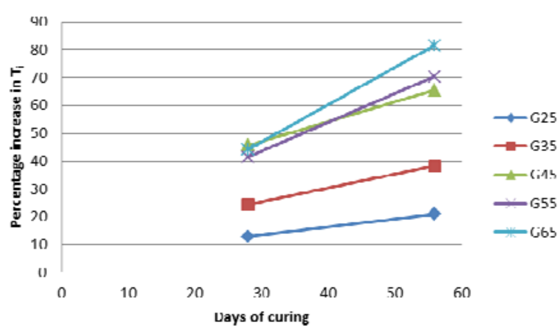

Fig 3. Change in Time to Corrosion Initiation of GGBS specimens with respect to control specimen (C).

All specimens with GGBS replacements showed a higher value of T_i compared to normal concrete specimens with percentage increase having an ascending value up to 45 % replacement after which a slight decrease was seen at 28 days curing, whereas there was a continues increase in T_i seen at 56 days of curing. Fig 3 gives the graphical representation of the change in T_i of GGBS specimens with respect to T_i of control specimen (C).

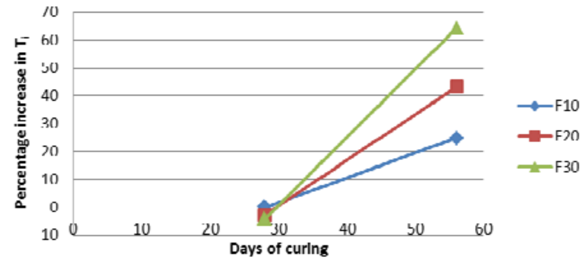

Fig 4. Change in Time to Corrosion Initiation of Fly Ash specimens with respect to control specimen (C).

Specimens having Fly Ash replacements had equal to slightly lower T_i value at 28 days of curing with increase in percentage replacements but all the specimens had a higher T_i at 56 days of curing. Fig 4 gives the graphical representation of the change in T_i of Fly Ash specimens with respect to T_i of control specimen (C).

VI. CONCLUSION

(i) The Concrete specimens made of blended cement had a higher corrosion resistivity compared to normal cement.

(ii) This behavior can be validated by the increase in pore refinement associated with use of mineral admixtures like GGBS and Fly Ash which hinders chloride ingress into the concrete which causes corrosion.

(iii) The specimens made of GGBS replacements had a higher time to corrosion initiation at early age whereas Fly Ash specimens had higher values at a later age of curing.

(iv) GGBS specimens achieved a maximum increase in Ti of nearly 46% at 28 days of curing for specimen having 45% of GGBS replacement and a maximum increase in Ti of 81% at 56 days of curing for specimen with 65% of GGBS replacement when compared to control specimens made of OPC.

(v) Fly Ash specimens had similar Ti values when compared to the control specimens at

28 days of curing but had a maximum increase of 64% at 56 days for specimen having a Fly Ash replacement of 30%.

(vi) From the results it is evident that use of mineral admixtures improves the corrosion resistivity of the concrete thus giving a longer service life to the structure. Even though loss of early strength is a demerit associated with high percentage dosages, it is economical and long lasting compared to normal concrete.

(vii) Thus use of mineral admixture is advisable for concreting in harsh environments like for marine structures to achieve longer service life.

REFERENCES

[1] Ahmed A. Abouhussien and Assem A. A. Hassan, “Experimental and Empirical Time to Corrosion of Reinforced Concrete Structures under Different Curing Conditions”, Advances in Civil Engineering, Hindawi Publishing Corporation, Volume 2014.

[2] Dimitri V. Val, Leonid Chernin and Mark G. Stewart, “Experimental and Numerical Investigation of Corrosion-Induced Cover Cracking in Reinforced Concrete Structures”, Journal of Structural Engineering, ASCE, pp 376-385, April 2009.

[3] D. Suresh and K. Nagaraju, “Ground Granulated Blast Slag (GGBS) In Concrete – A Review”, IOSR Journal of Mechanical and Civil Engineering, Volume 12, Issue 4 Ver. VI, pp 76-82, Jul. - Aug. 2015.

[4] Haijun Zhou, Jinlong Lu, Xi Xv, Yingwu Zhou and Feng Xing, “Experimental study of bond-slip performance of corroded reinforced concrete under cyclic loading”, Advances in Mechanical Engineering, Volume: 7 issue: 3, SAGE journals, April 2015.

[5] Michael Thomas, “ Optimizing the Use of Fly Ash in Concrete”, Concrete Thinking for a sustainable world, PCA, Available:http://www.cement.org/docs/default-source/fc_concrete_technology/is548-optimizing-the-use-of-fly-ash-concrete.pdf