A Simplified Model for Prediction of Compressive Strength of Concrete Containing Fly Ash at Various Ages

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Abstract-In this research a correlation between simple and easily obtained common mix parameters have been developed to estimate the strength of the pozzolanic concrete containing Fly Ash. Experimental data from nine sources was obtained and then analyzed using multiple regressions. The parameters selected for the model development include concrete age, water to binder ratio (W/B), Fly Ash replacement, Fineness of Fly Ash, Tricalcium Silicate (C_3S) and Dicalcium Silicate (C_2S) content.The derived model was designed to predict the compressive strength f_c' of Fly Ash concrete up to ±30% precision. The model isdeveloped for individual ages of 7, 28, 90/91 days.

Keywords-Concrete, Fly Ash, Compressive Strength, Statistical Model, Pozzolanic Reaction

I. INTRODUCTION

Fly ash doesn't have cementitious properties like cement have but due to the fineness of its particles and a greater surface area it can be used as a percentage replacement material of binder i.e. cement. When in contact with water it chemically reacts with calcium hydroxide so the amount of calcium silicate gel is increased in concrete which imparts better mechanical properties to concrete [i]. Therefore it can be said that fly ash is a valuable raw material because of its pozzolanic characteristics. Fly ash in concrete has known healthy effects on many properties of concrete that include but not limited to compressive strength, plasticity, permeability, sulphate resistance and durability [i].

Compressive strength being one of the most important property need careful estimates while performing mix designs. Different models are available to predict the strength of concrete with or without Fly Ash. Many parameters are required for reliable mix design. Compressive strength prediction models for pozzolanic concrete differs from ordinary Portland cement concrete in the sense that they need the inclusion of physical and chemical properties of pozzolans as well. Reference [ii-iii] considered only one parameter i.e. water cement ratio for concrete compressive strength estimation. Reference [iv] in his model in addition to water cement ratio incorporated effect of unit weight of concrete and its age. Reference [v] Model was complicated as they incorporated type and quantity of glassy phase for strength estimation. Reference [vi] proposed a model containing some complicated parameters like gas constant R, curing temperature and initial apparent activation energy E_0 etc.

In this research a correlation between simple and easily obtained common mix parameters have been developed to estimate the strength of the pozzolanic concrete. Pozzolanic concrete (containing Fly Ash) experimental data from nine sources [vii-xv] was obtained and then analyzed using multiple regressions. The parameters selected for the model development include concrete age, W/B ratio, FA replacement, Fineness of FA and bogue compounds (C_3S and C_2S).

II. STRENGTH PREDICTION MODELS

Reference [ii] proposed the simplest model for the strength estimation of concrete. He proposed that water cement ratio controls the strength development for a given concrete, as long as the cement type, conventional aggregates, placement conditions, curing conditions, and test conditions remained constant. He proposed equation 1, based on the concept that there is an inverse relation between the water to cement ratio and the strength of the concrete.

$$\mathbf{f_c} = \left(\frac{\mathbf{A}}{\mathbf{B}^{\frac{w}{c}}}\right) \quad (1)$$

In above equation A, B = empirical constants for a mix and w/c = water to cement ratio.

Reference [iii] model for the strength estimation was also based on w/c ratio. He presented following equation

$$\mathbf{f_c} = \frac{\alpha \frac{w}{c}}{\left(\beta + \lambda \frac{w}{c}\right)^n} \quad (2)$$

Where: α, β, λ and n = the empirical constants, w/c = water to cement ratio

Reference [iv] used historical concrete mix design and strength test data in Iowa and developed statistical model to predict strength and other concrete properties. In their study researchers considered w/c ratio, unit weight of concrete and time as the strength prediction model parameters.

$$f_c = A + Bx\left(\frac{w}{b}\right) + Cuw + D\ x\ CMF + E\ x\ Log(t) - F\ x\left(\frac{w}{b}\right)x\ uw - G\ x\ uw\ x\ CMF \quad (3)$$

Where: A, B, C, D, E, F, G are Empirical constants, w/b = w/c ratio, *uw*= Unit weight of concrete, *CMF* = Cementitious materials factor and *t* = Time after hydration or age in days.

Reference [vi] considered the simplest possible geometrical and mechanical model of the structure of hardened concrete. He assumed that the strength'*s*' of the cement paste is proportional to the cross-sectional area of the solid matrix matter (i.e. cement gel), in a plane through the center of the pore, perpendicular to the direction of the applied uniaxial compressive load. Herelated the strength with w/c ratio, degree of hydration of cement 'm', where 0<m<1, and the strength of Hydrated Portland Cement gel s_o. The model proposed by Hansen is presented in Equation 4.

$$s = \left[1 - 1.22\left(\frac{\left(\frac{w}{c}\right) - 0.36m}{\left(\frac{w}{c}\right) - 0.32}\right)^{0.66}\right] x\ s_{\circ} \quad (4)$$

Above equation was then converted into more simplified form in equation 5.

$$s = A\ x\left(\frac{c}{w}\right) + E \quad (5)$$

Where: *s* = strength of concrete (MPa), c = cement constant of concrete (kg/m^3), w = free water content of concrete (kg/m^3), and A, E = constants for given materials, age and curing conditions of concrete.

Reference [xvi] derived an estimation equation that can express coefficient α, which indicates the activity of FA as a binder, in the form of a function of age, FA content, and Blaine specific surface area of FA. He found that addition of FA as fine aggregate replacement increases early strength, however when replaced as cement it reduced the early strength of concrete. Proposed equation 6 is presented below.

$$f_c(t) = \left(\frac{t}{a + bt}\right)\left(\frac{\alpha_1 \alpha_2 FA + C}{W}\right) + B \quad (6)$$

Where f_c' (t) = compressive strength at t days (N/mm^2), t = age (days), a and b = experiment constants, α_1 = function of FA/C, α_2 = function of specific surface area by Blaine, FA= fly ash content (kg/m^3), C = cement content (kg/m^3), W= unit water content (kg/m^3), and B = constant.

Reference [xvii] proposed prediction model shown in equation 7 using apparent activation energy to estimate the variation of compressive strength of fly ash concrete with aging.

$$\frac{S}{S_{28}} = R_u\left\{1 - \frac{1}{\sqrt{1 + A\left[e^{-\frac{E_0}{RT}e^{-\alpha t}} + e^{-\frac{E_0}{RT}e^{-\alpha t_0}}(t - t_0)\right]}}\right\} \quad (7)$$

Where *S* = compressive strength, S_{28}= 28-day f_c', R_u= limiting relative f_c', A & α = constant, R = gas constant, T = curing temperature (K), E_0= initial apparent activation energy (J/mol), t = age (days), and t_0= age (days) when the strength development is assumed to begin.

Reference [v] proposed a model based on type and quantity of glassy phase and chemical composition of FA. They prepared the model for 10% to 50% of FA replacement and for ages of 28, 91 and 365 days.

$$CS = c_1\left(\frac{K}{A} \times 10\right)^{c_2} + c_2\,(CaO)^{c_4} + c_5\,(LOI)^{c_6} + c_7\left(\frac{Fineness}{1000}\right)^{c_8} \quad (8)$$

Where CS = compressive strength and c_1-c_8= coefficients determined by the least square technique.

Reference [xi] used chemical composition like glass content and the fineness of fly ash and lime mortar and related them to the compressive strength.

Reference [viii] proposed a model that incorporated the fineness and loss on ignition (LOI) of Ordinary Portland Cement or the fly ash concrete. He discovered that the fineness and loss on ignition have a good correlation with concrete compressive strength.

Reference [xxiv] did a statistical analysis and found the compressive strength of concrete mixes at any age with the help of rate of strength gain constant (*A*) and grade of strength constant (B).

$$f_t = A\ln(t) + B$$
$$B = 0.005\,(f_c)^{2.20} \quad (9)$$
$$A = 1.4035\ln(B) + 2.9956$$

Where, (ft) is the compressive strength at age (t) days and (A) and (B) are constants.

Reference [xxv] found the compressive strength with his model using regression analysis

$$R_c = b_1X_1 + b_2X_2 + b_3X_3 \quad (10)$$

Where R_c compressive strength of concrete, X_1 is age of specimen, X_2 is the fly ash and X_3 is the unit weight of the samples. The coefficients b_1, b_2 and b_3 are obtained from multiple linear regression analysis

Reference [xxvi] measured compressive strength of concrete using Support Vector Machines (SVM), they found that the influence of FA characteristic parameters in the compressive strength of concrete was trivial. Also the Blaine reveals little influence.

A. Advantages of the Proposed Model Over Existing Ones

Model presented in this work not only complies with the essential strength parameters but also incorporate simple parameters that can be obtained with specified mix proportions of concrete and the chemical composition of the FA and cement. In this research a correlation between simple and easily obtained common mix parameters has been developed to estimate the strength of the pozzolanic concrete.

III. MODEL DEVELOPMENT

In this research pozzolanic concrete (here Fly Ash) data is obtained from different research works and journals and then analyzed using multiple regressions. The parameters selected for the model development include age, W/B ratio, FA replacement, Fineness of FA and bogue compounds (C_3S and C_2S). The bogue compounds were calculated using simple equations as follows.

$$\mathbf{C_3S = 4.071 \times CaO - 7.6 \times SiO_2 - 6.718 \times Al_2O_3 - 1.43 \times Fe_2O_3 - 2.852 \times SO_3} \quad (11)$$

$$\mathbf{C_2S = 2.867 \times SiO_2 - 0.7544 \times C_3S} \quad (12)$$

The parameters are ought to be the same for each data. Furthermore the statistical models developed in the present research have been checked, using individual data from other studies, for its validation. The data used for checking ought to have same limitations for the data parameters.

A. Limitation of Parameters Used

As the data used in the present study is obtained from different sources, so it has been taken into account that the data should not differ too much. Hence certain criteria wereset, so that the range of parameters used for the design of model remains closely correlated. Following are the limitations that are followed for the strength prediction model.

I.	Age	3-90 days
II.	W/B	0.28-0.70
III.	FA replacement	5-55%
IV.	Fineness of FA	240-500 m^2/kg
V.	Concrete f_c'	NSC

B. Model Development Methodology

The statistical analysis is an iterative process and need special considerations for the model development. The process involves several stages in which the impact of several parameters, their correlations with each other and with concrete strength, was evaluated. So for the model development data has to be assembled carefully.

The process was completed in two stages. In first stage the data was assembled form different work of authors from References [vii-xv] and all the anomalies were reviewed and the discrepancies were removed, if any. All the missing data was calculated or assumed when required, and the outliers were eliminated. The data used for the analysis is provided in appendix A-1 for the interest of readers. In second step the parameters that appeared to relate significantly with the strength of concrete were selected.

The variables selected for the model designing were tested to formulate an appropriate prediction model form. Only those variables were kept that significantly affect the f_c' of concrete. The compressive strength was found to correlate well with the power relationships.

The iteration process was done for the preparation of a better prediction model. This was done by considering several power relationships between the responses i.e. f_c' and the variables. Only the best correlations were kept and implied. As it was an iteration process so it requires multiple revisions for the formation of ultimate model. Software MINITAB was used for analysis of data.

C. Final Equation for Strength Estimation

The model was developed for separate ages of 7, 28, 90/91 days. The coefficients are presented in appendix A-2.

Several models were attempted for the input parameters in MINITAB software as described earlier. Separate Model developed for the measurement of compressive strength of FA concrete at specified age 7, 28, 90 is given below.

$$f'_{c\,(age)} = \left[\alpha_2 \frac{1}{B^{0.33}} + \alpha_3 C^{0.33} + \alpha_4 \frac{1}{D} + \alpha_5 e^{E^2} + \alpha_6 e^{\left[\frac{F}{1000}\right]}\right]^2 \quad (13)$$

In above equation, B = W/B ratio, C = C_3S %, D = C_2S %, E = % FA replacement and F= FA Blaine's fineness in m^2/kg

Coefficients of variables α1, α2, α3, α4, α5 and α6 were obtained through the software Minitab with the iteration process. They are presented in appendix A-2

D. Parameters Affecting the Proposed Model

The factors that affect significantly the proposed model were found to be Age in days, W/B ratio, C_3S %, C_2S % and FA Blaine's fineness. So they only these parameters were used for the formation of the final model.

E. Model Examination

Accuracy of developed equation was checked by employing following technique.

In first step graph was prepared for the experimental and model values of the compressive strength of concrete.

In second step deviation of results from mean value was calculated. Total four graphs were prepared. Graphs shown in Fig. 1-3 were drawn to check the accuracy of equation 13. Fig. 1 was drawn for 7days age whereas graphs shown in Figures 2 and 3 were drawn for 28 days and 90days concrete strength.

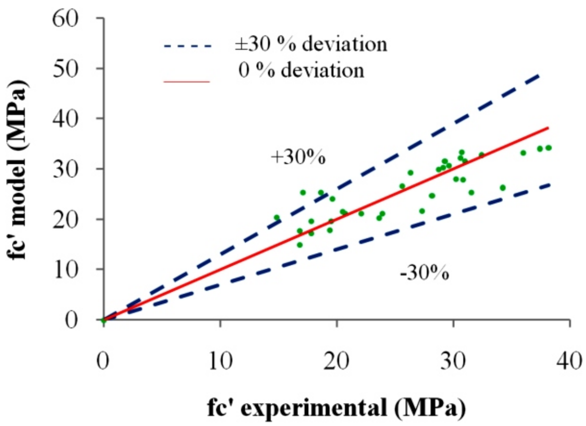

Fig.1. Exp. & Mod. Values for Final Separate Model (for 7 days)[A-1]

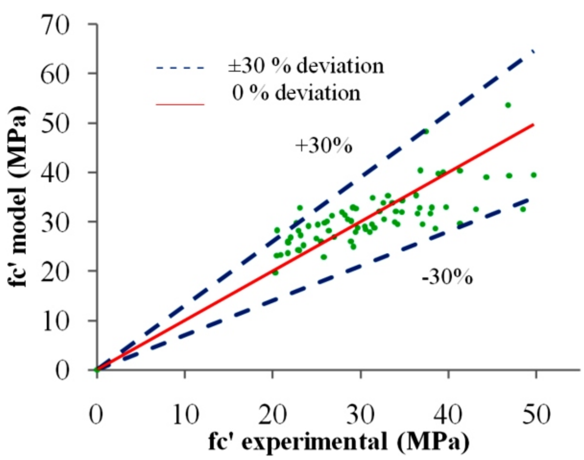

Fig. 2. Exp. & Mod. Values for Final Separate Model (for 28 days)[A-1]

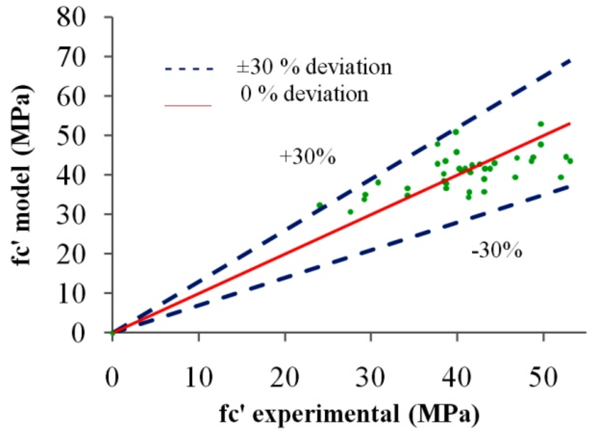

Fig. 3. Exp. & Mod. values for Final Separate Model (for 90/91 days) [A-1]

It was observed that in all figures data is confined within the allowable limits of ±30 %.

IV. Validation of the Developed Model

Developed model was verified by selecting data other than that used for development of model. The data for validation is taken from References [xx-xxiii]. The data used for the validation of the proposed model is provided in appendix A-3.

For validation of model graphs were drawn between experimental and model values. Figures 4 -8 were drawn to validate separate model developed for specified strengths. After the validation of models it was observed that the data from the other researchers used in the model given in equation 13 fits within the limits of ±25%. This shows that the proposed models work effectively.

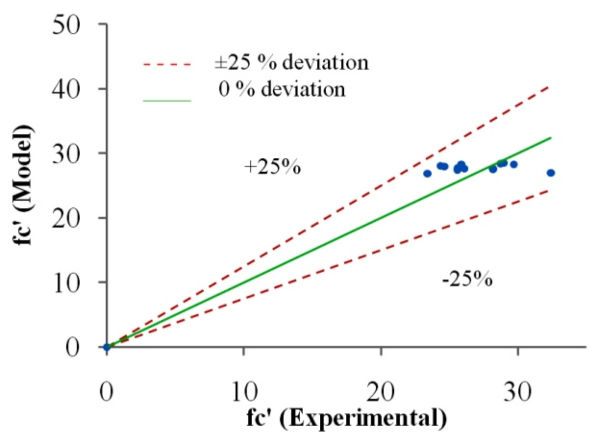

Fig. 4. Exp. & Mod. Values data for validation of Separate Model for 7 days [A-5] Source: Reference [xxii]

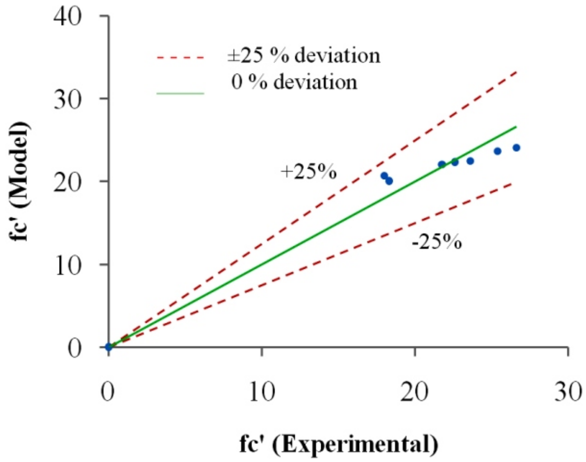

Fig. 5. Exp. & Mod. values data for validation of Separate Model for 7 days [A-5] Source: Reference [xvii]

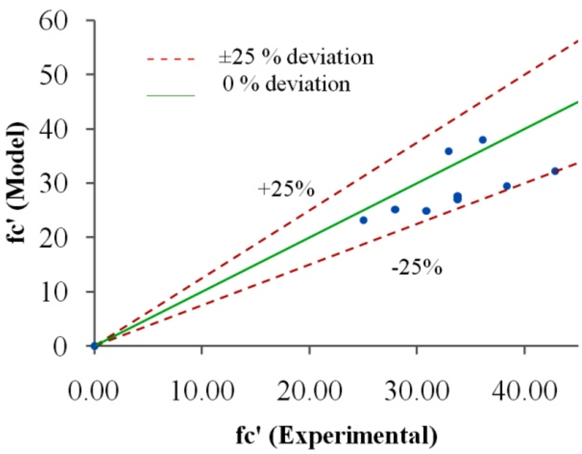

Fig. 6. Exp. & Mod. Values for validation of Separate Model for 28 days [A-5] Source: Reference [xvii]

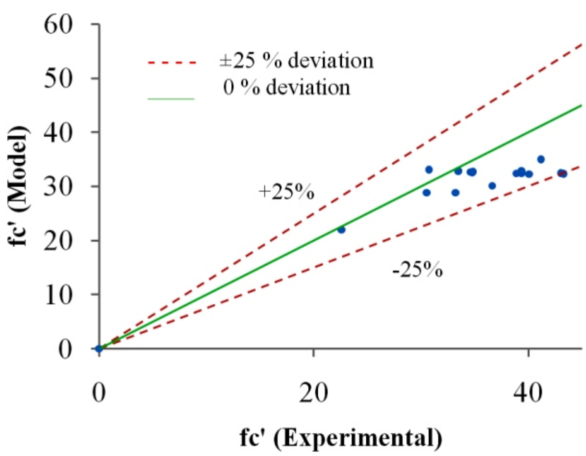

Fig. 7. Exp. & Mod. values for validation of Separate Model for 28 days [A-5] Source: Reference [xx]

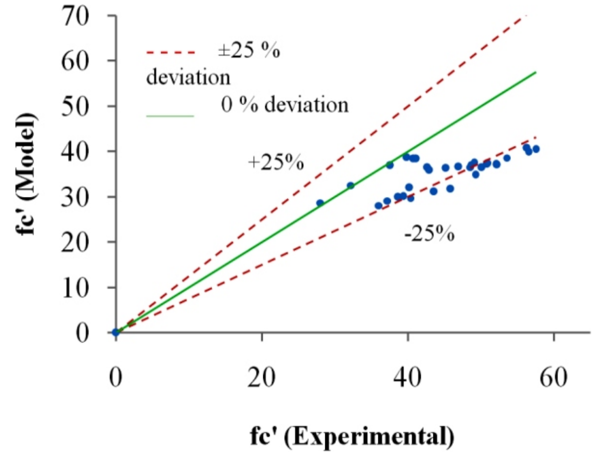

Fig. 8. Exp. & Mod. Values for validation of Separate Model for 90/91 days [A-5] References [xvii], [xx], [xxii]

V. CONCLUSIONS

1. The final model proposed for the prediction of f_c' includes simple parameters that can be obtained easily from concrete mix proportions and chemical and physical properties of the concrete mix and FA content.
2. The coefficients of key parameters used in the formulation of model show similar trends as observed in the literature.
3. The derived model was designed to predict the f_c' of Fly Ash concrete upto ±30% precision. But through the validation of the model it was observed that the model behaves well for validation data. The graphs for validation show that the model fits within ±25% precision level nicely.
4. The proposed model is based on multivariable regression analysis so for the development of model ANN (artificial neural network) is recommended.

Notations

NSC	----- Normal Strength Concrete
f_c'	-----Concrete Compressive Strength
FA	----- Fly Ash
w/c	----- Water to Cement Ratio
B	----- Binder Content
W	----- Water Content in concrete
W/B	----- Water to Binder Ratio
C_3S	----- Tricalcium Silicate
C_2S	----- Dicalcium Silicate

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A- 1

WHOLE DATA USED FOR THE MODEL FORMULATION

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
Source Data From Reference [xii]																
32.5	3	0.50	0	0	0	0	0	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.00	0
35.5	3	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	235.1
29.2	3	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	235.1
27	3	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	235.1
30.8	3	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	384.9
29	3	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	384.9
27.8	3	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	384.9
36.7	3	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	523.9
35.6	3	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	523.9
34.2	3	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	523.9
34.20	7	0.50	0	0	0	0	0	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.00	0
30.80	7	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	235.1
29.60	7	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	235.1

*The standard cement chemical composition was used as per ASTM C 150 where found missing in researcher's data.

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
28.70	7	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	235.1
32.40	7	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	384.9
30.60	7	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	384.9
29.30	7	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	384.9
38.20	7	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	523.9
37.40	7	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	523.9
36.00	7	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	523.9
43.10	28	0.50	0	0	0	0	0	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.00	0
39.70	28	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	235.1
38.10	28	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	235.1
36.80	28	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	235.1
41.30	28	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	384.9
39.40	28	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	384.9
38.80	28	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	384.9
49.70	28	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	523.9
46.90	28	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	523.9
44.30	28	0.	45.	23.5	4.91	18.	1.	19.	5.10	3.51	63.	2.	61.0	8.82	0.15	523.9

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
		50	98	5		67	47	13			29	83	0			
46.70	90	0.50	0	0	0	0	0	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.00	0
43.10	90	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	235.1
41.40	90	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	235.1
40.50	90	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	235.1
44.30	90	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	384.9
42.60	90	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	384.9
41.70	90	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	384.9
52.60	90	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.05	523.9
48.80	90	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.10	523.9
46.90	90	0.50	45.98	23.55	4.91	18.67	1.47	19.13	5.10	3.51	63.29	2.83	61.00	8.82	0.15	523.9
Source Data From Reference [xiv]																
30.70	7	0.37	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.14	270
29.10	7	0.39	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.26	270
17.10	7	0.39	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.40	270
30.20	7	0.44	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0
26.30	7	0.44	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.14	270

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
19.60	7	0.50	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.26	270
14.80	7	0.48	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.40	270
25.60	7	0.47	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0
18.60	7	0.53	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.14	270
46.80	28	0.33	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0
37.40	28	0.37	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.14	270
33.10	28	0.39	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.26	270
23.10	28	0.39	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.40	270
36.30	28	0.44	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0
33.60	28	0.44	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.14	270
25.90	28	0.50	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.26	270
20.50	28	0.48	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.40	270
32.60	28	0.47	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0
22.70	28	0.53	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.14	270
49.70	91	0.33	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0
39.80	91	0.37	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.14	270
37.70	91	0.	61.	25.5	4.2	1.4	0.	20.	5.2	2.3	64.	2.	55.0	19.0	0.26	270

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
		39	4			4	16	9			4	9	0	0		
38.70	91	0.44	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0
38.40	91	0.44	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.14	270
29.20	91	0.50	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.26	270
34.20	91	0.47	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0
Source Data From Reference [ix]																
16.70	3	0.48	48.9	23.9	3.4	15.3	0.3	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.33	314
30.70	3	0.37	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.14	270
29.10	3	0.39	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.26	270
17.20	3	0.39	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.40	270
30.20	3	0.45	0	0	0	0	0	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.00	0
26.40	3	0.44	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.14	270
19.70	3	0.51	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.26	270
14.80	3	0.48	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.40	270
25.60	3	0.47	0	0	0	0	0	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.00	0
18.70	3	0.54	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.14	270
41.30	91	0.48	48.9	23.9	3.4	15.3	0.3	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.33	314

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
43.10	91	0.39	48.9	23.9	3.4	15.3	0.3	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.40	314
27.60	91	0.53	48.9	23.9	3.4	15.3	0.3	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.40	314
30.80	91	0.42	48.9	23.9	3.4	15.3	0.3	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.43	314
24.00	91	0.52	48.9	23.9	3.4	15.3	0.3	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.43	314
49.70	91	0.33	0	0	0	0	0	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.00	0
39.90	91	0.37	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.14	270
37.70	91	0.39	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.26	270
38.70	91	0.45	0	0	0	0	0	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.00	0
38.40	91	0.44	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.14	270
29.30	91	0.51	61.4	5.5	4.2	1.44	0.16	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.26	270
34.20	91	0.47	0	0	0	0	0	20.33	4.36	2.99	62.92	3.23	59.90	13.90	0.00	0
Source Data From Reference [x]																
17.80	7	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
19.50	7	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
19.40	7	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
16.80	7	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
23.90	7	0.28	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
22.10	7	0.28	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
20.70	7	0.28	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
34.70	28	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
27.90	28	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
31.60	28	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
31.50	28	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
29.10	28	0.28	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
36.70	28	0.28	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
43.80	91	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
40.20	91	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
43.20	91	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
40.90	91	0.33	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
38.60	91	0.28	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
53.10	91	0.28	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
48.60	91	0.28	47.1	23	20.4	1.21	0.67	22.52	3.9	2.99	63.15	2.8	47.40	28.89	0.56	289
Source Data From Reference [xiv]																
17.80	7	0.71	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
27.30	7	0.50	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.31	370
28.20	7	0.48	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.31	370
16.80	7	0.45	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.55	370
23.60	7	0.39	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.50	370
25.80	28	0.71	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.00	0
20.30	28	0.71	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.31	370
38.50	28	0.50	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.31	370
41.30	28	0.48	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.31	370
29.20	28	0.45	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.55	370
34.20	28	0.39	61.4	25.5	4.2	1.44	0.16	20.9	5.2	2.3	64.4	2.9	55.00	19.00	0.50	370
Source Data From Reference [xv]																
20.00	3	0.50	0	0	0	0	0	20.80	5.20	3.80	64.30	2.00	57.61	16.17	0.00	0
25.00	3	0.44	39	20.8	11.6	13.6	3.65	20.80	5.20	3.80	64.30	2.00	57.61	16.17	0.40	930
31.50	7	0.50	0	0	0	0	0	20.80	5.20	3.80	64.30	2.00	57.61	16.17	0.00	0
20.50	7	0.46	40.1	21	11.8	12.7	2.25	20.80	5.20	3.80	64.30	2.00	57.61	16.17	0.40	300
31.00	7	0.44	39	20.8	11.6	13.6	3.65	20.80	5.20	3.80	64.30	2.00	57.61	16.17	0.40	930
48.50	28	0.50	0	0	0	0	0	20.80	5.20	3.80	64.30	2.00	57.61	16.17	0.00	0

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
30.50	28	0.46	40.1	21	11.8	12.7	2.25	20.80	5.20	3.80	64.30	2.00	57.61	16.17	0.40	300
52.00	90	0.50	0	0	0	0	0	20.80	5.20	3.80	64.30	2.00	57.61	16.17	0.00	0
41.50	90	0.46	40.1	21	11.8	12.7	2.25	20.80	5.20	3.80	64.30	2.00	57.61	16.17	0.40	300
Source Data From Reference [xxiii]																
21.73	28	0.70	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
26.37	28	0.62	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
28.51	28	0.55	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
33.99	28	0.51	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
22.04	28	0.54	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.33	393
24.08	28	0.50	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.27	393
26.16	28	0.49	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.23	393
28.23	28	0.47	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.18	393
29.46	28	0.45	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.15	393
21.76	28	0.71	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
22.92	28	0.62	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
28.93	28	0.56	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
32.13	28	0.51	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
34.73	28	0.46	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
23.17	28	0.54	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.30	393
25.14	28	0.50	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.25	393
26.75	28	0.47	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.21	393
29.14	28	0.44	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.17	393
31.36	28	0.41	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.14	393
20.88	28	0.83	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
23.03	28	0.78	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
28.90	28	0.70	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
31.04	28	0.63	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
37.05	28	0.58	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
20.46	28	0.64	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.36	393
23.48	28	0.60	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.30	393
26.96	28	0.57	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.25	393
29.67	28	0.53	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.20	393
33.85	28	0.51	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.16	393
21.73	28	0.	0	0	0	0	0	20.	5.2	2.3	64.	2.	55.0	19.0	0.00	0

f_c' (MPa)	Age (days)	W/B	Fly Ash					Cement*					Bogue Compounds		%FA Replacement/100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
		81						9			4	9		0		
25.49	28	0.70	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
29.39	28	0.63	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
31.29	28	0.58	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
36.46	28	0.52	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0
22.85	28	0.62	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.33	393
24.96	28	0.57	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.27	393
30.55	28	0.53	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.23	393
32.66	28	0.49	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.19	393
37.93	28	0.47	43	19.9	23.7	5.7	2.7	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.16	393

A-2

TABLE FOR COEFFICIENTS OF INDEPENDENT VARIABLES OF FINAL MODEL USING SOFTWARE ANALYSIS

α	Predictor Non-constant	Coefficients for Final Model using Control & FA mixes		
		b	c	d
		Separate model for specific ages		
		7 Days	28 Days	90/91 Day
α_2	$\frac{1}{\left(\frac{W}{B}\right)^{0.33}}$	4.74	4.48	5.33
α_3	$(C_2S(\%))^{0.332}$	0.588	0.075	-0.361

α_4	$\frac{1}{\ln(C_2S(\%))}$	1.05	2.28	2.06
α_5	$e^{\left(\frac{FA\%}{100}\right)^2}$	-4.67	-2.14	-1.79
α_6	$e^{\left[\frac{FA_{Blaine}\left(\frac{m^2}{kg}\right)}{1000}\right]}$	0.68	-0.285	0.597

A-3

WHOLE DATA FOR THE VALIDATION OF THE PROPOSED MODELS

fc' (MPa)	Age (days)	W/B	Fly Ash					Cement					Bogue Compounds		% FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
Data Source from Reference [xx]																
16.34	3	0.29	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	310.00
16.64	3	0.29	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	310.00
31.85	3	0.30	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	310.00
10.90	3	0.40	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	287.00
20.22	3	0.39	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	287.00
26.14	3	0.39	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	287.00
24.01	7	0.29	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	310.00
18.60	7	0.29	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	310.00
38.00	7	0.30	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	310.00
14.40	7	0.40	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	287.00

fc' (MPa)	Age (days)	W/B	Fly Ash					Cement					Bogue Compounds		% FA Replacement / 100	FA Blaine m²/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
25,36	7	0.39	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	287.00
34.30	7	0.39	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	287.00
33.25	28	0.29	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	310.00
30.55	28	0.29	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	310.00
57.00	28	0.30	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	310.00
22.60	28	0.40	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	287.00
36.60	28	0.39	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	287.00
45.85	28	0.39	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	287.00
40.75	90	0.29	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	310.00
41.10	90	0.29	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	310.00
60.20	90	0.30	50.20	28.60	13.2	2.6	0.6	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	310.00
28.01	90	0.40	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.70	287.00
42.65	90	0.39	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	287.00
54.55	90	0.39	44.9	25.20	7.50	2.40	0.28	20.80	4.90	3.10	63.30	3.00	53.71	19.12	0.50	287.00
Source Data from Reference [xxi]																
14.57	3	0.66	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0.00

fc' (MPa)	Age (days)	W/B	Fly Ash					Cement					Bogue Compounds		% Replacement FA / 100	FA Blaine m²/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
17.91	3	0.57	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0.00
20.74	7	0.66	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0.00
24.76	7	0.57	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0.00
28.51	28	0.66	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0.00
32.43	28	0.57	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0.00
34.82	91	0.66	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0.00
36.91	91	0.57	0	0	0	0	0	20.9	5.2	2.3	64.4	2.9	55.0	19.00	0.00	0.00
Source Data from Reference [xxii]																
24.36	7	0.49	55.1	21.10	5.20	6.70	0.50	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	362.00
26.09	7	0.49	53.4	22.00	6.30	6.80	0.50	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	319.00
25.59	7	0.49	50.9	25.30	8.40	2.40	0.30	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	290.00
25.66	7	0.49	57.6	29.00	5.20	0.30	0.20	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	312.00
24.68	7	0.49	52.2	27.40	9.20	4.40	0.45	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	351.00
25.91	7	0.49	50.9	28.90	5.40	1.40	0.40	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	377.00
23.45	7	0.49	46.2	31.30	8.50	1.80	0.50	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	237.00
28.72	7	0.49	38.4	13.00	20.60	14.60	3.30	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	392.00
29.71	7	0.49	39.5	19.50	5.70	24.70	1.80	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	377.00

fc' (MPa)	Age (days)	W/B	Fly Ash					Cement					Bogue Compounds		% FA Replacement / 100	FA Blaine m²/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
29.00	7	0.49	36	19.80	5.00	27.20	3.15	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	401.00
28.23	7	0.49	50.5	17.20	5.90	15.80	1.00	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	300.00
32.45	7	1.49	0	0	0	0	0	21	4.60	3.00	64.10	2.70	58.5	16.11	0.00	0.00
38.85	28	0.49	55.1	21.10	5.20	6.70	0.50	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	362.00
34.80	28	0.49	53.4	22.00	6.30	6.80	0.50	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	319.00
33.50	28	0.49	50.9	25.30	8.40	2.40	0.30	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	290.00
34.63	28	0.49	57.6	29.00	5.20	0.30	0.20	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	312.00
34.73	28	0.49	52.2	27.40	9.20	4.40	0.45	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	351.00
39.37	28	0.49	50.9	28.90	5.40	1.40	0.40	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	377.00
30.69	28	0.49	46.2	31.30	8.50	1.80	0.50	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	237.00
40.08	28	0.49	38.4	13.00	20.60	14.60	3.30	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	392.00
42.99	28	0.49	39.5	19.50	5.70	24.70	1.80	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	377.00
43.24	28	0.49	36	19.80	5.00	27.20	3.15	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	401.00
39.37	28	0.49	50.5	17.20	5.90	15.80	1.00	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	300.00
41.13	28	0.49	0	0	0	0	0	21	4.60	3.00	64.10	2.70	58.5	16.11	0.00	0.00
52.21	90	0.49	55.1	21.10	5.20	6.70	0.50	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	362.00

fc' (MPa)	Age (days)	W/B	Fly Ash					Cement					Bogue Compounds		% FA Replacement / 100	FA Blaine m²/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
46.93	90	0.49	53.4	22.00	6.30	6.80	0.50	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	319.00
45.17	90	0.49	50.9	25.30	8.40	2.40	0.30	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	290.00
48.51	90	0.49	57.6	29.00	5.20	0.30	0.20	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	312.00
48.58	90	0.49	52.2	27.40	9.20	4.40	0.45	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	351.00
50.80	90	0.49	50.9	28.90	5.40	1.40	0.40	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	377.00
42.89	90	0.49	46.2	31.30	8.50	1.80	0.50	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	237.00
50.90	90	0.49	38.4	13.00	20.60	14.60	3.30	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	392.00
52.03	90	0.49	39.5	19.50	5.70	24.70	1.80	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	377.00
49.04	90	0.49	36	19.80	5.00	27.20	3.15	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	401.00
50.10	90	0.49	50.5	17.20	5.90	15.80	1.00	21	4.60	3.00	64.10	2.70	58.5	16.11	0.20	300.00
49.22	90	0.49	0	0	0	0	0	21	4.60	3.00	64.10	2.70	58.5	16.11	0.00	0.00
Source Data from Reference [xvii]																
15	3.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	331.80
13	3.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	331.80
19	3.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	331.80
16	3.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	331.80
15	3.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	331.80

fc' (MPa)	Age (days)	W/B	Fly Ash					Cement					Bogue Compounds		% FA Replacement / 100	FA Blaine m²/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
13	3.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	331.80
34	3.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	331.80
32	3.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	331.80
29	3.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	331.80
24	3.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	331.80
40	3.00	0.35	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	331.80
34	3.00	0.35	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	331.80
27	3.00	0.35	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	331.80
43	3.00	0.32	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	331.80
40	3.00	0.32	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	331.80
29	3.00	0.32	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	331.80
24	7.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	332.80
22	7.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	333.80
18	7.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	334.80
27	7.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	335.80
25	7.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	336.80

fc' (MPa)	Age (days)	W/B	Fly Ash					Cement					Bogue Compounds		% FA Replacement / 100	FA Blaine m²/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
23	7.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	337.80
18	7.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	338.80
33	28.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	339.80
34	28.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	340.80
28	28.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	341.80
25	28.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	342.80
36	28.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	343.80
38	28.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	344.80
34	28.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	345.80
31	28.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	346.80
50	28.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	347.80
50	28.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	348.80
48	28.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	349.80
43	28.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	350.80
39	90.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	351.80
40	90.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	352.80

fc' (MPa)	Age (days)	W/B	Fly Ash					Cement					Bogue Compounds		% FA Replacement / 100	FA Blaine m^2/kg
			SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	SiO_2	Ai_2O_3	Fe_2O_3	CaO	SO_3	C_3S %	C_2S %		
37	90.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	353.80
36	90.00	0.60	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	354.80
40	90.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	355.80
46	90.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	356.80
44	90.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	357.80
39	90.00	0.55	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	358.80
56	90.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.00	359.80
58	90.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.10	360.80
57	90.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.20	361.80
54	90.00	0.40	55.10	34.90	3.70	3.60	0.20	22.52	3.90	2.99	63.15	2.80	47.5	28.75	0.30	362.80

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EXPERIMENTAL VS MODEL VALUES OF SEPARATED MODEL FOR VALIDATION

VALIDATION DATA FOR SEPERATE MODELS															
7 DAYS DATA				28 DAYS DATA						90/91 DAYS DATA					
Mehta (1985)		Han et al. (2003)		Atis (2005)		Mehta (1985)		Han et al. (2003)		Mehta (1985)		Han et al. (2003)		Atis (2005)	
f_c' exp.	f_c' mod.	f_c' exp.	f_c' mod.	f_c' exp.	f_c' mod.	f_c' exp.	f_c' mod.	f_c' exp.	f_c' mod.	f_c' exp.	f_c' mod.	f_c' exp.	f_c' mod.	f_c' exp.	f_c' mod
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24.36	25.79	23.6	28.74	33.25	28.43	38.85	30.92	32.90	35.84	52.21	37.40	38.6	41.71	40.75	43.26
26.09	25.00	21.8	22.91	30.55	27.60	34.80	30.13	33.80	27.59	46.93	36.52	40.3	34.33	41.10	42.43
25.59	24.40	18	20.38	22.60	19.77	33.50	29.48	28.00	25.12	45.17	35.83	37.2	32.44	28.01	35.04
25.66	24.51	26.6	30.73	36.60	27.20	34.63	29.52	25.00	23.19	48.51	35.92	36	31.38	42.65	36.94
24.68	25.47	25.4	24.70	45.85	27.55	34.73	30.52	36.10	37.97	48.58	37.00	40.2	43.36	-	-
25.91	25.97	22.6	22.06	-	-	39.37	30.99	38.30	29.46	50.80	37.54	45.8	35.83	-	-
23.45	23.50	18.3	19.41	-	-	30.69	28.52	33.80	26.90	42.89	34.78	43.5	33.89	-	-
28.72	27.42	-	-	-	-	40.08	32.76	30.90	24.91	50.90	39.30	39.3	32.81	-	-
29.71	27.20	-	-	-	-	42.99	32.61	49.70	46.88	52.03	39.09	56.3	50.12	-	-
29.00	27.98	-	-	-	-	43.24	33.49	50.30	37.36	49.04	40.00	57.5	42.00	-	-
28.23	25.03	-	-	-	-	39.37	30.31	48.00	34.47	50.10	36.63	56.5	39.90	-	-
32.45	30.36	-	-	-	-	41.13	34.83	42.80	32.21	49.22	40.40	53.5	38.72	-	-