Experimental Studies on the Prediction of Corrosion Levels in Reinforced TMT bars in SCC Exposed to Marine Environment

R. Rukmini, K.V. Ramana, V. Giridhar Kumar

Abstract: ***Reinforced concrete structures have good potential to be durable and capable of withstanding adverse environmental conditions. Failures in R.C.C structures do still occur as a result of premature reinforcement corrosion. Corrosion of steel has been recognized as one of the major durability problems in R.C.C structures. Damage due to corrosion of steel bars considerably reduces the strength, serviceability and life of structural components. Inspection and continuous monitoring techniques are necessarily to be carried out to assess the steel corrosion in buildings and bridge components in order to ensure their safety, durability for longer time. These techniques are essentially required for easy maintenance and repairs of the structural components also. Few investigations were carried out to study the corrosion levels in reinforced steel bars exposed to marine environment. Very few investigations were carried out so far to predict the corrosion levels in SCC exposed to salts and chemical environments. The present paper outlines the investigations carried out to predict the corrosion levels in TMT bars in Normal Conventional Concrete (NVC) and Self compacting concrete (SCC) exposed to marine environment . It also shows the severity of concrete exposure condition on the progressive corrosion in TMT bars when immersed in salt solution.***

Keywords: ***Reinforcement corrosion, Self Compacting Concrete (SCC), De-ionized water, Reinforced Thermo Mechanically Treated (TMT) bars, marine environment, Potential difference, Saturated Calomel Electrode (SCE), Open Circuit Potential (OCP) method.***

I. INTRODUCTION

Reinforced concrete is a widely used construction material for buildings, bridges, platforms and underground structures such as tunnels and pipelines. In general, reinforced concrete is a durable material that withstands severe exposure conditions like marine and industrial environments. Majority of reinforced concrete structures show high durability and good long term performance under adverse exposure conditions. Still large amount of structural concrete failures are identified as a result of reinforcement corrosion in steel bars. Corrosion is a process of chemical or electrochemical reaction between a metal and its surrounding environment that causes a deterioration of the parent metal and changes in its properties. Carbonation of concrete and the ingress of chloride ions into concrete are the major causes of corrosion of steel in reinforced concrete structures. Depassivation leads to the rapid corrosion of steel and progressive deterioration of concrete in structures.

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R. Rukmini, P.G Student, Department of Civil Engineering, G. Pulla Reddy Engineering College, Kurnool 518007 (A.P) India.

K. V. Ramana, Assistant Professor, Department of Civil Engineering, G. Pulla Reddy Engineering College, Kurnool 518007 (A.P). India.

V. Giridhar Kumar, Assistant Professor, Department of Civil Engineering, G. Pulla Reddy Engineering College, Kurnool 518007 (A.P). India.

Formation of rust due to corrosion in steel sets up expansive stresses in concrete which further leads to the cracking and spalling of concrete cover. Loss due to the corrosion consumes considerable portion of the budget of the country by the way of restoration and reconstruction measures of concrete. Proper monitoring for corrosion prevention in bars at appropriate time will make enormous savings of economy and thus leads for the best performance of the structure throughout its life. Quality control, good maintenance and proper planning along with non - destructive inspection methods and monitoring techniques help to detect corrosion levels in steel at early stages. Repairing, retrofitting and rehabilitation of corroded structures are complex and quite expensive methods. They require special treatments like cement grouting for the cracked concrete zone. Corrosion monitoring techniques will give quite complete information of timely changing conditions of embedded steel in R.C.C structures. It is necessary to study about the problems associated with the corrosion in steel and its possibilities to occur in NVC and SCC structural components. These studies ensure for the safety and serviceability measures to be carried out in time. Present investigations concern about the experimental studies carried out to predict the corrosion levels in embedded TMT bars in SCC (Grades M 20 and M 25) when exposed to the marine environment. NVC and SCC specimens are immersed in De-ionized water with different concentrations of NaCl and $MgSO_4$ for immersion periods of 28, 60 and 90 days. Corrosion levels in TMT bars after the immersion period were then predicted by Open Circuit Potential Method (OCP Method) with Saturated Calomel Electrode (SCE). **Nagataki Fujiwara (1992)** had conducted slump flow test on the properties of SCC mix to determine the workability characteristics of the mix. They had also performed the segregation test on SCC mixes made with locally available materials. The tests concluded that the slump flow required for self compacting concrete mixes ranges from 500 to 700 mm. [1] **Naik and Singh (1997)** had conducted tests on SCC mixes which contain 15 % to 25% class F and class C fly ashes to evaluate compressive strength. They also examined the effects of moisture and temperature during the curing regime period. Investigations showed that the concretes containing Class - C fly ash moist cured at 23^0 C developed high early age (1 to 14 days) compressive strengths when compared to those concretes containing Class - F fly ash. Long term compressive strength (more than 90 days) of mixes containing Fly ash is not much significantly influenced by the class of Fly ash.

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Tests are also conducted on air - cured SCC concrete mixes containing Class - F and Class - C Fly ash. The air - cured containing class - F Fly ash did not develop strengths equivalent to air - cured normal concretes and air - cured concretes containing class C Fly ash developed relatively greater compressive strengths than air - cured concretes containing class - F Fly ash. The compressive strengths of concrete mixes containing either class of Fly ash have been increased with an increase in curing temperature. [2] **Bauzoubaa and Lachemi (2001)** had conducted experimental investigations to study the performance of SCC made with high volumes of Fly ash. Nine SCC mixes and one control concrete mix has been studied during the experimental investigations. The cementatious material content was maintained constant (400 kg/m^3) and water - binder ratios ranged from 0.35 to 0.45. In the SCC mixes cement has been replaced by 40%, 50%, and 60% by class - F fly ash. Tests were carried out to study the viscosity and stability properties of fresh concrete mixes. The mechanical properties of hardened concrete such as compressive strength and drying shrinkage are also determined. The compressive strengths of SCC mix ranges from 26 to 48 MPa. They also stated that economical SCC mixes could be successfully developed by incorporating high volumes of Class F fly ash. [3] **Nan Su *et al* (2001)** proposed a new mix design method to develop SCC mixes. They concluded that the amount of aggregates, binders, mixing water as well as dosage and type of super plasticizer are the major factors to influence the properties of SCC mixes. The amounts of coarse and fine aggregates are first determined. The paste of cementitious materials (binders) is then filled into the volume of these aggregates to ensure that the prepared SCC mixes has desired flow and filling abilities and self compacting properties. Tests were carried to examine the properties of SCC mixes in fresh and hardened states to assess the performance of SCC. Results indicated that the proposed new design method could be used successfully to develop high quality SCC mixes. Tests showed that this method is simpler and easier for implementation and less time consuming than JRMCA method. (Japanese Ready - Mixed Concrete Association).

The method requires small amounts of binders and saves cost. [4] **Bertil Persson (2001)** has carried out experimental and numerical studies on the mechanical properties of self compacting concrete and normal conventional concrete. He studied about the compressive strength, elastic modulus, creep and shrinkage properties of SCC and NVC mixes. Studies are carried out on eight mix proportions of sealed or air - cured specimens with water - binder ratio (w/b) varying between 0.24 and 0.80. Studies are carried out on the creep, strength and the relative humidity at 90 days. Results showed that the elastic modulus, creep and shrinkage of SCC mixes did not differ significantly from the corresponding properties of NVC. [5] **Subramanian and Chattopadhyay (2002)** had carried out several trials to arrive at an approximate mix proportion of self compacting concrete and the dosages of VMA and SP to be used to produce an economical SCC mix. On the basis of these trials it was discovered that self compactability could achieved when Ca content was restricted to 46 % and sand content in the mortar portion is varied from 36 % to 44% . Again water - powder ratio is varied from 0.3 to 0.7. They conducted several tests related to the tendency of the concrete to bleed and its ability to pass the U- tube test. They concluded that a combination of 0.1% of Welangum and 0.53% by weight of water acrylic co-polymer type SP had produced a satisfactory self compacting concrete. [6] **Hajime Okamura and Masahiro Ouchi (2003)** had proposed a mix design method for SCC which is based upon paste and mortar studies for super plasticity compatibility followed by trail mixes. These investigations emphasized the need to test the trail mix of SCC for passing ability, filling ability and flow ability and segregation resistance for relevant. [7] **Paratibha Aggrawal (2008) *et al*** presented a procedure for the design of self compacting concrete mixes based on their experimental investigations. During their investigations scc was developed without using viscosity modifying agent the properties of mixes like passing ability, filling ability and segregation resistance are found well within the requirements for the w/b ratio ranging between 1.18 to 1.125. investigations revealed that the compressive strength at the age of 28 days was around 25 MPa to 33 MPa by using OPC 43 grade cement and keeping the cement content around 350 kg/m^3 to 415 kg/m^3. [8] **Girish (2010) *et al*** carried out investigations to find out the influence of paste and powder content on scc mixes. Tests were conducted with water content varying from 175 l/m^3 to 210 l/m^3 with three different paste contents. Slump flow, V- funnel and J - Ring tests were carried out to study the performance of SCC. Results showed that the flow properties of SCC increased with an increase in the paste volume. Slump flow of fresh SCC has been increased almost linearly and in a significant manner, as the powder content of SCC is increased. Results also concluded that the paste plays an important role in the flow properties of fresh SCC in addition to water content. As the paste content is increased, the passing ability as indicated by J - Ring has been improved. [9] **Mayur B. Vanjare, Shriram H. Mahure (2012)** had carried out an experimental studies on incorporating Glass Powder (GP in different for production of self-compacting concrete. Test results show that partial replacement of cement by the addition of glass powder in SCC mixes had reduced the self-compatibility characteristics like filling ability, passing ability and segregation resistance of the mix. The flow values had been decreased by an average of 1.3%, 2.5% and 5.36% for glass powder replacements of 5%, 10% and 15% respectively. [10] **Surabhi.C.S, Mini Soman, Syam Prakash.V** carried out experimental studies on the proportions of cement content in the SCC mix when replaced with various percentages of limestone powder. The fresh and hardened properties of different percent mixes were studied. It is observed that limestone powder can be effectively used as a mineral additive in SCC. Test results had concluded that the 7 - day and 28 - day compressive strength of the mixes had been increased with the increase in limestone powder content upto 20%. This improvement in 28 - day compressive strength of the mix at is about 20% for a partial replacement of cement with about 20 percent limestone powder. Further addition of limestone powder had reduced the strength of mix.

The hardened properties of the mixes like cylinder compressive strength, split tensile strength, flexural strength and modulus of elasticity had been improved with the addition of limestone powde[11] **Suraj N. Shah., Shweta S. Sutar, Yogesh Bhagwat** had carried out experimental studies to find the effects of addition of red mud (a waste product from the aluminum industries) and foundry waste sand (a waste product from foundry) on the properties of self-compacting concrete. Investigations had showed that the maximum compressive strength of self-compacting concrete with the combination of admixtures **(SP + VMA)** were obtained by adding 2% foundry waste sand as partial replacement. [12] **Guneyisi et al(2005)** conducted studies on concretes having two different water cement ratios and two different cement contents by using a plain and four different blended Portland cements by testing specimens subjected to three different curing procedures (uncontrolled, controlled and wet curing).The results showed that the wet curing was essential to achieve higher strength and durability characteristics for both plain and especially blended cement concretes. It also proved that cement type, w/c ratio, age and curing procedures had significant effect on both strength and durability characteristics of concretes. [13] **Hamid Soleymani and Mohamood Ismail (2004**) conducted a laboratory study to estimate the corrosion activity of reinforcing steel embedded in two types of concrete, ordinary and high performance, using different corrosion measurement methods and to compare them. In their experiment, High performance concrete specimens showed lower corrosion testing results. [14] **Cabrera(1996)** has found a relationship between corrosion rate and crack pattern and intensity by using concrete beam s subjected to accelerated corrosion . The results show that there is an inverse relation between reinforcement cover and degree of corrosion. He also found a relationship between corrosion rate and loss of structural serviceability from measurements of bond strength, cracking and deflection of concrete beams. It was found that fly ash concrete exhibited better resistance to corrosion damage than normal Portland cement. [15]

II. EXPERIMENTAL PROGRAMME

The experimental programme consisted of procurement of materials, tests for physical properties of cement, coarse and fine aggregates and mix design procedure for normally vibrated conventional concrete and self compacting concrete in accordance with I.S specifications (in accordance with SP:23-1982 and I.S :10262- 2009) and Nan Su method respectively. It includes preparation of test specimens and to make the test reports for the compressive strength of M 20 and M 25 grade conventional and self compacting concretes. Preliminary investigations are carried out initially to find the compressive strength of plain conventional and self compacting concrete by accelerated curing method. Average corrosion activity levels raised in the specimen TMT bars when immersed in de - ionised water with and without NaCl and $MgSO_4$ salts are measured by Open Circuit Potential Method. Specimens are immersed in two different concentrations of NaCl (0.20 M and 0.25 M) and $MgSO_4$(0.02 M and 0.025 M) for 28,45, 60 and 90 days. These test results and values are tabulated in Table 2 for reference purpose.

A. Materials

OPC of 53 - Grade was used in both NVC and SCC throughout the experimental investigations. Locally available river sand with fineness modulus 3.07 and belonging to grading zone I of I.S: 383 was used as fine aggregate for preparing Normal conventional concrete and Self compacting concrete. Similarly, coarse aggregate of 25- mm maximum nominal size with fineness modulus 6.31 was used to prepare two types of concrete of Grades M20 and Grade M25 respectively for NVC and SCC. Class - F Fly ash from Raichur Thermal Power Plant, Raichur, (Karnataka State) and GGBS from local steel industry nearby Kurnool, (Andhra Pradesh State) were used to prepare self compacting concrete. No plasticizer has been used to prepare Normal conventional concrete where as **CONPLAST SP430** @ the rate of 1.1 % and viscosity modifying agent (VMA) at the rate of 5 ml per 50 kg (one bag) of cement were used to prepare self compacting concrete of two grades (M 20 and M 25).

B. Concrete Mix Proportions

Four concrete mixes designated as **A/20 NVC, B/25 NVC, C/20 SCC, D/25 SCC** were used in the experimental investigations. Mixes designated as A/20NVC (0.52:1:1.88:3.08), B/25 NVC (0.45:1:1.74:2.86) belongs to Normally Vibrating Concrete where as C/20 SCC (0.42:1:1.997:1.18) and D/25 SCC (0.40:1:1.85:1.16) belongs to Self Compacting Concrete respectively. These mixes were used to cast the test specimens to predict the corrosion levels when subjected to marine environment. One set consisting of 20 specimens of size **(100 mm x 100 mm x 450 mm)** with conventional M20 grade design mix and another set consisting of 20 specimens of same size with M20 grade SCC design mix were casted. Same number of specimens were casted for the two varieties of concrete (NVC and SCC) for M25 grade design mix also. Each concrete specimen is reinforced with one TMT bar of 16 - mm diameter and 350 mm length. The weight of TMT bars was noted initially before it is placed into concrete inside the moulds.

C. Preparation of Test Specimens

The exact proportions of cement, sand, and crushed granite metal of 25- mm size were weighed and mixed thoroughly with pure water to produce the concrete mix. Concrete was filled in the moulds for a length of 450mm. The position of the TMT steel bar at the time of concreting was so adjusted that it is placed horizontally near the central height of the mould and to obtain a projection of 50 mm to one side of the specimen. Workability characteristics of fresh conventional concrete were measured by slump and compaction factor methods. Filling, flowing and passing ability characteristics of self compacting concrete were maintained in accordance with **EFNARC guidelines**. These values corresponding to NVC and SCC are recorded and noted. Specimens are compacted on a vibrating table for proper compaction and kept for set for 24 hours.

The top surfaces of specimens were then leveled and made flush using a trowel. Specimens were demoulded a day after casting and cured in water till the date of testing.

One set of concrete specimens of M20 and M25 grades of NVC and SCC were kept in De-ionised water without salts for 28, 45, 60 and 90 days immersion period. Similarly another two sets of concrete specimens of same grade of NVC and SCC were immersed in De- ionised water with different concentrations of **Na Cl (0.20 M and 0.25 M) and Mg SO_4 (0.02 M and 0.025 M)** for the same immersion period .Preparation and casting of concrete specimens are shown in **Figure 1**.

Figure 1. Preparation and Casting of Specimens

The moulds were then stripped off after 24 hours. One set of concrete specimens of M20 and M25 grades of NVC and SCC were kept in De-ionised water for 28, 45, 60 and 90 days immersion period. Similarly another two sets of concrete specimens of NVC and SCC were immersed in De-ionised water with different concentrations of **Na Cl (0.20 M and 0.25 M) and Mg SO_4 (0.02 M and 0.025 M)** for the same immersion periods of 28, 45, 60 and 90 - days in order to compare the corrosion levels with those of De - ionized water without salts. The details of immersed specimens and different concentrations of NaCl and $MgSO_4$ are summarized in **Table 1.** The prepared concrete specimens are shown in the **Figure 2.**

Figure 2. SCC Specimens

D. Test Procedure

The corrosion activity levels in the reinforced TMT bars of the concrete specimens subjected to marine environment were predicted by Open Circuit Potential (OCP) method. In this method, a Saturated Calomel Electrode (SCE) was used as a reference electrode. Concrete specimens were immersed in De-ionised water and salt solutions for periods of 28, 45, 60 and 90 days respectively .The positive terminal of the voltmeter is connected to the end of the TMT bar projecting out from the specimen and the negative terminal is connected to the reference electrode. The potential difference between the distinguished points over the concrete specimen is measured with Saturated Calomel Electrode (SCE) .Test setup for Open circuit potential method was shown in the **Figure 3.**The prediction of corrosion activity levels by open circuit potential method is shown in the **Figure 4.**

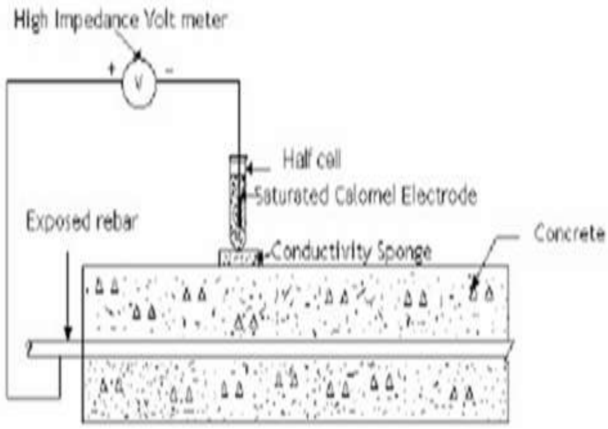

Figure 3. Test Set up for OCP Method

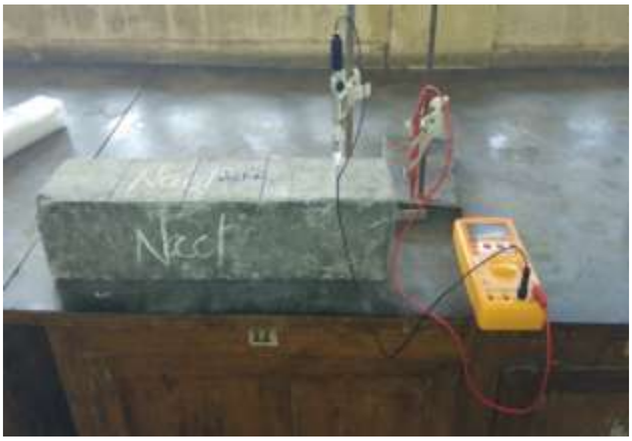

Figure 4 . Prediction of Corrosion Levels by OCP Method

III. RESULTS AND DISCUSSION

Table 1 shows the corresponding standard corrosion activity levels in milli Volts (- mV) specified by ASTM C 876 - 91for low, intermediate, high and severe risk conditions of exposure for normally vibrated concrete and self compacting concrete by Open Circuit Potential method. Table 2 shows the experimental test results for M20 and M25 grade NVC and SCC for different exposure conditions of de-ionized water with and without salts.

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These values were compared with those values given by ASTM C 876 - 91 standards shown in Table 1. The probability of reinforcement corrosion in bars exposed to salt environment is predicted and shown in Table 2. The corrosion activity levels in TMT bars for different exposure conditions are graphically shown in Figures 5 to 7. It is concluded that self compacting concrete is ideally good to reduce corrosion in TMT bars when compared to normal conventional concrete when exposed to same concentrations of NaCl and $MgSO_4$. salts.

Table 1. Corrosion Condition (ASTM C 876 - 1991)

Open circuit potential (OCP) values, - m V		Corrosion condition
(mV vs. SCE)	(mV vs. CSE)	
< - 426	< - 500	Severe condition
< - 276	< - 350	High (<90% risk of corrosion)
- 126 to - 275	- 350 to - 200	Intermediate (risk of corrosion)
> - 125	> - 200	Low(10% risk of corrosion)

Table 2. Prediction of Corrosion Levels for Different Exposure Conditions

Sample set no.	Type of Concrete	Grade of Concrete	Exposure condition	Average Open Circuit Potential Values (- m V)				Corrosion condition
				28 - days	45 - days	60- days	90 - days	
1	NVC	M 20	De-ionised water	93	108	110	142	Intermediate
		M25	De -ionised water	83	92	95	121	Low
2	SCC	M 20	De- ionised water	15	23	37	57	Low
		M25	De -ionised water	14	18	18	27	Low
3	NVC	M 20	NaCl - 0.20M	199	240	230	244	Intermediate
		M25	NaCl - 0.20M	161	185	190	221	Intermediate
4	SCC	M 20	NaCl - 0.20M	81	87	94	126	Intermediate
		M25	NaCl - 0.20M	57	72	89	104	Low
5	NVC	M 20	NaCl - 0.25M	210	226	277	309	High
		M25	NaCl - 0.25M	187	200	210	215	Intermediate
6	SCC	M 20	NaCl - 0.25M	109	112	121	123	Low
		M25	NaCl - 0.25M	100	102	105	113	Low
7	NVC	M 20	MgSO4 - 0.02M	133	135	138	145	Intermediate
		M25	MgSO4 - 0.02M	100	110	113	131	Intermediate
8	SCC	M 20	MgSO4 - 0.02M	42	57	56	64	Low
		M25	MgSO4 - 0.02M	35	40	44	55	Low
9	NVC	M 20	MgSO4 - 0.025M	129	156	167	186	Intermediate
		M25	MgSO4 - 0.025M	103	110	102	112	Low
10	SCC	M 20	MgSO4 - 0.025M	64	80	90	99	Low
		M25	MgSO4 - 0.025M	51	60	59	72	Low

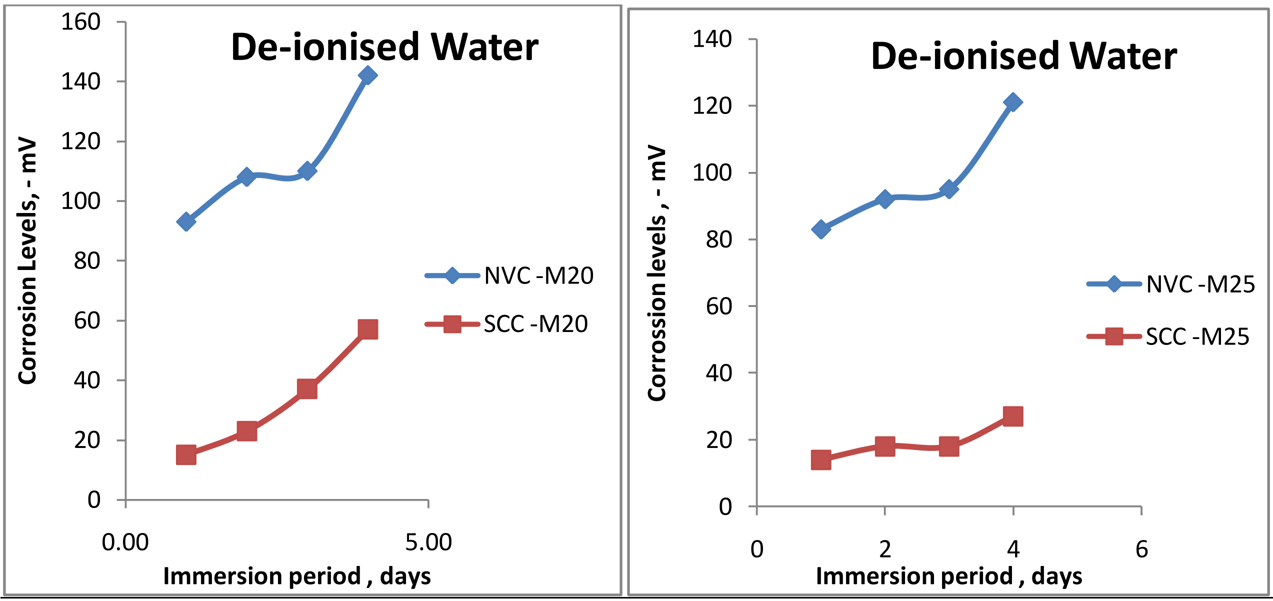

Figure 5: Corrosion levels in De-ionised water

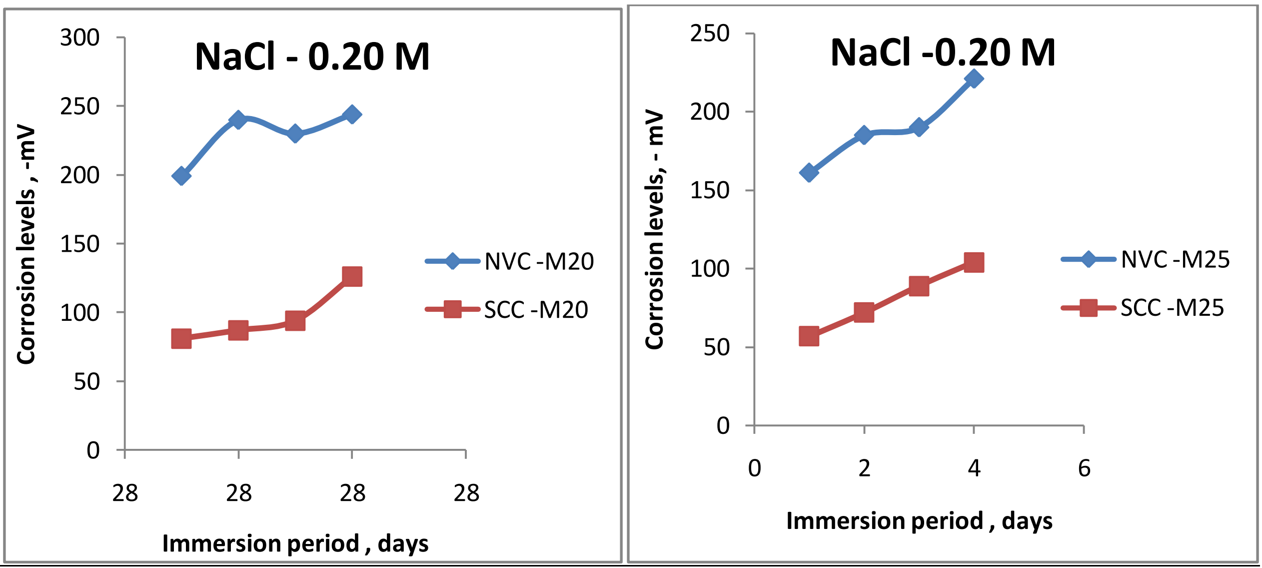

Figure 6: Corrosion levels in NaCl - 0.20 M

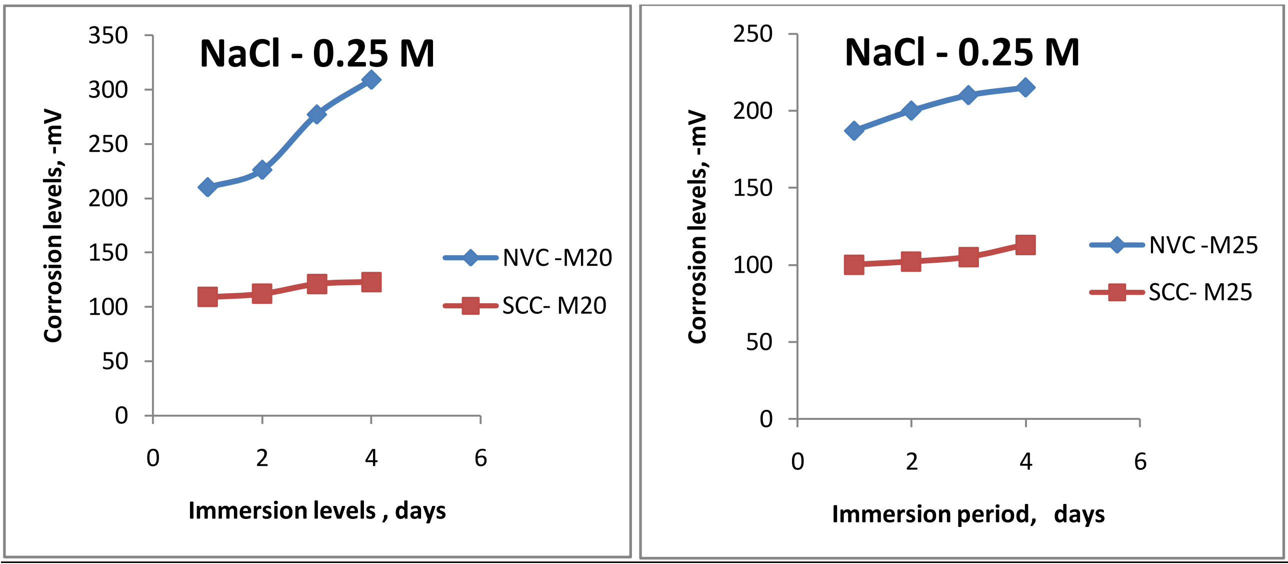

Figure 7: Corrosion levels in NaCl -0.25 M

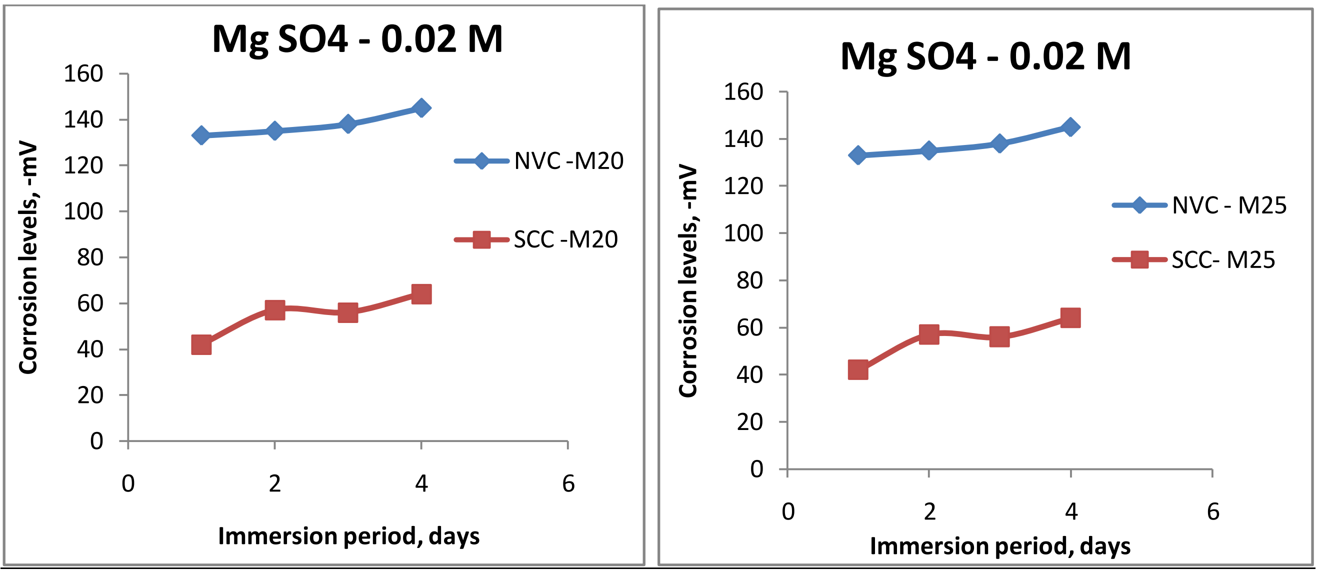

Figure 8: Corrosion levels in MgSO4 - 0.02 M

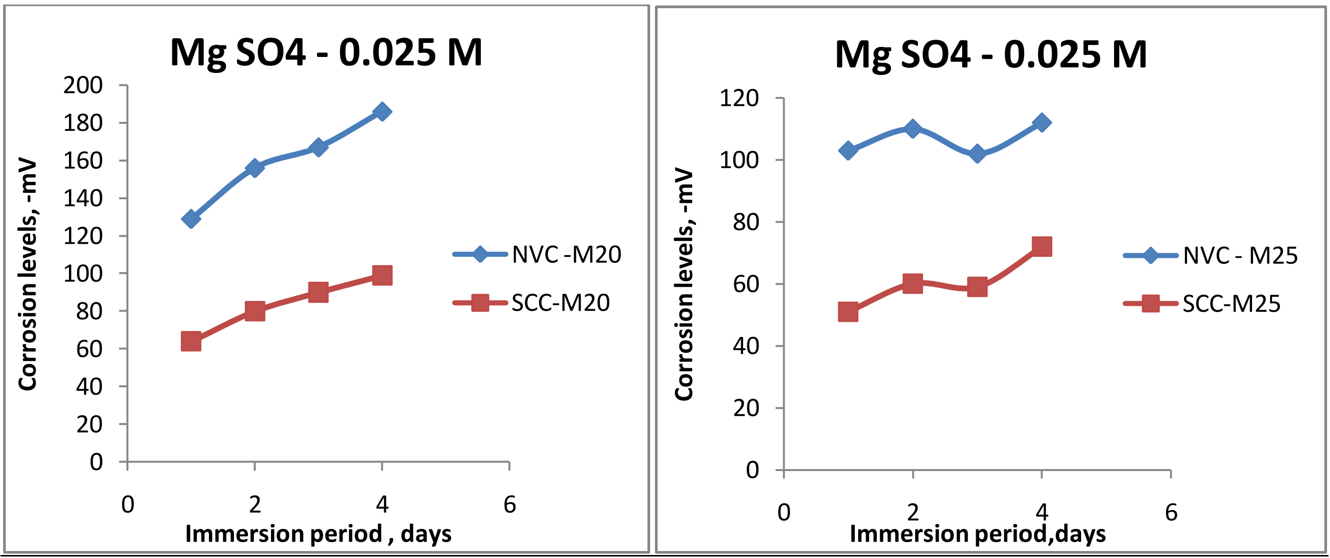

Figure 9: Corrosion levels in MgSO4 - 0.025 M

IV. CONCLUSIONS

The following conclusions were drawn from the experimental investigations on SCC and NVC specimens:

1. Corrosion activity levels in TMT bars for the specimens immersed in NaCl solution are observed to be higher than those for the specimens immersed in $MgSO_4$ solution for normal conventional concrete as well as self compacting concrete.
2. Corrosion activity levels in TMT bars for self compacting concrete specimens are observed to be lower than those for normal conventional concrete specimens, when immersed in different concentrations of NaCl and Mg SO_4 solutions for the same immersion period.
3. High corrosion levels in TMT bars when exposed to NaCl and Mg SO_4 salt solutions cause significant changes in the mechanical properties of steel.
4. Corrosion reduces yield strength, ultimate tensile strength and may cause increase in the percent elongation in TMT bars. This causes early fracture in bars and my affect the other similar properties of TMT bars when bars and concrete are exposed to severe and extreme exposure conditions.
5. SCC specimens perform better than Normal concrete specimens, when structural elements are subjected to surrounding corrosion environment.
6. Further investigations are to be carried out to study the effects of long term exposure conditions of salt environment on the strength and behaviour of TMT bars including NVC and SCC.

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AUTHOR PROFILE

R. Rukmini is currently pursuing M.Tech (Structural Engineering) in Civil Engineering Department at G. Pulla Reddy Engineering College (Autonomous), Kurnool, A.P. She is presently investigating over the corrosion mechanisms, effects of carbonation, chlorides and sulphate attack over embedded steel in concrete. The present project work is one of the NDT methods to investigate the monitoring techniques to predict the corrosion levels in self compacting concrete which is meant as a part of the intended course work for the completion of M.Tech. (Structural Engineering) Degree.

K. V. Ramana is presently working as Assistant Professor in the Department of Civil Engineering, G. Pulla Reddy Engineering college (Autonomous) , Kurnool A.P. He has overall experience of 6 years in teaching and civil engineering construction. His interested research areas include the applications of material composites in concrete, experimental stress analysis and fracture mechanics.

V. Giridhar Kumar is presently working as Assistant Professor in the Department of Civil Engineering, G. Pulla Reddy Engineering College (Autonomous), Kurnool A.P. He has an academic experience of 14 years in teaching and 6 years in civil engineering construction. His interested research areas include the applications of material composites in concrete, finite element method and its applications in civil engineering and steel structures. He is a member of 'The Institution of Engineers (India)', Kolkata. For queries contact***:*** giridharkumar1967@gmail.com