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PREDICTIVE REGRESSION MODEL FOR CHLORIDE ION PENETRATION AND COMPRESSIVE STRENGTH OF GGBS CONCRETE

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Abstract: This study looks at the mathematical modelling of the compressive strength of concrete cube specimens that have been cured at 3, 7 and 28 days as well as the resistance to chloride penetration in cylindrical concrete specimens that have been treated at 28 days and incorporate Ground Granulated Blast Furnace Slag (GGBS). Various concrete samples were subjected to laboratory testing to determine compressive strength and chloride penetration. GGBS has been used as a replacement for ordinary Portland cement (OPC) in amounts of 0%, 5%, 10%, 15%, 20%, 25%, and 30%. Then, cylindrical specimens and concrete cubes were produced appropriately. Cubes were subjected to a compressive strength test, and cylindrical specimens underwent a Rapid Chloride Penetration Test (RCPT). Two predictive regression models have been created, one for the charge passed Q @28days in cylindrical concrete specimens and the other for the compression strength (CS) of concrete cubes at 3, 7, and 28 days. Chloride penetration prediction model Q @28 Days has values for R Square, Adjusted R Square, Standard Error, and P value of 0.97, 0.71, 210.81, and 0.032. Both mathematical models have higher accuracy, correlation with experimental data, and coverage of the whole range of data.
Keywords: RCPT; GGBS; OPC; Predictive Models; Concrete

1. Introduction:

Ground Granulated blast furnace slag utilization is more favorable with concrete mix at coastal regions. Historical data and previous study concluded that at coastal areas slag bring long duration water tightness and also work as catalyst for chloride ion immobilize mechanism. But it is observed from service life of structures that such admixtures are being useful to convinced echelon as they couldn't be able to take part in development of initial strength process.[1]

Basha, B. G., Rao etal (2020) used ground granulated blast furnace slag (GGBS) to added on concrete at with replacement of 0%, 30%, 50%, 70% with 5% silica fume and 0.3, 0.4 & 0.5 w/c ratios to estimate its strength and chloride penetration. 12 mixes each of 15 cubes were casted. Second law of Fick's is used for forecasting of chloride value at various depths.[2]

James, A., Bazarchi etal (2019) studied that Deterioration due to corrosion is a major factor which influence the durability of RCC structures. RCC Structures are exposed to hostile marine environments in Cities which are situated in coastal region.[3]

Neves, R., Silva, etal (2018) found that Steel corrosion is one of the major threats to the service life of RCC structures and chloride penetration promote the corrosion development. MLR method was used to a dataset acquired from the literature. The dataset consists of 942 case studies from 33 publications. One of these models is projected to forecast the chloride diffusion coefficient from accelerated non-steady state migration tests whereas the other model predicts the charge transport in RCPT test.[4]

Papadakis, V. G. etal (2000) used the experimental programme to simulate the main deterioration mechanisms in reinforced concrete (carbonation and chloride penetration). It was established that for all SCM tested, the carbonation depth diminished as aggregate substitute by SCM enlarge and cement substitution by SCM increase.[5]

The main motive of present study and investigation is to examine influence of GGBS on compressive strength and developed the regression model for Compression strength at 3,7 and 28 days. RCPT test has been conducted on various cylindrical specimens and then after we developed a forecasting regression model for total charge (Q in Coulomb) at 28 days of various cylindrical concrete specimens.[6]

2. Experimental Investigation:

In order to understand the influence of GGBS content in concrete at mechanical properties like compressive strength and durability property like chloride ion penetration, we first select the properties of various mixing material which will be constitute of resultant developed concrete and appropriate mix design ratio to develop a suitable Grade of Concrete.

2.1 Materials: Properties of various Materials used in development of concrete specimens are as under below:

a) Ultra tech OPC -53 Grade cement has been used as per IS 4031:1968.
b) River Sand was used as Fine Aggregate confirm to Zone-II of IS 383:2016.
c) Locally available crushed 20mm and 10mm coarse aggregates were used.
d) Ground Granulated blast furnace slag is obtained during the manufacturing process of iron in blast furnace.
e) Super plasticizer FOSROC (Aura mix 400) has been used as water reducing admixture.

2.2 Mix Design: Concrete mix design process of M30 Grade is executed as per Indian standard 10262:2009 & 456:2000. Table 1 shows Mix design cubic per meter of M30 Grade. Then after, various cylindrical and cubical concrete specimens have developed for M30 Grade accordingly.

Table1. Mix Design of M30 Grade Per Cubic Meter

S. No.	Mix	Cement	GGBS	% GGBS	FA	CA	Water	W/C
1.	M-1	422.72	0	0	684.76	1138.32	186	0.44
2.	M-2	401.58	21.14	5	684.76	1138.32	186	0.42
3.	M-3	380.45	42.27	10	684.76	1138.32	186	0.42
4.	M-4	359.31	63.41	15	684.76	1138.32	186	0.40
5.	M-5	338.18	84.54	20	684.76	1138.32	186	0.40
6.	M-6	317.04	105.68	25	684.76	1138.32	186	0.39
7.	M-7	296.04	126.68	30	684.76	1138.32	186	0.39

2.3 RCPT Test (ASTM C1202): RCPT Test is being conducted on various cylindrical concrete specimens. Charge is passed through specimens via Rapid Chloride Permeability Test (RCPT) machine. If charge reading in coulomb is more, than it suggests, concrete is more preamble and less impermeable in case of vice versa.

3. Results:

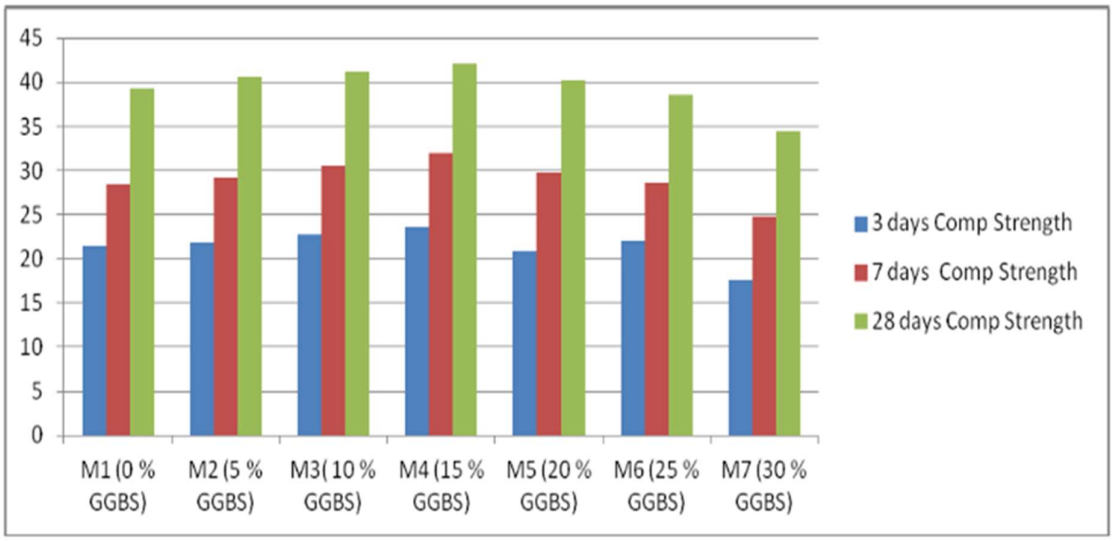
Compressive strength results of various concrete mixes with GGBS accumulations at age of 3, 7 and 28 days are discussed here and rapid chloride penetration test as per ASTMC1202 conducted for various cylindrical concrete specimens with diverse GGBS content at 28 days period. Then after, Predictive Regression Model has been developed for both Compressive Strength @3, 7, 28 days and Charge Passed @28 Days in various concrete specimens.

3.1 Compressive Strength: Compressive strength of various concrete cubes (at age of 3, 7 and 28 days) has been measured as per code IS 516 and Table 2 below shows the compressive strength of various concrete specimens at 3, 7 and 28 days curing with diverse GGBS content. Figure 1 shows the bar chart comparison of all samples with GGBS accumulation.

Table 2. Compressive Strength of various concrete specimens @3, 7 and 28 days

Mix/Compressive Strength (MPa)	3 Days	7 days	28 days
M1	21.41	28.48	39.26
M2	21.91	29.22	40.58
M3	22.72	30.54	41.27
M4	23.65	32.03	42.15
M5	20.89	29.72	40.18
M6	21.94	28.54	38.56
M7	17.58	24.82	34.47

Figure 1: Bar chart for compressive strength at 3 ,7 and 28 days



3.2 RCPT Test Results: RCPT test results on various cylindrical concrete specimens incorporating GGBS are as under below in Table 3 and Figure 2 shows the bar chart comparison of charge value at 28 days via RCPT test in all diverse concrete sample with GGBS addition.

Table 3. Value of Total charge in Coulomb @28 days via RCPT test

Mix	Q @28 days
M1 (0 % GGBS)	2945.5
M2 (5 % GGBS)	2679.5

M3(10 % GGBS)	2194.56
M4 (15 % GGBS)	1595.88
M5 (20 % GGBS)	820.55
M6 (25 % GGBS)	648.56
M7 (30 % GGBS)	429.45

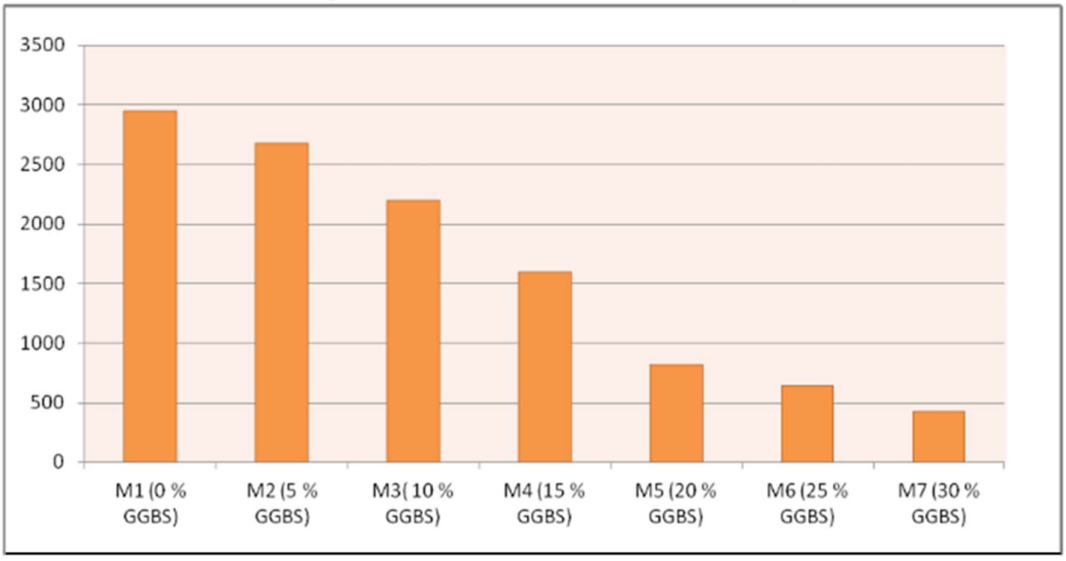


Figure 2: Bar chart for RCPT Results for various concrete specimens at 28 days

4. Predictive Regression Model: Two Predictive Regression Models has been developed, one for compressive strength (CS) of concrete cubes at 3, 7 and 28 days and other for charge passed Q @28daysin cylindrical concrete specimens via RCPT test.

4.1 Regression Model for Compressive Strength: Regression function is being developed for compressive strength (3, 7 and 28 days age of concrete cube specimens) as dependent variable and GGBS, water cement ratio and cement as independent variable.

Compressive strength = f (Cement, GGBS, Water Cement Ratio)

i.e. $$CS = f(C, GGBS, W/C)$$

$$CS\ (Day) = a_1 + a_2 * Cement + a_3 * GGBS + a_4 * W/C$$

Where a1, a2, a3 & a4 are coefficients belongs to real numbers

Regression equation for Compressive Strength at 3 days

$$= 5.0594 \times 10^{-2} \times C - 0.12842 \times GGBS - 129.79 \times W/C + 132.801$$

Figure 3 shows the correlation curve between experimental and predicted compressive strength at 3 days age concrete samples with GGBS accumulation and corresponding value of R Square, Adjusted R Square, Standard Error, P value are 0.97, 0.93, 0.558 and 0.044, respectively.

Regression equation for Compressive Strength at 7 days

$$= -6.218 \times 10^{-2} \times C - 0.1801 \times GGBS + 324.6485 \times W/C + 0.018760$$

Value of R Square, Adjusted R Square, Standard Error, P value are 0.88, 0.69, 1.312 & 0.176 respectively and figure 4 shows the experimental and predicted compressive strength at 7 days cured specimens.

Regression equation for Compressive Strength at 28 days

$$= 9.584 \times 10^{-2} \times C - 0.08148 \times GGBS - 308.235 \times W/C + 172.8654$$

Value of R Square, Adjusted R Square, Standard Error, P value are 0.93, 0.82, 1.146 & 0.15 respectively and figure 5 shows the experimental and predicted compressive strength at 28 days cured specimens.

Figure 3: Experimental and Predicted Compressive Strength at 3 days curing

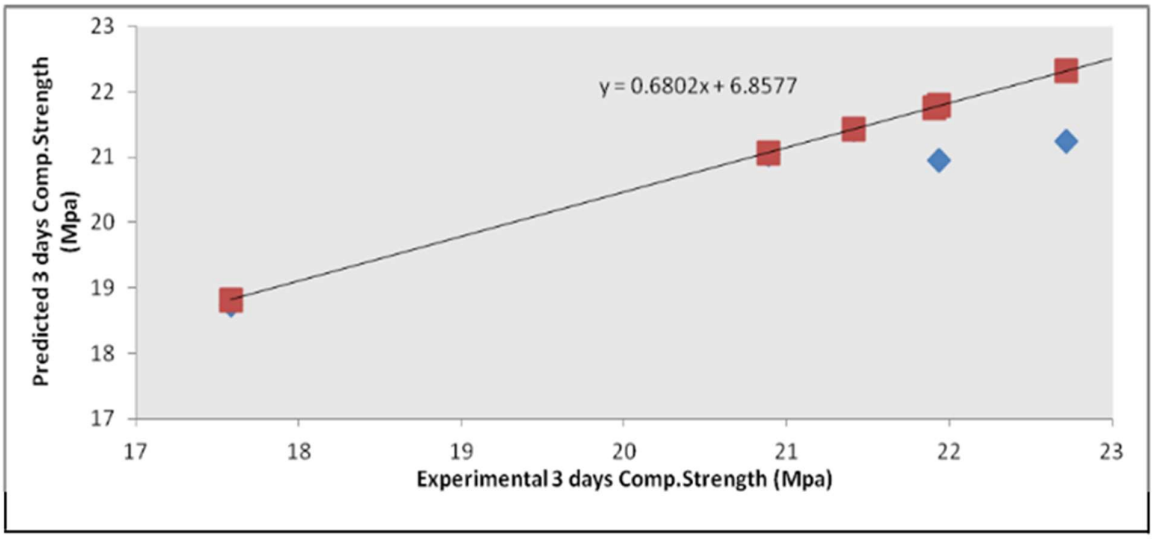


Figure 4: Experimental and Predicted Compressive Strength at 7 days curing

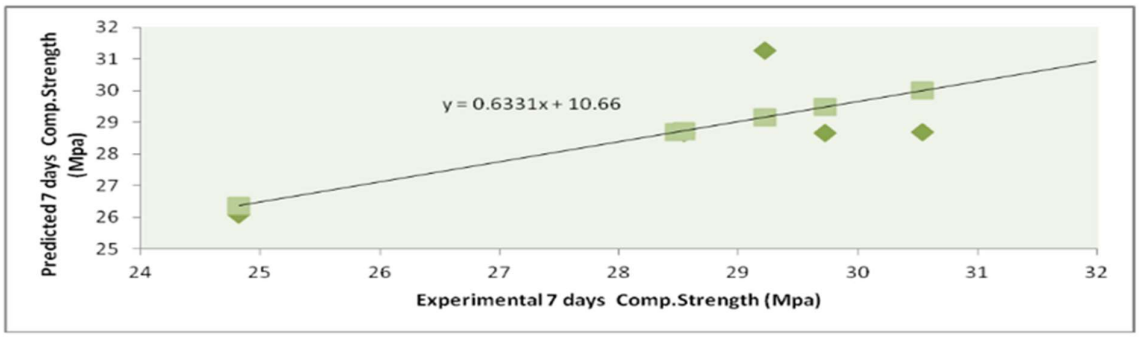
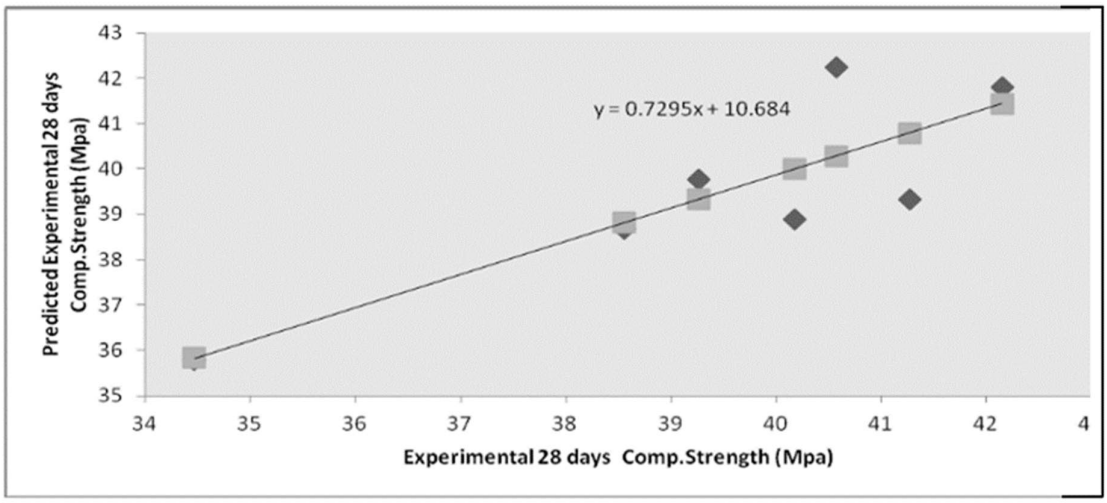


Figure 5: Experimental and Predicted Compressive Strength at 28 days curing



4.2 Regression Model for Total Charge @28 days: In the numerous regression investigation regression function is being developed considering cement, GGBS and water cement ratio as independent variable and total charge as explanatory variable for various cylindrical concrete specimens cured at age of 28 days.

Total Charge = f (Cement, GGBS, Water Cement Ratio)

i.e. Q = f (C, GGBS, W/C)

Q (@28 Day) = $a_1 + a_2$* Cement + a_3*GGBS + a_4*W/C

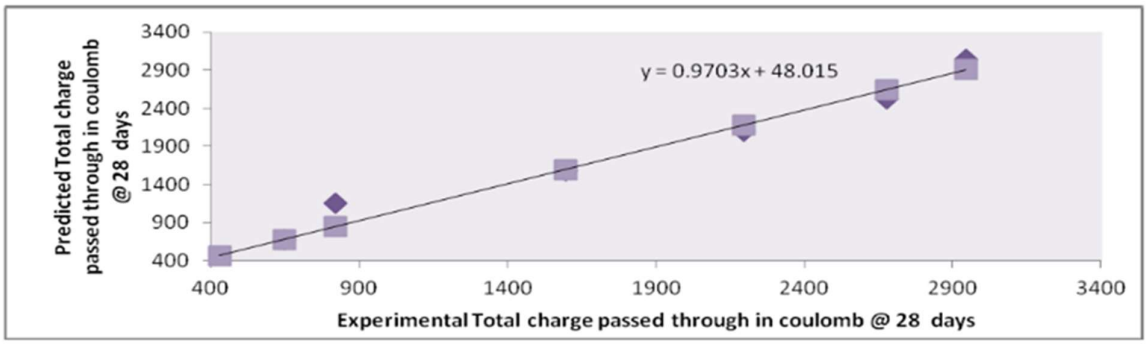
Where a1, a2, a3 & a4 are coefficients belongs to real numbers

Regression equation for Total Charge at 28 days

$$= 4.584 \times 10^{-4} \times C - 20.2928 \times GGBS + 4189.3492 \times W/C + 1191.18$$

Figure 6 shows the Experimental and Predicted RCPT Values (Total Charge @ 28 days) and Value of R Square, Adjusted R Square, Standard Error, P value are 0.97, 0.71, 210.81 and 0.032 respectively.

Figure 6: Experimental and Predicted RCPT Value at 28 days curing



5. Conclusions:

Various concluding remarks of this research study are under below:

1) With the accumulation of 15% & 20% of Ground Granulated blast furnace slag as partial substitute of Cement for M30 grade of concrete, there is an enlarge in compression strength of concrete as compared to solitary when no substitution had been made.
2) The proposed model has good precision and further it could be used in practical engineering for forecasting.
3) Both Predictive Model exhibits good accuracy, precision, less percentage difference error & better agreement with Experimental actual data's results of Compressive Strength Test and RCPT test.
4) In sight of Experimental test results, the concrete with GGBS exhibits low, very low or insignificant chloride ion permeability which means it is durable concrete at 28 days itself. One important remark is that accumulation of slag absolutely reduces the concrete pores and assist for imperviousness
5) From the experimental outputs, it is interpreted that Cl- ions permeability is huge with higher water binder ratios.
6) Concrete with GGBS can be suggested further for precast construction where benchmark strength and durability are requisite and cast-in-situ constructions.

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