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Research Article

Influence of nano-modification on mechanical and durability properties of cement polymer anticorrosive coating

Shoib Bashir Wani [a,*], Junaid Ahmed [a], M. S. Haji Sheik Mohammed [a], Tahir Hussain Muntazari [b], Nusrat Rafique [c]

[a] *Department of Civil Engineering, B. S. Abdur Rahman University, Vandalur, Chennai 600048, India*
[b] *Department of Civil Engineering, National Institute of Technology Srinagar, J&K 190006, India*
[c] *Department of Geography & Regional Development, University of Kashmir, J&K 190006, India*

ABSTRACT

In the present study performance evaluation of nano-modified cement polymer anticorrosive coating (CPAC) was undertaken by conducting the Chemical Resistance Test (CRT), Applied Voltage Test (AVT), Bond Strength Test (BST), Accelerated Corrosion Test (ACT) and Coating Flexibility Test (CFT). The site oriented coating comprises of nitrite, styrene-butadiene polymer and other additives. The anticorrosive polymer solution is compatible with concrete or cement when uniformly mixed with fresh ordinary portland cement (OPC). Totally forty-five specimens were subjected to various performance evaluation tests. In CRT observations were made on drilled and undrilled specimens after 45 days test period in liquid and vapour phase. The coating did not blister, soften and lose bond in all the tested medium during CRT and meet the requirement of BIS 13620-1993 and ASTM A775/A775M.The coating has the ability to withstand the electrochemical stresses during one-hour AVT. In the BST, single and double coated rebars showed +126.96% and +46.08% greater usable bond strength respectively than uncoated rebar. In the ACT, there is a significant escalation in time of cracking of specimens of double-coated reinforced rebars by 2 times as compared to uncoated rebars. Cracking time for single coated reinforced rebars was found 1.6 times more than uncoated rebars. In the CFT, coating completely in the inner and the outer radius of the 180° bend rebar fails to meet the requirements of BIS and ASTM standards. Thus the coating has to be applied subsequent to cutting and rebar twisting is finished.

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1. Introduction

The durability problem of concrete structures reinforced with high yield strength deformed (HYSD) rebars is worldwide. Many concrete structures deteriorate prematurely, and repair and maintenance costs amount to substantial proportions of public and private sector budgets. Vishnu et al. (2012) commented as: “In reinforced concrete (RCC), the tensile strength of steel and the compressive strength of concrete work together to allow the member to sustain the stresses over considerable spans. However, failures in concrete structures do still occur as a result of premature reinforcement corrosion”. Neville (1987) suggest reasons for “durability problems as poor understanding of deterioration processes, inadequate acceptance criteria of site concrete, and changes in cement properties and construction practices. Nevertheless, the greatest threat to durability of concrete structures is undoubtedly corrosion of embedded reinforcing steel, leading to cracking, staining, and spalling of the cover concrete. This, in turn, can lead to unserviceable structures that may be compromised in respect of safety, stability, and aesthetics”. Alekseev et al. (1990) commented on the above scenario as “the durability of reinforcement

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* *Corresponding author.* Tel.: +91-962-223-8788 ; E-mail address: shoibbwani@gmail.com (S. B. Wani)

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specimens with a stepped (deformed) profile may be roughly an order less than that of smooth specimens since the former have stress concentrators on the surface at the bases of projections, which represent sites of preferential formation of cracks". According to the 2005 report from the Ministry of Shipping, India loses Rs 2,500 crores annually due to corrosion which will be more as of present time.

Gidion Turu'allo (2006) stated that when steel reinforcement is encased in sound dense concrete, the entire surface of the steel is covered by a stable protective oxide film that forms an alkaline environment created by the hydration of the cement in the concrete. Under these circumstances, no corrosion of the reinforcement can occur. However, if the protective oxide film is locally destroyed, for example by the introduction of chloride ions, areas of different potential can be set up on its surface. This difference in potential can result in electrochemical corrosion cells forming between areas on the reinforcement where the protective film has been destroyed and the remainder of the surface where the film is still intact. Such cells create minute electric currents which flow through the reinforcement in one direction and return through the concrete by electrolytic conduction. The areas where the electrons leave the reinforcement to enter the concrete are called anodes and they corroded, whereas the areas where the current re-enters the reinforcement do not corrode and are called cathodes. Corrosion takes place at the anode with metal ions going into solution (refer Eq. (1)).

$$Fe \rightarrow Fe^{++} + 2e^{-} \qquad (1)$$

The cathode simply provides the mechanism for the removal of electrons left in the reinforcement by the corrosion process (refer Eq. (2)). Fig. 1 shows the schematic representation of the basic process of corrosion of steel in concrete.

$$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \qquad (2)$$

Since corrosion is the reaction of a metal with its environment, control can be achieved either through modifications in the metal or the environment. The economy is the overriding factor and for this reason, cheaper and less corrosion-resistant materials are often preferred. Numerous measures have been taken to prevent corrosion of the embedded steel in concrete. In the present study performance evaluation of nano-modified CPAC was undertaken by conducting various mechanical and durability tests. The nano-modification was done by Titanium dioxide (TiO_2).

Fig. 2 shows the scanning electron microscope (SEM) images of the coating.

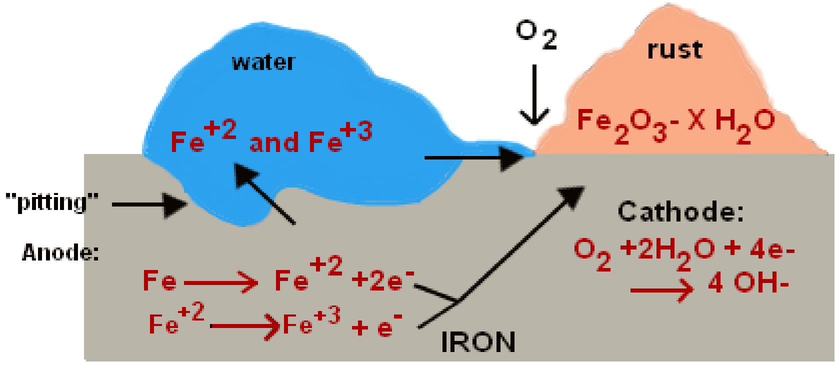


Fig. 1. Schematic representation of process of corrosion of steel in concrete.

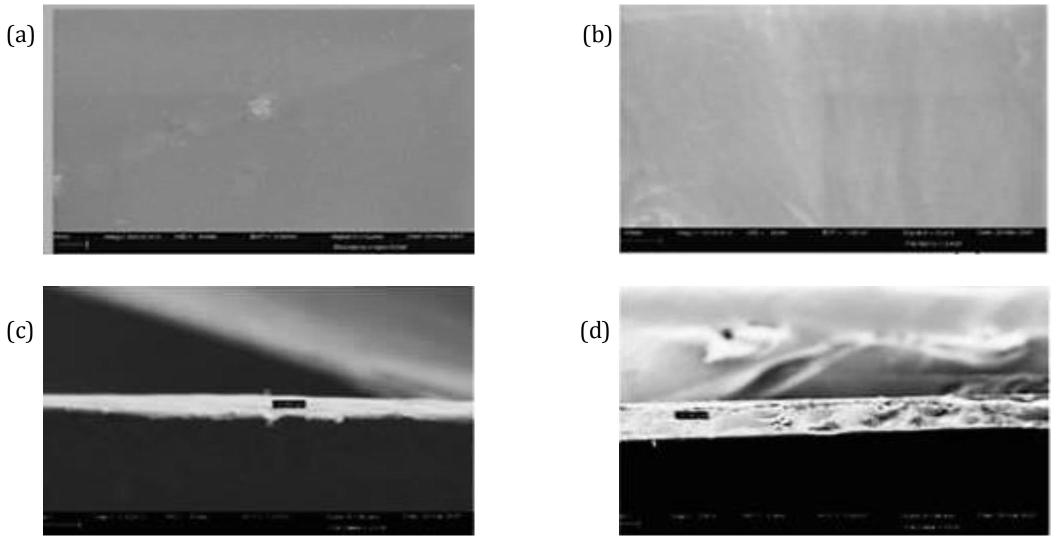


Fig. 2. SEM images of a) Plain CPAC; b) TiO_2 modified CPAC; c) Cross-sectional view of 1coat coating; d) Cross-sectional view of 2-coat coating. All images have a magnification level of approximately 100,000 times.

2. Materials and Material Properties

The materials used for the experimental study include 53 grade OPC approved by BIS 12269 (1987), 20 mm downgraded coarse aggregate (CA), locally available river sand as fine aggregate (FA) of zone II as specified in BIS 383 (1970), potable water, commercially available 12 mm and 16 mm HYSD rebars of grade Fe-500 conforming to BIS 1786 (2008) and nano-modified CPAC.

The basic properties of the cement such as specific gravity, consistency, initial setting time and final setting were found as per BIS 4031-Part 2 and 5 (1988) and the properties of aggregates were found in accordance to BIS 2386-Part 3 (1963). The basic properties of cement, FA and CA obtained and standard values are tabulated in Table 1.

Based on the above material properties, the mix design ratio for M 25 concrete grade was formulated as per BIS 10262 (2009) as shown in Table 2.

The mould, mixing and curing of specimens conform to the requirements as specified in BIS 516 (1959). The average 28 days compressive strength for M25 grade of concrete was recorded as 34.85 MPa. The calculated target mean strength was 31.6 MPa. Therefore the obtained mix design ratio was well within the standard.

Table 1. Properties of cement, fine aggregate and coarse aggregate.

Description	Obtained Value	BIS Recommended Range
Consistency	27 %	> 25%
Initial setting	Minutes	> 30 minutes
Final setting	5 hours and 30 minutes	< 60 hours
Cement - Specific gravity	3.10	-
Fine aggregate - Fineness Modulus	3.05	2.9-3.2
Fine aggregate - Specific Gravity	2.53	2.4-2.6
Coarse aggregate - Fineness Modulus	7.4	6.5 – 7.5
Coarse aggregate - Specific Gravity	2.79	-

Table 2. Design mix proportions for 1m^3 of concrete.

Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (litre/m^3)
340	643.54	1136.41	186
1	1.89	3.34	0.5

Formulated mix ratio was 1: 1.89: 3.34 and estimated w/c ratio was 0.5.

2.1. Development of nano-modified cement polymer anticorrosive coating system

The nano-modified CPAC on the rebars was applied following BIS 13620 (1993) guidelines. “The site oriented cement polymer anticorrosive coating (passivating type) comprises of nitrite, styrene-butadiene polymer and other additives” as stated by Sheik et al. (2014). The polymer solution is milky white in colour, pH around 12.50 and a density of 1.03 g/cc. This anticorrosive polymer solution is compatible with concrete or cement paste when uniformly mixed with fresh OPC.

The process involves the removal of rust and scales from the steel rebars by hard wire brush and application of coatings by brushing (Shanmugapriya et al., 2015). The nano-modified CPAC was prepared by incorporating 5 gram of Nano Titanium Dioxide (Nano TiO_2) in 1 litre of CPAC. Fig. 3 shows the sequence of the coating process and Fig. 4 shows the view of coated rebars.

3. Experimental Investigation

To evaluate the protective coating on reinforcement rebars, the following criteria were taken into account (Gunaselvi et al., 2015):

- The protective coating should have excellent corrosion-resisting properties.
- The coating should not affect the bond strength of steel to concrete.
- The coating shall withstand the handling stress at the site.

The tests conducted to evaluate the performance of protective coating systems are as under:

- Chemical Resistance Test.
- 2V Applied Voltage Test.
- Bond Strength Test.
- Accelerated Corrosion Test.
- Coating Flexibility Test.

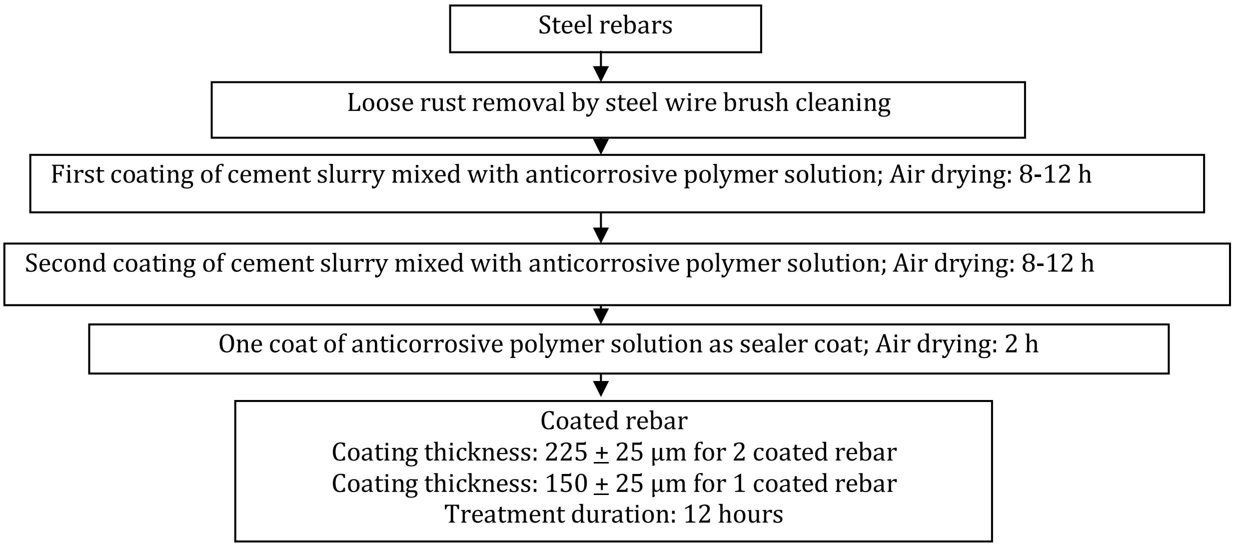


Fig. 3. A sequence of nano-modified cement polymer anticorrosive coating process.

Fig. 4. View of nano-modified cement polymer anticorrosive coated rebars.

3.1. Chemical resistance test

This test was conducted for evaluating the resistance of the coating materials when exposed to various concentrations of reagents. This test was done as per ASTM A775/A775M (1995) and BIS 13620 (1993). Four specimens in CPAC and twelve specimens in Nano TiO_2 modified CPAC were tested. Also, four specimens of Nano TiO_2 modified CPAC with 6mm holidays were tested. In total 20 specimens were tested. The specimens were tested in distilled water, 3M aqueous solution of $CaCl_2$, 3M aqueous solution of NaOH and saturated $Ca(OH)_2$.

Coated rebars of 12 mm diameter and 200 mm length were used. Specimens were positioned vertically in a container and the reagents filled in such a way that the liquid level covers one half of the coated portion. A rubber cork was provided at the bottleneck to prevent the evaporation of the reagents and contamination. Fig. 5 shows the schematic diagram of the chemical resistance test setup.

The test was continued for 45 days at room temperature. After the testing period, the performance of the coating was evaluated based on the blistering, softening, bond loss and development of holes on the rebar surface.

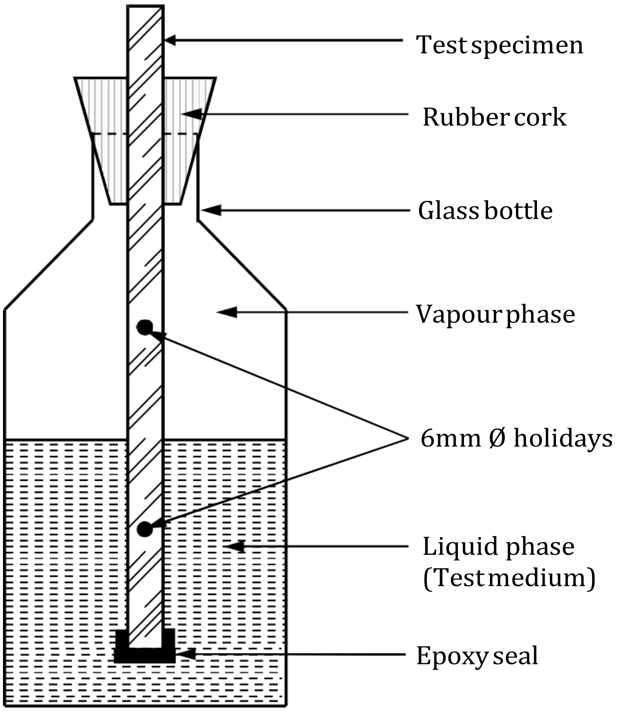


Fig. 5. Schematic view of chemical resistance test setup.

3.2. Applied voltage test

The effects of electrochemical stresses on the bond of coating to steel and film integrity of the coating were assessed by conducting AVT. This is an accelerated type of corrosion test carried out as per BIS 13620 (1993). By varying the thickness of Nano TiO_2 modified CPAC by 2 coats, 3 coats and 4 coats, a total of three specimens were subjected to the test. Coated rebars of 16 mm diameter and 600 mm length have been used.

In the test setup, two numbers of coated rebars, one acts as a cathode and other acts as an anode. Copper wires of 14 mm gauge were clipped at one end of each rebar. The other end of the rebars were sealed with M-seal and coated with an insulation varnish up to a length of 25 mm. The exposed coating surface area on which the test was conducted was restricted to less than 232 cm^2. The remaining exposed area has to be applied with an insulating varnish. A non-conductive plastic container of size 150 mm x 150 mm x 620 mm was used for the test. The container was filled with 7% sodium chloride (70g/lit) solution up to a height of 580 mm. The coated rebars were suspended vertically to have a clearance of 25 mm from the bottom, 40 mm from the sides and 40 mm between the rods. A potential of 2V was impressed for a period 60 minutes between the coated rebars. Fig. 6 shows the schematic diagram of applied voltage test setup.

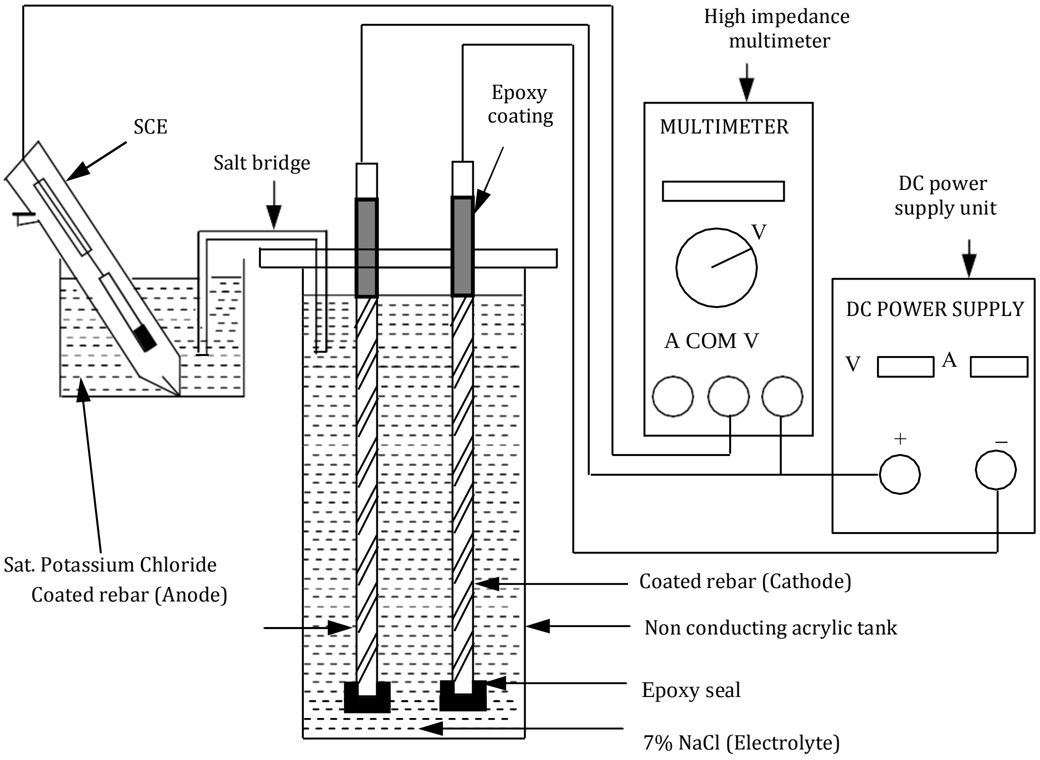


Fig. 6. Schematic view of applied voltage test setup.

A saturated calomel electrode (SCE) with saturated potassium chloride as electrolyte and salt bridge made of agar-agar was used for measuring reference electrode potential. The potential measurements of SCE were observed at every 5 minutes interval during the test period using high impedance multimeter. The current development was also monitored at regular intervals to observe the evaluation of hydrogen gas at the cathode during the test. After the completion of the test, corrosion products of iron at the anode were observed and noted.

3.3. Bond strength

This test has been conducted to find the influence of the protective coating on the bond strength of reinforcement with concrete. Pull out tests were carried out on coated rebars with varying coating thickness and also on uncoated rebars as per BIS 2770 Part I (1997) considering the modifications outlined in BIS 1786 (2008). The test results were compared following BIS 13620 Annexure A-5 (1993).

Totally nine specimens were subjected to the test. Three specimens in control and three specimens each in single and double coated Nano TiO_2 modified CPAC. Concrete cubes of size 150 mm×150 mm ×150 mm were cast with 16 mm diameter HYSD rebars (both coated and uncoated) provided up to 20 mm from the bottom face of the cube. The rebar extended over the top face of the cube by sufficient length to facilitate gripping in the UTM. As per BIS 2770 (1997) and BIS 516 (1959), a helical of 6mm diameter, MS rebar conforming to Grade I of BIS 432 Part I (1982) at 25 mm pitch was provided as reinforcement. To avoid the bond near the loaded end, a plastic sleeve of length 70 mm was provided on the rebar in each specimen. Test specimens were immersed in a curing tank for 28 days. Fig. 7 shows the placement of reinforcement inside the mould.

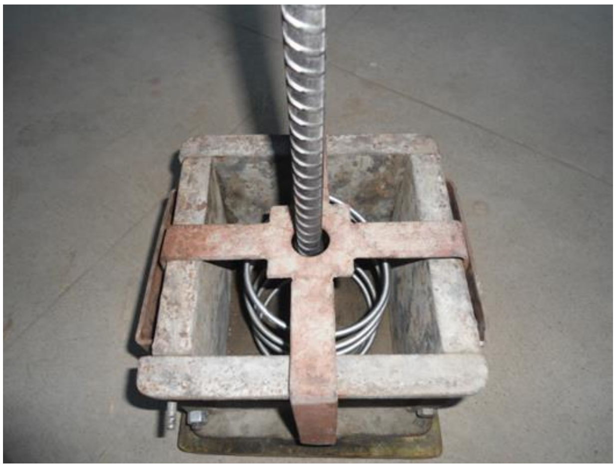


Fig. 7. Placement of reinforcement inside the mould.

The specimens were capped with Plaster of Paris on the loaded end face to obtain a good levelling surface. The load was calibrated with centre hole load cell of 500 kN (Model: ELC-30S) which was placed beneath the loaded end face of concrete cube specimen.

Fig. 8 shows the schematic diagram of the pull-out test setup. Sophisticated dial gauge with a least count of 0.0025 mm was used to measure free end slip and a dial gauge with 0.025mm least count was used to measure loaded end slip. The observation parameters for performance evaluation includes load at 0.025mm free end slip, ultimate failure load, load - slip behaviour at the free end and loaded end and failure mode cum pattern. The load value obtained from 0.025 mm free end slip was used to calculate usable bond strength. Eq. (3) is recommended to calculate bond stresses.

$$u = F/\pi\, dr\, lr \tag{3}$$

where F is the force in rebar, dr is the diameter and lr is the bond length of the rebar. Since the test specimen was provided with helical spring reinforcement, failure pattern was pull-out of rebar instead of a concrete failure by splitting.

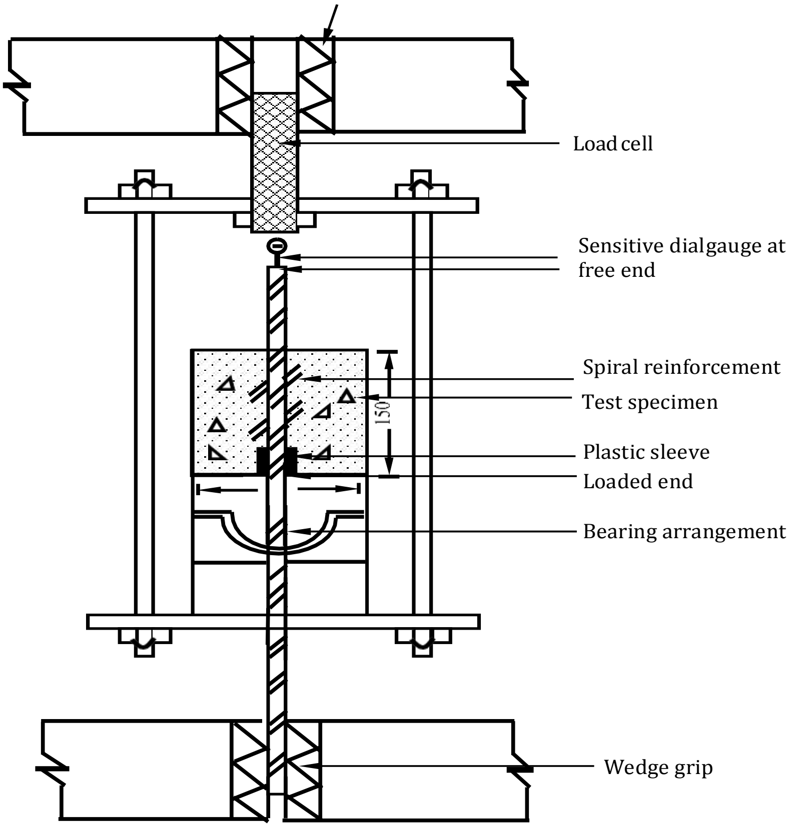


Fig. 8. Schematic view of pull-out test setup.

3.4. Accelerated corrosion test

The accelerated corrosion test (ACT) was conducted to evaluate the resistance of uncoated and coated rebars in enhanced electrochemical corrosion medium. “The test was carried out as per the procedure prescribed by the Structural Engineering Research Centre (SERC), Chennai, India and Central Electrochemical Research Institute (CECRI), Karaikudi, India” (Gunaselvi et al., 2015). Total of nine specimens were subjected to ACT including three control specimens, three specimens each in 1coat and 2coated Nano TiO_2 modified CPAC. The 16 mm diameter and 120 mm long test rebars were centrally embedded in concrete specimens of 70 mm diameter and 115 mm height giving bottom cover as 20mm. The embedded rebar projected 25 mm above the concrete cylinder and it acts as an operational electrode. The bottom portion of the rebar was masked with M-seal and the top portion was faced and clipped with 14 mm copper wire gauge. Also, the specimen was sealed from top and bottom by polymer cementitious coating to ensure chloride intake from the lateral surface of the specimen.

The container which acted as cathode/counter electrode was filled with 3% NaCl up to the height of the specimen. Anode and cathode were joined to a constant potential of 9V DC supply. The time of appearance of the first crack was adopted to measure the comparative coating resistance against chloride intake and successive deterioration. Fig. 9 shows the schematic diagram of an ACT.

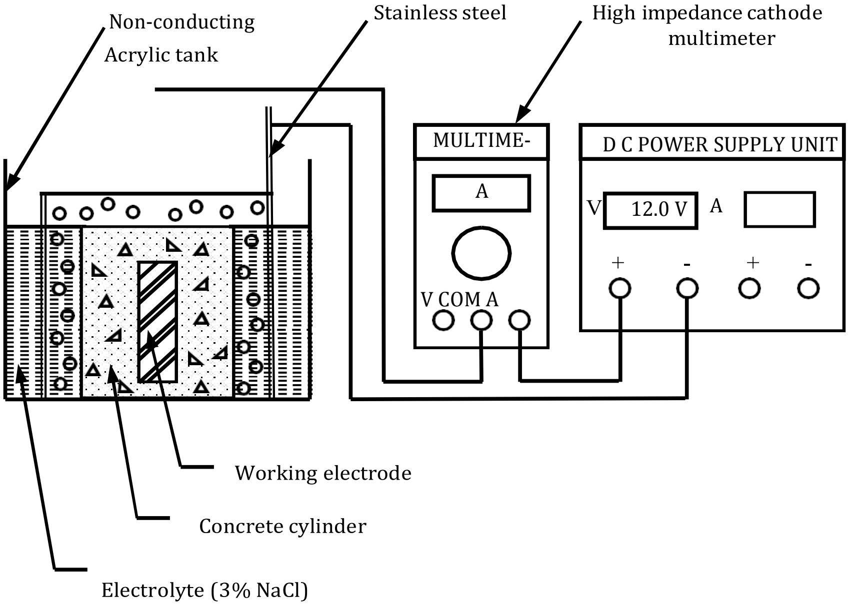


Fig. 9. Schematic view of accelerated corrosion test setup.

3.5. *Coating flexibility test*

Reinforcement rods are subjected to cutting, bending and shaping operation before they are laid in concrete. To resists these mechanical stresses, the coating should exhibit good flexibility characteristics. Coating flexibility test (CFT) was done as per BIS 13620 Annexure A-4 (1993) and ASTM A775/A775M (1995). The coated rebars of 16 mm diameter and 1 m length were used in the test. The coated rebar was positioned in bar bending arrangement such that the longitudinal ribs and the mandrel radius are in 90° planes. "The rebars were bent around 150 mm diameter mandrel to 180° after a rebound with suitable levers. Thermal equilibrium of 240+20°C was maintained during the test". Fig. 10 shows the CFT test setup.

Fig. 10. Coating flexibility test in progress.

4. Results and Discussion

Totally forty-five specimens were subjected to various performance evaluation tests. The performance of the coated rebars has been evaluated by conducting the following test and it has been discussed.

- Chemical Resistance Test.
- 2V Applied Voltage Test.
- Bond Strength Test.
- Accelerated Corrosion Test and
- Coating Flexibility Test

4.1. *Chemical resistance test*

Tables 3 and 4 show the observation on CRT for specimens coated with CPAC and nano-modified CPAC. No rust spots were observed in distilled water, 3M sodium hydroxide and saturated calcium hydroxide mediums. In

3M calcium chloride medium, only few rust spot at the interface were observed. The occurrence of rust spot in 3M calcium chloride may be due presence of weak spots in the coating and also due to reduced coating thickness, particularly in ribbed areas.

Table 5 shows the observation on CRT for specimens with holidays. Only in 3M calcium chloride medium few rust spots were observed in both liquid and vapour phase. In all other mediums, no rust spots were observed. The coating did not blister, soften, loss bond in all mediums during the test period. The coating surrounding the intentionally made holes exhibit no undercutting during the 45 days test period in all the medium. Fig. 11(a) shows the view of coated rods immersed in 3M $CaCl_2$ after test period and Fig. 11(b) shows the view of the drilled specimen after subjected to the CRT.

Table 3. Observation on chemical resistance test 1.

S. No.	Medium	Observation on coating	
		Liquid phase	Vapour phase
1	Distilled water	No blistering, softening, disbondment, decolourisation and rust spots	No blistering, softening, decolourisation, disbondment and rust spots
2	Sat. $Ca(OH)_2$	No blistering, softening, decolourisation, disbondment and rust spots	No blistering, softening, decolourisation, disbondment and rust spots
3	3M NaOH	No blistering, softening, discolourisation, disbondment and rust spots	No blistering, softening, decolourisation, disbondment and rust spots
4	3M $CaCl_2$	No blistering, softening, decolourisation and disbondment. Rust spots at the interface	No blistering, softening, decolourisation, disbondment and rust spots

Coating: Cement polymer anticorrosive coating. Test duration: 45 days. Test temperature: 27°C.

Table 4. Observation on chemical resistance test 2.

S. No.	Medium	Observation on coating	
		Liquid phase	Vapour phase
1	Distilled water	No blistering, softening, disbondment, decolourisation and rust spots	No blistering, softening, decolourisation, disbondment and rust spots
2	Sat. $Ca(OH)_2$	No blistering, softening, decolourisation, disbondment and rust spots	No blistering, softening, decolourisation, disbondment and rust spots
3	3M NaOH	No blistering, softening, decolourisation, disbondment and rust spots	No blistering, softening, decolourisation, disbondment and rust spots
4	3M $CaCl_2$	No blistering, softening, decolourisation and disbondment. Rust spots at the interface.	No blistering, softening, decolourisation disbondment and rust spots

Coating: TiO_2 modified cement polymer anticorrosive coating. Test duration: 45 days. Test temperature: 27°C.

Table 5. Observation on chemical resistance test 3.

S. No.	Medium	Observation on coating	
		Liquid phase	Vapour phase
1	Distilled water	No undercutting of the film around the intentional damage.	No undercutting of the film around the intentional damage.
2	Sat. $Ca(OH)_2$	No undercutting of the film around the intentional damage.	No undercutting of the film around the intentional damage.
3	3M NaOH	No undercutting of the film around the intentional damage.	No undercutting of the film around the intentional damage.
4	3M $CaCl_2$	No undercutting of the film around the intentional damage.	No undercutting of the film around the intentional damage.

Coating: TiO_2 modified cement polymer anticorrosive coating with holidays. Test duration: 45 days. Test temperature: 27°C.

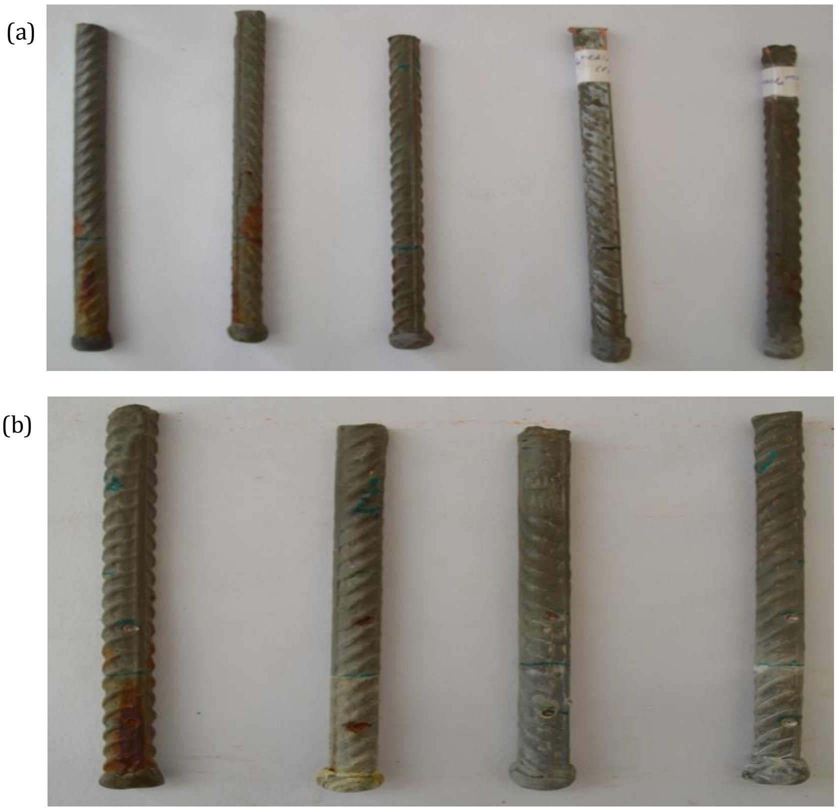


Fig. 11. (a) View of coated specimen immersed in 3M $CaCl_2$ medium after the test; (b) View of drilled specimen after subjected to the chemical resistance test.

4.2. Applied voltage test

The duration of the AVT was one hour. The potential was developed by a D.C power supply of capacity 0-30 Volts. The coating failure was evident by the evaluation of hydrogen gas at the cathode or the appearance of corrosion products of iron at the anode. It was noticed that when a potential of 2V is applied between the coated rebars, there is a steep increase in potential from the open circuit in a 7% NaCl medium. There was no current development during the test period. Table 6 shows the observation of AVT.

Table 6. Observation on applied voltage test for nano-modified CPAC.

Voltage applied	Type of coating	Anode (at the end of test)	Cathode (during the test period)
2.0 Volt (7% NaCl)	Double Coat	Severe corrosion products of Iron.	No evaluation of Hydrogen gas.
	Triple Coat	Two to three corrosion products of Iron	No evaluation of Hydrogen gas.
	Four Coat	No Corrosion Products of Iron.	No evaluation of Hydrogen gas

Table 6 shows that in a double-coated specimen, there was no evaluation of hydrogen gas at the cathode and few rust spots at the anode have been observed. In triple coated specimen, there was no evaluation of hydrogen gas at the cathode and two to three rust spots have been observed in the anode. In four coated specimen, there was no evaluation of hydrogen gas at the cathode and no rust spot at the anode. Fig. 12(a) shows potential vs time behaviour of double, triple and four coated Nano TiO_2 modified CPAC rebar.

For double-coated rebar, there was an increase in potential values of 0.682V observed immediately upon impressing 2V from Open Circuit Potential of - 0.386 mV. Afterwards, there is a similar potential value until the end of the test period. For triple coated rebar there was an increase in potential values of 1.482 mV observed immediately upon impressing 2V from Open Circuit Potential of - 0.192 mV. It was observed that there was a decrease in potential value for 5 minutes and afterwards there is a similar potential value until the end of the test period. For four coated rebar there was an increase in potential values of 2.282 mV observed immediately upon impressing 2V from Open Circuit Potential of - 0.082 mV. It was observed that there was a decrease in potential value for the first 10 minutes and afterwards there was a similar potential value until the end of the test period. Fig. 12(b) shows the coated rebars after subjected to AVT.

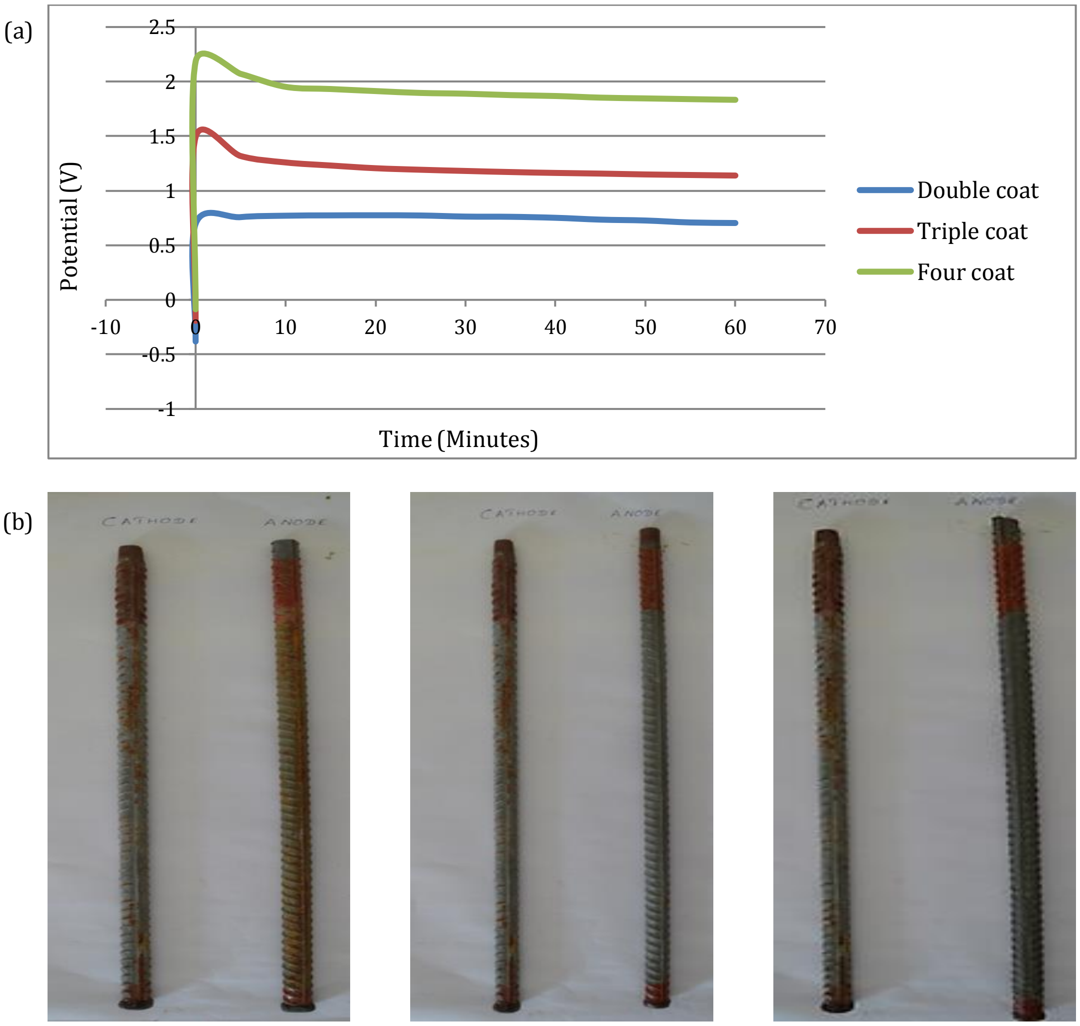


Fig. 12. (a) Potential vs time behaviour of double, triple and four coated Nano TiO_2 modified CPAC rebar; (b) Two, three and four coated specimen after subjected to applied voltage test.

4.3. Bond strength test

The bond strength results of rust-free uncoated rebar were compared with Nano TiO_2 modified CPAC (single and double coating) rebars. The 0.025 mm FE slip was considered for evaluating usable bond strength. Table 8 shows the mean results of pull-out tests for coated and uncoated bars. It was observed that the ultimate load-carrying capacity of nano-modified CPAC single and double coated rebars were 94 kN and 84.32 kN respectively. However, for uncoated rebar, the ultimate load-carrying capacity was 70 kN. From the values, it is observed that single and double coated rebar carries more than 34.29% load and 20.46% load respectively when compared to uncoated rebars. Usable bond strength for single coated rebar is 126.96% and double-coated rebar is 46.08% more when compared to uncoated rebars. Single coated rebar shows better results than double-coated rebar in both load-carrying capacity and usable bond strength. Table 7 shows the BST results.

Fig. 13 shows load vs slip behaviour of 16 mm diameter uncoated and nano-modified cement polymer anti-corrosive coated rebars.

Table 7. Observation on bond strength test for uncoated, single and double coated nano-modified CPAC.

S. No.	Type of Rebar	Load (kN)			Usable Bond Strength (MPa)	Variation (%)
		0.025mm FE slip	0.25mm LE slip	Ultimate Load (kN)		
1	Uncoated rebar	9.25	3	70	2.3	-
2	Single coated CPAC rebar	21	8.5	94	5.22	+126.96
3	Double coated CPAC rebar	13.5	4.75	84.32	3.36	+46.08

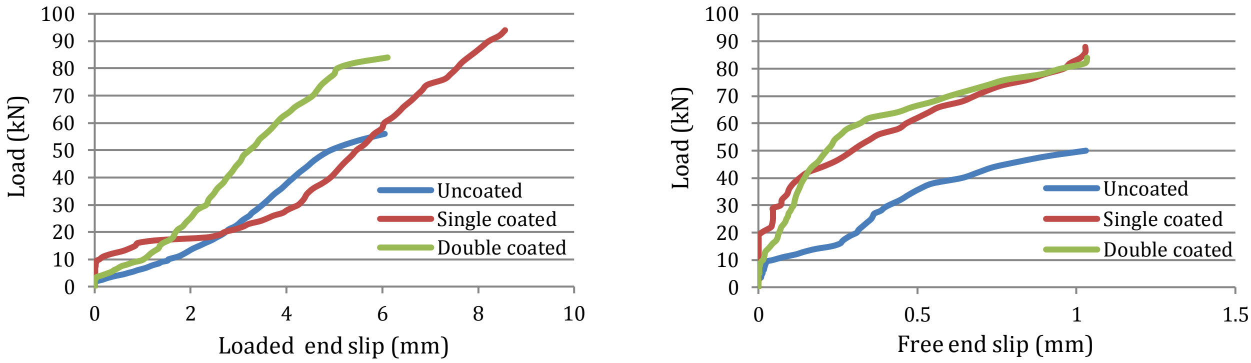


Fig. 13. Load-slip behaviour of 16 mm diameter uncoated and nano-modified CPAC rebars.

4.4. Accelerated corrosion test

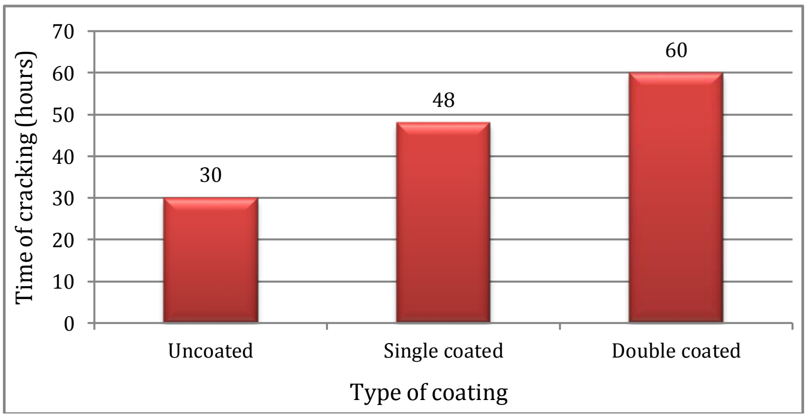
Fig. 14(a) shows the comparison of cracking time for uncoated and (single and double) coated rebars in control concrete. It was observed that for all the coated rebars, time to cracking was higher when compared to uncoated control rebars. There was an appreciable increase in cracking time for double-coated Nano TiO_2 modified cement polymer anticorrosive coated rebars of the order of 2 times as compared to uncoated rebars. Cracking time for single coated Nano TiO_2 modified cement polymer anticorrosive coated rebar was 1.6 more than uncoated rebar.

Fig. 14(b) shows the condition of cracked specimens after completion of ACT. The specimens were broken open and observations were noted. Fig. 14(c) shows the condition of the coated rebar and concrete at the end of the test. It was observed that the uncoated rebars were corroded more and the coating is more adhesive to the concrete than rebar.

4.5. Coating flexibility test

Three specimens of nano-modified CPAC rebars were subjected to CFT. It was noticed that for the specimen subjected to the test, cracking and disbondment of the coating was observed on both outside and inside radius of the 180° bent rebar. According to BIS and ASTM codal provisions, no cracking of the coating shall be visible to a person with a normal or corrected vision on the outside radius of 180° bend rebars. Therefore the coating has to be applied after cutting and bending operation is over.

(a)



(b)

Uncoated Single coated Double coated

Fig. 14. (continued)

Fig. 14. (a) Comparison of cracking time for nano-modified CPAC coated (single and double) and uncoated rebar in control concrete; (b) Cracked specimens (uncoated, single and double coated) after subjected to accelerated corrosion test; (c) Condition of concrete and coated rebar at the end of accelerated corrosion test.

5. Conclusions

In the study performance evaluation of nano-modified Cement Polymer Anticorrosive Coating (CPAC) was undertaken by conducting the Chemical Resistance Test (CRT), Applied Voltage Test (AVT), Bond Strength Test (BST), Accelerated Corrosion Test (ACT) and Coating Flexibility Test (CFT). Totally, forty-five specimens were tested to evaluate the performance of the coating. Based on the test results, the following conclusions were drawn:

- The coating did not blister, soften, lose bond in all the tested medium during the chemical resistance test and meets the requirement of BIS 13620 (1993) and ASTM A775/A775 M (1995).
- The coating has the ability to withstand the electrochemical stresses during one hour applied voltage test and passes the Indian standard code requirements.
- The results of the pull-out showed that the usable bond strength for single coated rebar is 126.96% and double-coated rebar is 46.08% more than uncoated rebars. Single coated rebar shows better results than double-coated rebar in both load-carrying capacity and usable bond strength.
- In accelerated corrosion test there is an appreciable increase in cracking time for double-coated Nano TiO_2 modified cement polymer anticorrosive coated rebars of the order of 2 times as compared to uncoated rebars. Cracking time for single coated Nano TiO_2 modified cement polymer anticorrosive coated rebar was 1.6 more than uncoated rebar.
- In the CFT, coating completely in the inner and the outer radius of the 180° bend rebar fails to meet the requirements of BIS and ASTM standards. Therefore the coating must be applied subsequent to cutting and rebar twisting is finished.
- Overall from the test results, it can be concluded that the TiO_2 modified cement polymer anti-corrosive coating offers appreciable corrosion resistance properties, satisfying the codal requirements in critical aspects and therefore can increase the durability of RCC structures several folds.

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