Additional Requirement in Concrete Cover Specifications as Per IS-456(2000) For Durable R.C. Structures

M. N. B. S. Anvith, A. Venkateswara Rao, B. Kameswara Rao

Abstract: Concrete cover to the reinforcement is to protect the reinforcement against corrosion. Corrosion of steel is one of the factors which influences the durability and serviceability of structure. Presence of moisture, humidity, oxygen and exposure conditions causes corrosion of reinforcing bars. Indian standard code(IS456:2000) specifies cover requirements in clause 26.4, table 16 and table 16A not considered the type of cementitious material, minimum content of cementitious material, and maximum water/binder ratio. Whereas the international codes such as ACI-318, BS-8110,CP-65 and NZs-3101 have considered the above parameters in specifying the concrete cover requirements. In this present study, the effect of the type of cementitious material, content of cementitious material, water/binder ratio etc. are studying by replacing cementitious material. Accelerated corrosion 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 GGBS replacement) of concrete at a constant cover influenced by the constant current potential of 60V was experimentally investigated. Steel bars (ø10 mm) were weighted to determine the corrosion effects in terms of weight loss and behavior of corrosion is determined. The cubes of dimension 15 cm x 15 cm x 15cm with M_{30} and M_{40} grades of concrete with different OPC combinations (OPC + 40% of GGBS, OPC + 70% of GGBS and OPC) were casted by placing a rounded steel bar with a cover of 4 cm from a face of cube.

Index Terms: *cover, corrosion, cementitious, reinforcement.*

I. INTRODUCTION

Concrete cover is one of the most important factor to protect steel from corrosion at any exposure conditions [1]. Durability of concrete is depends upon concrete cover and mineral admixture. The thickness of a cover is least distance between the surface of embedded reinforcement and the outer surface of the concrete. Due to exposure conditions minimum thickness of concrete cover should be provided i.e. to protect rebar against corrosion, thermal insulation and embedding the bar sufficiently to prevent from slipping when stressed and structural member to be durable minimum cover should be provided. Minimum cover requirements as per IS 456:2000 should not less than 15mm For slab or wall, 30mm - beams, 40mm- column, when the column dimension is 200mm and diameter of bar is 12mm clear cover-20mm to be provided. For footings-50mm, for footings direct contact with ground (without plain concrete) a clear cover of 75mm is to be provided [1]. These cover requirements did not consider the type of cement, grade of concrete, minimum water/cementitious material ratio, size of aggregate and air content in concrete. But in other codes such as ACI-318(1995) [2], BS-8110(1995) [3], CP-65-1(1999) [4] and NZs 3101(1995) [5] have considered the above parameters for minimum clear cover requirements in concrete. Due to this the requirements of concrete cover will be reduced compare to the nominal cover requirements provided in IS:456-2000.

The use of mineral admixture in a concrete increases the pore structure and reduce environmental damage. The primarily for durability, a good quality concrete with low porosity i.e., low permeability is necessary [8]. The durable concrete increases corrosion protection. The improvement of pore structure in concrete reduces permeability.

If the concrete cover increases similarly crack width increases. Cracking of concrete is caused due to tensile stress or bending. Structural cracks are significantly influence on serviceability and durability. In the serviceability criteria reduction on stiffness and deformation in the durability criteria chloride ion attack or carbonation causes corrosion to reinforcement [9]. Limiting of crack width depends on conditions of exposure. In spite of more concrete cover to resist against an exposure condition [10]. According to prediction formula as per IS:456-2000 an increase in concrete cover increases crack width 0.5mm thickness of concrete cover decreases 0.5% reduction of crack width. If depth of concrete cover increases transverse tensile stress increases and crack develops at cover position. By using mineral admixtures in a concrete or use of pozzolanic cements causes thick pore structure thus reduces concrete cover in structural members.

Percentage of GGBS compositions in concrete is 40% and 70% and caste a cubes. These cubes are casted for compressive strength and corrosion test.

A. Mechanism of corrosion

The corrosion occurs with a help of moisture, humidity, oxygen and exposure condition. Corrosion is a result of deterioration or destruction of material when exposed to various exposure conditions [6]. Water and oxygen acts as a chemically ‘driving forces’ for corrosion through flow of electric current and electrochemical process, which results in and chemical reaction. Steel has a significant surface

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characteristic to forms a composition cells compare to aluminium conduit pipes. These composition cells form nearer to reinforcing steel due to dissolve ions of alkali and chloride ions. Some ions were dissolved to dissolution of steel in these to form a gap in between ions with a mechanism of anode and cathode

Anode: $Fe \rightarrow Fe^{2+} + 2e^-$

Cathode: $\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$

Anode reaction, in the dissolution of iron, electrons are liberated around a steel i.e., oxidation of iron to ferrous iron. In the (Cathode Reaction) these liberated ions are consumed by oxygen in the presence of water to give a OH- ion concentration. The exposures such as carbonation, chloride ions, and moisture decreases Ph of concrete within the range of less than 10.5 by decreasing alkali nature of concrete breaks a passive layer in around steel bar and form an earlier corrosion [7].

Following reactions are taken place after the anodic reaction, causing formation of rust.

$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$ (Ferrous Hydroxide)

$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$ (Ferric Hydroxide)

$2Fe(OH)_3 + \rightarrow 2H_2O + Fe_2O_3.H_2O$ (Rust)

B. Corrosion aspects

Air voids in concrete causes more permeability and porosity, it causes improper gradation in aggregates and improper compaction. The solution in air voids is replaced by an air-entrained shall be tolerance on air content as delivered in ± 1.5 percent. It depends on a grade of concrete, size of aggregate and exposure conditions. The percentage of air content varies with respect to size of aggregate, exposure condition and grade of the concrete.

Concrete carbonation is defined as development of carbon content rate with respective time in a concrete. It causes due to exposure condition such as (Relative humidity, temperature and co_2 emission) in a concrete. By concrete composition with water binder ratio and binder type [11]. The results of rate of increasing corrosion density at humidity 95% with a temperature 20-40℃. At low humidity with a high temperature no presence of moisture at pore structure. The presence of moisture and oxygen causes corrosion of reinforcement in concrete. The corrosion in reinforcement depends on pore structure, degree of pore moisture and thickness of cover. The concrete which has high permeability and porosity easily transmit gases and moisture in which lower water/cementitious material ratio reduces the porosity and gases diffusion. Concrete which has higher percentage of blended content in Portland cement reduces pore structure alkanity, ion concentration and distance between position of ions so it turn increases ion mobility. But high cao fly ash possesses good resistance against carbonation, addition of mineral admixture up to 15% combined with Fly ash and GGBS.

Chloride is one of the major reasons to form corrosion of steel in reinforced concrete. Major source of chloride attack due to de-icing or sea water. Cement, water and aggregate are the significant source of chloride attack.[6] By this chloride content of cement is limited up to 0.1%. Chloride attack in two forms (i) bounded chloride (ii) free chloride. Bounded chloride can be classified as chemically bounded chloride, due to hydration of cement and physically bounded chloride, due to solution of absorbed gel pores. Free chloride by exposure when chloride attacks in steel by a pore structure. These chloride ions are penetrating into a pore structure and forms chloride ions. These ions break a passive layer of steel with a help of oxygen, moisture, and humidity. The passive layer of steel is depends on Cl^- concentration and OH^+ ions concentration. These chloride ions after long time its starts a pitting corrosion to steel.

C. Reduction of corrosion

Hongxla Qiao, Corrosion of reinforcement causes by chemical attack due to inappropriate chosen of type of cement, condition of exposure, cement content, water/binder ratio, size of aggregate, air content in concrete and grade of concrete. Addition of mineral admixture reduces not only the cement content but also carbonation, Freezing and thawing, resistance against sulphate attack, alkali silica reaction and chloride ion penetration. Both the water and cementitious material are responsible for binding everything together. The maximum water/cementitious ratio is related with grade of concrete and minimum cement content. It gives prevention of corrosion in reinforcement. The water/cementitious ratio depends on a exposure conditions and (% content of pozzolona with respect to cement) it is specified in IRC-44 Table-6

II. RESEARCH SIGNIFICANCE

A. ACI Committee (ACI: 318-1995)

For concrete cover requirement, ACI:318 code considering Grade of concrete, cast in situ, precast nearer to plant, prestressed concrete, exposure classifications, type of binder, diameter of bar, size of aggregate, percentage of air in concrete, and binder content.

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

For concrete cover requirement, BS: 8110 Part-1code considering Grade of concrete, type of binder, exposure classifications, diameter of bar, size of aggregate, percentage of air in concrete, binder content and water/cementitious ratio.

C. Singapore CP: 65 Part-1(1997)

For concrete cover requirement, CP:65 Part-1code considering Grade of concrete, type of binder exposure classifications, diameter of bar, size of aggregate, percentage of air in concrete, binder content and water/cementitious ratio.

D. NZS 3101: Part-1(2006)

For concrete cover requirement, NZS 3101:Part-1code considering Grade of concrete, type of binder, exposure classifications, diameter of bar, size of aggregate, percentage of air in concrete, binder content, water/cementitious ratio and life period of structure(50 and 100 years).

E. Indian standard IS: 456(2000)

For concrete cover requirement, IS:456(2000) code considering Grade of concrete, exposure classifications, diameter of bar, size of aggregate, and percentage of air in concrete.

III. METHODOLOGY

For testing we consider grade of concrete is M-30 and M-40(R.C.C) and reinforcing bar

A. Experimental program

Experimental program were conducted to find out compressive strength and rate of corrosion in steel. The grade of concrete is M30 and M40 (R.C.C) and blended with cementitious material is ground granulated blast furnace. GGBS is blended in concrete at 40% and 70% to both grades of concrete.

B. Material used

GGBS: It is a by product of steel industry. it is created from quickly quenching of molten slag from iron ore and ground into a powder. It consists essentially of silicates and alumina silicates of calcium and other bases. The substance is grounded into a fine powder with at least 80 percent less than 45 micron size.

Cement: Cement is main ingredient for manufacturing of concrete. Cement is used in this project is opc-53 conforming to IS-12269:1987

Water: Water conforming to as per IS-456:2000 was used for mixing and curing of specimens

Coarse Aggregate: Size of coarse aggregate is generally greater than 4.75mm. We used in these project is 12.5 mm which specifies according to IS-383

Fine Aggregate: Locally available river sand according conforming to zone II as per guidelines of IS-383 was used as fine aggregate.

Concrete mixers: Mix design is essential part in manufacture of concrete. Design mix shows greater properties in concrete .design mix according to IS-10262(2016).

C. Mix design for M30 and M40 grade concrete

After conducting several trails. The final mix design trails are tabulated in Table I.

Table I: Weight of mix proportions in concrete Mix proportions

Grade of concrete	M30	M40	M30	M40	M30	M40
Percentage of GGBS	Zero	zero	40%	40%	70%	70%
Weight of cement	323	350	194	210	97	105
Weight of GGBS	Plain	plain	129	140	226	245
Weight of water	145	140	145	140	145	140
Weight of Coarse aggregate	1333	1327	1319	1320	1323	1318
Weight of fine aggregate	705	702	698	697	699	697
Weight of admixture	1.29	2.10	1.29	2.10	1.05	1.62

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

D. Impressed Current Technique

Impressed current technique for accelerated corrosion is used in concrete durability tests. These tests can be conducted in a short period. Corrosion is persuaded by applying an electro chemical potential difference between cathode and anode (reinforcing steel). Constant current is applied from DC source to the steel embedded in the concrete. Percentage of actual or real loss of steel in corrosion is calculated by percentage of weight.

E. Fabrication

The details of specimen are shown in fig. 1. Each specimen consists the cubical volume of 150 mm x 150 mm x 150 mm (total: 6 x 3 = 18). 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. Cube moulds were 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 to set for 24 hours and then remolded. 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.op

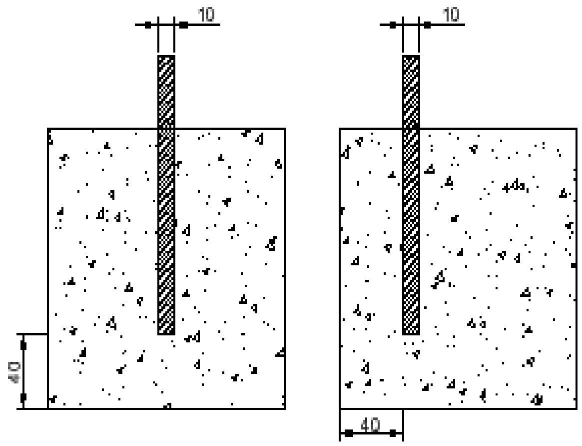

Fig. 1: Details of test specimen (all dimensions in mm)

Table II: Details of cover requirement and diameter of bar

Specimen	Grade	Composition (OPC+% GGBS)	Diameter of steel bar (mm)	Cover (mm)
P3	M30	OPC+ 0% GGBS	10	40

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P4	M40	OPC+ 0% GGBS	10	40
P3-G4	M30	OPC+ 40% GGBS	10	40
P3-G7	M40	OPC+ 70% GGBS	10	40
P4-G4	M30	OPC+ 40% GGBS	10	40
P4-G7	M40	OPC+ 70% GGBS	10	40

F. 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. 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.

The current intensity was decided to get the desired theoretical degree of corrosion in the steel. Faraday's law was used to determine the theoretical loss of mass. Specimens were subjected to constant current potential of 60V all the specimens were placed in water (electrolyte) and current is applied by the means of DC source. They are allowed to corrosion. At a certain period, steel starts getting corroded and cracks on the concrete blocks were observed. 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. 2. All the steel bars were cleaned of rust with kerosene. The final weights of steel were noted to determine the actual weight loss.

Fig. 2: Impressed current technique and breaking of cube

IV. RESULTS AND DISCUSSION

Table III shows the rate of corrosion at each sample.

Table III: Rate of corrosion at each sample

Specimen	Time Elapsed (hours)	Current Potential (V)	Rate of corrosion Sample		
			1	2	3
P3	480	60	130	124	121
P4	480	60	89	80	79
P3-G4	480	60	29	25	30
P3-G7	480	60	2	2	5
P4-G4	480	60	5	3	1
P4-G7	480	60	-3	-3	-3

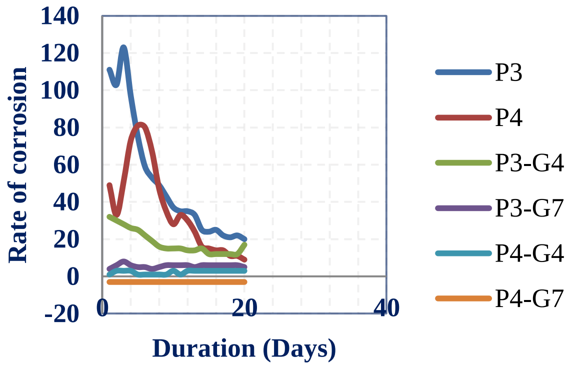

Fig. 3: Rate of corrosion vs Duration

Initially plain concrete of both grades absorb more current compare 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 GGBS 70% shows a high corrosion resistance compare to plain and GGBS 40% 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.

Table IV: Percentage of corrosion at each sample

Specimen	W1 (initial weight)	W2(final weight)	Percentage weight loss due to corrosion (W1-W2)/W1
P3	98	86	0.12%
P4	99	92	0.07%
P3-G4	98	96	0.02%
P3-G7	98	96	0.02%
P4-G4	99	96	0.03%
P4-G7	98	96	0.02%

W_1 – initial weight of the steel bar

W_2 – final weight of the steel bar

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By checking weight at each sample before and after corrosion determine percentage of corrosion at each sample.

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 (GGBS concrete).

V. 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 GGBS 70% shows a high corrosion resistance compare to plain and GGBS 40% 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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