Verification of Nominal Cover Requirements Specified by is 456:2000

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Abstract: At present Corrosion of reinforced concrete structures is one of the serious issues involving the durability and serviceability of the structure. Though a Reinforced Concrete Structure is designed for a service life, it is not lasting longer. The durability of concrete is affected by corrosion. Adequate cover is required for any reinforced concrete structure in order to protect it from corrosion. Indian code (IS 456: 2000) has specified the cover based on durability requirement as well as for fire requirements. British code (BS:8110), New Zealand code (NZS 3101: Part-1(2006)) and American code (ACI 381-95) has also given some code provisions for concrete cover. It is observed that the Indian code has not taken factors like concrete quality,cementitious material and water/cementitious ratio. So, the Indiancode requires the above considerations. Acceleratedcorrosion by Impressed Current Technique is used in concrete durability tests.In this study, the behavior of corrosion in steel embedded in different combinations (grades and fly ash replacement) of concrete at a constant cover influenced by the constant current potential of 60V was experimentally investigated.The composite cement was prepared by using Ordinary Portland cement (OPC) and Fly Ash. Steel bars(ø10 mm)were weighted to determine the corrosion effects in terms of weight loss.The cubes of dimension 15 cm x 15 cm x 15cm with M30 and M40 grades of concrete with different OPC combinations (OPC + 30% of Fly ash, OPC + 60% of Fly ash and OPC) were castedby placing a rounded steel bar with a cover of 4 cmfrom a face of cube.

Index Terms:Cover, Durability, Corrosion, Current, Fly Ash, Steel

I. INTRODUCTION

In general, cover is defined as a portion of the structure to keep away the external effect like corrosion (FeO or rust) due to exposure conditionsand to give an opposition to fire from rebars. The depth of cover depends on the type of structural membrane and the environmental risk.A concrete cover plays an important role in the safety of a building structure. If it is not done well or monitored properly it cause failure to the structure and the durability of the structure decreases. Proper attention should be taken on the covers while constructing the structural elements or the marine structures as they are exposed to weathering conditions or environmental risks. Failure to enough requirements for the concrete cover may reduce the lifespan of the building and it fails in the early lifespan. Different countries have given different nominal covers to reinforcement meeting their requirements. Indian code (IS:456-2000) hasnot considered the cover requirements like concrete quality, cementitious material and water/cementitious ratio. WhereasBritish code (BS:8110), American code (ACI 318-95) and New Zealand code (NZS 3101: Part-1(2006)) has considered the above parameters for minimum cover requirements for concrete.There is need in consideration of the above elements.

Concrete usually provide protection from corrosion due to its high alkaline nature. It passivates the steel. When CO_2 combines with moisture, it starts carbonation of steel. It decreases the alkaline nature of concrete. When corrosion causing factors attacks steel, is starts destroying it. In order to stop this process, the concrete cover should be maintained according to required conditions to resist the corrosion and the mechanical properties of the concrete should be improved. In normal pH value for concrete is greater than 12 and this value is adequate to protect concrete from corrosion. Due to environmental effects the value of pH decreases, and it causes corrosion to steel-reinforced concrete.

The environment just around reinforcing bar in the concrete more closely has a very high pH almost in between 12 to 13. This is because of the hydration of C3S, C2S, C3A, C4AF of any phase of cement. When it hydrates leads to the formation of hydration products and a lot of calcium hydroxide. The calcium hydroxide when it is deposited with in the pore system it dissociates into calcium and hydroxyl ions and these hydroxyl ions cause the pH to be 12 or 13. So, in principle the reinforcing bars are in an environment which is extremely basic. Because of the high pH environment, a dense film of γ-iron oxide which acts as a passivating film is formed on the surface of the reinforcing bar. As long as this film is intact, the iron surface is not open to reaction with oxygen and water and it doesn't corrode. therefore, the reinforcement corrosion in concrete can happen under two conditions:

- When the passivating film is damaged.
- When there is change in the electro-chemical environment of the steel nothing but loss of film.

II. IMPRESSED CURRENT TECHNIQUE

Impressed current technique is a method used to study the behavior of steel by inducing corrosion by means of DC source. These tests can be conducted in a short period. Corrosion is persuaded by applying an electro chemical potential between cathode and anode (reinforcing steel). Constant current is applied from DC source to the steel

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embedded in the concrete. Percentage of actual or real loss of steel in corrosion is calculated by percentage of weight. This method of corrosion has many advantages, it saves time and money.

III. RESEARCH SIGNIFICANCE

A. ACI Committee (ACI:318-1995)

ACI:318code has considered cast in situ, precast nearer to plant,grade of concrete,prestressed concrete, exposure classificationssize of aggregate, diameter of bar, size of aggregate, type of binder, percentage of air in concrete, and binder content for concrete cover.

B. British standard BS: 8110 Part-1(1997)

8110 Part-1code has consideredgrade of concrete, type of binder, exposure classifications, size of aggregate, diameter of bar, percentage of air in concrete, binder content and water/cementitious ratio for concrete cover.

C. NZS 3101: Part-1(2006)

NZS 3101: Part-1(2006) has considered grade of concrete, Type of cement, Percentage of air content, Size of aggregate, Water /cementitious ratio, Diameter of bar, Exposure classification, Chemical attack, Cement content, Life period of structure for concrete cover

D. Indian standard IS:456(2000)

IS:456(2000) code has considered Grade of concrete, exposure classifications, diameter of bar, size of aggregate, and percentage of air in concrete for concrete cover.

The key parameters strength, porosity and durability are closely related among themselves. If we want high strength, we would like to have low porosity similarly if the porosity is low the durability would be high because it is the porosity in the hydration products that facilitates the movement of detrimental material whether it is chloride ions or sulphates or even carbon dioxide into the concrete. Pore structure or porosity of concrete matrix depends on Water cement ratio, cement content, cement type. If the pore structure of the concrete is very dense and pores are not interconnected, then the ease of movement of the deleterious ions will be low. So, depending on the water cement ratio, cement content, cement type and grade of concrete we will have different pore structure. Therefore, type of cement and grade of concrete have vital role in the resistance of concrete against deterioration but in IS 456:2000 the cover requirements specified for concrete members are irrespective of grade of concrete and type of cement being used so that this might be a major gap.

IV. MATERIALS AND MIX DESIGN

Normal strength concrete was used in this study of corrosion. Ordinary Portland cement of 53 grade was used for this study and supplementary cementitious material (Fly Ash) which was collected from NTPC, Vijayawada. The sand used in this study as a Fine aggregate (FA) was collected Krishna river bed. Coarse aggregate (CA) was taken from locally available crushers. The size of the coarse aggregate is 10mm and 20 mm. The reinforcing steel bars used is the mild steel of diameter (ø10 mm). Stain less steel plate was used with an area of15 cm x 15 which acts as cathode for which the current should flow through concrete to the reinforcing steel bars.Naphthalene based chemical admixture was used in this experiment to achieve desirable properties. Mix design was carried out for M30 and M40 grades based on the specifications of IS 10262:2009. The mix design details are given in Table I.

Table I: Mix design details

Grade of concrete	M30	M40	M30	M40	M30	M40
Percentage of Fly ash	0%	0%	30%	30%	60%	60%
Weight of water	145	140	148	140	148	146
Weight of cement	323	350	229	245	131	146
Weight of fly ash	0	0	99	105	198	219
Weight of CA	1333	1327	1303	1303	1278	1257
Weight of FA	705	702	689	688	676	219
Weight of admixture	1.29	2.1	1.64	2.10	1.97	2.56

In the above table, all units are in kg/m^3

V. TEST SPECIMEN FABRICATION

Each specimen consists the cubical volume of 150 mm x 150 mm x 150 mm (3x 6 = 18) with the percentages of Fly Ash as shown in Table II. Each cube was reinforced with a steel bar with a cover of 40 mm from a face and bottom of the cube as shown in Fig. 1. Fabrication of cubes was undertaken by few stages. Cubemouldswere cleaned and oiled in the inner surfaces. Steel bar was placed firm in the cube and concrete was filled in cube specimens in the form of layers. After casting they were allowed toset for 24 hours and then demolded. Specimens were cured in the curing water tank for the period of 28 days. After that all the five faces of cubes were painted with damp proof except the face with a steel bar of cover 40 mm. They are allowed to dry at room temperature.

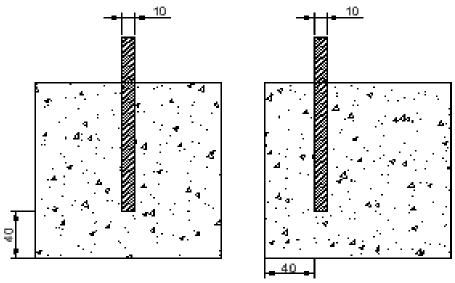

Fig. 1: Details of test specimen (all dimensions in mm)

Table II: Specimen fabrication details

Specimen	Grade	Composition (OPC+% Fly Ash)	Diameter of steel bar (mm)	Cover (mm)
M3	M30	OPC+ 0% Fly Ash	10	40

M4	M40	OPC+ 0% Fly Ash	10	40
M3-F3	M30	OPC+ 30% Fly Ash	10	40
M3-F6	M40	OPC+ 60% Fly Ash	10	40
M4-F3	M30	OPC+ 30% Fly Ash	10	40
M4-F6	M40	OPC+ 60% Fly Ash	10	40

VI. TEST SETUP AND PROCEDURE

Setup for accelerating corrosion in the reinforcement by impressed current technique consists of DC power supply source, an electrolyte and counter electrode. Typical layout of accelerating corrosion is shown in Fig. 2. The negative terminal of DC power source is connected to counter electrode i.e., cathode and the positive terminal to steel bar embedded in concrete i.e., anode. The DC is impressed from counter electrode (cathode) to the rebar with the help of electrolyte. A cubical steel reinforced concrete test specimen and setup for accelerated corrosion study using the impressed current technique. Test setup is shown in Fig. 3.

Specimens were subjected to constant current potential of 60 V.All the specimens were placed in plain water (electrolyte) and current is applied by the means of DC source. Theyare allowed to the corrosion process. At a certain period, steel starts getting corroded and cracks on the concrete blocks were observed. It is shown in Fig. 4.The initial weights of the steel are to be noted before testing. After spalling is formed cubes, they were broken, and steel bars were removed. Removal of steel bars is shown in Fig. 5. All the steel bars were cleaned of rust with kerosene. The final weights of steel were noted to determine the actual weight loss.Percentage weight loss due to corrosion is calculated by using following formula.

$$\text{Percentage weight loss due to corrosion} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} X\,100$$

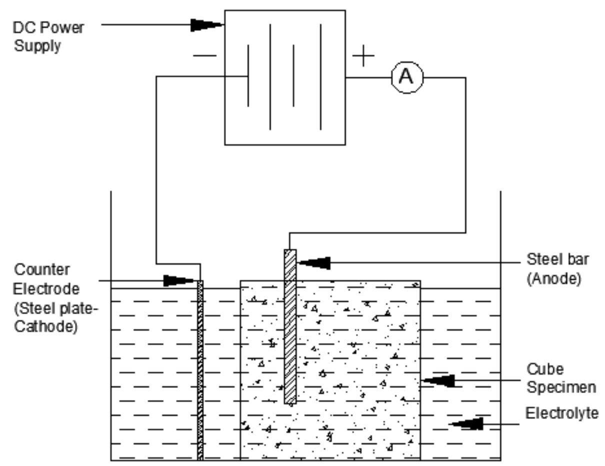

Fig. 2: Typical layout of accelerated corrosion

Fig. 3: Test setup

Fig. 4: Formation of corrosion and cracks

Fig. 5: Removal of steel bars

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VII. EXPEMENTAL RESULTS AND DISCUSSION

Table III: Details of rate of corrosion

Specimen	Time Elapsed (hours)	Current Potential (V)	Rate of corrosion		
			Sample		
			1	2	3
M3	480	60	113	109	109
M4	480	60	82	85	83
M3-F3	480	60	49	55	52
M3-F6	480	60	31	23	30
M4-F3	480	60	15	22	20
M4-F6	480	60	11	13	8

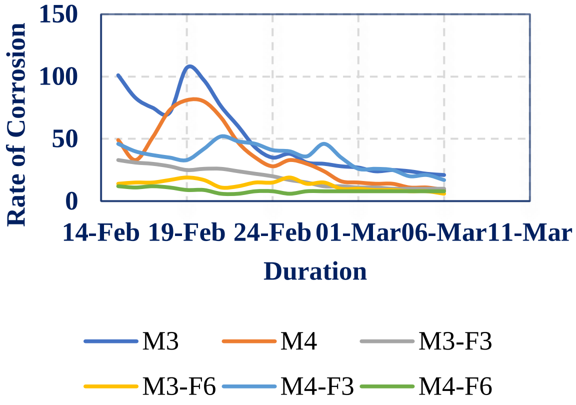

Fig. 6: Rate of Corrosion vs Duration

Details of corrosion is shown in Table III. Initially plain concrete of both grades absorbs more current compared to blended concrete. Absorption of current is low for blended concretes because it has high pore structure compare to plain concrete. In both M30 and M40 grades of concrete at Fly ash 30% shows a high corrosion resistance compare to plain and Fly ash 60% of both M30 and M40 grades of concrete. Absorption of current is high rate of corrosion and crack propagation in concrete due to corrosion is high. By using impressed current technique. Blended concrete gives more corrosion resistance than plain concrete. Percentage weight loss due to corrosion is shown in Table IV. Rate of Corrosion vs Duration graph is shown in in Fig. 6.

Table IV: Percentage weight loss due to corrosion

Specimen	W_1 (gm)	W_2 (gm)	Percentage weightloss due to corrosion
M3	98	86	12.24
M4	99	76	23.23
M3-F3	98	92	6.12
M3-F6	98	86	12.24
M4-F3	99	94	5.05
M4-F6	99	92	7.07

W_1 – initial weight of the steel bar
W_2 – final weight of the steel bar

By determining weight of each sample before and after corrosion percentage of corrosion for each sample is determined. By comparing plain concretes M30 and M40, M40 gives more corrosion resistance than M30. Grade of concrete increases corrosion resistance increases.

In plain concretes M30 and M40 grades corrosion resistance is less compare to M30 and M40 grades of blended concrete (Fly Ash concrete).

VIII. CONCLUSION

- Corrosion of reinforcement to be reduced by low porosity (or) high pore structure of concrete. Pore structure in concrete depends on a fineness in concrete which reduces carbonation attack, chloride ion penetration, mechanism of freezing and thawing, humidity and oxygen (or) gases penetration.
- High fines in concrete gives low porosity so that which reducing thickness of concrete
- In the above international codes such ACI-318, BS-8110, NZs-3101and CP-65 considering grade of concrete, water/cementitious ratio, life period of structure, type of cement, minimum binder content, type of casting (cast in situ, pre-cast and prestressed) exposure classification, chemical attack and diameter of bar
- By comparing above international codes. Is-456:2000 not considering type of cement, type of casting (pre-cast, cast in situ, and prestressed) and life period of structure
- By using percentage weight loss corrosion technique, comparing plain concretes M40 grade of concrete shows more corrosion resistance than M30 grade of concrete
- By comparing M30 and M40 plain concretes show less corrosion resistance compare to blended concrete
- By using impressed current technique. In both M30 and M40 grades of concrete at Fly ash 30% shows a high corrosion resistance compare to plain and Fly ash 60% of both M30 and M40 grades of concrete
- By using impressed current technique Blended concrete gives more corrosion resistance than plain concrete.

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