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Influence of Protective Coatings on Corrosion Resistance in Transmission Line Tower Foundations

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Abstract:
Concrete is one of the most widely accepted materials for civil engineering structures due to its inherent properties; especially its strength to sustain imposed loading conditions. 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. On account of technical and economical concern, efforts are being made to enhance the service life of concrete structures by various methods..The reliability of the electric power system is essential in the modern world. 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 .

Corrosion of galvanized transmission line tower stubs just above the concrete chimney has occurred at several locations in Tamil nadu. 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. 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 will initially occur in the presence of aggressive chloride ions. An important consequence of pitting is that the localized attack may be very service, which may lead to structural catastrophe.

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. Individual and combined effect of coatings have been evaluated using half cell potentiometer test. The parameters involved for the deterioration of stub concrete and stub angle of transmission tower foundations had been discussed and concluded that three level coatings explained in the paper performs effectively in resisting corrosion of transmission tower stubs.

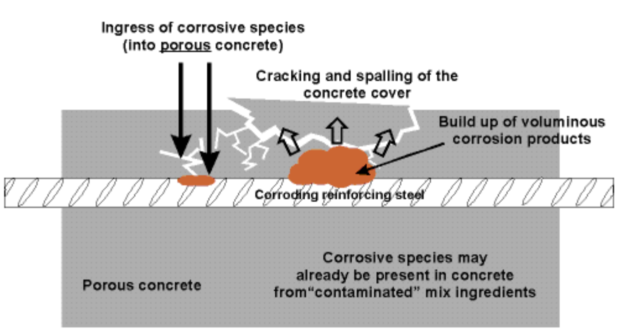
Introduction:

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 1,15,000 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.

Laboratory investigations:

Fig.1. Transmission stubs exhibiting a form of pitting/ crevice corrosion.

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.

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Protective Materials Descriptions

I)Flexibond ACSR (Polymer Based) –M ix 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 sealingWhen 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/mortarIt 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)

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

Fig:3 Recron 3S Fibre

V) Epoxy Coated Angle

Fig :4: Epoxy Coated Angle

Specimen Details

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 FACSR (Two level Coating)
CS 6 = Epoxy Coated Angle + Conventional Concrete(Two Level Coating)
CS 7 = FACSRCoated Angle + Admix Concrete + Externally Coated byFACSR (3 Level Coating)
CS 8 = Plain Angle + Recron Mixed Concrete.(Single level Protection)
CS 9 = Plain Angle + Corrosion Inhibitor Mixed Concrete

Note : 1) Conventional Concrete means M20 concrete with 20% flyash as CRM.
2) Admix Concrete means , Concrete mixed with Chemical admixture (Silplas Super)
3) CS – Cylinder Specimen

Details of Specimens :

- ISA 50 X50X6mm(Coated and Uncoated) angle embedded Concrete (Cylinder 150Ø X 300mm)Specimen cast in Laboratory.
- Concrete of M20 grade is produced from 20mm down graded aggregate, locally available sand 43 grade Ordinary Portland cement and potable water.

Fig:5: Half Cell test in Specimens

Fig:6:Cast Specimen

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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.

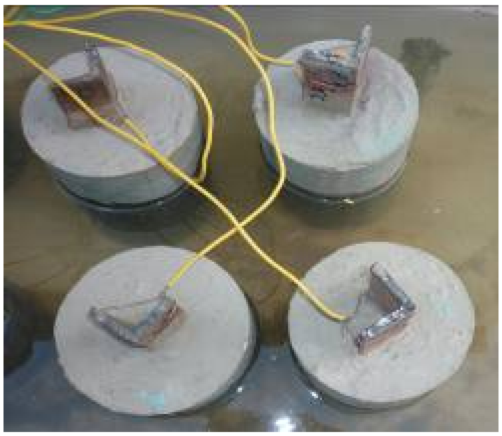

Fig: 7 Externally Coated by FACSR Specimens

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.

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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

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 half cell -readings were taken periodically (after the curing period) to assess the level of Corrosion.

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.

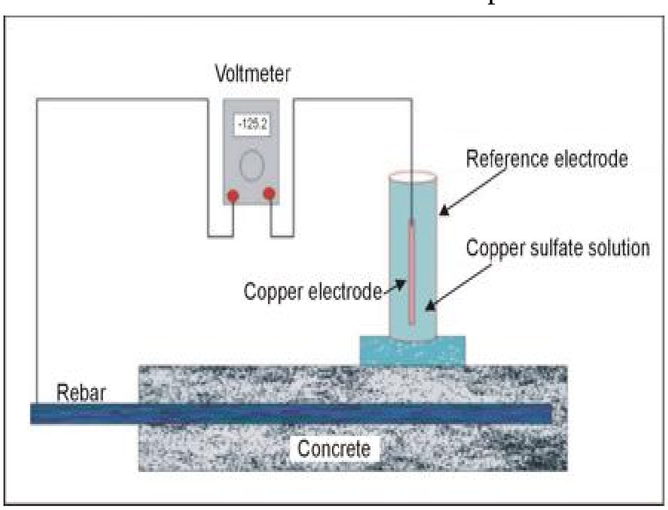

Fig:13 Half Cell test Set up

JCSE The Journal of Corrosion Science and Engineering
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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.

Results and Discussion

Table No 1- ASTM Standard value for HCP.

Corrosion	Potential Range
>95%	More negative than-350MV
50%	-200 to -350MV
<5%	More positive than -200M

Half cell potentiometer Results

Half cell potentiometer readings were taken on specimen every 50 hours. The experimental set up is as shown in the ***figure13* . *Table 2*** and ***Figure14,15,16*** shows the variations of half cell potentiometer readings with accelerated time.

Table No 2 – Hall Cell potential Value Vs Time in Hrs

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

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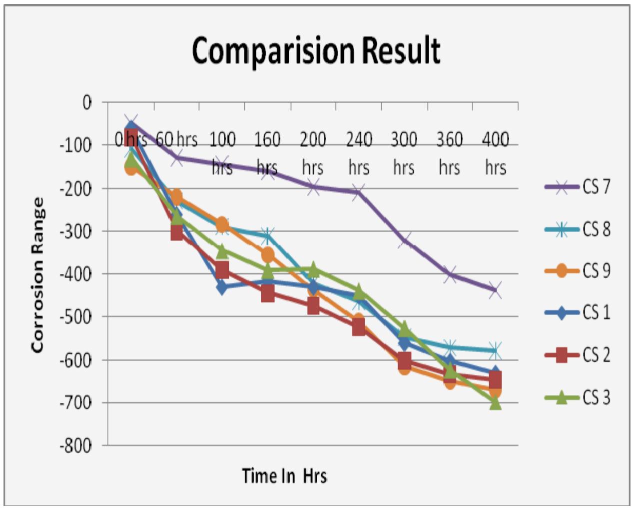

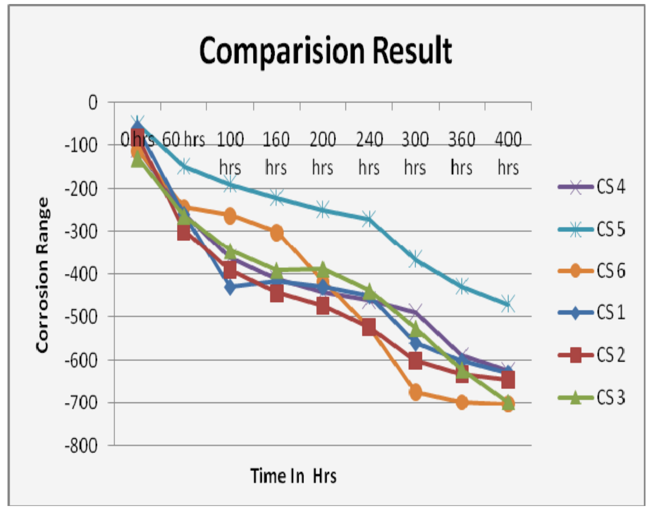

Fig : 14 : Half Cell Comparison Value

Fig: 15: Half Cell Comparison Valu

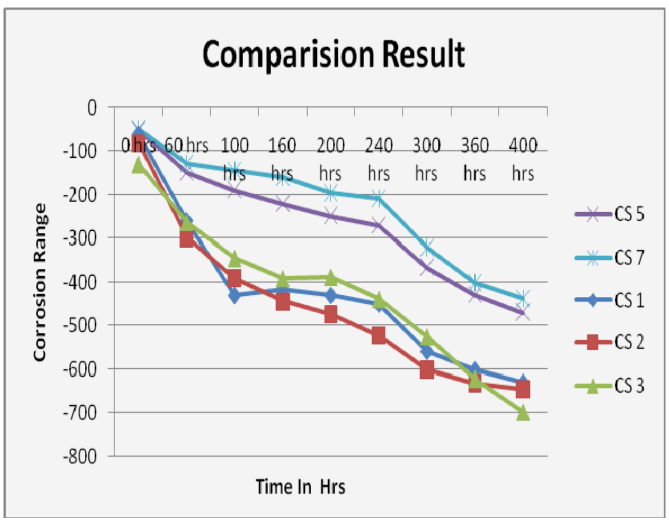

Fig:16: Half Cell potential Value Comparison

Fig : 17: Cracked Specimen

Figure 17 shows that , the crack propagation which occurred in Corrosion inhibitor mixed concrete specimen. The Specimen get cracked after 280 hrs.

The ***Figure14,15,16*** 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.

Impressed Voltage Test Results

Impressed Voltage readings were taken on specimen every 50 hours upto 300 hrs.***Table 3 and Fig 18,19,20,*** shows the variations of Impressed Voltage readings with accelerated time

Table No : 3 – Impressed Voltage values

Time	CS 1 (mA/cm²)	CS 2 (mA/cm²)	CS 3 (mA/cm²)	CS 4 (mA/cm²)	CS 5 (mA/cm²)	CS 6 (mA/cm²)	CS 7 (mA/cm²)	CS 8 (mA/cm²)	CS 9 (mA/cm²)
0 hrs	0.2	0.2	0	0.1	0	0	0	0	0
50 hrs	1.05	1	0.52	0.61	0.32	0.59	0.23	0.49	1.09
100 hrs	1.3	1.29	0.79	0.82	0.56	0.62	0.39	0.63	1.69
150 hrs	1.6	1.5	1	1.2	0.75	0.98	0.46	0.98	1.9
200 hrs	2.3	2.4	1.32	1.46	1.02	1.3	0.62	1.26	2.52
250 hrs	2.76	2.69	1.59	1.82	1.15	1.69	0.85	1.49	2.95
300 hrs	3	2.9	1.8	2	1.3	1.9	1	1.6	3.2

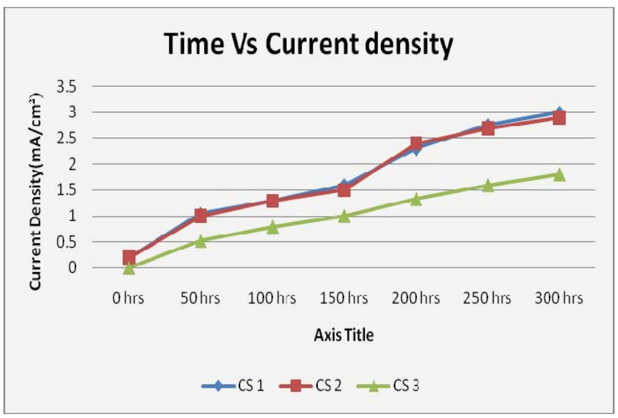

Fig:18: – Current Density Value of CS 1,2,3

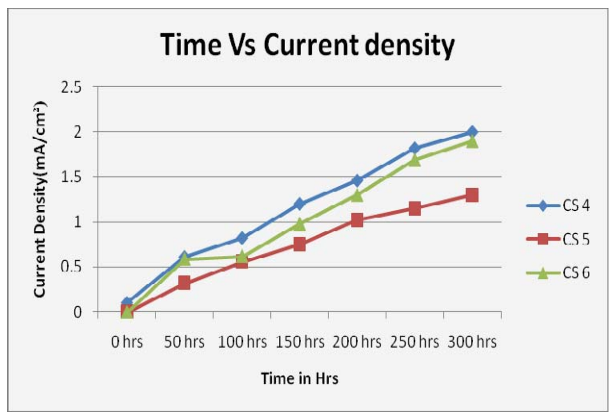

Fig: 19: – Current Density Value of CS 4,5,6

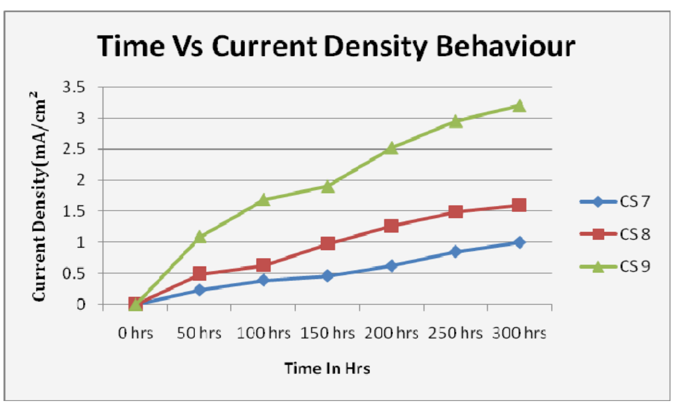

Fig: 20: – Current Density Value of CS 7,8,9

The Figure 18,19,20 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 Coatin

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) specimen also shows the same trend as two level coated specimen. Approximately three times , more than that of uncoated specimen.
6. Epoxy Coated angle with conventional concrete specimen shows about twice time required for initiation of corrosion.
7. From the impressed voltage test results, the same trend has been confirmed.
8. 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.
9. The three level coating(With external surface coating) specimen gives very good results followed by two level coating specimen.

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