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Research Paper

Anti-Corrosive Steel Rebar Coating Using Polyurethane and Latex

Engineering

KEYWORDS : Corrosion; Polyurethane; Latex; Coatings; Durability

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ABSTRACT

Corrosion is the significant factor of affecting the reinforced concrete structure's durability. The main concern of this work is towards anti-corrosive coating to steel components such as plates and rods. Two types of binders such as Polyurethane (water soluble, single carbonate system) and Latex was used for effective anticorrosive coating. To evaluate the performance of coating, various mechanical and chemical tests such as flexibility, bendability, abrasion and adhesive test were carried out. The results were analysed focussing on corrosion resistance of the best coatings.

Introduction

Reinforced concrete structures have the potential to develop high strength and durability. They are increasingly applied in various infrastructures and in different environments. However the premature failure of structures and the failure of aged structures due to reinforcement corrosion have become a matter increasing concern [1]. Reinforcement corrosion, popularly known as "steel cancer" is generally caused by carbonation or the free chloride ingress. These are the main reasons attacking the durability and strength of reinforced concrete structures. Concrete alkalinity is mainly due to the presence of calcium hydroxide, potassium hydroxide and sodium hydroxide. The pH of concrete lies between 12 and 13. This high pH of concrete results in the formation and maintenance of passive film (oxide layer) on the surface of the reinforcing steel. As long as this passive film is intact, the rate of corrosion is low. If the oxide layer is broken, oxygen can react with steel ultimately leading to corrosion. Hence steel rebars are passivated by the oxide film that protects steel. The oxide film itself is a product of initial corrosion of the steel rebar. In order for corrosion to occur, the steel rebar has to be depassivated. In the presence of an aggressive ion like the chloride ion, the passive film is destroyed and a process of localised corrosion is initiated. Otherwise in the presence of carbondioxide, carbonation of the concrete is possible by the reaction of atmospheric CO_2 with cement paste which lowers pH thereby causing corrosion [2].

It is important that this problem of reinforcement corrosion is addressed, in order to preserve the reliability and high performance of the reinforced concrete structures. A lot of protective techniques are adopted recently in an attempt to lessen or eliminate the detrimental effects of corrosion. For instance, the partial replacement of cement with fly ash reduces corrosion by decreasing penetration of harmful ions into concrete. The use of super plasticizers and mineral admixtures like fly ash, granulated blast furnace slag and pozzolanic materials also reduce corrosion rate [3, 4].

In this paper, "Anti-corrosive steel rebar coating" is attempted as an approach towards reducing reinforcement corrosion [5-7]. Two types of materials namely Polyurethane and Latex were chosen as binders which are less polluted material to the environment. 33 types of coatings were prepared, compared and tested for best performance. The attempt in this work is to observe the corrosion resistance behaviour of these anti-corrosive coatings in addition to evaluate the corrosion resistance of these coatings and recognize the best coatings in that regard.

Materials and Methods

Materials used

For the corrosion study, water soluble polyurethane (product of Asian paint) and water proofing latex purchased from madurai were used as binders. The functional filler materials such as fly ash, OPC, Feldspar, China Clay, Kaolin, Micro silica, Clay were purchased locally. The chemical components like Al_2O_3, TiO_2, $Zn_3(PO_4)_2$, Fe_2O_3, Silica Fume were procured from Himeda company which are LR grade. The steel plate of size 100mm × 150 × 0.8mm, 100mm × 100mm × 0.8mm, 100mm × 75mm × 0.2mm and 100mm × 20mm × 0.8mm were used. One feet length of 8mm, 10mm and 16mm Fe 415 HYSD bars were used as testing specimens.

Test specimens

The Steel plate specimens 100mm × 75mm × 0.2mm and 100mm × 20mm × 0.8mm were utilized to evaluate the flexibility, Bend ability & adhesion capacity of the steel coating shown in fig 1. The steel plate 100mm × 150 × 0.8mm and steel rebars were used to evaluate the corrosion resistance capacity in the marine environment.The steel plate & rebars were cleaned and remove the corrosion by using the pickling solution (Clerk's solution) shown in fig 2. Following the cleaning, steel & rebars were washed two times in tap water shown in fig. 3.

Fig. 1 Test specimens before pickling

Fig. 2 Pickling process

Fig. 3 After pickling

Coatings used

The different types of coating system are as follows in the table 1. After the surface preparation the coatings were applied on the surface of the specimen twice by using the brush is shown in fig. 4 and 5

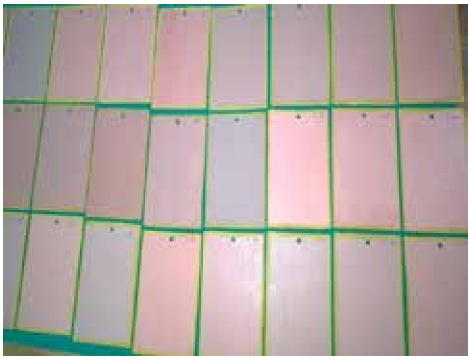

Fig. 4 Coated plates

Fig. 5 Coated rods

Testing

Dry Film Thickness Test (ASTM D1186)

The coated plate was measured by Elektrophysik exacto. The surface coatings were applied on the steel plate 100mm x 100mm x 75mm size. The coated plates were kept in oven at 60ºC for 3 hours. The elektrophysik exacto instrument shown in fig. 6 was kept over the coated plate when measuring the thickness of coating. The dry film thickness of coating was measured in various places on the plate and average value of thickness was taken. The average thickness of each coating is shown in table 4.

Bendability Test

The coated steel plate of size 100mm × 20mm × 0.8mm was made to bend to 45°, 90° and 180° and it was observed for the crack formation at stress concentration area. The bended coated plates are shown in fig. 7 and 8

Fig. 6 Measuring coating thickness

Fig. 7 Coated plates bent to 90°

Fig. 8 Coated plates bent to 180°

Table 1 Composition of Different Coating Systems

Coating No.	Materials used
1	Polyurethane (PU) + Fly Ash + Al_2O_3 + TiO_2 + Fe_2O_3 + Silica Fume
2	PU + Fly Ash + Common
3	PU + Clay + Common
4	PU + Microsilica + Common
5	PU + Kaolin + Common
6	PU + Chinaclay + Common
7	PU + Feldspar + Common
8	PU + Feldspar + Microsilica + Common
9	PU + Fly Ash + Microsilica + Common
10	PU + Fly Ash + Feldspar+ Microsilica + Common
11	PU + Fly Ash + Chinaclay + Common
12	PU + Microsilica + Chinaclay + Common
13	PU + Chinaclay + Feldspar + Common
14	PU + Microsilica + Clay + Common
15	Latex + Fly Ash + Common
16	Latex + OPC + Common
17	Latex + Clay + Common
18**	PU + Fly Ash + Microsilica + Common
19	Latex + Microsilica + Common
20	Latex + Kaolin + Common
21	Latex + Chinaclay + Common
22	Latex + Feldspar + Common
23	Latex + Feldspar + Microsilica + Common
24	Latex + Fly Ash + OPC + Common
25	Latex + Fly Ash + Microsilica + Common
26	Latex + Microsilica + Clay + Common
27	Latex + Fly Ash + Chinaclay + Common
28	Latex + Chinaclay + Microsilica + Common
29	Latex + Chinaclay + Feldspar + Common
30	Latex + Fly Ash + Feldspar + Microsilica + Common
31**	Latex + Fly Ash + Microsilica + Common
32	Latex + OPC + Microsilica + Common
33	Latex + OPC + Chinaclay + Common
* Common = Al_2O_3 + TiO_2 + $Zn_3(PO_4)_2$ + Fe_2O_3 + Silica Fume ** Twice the amount of Silica Fume	

Hardness Test (ASTM D3363)

Hardness is the resistance to scratching or indentation. Measurement of film hardness by pencil test is a rapid and inexpensive method, normally adopted for organic coatings using pencils ranging from softer to harder (6B to 6H). This test was carried out on all thirty three coatings as per the procedure given in ASTM D3363 and results are adopted in table 4.

Abrasion Test

The coated steel plate 100mm × 100mm × 0.8mm was used for abrasion test. The dry coated plate weight was measured and 10 times the coated plate was scribed by using E4 320 emery sheet shown in fig. 9 and 10. After the abrasion, the plate weight was taken to determine the weight loss and thickness loss of the coating is shown in table 4.

Flexibility Test (ASTM D522)

The Flexibility test was done by conical mandrel bend test apparatus as per ASTM D522 standards. The thin plate of 100mm x 75mm x 0.2mm was used in this test. Fig. 11 illustrated the structure of mandrel conical apparatus; one end of the apparatus is 3mm diameter to gradually increasing up to 38mm diameter at the end of 200mm length. The plates were fixed in the conical mandrel Bend apparatus, and tighten the wing nuts using rolled handle. The thin plate was bending up to 180° in a single step. Cracks were observed from 3mm Φtoward higher end of the cracks in plate. The wing nuts were loosening to taken out the bent plate. The cracks were measured and the results are shown in table 4.

Film Adhesive Test

The coated steel plate 100mm x 75mm x 0.2mm was used for measuring the adhesive strength of the coating film on the metal substrate. The instrument used for measuring adhesive strength was "Tensometer", which is electrically operated and is so designed that the tensional force can be applied perpendicular to the coated surface, when the coated specimen was held vertically. This test was conducted on all thirty three coatings and results are reported in table 4.

Fig. 9 Scraped by emery sheet

Fig. 10 Weight measured after abrasion

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Fig. 11 Conical mandrel apparatus

Environmental Exposure Study (ASTM D 1654)

The environmental exposure study that can be used for evaluate the rate corrosion occurred in the surface area. Before exposure study, one side of the coated plate scribed as other side is left unscribed and all sides are dipped in the wax because the reason for resist the corrosion in edges shown in fig. 12 and 13. After that the coated specimens were exposed to environment in such a way of hanging in a rope. All the coated specimens have under gone extreme climates condition like raining, windy, summer etc. Everyday three times sodium chloride solution was sprayed on the coated to create seashore atmosphere for 400 hours. The exposure specimens are shown in fig. 14.

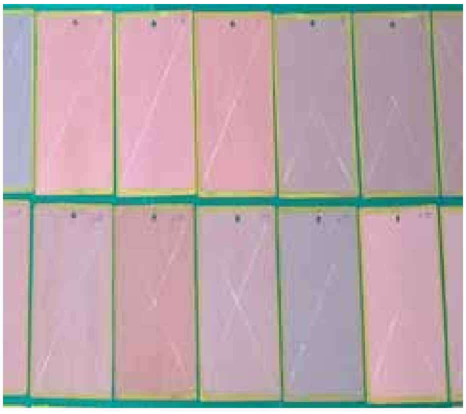

Fig. 12 Scribed specimens

Fig. 13 Unscribed specimens

Fig. 14 Salt spray spray

Evaluation of scribed specimens (ASTM D 1654)

This method describes the evaluating basic corrosion performance in the scribed plates as per ASTM D1654. Scribing tools is carbide – tipped pencil type tool is recommended. Prepare each specimen for testing by scribing it in such a manner that the scribe has be exposed lengthwise when positioned in the test cabinet. Scribe the specimen by holding the tool at approximately a 45^0 angle to the surface. Position the tool so that only the carbide tip is in contact with the surface. Pull the scribing to obtain a uniform V – cut through the coating that is being tested the scribed specimens shown in fig. 15. Rate of corrosion or loss of coating extending from a scribe mark as prescribed in table 2. Record the representative mean, maximum, and minimum creepage from the scribe shown in fig. 16 and note the creep values in millimeters or rating number.

Fig. 15 Before exposure study

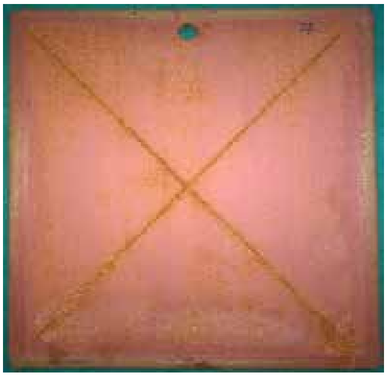

Fig. 16 After exposure study

Evaluation of Unscribed Specimens (ASTM D 1654)
Evaluate unscribed specimens for corrosion spots, blisters and other type of failure that may occur shown in fig. 17 and 18. Record percent failed area or convert percent failure to rating numbers in accordance with table 3.

Fig. 17 Before exposure study

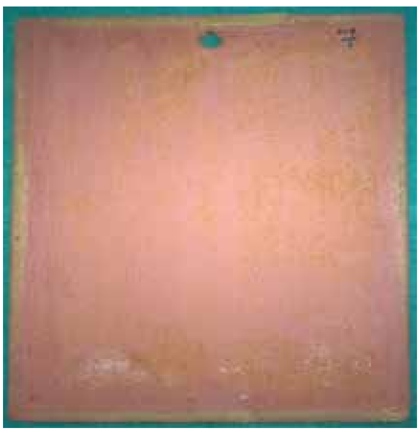

Fig. 18 After exposure study

Table 2 Rating of Failure at Scribe

Creepage (mm)	Rating Number
Zero	10
Over 0 to 0.5	9
Over 0.5 to 1	8
Over 1 to 2	7
Over 2 to 3	6
Over 3 to 5	5
Over 5 to 7	4
Over 7 to 10	3
Over 10 to 13	2
Over 13 to 16	1
Over 16 to more	0

Table 3 Rating of Unscribed Areas

Area Failed %	Rating Number
Zero	10
Over 0 to 0.5	9
Over 0.5 to 1	8
Over 1 to 2	7
Over 2 to 3	6
Over 3 to 5	5
Over 5 to 7	4
Over 7 to 10	3
Over 10 to 13	2
Over 13 to 16	1
Over 16 to more	0

Results and Discussion
The Table 1 shows the combination of the mixes for coating, total coatings are evaluated for corrosion protection of steel in aggressive medium. It compasses on thirty three coatings with polyurethane and latex as a binder. Following the results used to evaluate its corrosion protection in normal and aggressive environments. Physical and Mechanical test results are shown in Table 4. Bendability, flexibility and hardness test remarks are shown in table 6. From the experimental results in environmental exposure study, the latex coating exposed the good corrosion resistance to the steel rebar. By adding micro silica gives good bonding which will prevent the corrosion of steel rebar's. However the Anti-corrosive coating contain chemical bonding because of OH group in binders and also good mechanical bonding due to its steel uneven surface and fine filler materials in coating produce good anchorage with steel rebars.

Dry Film Thickness Test
Various thickness of coating measured thickness using measuring gauge on coated specimens. The average thicknesses are shown in table 4. The thickness of coatings was measured in microns. Polyurethane showed lesser thickness than latex.

Bendability Test
This test was done on thirty three anti corrosive coatings, no cracks are found at the stress concentration area and the results are shown in table 4.

Hardness Test
This test was carried out on all thirty three coatings as per the procedure given in ASTM D3363 and results are adopted in table 4. Capacity of hardness is good for all coatings.

Abrasion Test
In this test, the weight loss and coating thickness loss due to abrasion is determined and the results are shown in table 4. Weight and thickness loss of latex coating showed lesser value compared to polyurethane coating.

Flexibility Test
The Flexibility test was done by conical mandrel bend test apparatus as per ASTM D522 standards. There is no crack formation and the results are shown in table 4.

Film Adhesive Test
The adhesive strength of the coating is evaluated for all coatings and the results are shown in table 4.

Evaluation of scribed and unscribed specimens
The creepage and area failed for coated steel plate is measured as per the ASTM D 1654 and the results are shown in table 5. Coatings 2, 14, L19 and L32 showed good result in corrosion resistance.

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Table 4 Test Results

SI. No.	Specimen ID	Coating Dry Film Thickness (μ)	Adhesive Strength (N/mm²)	Hardness Test (6H)	Bendability	Flexibility	Abrasion Loss	
							Coating Thickness (μ)	Weight (mg)
1	1	77	8.21	P	P	P	21	20
2	2	79	8.32	P	P	P	14	30
3	3	67	7.11	P	P	P	21	30
4	4	99	7.31	P	P	P	35	40
5	5	83	6.67	P	P	P	30	30
6	6	91	6.46	P	P	P	27	30
7	7	79	7.12	P	P	P	10	20
8	8	88	6.18	P	P	P	31	50
9	9	62	5.96	P	P	P	12	20
10	10	104	5.84	P	P	P	32	30
11	11	86	6.63	P	P	P	21	20
12	12	84	6.83	P	P	P	18	40
13	13	84	6.73	P	P	P	32	50
14	14	97	8.69	P	P	P	35	50
15	L15	90	8.11	P	P	P	31	10
16	L16	110	7.92	P	P	P	40	20
17	L17	138	8.33	P	P	P	41	10
18	PU18	113	7.82	P	P	P	59	20
19	L19	191	8.74	P	P	P	95	20
20	L20	96	7.98	P	P	P	29	20
21	L21	93	8.01	P	P	P	30	10
22	L22	84	8.31	P	P	P	27	10
23	L23	88	7.33	P	P	P	20	20
24	L24	105	7.41	P	P	P	37	10
25	L25	125	7.69	P	P	P	39	10
26	L26	155	8.14	P	P	P	48	30
27	L27	129	7.66	P	P	P	52	10
28	L28	92	7.43	P	P	P	29	20
29	L29	87	7.14	P	P	P	25	20
30	L30	84	7.63	P	P	P	37	10
31	L31	57	7.54	P	P	P	8	10
32	L32	136	8.94	P	P	P	35	30
33	L33	92	7.32	P	P	P	36	20

Table 5 Evaluation of Scribed and Unsribed Specimens

SI. No.	Specimen ID	Scribed Panel		Unscribed Panel		**Remarks**
		Creepage (mm)	Rating No.	Area Failed %	Rating No.	
1	1	15	1	30	3	-
2	2	1	8	40	3	Corrosion Resistance
3	3	5	5	70	1	-
4	4	1	8	60	1	-
5	5	1	8	40	3	-
6	6	8	3	35	3	-
7	7	1.5	7	25	4	-
8	8	5	5	35	3	-
9	9	4	5	75	0	-
10	10	3	6	45	2	-
11	11	7	4	20	5	-
12	12	3	6	2	8	-
13	13	9	3	65	1	-
14	14	1	8	20	5	Corrosion Resistance
15	L15	2	7	25	4	-
16	L16	1	8	2	8	-
17	L17	1	8	4	7	-
18	PU18	1	8	55	1	-
19	L19	1	8	8	6	Corrosion Resistance
20	L20	2	7	40	3	-
21	L21	5	5	15	5	-
22	L22	5	5	30	4	-
23	L23	1	8	15	5	-
24	L24	4.5	5	1	9	-
25	L25	1	8	10	6	-
26	L26	1	8	1.5	9	-
27	L27	4	5	75	1	-
28	L28	1	8	25	4	-
29	L29	4	5	90	0	-
30	L30	1	8	35	3	-
31	L31	1	8	95	0	
32	L32	2.5	6	1.5	9	Corrosion Resistance
33	L33	1.5	7	12	5	-

Conclusion

On the basis of results presented in this paper, the following conclusions have been drawn

- The anti-corrosive coating is the best corrosion protection; eco-friendly coating it does not pollute the environment.
- Polymer based polyurethane and latex applied on steels provide a very effective protection against corrosion as a result of the combination of excellent adhesion to metal substrates and barrier properties.
- From all the above test results, coatings 2, 14, L19 and L32 are the success full anti-corrosive coating. The other coatings need some improvements for good anti-corrosive coating.

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