Effect of Fly Ash on Corrosion Potential of Steel in Concrete

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Abstract –*This paper presents the details of a study on the effect of fly ash on the corrosion potential of steel in concrete. The variables considered include fly ash content (15% and 20%) and w/b ratio (0.40 ,0.45 and 0.50). Concrete specimens of size 280mm ×150mm× 115 mm were cast with different mix proportions based on the variables considered. The total content of cementitious material was kept at 300 kg per cubic meter of concrete. Alternate wetting and drying method with 3% NaCl solution was adopted to study the corrosion potential of steel in concrete. Total corrosion current was calculated as per the ASTM standard for a period of 120 days. Based on the study, it could be concluded that, by properly selecting the replacement quantity of fly ash (20%) and w/b ratio (0.40), the corrosion potential of steel in concrete could be reduced very much and at the same time the strength properties could be enhanced.*

Key Words: Corrosion, Chloride induced corrosion, Fly Ash, Accelerated corrosion technique, Alternate wetting and drying, Macrocell corrosion test.

1. INTRODUCTION

Structural concrete is the widely used material in construction. However, the corrosion in steel embedded in concrete is a major factor causing distress to the concrete structures. The cracking and spalling of concrete associated with corrosion in reinforcement is a major concern in areas with marine environments and in areas where deicing salts are used. Corrosion of steel embedded in concrete plays a vital role in the determination of life and durability of the concrete structures [1]. Different methods are being adopted to reduce the corrosion potential of steel in concrete such as, cathodic protection, surface treatment of rebars, surface treatment of concrete surface, use of corrosion inhibitors in concrete, and the use of mineral admixtures in concrete[2].

The most common mineral admixtures used in concrete include Silica Fumes, Ground Granulated Blast Furnace Slag, and Fly Ash[3]. These admixtures are produced from the waste materials generated by silicon metal industry, steel industry and coal thermal power plants, respectively. Theses mineral admixtures are being widely used in concrete in specified quantities to improve various physical properties of concrete.

Production of fly ash from thermal power plants is a major environmental issue and its disposal by using in concrete production has been studied extensively in the past two decades. Depending on the content of calcium, fly ash is classified into class C and class F by ASTM [4] and each type has its own role to play in improving the physical properties of concrete like workability, permeability, durability, resistivity, resistance to chloride intrusion, carbonation, etc.. [5-13]

In general, a good quality concrete, designed with sufficient cement content and low water to binder ratio, reduces the permeability of concrete and hence reduces the corrosion potential of embedded steel. However, there are many ordinary concrete structures being constructed with poor quality control and with low cement content. There is only limited study reported in literature addressing the corrosion potential of embedded steel in such structures.

Hence, for the present study, an attempt has been made to understand the effect of class F fly ash on corrosion potential of steel in concrete with low cement content (300 kg cement per cubic meter of concrete) and with varying water to binder ratios (0.40, 0.45 and 0.50).

2. EXPERIMENTAL STUDY

2.1 Materials

Cement used was of 53 grade Ordinary Portland Cement. The physical properties of cement tested as per the Indian Standard specifications are given in Table 1.

The class F fly ash used had a specific gravity of 2.03.

Crushed granite coarse aggregate of nominal size 12 mm and manufactured fine aggregate (crushed granite) was used for the present study. The physical properties of fine and coarse aggregates are presented in Table 2.

Super plasticizer with a commercial name Conplast SP430 was used to make concrete workable.

Table -1: Physical properties of cement

SL NO	Properties	Obtained value	IS Specification
1	Specific gravity	3.01	IS:2720(Part 3)
2	Standard consistency	33%	IS:4031(Part 4)
3	Initial setting time(minutes)	41	IS:4031(Part 5)
4	Final setting time(minutes)	193	IS:4031(Part 5)

Table -2: Physical properties of aggregate

Properties	Value	
	Fine aggregate	Coarse aggregate
Specific gravity	2.95	2.71
Fineness modulus	2.46	--
Water absorption	3.2	0.29

The reinforcement bars used for the test was TMT HYSD bars of 12 mm dia. Potable water was used for making concrete as well as for curing of specimens.

2.2 Mixture proportion

Mixture proportions have been arrived based on the Indian Standard code of practices [14]. Based on the different variables considered for the present study, nine mixture proportions were prepared and Table 3 presents the quantities of constituent material required for one cubic meter of concrete.

Table -3: Quantities of materials per cubic meter of concrete

Mix ID	Cement (kg)	Fly ash (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Super plasticizer (kg)	Water (L)
CCW1	300	0	746.43	1313.31	6.0	117.75
CCW2	300	0	731.19	1286.49	6.0	131.4
CCW3	300	0	716.44	1260.56	6.0	146.4
F1W1	255	45	738.86	1299.98	6.0	116.4
F1W2	255	45	724.11	1274.07	6.0	131.4
F1W3	255	45	709.37	1248.11	6.0	146.4
F2W1	240	60	736.49	1295.84	6.0	116.4
F2W2	240	60	721.76	1269.9	6.0	131.4
F2W3	240	60	707.01	1243.97	6.0	146.4

Here, CC stands for control concrete; F1 and F2 stands for respectively 15% and 20% of Fly Ash in concrete; W1, W2 and W3 stands for the water binder ratios of 0.40, 0.45 and 0.50 respectively.

2.3 Specimen Preparation

The various ingredients for concrete were mixed in a pan mixture .Slump test was carried out to ensure uniformity in the concrete mix.The specimen for corrosion test was prepared as per the ASTM standard [15]. Concrete prisms of size 280 mm × 115 mm × 150 mm (L x Wx H) were prepared in specially prepared steel moulds. Before placing concrete in the mould, two 12 mm diameter HYSD reinforcing bars were placed at 25 mm from the bottom of the mould (cathode) and one bar was placed at 25 mm from the top (anode). These bars were initially insulated with an epoxy coating as per the ASTM guidelines.

Concrete was placed in the moulds in three layers and compacted with the help of a table vibrator. The specimens were demolded after 24 hours from the time of casting and were kept in curing tank for another 27 days. Standard cubes of size 150 mm were also prepared along with the prisms for the determination of the concrete strength on 28th day.

After 28th day from the date of casting, the top surface of the prism was roughened with the help of a steel wire brush and kept in the laboratory environment for normal drying of the specimen. After two weeks from the date of keeping the specimen outside the curing tank, the four vertical sides of the concrete prism were coated with epoxy. A dam of size 150mm × 75mm × 75 mm was made with Perspex sheet and was then fixed centrally over the top of the roughened face. The top surface outside the dam was then coated with epoxy. One end of the rebar was soldered with a copper wire and a 100 ohm resistor was placed between the top and bottom bars. Figure 1 shows the typical photograph of corrosion test specimen ready for the test.

Fig. 1: Corrosion test specimen

2.3 Corrosion test

After 30 days from the date of removal of specimen from the curing tank, the corrosion test was started. The test specimens were kept on two non-electrically conducting supports to ensure air flow under the specimen.

One test cycle consists of wetting the specimen by filling the dam with 3% NaCl solution to a height of about 40 mm for two weeks and then removing the salt solution by vacuuming out and keeping the specimen in dry condition for another two weeks. A plastic loose fitting cover was placed on top of the dam to minimize evaporation of the salt solution. This cycle of wetting and drying was continued till 120^{th} day.

Voltage readings across a 100 Ω resistor were taken at the beginning of the second week of ponding with the help of a voltmeter. The current through the resistor, Ij, could be calculated from the measured voltage, Vj, using the equation

$$i_j = V_j / 100$$

The total integrated macrocell current over a time period, which is a measure of corrosion potential of embedded steel in concrete, was then calculated using the relation

$$Tc_j = Tc_{j-1} + [(t_j - t_{j-1}) \times (i_j + i_{j-1})/2]$$

Where
Tc = total corrosion current (coulombs)
t_j = time (in seconds) at which measurement of the macrocell current was taken, and
i_j = macrocell current (amps) at time, t_j

Figure 2 shows the corrosion test specimen showing the method of measurement of voltage across the resistor.

Fig. 2: Macrocell corrosion test set up showing voltage measurement

3. RESULTS AND DISCUSSIONS

A total of 27 corrosion test specimen and cubes were prepared for the present study. Each value in tables and figures is the average of three test results.

Chart 1 shows typical graph showing the variation of 28^{th} day cube compressive strength of concrete with w/b ratio. It could be observed from chart 1 that, the effect of w/b ratio on strength of concrete follows Abram's law in all the three mixes considered.

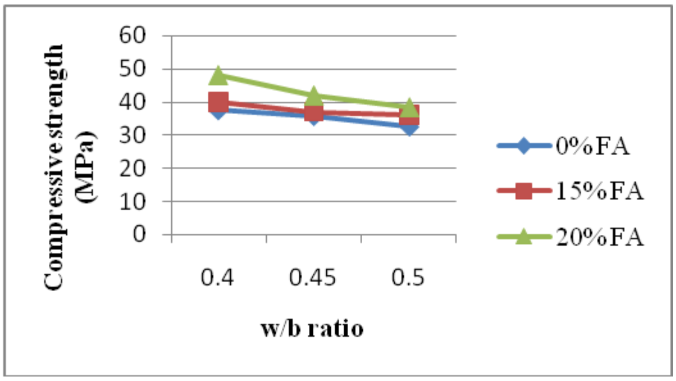

Chart -1: Variation of 28^{th} day cube compressive strength of concrete with w/b ratio

Further, the addition of Fly ash enhances the compressive strength of concrete. It could also be observed that, 20% fly ash content in concrete gives maximum enhancement in compressive strength and depending on the w/b ratio, its value ranges from 15% to 22%.

Chart 2 shows the corrosion potential of steel in concrete expressed in terms of total corrosion current for varying percentage of fly ash and for a w/b ratio of 0.40.

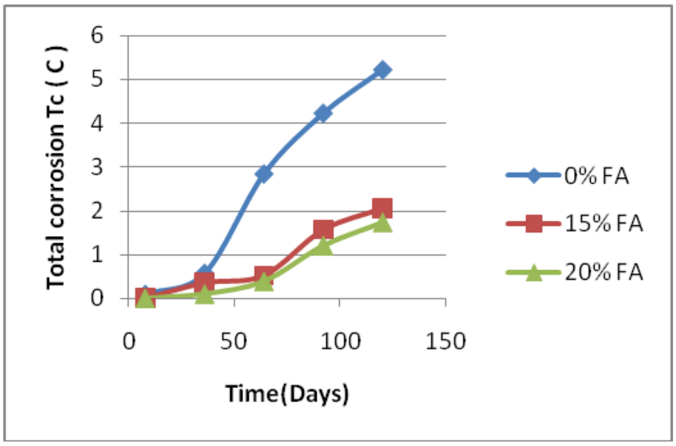

Chart -2: : Variation of total corrosion current with time for concrete with fly ash and for a w/b ratio of 0.40

Charts 3 and 4 shows the corrosion potential of steel in concrete for a w/b ratio of 0.45 and 0.50 respectively. For the present study, the corrosion potential of reinforcement in concrete has been studied for a period of 120 days and Table 4 shows the total corrosion current in specimens obtained at 120th day.

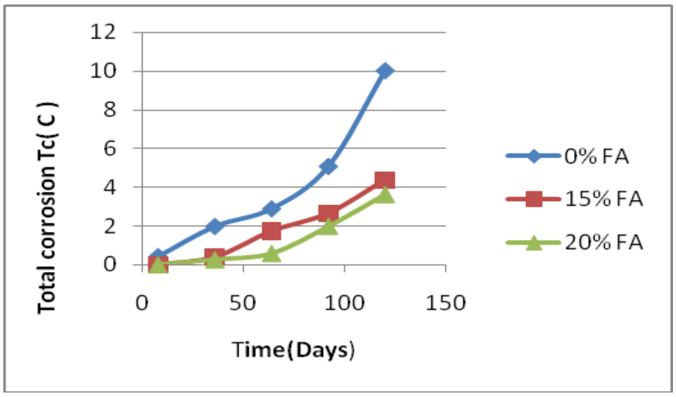

Chart -3: Variation of total corrosion current with time for concrete with fly ash and for a w/b ratio of 0.45

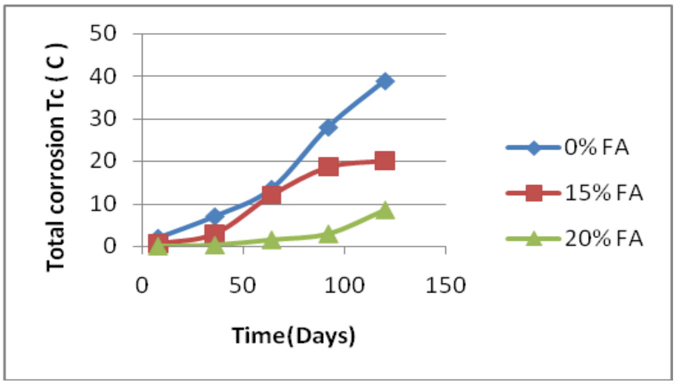

Chart -4: Variation of total corrosion current with time for concrete with fly ash and for a w/b ratio of 0.50

Table 4: Total corrosion current on 120th day

SL No	Mix ID	Total corrosion current, Tc (C)
1	CCW1	5.21
2	CCW2	10
3	CCW3	38.9
4	F1W1	3.63
5	F1W2	4.54
6	F1W3	12.54
7	F2W1	2.65
8	F2W2	2.98
9	F2W3	10.13

From charts 2 to 4, it could be observed that, the water to binder ratio is the primary factor causing corrosion steel in concrete .The specimens with w/b ratio of 0.4 shows less corrosion potential where as specimen with a w/b ratio of 0.5 shows higher corrosion potential.

It could be observed that the addition of fly ash in concrete reduces the corrosion potential of steel in concrete and 20% fly ash in concrete yields lowest corrosion potential.

For the present study, with 300 kg cementitious material per cubic meter of concrete, the corrosion potential of steel in concrete could be reduced by about 71% when 20% cement is replaced with fly ash and with a w/b ratio of 0.40.

4. CONCLUSIONS

Based on the study conducted on concrete mixes having 300 kg cement per cubic meter of concrete and with 15% and 20% fly ash as replacement of cement, following conclusions could be derived.

- Irrespective of the w/b ratio considered (0.40 to 0.50) the replacement of OPC with fly ash improves the compressive strength of concrete
- For the present study, compared with OPC concrete having a w/b ratio of 0.40, a maximum enhancement in cube compressive strength of 22% could be achieved when cement was replaced with 20% fly ash.
- Concrete with higher water to binder ratio will lead to a higher corrosion potential in embedded steel.
- Use of fly ash in concrete reduces the corrosion potential of steel in concrete.
- The total corrosion current on 120th day's observation was lowest for the concrete with 20% fly ash content and for a w/b ratio of 0.40. This is about 71% less compared to the corresponding specimen with OPC.

Based on the present study, it can be concluded that, by properly selecting the replacement quantity of fly ash (20%) and w/b ratio (0.40), the corrosion potential of steel in concrete could be reduced very much and at the same time the strength properties could be enhanced.

ACKNOWLEDGEMENT

This study was carried out with the financial support from Kerala State Council for Science, Technology and Environment under the research project No. ETP/10/2012/KSCSTE.

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