Studies on the evaluation of the performance of organic coatings used for the prevention of corrosion of steel rebars in concrete structures

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ABSTRACT

Corrosion of steel rebars in reinforced concrete constructions, particularly those located in marine environments and industrially polluted areas is one of the major problems baffling the construction industry all over the world including India. A suitable protective coating to rebar is found to improve the durability of such structures under aggressive exposures. The performance of a few polymeric coatings based on different resins such as acrylic polyol-aromatic isocyanate, polyester polyol-aromatic isocyanate, acrylic resin and epoxy–silicone–polyamide containing ordinary Portland cement or flyash as extenders and titanium dioxide and zinc phosphate as main pigments on rebar in concrete has been evaluated using mechanical strength tests and accelerated corrosion tests. It is observed that, of the 16 coating formulations, four have been found to perform well as effective and durable coatings.

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1. Introduction

Now a day the durability performance of concrete structures has been causing great concern among researchers and designers all over the world. Among several degradation processes of reinforced concrete, the corrosion of steel reinforcements is of much greater importance. Embedded steel in concrete gets corroded through two reactions which are environmentally related, such as carbonation of concrete and chloride diffusion in concrete. The presence of moisture in the atmosphere also plays an important role in both the cases. Under normal environmental conditions, steel reinforcements in concrete do not corrode, due to the high alkalinity of concrete around steel bars [1]. When the depth of carbonation of concrete reaches the reinforcement level, pH of concrete surrounding the steel is lowered and the corrosion of steel is initiated. In the case of chloride diffusion, when diffused chlorides accumulated at the reinforcement level to a threshold limit, corrosion of steel is initiated by destroying the passive film formed over the steel surface. Such a situation can be obviated to some extent by

 (i) improving the quality of concrete [2] and increasing its cover thickness,
 (ii) providing a protective coating on the surface of concrete [3],
(iii) using corrosion inhibitors [4],
(iv) implementing cathodic protection of the surface [5] and,

(v) protecting the steel reinforcement in concrete [6].

Among the protective measures, giving a durable and adhesive coating to the rebar is considered as a most feasible and cost-effective option from technical and economical reasons. Three types of materials such as metallic coatings, inorganic coatings and organic (polymeric) coatings are available for coating the steel reinforcement. Organic coatings are generally adopted in most part of the world owing to their simplicity in application, flexibility, toughness, adhesion, chemical resistance and their durability. A stable organic coating serves as a barrier for isolating steel from moisture, chlorides and oxygen. Among different organic coatings such as coal tar epoxy, asphalt, chlorinated rubber, vinyl and epoxy coatings, the protection of rebar by epoxy coatings is the most prevalent [7,8]. Acrylic latex coatings have been found to greatly bring down the corrosion rate of steel bars in concrete [4]. Shreekant Patil and Shenoy [9] have examined the utility of polyurethane coatings for the corrosion protection of reinforced rebars in concrete structures and found that these coatings offer good protection. Agarwal et al. [10] have developed epoxy phenolic interpenetrating polymer network (IPN) system to protect steel reinforcement in concrete from corrosion and found that this system offers excellent protection. Manjrekar et al. [11] have observed that polymer–cement–inhibitor (PCI) coating on steel provided an effective impermeable barrier as well as an effective passivating environment for embedded steel bars. Kumar et al. [12] have developed a phenol polymer coating for steel rebars embedded in concrete and found that this coating provides an excellent protection to steel rebars in chloride environments.

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In the present study, 16 different polymeric coating compositions have been prepared using four different resins such as acrylic polyol-aromatic isocyanate, polyester polyol-aromatic isocyanate, acrylic resin and epoxy–silicone–polyamide. These formulations consist of either ordinary Portland cement (OPC) or flyash as the extender pigment and titanium dioxide and/or zinc phosphate as main pigments. All these coatings have been examined for their mechanical properties, and their durability and effectiveness as rebar coatings by accelerated corrosion test.

2. Experimental details

2.1. Materials used

Ordinary Portland cement	Conforming to IS: 8112, 43 grade, "Dalmia" brand
Graded fine aggregate	Screened river sand with fineness modulus equal to 2.6 conforming to grading zone III of IS: 383, 1970
Graded coarse aggregate	Well-graded blue granite passing through 12 mm sieve and retained in 4.75 mm sieve with a fineness modulus of 6.72 was used
Flyash used for coating	Procured from Neyveli lignite corporation, Neyveli, Tamilnadu and sieved through 50 μ sieve.
Silica fume used for coatings	Procured from M/s. Krishna ConChem Products Pvt. Ltd., Mumbai, India
Steel panels used	Cold rolled mild steel plates of size 50 mm × 75 mm were used for salt spray, adhesion and hardness tests. Panels of size 100 mm × 150 mm were used for flexibility and impact resistance tests. Panels of size 100 mm × 100 mm were used for abrasion resistance measurements
Steel rebars used	Cold twisted deformed bars of 8 mm, 10 mm, 12 mm and 16 mm diameter were used
Chemicals used	NaCl, NaOH, CaCl$_2$, SnCl$_2$, Sb$_2$O$_3$ and HCl were of AR grade. All solutions were prepared using double distilled water

All experiments were carried out at an ambient temperature of $32 \pm 1\,^\circ$C.

Resins used:

(a) Acrylic polyol (GP bond 141),
(b) Polyester polyol (TACO POL-C-1),
(c) Aromatic isocyanate (TACO BOND P-1-75).

Above resins were procured from M/s. Grand Polycoats, Vadodara, Gujarat, India.

(d) Silicone resin procured from M/s. Metroarck Pvt. Ltd., Kolkotta, India.
(e) Polyamide (SYNPOL 115), procured from M/s. Synthetic Polymers Pvt. Ltd., Ahmedabad.
(f) Epoxy (Araldite) was prepared from M/s. Ciba Geigy Hindustan Ltd., Mumbai.

Above resins were characterised using gel permeation chromatography system supplied by M/s. Shimadzu Corporation, Tokyo, Japan and results are given in Table 1.

Table 1
Values of molecular weigh (M_w) and dispersity index obtained from gel permeation chromatography

Resin	Molecular weight (M_w)	Dispersity index
Acrylic polyol	18,443	2.52
Polyester polyol	4,664	1.79
Acrylic resin	4,017	13.0
Epoxy	784	1.02
Silicone	5,294	1.85
Polyamide	1,627	1.09
Aromatic isocyanate	1,319	5.68

Table 2
Nomenclature for coating systems

No.	Coating system	Composition
1	System A1	Resin: acrylic polyl + aromatic isocyanate Pigment: anatase TiO$_2$, Zn$_3$(PO$_4$)$_2$ and OPC
2	System A2	Resin: acrylic polyl + aromatic isocyanate Pigment: anatase TiO$_2$, Zn$_3$(PO$_4$)$_2$ and flyash
3	System A3	Resin: acrylic polyl + aromatic isocyanate Pigment: Zn$_3$(PO$_4$)$_2$ and OPC
4	System A4	Resin: acrylic polyl + aromatic isocyanate Pigment: Zn$_3$(PO$_4$)$_2$ and flyash
5	System B1	Resin: polyester polyl + aromatic isocyanate Pigment: Anatase TiO$_2$, Zn$_3$(PO$_4$)$_2$ and OPC
6	System B2	Resin: polyester polyl + aromatic isocyanate Pigment: anatase TiO$_2$, Zn$_3$(PO$_4$)$_2$ and flyash
7	System B3	Resin: polyester polyl + aromatic isocyanate Pigment: Zn$_3$(PO$_4$)$_2$ and OPC
8	System B4	Resin: polyester polyl + aromatic isocyanate Pigment: Zn$_3$(PO$_4$)$_2$ and flyash
9	System C1	Resin: acrylic resin Pigment: anatase TiO$_2$, Zn$_3$(PO$_4$)$_2$ and OPC
10	System C2	Resin: acrylic resin Pigment: anatase TiO$_2$, Zn$_3$(PO$_4$)$_2$ and flyash
11	System C3	Resin: acrylic resin Pigment: Zn$_3$(PO$_4$)$_2$ and OPC
12	System C4	Resin: acrylic resin Pigment: Zn$_3$(PO$_4$)$_2$ and flyash
13	System D1	Resin: epoxy, silicone, polyamide Pigment: anatase TiO$_2$, Zn$_3$(PO$_4$)$_2$ and OPC
14	System D2	Resin: epoxy, silicone, polyamide Pigment: anatase TiO$_2$, Zn$_3$(PO$_4$)$_2$ and flyash
15	System D3	Resin: epoxy, silicone, polyamide Pigment: Zn$_3$(PO$_4$)$_2$ and OPC
16	System D4	Resin: epoxy, silicone, polyamide Pigment: Zn$_3$(PO$_4$)$_2$ and flyash

2.2. Preparation of mild steel panels and rods

Mild steel panels and rebars of required sizes and free from all types of imperfections were cleaned using Clarkes solution, rinsed well using running water, degreased thoroughly using trichloroethylene and finally dried.

2.3. Preparation of coating formulations

Resins used in this study were selected in view of the fact that they are known to offer better mechanical and barrier properties. Zinc phosphate was used as the main pigment in all formulations, but titanium dioxide was used in some formulations. Ordinary Portland cement or flyash were used as extender pigments. Pigment volume concentration (PVC), for all coatings were kept as 40%, volume of the solid was kept as 60% and that of solvent was kept as 40% with an idea of decreasing the gloss and increasing the surface roughness of coating, thereby the bond strength between the steel rebar and concrete. Table 2 gives coating formulations for all the 16 coatings used in the present study.

2.4. Procedure

2.4.1. Determination of mechanical properties of coatings

After pickling and degreasing, formulated coatings were applied in two coats using a brush, so as to have a uniform film thickness and then allowed to cure for a week in the laboratory environment.

Table 3
Values of coating thickness and adhesive strength of different coatings

Coating system	Coating designation	Average dry film thickness (μm)	Adhesive strength of the coating	
			Load at failure (KN)	Stress at failure (KN)
Acrylic polyol-aromatic isocyanate (two-pack system)	A1	95 ± 5	8.793	18.27
	A2	95 ± 5	8.772	17.86
	A3	95 ± 5	8.614	17.54
	A4	95 ± 5	8.917	18.16
Polyester polyol-aromatic isocyanate (two-pack system)	B1	95 ± 5	8.992	18.31
	B2	95 ± 5	9.147	18.63
	B3	95 ± 5	8.961	18.25
	B4	95 ± 5	9.102	18.53
Acrylic resin (single-pack system)	C1	95 ± 5	8.762	17.84
	C2	95 ± 5	8.914	18.15
	C3	95 ± 5	8.432	17.17
	C4	95 ± 5	8.991	18.31
Epoxy–silicone–polyamide (two-pack system)	D1	95 ± 5	10.748	21.89
	D2	95 ± 5	10.899	22.19
	D3	95 ± 5	10.789	21.97
	D4	95 ± 5	10.910	22.22

Different mechanical properties of these coating were determined using different techniques.

2.4.1.1. Measurement of thickness and adhesive strength of coatings. Dry film thickness (dft) of all coatings were measured using magnetic thickness gauge meter. The adhesive strength of all coatings on the metal substrate was also measured using tensometer. Results are given in Table 3.

2.4.1.2. Flexibility test. This test which enables the measurement of resistance to cracking (flexibility) was carried out on all coated specimens as per ASTM D522 standard using a conical mandrel and results are given in Table 4.

2.4.1.3. Impact resistance test. Impact resistance of all coatings coated on panels to impact load was measured as per ASTM D2794 and results are given in Table 4.

2.4.1.4. Salt spray (Fog) test. Salt spray (Fog) test which is an accelerated corrosion test was carried out on all coated steel panels of size 50 mm × 75 mm with and without diagonal scribes on coated

panels as per ASTM B117 standard in a salt spray chamber. Results are given in Table 5.

2.4.1.5. Electrochemical impedance spectroscopy. Electrochemical impedance measurements were carried out as described earlier [13] using all coated samples with exposed surface area of 1 cm^2 and using 3% NaCl as the electrolyte. Bode plots were obtained for different durations such as 1 h, 24 h, 168 h, 360 h and 720 h. Values of film resistance or charge transfer resistance (R_t) were obtained from the equivalent circuit model for the metal/solution interface for all coatings and results are given in Table 6.

3. Results

3.1. Gel permeation chromatography

Table 1 gives values of molecular weight and dispersity index for different resins used in this study for preparing different coating formulations. Resins of low molecular weight such as epoxy, polyamide, acrylic resin, polyester polyol and silicone give very low values of dispersion index equal to 1 or slightly more than 1. But aromatic isocyanide gives a very high value of disper-

Table 4
Results of flexibility and impact tests

Coating system	Coating designation	Flexibility test as per ASTM D522	Impact test as per ASTM D2794 (weight 1.8 kg and height of fall 1.2 m)
Acrylic polyol-aromatic isocyanate (two-pack system)	A1	Passed (3 mm)	Passed
	A2	Passed (3 mm)	Passed
	A3	Passed (3 mm)	Passed
	A4	Passed (3 mm)	Passed
Polyester polyol-aromatic isocyanate (two-pack system)	B1	Passed (3 mm)	Passed
	B2	Passed (3 mm)	Passed
	B3	Passed (3 mm)	Passed
	B4	Passed (3 mm)	Passed
Acrylic resin (single-pack system)	C1	Passed (6 mm)	Passed
	C2	Passed (3 mm)	Passed
	C3	Passed (6 mm)	Passed
	C4	Passed (3 mm)	Passed
Epoxy silicone-polyamide (two-pack system)	D1	Passed (3 mm)	Passed
	D2	Passed (3 mm)	Passed
	D3	Passed (3 mm)	Passed
	D4	Passed (3 mm)	Passed

Table 5
Results of coated specimens exposed in salt spray (Fog) test chamber for 720 h

Coating composition	Rating of failure (ASTM D1654)				Degree of blistering (ASTM D714)
	Scribed		Unscribed		
	Rating number	Creepage (mm)	Rating number	Percentage of area corroded	
A1	9	0.5	9	1	Few small clusters blister size no. 8
A2	7	2.0	7	6	Few small clusters blister size no. 6
A3	7	2.0	6	10	Few small clusters blister size no. 4
A4	9	0.5	3	40	Few small clusters blister size no. 8
B1	5	4.0	6	8	Few small clusters blister size no. 8
B2	9	0.5	8	2	Few small clusters blister size no. 8
B3	6	3.0	6	4	Few small clusters blister size no. 4
B4	7	2.0	9	0.5	Few small clusters blister size no. 8
C1	4	5.0	6	10	Few small clusters blister size no. 8
C2	6	3.0	6	10	Few small clusters blister size no. 8
C3	6	3.0	8	2	Few small clusters blister size no. 8
C4	7	2.0	8	2	Few small clusters blister size no. 8
D1	4	7.0	6	8	Few small clusters blister size no. 8
D2	8	1.0	9	1	Few small clusters blister size no. 8
D3	5	4.0	9	1	Few small clusters blister size no. 8
D4	9	0.5	9	1	Few small clusters blister size no. 8

Medium used duration of the experiment.

sion index, inspite of the fact that it is a low molecular weight resin.

3.2. Measurement of thickness of different coatings and their strength of adhesion to the metal substrate

It is found from Table 3 that all coatings have a uniform thickness of $95 \pm 5\,\mu$m. It can be seen from the table that epoxy–silicone–polyamide coatings give a better adhesion to the metal substrate than all other coatings. It is also found that the single-pack system namely acrylic resin gives lower values of adhesive strength. Polyester polyol-aromatic isocyanate coating give better adhesion than acrylic polyol-aromatic isocyanate coating.

3.3. Measurement of flexibility and impact resistance of coatings

Table 4 gives results of flexibility and impact tests conducted on all coatings. It can be seen that acrylic resin coatings C1 and C3 failed at 3 mm diameter of the cone, but passed at 6 mm diameter cone.

Table 6
Capacitance (C_c) and charge transfer resistance (R_t) values for different coating evaluation from Bode plots

Coating designation	Charge transfer resistance (R_t) $\Omega\,cm^2$	Coating capacitance (C_c) $F\,cm^{-2}$
A1	1.93×10^6	3.12×10^{-10}
A2	1.12×10^4	1.66×10^{-9}
A3	0.31×10^4	1.03×10^{-9}
A4	2.11×10^3	1.33×10^{-8}
B1	3.84×10^6	7.16×10^{-10}
B2	6.47×10^6	6.13×10^{-11}
B3	2.13×10^5	9.41×10^{-9}
B4	7.12×10^5	2.19×10^{-9}
C1	4.67×10^4	3.22×10^{-8}
C2	1.21×10^4	3.94×10^{-8}
C3	6.14×10^4	4.41×10^{-8}
C4	2.87×10^4	4.18×10^{-8}
D1	2.80×10^7	4.3×10^{-11}
D2	6.83×10^6	2.17×10^{-10}
D3	8.76×0^5	7.02×10^{-9}
D4	6.44×10^7	3.33×10^{-11}

Duration of the experiment: 30 days.

All other coatings exhibited very good flexibility. All the coatings passed the impact test.

3.4. Salt spray (Fog test)

Table 5 gives the results of salt spray test carried out using all coated panels, both scribed and unscribed for a duration of 720 h. It can be seen from this table that epoxy–silicone–polyamide coating (D1–D4) give better performance than other three resin coating systems. Among these coatings, D4 and D2 with less creepage at scribes and less percentage of area corroded at unscribed panels are found to be most effective and serve as good coatings. Even though acrylic polyol + aromatic isocyanate resin coatings (A1–A4), show better corrosion creepage resistance at scribes, but unscribed panels show more areas in the range of 1–40% corroded. Among these coatings, coating A1 with better creepage at scribes and less corroded areas in unscribed panels show better performance. Next comes in the order of performance, polyester polyol + aromatic isocyanate coating (B1–B4). Among these coatings, coating B2 with less creepage (0.5 mm) and with a rating of 9 shows better performance.

Acrylic resin coating (C1–C4) with more creepage at scribes and considerably less rating do not perform as good coatings. Moreover, they show more area corroded in unscribed panels. It can be seen from results obtained in this study that only four out of sixteen coatings such as A1, B2, D2 and D4 have required qualities for good and durable coatings.

3.5. Electrochemical impedance spectroscopy

Bode plots were obtained for all the coatings and values charge transfer resistance or film resistance (R_t) and coating capacitance (C_c) obtained from the equivalent circuit model for all the coated metal/solution interfaces for a period of 30 days and given in Table 6. It has been observed from studies at different durations that values of R_t increases with time and reaches a steady value on 30th day. A quite opposite trend has been observed in the case of C_c value for the corresponding time interval. Coatings having R_t values of $10^6\,\Omega\,cm^2$ and more have been proved to be most effective rebar coatings. On this basis, coatings such as A1, B2, D1, D2 and D4 have been found to be durable and effective.

4. Discussion

4.1. Gel permeation chromatography

It is found from Table 1 that resins of low-molecular weight such as epoxy and polyamide have values of dispersity index equal to 1.017 and 1.094, respectively. These resins have good elastic modulus and abrasion resistance [14]. This uniform dispersity of resin molecules gives lower stress corrosion cracking sensitivity and better chemical resistance to coatings [15,16]. Even though aromatic isocyanate has a lesser value of molecular weight than polyamide, it gives a very high value of dispersity index. So this resin has lesser chemical resistance compared to polyamide and epoxy resins. Resins of high-molecular weight such as acrylic polyol, polyester polyol, silicone and acrylic resin have dispersity index more than 1. This fact shows that these resins are branched polymers having higher viscosity and lower elastic modulus. They have lesser chemical resistance than epoxy and polyamide resins.

4.2. Thickness and adhesion strength of coatings

It can be seen from Table 2 that maximum adhesive strength is exhibited by epoxy–silicone–polyamide resin followed by polyester polyol-aromatic isocyanate systems, acrylic polyol-aromatic isocyanate and acrylic resin in the decreasing order. Excellent adhesion provided by epoxy–silicone/polyamide system and polyester polyol resin-based coatings can be attributed to the presence of polar groups such as OH and NH_2 which favour more adhesion of the coating on the metal substrate. It can also be due to the presence of ether groups along the chain which can provide for interactions both with the steel surface and other molecules in the coating. The backbone of the resin consists of alternating flexible 1–3 glycidyl ether and rigid bisphenol A groups. Such a combination can provide flexibility necessary to permit multiple adsorption of hydroxyl groups on the steel substrate [17]. In addition to this, the presence of zinc phosphate in the coating provides improved drying and adhesion of coating to the steel substrate [14]. Zinc phosphate reacts with the steel surface and forms a tightly adherent corrosion resistant layer at the coating/metal substrate interface [18]. In acrylic formulation no polar groups are present and hence the adhesion can be due to van der Waals interactions [19].

4.3. Flexibility and impact resistance of coatings

Results of conical mandrel flexibility test conducted on all the coatings as shown in Table 4, bring out the fact that acrylic resin coatings C1 and C3 failed at 3 mm diameter of the cone and passed at 6 mm diameter. All other coatings have been found to possess good flexibility characteristics. The failure of acrylic resin coatings can be attributed to the formation of large free volumes, microvoids and stress concentration created during the film formation and curing as the solvent evaporates [20–22]. Large free volume in the dry film brings down the flexibility of the film [23,24]. Acrylic coating which is hard and glossy has more tendency to break than reform [25]. Polyester polyol-aromatic isocyanate and acrylic polyol/-aromatic isocyanate resins exhibit good flexibility due to cross-linking by isocyanate group. Linear and difunctional polyol chain can give more flexibility to the film [14].

Results of the impact test carried out on all coatings indicate that all the coatings have passed the impact test. It is difficult to predict the impact resistance of a coating from characteristics of resins and pigments, because the visco-elastic behaviour of coating, on impact produces complicated stress–strain profile at an extremely short time [26,27].

4.4. Salt spray (Fog) test

It can be seen from Table 6 that epoxy–silicone/polyamide coatings perform better than acrylic polyol-aromatic isocyanate coatings and polyester polyol-aromatic isocyanate coatings. Acrylic coatings showed very poor performance. Epoxy–silicone–polyamide coatings showed good performance, because amide linkage present in it restricts the ingress of cations through the coating film [28]. In this coating, the modification of epoxy by silicone is accomplished by reacting methoxy groups of methoxy polysilicone intermediate with secondary hydroxyl group in the epoxy resin. In this case OH group on epoxy resin is used rather than epoxide group [29]. Epoxy groups on the molecule are not affected and the resulting silicone-modified epoxy resin is cured by polyamide curing agent. The resulting resin film is highly water and chemical resistant and shows good performance. Moderate performance of coatings such as acrylic polyol-aromatic isocyanate and polyester polyol-aromatic isocyanate can be attributed to their tendency to absorb very small amount of water from the environment and create a strong hydrogen bonding with water, which in turn decreases interchain hydrogen bonding. This results in plasticization of the coating. It is also confirmed that polyurethane linkage based on aromatic isocyanate are more vulnerable to moisture absorption than those based on aliphatic. Ester linkages in these coatings is vulnerable to hydrogen. The poor performance of acrylic coatings in the salt spray tests can be attributed to their poor adhesive strength and poor resistivity of the coating. The poor barrier properties of many acrylic resins are generally related to their insufficiency in complete coalescence rather than their low-molecular weight [30]. Polyester polyol resin systems have more resistance to oxygen transmission than water transmission.

Studies using salt spray test bring out the fact that only four out of sixteen coatings gave good performance and their performance can be rated as

D4 > A1 > B2 > D2

4.5. Electrochemical impedance spectroscopy

Bode plots were obtained for all coatings for different durations ranging from 1 h to 720 h and values of charge transfer resistance (R_t) and coating capacitance (C_c) were obtained for all the coating from these plots. It is found that R_t values decrease from initial (1 h) values upto a duration of 24 h and then increase and become steady at the end of 360 h. No further increase in R_t values are noticed till the end of 720 h. Initial decrease in R_t values can be attributed to the uptake of electrolyte through capillaries and microspores present in the coating. On the contrary there is a sharp increase in coating capacitance values during this small interval. This can be ascribed to the reorientation in the mode of distribution of water within the coating film. Increase in R_t values can be attributed to the formation of a passive layer on the metal substrate in contact with the coating. Water permeates through the coating and reacts with the zinc phosphate present in the coating and results in the formation of phosphate passive layer over the steel substrate [14,31,32]. In addition to this, the formation of a complex salt in combination with the phosphate pigment component occurs, which then reacts with corrosion products yielding finally a layer which strongly adheres to the metal substrate [33]. The complex salt formation plugs capillaries and pores present in the coating film and results in an increase of R_t values with time till it becomes steady at the end of 360 h.

Table 6 gives steady values of charge transfer resistance or film resistance (R_t) and double layer capacitance (C_c) obtained at the end

of 720 h for all coatings. It has been reported by Skerry and Eden [34] that coatings having R_t values of $10^6\,\Omega\,cm^2$ and more continue to protect the mild steel substrate from aggressive chloride ions. It is found from the table that only coatings such as A1, B2, D1, D2 and D4 show values equal to $10^6\,\Omega\,cm^2$ or greater than $10^6\,\Omega\,cm^2$. Based on the values of film resistance (R_t) the performance of coatings can be rated as

D4 > D1 > B2 > D2 > A1

A thorough examination of all coating systems using different mechanical tests, accelerated corrosion tests and electrochemical impedance spectroscopy brings out the fact that only four coatings A1, B2, D2 and D4 have performed well in all the tests. These coatings possess all good qualities required for a good rebar coating such as good adhesion, non-porosity, chemical resistance and corrosion resistance. Their performance can be rated as

D4 > A1 > B2 > D2

5. Conclusion

A systematic evaluation of the performance of four different coating systems involving 16 different coatings using mechanical tests and accelerated tests clearly brings out following main conclusions:

(i) Coatings based on a two-pack system such as epoxy–silicone–polyamide resins perform better than other three resin systems used.
(ii) A single-pack system such as acrylic resin, cannot be used as a good rebar coating.
(iii) Other two-pack systems such as acrylic polyol-aromatic isocyanate and polyester polyol-aromatic isocyanate show a moderate performance as rebar coatings.
(iv) Coatings with good adhesion can be obtained even on pickled steel surface.
(v) Among coatings used in this study only four coatings such as A1, B2, D2 and D4 are found to perform well and their performance can be rated as

D4 > A1 > B2 > D2

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