Experimental studies on the Prediction of Corrosion levels in Reinforced TMT bars in NVC & SCC exposed to Marine environment

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ABSTRACT: Reinforced concrete structures have good potential to be durable and capable of withstanding adverse environmental conditions. Failures in RCC 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. The damage due to corrosion of steel bars considerably reduces the strength, serviceability and life of structure. 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 required for the easy maintenance and repairs of the structural components also. Few investigations were carried out to study the corrosion levels in reinforced concrete exposed to the marine environment. Very few investigations were carried out to predict the corrosion levels in reinforced self-compacting concrete so far. Problems associated with the corrosion and its possibility of occurrence in steel embedded in normal conventional concrete and self-compacting concrete are necessarily to be studied. They are very important to ensure the safety and serviceability of the structural components also. The present work concerns about the experimental studies carried out to predict the corrosion levels in the TMT bars embedded in self-compacting concrete (Grades M 30 and M 35) 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 curing periods of 28, 45, 60, and 90 - days respectively. Corrosion levels in the TMT bars after the specified immersion period were then predicted by measuring the potential difference between specified points over the specimens with Saturated Calomel Electrode (SCE) by Open Circuit Potential Method (OCP Method). This paper outlines the investigations carried out to study the i) Corrosion levels in the TMT bars in Normal Conventional Concrete (NVC) and Self compacting concrete (SCC) exposed to marine environment and ii) severity of the exposure condition on the progressive corrosion of TMT bars.

Key words: Reinforcement corrosion, self-compacting concrete, De-ionized water, Reinforced TMT bars, marine environment, Potential difference, Saturated Calomel Electrode, Open Circuit Potential method.

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 capable of withstanding severe exposure conditions which include marine and industrial environment. Majority of concrete structures show high durability and good long term performance but there are still large amount of failures as a result of corrosion of reinforced steel. Corrosion is the chemical or electrochemical reaction between a metal and its surrounding environment that produces a deterioration of the metal and its properties. Carbonation of concrete or the ingress of chloride ions into concrete are the major causes of corrosion of steel in reinforced structures. Depassivation of steel leads to rapid corrosion of steel and progressive deterioration of concrete in structures. Formation of the rust due to the corrosion sets up expansive stresses in concrete which leads to the cracking and spalling of concrete cover. Corrosion loss consumes considerable portion of the budget of the country by way of restoration measures or reconstruction. Proper monitoring and taking suitable measures for corrosion prevention at appropriate time could make enormous savings and leads for the best performance of the structure. Quality control, good maintenance and proper planning need non - destructive inspection methods and monitoring techniques to detect corrosion levels in steel at early stages. Repairing, retrofitting and rehabilitation of corroded structures are complex and quite expensive and require special treatments for cracked concrete zone by cement grouting. Corrosion monitoring techniques give quite complete information of timely changing conditions of embedded steel in RCC structures.

LITERATURE REVIEW

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. 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)

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)

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)

Venkateswara Rao *et al* (2010) had developed standard and high strength self-compacting concrete mixes with different sizes of a coarse and fine aggregate based on Nansu's mix design procedure. Test results had indicated that self compacting concrete can be developed with all sizes of graded aggregate which satisfy the SCC characteristics. The mechanical properties of hardened mixes such as compressive strength, flexural strength and split tensile strengths were found at the end of 3, 7 and 28 days for standard and high strength SCC mixes with different sizes of aggregate. The optimum size of aggregate was found to be 10mm for standard self-compacting concrete (M30), where as it was 16 mm for high strength self compacting concrete (M 70) though the intermediate range of aggregate could also develop properties which satisfy the criteria for SCC. Test results on M30 and M70 grade concretes confirmed that the filling ability, passing ability and segregation resistance were better for higher grade concretes for the same size of aggregate. It is concluded that this is due to the higher fines content in M70 concrete. It was also noted that 10 mm size aggregate and 52% fly ash content had resulted in highest mechanical properties in standard SCC. Similarly 16 mm size aggregate with 31% fly ash content had resulted in highest maximum strength in the case of high strength SCC mixes.(10)

John J. Myers *et al (2012)* had carried out experimental investigations on the hardened properties of SCC that affect structural performance (For example, bond, shear, loss of prestress) and durability (For example, freeze - thaw resistance, permeability), particularly the influence of locally available aggregates and sensitivity in the SCC mix design. Sensitivity means that the impacts of relative small changes in the mix design that on the performance of the material and also the critical factor for a material such as concrete.(11)

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.(12)

Chockalingam. M (2014) has carried out experimental investigations to evaluate self compacting concrete which gets compacted under its own self weight. In his experimental work, different percentages of Marble Powder (MP) and Silica fume (SF) are added. Experiments are carried out for the effective replacement of cement with silica fume (0%, 15%, 20%,25%, 30%) and Marble powder (15%). Several tests such as slump flow, V-funnel, L-box, U-box are carried out to determine optimum parameters for the self-compact ability of mixtures. Test on Compressive strength, flexural strength and deform at ion characteristics of the specimens are studied. The results obtained from these tests are compared with conventional concrete specimens. The load deflection curves are also drawn. The results show that 15% to 20% replacement of cement with silica fume and 15% marble powder improves the properties of SCC. (13)

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 powder.(14)

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.(15)

Jamal Shannag and Suzan (2006) conducted an experimental investigation on concrete beams which were subjected to corrosion after the cover zone was replaced with different high performance fiber reinforced cementitious composites. The beams with cover containing 50/50 blend of brass coated and hooked steel fibres showed best flexural performance.(16)

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. (17)

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. (20)

EXPERIMENTAL PROGRAMME

The experimental programmer consisted of procurement of materials for investigations, tests for physical properties of cement and aggregates, mix design procedures for normally vibrated conventional concrete and self compacting concrete in accordance with I.S specifications (SP: 23 - 1982 and I.S: 10262 - 2009) and Nan Su method respectively.

It also include preparation of test specimens and making test reports for plain conventional and self compacting concretes of M30 and M35 grades respectively. Preliminary investigations are also made to find the compressive strength of plain conventional and self compacting concrete specimens by accelerated curing method and boiling water method. The average values of corrosion activity levels raised in the reinforced TMT bars in the concrete immersed in de - ionised water with two different concentrations of NaCl (0.20 M and 0.25 M) and Mg SO_4 (0.02 M and 0.025 M) after 28, 45, 60 and 90 days period are measured by Open circuit Potential Method and noted.

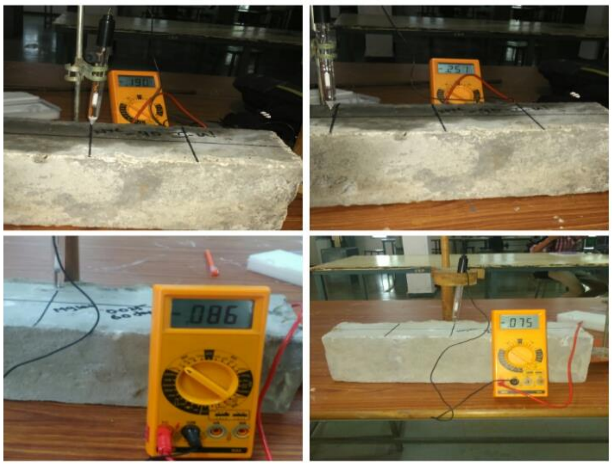
Materials

OPC of 53 - Grade was used 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 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 Grades M20 and Grade M25 respectively for both 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 of cement have been used to prepare self compacting concrete.

Preparation of specimens and Mix proportions

Four concrete mixes designated as A/30 NVC, B/35 NVC, C/30 SCC, D/35 SCC were used in the experimental investigations. Mixes designated as A/30NVC (0.45:1:1.755:2.88), B/35 NVC (0.43:1:1.634:2.75) belongs to Normally Vibrating Concrete where as C/30 SCC (0.45:1:1.997:1.18) and D/35 SCC (0.43:1:1.85:1.16)s 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 numbers of specimens were casted for the two varieties of concrete for M25 grade design mix also. Each Specimen is reinforced with 1 No. of 16 - mm diameter TMT bar of 350 mm length. The initial weight of each TMT bar was noted and then placed inside the moulds. The exact proportion of cement, sand, and crushed granite metal of 25- mm size were weighed and mixed thoroughly with pure water to produce the concrete. The concrete was then filled in the moulds for a length of 450mm. The position of the reinforced TMT bar at the time of concreting was so adjusted that the position of the same would be in the middle of the mould and to obtain a projection of 50 mm on one side of the specimen. The workability characteristics of fresh conventional concrete were measured by slump and compaction factor methods and those of self-compacting concrete were maintained in accordance with EFNARC guidelines. These values were recorded and noted. Specimens were compacted on a vibrating table for proper compaction and kept for set for 24 hours. After filling the moulds with concrete, the top surface of specimens was then leveled using a trowel. Specimens were demoulded a day after casting and cured well in water till the date of testing.The moulds were stripped off after 24 hours. One set of concrete specimens of M 20 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 1.



Test procedure

The corrosion activity levels in the Reinforced TMT bars of the concrete specimens subjected to alkaline 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 and then taken out for further investigations. The positive terminal of the voltmeter was connected to the end of the TMT bar projecting out from the specimen and the other terminal was connected to the reference electrode. The corresponding potentials between the salient points over the concrete specimens were measured with Saturated Calomel Electrode (SCE) and recorded. Test setup for Open circuit potential method was shown in Figure 2.

RESULTS AND DISCUSSION

ASTM C 876-91 specifies the OCP values and corresponding corrosion activity levels values in -mV(milli Volts) which specify low, intermediate, High, Severe risk conditions respectively.

These values are given in Table 2. The obtained test results were compared with the values given by ASTMC 876 - 91 standards and the probability of reinforcement corrosion under marine environment was predicted & shown in Table 3. It can be observed that the self-compacting concrete ideally behaves in a better manner than normal conventional concrete to reduce the corrosion activity levels in TMT bars, when concrete and steel bars were exposed to same concentrations of NaCl and Mg SO_4.

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

Open circuit potential (OCP) values		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

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 30	De-ionised water	93	108	110	142	Intermediate
		M35	De -ionised water	83	92	95	121	Low
2	SCC	M 30	De- ionised water	15	23	37	57	Low
		M35	De -ionised water	14	18	18	27	Low
3	NVC	M 30	NaCl - 0.20M	199	240	230	244	Intermediate
		M35	NaCl - 0.20M	161	185	190	221	Intermediate
4	SCC	M 30	NaCl - 0.20M	81	87	94	126	Intermediate
		M35	NaCl - 0.20M	57	72	89	104	Low
5	NVC	M 30	NaCl - 0.25M	210	226	277	309	High
		M35	NaCl - 0.25M	187	200	210	215	Intermediate
6	SCC	M 30	NaCl - 0.25M	109	112	121	123	Low
		M35	NaCl - 0.25M	100	102	105	113	Low
7	NVC	M 30	MgSO4 - 0.02M	133	135	138	145	Intermediate
		M35	MgSO4 - 0.02M	100	110	113	131	Intermediate
8	SCC	M 30	MgSO4 - 0.02M	42	57	56	64	Low
		M35	MgSO4 - 0.02M	35	40	44	55	Low
9	NVC	M 30	MgSO4 - 0.025M	129	156	167	186	Intermediate
		M35	MgSO4 - 0.025M	103	110	102	112	Low
10	SCC	M 30	MgSO4 - 0.025M	64	80	90	99	Low
		M35	MgSO4 - 0.025M	51	60	59	72	Low

CONCLUSIONS

1. Corrosion activity levels in the 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 the 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 cause significant changes of mechanical properties of steel. Corrosion may reduce Yield strength, Ultimate strength and increase Percent elongation in the bars. . This may cause fracture strength and other similar properties for severe and extreme exposure conditions.

4. Effects of long term exposure conditions of marine environment on the behaviour and strength of TMT bars are to be studied for further investigations.

5. SCC specimens perform better than Normal concrete specimens , when structural elements are subjected to surrounding corrosion environment.

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