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Effect of reinforcement corrosion on flexural behaviour of concrete beams

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Abstract:

Properly designed and constructed steel reinforced cement concrete structures are normally expected to provide relatively maintenance free service for at least 40years. This expectation is based on a consideration that steel is passivated and hence not subjected to corrosion, in highly alkaline (PH12.5-13.5) environment which is produced due to formation of $Ca(OH)_2$ and other alkaline products during the hydration of cement.

The steel concrete losses passivation due to effect of chloride iron on passivating film and reaction between atmospheric carbon dioxide and alkali in concrete and is subjected to corrosion by normal electro chemical corrosion process. Once started, corrosion continues by self-generating mechanism.

The present paper deals with the corrosion mechanism of steel reinforcement and its influence on structural behaviour of concrete beams. Reinforced concrete beam will be designed as per standard specification using M_{20} grade of concrete and will be subjected to corrosion using chemical as well as electro chemical techniques. The condition of rebar will be periodically accessed through potential measurement. At the end of the test period structural behaviour of beams will be studied. The investigation is expected to throw more light on the process of reinforcement corrosion and its effect on the flexural behaviour of concrete beams.

Keywords:

electro chemical techniques, Reinforced concrete beam, M_{20} grade of concrete, RCC structures, rust stains, concrete spalling

1. Introduction:

Reinforcement steel embedded in cement concrete is believed to be safe from corrosion for its lifetime. Until recently, durability of reinforced and pre-stressed concrete structure was taken for granted. This scenario is fast changing now. While RCC structures live really long, with or without serious maintenance, many start showing distress in five to ten years.

Corrosion failure of concrete structure is often sudden and without warning even though there may be apparent symptoms of rust stains, concrete spalling etc. Collapse of Mondovi Bridge in Goa was not anticipated in spite of external distress sign and collapse lead to human causality. This leads to high maintenance cost or premature replacement of the structure.

Corrosion is a natural phenomenon and corrosion of steel is most common. In India, due to tropical climate, the corrosion problem is more serious than those cold countries. The damaged caused by rebar corrosion in concrete structures has been considered as one of the major durability problems affecting the service life of concrete structures. The most widespread problem of premature deterioration however is caused by corrosion of steel reinforcement.

2. Corrosion process:

Once the ability of concrete to maintain steel reinforcement in a passive (i.e., non-corroding) condition has been lost, then rusting takes place. This corrosion process is described adequately in equation (1), which shows the conjoint action of moisture and dissolved oxygen on iron to produced ferrous hydroxide

$$Fe + ½\ O_2 + H_2O \rightarrow Fe\ (OH)_2 \qquad ....(1)$$

This hydroxide reaction product is converted by means of furthered oxidation to the mixture of hydrated oxides commonly recognized as rust. Although equation (1) is useful over all the representation of the corrosion process, it is not particularly informative about the mechanism by which the reaction takes place. It is help full to consider the metallic and non-metallic reactants separately.

$$Fe \rightarrow Fe_2 + 2\ e- \qquad ....\ (2)$$

$$½\ O_2 + H_2O + 2\ e-- \rightarrow 2O- \qquad ....\ (3)$$

Equations (2) and (3) involve electrons as well as chemical species. This suggests that the corrosion of iron proceeds via on electrochemical mechanism, a fact that is now well established. Equation (2) represents the oxidation of iron from uncharged species (i.e., the metal) to a positively charged ion with the liberation of electrons.

Equation (3) describes the equation of nonmetallic solution species (in this instants dissolved molecular oxygen to hydroxyl ions), the process that consumes electrons. In electro chemical terminology, oxidation (electrons releasing) reaction is termed as anodic process; they proceed at the sites on the metal termed anodes. Reduction (or electron consuming) reaction is termed cathodic, and takes place at cathodes. Each electron, which is released into the metal as the result of an anodic reaction is consumed in a cathodic reaction. This maintains electrical neutrality, a fact that is consistent with the observation that corroding metals do not charger. It is worth nothing that if equation (2) and (3) are added together, the electrons can be cancelled from each side and the result is equation (1).

3. Experimental programme:

The material used in present study is 43 grade cement, locally available sand, 20mm normal sized aggregate and water. Experimental beams of size 500x100x100mm were cast. The grade of concrete was M_{20}. Water / Cement ratio used was 0.5. 8mm dia mild steel reinforcement was placed concentric at the tensile zone and the clear cover was maintained at 20mm as shown in fig. 1.

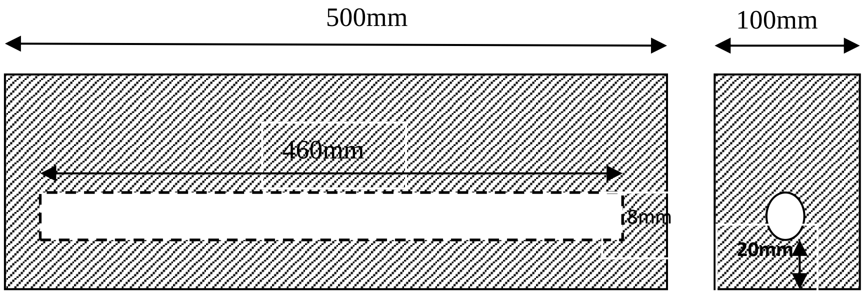

Figure. 1: Schematic representation of specimen

In this study, three systems were evaluated. In system 1 the specimens were made as control and cured in potable water for 28 days. In system 2 specimens were cured in potable water for 7 days and then cured in 3.5% sodium chloride solution for 21 days. This is to chemically accelerate the corrosion of reinforcement. In system 3 the embedded steel reinforcement was subjected to accelerated corrosion by external applied anodic current of 500mA. The idea was to electrochemically accelerate the corrosion of reinforcement. In system 3, the specimen was initially cured in potable water for 7 days and subjected for accelerated corrosion for 21 days.

The specimens were tested in flexural testing machine to find out deflection for a gradual increase in load. Table.1 shows the flexural load, deflection and crack width of the test specimens. Figure.2 shows the Load-Deflection behaviour for the test specimens.

4. Load bearing capacity:

From the table, it is observed that the load carrying capacity of the system-2 is reduced by 14.6% and the load carrying capacity of system-3 is reduced by 33.6% compared to the control system. The effect of electro chemical acceleration of reinforcement corrosion is twice that of chemical acceleration.

As per IS 456:2000 clause 23.2, the limit state of serviceability for deflection is $\frac{Span}{350}$ (or) 20mm whichever is less.

The effective span of the test specimen was 460mm.

Therefore allowable deflection = $\frac{460}{350}$ = 1.314mm.

From the table.1, it is observed that the deflection in system 1 is only 0.81mm and therefore it satisfies the serviceability requirements. The deflection of the system-2 specimen is 0.95mm.

Table. 1: Load, deflection and crack width

Description	Control Specimen (System-1)	Specimen in NaCl (System-2)	Anodically Polarized Specimen (System-3)
Failure Load (KN)	18.9±0.9	16.15±0.35	12.55±0.95
Deflection (mm)	0.81±0.04	0.95±0.01	1.64±0.08
Max Crack width (mm)	0.19±0.09	0.45±0	0.75±0.05

In system-2, the deflection is 1.17 times more than that of system-1 specimen. However, the value is still within the permissible limit of 1.314mm. The deflection observed in system-3 is, 1.64mm. In system-3 the deflection observed is twice the deflection of the system-1. System-

3 fails the serviceability requirement. The excessive deflection in system-3 is solely due to reinforcement corrosion brought about by electrochemical acceleration.

5. Crack width:

Limit state of serviceability for surface width of crack is 0.3mm, where cracking is not harmful and does not have any serious adverse effects upon the preservation of reinforcing steel nor upon the durability of the structures. In members where cracking in the tensile zone is harmful either because they are exposed to the effects of the weather or continuously exposed to moisture or in contact soil or ground water, an upper limit of 0.2mm is suggested for the maximum width of crack. For aggressive environment such as severe category the assessed surface width of cracks should not exceed 0.1mm.

From table.1, crack width in system-1 is 0.19mm. System-1 is in mild exposure and crack width is within the acceptable limit of 0.3mm. System-2 and system-3 fails the acceptability criterion specified for aggressive environment.

6. Corrosion rate:

Table. 2 shows the weight loss (due to corrosion) of the steel reinforcement embedded in concrete and the corresponding corrosion rate in mmpy.

Table. 2: Weight loss versus corrosion rate

Sl. No.	System	Initial Weight (g)	Final Weight (g)	Corrosion rate (mmpy)
1	System1	182.4±0.4	182.35±0.25	0.01989
2	System2	182.3±0.3	178.50±1.15	1.4593
3	System3	182.05±0.25	176.10±1.25	2.2929

From table. 2, the corrosion rate observed in system-1 is 0.02 mmpy. In system-2 the corrosion rate observed is 1.46 mmpy. This increase in corrosion rate is due to the action of chloride ions at the steel surface, which induces corrosion. In system-3, the corrosion rate observed is 2.29

mmpy. This is nearly 1.6 times that obtained for system-2. Obviously electrochemical acceleration is 1.6 times compared to chemical acceleration.

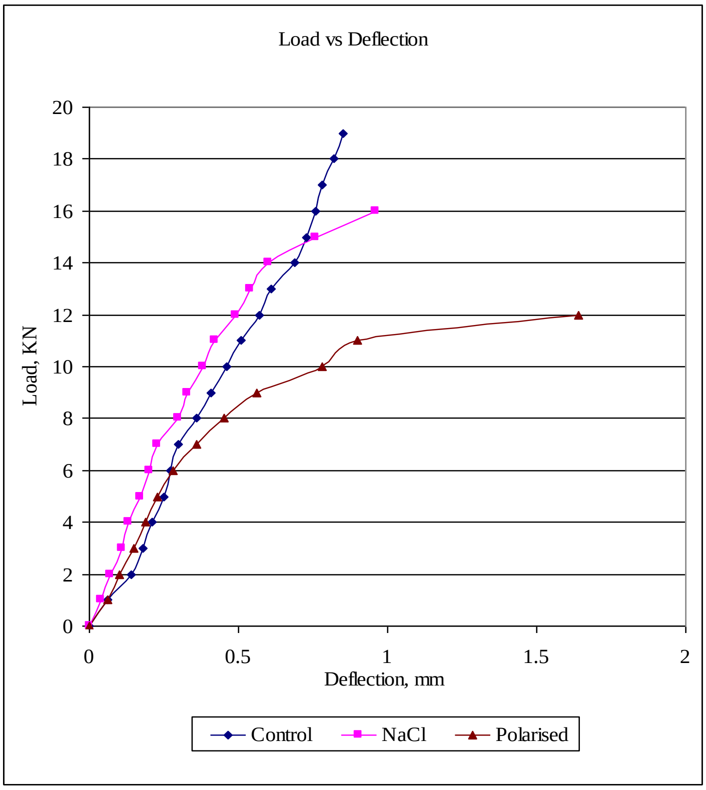

Figure. 2: Load Vs deflection

7. Potential time behavior:

Fig. 3 shows the potential trend of embedded steel in concrete. From the figure, it is observed that the potential of rebars in system-1 moves slightly in the negative direction and then remains constant at -485mV Vs SCE.

In system-2, the potential gradually increases in the negative direction and at the end of 7 days gets stabilized at -560mV Vs SCE. The potential shift is about 75mV and this shift is due to chloride concentration gradient. The chloride ions from NaCl solution move through the pores and initiates corrosion on steel reinforcement and as a result potential moves in the more negative direction.

In system-3, the embedded reinforcement has been anodically polarized and as a result the potential is shifted in positive direction. The potential gradually increases in the positive direction and at the end of 17 days gets stabilized at -365mV Vs SCE. The potential shift in the positive direction is about 120mV.

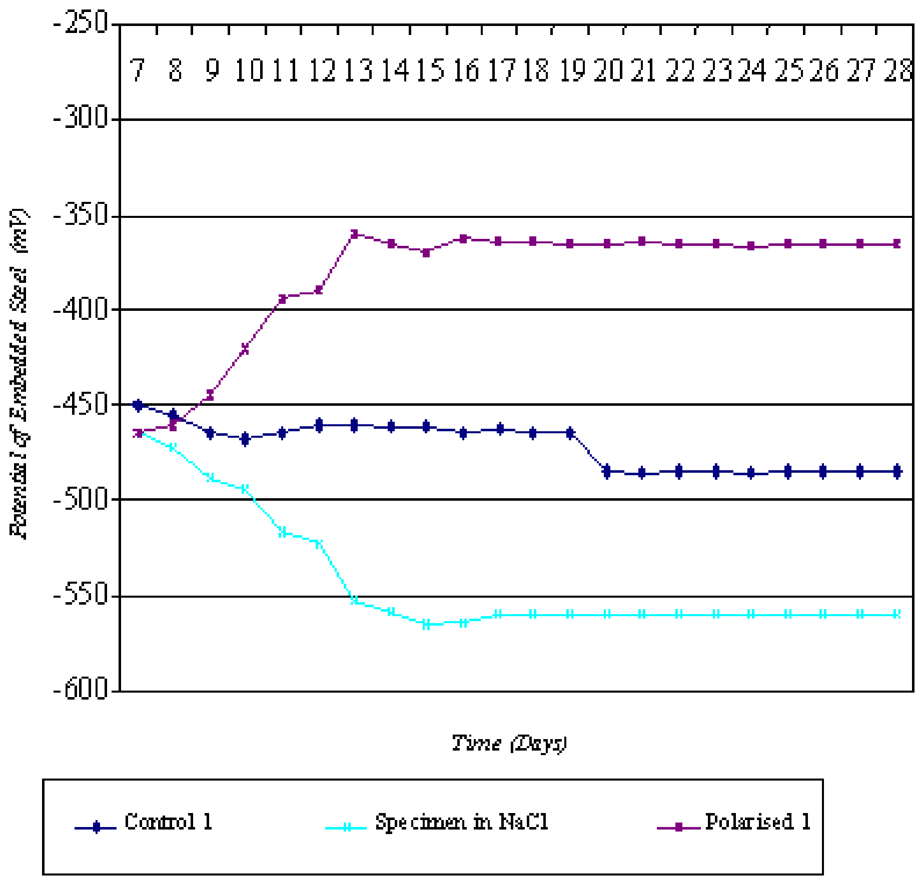

Figure. 3: Potential trend of embedded steel

8. Conclusions:

The following broad conclusions were obtained from the above investigation.

8.1. Studies conducted on influence of corrosion reveal that:

1. When the concrete beams are cured in tap water for 28 days as per field practice M_{20} grade concrete is able to satisfy the limit state of deflection. Steel reinforcement embedded in M_{20} concrete has a corrosion rate of 0.02mmpy. At this corrosion rate the M_{20} concrete beam is able to satisfy the serviceability requirements in terms of deflection. However, it fails to satisfy the limit state of crack width.

2. When the concrete beams are cured in tap water for 7 days and then cured in 3.5% sodium chloride solution for 28 days. Steel reinforcement embedded in M_{20} concrete beam has a corrosion rate of 1.46 mmpy. At this corrosion rate M_{20} concrete beam is able to satisfy serviceability requirements in terms of deflection. However, it fails to satisfy limit state of crack width.

3. When the concrete beams are cured in tap water for 7 days and then anodically polarized in 3.5% sodium chloride solution for 21 days. Steel reinforcement embedded in M_{20} concrete beam has a corrosion rate of 2.29mmpy. At this corrosion rate M_{20} concrete beam is not able to satisfy limit state of serviceability requirements specified for deflection and crack width.

Figure. 4: Set up of flexural strength test

Figure. 5: Accelerated corrosion

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