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Mathematical Model for Strength Prediction of Concrete under Influence of GGBS and Fly Ash

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Abstract: ***There are many variables of concrete that affect its strength gaining characteristics. This study is a research to use the early compressive strength test result to evaluate compressive strength at different ages. Proper use of the early day compressive strength result to predict characteristic strength of normal weight concrete has been investigated. A simple model capable of predicting the compressive strength of concrete at any age is proposed for locally available aggregate concrete. The model develops a rational polynomial equation having only two coefficients. This study also proposes a simple justified relationship between the coefficient α (strength at infinite time) with the strength values of concrete of a particular day. This relation almost make simple to understand and reliable to any the concrete strength prediction model. The developed model is validated for commonly used for local aggregate concrete. Data used in this study are collect from some previous studies of research scholars and recent experimental works of us at RCC lab of MBM Engineering College Jodhpur. along with data sets of conventional concrete (CC), we have also considered influence and variation of GGBS and FLYASH in Conventional concrete and we have selected the various data sets for M1 (GGBS & FLY ASH),M2(GGBS) & M3(FLY ASH) member group .The research carried with the model using different data exhibit reliable prediction of concrete strength at different ages (7, 14, 28 days.) with good accuracy.***

Keyword**: Strength prediction, concrete, ground granulated blast Furness slag, fly ash .**

I. INTRODUCTION

Compressive strength of concrete is the main parameter for quality of concrete .it is generally obtained by testing of concrete cube or cylinder at various days (age). Design of any structure depends upon results of characteristics strength of concrete It is calculated for a concrete sample that has been cured for 28 days .it is determined by crushing test for standard concrete cube or cylinder .almost all standard codes and guidelines has recommended 28 days concrete strength .in construction projects time and economic factors are important .but for quality control assurance waiting for 28 days is necessary and it could not be avoided. So an easy and reliable method for predicting strength of concrete at any age requirement for present days for large scale construction projects so that it could be decided at any stage of construction project to continue project or manage the weak concrete. So early management in project is very important and it could save both time and economy. In general to develop a model for particular system it is necessary to have knowledge of explicit mathematical input (independent variable)and output(dependent variable).but modeling such explicit function is to be cumbersome and not easily plugged in a particular system .therefore most of prediction model is prepared on the basis of relations between concrete strength and its ingredients properties .different scientists and researchers has approached such model by considering various parameter involved in concrete strength and choosing dependent and independent variable which effects the behavior and properties of concrete strength. This research paper is focused on how to use early and previous age strength test result to predict the concrete strength at various days (age).we have considered influence of GGBS and FLYASH along the general constituents (Cement (C), Coarse aggregate (CA) Fine aggregate (FA) and Water (W) in various sets of data in different member group (CC, M1, M2, M3). CC refer to 28 data sets of strength of conventional concrete , M1 refer to 8 data sets of strength Concrete under influence and variation of GGBS and FLY ASH , M2 refer to 15 data sets of strength Concrete with under influence and variation of GGBS and M3 refer to 21 data sets of strength Concrete under influence and variation of FLY ASH. We have established relationship between concrete strength and age in mathematical prediction model. Statistical techniques have been used to develop regression equation which can predicts strength and used to find various constant involved in mathematical model. We have used the various test results of compressive strength of concrete from RCC LAB of MBM Engineering College Jodhpur. Some test has been conducted freshly in Lab and some strength data's has been taken from previous work of literature of research scholars who has evaluated the strength of concrete in past in this RCC lab. All predicted result has been good correlation with actual results with significant accuracy.

II. PREVIOUS STUDIES AND RESEARCH

Concrete compressive strength is composite process and depends on several parameters.

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There are several research has been already done on this. it's necessary to have knowledge of strength attainment pattern in concrete which can make possible for prediction of concrete characteristic strength at any age and helps to get thought on quality of concrete with conformity of design requirement .Various enhanced methods including artificial neural networks , computational modeling and mathematical modeling has been used in concrete strength prediction .many researchers has also used statistical techniques to solve the problem strength prediction at different days.

a number of studies has focused on linear and non linear regression model which could help to generate curve fitting equation and improve accuracy of prediction model. A linear trend line usually shows that something is increasing or decreasing at a steady rate. A linear trend line uses the following equation to calculate the least squares fit for a line a number of research efforts have concentrated on using linear regression model to improve the accuracy of prediction. Most popular linear regression equation which is often used in strength prediction, relates water-cement ratio (w/c) to strength of concrete. Exclusion of references, it should be less than 5%.

$$f = \alpha_0 + \alpha_1(w/c)$$

Where, f = compressive strength of concrete.

α_0, α_1 are coefficients.

The origin of the above equation is Abram's inspire for multi variable linear regression equation.

$f = \emptyset(x_1, x_2, x_3 \dots \dots \dots x_n)$

Or, $f = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \dots \dots \dots \dots \dots \dots \dots \dots$

Where $x_1, x_2, x_3 \dots \dots \dots$ are independent variables which can be replaced by the factors that influences the concrete behavior like water-cement ratio (w/c), quantity of cement (C), quantity of coarse aggregate (CA) quantity of fine aggregate (FA, GGBS, FLYASH etc in the concrete mix and α_0 , α_1 , α_2 are equation coefficients for regression model.

We can also choose multivariable power equation as an effective model for prediction of strength of different ages of concrete. The general format of the equation is given below.

$$f = \alpha_0 X_1^{\alpha_0} X_2^{\alpha_1} X_3^{\alpha_2} X_1^{\alpha_3} \dots \dots \dots X_m^{\alpha_m}$$

$$f_{age} = \alpha_o C^{\alpha_o} W^{\alpha_1} FA^{\alpha_2} CA^{\alpha_3} (W/C)^{\alpha_4} GGBS^{\alpha_5} FLYASH^{\alpha_6}$$

The values of α_0 , α_1 , α_2 ……. are determined from regression analysis of the statistical data and it is possible to predict the strength of concrete for a particular age directly. Most of the models discussed above consider different index properties of concrete which influence the strength gaining behavior. This study is an exception because it shows the importance of using only the strength test result of a particular day as an alternative of using the other index parameters.

III. DATA ACQUIREMENT

Modeling a problem in concrete strength is actually nothing but to evaluate relationship between various parameter and variable. To justify the relationship we need therefore large number of experiment data and results. data and results used in this research has been taken from experiment conducted recently in RCC Lab of MBM Engineering College Jodhpur and some results has been taken from literature of previous work consists of experiments which has been conducted in past in this lab. Obviously different data in different environment and parameter condition increase the validity and accuracy of model. Total of four member group data has been acquired .first member is Conventional concrete (CC) consists of 28 sets , second member M1 consist of 8 sets with variation of GGBS and FLY ASH, third member M3 consists of 15 sets with variation of GGBS and Last member M3 consists of 21 sets with variation of FLYASH. Locally available aggregate and ordinary Portland cement (OPC) has been used in all four member. We have considered influence of GGBS and FLYASH along with general ingredient of concrete (Cement (C), Coarse aggregate (CA), Fine aggregate (FA) and Water (W) on the compressive strength of concrete. Different mix proportion of various ingredients has been selected for study.

Table- I: Property Ranges Of First Member Group To Fourth Member Group Test Data

	Units	*CC*	*M1*	*M2*	*M3*
Cement	Kg/m^3	350 - 385	242 - 308	236 - 296	227 - 305
GGBS	Kg/m^3	0	32 - 74	96 - 116	0
FLYASH	Kg/m^3	0	35 - 72	0	97 - 113
Fine Aggregate	Kg/m^3	735 - 785	720 - 772	728 - 782	733 - 736
Coarse Aggregate (10mm)	Kg/m^3	385 - 435	355 - 420	392 - 411	386 - 402
Coarse Aggregate (20mm)	Kg/m^3	595 - 655	482 - 652	477 - 647	527 - 632
Water	Kg/m^3	140 - 182	145 - 176	151 - 182	147 - 172
Admixture	Kg/m^3	3.2 - 4.1	3.3 - 4.5	3.3 - 4.2	3.4 - 4.5
W/C ratio					
Fines modulus of fine aggregates		2.52 - 2.72	2.46 - 2.72	2.5 - 2.7	2.5 - 2.72
7 days	Mpa	11.12 - 16.54	10.97 - 18.72	11.02 - 19.62	12.11 - 17.21
14 days	Mpa	22.12 - 28.52	23.72 - 29.11	23.56 - 28.77	20.21 - 28.51
28 days	Mpa	33.12 - 39.42	31.71 - 44.21	30.15 - 42.11	31.15 - 43.51

IV. MATHEMATICAL MODEL

We know that in order to create a mathematical model it is pre requirement of a function which can define and establish relationship between parameters involve in model. Accurate and well define knowledge of behavior of system with practical and experimental results are necessary to develop a significant model. This research is focus on to evaluate predictable concrete strength from early day test results.

Model I. Investigation shows that on plotting curve between strength and days

for data set of first member group (CC) ,strength establish a correlation with its age according to following equation:

$$f_c(d) = \left(\frac{d}{d+\alpha}\right)\beta \text{----------} \quad (1)$$

Where, fc (d) is function defining strength depends on (d) days.

α and β are constants for each curve but different for different data sets (graph).

This equation has been developed according to data set of first member group (CC).

It could also mentioned that equation 1 is resembled to equation proposed by ACI committee (ACI 209-71) for predicting compressive strength of concrete at any age based on 28 days strength.

$$(f_c')_t = [t/(a+b.t)]\,(f_c')_{28d} \text{ ---} \quad (2)$$

Where, a and b are constants

$(fc')_{28d}$ = 28 day cylinder crushing strength and t is time in days

However for this research equation 1 is basic equation to express strength of concrete as function of age where α and β are constants .it is also observed that strength is controlled by values of α and β in order to proper use of equation 1 it is required to obtain value of α and β in each separate case. We found that unit of α is days and β is stress.

Easiest way to compute value of α and β is to use strength test results of two different age(days) and solve two equation simultaneously .

Another approach to find value of α and β is to use regression analysis. in that approach we can generate a polynomial function in which α could express in form of β and $f_c(d)$.

$\alpha = A + B\beta + C\,f_c(d) + D\beta\,f_c(d) + E(f_c(d))^2 \ldots (3)$

Where, A, B, C and D are coefficients and fc(d) is strength of concrete at d^{th} days.

The value of these 5 coefficients shall differ for strength test results for different days and could be computed from regression analysis for various sets of data for particular days test. Now let if strength of particular 7 and 14 days are known than equation 1 and 3 can solved along with values of A, B, C, D and E will give value of α and β for particular concrete after getting value of α and β equation 1 could be used for different ages.

Model 2: Equation 1 and 3 of first model has potential to predict strength of concrete for various days but it has 5 coefficients which can make it cumbersome. also many constant are difficult to handle . if we could reduce the number of constant our model shall be more accurate and significant .when we had more analyzed the first model we observe that value of α Could more easily obtained if we use power equation of regression analysis instead of polynomial .so from statistical techniques of regression we can write power equation:

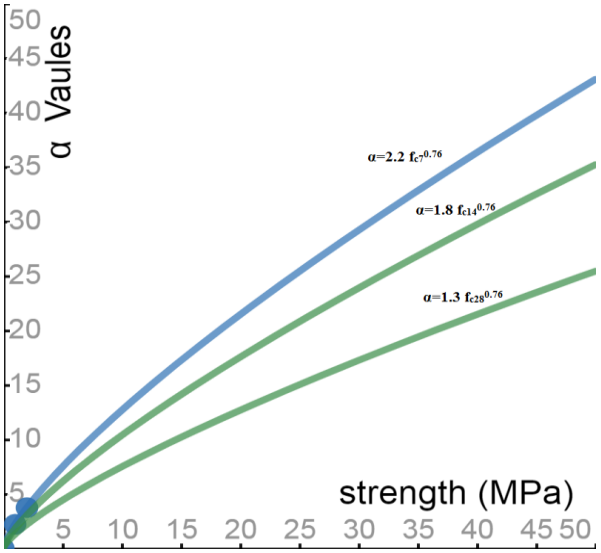
$$\alpha = k\,(f_c(d))^R \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$f_c(d)$ is strength of concrete at d^{th} days and k and R(is the coefficient of correlation) are coefficients.

When we plugged the data's of member 1 group CC and member 2 group M1 we get best fit equation (curve fitting) and obtained the value of k and R. we observed the pattern that value of k varies for strength results of various days but value of R unchanged and approach to 1.we selected the value of R to 0.76 by slightly rounding off to nearest decimal. Computed values of k and R are in table 2 and by using value of k and R we obtained value of strength for 7, 14, and 28 days which are in table 3. Than we computed value of β using strength result of 7, 14 and 28 days and get value of α in last step. Finally after evaluating value of α and β equation 1 could predict the strength of concrete at any age (days).

Table Ii: Values Of Coefficients K For Different Days Strength

Concrete age d (days)	*k*	*R*	*Statistical equation*
7	2.2	0.76	$\alpha = 2.2\,f_{c7}^{0.76}$
14	1.8	0.76	$\alpha = 1.8\,f_{c14}^{0.76}$
28	1.3	0.76	$\alpha = 1.3\,f_{c28}^{0.76}$



graph i: variation α values with strength of concrete

V. PERFORMANCE EVALUATION

The recognition of any model is basically depending upon its performance. There are various steps for measuring that .use of statistical variables is a best method for performance analysis. which is related to classification of output results from model with actual or lab results .the three important statistical variables like average absolute error (AAE), root average square error (RASE) and general efficiency (GE) can evaluate the performances of predicted mathematical model equations .

$$AAE = \frac{1}{n}\sum_{i=1}^{n} | P_i - R_i |$$

$$RASE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} | P_i - R_i |^2}$$

$$GE = \{1 - \frac{1}{n}\sum_{i=1}^{n}\frac{|P_i - R_i|}{R_i}\} \times 100\ \%$$

Where, R_i = Real value, P_i = Predicted value and n = number of data's

A total of 72 data sets used in this study .among them 36 sets of data are used for modeling the problem and rest are used for performance evaluation.

First and second member group data (CC and M1) are used for development of the model and others (M2 and M3) are used for performance test.

VI. RESULTS AND DISCUSSIONS

The proposed model makes use of the strength gaining characteristics of normal weight concrete. Two member groups (CC & M1) of test data are used to develop the model while its performance is checked with four groups (CC, M1, M2 & M3) of test results. Performance evaluation is done with different data groups and the prediction is made for a particular day .The performance measuring statistical parameters are used to check the efficiency .three important statistical variables like average absolute error (AAE) ,root average square error (RASE) and general efficiency (GE) are used for the performances of the proposed model for every group of data sets. Chart 2 shows variation of efficiency of prediction for different groups of data. It varies from 86.88 to94.15 % which is within a narrow band. From overall observation, it may be concluded that all the performance measuring parameters are within acceptable range.

Table III: Predicted Strength Using Proposed Model For First Member Group Data (Cc)

Mix no.	*Real Strength (R_i)*			*Predicted strength (P_i)*			
	7 Days	14 days	28 days	Using 7 days values		Using 14 days values	
				14days	28days	7days	28days
1	11.12	22.12	33.12	22.42	33.23	11.24	33.16
2	11.21	22.33	33.33	22.89	33.54	11.55	33.34
3	11.33	22.66	33.77	23.12	33.96	11.01	33.86
4	11.48	22.91	34.11	22.12	34.50	11.34	34.32
5	11.59	23.04	34.44	23.62	34.74	12.33	34.55
6	11.83	23.11	34.77	23.70	34.96	11.08	34.66
7	12.44	23.22	35.04	23.75	35.33	12.67	35.22
8	12.94	23.31	35.11	23.89	35.45	13.14	35.28
9	13.03	23.41	35.45	23.77	35.71	13.41	35.55
10	13.55	23.64	35.66	23.91	35.95	13.78	35.71
11	13.88	23.88	35.88	24.03	36.12	13.95	36.03
12	14.09	24.44	36.05	24.67	36.24	14.33	35.95
13	14.67	24.88	36.44	25.06	36.11	14.87	35.77
14	14.97	24.97	36.89	25.17	36.24	15.17	36.95
15	15.04	25.03	37.04	25.33	37.14	15.23	37.18
16	15.12	25.11	37.41	25.62	37.11	15.33	37.31
17	15.23	25.33	37.67	25.66	37.44	15.44	37.36
18	15.44	25.44	37.91	25.84	37.55	15.56	37.37
19	15.58	25.77	38.01	25.96	38.35	15.77	38.18
20	15.77	25.88	38.11	26.12	38.04	16.27	38.08
21	15.89	26.11	38.21	26.31	38.65	16.23	38.11
22	15.95	26.23	38.44	26.48	38.44	16.34	38.22
23	16.01	27.77	39.09	28.32	39.13	16.66	39.11
24	16.12	27.94	39.13	28.17	39.56	16.78	39.44
25	16.23	28.12	39.21	28.39	39.44	17.06	39.33
26	16.34	28.33	39.30	28.78	39.04	17.33	39.11
27	16.47	28.44	39.37	28.94	39.11	17.67	38.24
28	16.54	28.52	39.42	29.55	40.17	17.94	38.00

Table IV: Performance Summary for Second Member Group Data (M1)

Base strength	7 days		14 days	
Predicted strength(P_i)	14days	28days	7 days	28 days
AAE	1.33	2.01	1.34	1.54
RASE	1.14	1.45	1.04	1.28
GE (%)	87.42	88.37	84.44	85.38

Table V: Predicted Strength Using Proposed Model for Third Member Group Data (M2)

Mix no.	Real strength (R_i)			Predicted strength (P_i)			
	7 days	14 days	28 days	Using 7 days values		Using 14 days values	
				14days	28 days	7 days	28 days
1	11.02	23.56	30.15	23.75	30.20	11.00	30.10
2	11.67	23.68	30.99	23.93	31.04	11.57	30.19
3	12.40	24.14	31.63	24.44	31.53	12.10	31.53
4	13.25	24.88	32.54	25.00	32.44	13.88	32.24
5	14.67	25.33	33.78	25.44	33.68	14.97	33.68
6	15.48	25.68	34.08	25.78	34.33	15.78	34.08
7	16.14	26.77	35.17	26.93	35.07	16.34	35.11
8	16.89	26.94	36.83	27.02	36.94	17.09	36.63
9	17.33	27.15	37.33	27.35	37.55	17.46	37.83
10	17.88	27.39	38.55	27.39	38.67	17.88	38.75
11	18.10	27.59	39.44	27.89	40.14	18.33	39.00
12	18.36	27.93	40.12	28.01	40.34	18.56	41.42
13	19.44	28.17	41.50	28.44	41.17	19.54	41.20
14	19.55	28.52	42.00	28.77	42.56	19.75	42.45
15	19.62	28.77	42.11	29.17	42.07	19.94	42.08

Table VI: Performance Summary for Third Member Group Data (M2)

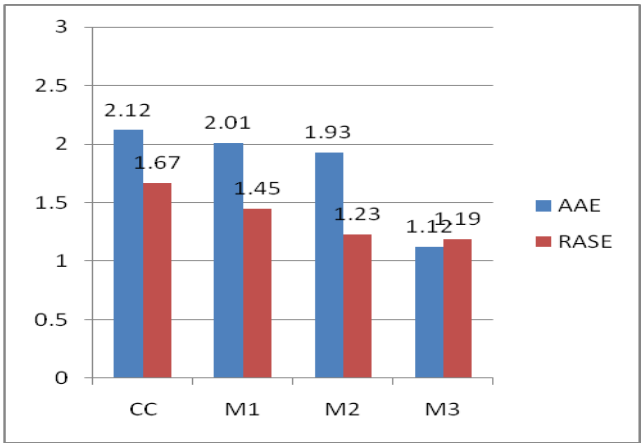
Base strength	7 days		14 days	
Predicted strength (P_i)	14days	28days	7 days	28 days
AAE	1.15	1.93	1.05	1.32
RASE	1.07	1.23	0.92	1.17
GE (%)	90.32	91.29	91.55	92.03

Table VII: Predicted Strength Using Proposed Model for Fourth Member Group Data (M3)

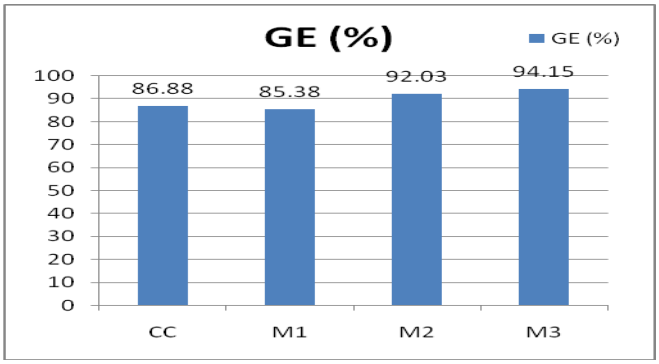
Mix no.	*Real strength (R_i)*			*Predicted strength (P_i)*			
	7 days	14 days	28 days	Using 7 days values		Using 14 days values	
				14days	28 days	7 days	28 days
1	12.11	20.21`	31.15	20.31`	31.5	12.55	31.04
2	12.33	21.12	32.88	21.34	32.56	12.66	32.06
3	12.89	22.23	33.33	22.43	33.13	12.95	33.05
4	12.94	22.67	34.78	22.77	34.08	13.06	34.17
5	13.4	23.12	35.04	23.22	34.77	13.68	35
6	13.78	23.44	35.44	23.91	35.1	14	35.24
7	14.19	24.66	36.55	24.77	36.11	14.77	36.05
8	14.44	25.03	36.91	25.11	36.61	14.67	36.4
9	14.77	25.19	37.35	25.45	37.1	14.89	37
10	15.03	25.91	38.12	26.13	38.01	15.45	38.01
11	15.33	26.02	38.33	26.21	38.06	15.56	38.06
12	15.77	26.15	38.66	26.31	38.07	15.97	38.09
13	15.91	26.44	38.88	26.54	38.68	16.08	38.68
14	16.03	26..96	39.13	26.76	39.03	16.09	38.13
15	16.14	27.07	39.44	27.33	39.14	16.1	38.08
16	16.44	27.44	40.04	27.34	39.03	16.37	38.01
17	16.55	27.88	41.43	27.58	38.91	16.57	38
18	16.77	28.13	42.56	28.06	42.11	16.66	42.07
19	16.93	28.37	43.08	28.7	43.01	17	42.12
20	17.1	28.44	43.33	28.04	43.12	17.07	42.27
21	17.21	28.51	43.51	28.15	43.16	17.21	43

Table Viii: Performance Summary for Fourth Member Group Data (M3)

Base strength	7 days		14 days	
Predicted strength (P_i)	14days	28days	7 days	28 days
AAE	0.84	1.12	0.95	1.09
RASE	0.91	1.19	0.79	1
GE (%)	91.77	92.88	93.88	94.15



Bar Chart I: Variation of Aae and Rase Value for Various Member Groups



Bar Chart Ii: Variation of Ge (%) Value for Various Member Groups

VII. CONCLUSION

Following conclusion can be made on the basis of this research paper:

This paper shows a simplified mathematical model for predicting strength of concrete at various days using any single day concrete strength test result.

The proposed model show important of two constant α and β which control the concrete strength with age (days).

This research show that there is power equation relationship between α and concrete strength of particular day and a proper relation could establish between α value and 7,14,and 28 days strength

Through this model we able to predicted the strength of conventional concrete (CC) with variation of GGBS and FLYASH. (Strength Data sets belongs to group Member M1, M2 and M3).

This proposed model has been also verified with different data sources and its show a significant efficiency to predict concrete strength.

It could be potential and reliable method for assessing the design strength of concrete from early age test result which can help to reduce both time and cost of large scale construction projects.

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