

Protective Coatings on Concrete Surface for Corrosion Prevention of Steel

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Abstract. The presence of micro cracks, pores, voids, fissures and capillaries on the concrete surface permits the ingress of water and other aggressive species from the environment into the concrete which leads to deterioration of concrete and corrosion of embedded steel in concrete. One of the best ways to manage this durability issue is surface coatings to concrete. Coating usually covers all such defects and furnishes uniform durable surface finish. In this study, several coatings were developed by using polyvinyl acetate (PVA) as binder with some functional pigments such as Silica fume, Nano silica, Micro silica, Alumina clay, TiO₂, etc., These coatings were subjected to various durability tests such as Field exposure, Chemical exposure, Flame exposure, Chloride ion diffusion, Impressed voltage test and TAFEL extrapolation techniques and the best coatings are selected based on regress tests and analysis.

Keywords: Durability, Polyvinyl acetate, Flame test, Chloride diffusion, Nano silica, Silica fume

I. INTRODUCTION

Concrete is the major construction material used in structures all over the world [1]. Concrete acquires properties like Strength, Durability, Excellent thermal stability and Fire resistance. Therefore, concrete occupies topmost priority in Construction industry [1]. However, deterioration of concrete is the primary concern for the civil engineers [2- 4].

This deterioration may be due to the presence of various defects on concrete surface such as pores, capillaries, micro cracks, fissures, etc, that permits penetration of aggressive species into the concrete. By implementing the following suggestions, Deterioration of concrete can be greatly reduced [5]:

- Proper structural design,
- Cathodic protection (to steel reinforcement)
- Use of Corrosion inhibitors,
- Use of coatings on steel reinforcement,
- Concrete surface coatings.

Protective concrete surface coatings serve as one of the best remedies in the avoidance of concrete deterioration, in terms of its performance and cost [6]. These coatings act as a barrier and prevent the entry of aggressive medium into concrete. Thus, coatings assist insulation to concrete surface against outer environmental factors.

The migration of moisture and other agents such as Chlorides, Sulphates can cause durability issues. The common durability problems in concrete are [7]:

1. Corrosion of steel by Chlorides,
2. Carbonation,
3. Sulphate and other chemical attack,
4. Alkali-aggregate reaction,
5. Freezing and thawing damage.

In majority of cases, corrosion of steel reinforcement is a major reason for destruction of concrete structures [8]. Corrosion can be termed as 'cancer' for concrete and it also weakens the concrete due to its proneness to corrosion thereby minimizing the durability and service life of concrete.

In this study, various concrete surface coatings in combination with polyvinyl acetate (PVA) as binder were formulated and the best coatings are selected on the basis of Field exposure study, Chemical resistance and Water absorption. The best coatings are taken for anti-corrosive examinations.

II. EXPERIMENTAL PROGRAM

A. Materials and Mixture Proportions

Pozzolana Portland Cement (PPC) of grade 43, conforming to IS Standards, was used in the preparation of mortar specimens. Washed river sand, passing through 600 microns sieve having Fineness modulus of 2.48 and specific gravity of 2.63, was used as fine aggregate. Water being used in mixture was potable water (Tap water) which was free from contaminants. The specimens were prepared with a water-cement ratio of 0.40. The mortar specimens were prepared with cement to sand ratio of 1:3.

Functional materials such as Fly ash, Micro silica, Nano silica, Silica fume, Alumina clay, Bentonite, Kaolin were used in the preparation of coatings. The following chemicals were purchased from local laboratory chemicals' suppliers:

- Polyvinyl acetate,
- Aluminium oxide,
- Titanium dioxide.

B. Test Specimens

Mortar square tile specimens of 100 mm x 100 mm x 10 mm, as shown in Fig. 1, were cast to evaluate water absorption, chemical resistance and field exposure of all the coatings.

- For water absorption, each square tiles was cut into two equal tiles of size 100 mm x 50 mm x 10 mm.
- For chemical resistance, each square tiles was cut into four equal small tiles of size 50 mm x 50 mm x 10 mm.

Cylindrical mortar specimens, 83 mm in diameter and 50 mm in height, having a hollow core with 40 mm diameter and 25 mm height, as shown in Fig. 2, were cast to evaluate water absorption of all the coatings. The hollow core specimen, a new kind of sampling, was invented in CSIR-CECRI laboratory.

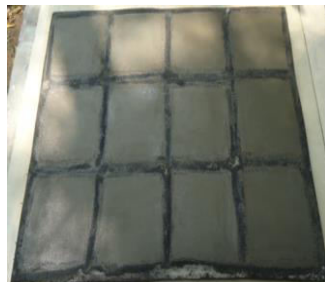


Fig. 1 Rubber mould with cast Mortar tiles



Fig. 2 Finished Hollow core Specimens



Fig. 3 Coating by Brush

Square tile specimens (100 mm x 100 mm x 10 mm) were cast by using rubber moulds. Hollow core specimens (outer – 83 mm x 50 mm and inner – 40 mm x 25 mm) were cast by using PVC pipes being inserted at the centre when the cylindrical moulds were partially filled with mortar and finally lifted after finishing.

After 24 hours of casting, the specimens were demoulded and curing was done for four weeks. Specimens were placed in the oven for 24 hours at 105 °C to push out the excessive moisture. Further, they were air dried at room temperature for 24 hours prior to coating them with surface coatings.

C. Surface Preparation

The surface of the mortar specimens were dripped with water just before applying the coatings [5]. After preparation of the surface, the coatings were applied with a brush as shown in Fig. 3 and dried for 24 hours at room temperature.

D. Coatings Used

The surface coatings were formulated by using PVA as binder with some functional pigments and their combinations are given in Table I:

TABLE I
LIST OF COMPOSITION OF COATINGS

S. No	Specimen Composition	Remarks
1	PVA + Fly Ash + Silica Fume	Brush Applied
2	PVA + OPC + Fly Ash + Silica Fume	Brush Applied
3	PVA + Kaolin + Silica Fume	Brush Applied
4	PVA + Kaolin + Fly Ash + Silica Fume	Brush Applied
5	PVA + Bentonite + Fly Ash + Silica Fume + TiO ₂	Brush Applied
6	PVA + OPC + Silica Fume + TiO ₂	Brush Applied
7	PVA + Fly Ash + Silica Fume + TiO ₂	Brush Applied
8	PVA + Kaolin + Fly Ash + Silica Fume + TiO ₂	Brush Applied
9	PVA + Al ₂ O ₃ + Fly Ash + Silica Fume + TiO ₂	Brush Applied
10	PVA + OPC + Fly Ash + Silica Fume + TiO ₂	Brush Applied
11	PVA + Al ₂ O ₃ + Kaolin + Silica Fume + TiO ₂	Brush Applied
12	PVA + Al ₂ O ₃ + Bentonite + Silica Fume + TiO ₂	Brush Applied
13	PVA + Al ₂ O ₃ + Alumina Clay + Silica Fume + TiO ₂	Brush Applied
14	PVA + Alumina Clay + Bentonite + Silica Fume + TiO ₂	Brush Applied
15	PVA + OPC + Nano Silica + TiO ₂	Brush Applied
16	PVA + Fly Ash + Nano Silica + TiO ₂	Brush Applied
17	PVA + OPC + Fly Ash + Nano Silica + TiO ₂	Brush Applied
18	PVA + Alumina Clay + Fly Ash + Nano Silica + TiO ₂	Brush Applied
19	PVA + OPC + Al ₂ O ₃ + Nano Silica + TiO ₂	Brush Applied
20	PVA + OPC + Bentonite + Fly Ash + Nano Silica	Brush Applied
21	PVA + Al ₂ O ₃ + Nano Silica + TiO ₂	Brush Applied
22	PVA + OPC + Fly Ash + Nano Silica	Brush Applied

where,

PVA – Polyvinyl acetate, OPC – Ordinary Portland Cement, TiO₂ – Titanium dioxide and Al₂O₃ – Aluminium oxide

TEST PROCEDURE

A. Field Exposure Study

The surface coatings were applied on one face (top surface) of the square tile specimens measuring 100 mm x 100 mm x 10 mm. The coated specimens were exposed to sunlight in a wooden stand and were subjected to weathering action as shown in Fig.4. The specimens were visually observed periodically and checked for defects.



Fig. 4 Field Exposed specimens

B. Chemical Resistance

Square tile specimens of 50 mm x 50 mm x 10 mm were coated on five faces (except bottom surface) with the surface coatings. The coated specimens were immersed in the following chemical solutions as shown in Fig. 5:

- 1% Hydrochloric acid solution,
- 1% Sulphuric acid solution,
- 1% Magnesium sulphate solution,
- 1% Urea solution,
- Distilled water.

The immersed specimens were visually studied periodically for signs of coating deterioration such as swelling, cracking, scaling, discoloration and crumbling of edges.

C. Water Absorption

1) *Tiles*: Half tile specimens of 100 mm x 50 mm x 10 mm were coated on all the faces and dried for 24 hours. The coated specimens were initially weighed and then immersed in a water tank as shown in Fig. 6. The increase in weight of the immersed specimens was recorded at regular intervals up to 48 hours and plotted against time. This weight increase indicates water absorption of the coated and uncoated specimens.

2) *Hollow Core*: The coatings were applied on the hollow core (40 mm ϕ x 25 mm) of cylindrical specimens (83 mm ϕ x 50 mm). The coated specimens were weighed initially and then the hollow core was poured with water as shown in

Fig. 7. The reduction in water level in the hollow core due to water absorption was noticed at regular intervals by refilling the hollow core (for every 1 hour) up to 24 hours. The water absorption percentages were obtained by correlating the recorded values and plotted against time.

III. RESULTS AND DISCUSSION

A. Field Exposure Study

After 10 days of complete exposure to weather, the coated specimens were visually examined and some observations were made. The specimens 12 and 14 turned white from light yellowish colour. Chaulking was observed in the specimens 5 and 6. Other coatings were intact.

B. Chemical Resistance

The chemical resistance of the coatings was interpreted by visual inspection of the coated specimens exposed to 1% concentration of the following chemical solutions for 10 days and some clarifications were made.

1) *HCl*: Slight Discoloration was noticed in specimens 5 and 14. Specimen 15 started slight Itching. Other coated specimens were intact.

2) *H₂SO₄*: Specimen 1 showed slight enlargement of cement particles. Specimen 5 showed more formation of blisters while specimen 15 showed blisters formation in a few locations.

3) *MgSO₄*: Formation of holidays was observed in Specimen 3. Slight formation of blisters was seen in Specimen 11. Specimen 14 started Itching.

4) *Urea*: No changes were observed during examination.

5) *Distilled water*: No leaching of materials was observed during examination.

After understanding the observations of chemical resistance, it was seen that the coating containing Bentonite and Alumina clay showed minor surface damages.

C. Water Absorption

1) *In Half Tiles*: The total increase in weight by the coated and uncoated specimens after 48 hours is shown in Table II. As expected, the uncoated specimens absorbed water at a very rapid rate and the coated specimens absorbed less water. The total water absorption in the uncoated specimen was about 9.46% by weight. The water absorption in the specimens coated with coatings using Kaolin, Bentonite and Nano silica was in the range of 1.03 – 2.37%. The specimens coated with coatings using TiO₂, Al₂O₃ and OPC absorbed in the range of 3.67 – 6.01% water. The rate of water absorption of the uncoated and coated specimens in Table II was calculated by using Eqs. (1)

$$\text{Rate of Water absorption} = \frac{(\text{Saturated weight} - \text{Dry weight})}{\text{Dry weight}} \times 100 \quad (1)$$

2) *In Hollow core*: The total quantity of water required to refill the hollow core of the coated and uncoated specimens at regular intervals is shown in Table III. As expected, the uncoated specimens required more water to get saturated while the coated specimens required less water. The uncoated specimens absorbed a high quantity of water (21 ml), at the end of 24 hours. The specimens coated with coatings using Kaolin, Bentonite and Nano silica absorbed least quantity of water in the range of 1 – 2 ml. The specimens coated with coatings using TiO_2 , Al_2O_3 and OPC absorbed more water (30 ml and 18 ml).

TABLE II
DETERMINATION OF RATE OF WATER ABSORPTION

Specimen No.	Dry Weight (in g)	Saturated Weight (in g)	Rate of Water Absorption (in %)
Uncoated	108.78	119.07	9.46
1	134.68	139.85	3.84
2	129.08	133.82	3.67
3	159.08	161.74	1.67
4	148.04	151.53	2.36
5	107.36	109.90	2.37
6	138.36	146.68	6.01
7	136.82	143.63	4.98
8	127.18	129.86	2.11
9	128.36	129.65	1.03
10	123.64	127.32	2.98
11	151.36	153.06	1.12
12	142.66	144.27	1.13
13	118.10	124.02	5.01
14	123.38	126.88	2.84
15	139.15	142.10	2.12
16	149.08	156.80	5.18
17	127.20	128.69	1.17
18	129.39	131.95	1.98
19	130.09	132.68	1.99
20	117.89	120.08	1.86
21	104.59	106.70	2.02
22	131.60	138.80	5.47



Fig. 5 Specimens immersed in different Chemical solutions



Fig. 6 Specimens immersed in Water



Fig. 7 Refilling the core

IV. CONCLUSIONS

- The coatings with Bentonite were least effective in Field exposure. All the other coatings were found to be good when exposed to 10 days of weather conditions.
- The coatings with Bentonite, Kaolin and Alumina clay were least effective in providing resistance against chemical attack. All the other coatings were relatively intact, after 10 days in 1% chemical solutions.
- The coatings with Kaolin, Bentonite and Al_2O_3 were the best in decreasing the water absorption into the mortar exhibiting low absorption rates. These specimens gained < 2% water by weight after 48 hours. The coatings with OPC showed high water absorption rates of more than 5% by weight.

TABLE III
DETERMINATION OF QUANTITY OF WATER ABSORBED

Specimen No.	Quantity of Water Poured Initially (in ml)	Quantity of Water Absorbed For Every 1 Hour (in ml)								Water Absorbed After 24 Hours (in ml)
		1 Hr	2 Hrs	3 Hrs	4 Hrs	5 Hrs	6 Hrs	7 Hrs	8 Hrs	
Uncoated	42	11	2	4	3	1	3	1	5	21
1	41	1	1		2				1	3
2	36	2			2				1	3
3	38	3			4				2	1
4	41	1			2				1	2
5	39	1			3				1	2
6	35	1			1				2	30
7	41				2				1	4
8	35	1			2				1	2
9	33	1			1				2	1
10	38	3			2				2	3
11	31	1			3				1	1
12	33	1			3				2	1
13	39				2				1	4
14	37	1			2				2	3
15	39	1			3				1	2
16	38	1			2				2	4
17	37	1			2				1	1
18	41	1			2				1	2
19	40	1							1	1
20	38	1			1				1	2
21	39				1				2	3
22	40	1			2				2	18

However, the coatings of same composition showed diverse performance in different tests. Therefore, it was concluded that the coatings 9, 11, 12 and 17 were found to be the best in common.

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