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Effects of Corrosion on Reinforced Concrete Beams with Silica Fume and Polypropylene Fibre

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***Abstract*—**Reinforced concrete has good durability and excellent structural performance. But there are cases of early deterioration due to a number of factors, one prominent factor being corrosion of steel reinforcement. The process of corrosion sets in due to ingress of moisture, oxygen and other ingredients into the body of concrete, which is unsound, permeable and absorbent. Cracks due to structural and other causes such as creep, shrinkage, etc also allow ingress of moisture and other harmful ingredients and thus accelerate the rate of corrosion. There are several interactive factors both external and internal, which lead to corrosion of reinforcement and ultimately failure of structures.

Suitable addition of mineral admixture like silica fume (SF) in concrete improves the strength and durability of concrete due to considerable improvement in the microstructure of concrete composites, especially at the transition zone. Secondary reinforcement in the form of fibre is added to concrete, which provides three dimensional random reinforcement in the entire mass of concrete.

Reinforced concrete beams of size 0.1 m X 0.15 m and length 1m have been cast using M 35 grade of concrete. The beams after curing process were subjected to corrosion process by impressing an external Direct Current (Galvanostatic Method) for a period of 15 days under stressed and unstressed conditions. The corroded beams were tested by applying two point loads to determine the ultimate load carrying capacity and cracking pattern and the results of specimens were compared with that of the companion specimens. Gravimetric method is used to quantify corrosion that has occurred.

***Keywords*—**Carbonation, Corrosion, Cracking, Spalling.

I. Introduction

CORROSION of reinforcing steel is a major problem facing the concrete infrastructures all over the world. Many structures in adverse environments have experienced unacceptable loss in serviceability and safety far earlier than anticipated due to the corrosion of reinforcing steel and thus need replacement, rehabilitation, or strengthening. Corrosion creates problem in reinforced concrete (RC) structures because of two reasons. First as steel corrodes, there is a corresponding drop in the cross-sectional area. Secondly, the corrosion products occupy a larger volume than the original steel which exerts substantial tensile forces on the surrounding concrete and causes it to crack and spall off.

Corrosion of reinforcement in concrete occurs as a result of chloride ion penetration and carbonation of the concrete. Poor construction practices and lack of cover enhance the corrosion probabilities. Among these, chloride ions are considered to be the major cause of premature corrosion of steel reinforcement. Chloride ions penetrate the concrete and initiate the corrosion reaction by destroying the protective film on the steel reinforcement. Steel in reinforced concrete structure corrodes when the concentration of chloride ion in concrete in contact with the steel bar exceeds a threshold limit. The tolerable limit for chloride in concrete varies with its pH values.

The damage to concrete resulting from corrosion of embedded steel manifests in the form of expansion, cracking and eventually spalling of the cover. In addition to loss of cover, a reinforced concrete member may suffer structural damage due to loss of bond between steel and concrete and loss of rebar cross sectional area - some times to the extent that that structural failure becomes inevitable [1].

II. Experimental Investigation

The steel reinforcement in concrete can be protected from corrosion by applying coating on rebars and providing modified environment around them. In this experimental work, an attempt is made to study the reduction of corrosion in rebars by applying Epoxy Nito Zinc Primer coating. The concrete beams, which consists of Ordinary Portland Cement (OPC) and Silica Fume (SF) were cast using coated and uncoated rebars and tested under both stressed and unstressed conditions. The Epoxy Zinc Rich Primer is a product of FOSROC Chemicals (India) Ltd. and available in the name of 'Nito Zinc Primer'.

A. Variables Considered

M 35 grade of concrete with Ordinary Portland Cement (OPC) and silica fume (replacing OPC 5% by weight) have been used. Uncoated rebars and rebars coated with Nito Zinc Primer were used. Selected specimens were added with Polypropylene fibre (0.6% by weight of Cement).

B. Preparation of Specimens

Beam specimens of section 100 mm X 150 mm and length

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1000 mm were selected. Bottom reinforcement of 2 numbers of 10 mm diameter, top reinforcement of 2 numbers of 8 mm diameter and shear reinforcement of 6 mm diameter two legged stirrups were used. The surface of rebars was derusted using wire brush and rust clear solution in order to remove any loose rust particles. The coating material was applied over the surface of the rebars with a brush and was allowed to cure. The initial weight of the rebars was taken and then the rebars were tied together to form the skeleton reinforcement cage. Twenty four numbers of beam specimens were cast using M35 grade of concrete. (Fig. 1). After curing for a period of 28 days, the specimens were transferred to Fibre Reinforced Plastic (FRP) tanks and were subjected to accelerated corrosion process.

Fig. 1 Mixing of Concrete for Casting of Beam Specimens

C. Arrangement of Beams and Application of Load

To investigate the initiation of chloride induced reinforcement corrosion in concrete structures under service loads, the specimens were clamped back to back for the purpose of simulating the loaded conditions in the field. (Fig. 2)The loading points are placed at 300 mm c/c by using angle and bolt connections and the beams were kept in a position one adjacent to another. For this research work, two types of loadings i.e. 5% above crack load and 5% below crack loads were considered. 5% above crack load was applied on 8 specimens and 5% below crack load was applied on 8 specimens. The loading on the beam specimens was exerted using torque wrench and was monitored periodically and kept constant.

A total of 24 beam specimens were cast. The number of specimens cast for different variables are as given in Tables I &II.

TABLE I
DETAILS OF SPECIMENS

Trial details	No. of Specimens
OPC	6
OPC+SF	6
OPC + POLYPROPYLENE	6
OPC + SF + POLYPROPYLENE	6
TOTAL	24

TABLE II
DETAILS OF LOADING OF SPECIMENS

	Un-Stressed	Stressed(5% ACL)	Stressed(5% BCL)
Coated	4	4	4
Uncoated	4	4	4
Total	8	8	8

ACL - Above Crack Load, BCL - Below Crack Load

D.Acceleration of Corrosion Process

Galvanostatic method was used to accelerate the corrosion process. Having the embedded steel as anode and an external stainless steel plate as cathode the beam specimens were impressed a selected current intensity under low voltage conditions for a period of 15 days. The specimens and steel plates were immersed in an electrolyte solution of 3% sodium chloride concentration [2] to simulate the conditions of sea water artificially. The current was applied using a regulated D.C. Rectifier. (Figs. 2 &3)

The current intensity was monitored and maintained at the desired constant level. While the specimens were subjected to the accelerated corrosion process, brown rust stains were noticed on the specimens and on the top surface of the electrolyte solution. Visual inspection was carried out for the presence of cracks in the specimens.

Fig. 2 Accelerated Corrosion process for stressed Condition

Fig. 3 Accelerated Corrosion Process for Unstressed Condition

E. Determination of Weight Loss of Steel

After undergoing the corrosion process, the beams were subjected to load test. Subsequently they were broken and the reinforcement cage was taken out separately. From the cage the main rods are separated. Initial preparation consists of removal of M-seal, binding wires etc. Then all the rods were placed in the chemical solution known as Reebaklens (a product of FOSROC CHEMICALS (INDIA) LTD) to remove loose rust particles. The rods were placed in the solution for 5 minutes and were taken out, cleaned and wiped. This process required about 25 minutes. The weights of rods were determined to estimate the weight loss in rebars and are given in Table III.

TABLE III
ULTIMATE LOAD AND PERCENTAGE OF WEIGHT LOSS

Sl.No.	Beam Specification		Ultimate Load (kN)	Weight of Rebars (gms)		Weight loss in %
	Combination	Stressing Condition		Initial	Final	
1	OPC 1	Unstressed-Uncoated	52.860	2.450	2.348	4.157
2	OPC 2	Unstressed-coated	55.520	2.449	2.378	2.912
3	OPC 3	Stressed - 5% ACL-Uncoated	51.826	2.439	2.294	5.959
4	OPC 4	Stressed - 5% ACL-Coated	52.623	2.396	2.338	2.424
5	OPC 5	Stressed - 5% BCL-Uncoated	53.826	2.431	2.315	4.769
6	OPC 6	Stressed - 5% BCL-Coated	54.435	2.437	2.377	2.459
7	OPC+SF 1	Unstressed-Uncoated	54.348	2.444	2.344	4.111
8	OPC+SF 2	Unstressed-coated	54.696	2.458	2.399	2.408
9	OPC+SF 3	Stressed - 5% ACL-Uncoated	51.234	2.433	2.323	4.514
10	OPC+SF 4	Stressed - 5% ACL-Coated	52.174	2.435	2.388	1.912
11	OPC+SF 5	Stressed - 5% BCL-Uncoated	54.148	2.448	2.349	4.062
12	OPC+SF 6	Stressed - 5% BCL-Coated	55.522	2.436	2.399	1.531
13	OPC+FIB 1	Unstressed-Uncoated	56.261	2.423	2.356	2.862
14	OPC+FIB 2	Unstressed-coated	60.870	2.431	2.399	1.311
15	OPC+FIB 3	Stressed - 5% ACL-Uncoated	54.174	2.438	2.332	4.359
16	OPC+FIB 4	Stressed - 5% ACL-Coated	57.609	2.450	2.407	1.743
17	OPC+FIB 5	Stressed - 5% BCL-Uncoated	56.174	2.438	2.333	4.303
18	OPC+FIB 6	Stressed - 5% BCL-Coated	59.783	2.446	2.408	1.543
19	OPC+SF+FIB 1	Unstressed-Uncoated	56.435	2.458	2.399	2.461
20	OPC+SF+FIB 2	Unstressed-coated	57.609	2.444	2.431	0.552
21	OPC+SF+FIB 3	Stressed - 5% ACL-Uncoated	54.348	2.451	2.373	3.277
22	OPC+SF+FIB 4	Stressed - 5% ACL-Coated	55.735	2.454	2.431	0.945
23	OPC+SF+FIB 5	Stressed - 5% BCL-Uncoated	56.522	2.467	2.402	2.725
24	OPC+SF+FIB 6	Stressed - 5% BCL-Coated	58.996	2.488	2.472	0.635

III. DISCUSSION ON TEST RESULTS

A. Effect of Coating and Stress on Corrosion

In the stressed specimens cracks were noticed in the middle portion, which opened path for the chloride ions to flow and atmospheric corrosive agents to reach the reinforcement. The corrosion initiation occurs very early in this case. It was noted that the rate of corrosion in the stressed beams is more than that of the unstressed beams.

1. Unstressed Specimens with OPC

The load carrying capacity of the specimens with coated rebars is 5.03 % more than that of the specimens with uncoated rebars.

2. Stressed Specimens (5 % ACL) with OPC

The load carrying capacity of the specimens with coated rebars is 1.53 % more than that of the specimens with uncoated rebars.

3. Stressed Specimens (5 % BCL) with OPC

The load carrying capacity of the specimens with coated rebars is 1.13 % more than that of the specimens with uncoated rebars.

In general, the load carrying capacity of unstressed specimens is higher than the stressed specimens subjected to corrosion. Also, the load carrying capacity of the specimens with coated rebars (stressed 5% above crack load & 5 % below crack load) is less than the specimens with uncoated rebars.

The load carrying capacities of various specimens are given in Figs. 4 to 7.

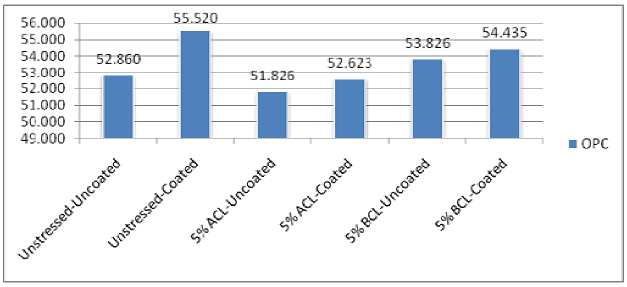

Fig. 4 Load Carrying Capacity for Specimens of OPC (in kN)

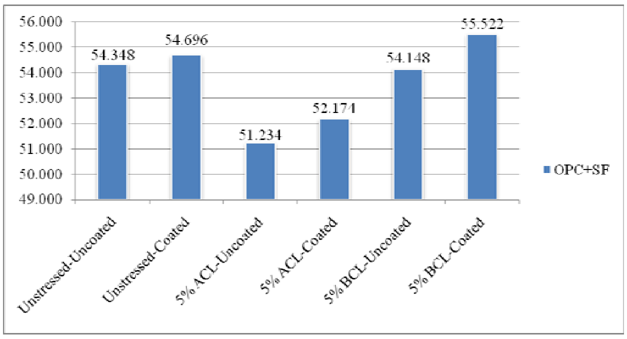

Fig. 5 Load Carrying Capacity for Specimens of OPC+SF (in kN)

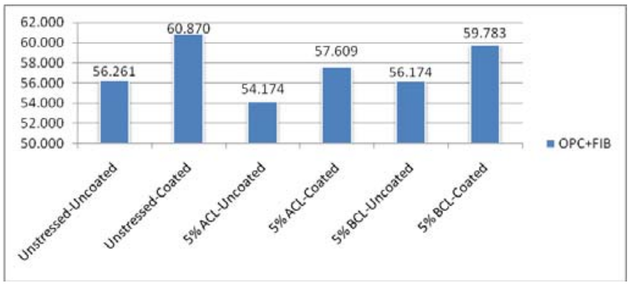

Fig. 6 Load Carrying Capacity for Specimens of OPC+Fibre (in kN)

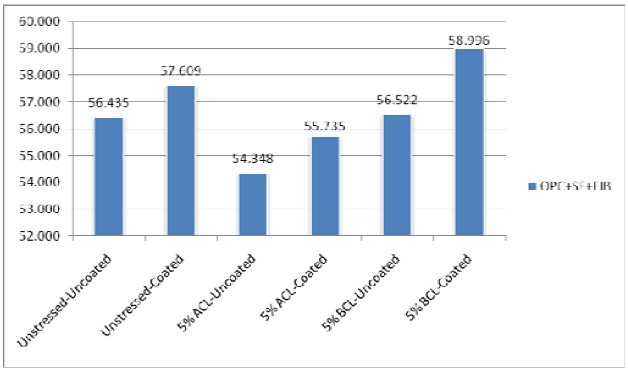

Fig. 7 Load Carrying Capacity of Specimens of OPC+SF+Fibre in kN

B. Effect of Silica Fume and Fibre on Rebar Corrosion

1.Stressed Specimens (5 % ACL) with OPC and SF

The specimens with coated rebars showed a weight loss of 57.64 % less than that of the specimens with uncoated rebars.

2.Stressed Specimens (5 % ACL) with OPC and Fibres

The specimens with coated rebars showed a weight loss of 60 % less than that of the specimens with uncoated rebars.

3. Stressed Specimens (5 % ACL) with OPC, Silica Fume and Fibres

The specimens with coated rebars showed a weight loss of 71.16 % less than that of the specimens with uncoated rebars. Measurement of weight loss of rebars is one of the methods used to quantify corrosion. Comparison of weight loss of rebars is as shown in Figs. 8 to 11.

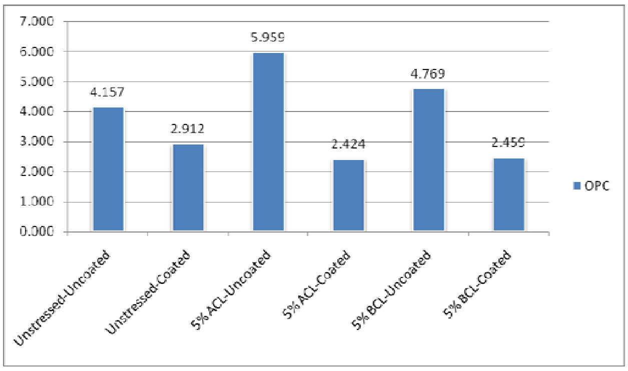

Fig. 8 Weight Loss of rebars for Specimens of OPC (in %)

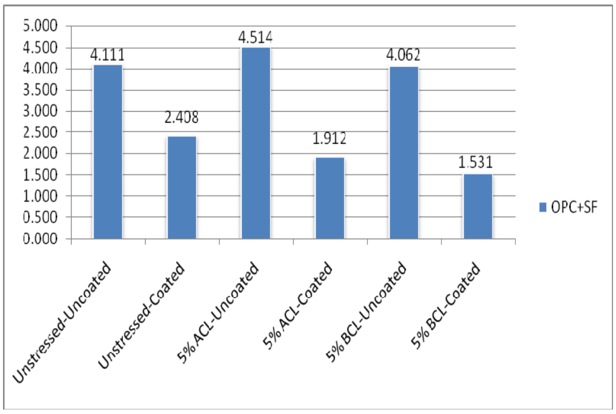

Fig. 9 Weight Loss of rebars for Specimens of OPC+SF (in %)

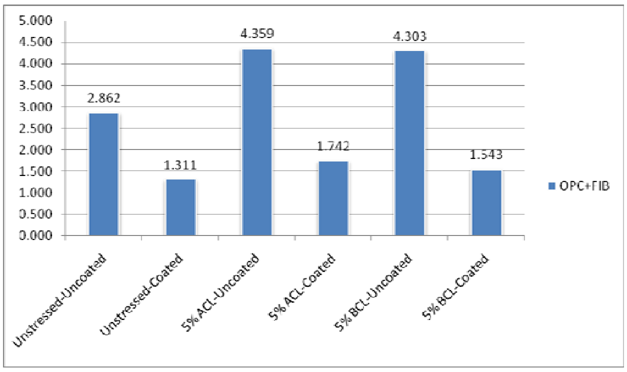

Fig. 10 Weight Loss of rebars for Specimens of OPC +Fibre (in %)

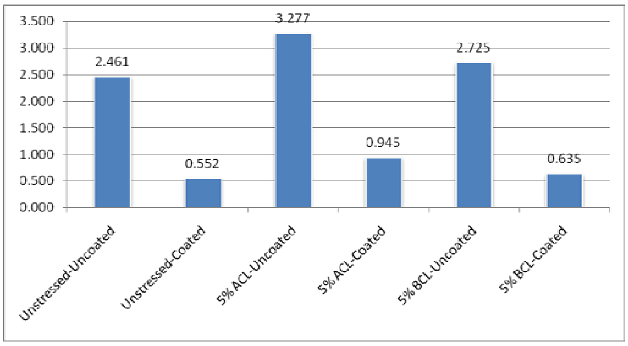

Fig.11 Weight loss of rebars for specimens of OPC+SF+Fibre (in %)

C. Effect of SF and Fibre on Compressive Strength

Cubes of size 150 mm X 150 mm X 150 mm were cast using M 35 grade of concrete and tested after 7days and 28 days for compressive strength for the following combinations.

- OPC
- OPC+SF (replacing cement - 5% by weight)
- OPC+Polypropylene Fibre (added @ 0.6% by weight of cement)
- OPC+SF+Polypropylene fibre

It was observed that the compressive strength is highest (40.59 N/mm2) for the cube with the combination of OPC, SF and Fibre. Fig.12 shows the 7 days and 28 days compressive strength values of the different combinations mentioned above.

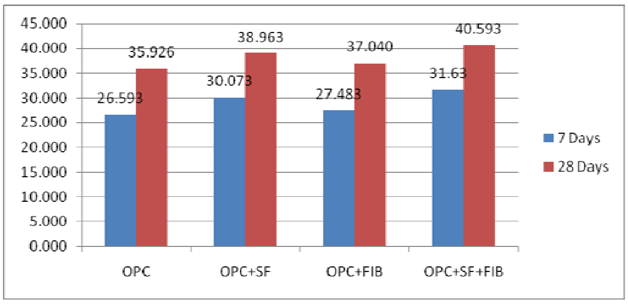

Fig. 12 Compressive Strength for Cube Specimens (in N/mm2)

D. Effect of SF and Fibre on Flexural Strength

Prisms of size 100 mm x 100 mm x 500 mm were cast using M35 grade of concrete and tested after 7days and 28 days for flexural strength of the concrete mix for the following combinations.

- OPC
- OPC+SF (replacing cement - 5% by weight)
- OPC+Polypropylene Fibre (added @ 0.6% by weight of cement).
- OPC+SF+Polypropylene Fibre

It was observed that the compressive strength is highest (40.59 N/mm2) for the cube with the combination of OPC, SF and Fibre. Fig. 12 shows the 7 days and 28 days compressive strength values of the different combinations mentioned above.

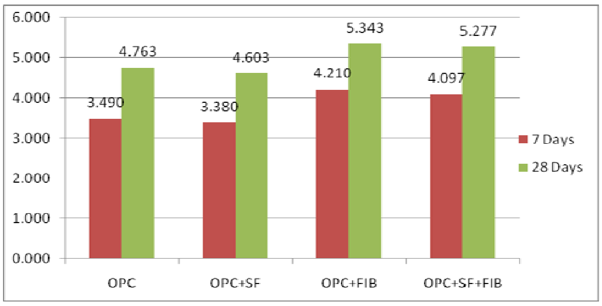

Fig.13 Flexural Strength for Prism Specimens (in N/mm^2)

IV. Conclusion

From the experimental studies, the following conclusions were drawn.

1. The rate of deterioration of concrete, under stressed condition was more than that of concrete under unstressed condition.
2. The load-induced specimens with initial cracks escalate chloride penetration and hence expedite the corrosion initiation.
3. The specimens with coated rebars showed a less weight loss than that of uncoated rebars when the specimens were subjected 15 days of accelerated corrosion process.
4. Cubes with cement partially replaced with SF by 5% and addition of Polypropylene fibre by 0.6%, showed the highest compressive strength at the age of 28 days.

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