EFFECT OF GGBFS ON CORROSION POTENTIAL OF STEEL IN CONCRETE

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Abstract - *Corrosion of reinforcement in reinforced concrete structures is one of the important reasons of premature failure in durability criteria, particularly along coastal regions. Supplementary cementitious materials (SCM) are widely used for enhancing the durability and other properties of concrete. In this paper an experimental investigation has been carried out to study the corrosion potential of steel in concrete when Ground Granulated Blast Furnace Slag (GGBFS) is added. Corrosion test specimen with 25% and 50% replacement of cement with GGBFS has been prepared along with the reference specimen with OPC (400 kg/m³) and w/b ratio varied from 0.40 to 0.50. Alternate wetting and drying procedure as per ASTM standard has been adopted for the present study. It has been observed that, by properly selecting the replacement quantity of GGBFS (25%) and w/b ratio (0.40), the corrosion potential of steel in concrete could be reduced very much, without affecting the compressive strength of concrete.*

Key Words: Corrosion, Chloride induced corrosion, Alternate wetting and drying, GGBFS, Macro cell corrosion test, RCC,

1. INTRODUCTION

Corrosion of steel in concrete is one of the major durability issues in RCC structures. There could be many reasons for the initiation of corrosion in steel. However, the most common reason is the chloride intrusion. Chloride intrusion in concrete is one of the major issues in marine environment as well as in industrial areas. [7,8]

The primary reason for the durability issues in concrete is the poor quality of construction. Properly designed constituent materials with low water to binder ratio are the key factors in achieving a durable concrete. Many mineral admixtures like GGBFS, Fly Ash, Meta Kaolin, Rice husk Ash, etc. are being used in concrete to enhance its durability. [2, 3, 5] Blast furnace slag is a waste product from steel manufacturing industry and is an environmental threat, if not disposed properly. Hence, use of this waste material in a properly processed form (GGBFS) in concrete helps to reduce the environmental pollution as well and makes the concrete eco-friendly.

Influence of GGBFS in concrete on strength, workability, etc. has been studied by many researchers. However, not many studies have been reported on the effect of GGBFS in concrete on the corrosion potential of steel in concrete.

There are different methods of testing corrosion potential of steel in concrete such as RCPT, Impressed current method, Alternate wetting and drying methods, etc.. Each method has its own merits and limitations. For the present study, alternate wetting and drying method has been adopted and the standard procedure proposed by the ASTM has been followed [9]. This method of test is suitable to study the influence of admixtures in concrete on the corrosion potential of embedded steel in it.

In general, the RCC buildings are being constructed with a cement content between 370 kg to 420 per cubic meter of concrete. Also, generally the water to binder ratio ranges between 0.40 to 0.50, unless the structure is a special one. Hence, 400 kg cement per cubic meter of concrete and three water to binder ratio, namely 0.40, 0.45 and 0.50 has been considered for the present investigation.

2. EXPERIMENTAL INVESTIGATION

2.1. Materials

2.1.1. Cement

Ordinary Portland Cement (OPC) of 53 grade was used for preparing concrete. Cement content of 400 kg/m³ was used in concrete mixes with 0.40, 0.45and 0.50 water-binder ratios (w/cm).The physical properties of cement are given in Table 1.

2.1.2. Aggregates

Crushed granite aggregate with a nominal maximum particle size of 12 mm was used as coarse aggregate. Crushed granite fine aggregate with a specific gravity of 2.46 and fineness modulus of 3.95 was used for the present study. The water absorption of coarse and fine aggregates was 0.41% and 3.2 % respectively, *2.1.3. Ground granulated blast-furnace slag (GGBFS)*

Ground Granulated Blast furnace Slag (GGBFS) with a specific gravity of 2.685 and Blaine specific surface area of 4000 cm^2/g was used for the study.

2.1.4. Admixture

A super plasticizer with a commercial name "Conplast SP 430" has been used for improving the workability of fresh concrete. The dosage of the admixture has been arrived based on trial mixes.

Table-1: Physical Properties of Cement

SL No.	Properties	Value	Test procedure as per
1	Specific gravity	3.01	IS: 2720(Part 3)
2	Standard consistency	33%	IS: 4031(Part 4)
3	Initial Setting time in minutes	41	IS: 4031(Part5)
4	Final Setting time in minutes	193	IS: 4031(part5)

2.2. Mixture proportion

A total of 9 mixture proportion was prepared for the present study. These proportions have been arrived at based on the BIS method [13] and Table 2 shows the quantity required for one cubic meter of concrete for different parameters considered.

Table -2: Quantities of materials per cubic meter of concrete

Mix ID	Cement (kg)	GGBFS (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Super plasticizer (kg)	Water (L)
CCW1	400	0	673.96	1185.82	5.0	156.4
CCW2	400	0	654.31	1151.23	5.0	176.4
CCW3	400	0	634.65	1116.65	4.0	196.4
G1W1	300	100	670.23	1179.25	5.0	157.0
G1W2	300	100	650.58	1144.67	5.0	177.0
G1W3	300	100	631.14	1110.47	4.0	197.6
G2W1	200	200	666.28	1172.30	5.0	157.0
G2W2	200	200	646.62	1137.71	5.0	177.0
G2W3	200	200	627.19	1103.52	4.0	197.6

Here, CC stands for control concrete; G1 and G2 stands for respectively 25% and 50% of GGBFS in concrete; W1, W2 and W3 stands for the water binder ratios of 0.40, 0.45 and 0.50 respectively.

2.3. Casting and preparation of specimen

The various ingredients for concrete were mixed in a pan mixture as per the procedure specified in Indian standard [10]. Slump test was carried out to ensure uniformity in the concrete mix. The specimen for corrosion test was prepared as per the ASTM standard [9]. Concrete prisms of size 280 mm × 115 mm × 150 mm (L x Wx H) were prepared in specially prepared steel moulds. Before placing concrete in the mould, two 12 mm diameter HYSD reinforcing bars were placed at 25 mm from the bottom of the mould (cathode) and one bar was placed at 25 mm from the top (anode). These bars were initially insulated with an epoxy coating in such a way that, a 200 mm length of bar is unprotected within the concrete prism. So, 40 mm length of the bar within each end of the prism as well as the protruding portion was covered with epoxy coating.

Concrete was placed in the moulds in three layers and compacted with the help of a table vibrator. The specimens were demolded after 24hours from the time of casting and were kept in curing tank for another 27 days. Standard cubes of size 150 mm were also prepared along with the prisms for the determination of the concrete strength on 28th day.

After 28th day from the date of casting, the top surface of the prism was roughened with the help of a steel wire brush and kept in the laboratory environment for normal drying of the specimen. After two weeks from the ate of keeping the specimen outside the curing tank, the four vertical sides of the concrete prism were coated with epoxy. A dam of size 150mm × 75mm × 75 mm was made with Perspex sheet and was then fixed centrally over the top of the roughened face. The top surface outside the dam was then coated with epoxy. One end of the rebar was soldered with a 14 gauge copper wire and a 100 ohm resistor was placed between the top and bottom bars. Figure 1 shows the typical photograph of corrosion test specimen as well as the corresponding cubes ready for the test.

Fig -1: Corrosion test specimens and cubes

A total of 27 corrosion test specimen and cubes were prepared for the present study.

2.4. Corrosion test

The corrosion test was started one month after the samples were removed from the moist room. The test specimens were first supported on two non-electrically conducting supports to ensure air flow under the specimen.

The first cycle of wetting and drying was started by filling the dam with 3% NaCl solution to a height of about 40 mm. The ponding was done for a period of two weeks, after which the salt solution was vacuumed off and the specimen was kept for another two weeks for drying under laboratory environment. A plastic loose fitting cover was placed over the dam to minimize evaporation of the salt solution. This cycle of wetting and drying continued till the end of the measurement.

Voltage across a 100 Ω resistor was measured at the beginning of the second week of ponding using a voltmeter. From the measured voltage, V_j, the current through the resistor, I_j, was calculated using the equation

$$i_j = V_j / 100$$

The total integrated macrocell current over a time period, which is a measure of corrosion potential of embedded steel in concrete was then calculated using the relation

$$TC_j = TC_{j-1} + [(t_j - t_{j-1}) \times (i_j + i_{j-1})/2]$$

Where;
TC = total corrosion (coulombs)
t_j = time (seconds) at which measurement of the macrocell current is carried out, and
i_j = macrocell current (amps) at time, t_j

3. RESULTS AND DISCUSIONS

3.1. Properties of fresh concrete

The slump values of different concrete mixes are given in Table 3.

Table -3: Slump values of different concrete mixes

Specimen ID	Slump(mm)
CCW1	85
CCW2	130
CCW3	150
G1W1	102
G1W2	123
G1W3	142
G2W1	95
G2W2	118
G2W3	150

It could be observed from Table 3 that, the workability of concrete with GGBFS increases compared with OPC concrete, provided other parameters are kept constant.

3.2. Properties of hardened concrete

Cube strength of different concrete mixes tested on the 28th day from casting is presented in Table 4. Each value in the table is the average of three test result.

Table-4: 28th day cube strength of concrete

Specimen ID	28 day Compressive strength (N/mm^2)
CCW1	48.5
CCW2	47.5
CCW3	46.0
G1W1	55.5
G1W2	45.0
G1W3	41.5
G2W1	52.5
G2W2	49.5
G2W3	49

From Table 4, it could be observed that, the cube strength of concrete enhances when GGBFS is added. The enhancement in strength depends on the GGBFS content and w/b ratio. For the present study, a maximum strength enhancement of 25% could be achieved with 25% GGBFS and with a w/b ratio of 0.40.

The corrosion potential of steel in concrete was calculated in terms of total corrosion current (Tc) fron the voltage measurement made at regular intervals. Due to time limitation, a maximum time period of 120 days has been considered for the present study.

Figures (Charts) 2 to 4 shows the variation of corrosion current with time for test specimens. While Fig. 2 corresponds to control concrete, Figs. 3 and 4 corresponds to concrete with 25% and 50% GGBFS respectively.

Table 5 presents the total corrosion current calculated on 120th day from the date of start of the corrosion test for the specimens.

From Figs. 2 to 4, it could be observed that, the primary parameter that enhances the corrosion potential of steel in concrete is the water to binder ratio. A lower w/b ratio reduces the corrosion potential of steel in concrete.

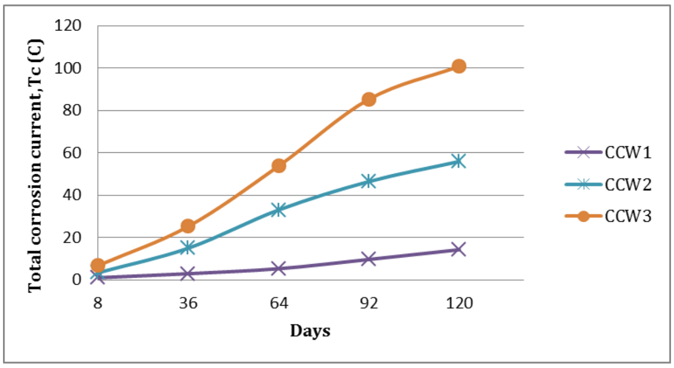

Chart -2: Variation of total corrosion current with time in control specimens

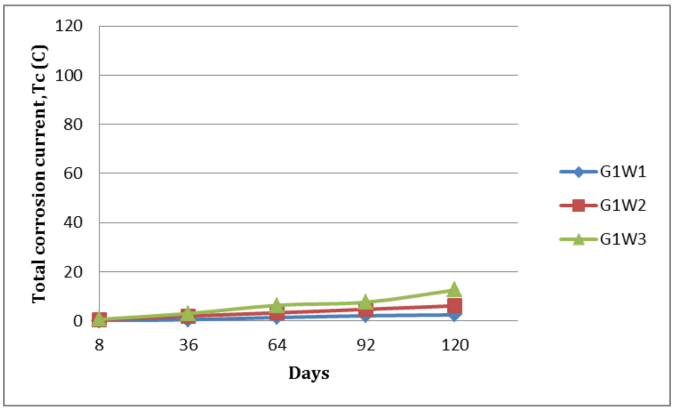

Chart-3: Variation of total corrosion current with time in specimens with 25% GGBFS

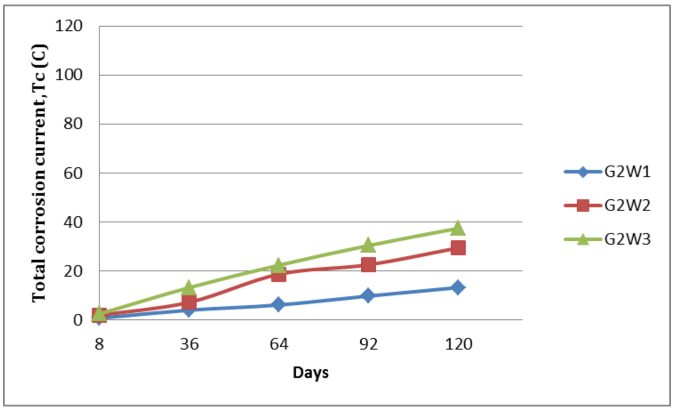

Chart-4: Variation of total corrosion current with time in specimens with 50% GGBFS

It could be further observed that, the addition of GGBFS in concrete reduceses the effect of w/b ratio on the corrosion potential of steel in concrete. For the present study, on 120th day, while steel in OPC concrete had an increase in corrosion potential by about 610% when w/b ratio was increased from 0.40 to 0.50, the corresponding increase in concrete with GGBFS was only 411% and 183% respectively for 25% and 50% GGBFS content.

Table-5: Total corrosion current on 120th day

Specimen ID	Total corrosion current, Tc (C)
CCW1	14.2
CCW2	55.87
CCW3	100.8
G1W1	2.45
G1W2	6.13
G1W3	12.54
G2W1	13.24
G2W2	29.44
G2W3	37.43

The effect of GGBFS in reducing the corrosion potential of steel in concrete is very much evident in Figs. 2 to 4. It could be observed that, with reference to 120th day's observation and for an OPC concrete with w/b ratio of 0.40, the concrete with GGBFS had less corrosion potential by about 83% and 7% respectively for 25% and 50% GGBFS content. On the other hand, compared with OPC concrete with a w/b ratio of 0.50, concrete with GGBFS had less corrosion potential by about 88 % and 63 % respectively for 25% and 50% GGBFS content.

4. CONCLUSIONS

Based on the study conducted on concrete mixes having 400 kg cement per cubic meter of concrete and with 25% and 50% GGBFS as replacement of cement, following conclusions could be derived.

- The replacement of OPC with GGBFS enhances the compressive strength of concrete and value depends on w/b ratio as well as the GGBFS content.
- For the present study, compared with OPC concrete having a w/b ratio of 0.40, a maximum enhancement in cube compressive strength of 13.7% could be observed when cement was replaced with 25% GGBFS.
- The primary reason for the cause of corrosion of steel in concrete is the w/b ratio of concrete for both OPC concrete and concrete with GGBFS.
- The GGBFS content in concrete reduces the corrosion potential of steel in concrete.
- The total corrosion current on 120th day's observation was lowest for the concrete with 25% GGBFS content and for a w/b ratio of 0.40. This is about 83% less compared to the corresponding specimen with OPC.

Based on the present study, it could be concluded that, by properly selecting the replacement quantity of GGBFS (25%) and w/b ratio (0.40), the corrosion potential of steel in concrete could be reduced very much, without affecting the concrete compressive strength.

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