
Performance Evaluation of Protective Coatings on Corrosion resistance in Transmission Line Tower foundations

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Abstract:

Corrosion of steel angles in concrete has become one of the menacing problems on durability aspects, which influence the service life of the structures. The life cycle cost of transmission tower foundations, which are corrosion prone has increasingly, become difficult to manage. Failures in their transmission line components amounts to thousands of dollars only in maintenance costs apart from other related expenditures. Many of these failures are corrosion related due to the exposure of the system materials to aggressive atmospheric and/or soil environments .

Transmission line towers running close to coastal area are attacked by chlorides and sulphates and the towers in the vicinity of chemical , petro chemical, fertilizer and other industries are subjected to aggressive chemical attacks. Because of the extreme climate conditions prevailing in certain areas, transmission line tower stubs/coping/muffing concrete have been severely deteriorated and stub angle were corroded very much. During submergence of stub steel above concrete chimney for some period in rainy season, water acting as salt dissolved electrolyte, the corrosion process is aggravated particularly in the presence of chlorides and phosphates. A mechanism of pitting or crevice corrosion will initially occur in the presence of aggressive chloride ions.. Application of Protective coating to steel angles and addition of admixtures to the concrete is one of the best method of controlling corrosion in steel angle. Effect of providing coatings on stub angle, addition of admixtures in stub concrete, corrosion inhibitors and barrier coatings on stub concrete against corrosion had been investigated in the laboratory under accelerated environmental condition.

Keywords: *Corrosion of Steel angle, protective coating techniques, tests.*

1. Introduction:

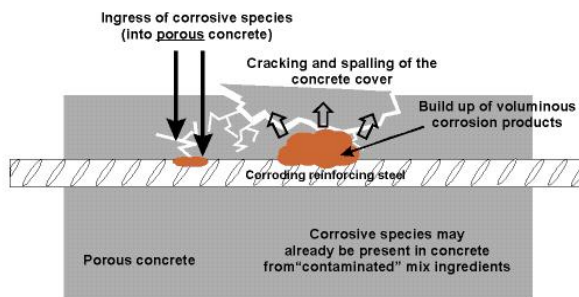
India has a large population distributed all over the country. In these modern days Power has become an essential requirement in our day-to-day life. Power is the important factory contributory much to the development of any nation. The present Power Generation of our country from all sectors is about 1,50,000 MW and it is expected to be doubled in another 10 years or so. The power from the generating stations are to be taken to the different places of requirement for further distribution to the users. For the evacuations of Power from the Generating stations to the place of utility across the country and also between sub-stations, transmission system are to be provided..

The disposition of the primary resources for electrical power generation in India, viz., Coal, Lignite, Hydro Potentials, wind energy, is quite uneven. This uneven distribution of generation resources adds the transmission requirement. The transmission tower structures plays a major role in power evacuation from generating to load centres. Failure of towers were observed due to natural calamities such as storm , flood, earthquake, landslides,

cyclone, design, construction faults, vandalisms and ageing., Besides above, in the locations where sub soil water salinity is very high like in coastal areas, there are lot of chances for rusting of tower stub encased in the concrete as well as the stub above the ground level.. If this is not attended in at proper time the tower may collapse under climatic conditions

This paper here under gives a brief account of corrosion of transmission tower foundations and presents an experimental study on effectiveness of different coatings against corrosion of transmission tower foundations.

Corrosion mechanism of tower foundations:



Owing to its highly alkaline nature (PH > 12) concrete possesses corrosion protective features and normally provides a non-corrosive environment for embedded stub steel, which is passivated in such a PH range.

However, during submergence of stub steel above concrete chimney for some period in rainy season in water acting as salt dissolved electrolyte, the corrosion process is aggravated particularly in the presence

of chlorides, sulphates and phosphates. The resultant produces of rust and complex compounds with chloride have a larger volume than the original material. This leads to the formation of local cracks and chip-off, which allows salt to penetrate further into the affected stub where the process of corrosion will be more and more accelerated. A mechanism of pitting or crevice corrosion as in the fig. 1. will initially occur in the presence of aggressive ions such as chlorides. These ions are responsible in the formation of pits on the surface, which accelerates corrosion attack. An important consequence of pitting is that the localized attack may be very severe which may lead to structural catastrophe.

2. Laboratory investigations:



To study the effectiveness of different coatings on angle, admixtures in concrete and coatings on concrete surface, many specimens were cast with the angles (as in the chimney portion of transmission line tower

foundation) in the lab and half cell - readings were taken at Zero hours (after the curing period). Then the cylinders were placed in galvanization process by accelerating. After every 20 hours of the accelerating process the half cell measurements were taken.

Protective Materials Descriptions

I) Flexibond ACSR (Polymer Based) – Mix Ratio - (1(Water):1(FACSR):3(Cement))

It is versatile binder cement - based systems, carefully formulated to give the best binding properties combined with modification of cement – water system. It is 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 & gives early strength to the system. It gives higher flexural & tensile strength properties to cement water system. It shall be used in injection grouting of cracks along with cement slurry grouting. The flexible properties of Flexibond ACSR makes the injection grouting to address the moving cracks sealing. When mixed with cement & water in the ratio of 1:1:3 = Flexibond ACSR : water: Cement & applied between the old & new concrete it serves the purpose of a binder between the old an new concrete and it is technically better than an epoxy binder because of the fact that Flexibond ACSR usage imparts breathable properties to cement system. If carefully selected filler is mixed with cement at the ratio of 1:1 and then mixed.

II) Silplas Super(2% By weight of Cement)

It is a superplasticiser formulated to give very high early strength and tested for confirmation of BIS 9103:1999 by IITM, Chennai . It is a brown color liquid with specific gravity nearly 1.00 at room temperature. The curing requirement is less compared to the normal concrete. Silplas super is a superplasticiser formulated to give very high early strength. 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 chloride free admixture. The decreased length change found in the evaluation makes this admixture more suitable for durable concrete. Use of this product makes the concrete to have less drying shrinkage property as seen in the shrinkage evaluation test . Increases young's modulus by 170% compared to normal concrete . Silplas super is a specially formulated from organic, activated silica and inorganic compounds after a long research and field trails.

III) Corrosion Inhibitor (Calcium Nitrate) (2% By weight of Cement)



Reinforcement corrosion is one of the major causes of degradation in concrete structures. Concrete normally provides reinforcing steel with excellent means of protection against corrosion. However, the pollution of concrete by aggressive species such as chloride and carbon dioxide leads to a decrease in pH and a breakdown of the passive film. It results in the corrosion of the steel-

reinforcing bar (rebar) and, in the long term, the deterioration of the concrete.

Fig 2: Calcium Nitrate(Salt Form)

IV) Recron 3S Fibre(2% By weight of Cement)



V) Epoxy Coated Angle



Fig:3 Recron 3S Fibre

Fig :4: Epoxy Coated Angle

Specimen Details

3. Mix proportion

1. M20 grade concrete was produced using only commercially available materials with normal mixing and Curing techniques.
2. The mix Design had been prepared as per IS 10362 specification. From the mix design the following Mix Proportions was arrived

Table : 1: Mix Proportion Details

Concrete Strength N/mm ²	Water / Cement ratio	Mix Proportion (To weight of Cement)			
		Cement	Fine Aggregate	Coarse Aggregate	W/ C ratio
20	0.49	1	1.43	3.1	0.49

Testing Specimens

1 Accelerated Corrosion test Specimen Details

- There are 22 numbers of ISA 50 X50X6mm(Coated and Uncoated) angle embedded Concrete (Cylinder 150Ø X 300mm)Specimen cast in Laboratory.

2 Bond Strength Test Specimens Details

- There are five numbers - MS of 12mm Ø rod embedded Concrete (Cylinder 100Ø X 200mm)Specimen cast in Laboratory.

3 Impressed Voltage Test Specimens Details

- There are 22 numbers of ISA 50 X50X6mm(Coated and Uncoated) angle embedded Concrete (Cylinder 150Ø X 300mm)Specimen cast in Laboratory.

4 Applied Voltage test Specimens

1. Two numbers of Epoxy Coated 25cm height steel angle
2. Two numbers of Demech Coated 25cm height steel angle
3. Two numbers of Flexibond ACSR Coated 25cm height steel angle
4. Two numbers of un Coated 25cm height steel angle

5 Chemical Resistance Test Specimens

1. Three numbers of Epoxy Coated 25cm height steel angle
2. Three numbers of Demech Coated 25cm height steel angle
3. Three numbers of FACSR Coated 25cm height steel angle
4. Three numbers of Un Coated 25cm height steel angle



Fig:5: Half Cell test in Specimens

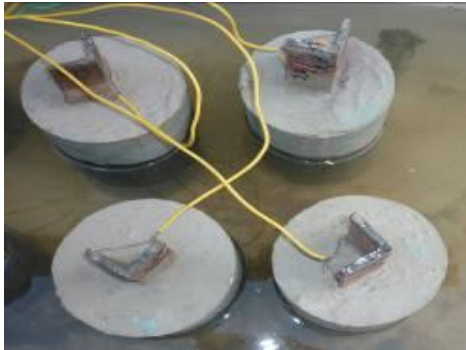


Fig:6:Cast Specimen

Protective Coating Systems and Protection levels.

Single Level Protection:

- Plain Angle with only OPC
- Plain angle with Conventional Concrete
- Plain Angle With Recron 3s fibre mixed concrete.
- Plain angle with corrosion inhibitor mixed concrete.



**Fig: 7 Externally Coated by FACSR Specimens
Coated Specimens**



**Fig:8 FACSR & Epoxy
Coated Specimens**



Fig :9: Corrosion Acceleration(Before Corrosion) Fig :10 FACSR Coated Angle

Two Level Protections

- Flexibond ACSR mixed with cement coating over the angle with Silplas Super & Fly ash mixed concrete.
- Flexibond ACSR mixed with cement coating to the angle with Conventional concrete .
- Epoxy Coating Over the Angle with Conventional concrete .
- Plain Angle with Conventional Concrete with Flexibond ACSR mixed with cement coating over the Concrete surface.



Fig :11 Accelerated Corrosion(After Corrosion) Fig:12 FACSR Coating Technique

Three Level Protections.

- Flexibond ACSR mixed with cement coating over the angle with Admix Concrete
With Flexibond ACSR mixed with cement coating over the concrete surface
- Demech Coated angle + Conventional Concrete + Externally coated by demech

Coated Specimen Details:

- CS 1 = Plain angle + Plain Concrete (without fly ash)
- CS 2 = Plain angle + Admix Concrete (Single level Protection)
- CS 3 = FACSR Coated Angle + Admix Concrete.(Two Level Coating)
- CS 4 = FACSR Coated Angle + Conventional Concrete (Single Level Coating)

CS 5 = Plain Angle + Conventional Concrete + Externally Coated by FACSRS (Two level Coating)

CS 6 = Epoxy Coated Angle + Conventional Concrete(Two Level Coating)

CS 7 = FACSRS Coated Angle + Admix Concrete + Externally Coated by FACSRS (3 Level Coating)

CS 8 = Plain Angle + Recron Mixed Concrete.(Single level Protection)

CS 9 = Plain Angle + Corrosion Inhibitor Mixed Concrete

CS 10 = Demech Coated angle + Conventional Concrete + + Externally Coated by Demech (3 Level Coating)

Note : 1) Conventional Concrete means M20 concrete with 20% flyash as CRM.

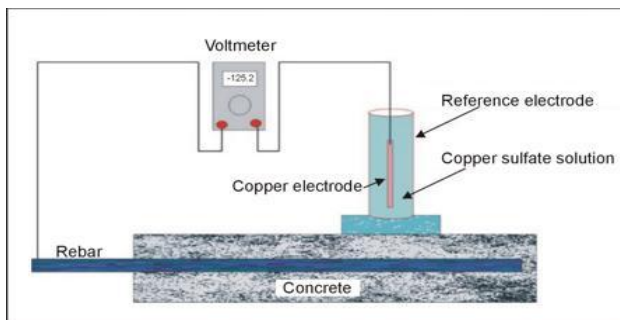
2) Admix Concrete means , Concrete mixed with Chemical admixture (Silplus Super)

3) CS – Cylinder Specimen

Experimental investigations in the Laboratory :

To study the effectiveness of different coatings on angle, admixtures in concrete and coatings on concrete surface , many specimens were cast in the lab and placed in the water tub , contain 3.5% NaCl mixed water. The specimens are connected with DC pack to induce corrosion, here positive terminal is connected with the steel angle and the negative terminal is connected with stainless steel plate to accelerate the corrosion .Then the level of corrosion were taken periodically by using half -cell potentiometer (after the curing period) .

Experimental Investigation by Half – Cell Potentiometer:



The half-cell is a hollow tube containing a copper electrode and immersed in copper sulfate solution. The bottom of the tube is porous and is covered in a sponge material. The copper sulfate 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 rebar and the concrete over the rebar. Large negative voltages (-350mV) indicate that corrosion may be taking place. Voltages smaller than about -200 mV generally mean corrosion is not taking place.

Fig:11 Half Cell test Set up

3.1 Impressed Voltage Test

This is an accelerated corrosion test carried out to assess the performance of coated angles coated specimens under accelerated electrochemical corrosion conditions. The test specimen comprises of 150mm Ø and 300mm height concrete cylinder coated and uncoated

angles were embedded centrally such that it gives a clear cover on all sides. The coated angles act as a working electrode. A non conductive plastic container was used for the test. The concrete cylinder was placed centrally in the container surrounded by stainless steel plate which act as cathode and filled with 3%NaCl electrolyte. A Constant potential of 12V was applied to the system using a DC power supply regulator. The variation in development of corrosion current was monitored at regular intervals using a high impedance multimeter. The time required for the relative resistance of coating material against chloride ingress and subsequent corrosion.

3.2 Bond Strength Test

The bond strength of reinforcing bar in concrete shall be determined with pull out specimens. The test specimens shall be coated and uncoated bars of 20mm nominal diameter. Bond



strength shall be calculated from the load at a measured slip of .025mm and 0.25mm. The age of the concrete shall be 28 days. The test shall be carried out applying axial force on the bar and by measuring the slip at free end of the bar. The test shall be continued up to the failure of the bond between bar and the surrounding concrete. The failure shall deemed to have occurred when the free end slip of

the bar exceeds .2mm. the load and slip measurements are recorded at a slip of .01mm , 1mm and at failure. The mean bond strength at the measured slip of .025mm and 0.25mm for coated bars shall not be less than 80percent of the corresponding mean bond strength for uncoated bars.

Chemical Resistance Test

Concrete is not fully resistant to acids. Most acid solutions will slowly or rapidly disintegrate Portland concrete depending upon the type and concentration of acid. Certain acids, such as oxalic acid and phosphoric acids are harmless. The most vulnerable part of the cement hydrate is $\text{Ca}(\text{OH})_2$ but C-S-H gel can also be attacked.



Silicious 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. At a pH value below 4.5, the attack is very severe. As the attack proceeds, all the cement compounds are 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 aluminates phase in cement to form calcium sulphoaluminate, which on crystallization can cause expansion and disruption of concrete.

4. Results and Discussion

1. Half cell potentiometer Results

Half cell potentiometer readings were taken on specimen every 50 hours. The experimental set up is as shown in the figure11 . Table 1 and Figure14,15 shows the variations of half cell potentiometer readings with accelerated time.

Table 1: Half Cell Potentiometer Value

Time In Hrs	CS 1	CS 2	CS 3	CS 4	CS 5	CS 6	CS 7	CS 8	CS 9	CS 10
0	-61	-80	-129	-107	-50	-111	-48	-108	-148	0
60	-260	-299	-263	-257	-148	-243	-129	-229	-219	0
100	-430	-390	-345	-362	-189	-262	-145	-289	-282	-103
160	-416	-444	-391	-411	-221	-301	-161	-311	-355	-158
200	-430	-473	-388	-444	-249	-417	-197	-421	-436	-193
240	-450	-522	-439	-461	-270	-522	-210	-463	-510	-223
300	-559	-601	-526	-489	-366	-673	-321	-547	-615	-259
360	-601	-631	-622	-589	-429	-698	-401	-571	-649	-291
400	-629	-645	-698	-625	-470	-702	-438	-578	-669	-309

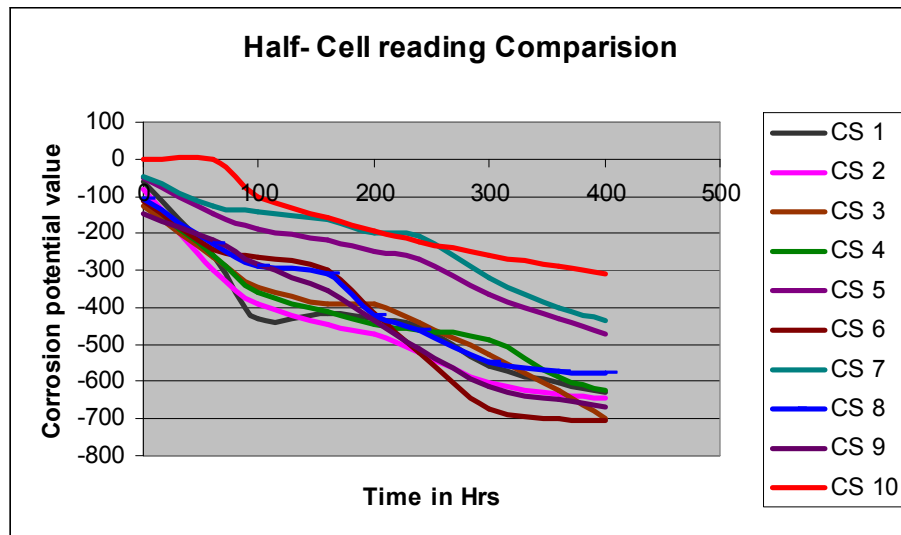


Fig : 14 : Half Cell Comparison Value

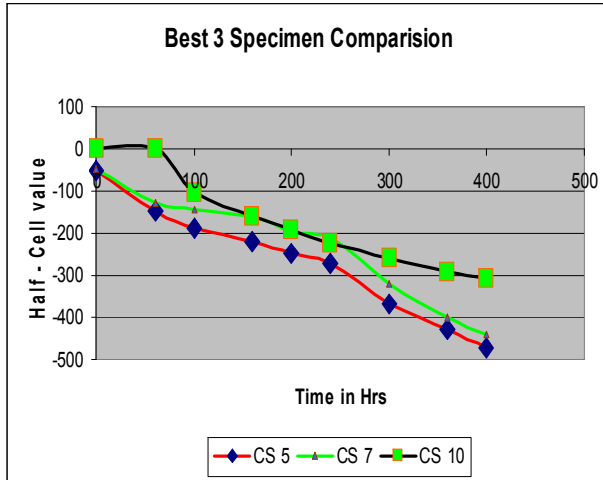


Fig:15: Half Cell potential Value Comparison

Fig : 16: Cracked Specimen

Figure 16 shows that , the crack propagation which occurred in Corrosion inhibitor mixed concrete specimen. The Specimen get cracked after 280 hrs.

The **Figure14,15**, shows the Time vs corrosion potential behavior of coated specimens in the Half CellPotentiometer test. It can be seen that there is a reduction in corrosion potential for Flexibond ACSR coated specimens compared to other specimens. This observation is due to a higher resistance of these coating materials against chloride ingress. The longer initiation period of Flexibond ACSR Coating is due to the Barrier nature of the Coating.

3.5 Impressed Voltage Test Results

Impressed Voltage readings were taken on specimen every 50 hours upto 300 hrs.**Table 2 and Fig 17,18,,** shows the variations of Impressed Voltage readings with accelerated time

Table 2: Impressed Voltage test Value

Time	CS 1	CS 2	CS 3	CS 4	CS 5	CS 6	CS 7	CS 8	CS 9	CS 10
0 hrs	0.2	0.2	0	0.1	0	0	0	0	0	0
50 hrs	1.05	1	0.52	0.61	0.32	0.59	0.23	0.49	1.09	0
100 hrs	1.3	1.29	0.79	0.82	0.56	0.62	0.39	0.63	1.69	0.23
150 hrs	1.6	1.5	1	1.2	0.75	0.98	0.46	0.98	1.9	0.59
200 hrs	2.3	2.4	1.32	1.46	1.02	1.3	0.62	1.26	2.52	0.76
250 hrs	2.76	2.69	1.59	1.82	1.15	1.69	0.85	1.49	2.95	0.82

300 hrs	3	2.9	1.8	2	1.3	1.9	1	1.6	3.2	1
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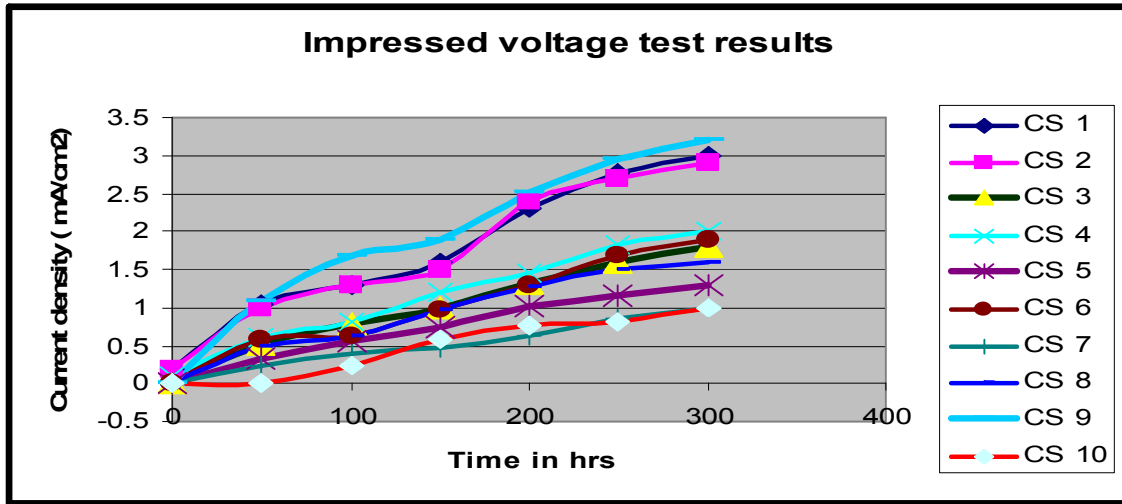
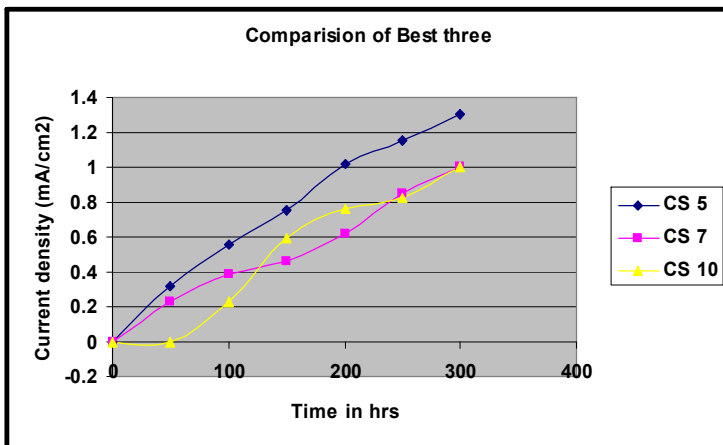


Fig:17: – Current Density Value of 10 Specimens



The Figure 17,18, shows the Time vs Current density behavior of coated specimens in the impressed voltage test. It can be seen that there is a reduction in current density for coated specimens compared to other specimens. This observation is due to a higher resistance of these coating materials against chloride ingress. The longer initiation period of Flexibond ACSR Coating is due to the

Barrier nature of the Coating. Incase of Un coated specimens as well as uncoated angles and Corrosion Inhibitors mixed specimens current density values are high when compared with (three Level Coating) Flexibond ACSR Coating.

Fig: 18: – Current Density Value of CS 5,7,10

Bond Strength Test

The Bond Strength Test has been carried out and the test results are presents here as shown in the table

Table : 3: Pull out Value

Slip	Load in KN
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	Demech	Epoxy	FACSR	Plain
1	0	1	0.5	0.8
2	0	1.4	1	1.1
3	0	2.4	4.5	2
4	0	7	9	6.8
5	4	8.5	14	8.2
6	7	9	17.4	11
7	11	-	-	15
8	17	-	-	

Applied Voltage Test Results

The Applied Voltage test has been carried out and the test results are presents here as shown in the table

Table : 4: Applied Voltage Test Readings

OBSERVATION ON APPLIED VOLTAGE TEST		
Type of Coating	Observation at the end of 1 hour	
	Anode	Cathode
FACSR Coating	No Corrosion Products of Iron	NO evolution of Hydrogen gas
Epoxy Coating	Light Rust Spots	Evolution of Hydrogen Gas
Demech Coating	No Corrosion Products of Iron	NO evolution of Hydrogen gas
Plain Angle	Innumerable rust Spots	Vigorous evolution of Hydrogen Gas

4. Conclusions

Based on the above experimental Study, the following conclusions are drawn.

1. It is observed that the coated specimens perform well when compared to the uncoated specimens.
2. It is observed from the Half cell potentiometer test, that the time required for the corrosion initiation level (-350 mV) for the two and three coated specimens are more than that of the single level protection and uncoated specimens
3. It can be seen that there is a reduction in current density for coated angles compared to uncoated stub angle specimens.
4. The specimen with two level coating(CS5)(with external surface coating) takes more (approximately three times) time for corrosion initiation.

5. Three level coated(with external surface coating)(CS7) and specimen also shows the same trend as two level coated specimen. Approximately three times , more than that of uncoated specimen.
6. Demech Coated specimen(CS10) Perform very well when compared with other coated specimen, both in Half cell test and impressed voltage tests, shows the same trend.
7. Epoxy Coated angle with conventional concrete specimen shows about twice time required for initiation of corrosion.
8. From the impressed voltage test results, the same trend has been confirmed.
9. From the result of both tests, it is observed that uncoated angle with concrete mixed with recron 3S fibre delays the corrosion period more than two times , when compared with other uncoated specimen with conventional concrete specimen.
10. The three level coating(With external surface coating) specimen gives very good results followed by two level coating specimen.
11. It can be seen that the bond strength , in the case of FACSR Coated specimen and Demech coated specimens, a similar bond strength values are observed , the value is 10.8% higher than the uncoated specimens
12. Reduction in bond strength of upto 30% for epoxy coated specimen were observed. Bond strength values were influenced by frictional resistance, adhesion, and mechanical interlocking.
13. Chemical Strength Test shows that demech coated specimen, and FACSR coated specimen are performed well in all test mediums when compared with epoxy and uncoated specimens.
14. It is observed that the demech Coated specimen performs very well in the Applied voltage test, there is No Corrosion Products of Iron in Anode and No evolution of Hydrogen gas in Cathode in First one hour test.
15. The same trend was observed in FACSR Coated Specimen.
16. After the completion of the Complete test, Demech Coated Specimen secured first position in Corrosion resistance, and FACSR secured second position in Corrosion resistance
17. In the vapour Phase demech Coated specimen perform very well and 5% of vapour occurred in FACSR Specimen.

Three Level Coating (Coated Angle +SIpllas super mixed Concrete +Externally Coated by Flexibond ACSR) and (Demech Coated Angle +Conventional Concrete +Externally Coated by Demech)& Two level Coating (Plain Angle + 20% cement replaced by Fly ash mixed Concrete +Externally Coated by Flexibond ACSR) exhibited excellent corrosion resistance. FACSR & Demech coated specimen posses good bond strength and both are having chemical resistance characters. Based on the results it was suggested that Flexibond ACSR and Demech coating has to be applied after 28 days curing over the specimen.

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