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EVALUATION OF SURFACE COATINGS FOR CONCRETE: ACCEPTANCE TESTS

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Literature suggests a number of formulations as surface coatings for concrete but the performance data on various compositions is lacking. There are no standard acceptance tests as regards concrete surface. Since the surface coating over concrete is to perform under dynamic condition it should have sufficient flexibility, adhesion coupled with impermeability and chemical resistance.

Three types of acceptance tests viz.

Cantilever precracked model slab test for flexibility and corrosion protection under load, resistivity measurements for testing impermeability and chemical resistance and adhesion test in a Monsanto Tensometer for adhesive strength have been proposed in this paper. All the tests yield quantitative data to enable us to assess the relative performance. A typical evaluation of about ten proprietory systems is also presented.

Key words : Surface coating, Cantilever loading, Resistivity, Adhesion Durability, factor.

INTRODUCTION

Concrete is permeable to water and solutions of chlorides and sulphates and such penetration of water and chemicals can bring about a gradual change in the conditions obtained at the reinforcing steel embedded in concrete leading to its corrosion [1]. Rebar embedded in concrete can be protected by several methods such as inhibitor admixtures, coating to steel and coating to concrete surface. The application of a more impermeable protective coating to prevent corrosion can be considered for both existing structures and those yet to be constructed.

The coatings should be adherent to the concrete surface, durable under the normal conditions of exposure and impermeable to water and atmospheric pollutants. During the last two decades, numerous organic and inorganic coatings have been developed for providing an improved external water proofing for concrete structures. These coatings are to be evaluated for their performance in the typical environment.

Different test methods have been used to evaluate the efficacy of a surface coating to concrete. It has been reported that the conventional salt spray cabinet exposure test does not give any indication on the durability of coatings under actual exposure [2]. Eventhough a Weatherometer can

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simulate the actual exposure conditions, it is difficult to accommodate the usual size of reinforced concrete specimens in the commercial units [3]. Considerable acceleration of reinforcement corrosion has been brought about by alternate wetting and drying test [4, 5]. About forty coating systems have been evaluated on 10×10×10 cm size R. C. C. cube specimens using an alternate wetting and drying, cycle test [6]. A temperature of 45° to 50°C for drying 10 ml of sea water per cycle for wetting and 3 cycles per eight hour working day had been used in such tests. Corrosion was found to take place within 45 days under this accelerated test. Complete rusting could be observed within 60 days. A 120 days test for coatings was recommended based on this test. A simple salt water immersion test with 10cm cube specimens has also been proposed [7]. But this test is an indirect quantitative test which characterises the coatings in terms of salt absorption. However final acceptance test was based on an alternate wetting and drying test performed on cracked R. C. C. slabs using 15% sodium chloride solution for wetting and drying at 21°C. Tests duration was about 168 days.

It is seen from ISI Hand Book 1985 [8] BSI Catalogue 1987 [9] 1985 Annual Book of ASTM Standards [10] that no standard acceptance tests for corrosion protection coatings on concrete surface (particularly for reinforced concrete) are available at present. Any surface coating on concrete meant to protect the embedded steel reinforcement from corrosion should fulfil the following requirements before acceptance.

Since the R. C. C. structures are subject to dynamic loading conditions leading to crack formation during service, the coating should have sufficient flexibility and capability to bridge over the cracks. The coating should have desired adhesion over the concrete surface and have the desired tolerance towards surface preparation. The coatings should maintain good electrical resistance to serve as an effective barrier against ingress of salts and moisture.

Keeping in view the above requirements, three different types of acceptance tests have been proposed in this paper.

i) Precracked Cantilever model slab test for testing flexibility and corrosion protection under load.

ii) Resistivity measurement using Four Probe Resistivity meter for testing impermeability and chemical resistance.

iii) Adhesive strength of the coatings on concrete surface by using Monsanto Tenso meter.

All the above tests yield quantitative data to enable us to assess the relative performance of different coating system. Ten proprietory systems were evaluated using the above test methods and the paint systems are graded.

EXPERIMENTAL

Precracked cantilever model slab test :

A notched and cantilever-loaded slab (Ref. Fig. 1) was used to produce crack of specified width parallel to the length of test specimen embedded in concrete. The slab was 900mm long, 250mm wide and 75mm thick. M20 Concrete with a water cement ratio of 0.5 was used. 6mm diameter mild steel bars were used as reinforcement in the slab. A notch was provided near the fixed end of the slab and at the other end 25mm diameter hole was provided. The purpose of the notch was to control the direction of the crack. Polished and weighed steel specimens were introduced both below the notch and at the free end of the slab. The steel reinforcement cage was derusted by pickling, rinsed in tap water and deionised water and air dried before use.

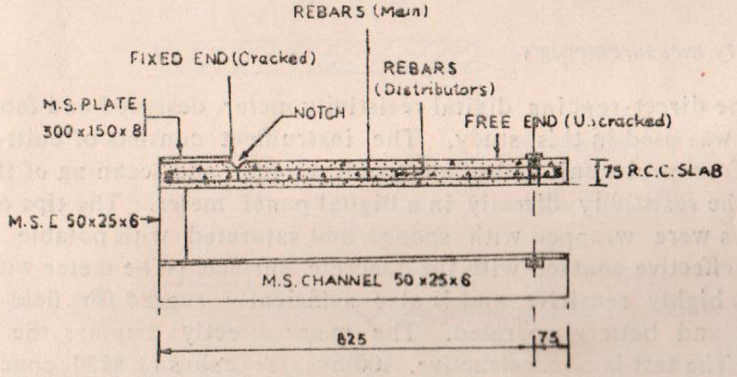

Fig. 1. Cantilever model slab

The precast slabs were cured in the distilled water for a period of 28 days. After the curing period was over, the slabs were removed from the water and their surfaces were dried by using hot air blowers. The top surface of the slab was sand blasted. The surface was then wiped with a clean dry cloth. The paint was brush applied over the sand blasted surface and allowed to cure.

The slab was fixed at one end in between two mild steel plates of 300×150×8 mm size and kept free at the other end. Using the 'Gifford Udall prestressing unit (Model Mark III, capacity 6000 Kg) the slabs were stressed and the downward deflection at the free end was gradually varied by tensioning a prestressing steel wire passing through a hole at the free end of the slab.

By this downward deflection at the free end, a single crack was formed along the root of the notch parallel to the test specimen and the width of the crack was accurately monitored by using a travelling microscope. After formation of a crack of specified width, the wedge-grips were locked in place at the end anchors and thus the downward load deflection on the slabs as well as the corresponding crack width could be permanently maintained throughout the test period.

The precracked slab along with the loading frame was taken to the exposure yard. There a 25 mm high bund was constructed along the edges of the slab using 1 : 1 cement mortar and the joints were sealed with epoxy to prevent leakage. They were then subjected to cycles of alternate wetting with 3% NaCl solution and drying. The number of days taken for the appearance of first rust spot at the notched surface was noted in each case. After the exposure period of 120 days, the slabs were broken open and the surface conditions of the rebar were visually examined. The test specimens were derusted and reweighed again and corrosion rates in mmpy, were calculated.

Resistivity measurements :

The direct-reading digital resistivity meter designed and fabricated at CECRI was used in this study. The instrument consists of built-in-spring loaded, four-probe unit and of electronic circuits and scanning of the data to display the resistivity directly in a digital panel meter. The tips of the four electrodes were wrapped with sponge and saturated with potable water, for making effective contact with the concrete surface. The meter with built-in probe is highly sensitive and is also sufficiently rugged for field use. It is portable and battery-operated. The meter directly displays the resistivity values. The test is nondestructive. 100mm size cubes of M20 concrete with water-cement ratio 0:5 were used in these studies. Curing was done in distilled water for a period of 28 days. After curing, test cubes were allowed to dry. Then all faces of the test cube were sand blasted and cleaned with dry cloth. The surface coatings were then applied to the required thickness.

The cubes were air cured for ten days and the initial resistivity was measured. During measurement the painted surface was kept dust free. After measurement, the cubes were subjected to alternate wetting in 3% NaCl Solution, and drying. At the end of 10 cycles resistivity was measured on all four vertical faces of each cube, and the values were recorded. The details of test setup is shown in Fig. 2.

Adhesion test :

A 20 KN capacity MONSANTO Tensometer was used for testing the adhesive strength of the paint over concrete surface. 50 mm diameter and 75 mm thick concrete cylindrical specimen was embedded into the concrete (MIX M20 with a water-cement ratio of 0.5) After curing the specimens for 28 days, it was taken out from water and air dried for a minimum period of 24 hours.

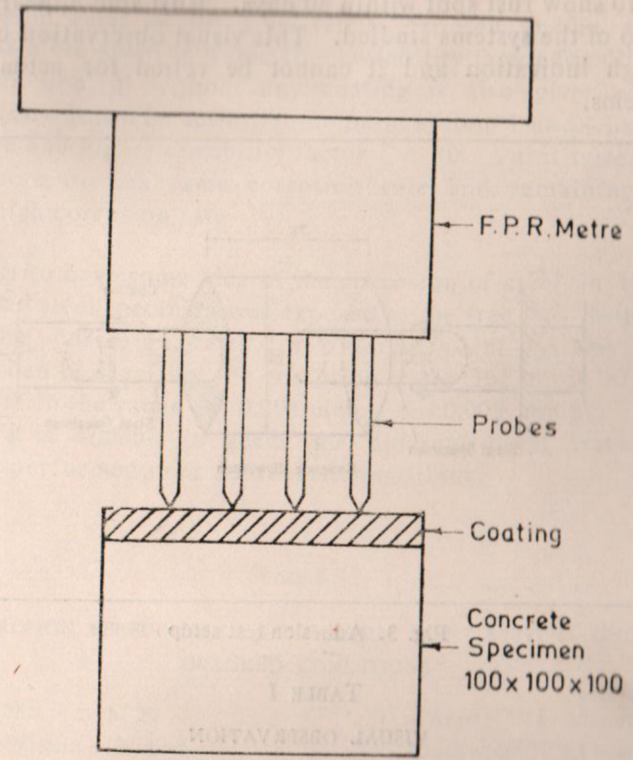

Fig. 2. Resistivity measurement

Then the flat surface of the concrete specimen was sand blasted and the dust was blown off using hot air blower. The surface was then cleaned with cloth and the specified paint system was applied with brush. Painted surface was air cured for ten days. Another 25 mm diameter and 50 mm long steel specimen was given a tack coat of araldite and then fixed to the middle portion of the painted surface of the coated concrete specimen described above. The joint was allowed to set for three days.

Then the specimen was fixed in the MANSANTO Tensometer for testing. During testing one end of the specimen was kept fixed and the other end was pulled at a rate of 1 mm/min. The maximum pulling force was recorded and adhesion strength was calculated by dividing the force by the surface area of contact (500 mm²) The test setup is shown in Fig. 3.

RESULTS AND DISCUSSION

Precracked cantilever model slab test :

Number of days taken for appearance of first rust spot at the notch for different paint systems are given in Table I. In the case of paint systems 1, 2, 3 rust spots do not appear even at 120 days. On the other hand systems 7 to 10 show rust spot within 40 days. Rust spot appear after about 90 days in two of the systems studied. This visual observation can be taken only as a rough indication and it cannot be relied for actual grading of different systems.

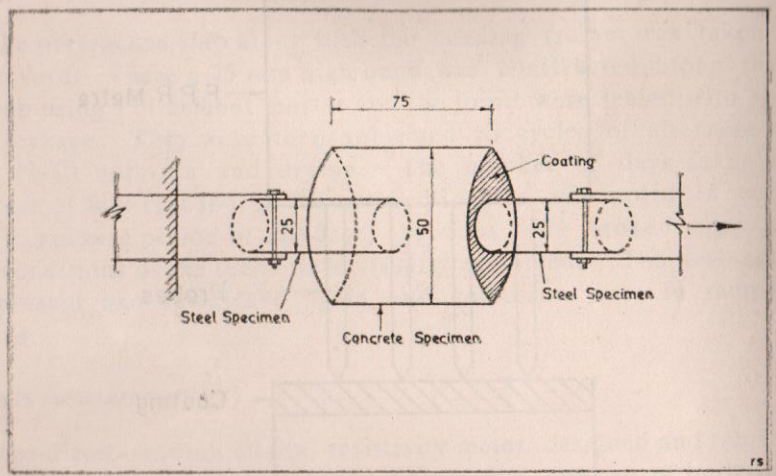

Fig. 3. Adhesion test setup

TABLE I

VISUAL OBSERVATION

Paint System	No. of days taken for first Rust Spot
Paint System 1	> 120
Paint System 2	> 120
Paint System 3	> 120
Paint System 4	92
Paint System 5	90
Paint System 6	65
Paint System 7	41
Paint System 8	37
Paint System 9	33
Paint System 10	23
Control without any coating	21

Corrosion rates of the steel rebars exposed at the cracked region below the notch are given in Table II. Durability factor for different systems compared with control without any coating is also given along with the corrosion rates. It can be seen that the paint system 1 and 4 have the lowest corrosion rate and higher durability factor i. e. 40. Paint systems 6, 3 and 2 are having more or less same corrosion rate and remaining systems are having very high corrosion rate.

In order to have some idea of the corrosion of steel in the uncracked region, weighed steel specimen was exposed at the free end with a cover of 20 mm. The corrosion rates for different paint systems are given in Table III. It can be seen that the corrosion rates for most of the systems (8 out of 10) lie in the range of 0.001 mmpy to 0.005 mmpy. This clearly indicates that it is difficult to grade the different paint systems based on corrosion test performed uner uncracked conditions.

TABLE II

CORROSION PERFORMANCE OF VARIOUS PAINT SYSTEMS UNDER CRACKED CONDITIONS

Concrete Mix : M 20 Cover : 15 mm
Exposure Period : 120 days Crackwidth : 0.1 mm

Paint System	Corrosion Rate (mmpy)	Durability Factor*
Paint System 4	0.0085	40.27
Paint System 1	0.0089	38.46
Paint System 6	0.0355	9.64
Paint System 3	0.0357	9.59
Paint System 2	0.0398	8.60
Paint System 5	0.0571	5.99
Paint System 9	0.1177	2.91
Paint System 10	0.1480	2.31
Paint System 8	0.1482	2.31
Paint System 7	0.2105	1.63
Control without coating	0.3423	1.00

* Durability factor with respect to control $= \frac{\text{Corrosion Rate without coating}}{\text{Corrosion Rate with coating}}$

TABLE III

CORROSION PERFORMANCE OF VARIOUS PAINT SYSTEMS UNDER UNCRACKED CONDITION

Concrete Mix : M 20 Cover : 20 mm
Exposure Period : 120 days

Paint Systems	Corrosion Rate (mmpy)
Paint System 6	0.0007
Paint System 1	0.0009
Paint System 5	0.0017
Paint System 3	0.0024
Paint System 10	0.0021
Paint System 8	0.0035
Paint System 7	0.0042
Paint System 4	0.0053
Paint System 2	0.0317
Paint System 9	0.0317
Control without coating	0.0464

Electrical resistivity :

Electrical resistivity values of different paint systems on coated concrete (after sufficient curing of paint film) and after 70 days of alternate wetting in 3% NaCl solution and drying are given in Table IV. It is observed that in certain cases there in considerable decrease in electrical resistivity while in certain other cases there is considerable increase in electrical resistivity after 70 days cyclic test. For four cases there is no marked difference. Excepting paint system 3, 5, 6 rest of the systems have a minimum resistivity of 20 kilo-ohm-cm at the end of 70 days of accelerated testing though mean deviation values are different. In the case of control system without coating the resistivity continuously decrease with time and attains a steadystate value of 4 $\pm$ 2 kilo-ohm-cm. Even though the minimum resistivity of coated concrete specimen is generally higher than the control there is no direct correlation between resistivity and performance of different paint systems

Adhesive strength :

The adhesive strength of different coating systems as evaluated using Mansanto Tensometer are given in Table V. It is seen that excepting the paint systems 5 and 6 all the remaining have a strength of more than 2N/mm^2. Highest values ($\approx$ 3 N/mm^2) have been obtained for paint systems 1 and 9 and paint systems 8 and 4 have 2.75 N/mm^2. Adhesive strength of paint systems 3, 2 and 7 lie in the range of 2.25 to 2.6 N/mm^2.

TABLE IV

ELECTRICAL RESISTIVITY OF THE COATED CONCRETE

Paint system	Before Test	After 70 days of alternate wetting in 3% NaCl soln. & drying
Paint System 1	77.5 ± 35.5	33 ± 16
Paint System 2	49.5 ± 28.5	50 ± 28
Paint System 3	27.5 ± 12.5	29 ± 17
Paint System 8	22.5 ± 10.5	48 ± 22
Paint System 6	22 ± 11	24 ± 13
Paint System 7	16.5 ± 11.5	57 ± 27
Paint System 9	16.5 ± 11.5	34 ± 15
Paint System 5	12.5 ± 5.5	15 ± 10
Paint System 4	12.5 ± 7.5	50 ± 29
Paint System 10	10 ± 6	47 ± 19
Control without coating	30 ± 9	4 ± 2

TABLE V

ADHESIVE STRENGTH OF COATINGS

Paint System	Adhesive Strength N/mm^2
Paint System 9	3.32 ± 0.15
Paint System 10	2.76 ± 0.10
Paint System 8	2.74 ± 0.43
Paint System 7	2.61 ± 0.57
Paint System 1	2.56 ± 0.40
Paint System 3	2.51 ± 0.20
Paint System 2	2.40 ± 0.87
Paint System 4	2.20 ± 0.15
Paint System 6	1.59 ± 0.04
Paint System 5	1.40 ± 0.17

Cost-benefit ratio :

The ultimate deciding factor for grading paint systems economically is the coat-benefit ratio. Based on the surface coverage the cost of each system per square meter was calculated. Ratio between the durability factor and unit cost was taken as cost-benefit ratio Cost Benefit Ratio for different paint systems are given in Table VI. Paint systems 4 & 1 appear most economical. Paint system 2 comes next.

TABLE VI

COST-BENEFIT RATIO FOR DIFFERENT COATINGS

Paint System**	Durability Factor 'D'	Cost/m² 'C' *	Cost-Benefit Ratio D/C
Paint System 4	40.27	65	0.619
Paint System 1	38.46	81	0.475
Paint System 2	8.60	90	0.096
Paint System 7	1.63	71	0.023
Paint System 10	2.31	154	0.015

* Subject to variation with time.

** Due to non-availability of cost not possible to workout cost-benefit ratio for remaining paint system.

CONCLUSIONS

1 It is shown that the efficacy of different surface coatings for concrete can be effectively and quantitatively assessed by conducting the alternate wetting with 3% NaCl solution and drying of reinforced concrete model slabs under cracked condition using the precracked cantilever loading system described in this paper.

2 It is also shown that secondary tests such as electrical resistivity measurements and adhesion tests are also required to be performed before accepting a system.

3 Cost-Benefit Ratio is the ultimate deciding factor.

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DISCUSSION

P. K. Sinha, International Metalizing and Engineering Co., Calcutta

Q : How to ensure from the resistivity measurements testing that the coating is completely chemically resistance?

A : Electrical resistance is only one of the parameters which can be continuously monitored and which can indicate the relative performance of different paint systems on concrete. A continuous fall in the resistance with time of testing may indicate deterioration. However the actual performance of the coating is evaluated from cantilever model load test.

K. Mani, Structural Engineering Research Institute, Madras

Q : Is it not necessary to evaluate the fatigue life of these coatings ?

A : Fatigue life of the coating is yet another parameter which may also be considered.

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