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A study on transmission line tower foundation in marine environment

Gurunaathan K*[1], Christian Johnson S[2], & Thirugnanam G S[3]
[1]Anna University, Chennai-600025, Tamilnadu, India,
[2]Excel Engineering College, Komarapalayam-637303, Tamilnadu, India,
[3]Institute of Road and Transport Technology, Erode-638316, Tamilnadu, India
*[E-mail: rajkamalgn@gmail.com]

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Experimental evaluations about the performance of transmission line tower foundation concrete with different mineral admixtures/chemical admixtures and coatings have been done by conducting tests such as rapid chloride penetration test, acid test, chloride immersion test, etc., Protective measures like woring provision, coatings with chemicals, have also been suggested based on the experimental studies to reduce crevice corrosion. Actual stub removed from the field has been used to examine the depth and pattern of cracks.

[Keywords: Transmission tower, Stub angle, Nano coating, Recron fibre, Demech chemical].

Introduction

The reliability of the electric power transmission is very much essential since the failures in the transmission line components will lead to a huge expenditure towards maintenance/replacement costs. Many of these failures are corrosion related as the materials are exposed to aggressive atmospheric/soil conditions. Corrosion of galvanized transmission tower stubs just above the concrete chimney has occurred at several locations running close to coastal area as they are attacked by chlorides and sulphates. The towers in the vicinity of chemical, petro chemical, fertilizer and other industries are subjected to aggressive chemical attacks. Because of the extreme climatic conditions prevailing in certain areas, transmission line tower coping concrete has been severely affected and stub angle get corroded[1,2]. During submergence of stub steel for some period during rainy season, the corrosion process gets aggravated, particularly in the presence of chlorides and phosphates with water acting as salt dissolved electrolyte. The resultant products of rust and complex compounds with chloride have a larger volume than the original material which leads to the formation of local cracks and chip-off that allows salt to penetrate further into the affected stub where the process of corrosion will get accelerated. A mechanism of pitting or crevice corrosion will initially occur in the presence of aggressive chloride ions which will consequently lead to severe structural failure. In order to assess the efficacy of the coatings for corrosion resistance, the tests such as accelerated corrosion test, impressed voltage test, chemical resistance test, and applied voltage test were conducted.

Materials and Methods

Ordinary Portland cement of 43 grade, conforming to IS: 8112, well graded blue metal aggregate passing through 12mm sieve and retained in 4.75mm sieve with specific gravity of 2.72, screened river sand of specific gravity of 2.61 conforming to grading zone III of IS: 383 – 1970, and clean, potable water have been used in the making of conventional concrete[3,4]. Fly ash produced from Mettur Thermal Power plant, Mettur, Tamilnadu, India sieved through 50μ sieve and the epoxy resin available in market has been used as admixtures. Silplas super, a super plasticizer formulated to give high early strength and tested for conformation to BIS 9103 is used in this study. The components in the admixture make most of the un-reacted lime to become inactive and impart better chemical resistance to concrete/mortar. It is a chloride free admixture making the concrete to have less drying shrinkage property. It increases young's modulus by 170% as compared to normal concrete.

Flexibond ACSR is a versatile binder cement based system formulated to give the best with modification of cement – water system. It is a blend of polymers & certain inorganic materials, which on mixing with cement – water system gives flexible properties at an appropriate ratio of Flexibond ACSR polymer & cement. It sets and gives early strength to the system. It also gives higher flexural & tensile strength properties to cement water system and shall be used in injection grouting of cracks along with cement slurry grouting[5]. When mixed with cement & water in the ratio of 1:1:3 [Flexibond ACSR: Water: Cement] and applied between the old & new concrete, it serves the purpose of a binder. It is technically better than an epoxy binder due to the fact that usage of Flexibond ACSR imparts breathable properties to cement system.

Concrete normally provides reinforcing steel with excellent means of protection against corrosion. However, the pollution of concrete by aggressive chemicals in the form of chloride and carbon dioxide leads to a decrease in pH and a breakdown of the passive film which results in the corrosion of the steel reinforcing bars and the deterioration of the concrete in the long run.

Recron 3S fibers reduce cracks during plastic and hardening stage. It reduces water seepage and protects the steel in concrete from getting corroded[6] and walls from dampening. The recommended usage of 12 mm Recron 3S is 900gm / cubic meter.

Koroguard GF is a glass flake reinforced system in which laminar glass fibres are embedded in solvent free matrix of epoxy resin. This high performance epoxy coating system is recommended for enhanced protection to metal and concrete against erosion, corrosion and attack of chemicals. It has extreme low permeability with relatively high abrasion resistance and chemical resistance.

Nano Zycosil is pale yellow coloured water soluble liquid with a density of 1.07 (@25^{0}C) and flash point more than100°C. It should comply with IS 12027-1987, IS 12054 – 1987, IS 3067-1987, and IS 13182-1991. The shelf life of this material is 2 years and the recommended storage temperature range is between 15^{0}C - 45^{0}C and should be kept away from rain or standing water. When the temperature goes below 10^{0}C, it has freezing tendency. It can be diluted with clean water and should be used within 48 hours.

Mix design for M20 grade was done as per IS 10362 specification. The mix proportion is given in Table 1.

Specimen details

Specimen 1= Plain concrete (without fly ash)

Specimen 2 = Plain concrete with 20 % cement replacement by fly ash

Specimen 3 = Plain concrete + Silplas super & 20% fly ash mixed Concrete.

Specimen 4 = Plain concrete with corrosion inhibitor

Specimen 5 = Plain concrete with Recron 3s fibres

Specimen 6 = Plain concrete with two level coating with Flexibond ACSR

Specimen 7 = Plain concrete with two level coating with Demech chemical

Laboratory specimens in different grades of concrete, with admixtures and steel angle surface coatings[7,8,9] were cast to observe the corrosion phenomena under accelerated test condition. For comparison purpose, uncoated angle specimens were also tested under similar accelerated test condition to determine the efficiency of the surface coating. The curing of test specimens is shown in Fig. 1.

Experimental investigations

One of the principal sources of corrosion problem is the ingress of chloride ions into porous concrete. It is often necessary to ascertain the impermeability of concrete to chloride ions as a quality control measure[10,11]. Since measurement of chloride diffusion co-efficient requires a long time for establishment of steady state conditions, a direct current (DC) potential is applied to accelerate migration of ions. In this present study, the Rapid chloride penetration test (RCPT) was performed as per ASTM C 1202. The test method consists of monitoring the amount of electrical current passed through 51 mm thick slices of 102 mm nominal diameter of cylindrical specimens for duration of six hours. The RCPT test set up is shown in Fig. 2.

The RCPT apparatus consists of two reservoirs. The specimen was fixed between two reservoirs using an epoxy bonding agent to make the test set up leak proof. One reservoir (connected to the positive terminal of the DC source) was filled with 0.3 N

Table 1 — Mix proportion by weight

Mix Proportion			
Cement	Fine Aggregate	Coarse Aggregate	Water/ Cement ratio
1	1.43	3.1	0.49

Fig. 1 — Curing of Testing Specimens

Fig. 2 — View of Rapid chloride penetration test set up

sodium hydroxide solution and the other reservoir (connected to the negative terminal of the DC source) with three percent sodium chloride solution. A DC of 60 V was applied across the specimen using two stainless steel electrodes and the current across the specimen was recorded at 30 minute interval for duration of six hours.

The specimens of size 150 mm X 150 mm X 150 mm were taken. After curing process, the cubes were allowed to dry within 24 hours in oven. Then the cubes were immersed in 10% of NaCl with water in 24 hours. After 24 hours they were allowed to dry. The alternate days of wetting and drying process were done. Finally, the weight of cubes was taken at the end of 10 days.

Concrete is not fully resistant to acids. Most acid solutions will slowly or rapidly disintegrate Portland cement concrete depending upon the type and concentration of acid. The most vulnerable part of the cement hydrate is $Ca(OH)_2$, but C-S-H gel can also be attacked. The siliceous aggregates are more resistant than calcareous aggregates. Concrete can be attacked by liquids with pH value less than 6.5. But, the attack is severe only at a pH value below 5.5 even as at a pH value below 4.5, the attack is very severe. As the attack proceeds, all the cement compounds get eventually broken down and leached away, together with any carbonate aggregate material. With the sulphuric acid attack, calcium sulphate formed can proceed to react with calcium aluminate phase in cement to form calcium sulpho aluminate, which on crystallization can cause expansion and disruption of concrete[12,13,14].

The specimens of size 150 mm X 150 mm X 150 mm cured for 28 days were taken and the weight of the cubes were measured. Then, the cubes were immersed in water with 3% by weight of sulphuric

Table 2 — Chloride ion penetrability based on charge passed

Charge passed (Coulombs)	Chloride ion penetrability
> 4000	High
2000 - 4000	Moderate
1000 - 2000	Low
100 - 1000	Very low
< 100	Negligible

acid for 10 days and the loss in weight of cube and its compressive strength were measured.

The half-cell is a hollow tube containing a copper electrode and immersed in copper sulphate solution. The bottom of the tube is porous and is covered with a sponge material. The copper sulphate permeates this sponge that can then be placed on a concrete surface allowing an electrical potential (voltage) to be measured. The objective of the method is to measure the voltage difference between the reinforcement and the concrete over the reinforcement. Large negative voltages (-) 350 mV indicate that corrosion may be taking place. Voltages smaller than (-) 200 mV generally mean corrosion is not taking place[15,16].

The chloride ion penetrability based on charge passed is shown in Table 2.

Results and Discussion

The current penetrability characteristics for different specimens are shown in Table 3 and the plot of current v/s time is shown in Fig. 3.

I. Specimen without fly ash

$$Q_1 = 900\,(I_0 + 2\,I_{30} + 2\,I_{60} + \ldots\ldots + 2\,I_{330} + 2\,I_{360})$$

$$= 900(0.135) + 2(0.160) + 2(0.170) + 2(0.180) + 2(0.190) + 2(0.195) + 2(0.20) + 2(0.22) + 2(0.23) + 2(0.24) + 2(0.24) + 2(0.255) + 2(0.265)$$

$= 4225.5$ coulombs [Chloride ion penetrability-high]

On similar lines,

II. Specimen with 20% fly ash replacement

$Q_2 = 2225.6$coulombs [Chloride ion penetrability-moderate]

III. Specimen with silplas super & 20% replacement of cement by fly ash

$Q_3 = 2192.0$ coulombs [Chloride ion penetrability-moderate]

IV. Specimen with corrosion inhibitor

$Q_4 = 4548.6$ coulombs [Chloride ion penetrability-high]

Table 3 — Current penetrability characteristics for different specimens

Time in Mins	Current in Amperes (60v DC)						
	Specimen I	Specimen II	Specimen III	Specimen IV	Specimen V	Specimen VI	Specimen VII
0	0.135	0.087	0.09	0.132	0.164	0.035	0.006
30	0.160	0.095	0.108	0.168	0.209	0.040	0.007
60	0.170	0.099	0.112	0.170	0.215	0.045	0.010
90	0.180	0.100	0.115	0.183	0.225	0.049	0.032
120	0.190	0.102	0.118	0.197	0.235	0.055	0.050
150	0.195	0.106	0.120	0.210	0.245	0.059	0.055
180	0.200	0.109	0.125	0.220	0.255	0.069	0.060
210	0.225	0.110	0.129	0.230	0.265	0.075	0.070
240	0.230	0.112	0.133	0.241	0.279	0.075	0.082
270	0.240	0.112	0.142	0.251	0.291	0.095	0.095
300	0.245	0.120	0.146	0.261	0.310	0.099	0.120
330	0.255	0.120	0.149	0.271	0.315	0.11	0.135
360	0.265	0.120	0.150	0.289	0.330	0.18	0.135

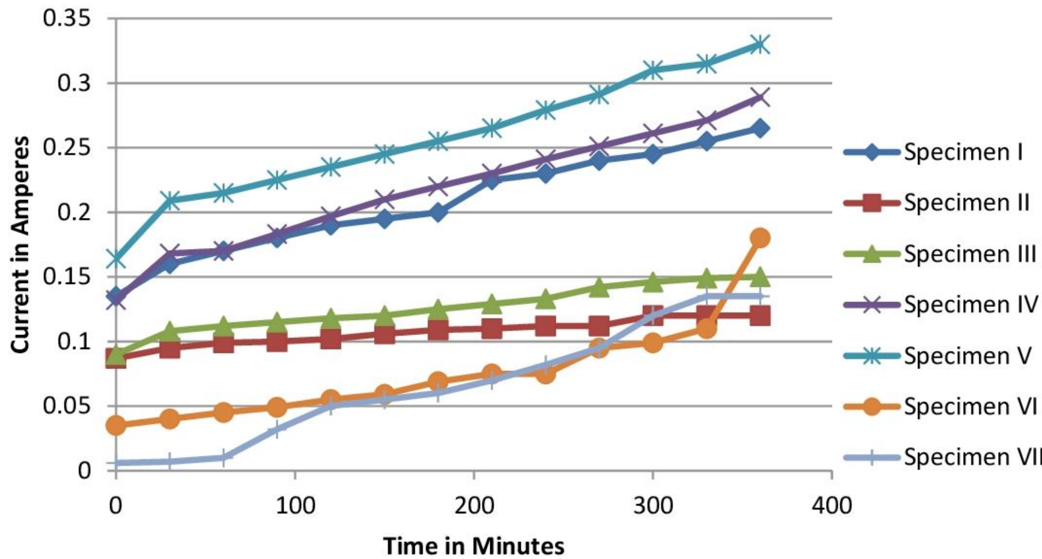

Fig. 3 – Current in Amperes v/s Time

V. Specimen with recron fibre concrete
Q_5 = 5860.8 coulombs [Chloride ion penetrability-high]

VI. Specimen with two level coating with flexibond ACSR
Q_6 = 1743.3 coulombs [Chloride ion penetrability-low]

VII. Specimen with two level coating demech chemicals
Q_7 = 1515.6 coulombs [Chloride ion penetrability-low]

The weight gains of the specimens are furnished in Table 4 and the weights gained after RCPT by the specimens are shown in Fig. 4.

The specimens, after immersion in H_2SO_4 solution for 10 days were tested for its physical properties and presented in Table 5.

Table 4 — Weight gain of the specimens

Specimen	Weight before RCPT in gram.	Weight after RCPT in gram.	Increase in weight in gram.	% of gain in weight
I	969	976	7	0.72
II	1034	1086	52	5.02
III	1002	1061	59	5.89
IV	1008	1019	11	1.09
V	992	1000	8	0.81
VI	926	932	6	0.62
VII	932	934	2	0.21

The deterioration of concrete due to acid attack is shown in Fig. 5. The Table 6 shows results of water absorption test carried out on the test specimens.

Nano coating material called Zycosil was applied on a cube specimen[17] and after setting, water was sprayed upon the surface. Water particles stood as on

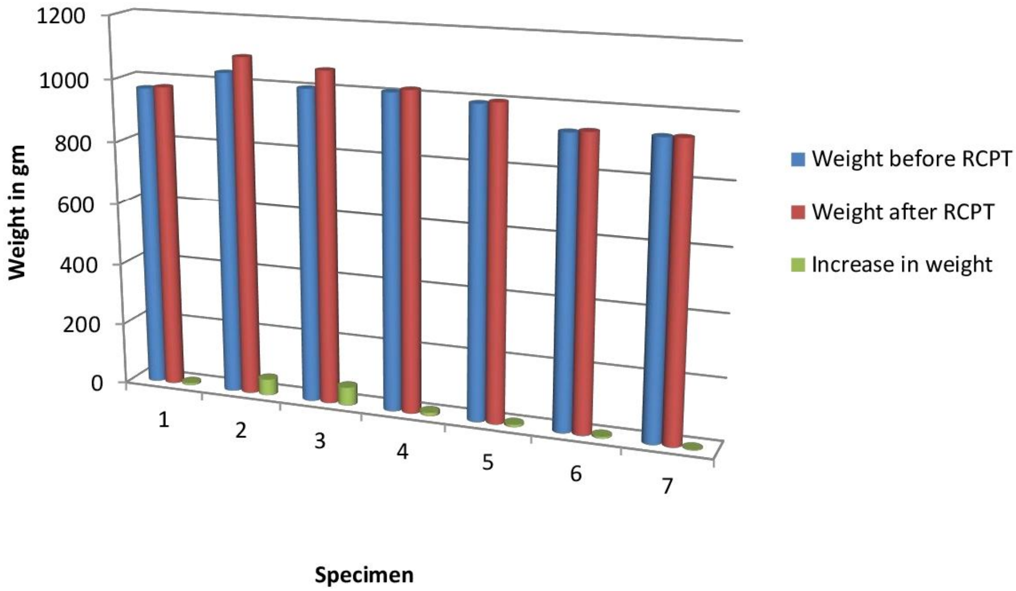

Fig. 4 — Weight gained by different specimens after RCPT

Fig. 5 — Deterioration of concrete due to acid attack

the top of lotus leaves. The specimen was scraped and again water was sprayed, till water was absorbed.

Fig. 6 & Fig. 7 show the specimen coated without and with zycosil respectively.

A model transmission line tower was fabricated and used for experimentation. Concrete has been cast around four legs as that of a coping. In order to eliminate crevice corrosion in the interface of the concrete and stub angle deep grout material of Demech chemical was poured and observation was made under accelerated corrosion[7,8].

Fig. 8 shows the model tower fabricated and tested in the laboratory.

Half cell potentiometer test results

The Accelerated corrosion test was carried out in the model tower and the test results are presented in Table 7. In all the legs, Demech deep grout woring

Table 5 — Acid attack results

Type of admixtures used	Weight before immersion in kg.	Weight loss in gram.	% of loss in weight
Silplas super	8.25	35	0.45
Flexibond coating	8.65	30	0.35
Recron	8.70	41	0.47
Calcium nitrate	8.35	16	0.19
Demech chemical	8.60	20	0.23

Table 6 — Water absorption test results

Type of specimen	Initial weight in kg.	Weight of cube after 1 day immersion in water in kg.	% increase in weight
Silplas super	8.150	8.225	0.92
Calcium nitrate	7.950	8.025	0.94
Recron	8.190	8.260	0.85
Flexibond coating	8.450	8.510	0.71
Demech chemical	8.400	8.450	0.50

Fig. 6 — Specimen coated without zycosil

Fig. 7 — Specimen coated with zycosil

Fig. 8 – Model tower

was tried against crevice corrosion. Table 7 shows the half cell potentiometer readings while Table 8 shows the observations made around the interface for crevice corrosion.

Total specimens of model tower foundation in coated concrete.

MTL 1: leg with conventional concrete
MTL 2: leg with corrosion inhibitor coating
MTL 3: leg with flexibond coating
MTL 4: leg with demech coating

Table 7 — Half cell potentiometer readings

Time	**MTL 1**	**MTL 2**	**MTL 3**	**MTL 4**
0 hrs	-98	-79	-21	0
50 hrs	-156	-103	-69	0
100 hrs	-233	-168	-96	0
150 hrs	-259	-298	-109	0
200 hrs	-301	-342	-126	0
250 hrs	-372	-360	-159	0
300 hrs	-397	-398	-168	0
350 hrs	-423	-413	-182	-39
400 hrs	-465	-444	-198	-68
500 hrs	---	---	-332	-364

Table 8 — Observations made around the interface for crevice corrosion

Time	**MTL 1**	**MTL 2**	**MTL 3**	**MTL 4**
0 hrs	No rust	No rust	No rust	No rust
100 hrs	No rust	No rust	No rust	No rust
200 hrs	No rust	No rust	No rust	No rust
300 hrs	Few rust spots	Few rust spots	No rust	No rust
400 hrs	Rust staining	Rust staining	No rust	No rust
500 hrs	Rust staining	Rust staining	Few rust spots	Few rust spots

Experimental study to investigate the effectiveness of coating on stub model embedded with galvanized stub angle:

In order to study the durability of transmission line tower foundations embedded with Galvanized stubs experimentally, four numbers of stub concrete were formed on the floor. After 28 days of curing, outer coating with flexibond ACSR was applied on one stub and in other leg demech chemical was coated. The remaining two legs were left uncoated to observe the difference. All the stubs were induced corrosion by spraying salt water, which had 3.5 % NaCl. The Half cell readings during 15 days of alternate wetting and drying cycle, were taken to ensure the corrosion formation. The flexibond coating on galvanized stub angle is shown in Fig. 9 even as the half cell potentiometer readings are given in Table 9.

The actual corroded towers were dismantled from the transmission line and the foundation was critically assessed for the deterioration of concrete and the level of corrosion in steel.

As a part of the study, two transmission line tower stubs, one in Coimbatore (Fig. 10) and other in Chennai (Fig. 11) were removed by excavation. The stubs of these towers were erected nearly 30 to 35 years ago, and the super structures had been already

Fig. 9 — Flexibond coating on galvanized stub angle

Fig. 10 — Removal of stub in Coimbatore (Inland)

Fig. 11 — Removal of stub in Chennai (Coastal)

dismantled for expansion purpose. After excavation, the tower stubs were cut, removed and transported to the laboratory to assess the loss of thickness of the steel angle.

The corrosion condition of the actual stubs dismantled from the field were experimentally assessed by measuring the corrosion level using half cell potentiometer test and measuring the loss of thickness of the steel angle present in the stub. The following are the tower stubs dismantled for the study.

i) Coimbatore, Othakalmandapam – Palladam line: 110 KV line – Tower No. 4, Length of stub: 1.5 m, Size of stub: Top: 25x25 cm, Bottom: 15x15cm.

Fig. 12 – Stub excavated in Coimbatore (Inland)

Fig. 13 — Stub excavated in Chennai (Marine environment)

Table 9 — Half cell potentiometer readings in galvanized stub angle

Time	Leg 1 Flexibond ACSR	Leg 2 Demech	Leg 3 Uncoated	Leg 4 Uncoated
1st day	-98	-79	-105	-110
2nd day	-101	-69	-150	-180
5th day	-89	-87	-170	-183
8th day	-106	-103	-197	-214
10th day	-115	-123	-210	-225
12th day	-154	-150	-223	-252
15th day	-159	-157	-245	-243

Table 10 — Crack depth and width of stub

Location	Position	Crack depth	Crack width
Inland (Coimbatore)	Top	30 cm	Less than 2mm
Coastal area (Chennai)	Top	45 cm	3mm- 4mm

ii) Chennai, Ennore Thermal Power Station to Manali - 110 KV line. – Tower No.28, Length of stub: 2.2 m, Size: 45x 45 cm.

Excavated tower was broken in the lab to study the crack depth and pattern and extent of deterioration of concrete. Table 10 shows the crack depth and width of stubs.

The stubs excavated in Coimbatore and Chennai were brought to testing laboratory and they are shown in Fig. 12 and Fig. 13 respectively.

Table 11 — Comparison of Chloride ion penetrability

Specimen	Charge passed in Coulombs	Chloride ion penetrability
I	4225.5	Moderate
II	2225.59	Moderate
III	2192.55	Moderate
IV	4548.6	High
V	5867.8	High
VI	1743.3	Low
VII	1515.6	Low

The rapid chloride penetration test reveals that the specimens with recron fiber, specimens with corrosion inhibitor, and specimens without fly ash allow more chloride to penetrate, whereas the specimens with silplas super, specimens with flexibond ACSR and specimens with demech chemical coatings show moderate and low level of chloride penetrability. The comparison of chloride ion penetrability among the specimens is made and tabulated in Table 11.

Charges passed in coulombs are very low for the specimens with Demech chemicals. Specimens with flexibond ACSR coating also more or less behave similar to the demech chemical coated specimens.

Conclusions

Two level coated specimens with Flexi bond ACSR and Demech chemicals are not allowing chlorides to penetrate through and hence they can be recommended for Transmission line foundations.

From the RCPT conducted, concrete mixed with silplas super and fly ash replacing 20% of cement performs very well.

Plain concrete with 20% cement replacement is also equally performing well.

The plain concrete without fly ash is allowing lot of chloride ions to penetrate and hence in the case of transmission line tower foundation, plain concrete with at least 20 % cement replacement should be used.

There is a considerable increase in weight after the test for the specimens with fly ash and specimens with super plasticizer and fly ash. The specimens coated with flexibond ACSR or Demech chemical, even though, those specimens contain fly ash and silplas super, the increase in weight is negligible. Hence, the concrete coated with flexibond ACSR or Demech chemical with fly ash replacing 20 % of cement and Silplas super plasticizer shows a higher level durability performance in the rapid chloride penetration test.

Recron 3s fiber mixed concrete and corrosion inhibitor mixed concrete is allowing lot of chloride to penetrate through, and hence it is not recommended.

Two level coating should be adopted in the transmission line tower foundation in order to protect the stub steel against corrosion.

In chemical resistance test, Demech and flexibond ACSR specimens proved that there is a lesser percentage of weight loss when compared to other specimens.

Also in the water absorption test, Demech and flexibond ACSR specimens show a lesser percentage of weight gain.

Specimens coated with nano coating [zycosil], show a superior form of water repellant. Even after scraping for 1 mm depth, the water particles stood similarly, thus showing a higher order of durability for coating on concrete surfaces.

Deep grouting out of Demech chemical for forming woring in the stub angle and concrete interface shows no symptoms of rust staining till 400 hrs of accelerated corrosion. Only at 500 hrs, a few rust spots were noticed.

From the half cell readings taken from tower model and stub model set on ground, it is observed that the galvanized stub angle shows a superior performance when compared to the mild steel stub angle.

From the actual stub excavated from the field, it is noticed that the stub excavated in the inland area has a lesser crack depth on the concrete portion than the stub excavated from coastal area.

As deep grouting out of demech grout for forming woring performs well, provisions may be made in the field for woring arrangement for preventing the crevice corrosion.

As nano coating out of zycosil shows a very good performance in resisting water adhesion, such nano coating can be recommended. However, other durability performance indices on specimens with nano coating on concrete and stub angle need to be studied further.

Hence, it is concluded and recommended that there is a need for applying three level polymer based coating like flexibond ACSR or Demech chemical on transmission tower foundations, which are to be laid in the coastal areas. Fly ash replacing cement by 20 %, addition of super plasticizer like silplas super in the concrete is also recommended.

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