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Corrosion Protection Characteristics of Fly Ash Blended Concretes made with Special Cement OPC 53-S

Kumar M K[#], Rao P.S.[$] and Swami B.L.P.[@]
[#]Scientist, DRDO, New Delhi, [$]Advisor, GVPCE, Visakhapatnam, [@]Professor, VCE, Hyderabad, India

***Abstract*— This paper reports results of investigation evaluating the Corrosion Protection Characteristics of Fly Ash Blended Concretes made with OPC 53-S cements. To the best of the knowledge of the authors this is the first attempt in India at studying the Corrosion Resistance of Concretes made with OPC 53-S cements. The corrosion rate of reinforcing steel was monitored using electrochemical techniques. Results indicate that the maximum beneficial effect due to fly ash against corrosion occurs with 30% replacement with OPC 53-S grade cement. Therefore, structures in which durability of concrete (against chloride ingress) is the primary criterion, pozzalans can be used to produce impermeable and corrosion resistant concrete.**

***Index Terms*— Cement, fly ash, Accelerated corrosion test, corrosion of steel bar.**

I. INTRODUCTION

Now a days, many concrete structures exposed to aggressive environment are increased drastically. The effect of corrosion on durability and age of such structures needs enhancement against the corrosion resistance. The usage of blended cement concretes was increased in the construction industry mainly due to the consideration of durability. The use of fly ash to replace a portion of the cement has resulted in significant cost savings, environmental protection and conservation of resources.

Durability of RC structures is reduced by rebar corrosion. Rebar corrosion happens when surrounding concrete fails to protect it. Rebar corrosion further damages the concrete during corrosion reaction and failure of concrete to protect it from aggressive environment. The protection methods include, coating of steel, larger cover thickness, better quality concrete, corrosion inhibitors, and cathodic protection. The corrosion resistance of concrete can be identified through accelerated corrosion test.

II. EXPERIMENTAL DETAILS

Materials Used

OPC 53-S : Conforming to IS 12269-1987, Amendment No.6, June 2000.

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Fine and Coarse Aggregates used: Fine aggregate was river sand conforming to Zone II as per IS 383[(13)] with a specific gravity of 2.53 and Fineness Modulus of 2.91. Crushed quarried granite chips were used as coarse aggregate with a specific gravity of 2.96, fineness modulus of 7.36 and water adsorption of 0.4 %.

Fly Ash : The fly ash collected from SSTPP; AP was utilized for analysis. The physical and Chemical properties were Conforming to IS: 3812 (part-1) -2003.

III. OBJECTIVE OF THIS STUDY

The IRS/T-40-1985 and IS 12269-1987, Amendment No.6, June 2000 permit C_3A up to 10% in OPC 53-S Grade Cement. C_3A is known to increase the risk of corrosion in concrete when compared with concretes made with cements which do not have C_3A. Hence it will be useful to study the corrosion resistance characteristics of cements made with OPC 53-S grade. The service life of a reinforced concrete member with regard to corrosion explained by Hussain et al. essentially consists of two parts – one the "initiation period" and the other the "propagation period". Initiation period is influenced by the quality of concrete. The model was based on the information obtained from literature study that partial replacement of cement with fly ash yields concrete with better corrosion resistance than concrete made only with OPC.

A. Accelerated Corrosion Test according to the SERC Method

Corrosion resistance studies were proposed to be carried out using an accelerated laboratory test method developed at Structural Engineering Research Centre (SERC) Chennai, Srinivasan et al. (2007), where the concrete specimen containing rebar is subjected to polarization under a constant voltage in a sodium chloride solution.

The experimental set up essentially consists of a non-metallic container, in which water mixed with 3.5% NaCl solution is poured to the required level. In this container, the cylindrical concrete specimen with rebar would be placed centrally and around this a circular stainless-steel plate is kept. The rebar of the concrete cylinder is connected through an electrical lead to a D.C. Power supply to the anode terminal (+ Ve) and the stainless-steel plate to the cathode terminal (- Ve). This set up forms an

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electrochemical cell with rebar acting as anode and stainless-steel plate as cathode. Number of such cells can be made and connected to a D.C. power pack of multichannel system. A constant voltage of about 3.0 V is applied from the D.C. Power pack.

For this applied voltage, there will be current response which can be measured using an ammeter and the current response will depend on the total resistance of the cell system. This applied voltage is to be kept constant and as the time passes, the chloride migration will increase and once sufficient chloride, equal to the critical chloride content for the type of steel rebar used reaches the steel surface, depassivation will occur and this will get reflected in a sudden increase in the current response. As the experiment continues, the current will increase indicating the activity of corrosion.

As the time goes, the current may increase only slightly and will remain fairly constant at a low level depending on the dosage of fly ash content. It is generally experienced that the polarisation test will normally require a period of 40 – 50 days by which time the rebar embedded in blended concrete specimens would undergo enough corrosion. The experiment is continued till cracks appeared on the test specimens.

B. Specimen Details

Corrosion studies were carried out on normal strength concrete of M40 grade but using OPC 53-S as the cement quality with and without fly ash as partial replacement. M40 grade concrete mixes M40-1 and M40-2 were designed using the data obtained from the tests on cement and aggregates and with trial mixes. The compositions of the mixes (with and without fly ash) adopted are given in the Table 1 & Table 2.

The specimens consist of concrete cylinders of size 75 mm dia x 150 mm in height with a 16mm rebar embedded centrally. The positioning of the steel rebar gave an equal cover thickness of 29.5 mm all-round and also at bottom of cylinder. Figure 1 shows the schematic view of the test specimen for 75 mm x 150 m cylinder. Inside the cylinder, a length of 91.0mm of embedded rebar was exposed and the remaining length was well protected by a plastic tube and sealed with epoxy. In the protruded length, a small portion was used to connect the lead wire for electrical connection.

The specimens were taken out after 28 days of curing under normal water and kept in the open atmosphere for 3 hours. These specimens were used for the accelerated corrosion test.

C. Design Mixes

M40 grade concrete mixes M40-1 and M40-2 were designed using the data obtained from the tests on cement and aggregates and with trial mixes, the mix proportions are shown in Table 1 and Table 2.

Table: 1 Mix Proportions of Concrete with OPC 53-S Cement (M40-1)

Mixes	Raw Materials in kg per m^3					
	C	F Ash	FA	CA	w/b ratio	Slump mm
0% FA	360	-	612	1082	0.48	78
10% FA	324	36	612	1082	0.48	84
20% FA	288	72	612	1082	0.48	98
30% FA	252	108	612	1082	0.48	129
40% FA	216	144	612	1082	0.48	136

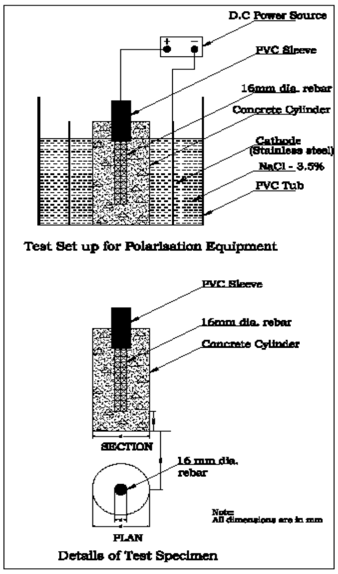

Fig: 1 Test set up for Polarisation Equipment

Table: 2 Mix Proportions of Concrete with OPC 53-S Cement (M40-2)

Mixes	Raw Materials in kg per m^3					
	C	F Ash	FA	CA	w/b ratio	Slump mm
0% FA	380	-	663	1160	0.50	82
10% FA	342	38	663	1160	0.50	96
20% FA	304	76	663	1160	0.50	108
30% FA	266	114	663	1160	0.50	124
40% FA	228	152	663	1160	0.50	146

IV. RESULTS & DISCUSSION

The current values in mA from the corrosion monitoring panel for different specimens having 0, 10, 20, 30 and 40% replacement of cement with fly ash of M40-1 grade of

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concrete are recorded. Figure: 2 shows the current Vs time for M40-1 grade of fly ash blended cement concretes made with cement OPC 53-S grade and a replacement of up to 40% with fly ash. Figure: 3 shows the current Vs time for M40-2 grade of fly ash blended cement concretes made with cement OPC 53-S grade and a replacement of up to 40% with fly ash. The points of change of slope at two locations of the specimens both for controlled concrete and blended cement concretes give the initiation time and the time for cracking.

From the Figure 3 it can be seen that time for depassivation in controlled concrete specimen is 18 days where as it is 28, 38, 64 and 56 days for the blended cement concrete specimens with a replacement of 10 to 40% of cement with fly ash.

From the results it can also be seen that the corrosion initiation period was extended by 4.2 times and 2.55 times more than that of controlled concrete made with OPC 53 -S Cement when 30% of cement is replaced with fly ash in M40-1 and M40-2 grades of concrete.

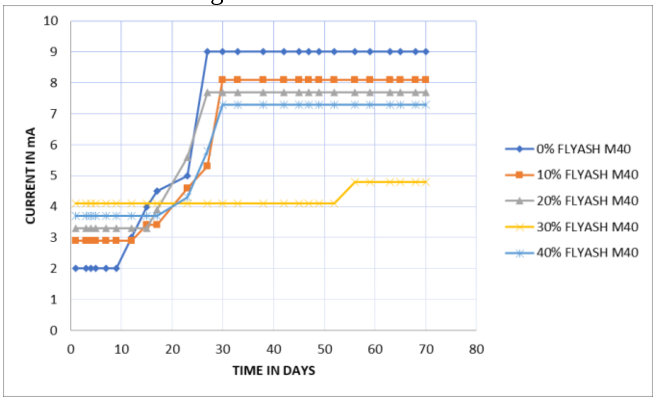

Fig: 2 Current Vs Time for fly ash blended cement concretes of M40-1 grade concrete.

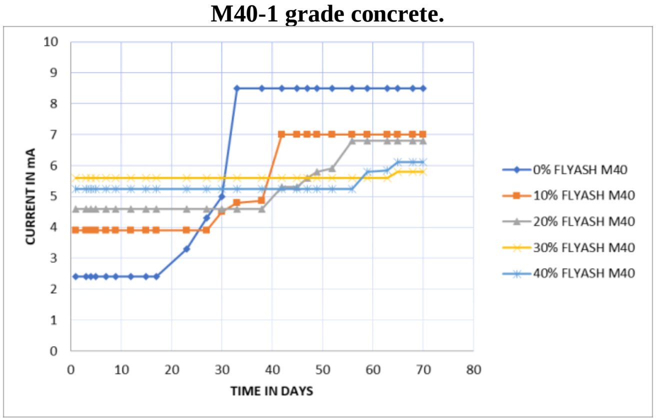

Fig: 3 Current Vs Time for fly ash blended cement concretes of M40-2 grade of concrete.

Prabhakar et al. (2011) conducted corrosion resistance studies using OPC 53 grade cement with and without fly ash as partial replacement of cement. The mix proportions and the strength at 28 days are shown in Table 3.

Table: 3 the Mix Proportions as per Prabhakar et al. (2011)

Mixes	Raw Materials in kg per m^3					
	C	F Ash	FA	CA	w/c ratio	28 day CS
0% FA	400	-	720	1272	0.55	43
18% FA	350	77	680	1292	0.52	45
25% FA	335	112	656	1299	0.50	33
35% FA	311	167	616	1307	0.47	36

Hence the Corrosion initiation time of concretes made with OPC 53-S cement and with partial replacement of cement with fly ash are compared with the results of Prabhakar et al. (2011) conducted using OPC 53 cement and with partial replacement of cement with fly ash are given in Table 4 and Figure 4.

Table: 4 The Corrosion Initiation time of different mixes compared with the results of Prabhakar et al. (2011)

Mix Details	Corrosion Initiation Time in days	Mix Details Prabhakar et al. (2011)	Corrosion Initiation Time in days
Control Concrete with OPC 53-S	18	Control Concrete with OPC 53	5
Mix with 10% Fly Ash	28	Mix with 18% Fly Ash	8
Mix with 20% Fly Ash	38	Mix with 25% Fly Ash	18
Mix with 30% Fly Ash	64	Mix with 35% Fly Ash	31
Mix with 40% Fly Ash	56	-	-

From the above results, the corrosion initiation time of concrete mixes made with OPC 53-S are much longer when compared with the initiation time in concrete mixes made with OPC 53 cement. Similarly, the concrete mixes made with OPC 53-S cement and with fly ash also show better resistance when compared with the OPC 53 cement and with fly ash.

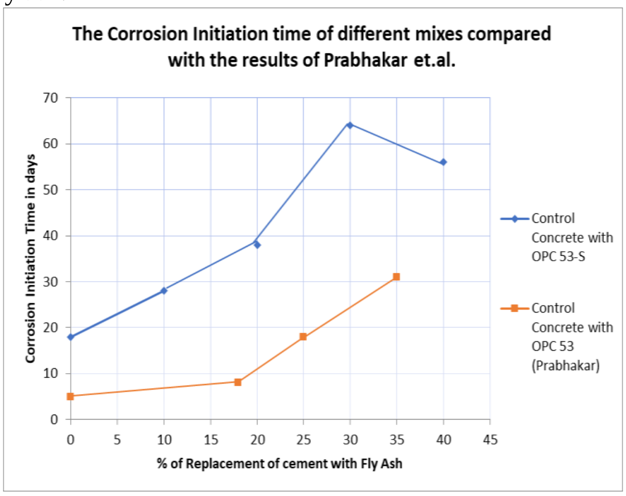

Fig: 4 The Corrosion Initiation time of different mixes compared with the results of Prabhakar et al. (2011)

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The depassivation time (i.e., the corrosion initiation time) and the time of cracking (when the specimen fails, means no further increase of current) for blended cement concrete specimens are given in Table 5 and Table 6.

Table: 5 Time for Corrosion Initiation and Cracking for M40-1 grade of concrete

Specimen Details	Initiation Time Ti (days)	Time for Cracking Tc (days)	Efficiency Factor	
			Based on Ti	Based on Tc
Controlled Concrete	10	26	-	-
Mix with 10% Fly Ash	12	26	1.20	1.00
Mix with 20% Fly Ash	18	28	1.80	1.07
Mix with 30% Fly Ash	52	56	5.20	2.15
Mix with 40% Fly Ash	24	28	2.40	1.07

Table: 6 Time for Corrosion Initiation and Cracking for M40-2 grade of concrete

Specimen Details	Initiation Time Ti (days)	Time for Cracking Tc (days)	Efficiency Factor	
			Based on Ti	Based on Tc
Controlled Concrete	18	32	-	-
Mix with 10% Fly Ash	28	42	1.55	1.31
Mix with 20% Fly Ash	38	56	2.11	1.75
Mix with 30% Fly Ash	64	66	3.55	2.06
Mix with 40% Fly Ash	56	58	3.11	1.81

The ratio of event time (initiation or cracking) with fly ash concrete to the event time with normal concrete is defined as "Efficiency Factor" [according to Prabhakar (2011)] and those factors are also shown in Tables 5 and 6. It can be seen that the maximum beneficial effect due to fly ash occurs with 30% replacement.

V. CONCLUSION

The following broad conclusions can be drawn from the above results

1. The corrosion initiation times of concrete mixes made with

OPC 53-S are much longer when compared with the initial time in concrete mixes made with OPC 53 cement.

2. Similarly, the concrete mixes made with OPC 53-S cement and with fly ash also show better resistance when compared with results from mixes using OPC 53 cement and with fly ash.

3.In the particular method of accelerated corrosion test used by the author, the ratio of event time (initiation or cracking) with fly ash concrete to the event time with normal concrete is defined as "Efficiency Factor" [according to Prabhakar (2011)]. The "efficiency factor" observed by the author are shown in Table 5 and 6. It was observed that the maximum beneficial effect due to fly ash against corrosion occurs with 30% replacement.

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AUTHOR BIOGRAPHY

Kumar M.K obtained his Doctorate from JNTU, Hyderabad. He has been working as Scientist, DRDO, New Delhi. His areas of interest are durability of reinforced concrete structures, corrosion of reinforcement in concrete structures including prediction of residual and service life.

Rao P.S, eminent Structural Engineer and renowned professor of Structural Engineering, retired from Indian Institute of Technology, Chennai. He obtained B.Tech (Hons) in Civil Engg., & M.Tech. in Structural Engg. from IIT, Kharagpur and Doctorate from Technical University, Munich, Germany in 1965. He was currently the Director General, GVP-SIRC at GVP College of Engineering, Visakhapatnam. He has guided 20 candidates towards the Ph.D. degree in Civil Engineering. His areas of interest are Tall structures, prestressed

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concrete structures, Design of Shell and folded plate structures, Durability of reinforced concrete structures.

Swamy B.L.P obtained his Doctorate from Indian Institute of Technology, Delhi. He has been working as a Professor at the department of Civil Engineering in Vasavi College of Engineering, Hyderabad. His areas of interest are durability of reinforced concrete structures, corrosion of reinforcement in concrete structures and assessment of distress and repair of concrete structures.