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Concrete Strength Prediction using Multi-Linear Regression Model: A case study of Nairobi Metropolitan

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Abstract: Early prediction of strength is key in effective and efficient planning for concrete construction projects. There are several empirical correlations that have been developed to determine concrete strength estimation from early age results though each model has its own limitations when applied. A multi-staged evaluation of the existing prediction models (BS modification factors, German model, Abrams model, Bolomey's model and ACI model) was performed for concrete strength data obtained from experimental work conducted under standard conditions in the laboratory. The data on compressive strength was obtained from concrete made from 6 different samples of fine aggregates whose physical and chemical properties had been determined. The limitations for each model was noted which then gave a basis for need for a statistical method that could predict strength more accurately. A multiple linear regression technique was used. The variables used to predict were water-cementations ratio, quantities of mix design constituents, physical and chemical properties of the fine aggregates. Multiple-linear regression models developed for this study yielded coefficients of determination (CODs) for concrete strength prediction at 7, 14, 28, 56, 112 and 180-days curing. The regression models were then validated using a different set of samples that were not included in the formulated models. The predicted values of compressive strength obtained using the regression models were found to be in agreement with the experimental results obtaining CODs of 0.7821, 0.7186, 0.8416, 0.755, 0.7695 and 0.8444 for 7, 14, 28, 56, 112 and 180 days respectively.

Keywords: Concrete Mix Design, Concrete Strength, Fine Aggregates.

I. INTRODUCTION

Compressive strength of concrete has been considered an index of concrete quality and the most important concrete property for many years [1]. The characteristic strength, that is the concrete grade, is measured by the 28-day cube strength [2]which is used routinely for control of production and contractual conformity purposes. Different researchers have intimated that the compressive strength depends on concrete components and curing regime [3]. Understanding the various factors and their complex interactions is therefore important in estimating and making a reasonable prediction of concrete strength gain with age.

Statistical methods have been used to predict concrete strength gain. Apart from speed, statistical modeling has advantages over other techniques and can be used to define confidence interval for the prediction [4]. However, the correlations developed in the existing models may result in different predictions of the strength in locations other than where they were originally developed. This discrepancy could be a consequence of using aggregates having different mineralogy as well as difference in preparation of concrete [5].

The selection of proper component materials and their proportions is the first step in concrete mix-design and it entails obtaining the product that would meet the specified strength, durability and workability. According to empirical results it should be emphasized that, different mix-design parameters are interdependent and therefore their influences cannot really be separated.

This study is a multi-staged evaluation of the existing models to determine their accuracy and identify their limitations while proposing a multi-linear regression model as a performance prediction model for concrete strength.

II. EXPERIMENTAL WORK

A. Materials

Cement - Normal Setting Ordinary Portland cement (CEM-1) of class 42.5 conforming to KS EAS 18-1:2001

Coarse Aggregate- Crushed aggregates of maximum size of 20mm sourced from Mlolongo quarry. Gradation test was done consistent with BS 812-1:1992 to ascertain suitability.

Fine Aggregate- Natural river sands from Mwingi (380 03' 35.66"N,000 58' 4.36"E), Machakos (370 26' 15.2"N, 010 20' 29.4"E)and Kajiado, (370 06' 43.7"N, 020 02' 28.9"E) Quarry dust and rock sand from Mlolongo (360 50' 31.5"N, 010 23' 11.1"E), and Naivasha sand from Naivasha quarry(360 21' 19" N 010 00' 47.6"E). The aggregates were graded in accordance to BS 812-1:1992.

Water- Treated tap water safe for drinking from Jomo Kenyatta university of Agriculture and technology.

B. Sample Preparation

Physical, chemical and mineralogical properties of raw materials

The physical, chemical and mineralogical properties of the fine aggregates collected from the various sources were established in accordance to the British and American standards. The chemical properties were determined by Atomic Absorption Spectrometry (Flame AAS instrument) and validated using X-Ray Fluoresce method (Bruker S1 Titan machine) at the Ministry of Mining laboratory in Nairobi. The mineralogical properties were established using the X-Ray diffraction method (Bruker D2 Phaser machine) at the Ministry of Mining laboratory in Nairobi and counter checked with the geological formation of the catchment areas.

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Table 1 Physical Properties of Fine Aggregates

Sno.	Test Parameter	Units	S-2	S-3	S-4	S-5	S-6	S-7
1	Specific gravity		2.12	2.06	2.24	2.31	**1.73**	2.27
2	Apparent S. gravity		2.57	2.5	2.6	2.63	2.36	2.59
3	Bulk density	Kg/M3	1497	1469	1407	**1613**	1327	**1684**
4	Water Absorption		8.3	8.62	6.31	5.16	15.3	5.37
5	Fineness Modulus		2.66	1.92	3.37	2.54	1.94	3.66
6	Silt and clay content	%	4.85	4.16	2.06	6.66	9.37	11.9
7	Sieve Analysis		C&M	F	C	C&M	F&M	C
8	Surface texture		Rough	Smooth	Coarse	Rough	Smooth	Coarse
9	Particle shape		R	R	A	R	R	Fl & E
C- Coarse, M- Medium, F- fine, R- Round, A-Angular, Fl- Flacky, E- Elongated								

Table 2 Chemical Properties of Fine Aggregates

Sno.	Test Parameter	S-2	S-3	S-4	S-5	S-6	S-7
1	SiO_2	76.00	78.00	67.00	80.00	69.00	65.00
2	Al_2O_3	11.00	9.00	17.00	10.00	14.00	19.00
3	Fe_2O_3	1.40	1.20	4.00	1.00	5.50	4.00
4	CaO	1.60	1.50	1.40	2.50	1.30	1.40
5	MgO	0.80	1.00	0.05	0.02	0.04	0.08
6	Na_2O	2.00	1.40	1.50	1.80	3.00	4.00
7	K_2O	1.00	1.00	3.00	1.00	1.80	1.60
8	TiO_2	0.30	0.17	1.40	0.12	0.30	0.60
9	LoI	0.72	1.04	3.50	1.70	2.00	3.80

C. Concrete mix design

The D.O. E (Department of Environment)/ British method was used to produce class 30 concrete for the different fine aggregates. This involved selecting and proportioning the constituents to give the required strength, workability and durability[2]. The key parameters affecting design of a concrete mix are water-cement ratio, coarse aggregate/total aggregate ratio and total aggregate/cement ratio. For specified strength and durability requirements, a water/cement ratio has to be selected. [6] In this experiment a designed mix was used with strength testing forming an essential part of the requirements for compliance[2].A characteristic strength of 30 N/mm^2 was specified with defective proportion of 2.5% yielding a standard deviation of 8N/mm2. A water /cement ratio of 0.52 was used (obtained from Table 2, Fig4 of the D.O.E)A slump of 10-30mm and a maximum crushed aggregate of 20mm was used yielding a free water content of 190 m^3 (Table 3 of the D.O.E). The aggregate was assumed to have a relative density of 2.7. The composition of Fine aggregate material was determined from the percentage passing Sieve no. 600µmm (Fig 6 – D.O.E). The respective constituents were then determined and varied based on the percentage of the material passing sieve no 600µmm.

Table 3 Concrete Mix Design of the samples

Sand type	Water/ Cement ratio	Water content (kgs)	Cement content (kgs)	Fine aggregate (kgs)	Coarse aggregates (kgs)
S2	0.52	190	365	656	1219
S3	0.52	190	365	525	1350
S4	0.52	190	365	788	1087
S5	0.52	190	365	656	1219
S6	0.52	190	365	562.5	1312
S7	0.52	190	365	787	1087

S2-Mwingi Sand,S3-Kajiado Sand,S4-Mlolongo Rock Sand,S5-Machakos Sand,S6-Naivasha Sand,S7-Mlolongo Quarry dust

III. RESULTS AND DISCUSSION

A. Concrete Compressive Strength prediction models overview

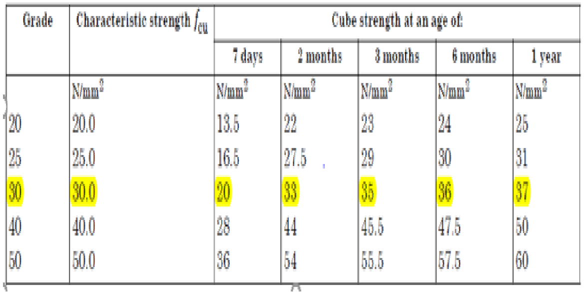
Fast construction has necessitated early estimation of concrete compressive strength. The urge is, in particular, due to the need for early stripping off the formworks and preventing non-working days. Knowing concrete strength gain pattern enables the prediction of the concrete characteristic strength at an early age and gives an idea about the quality of the concrete in compliance with the design requirement [1]. Concrete strength prediction is always done using compressive strength models which are developed from a conceptual postulation of how particles and hydrated cement interact and bond. Accordingly, controlling parameters are always identified in the development of these models [7].

B. Multi-staged evaluation

a. Concrete strength gain prediction based on the British standards BS8110

British code [8] gives modification factors for permissible compressive strength as 1.0, 1.10, 1.16, 1.2 and 1.24 for 1, 2, 3,6, and 12 months as minimum age of member when full design load is applied whereas, for high strength concrete, British code allowed to add 0, 4.2, 5.5, 7.7 and 10.2 MPa over the permissible strength at 28 days for 1, 2, 3, 6 and 12 months, respectively. Table 4 shows the predicted strength according to [8] for normal concrete.

Table 4 Predicted strength for normal concrete (BS 8110)



Grade	Characteristic strength f_{cu}	Cube strength at an age of:				
		7 days	2 months	3 months	6 months	1 year
	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
20	20.0	13.5	22	23	24	25
25	25.0	16.5	27.5	29	30	31
30	30.0	20	33	35	36	37
40	40.0	28	44	45.5	47.5	50
50	50.0	36	54	55.5	57.5	60

For class 30 concrete, the compressive strength results obtained from the samples compared to the BS cube strength at the given ages are as shown in figure 1

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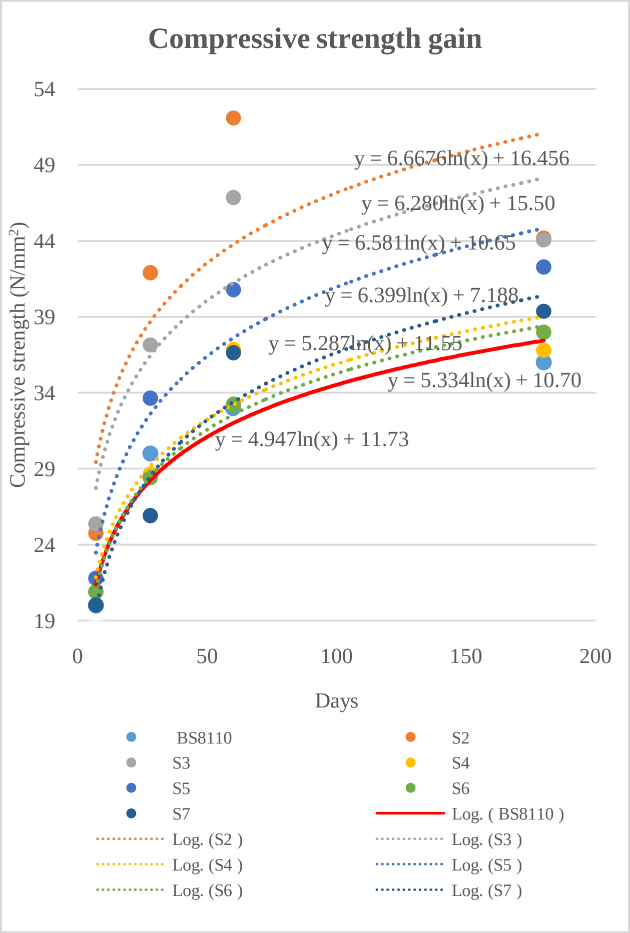

Figure 1 Observed Vs Predicted compressive strength gain based on BS 8110 (N/mm^2)

As observed in figure 1, samples S2, S3 and S5 achieved strength surpassing the predicted at all ages. Sample S2 had the highest strength followed by S3 and S5 which can be attributed to the high Silicon IV oxide concentrations in the samples responsible for strength development in concrete [9] among other contributing parameters. Samples S7, S4 and S6 did not achieve the predicted strength at 28days with sample S7 being the lowest in strength. This can be attributed to lower concentrations of Silicon (IV) oxide and Calcium Oxide in the aggregate samples that contributed to slower strength gain. The deviations from the predicted values could be explained by the use of different constituent materials, curing conditions and hydration regimes. Further, the BS strength prediction does not specify the criteria used to come up with the modification factors; i.e. type of cement used, constituent material properties, Quantities of materials used and curing conditions. Despite the absence of this data, the strength gain curves for the local fine aggregate material were well above the BS prediction curve. However, the huge difference in the curves qualifies the need for a refined model that would reduce the gap.

b. Concrete strength gain prediction based on the German's model

In Germany, the relation between 28-day strength fc28 and the 7-day strength, fc7 is taken to lie between,

$\boldsymbol{Fc28 = 1.4fc7 + 150}$ … … … … … …Equation 1

and

$\boldsymbol{Fc28 = 1.7fc7 + 850}$ … … … ..Equation 2[10]

Fc is being expressed in psi

where, fc7 and fc28 - strengths at 7 and 28 days, respectively.

Using this model, a comparison was made to the compressive strength observed from the samples as shown in table 5.

Table 5 Observed Vs Predicted compressive strength using German model (N/mm^2)

Samples	Actual Strength N/mm^2	Predicted lower range N/mm^2	Predicted upper range N/mm^2
s2	41.90	35.70	47.95
s3	37.17	36.72	49.19
s4	28.68	30.28	41.37
s5	33.64	31.53	42.89
s6	28.41	30.28	41.37
s7	25.91	29.08	39.91

It was observed that, samples S2, S3 and S5 fell within the range predicted values of the German model while samples S4, S6 and S7 fell below the predicted range. This can be attributed to their chemical concentrations. The deviation of the observed compressive strength values from the predicted values of the German model could be explained by the fact that the model does not take into account the constituent material properties, curing conditions and the cement type and hydration regime. The model also requires use of observed 7 days' compressive strength as a constant employed to predict concrete strength at 28days which may not be a good representation. This puts some doubt in the model.

c. Concrete strength gain prediction based on the Abrams model

Abrams law states that, "For a full compaction at a given age and normal temperature, the strength of concrete is inversely related to the water- cement ratio." [11]. The generally accepted rule is that an increase in the water/cement ratio decreases the concrete strength whereas a decrease in the water/cement ratio increases strength [12] .

$Fc = \frac{A}{B^\wedge w/c}$ … … … … ….Equation 3[13]

Where A and B are constants whose values depend on the quality of the cement used, the age of the concrete, curing conditions etc.

w/c- water cement ratio

For 7 days, A = 63.45 and B = 14 giving;

$\boldsymbol{Fc7 = \frac{A}{B^\wedge w/c} = \frac{63.45}{14^\wedge w/c}}$ … … … … … … …Equation 4

For 28 days, A = 96.3 and B = 8.2 giving;

$\boldsymbol{Fc28 = \frac{A}{B^\wedge w/c} = \frac{96.3}{8.2w/c}}$ … … … … … … … … …Equation 5

The values given for A and B are based on 28-day tests of 1 :4 mix, pebble aggregate graded 0-31.75mm., fineness modulus 5.75.Table 7 shows the comparison of the actual strength results to the predicted strength by Abram's model.

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Table 6 Observed Vs Predicted compressive strength using Abram's model (N/mm^2)

Days	Predicted strength N/mm2	Observed compressive strength N/mm2					
	Abrams	S2	S3	S4	S5	S6	S7
7	16.09	24.76	25.49	20.89	21.78	20.89	20.03
28	32.33	41.90	37.17	28.68	33.64	28.41	25.91

As observed in table 6, samples S2, S3 and S5 achieved strength surpassing the predicted strength at 7 and 28 days. This could be attributed to the high Silicon IV oxide concentrations in the samples responsible for strength development in concrete. Samples S7, S4 and S6 did not achieve the predicted strength at 28days with sample S7 being the lowest in strength. This can be attributed to lower concentrations of Silicon (IV) oxide and Calcium Oxide in the aggregate samples that contributed to slower strength gain. It was also observed that the actual results varied from values obtained from Abram's prediction model. In Abrams equation the strength of concrete at a given age and cured in water at a prescribed temperature is assumed to depend primarily on two factors only: the water/cement ratio and the degree of compaction [14]. This model is incomplete because different coefficients of proportionality values are needed whenever any factor affecting the strength of concrete changes. The coefficients of proportionality parameters depend on cement type and strength, aggregate gradations and proportions, admixtures, curing conditions, testing conditions, and age of concrete[7]. The model is also limited to predicting for 7 and 28days age only.

d. Concrete strength gain prediction based on the Bolomey's model

Further research by Bolomey culminated into coming up with the following relationship between concrete strength and its constituents for predicting the 28-day concrete strength,

$$Fc28 = 24.6\left(\frac{c}{w} - 0.5\right) \text{ ……………….Equation 6}$$

Where Fc28- strength at 28days
c- mass of cement
w- mass of water

Table 7 Observed Vs Predicted compressive strength using Bolomey's model (N/mm^2)

Strength N/mm^2	28 days
Predicted by Bolomey	34.93
s2	41.90
s3	37.17
s4	28.68
s5	33.64
s6	28.41
s7	25.91

It was observed that, samples S2, S3 and S5 fell within the range predicted values of the German model while samples S4, S6 and S7 fell below the predicted range. This can be attributed to their varying physical and chemical properties. All Observed compressive strength values deviated from the predicted values. This could be due to the fact that Bolomey's prediction model is assumed to depend primarily water/cement ratio only. It doesn't take into account other factors like quantities of constituent materials, material physical and chemical properties and curing conditions. The model is also limited to predicting 28 days' age only

e. Concrete strength gain prediction based on the ACI model

Research done by American Concrete Institute on prediction of creep, shrinkage and temperature effects in concrete structures also on analysis of the prediction models came up with the equation which can be used to predict the concrete strength over its lifetime.

$$f_{cm}(t) = f_{c28}\left(\frac{t}{4+0.85t}\right) \text{ …………...Equation 7[15]}$$

Where $f_{cm}(t)$ is the mean compressive strength at an age of t days (MPa)?

f_{c28} is the mean 28- day compressive strength (MPa)

All the samples had their strengths predicted at the respective days and compared to the actual compressive strength results as indicated in figure 2-7;

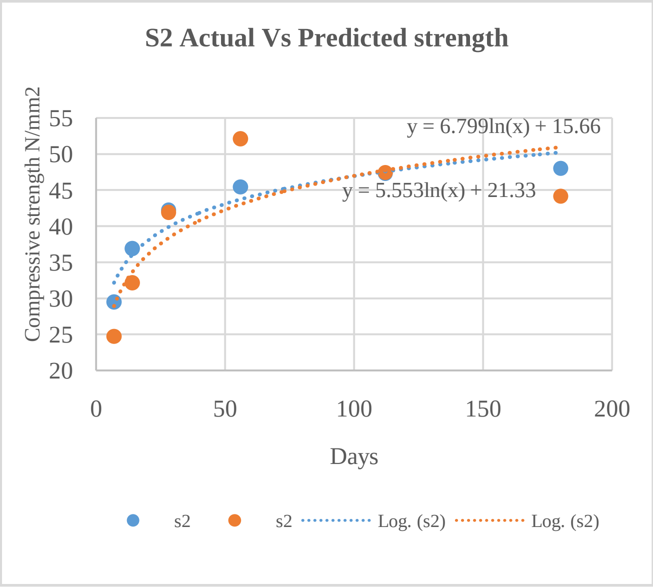

Figure 2 Observed Vs Predicted compressive strength gain for S2 (N/mm^2)

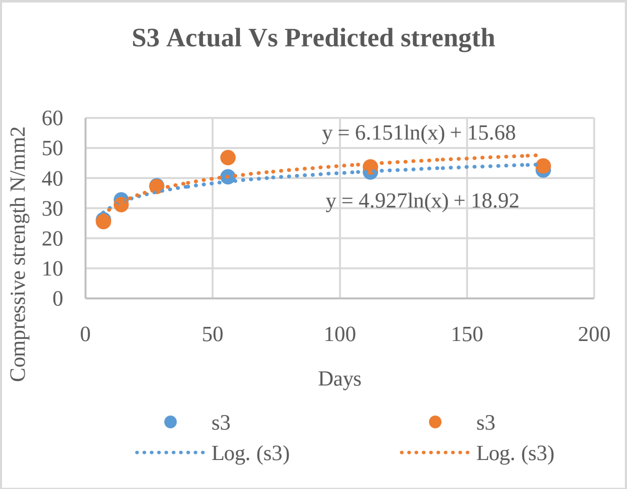

Figure 3 Observed Vs Predicted compressive strength gain for S3 (N/mm^2)

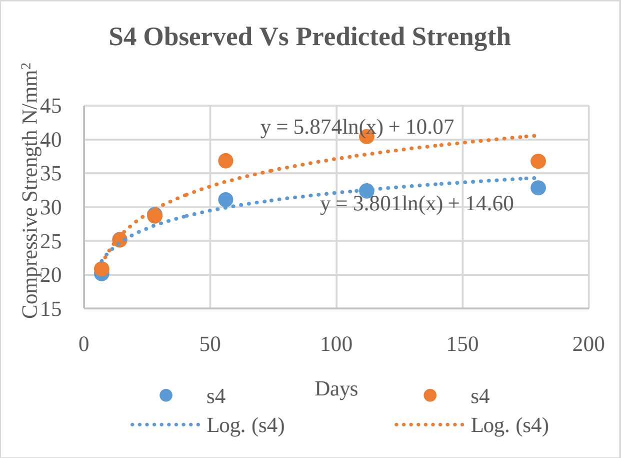

Figure 4 Observed Vs Predicted compressive strength gain for S4 (N/mm^2)

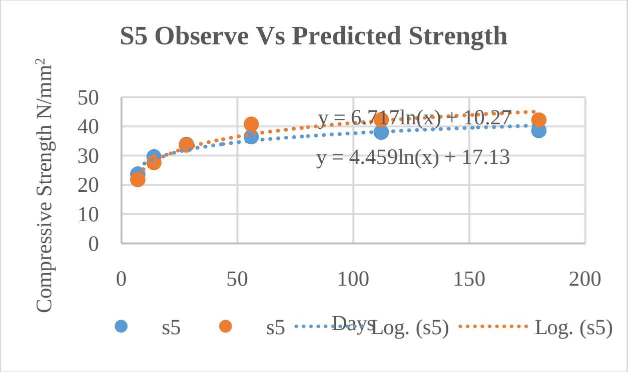

Figure 5 Observed Vs Predicted compressive strength gain for S5 (N/mm^2)

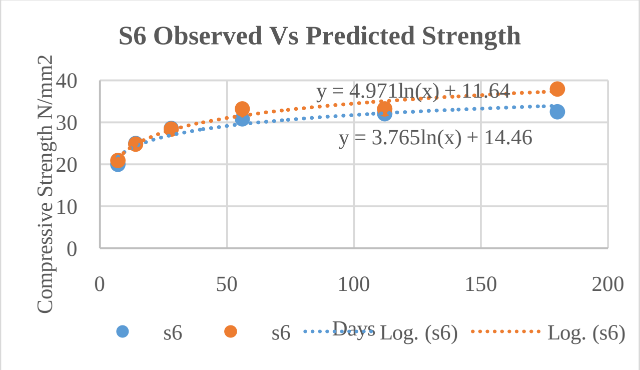

Figure 6 Observed Vs Predicted compressive strength gain for S6 (N/mm^2)

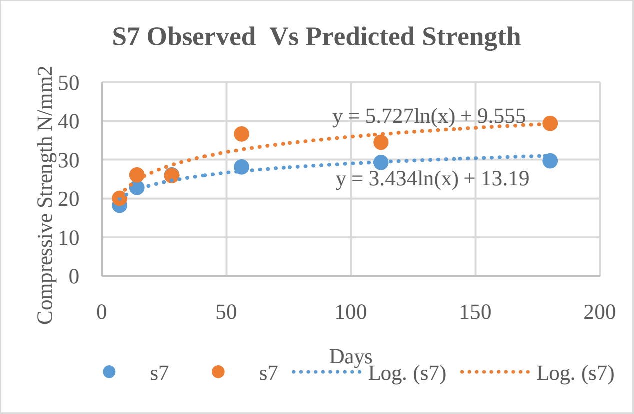

Figure 7 Observed Vs Predicted compressive strength gain for S7 (N/mm^2)

It was observed that at 7,14,28,56,112 and 180 days the concrete strength observed from concrete made from all the samples attained higher compressive strength than the predicted ACI values at the various stages. Concrete strength observed from samples S4, S6 and S7 show greater variable from the model predicted values and this can be attributed to their low silica concentrations among other contributing parameters. The deviation of the observed compressive strength values from the predicted values of the ACI model values could be explained by the fact that the model does not take into account the constituent material properties, curing conditions and the cement type and hydration regime. The model also requires use of observed 28 days compressive strength as a constant employed to predict concrete strength throughout the lifetime of concrete which may be erroneous.

C. Multi-linear regression model (MLRM)

The above models have various and varied limitations that limit their use in prediction of concrete strength. The prediction of concrete strength using water cement ratio, cement/water ratio and generation of a formulae based on observed results is not only erroneous but grossly understated and misleading. Other parameters which includes physical and chemical properties of the constituents of concrete and their influence on concrete strength cannot be overlooked. Therefore, efforts should be concentrated on models taking into account the influence of different constituents parameters on the concrete strength in order to have more reliable and accurate results for the prediction of concrete strength [16].

[17] extended Abrams model relating the water-cement ratio of concrete with strength with additional variables and uses least square regression to determine equation coefficients. This has further been modified into a multi-linear regression model which takes into account the quantities and qualities of the constituent materials while bringing cognizance to the fact that their effects on concrete are interdependent. This model can be used widely to predict the compressive strength of various types of concrete as shown in equations 8 and 9;

$f \;=$
$b1 + \; b2\frac{w}{c} +$
$C0,1$ ……………………………………..Equation 8

Linear Least Square Regression (referred to Abram)

$f \;= \; b1 \; + b2 \; w/\; c \; + \; b3 \; FA + \; b4 \; CA + \; b5 \; W + \; b6 \; C +$
$b7 \; SiO + \; b8 \; Al2O3 + \; b9 \; S\&C$ … … … … .. Equation 9

Multiple Linear Regression

Where:

f: compressive strength of concrete N/mm2
w/c: water/cement ratio
C: quantity of cement in the mix (kg)
CA: quantity of coarse aggregate in the mix (kg)
FA: quantity of fine aggregate in the mix (kg)
W: quantity of water in the mix (kg)
C: quantity of cement in the mix (kg)
SiO: Concentration of Silica (%)
Al2O3: Concentration of Alumina (%)
S&C: Concentration of Silt and Clay (%)

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The above parameters used in the multilinear regression model are derived from the degree of their importance in strength gain as captured in concrete theory and experimental observations.

Factors that affect the development of strength of concrete and consequently its durability include quality and quantity of cement used in the mix, grading of aggregates, maximum nominal size, shape and surface texture of aggregate, water/cement ratios, degree of compaction and the presence of clayey particles and organic matter in the mix [18][19].Chemical properties also have an influence on concrete strength and are not inert as they were earlier considered [10][14]

Fineness modulus is a measure of the fineness of aggregates. A higher fineness modulus implies a coarser aggregate hence requires more water to produce workable concrete [14]. Particle shape and texture greatly influence fresh concrete properties like workability and bond between the particles and are considered especially when in need of high compressive strength. Angular particles enhance the bond between the cement paste and the aggregates. Smooth and rounded particles require less water to achieve workability but have reduced bond between cement paste and the aggregates hence lower compressive strengths. Presence of impurities (clay and silt) in sand significantly contribute to reduction in compressive strength of concrete which has a great effect on concrete performance [20].

The chemical properties of aggregates have an influence on strength development of concrete. The main chemical constituents of importance are Silicon IV oxide, Aluminium III oxide and calcium oxide which influence the setting time, early strength and final concrete strength. Silica concentrations of between 70-90% prolong the setting time but increase the final concrete mix strength and alumina concentrations of between 8-12% reduce the setting time but increases the concrete strength. [9].

The data derived from the experimental programme in this work was used to develop a mathematical model that uses the mix proportions, physical and chemical properties and w/c ratio to represent the effect of these constituents on the compressive strength of concrete. A total of 18 samples of 150×150×150 mm size were cast for class 30 concrete using D.O.E (Department of Environment)/British method. This involved selecting and proportioning the constituents to give the required strength, workability and durability [2]. Out of the total 18 samples, 12 samples were used to formulate the model and the remaining 6 were used to validate the model.

Table 8 Mix Proportions of Concrete and Properties of Fine Aggregates used for formulation of the model

Samples	S2	S2	S3	S3	S4	S4	S5	S5	S6	S6	S7	S7
Strength (7 days)	23.64	24.98	25.51	25.56	21.67	22.36	22.13	21.96	21.29	20.79	20.47	20.13
Strength (14 days)	33.24	33.72	32.82	30.85	23.31	26.52	27.36	27.16	27.33	22.73	26.59	27.35
Strength (28 days)	43.61	38.74	29.91	37.17	28.47	29.78	34.49	34.35	28.93	30.44	29.09	22.40
Strength (56 days)	56.96	56.96	43.77	56.17	29.72	38.02	38.20	41.02	30.29	34.21	35.23	36.19
Strength (112 days)	43.78	50.24	39.21	48.38	41.32	40.75	43.38	43.32	29.77	33.56	35.03	33.72
Strength (180 days)	41.49	39.11	44.07	40.32	35.00	36.81	45.04	46.70	36.17	41.14	40.66	41.58
FA (kg)	656	656	525	525	788	788	656	656	562	562	788	788
CA (kg)	1218	1218	1350	1350	1087	1087	1218	1218	1312	1312	1087	1087
Water (kg)	190	190	190	190	190	190	190	190	190	190	190	190
Cement (kg)	365	365	365	365	365	365	365	365	365	365	365	365
SiO (%)	76	76	78	78	67	67	80	80	69	69	65	65
AlO (%)	11	11	9	9	17	17	10	10	14	14	19	19
Silt & Clay	4.85	4.85	4.16	4.16	2.06	2.06	6.66	6.66	9.37	9.37	11.90	11.90
w/c ratio	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52

Excel data analysis software was used to develop the regression model to predict the compressive strength of concrete at 7, 14, 28, 56, 112 and 180 days.

The regression analysis is carried out on the data set of Table 8 and values of regression coefficients b1 to b9 obtained are as shown in Table 9. The values of these coefficients are reflective of the effects of various qualities and quantities of the constituents on the compressive strength of concrete.

Table 9 Regression Coefficients

Parameters	Coefficients	7days	14days	28days	56days	112days	180days
Intercept	*b1*	-4442	-9983.7	1052.1	-22797	-6556.9	-1698.1
FA	*b2*	2.5131	5.7761	-0.1215	13.351	3.82995	0.82342
CA	*b3*	2.4661	5.6051	-0.2923	12.889	3.68236	0.84396
Water	*b4*	0	0	0	0	0	0
Cement	*b5*	0	0	0	0	0	0
SiO	*b6*	-1.826	-5.9489	-5.6753	-15.91	-3.7463	1.84927
AlO	*b7*	-4.404	-14.173	-13.639	-37.874	-10.182	2.53432
Silt & Clay	*b8*	0.3498	1.8801	1.2754	4.6507	0.63082	0.39074
w/c ratio	*b9*	0	0	0	0	0	0
Formulated equations fc = b1 + b2FA + b3CA+ b4W+ b5C + b6SiO+ b7Al2O3+ b8S&C + b9w/c							

From the coefficients displayed in Table 9, it is observed that, the major independent variables influencing concrete strength development at 7 days were observed to be; Alumina (Al203), fine and coarse aggregate quantities. At 14 days, the major independent variables were observed to be; Alumina (Al203), silica (SiO2), fine and coarse aggregate quantities. At 28 days, the major independent variables were observed to be; Alumina (Al203), silica (SiO2) and silt and clay content. At 56 days, the major independent variables were observed to be; Alumina (Al203), silica (SiO2), fine and coarse aggregate quantities. At 112 days, the major independent variables were observed to be; Alumina (Al203), silica (SiO2), fine and coarse aggregate quantities. At 180 days, the major independent variables were observed to be; Alumina (Al203) and silica (SiO2). Water and cement quantities were observed to not have any effect as they were constant for all samples.

D. Validation of the model

The acceptance and reliability of any model is mainly dependent on its performance. A popular method of performance analysis is use of statistical parameters, where output results obtained from the model are compared to observed field or laboratory results. The validation of the finally developed model was done by using a different set of compressive strength data not included in the formulation of the model. The regression coefficients thus obtained in the Table 9 were incorporated in equations 10-15 to get the final model for predicting the compressive strength of concrete at 7, 14, 28, 56, 112 and 180 days. Table 10 shows the data used for validating model

Table 10 Mix Proportions of Concrete and Properties of Fine Aggregates used for Validation

Samples	S2	S3	S4	S5	S6	S7
Strength(7 days)	25.65	25.42	18.65	21.26	20.58	19.50
Strength(14 days)	29.48	29.92	25.58	28.33	24.19	24.26
Strength(28 days)	43.35	37.18	27.80	32.10	25.86	26.23
Strength(56 days)	47.26	40.59	35.67	43.14	35.21	38.50
Strength(112 days)	48.37	43.63	39.30	40.34	36.27	34.70
Strength(180 days)	40.3	41.21	31.4	43.37	36.63	42.5
FA (kg)	656	525	788	656	562	788
CA (kg)	1218	1350	1087	1218	1312	1087
Water (kg)	190	190	190	190	190	190
Cement (kg)	365	365	365	365	365	365
SiO (%)	76	78	67	80	69	65
AlO (%)	11	9	17	10	14	19
Silt & Clay	4.85	4.16	2.06	6.66	9.37	11.9
w/c ratio	0.52	0.52	0.52	0.52	0.52	0.52

Thus, the final models for predicting compressive strength of concrete corresponding to class 30 grade concrete using the data set in Table 10 were formulated in equations 10- 15.

$$f\ 7 = -4442.45 + 2.513087\ FA + 2.466094\ CA + -1.8261\ SiO + -4.40378\ Al2O3 + 0.349783\ S\&C \ldots\ldots\ldots \text{....Equation 10}$$

$$f14 = -9983.715 + 5.776081\ FA + 5.605078\ CA + -5.948923\ SiO + -14.17272\ Al2O3 + 1.880092\ S\&C \ldots\ldots\ldots\ldots \text{..Equation 11}$$

$$f\ 28 = 1052.095 + -0.12146\ FA + -0.292348\ CA + -5.675315\ SiO + -13.63872 Al2O3 + 1.275438\ S\&C \ldots\ldots\ldots\ldots \text{..Equation 12}$$

$$f\ 56 = -22796.64 + 13.35121\ FA + 12.88869\ CA + -15.91008\ SiO + -37.87397\ Al2O3 + 4.65074\ S\&C \ldots\ldots\ldots\ldots \text{..Equation 13}$$

$$f\ 112 = -6556.8902 + 3.82995\ FA + 3.6823635\ CA + -3.7462981\ SiO + -10.182415\ Al2O3 + 0.6308164\ S\&C \ldots\ldots\ldots\ldots \text{..Equation 14}$$

$$f\ 180 = -1698.1237 + 0.8234198\ FA + 0.8439599\ CA + 1.8492703\ SiO + 2.5343231\ Al2O3 + 0.3907413\ S\&C \ldots\ldots\ldots\ldots \text{..Equation 15}$$

The relationship between the observed compressive strength results obtained from the experimental work and those predicted from the model are shown in figures 8-13

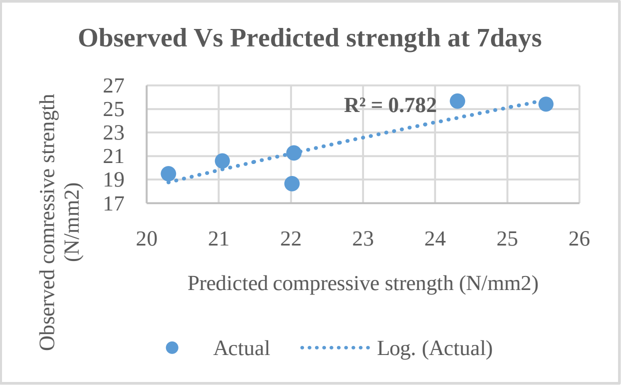

Figure 8 Observed Vs Predicted strength (N/mm^2) at 7 days

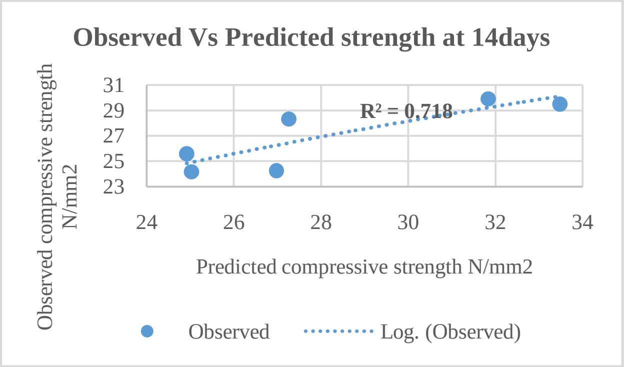

Figure 9 Observed Vs Predicted strength (N/mm^2) at 14 days

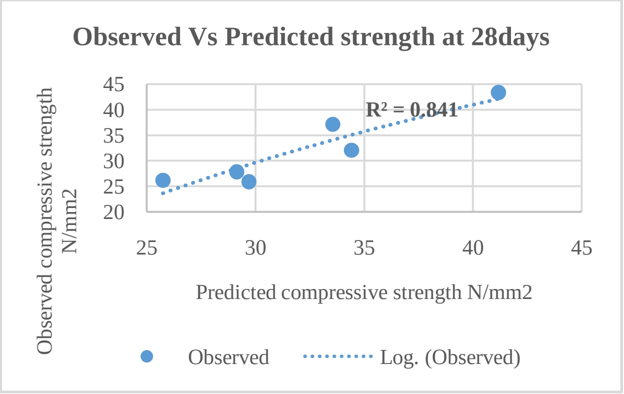

Figure 10 Observed Vs Predicted strength (N/mm^2) at 28 days

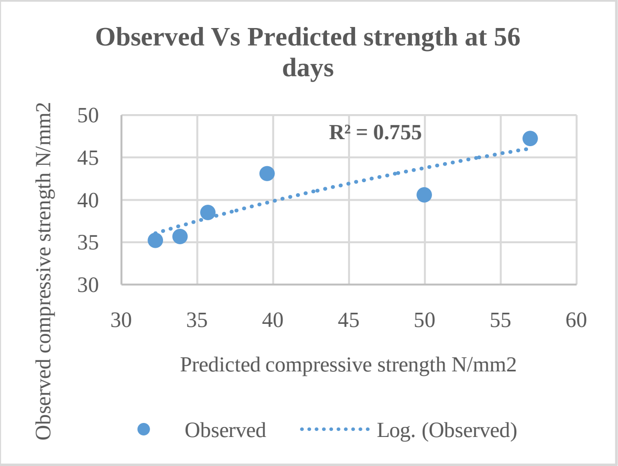

Figure 11 Observed Vs Predicted strength (N/mm^2) at 56 days

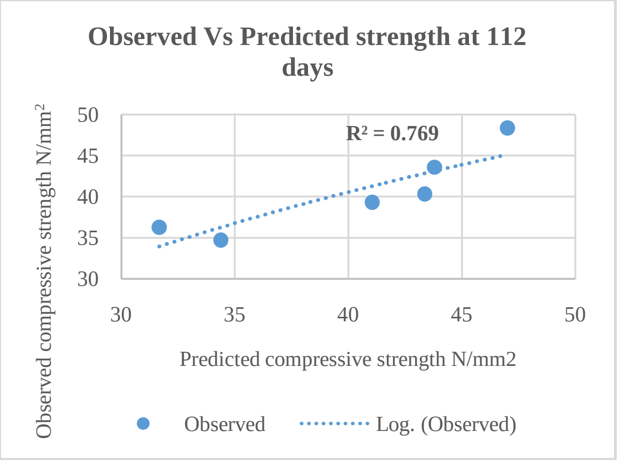

Figure 12 Observed Vs Predicted strength (N/mm^2) at 112 days

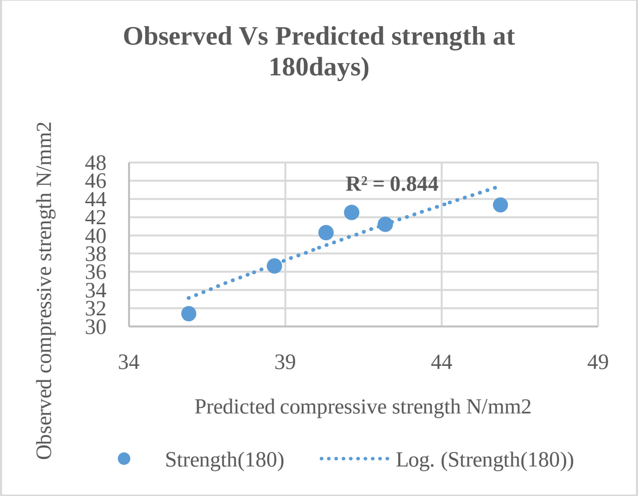

Figure 13 Observed Vs Predicted strength (N/mm^2) at 180 days

It is observed that the model has 78.2, 71.86, 84.16, 74.2, 76.95 and 85.44 percent correlation with the experimental data for 7. 14, 28, 56, 112 and 180days respectively. This implies that the observed and the predicted values for the compressive strength of concrete are in conformity with each other and therefore reliable for compressive strength prediction.

Comparison between MLR, BS &ACI models

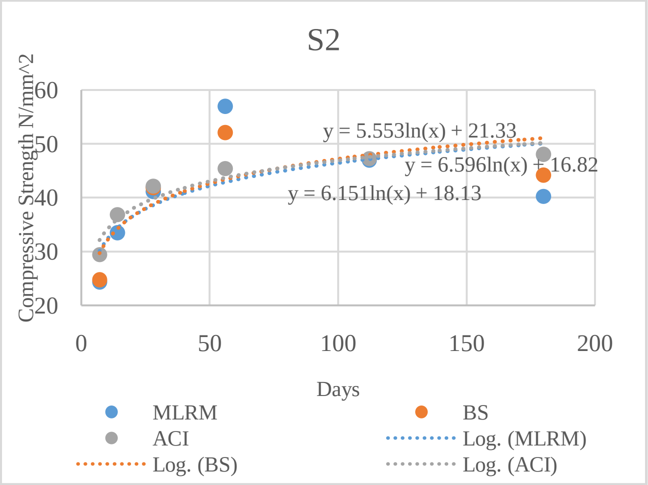

Figure 14 Comparison of Multi-linear regression, BS and ACI models for S2 Concrete compressive strength prediction

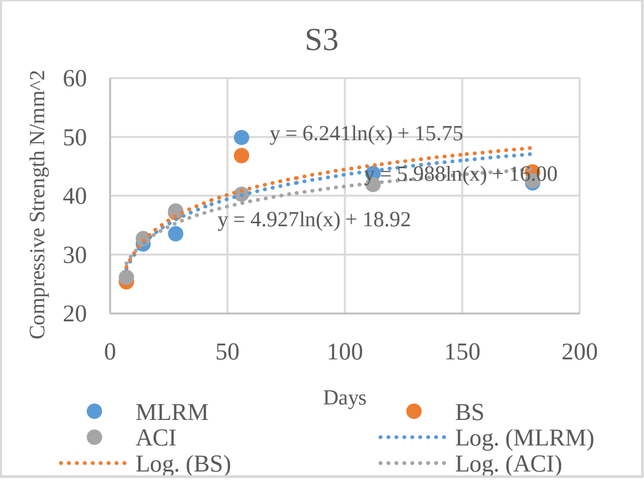

Figure 15 Comparison of Multi-linear regression, BS and ACI models for S3 Concrete compressive strength prediction

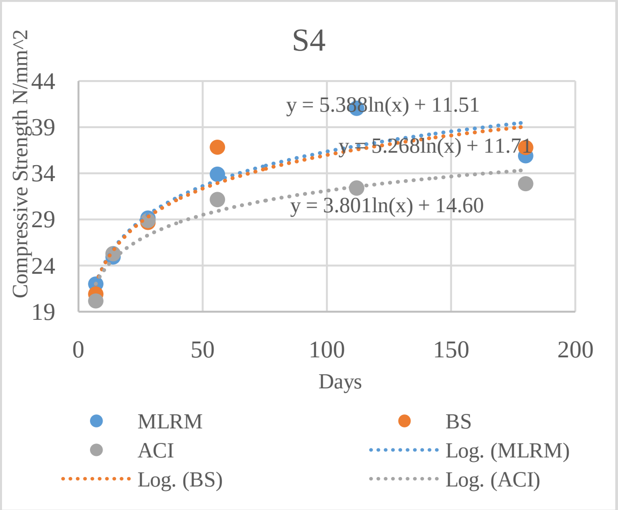

Figure 16 Comparison of Multi-linear regression, BS and ACI models for S4 Concrete compressive strength prediction

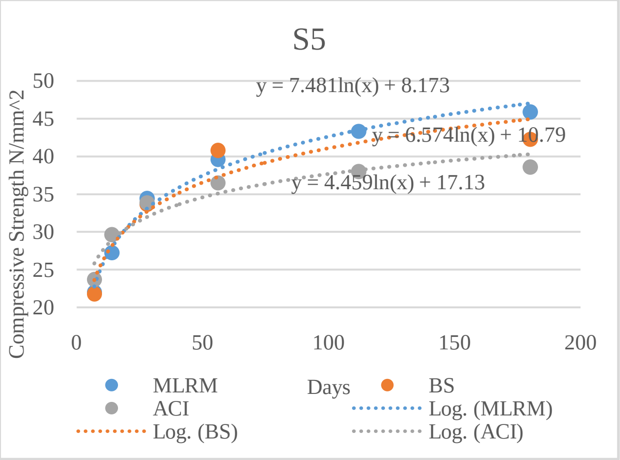

Figure 17 Comparison of Multi-linear regression, BS and ACI models for S5 Concrete compressive strength prediction

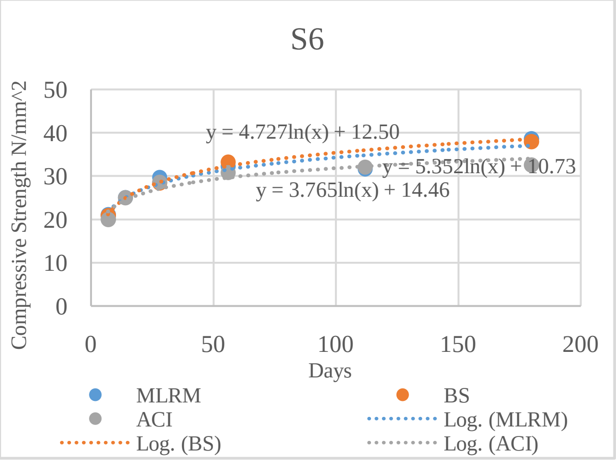

Figure 18 Comparison of Multi-linear regression, BS and ACI models for S6 Concrete compressive strength prediction

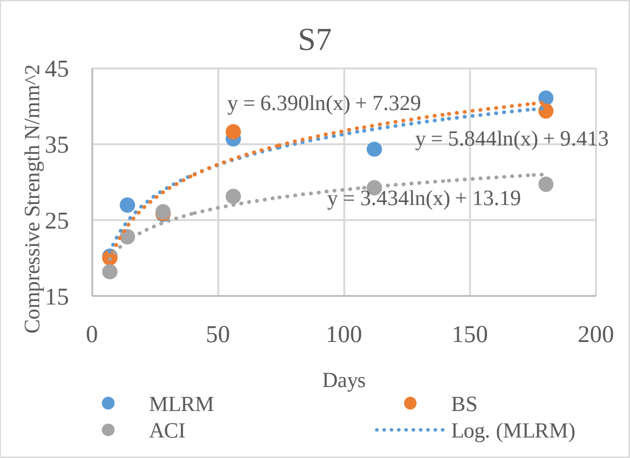

Figure 19 Comparison of Multi-linear regression, BS and ACI models for S7 Concrete compressive strength prediction

From figure 14-19, it is observed that when compared for all the different fine aggregates, the prediction curves obtained from multi-linear regression compared closely with the British Standard curves. This could be because the mix design and the laboratory conditions used to attain the experimental results were in accordance to the BS codes thus the close comparison. But while the BS is about modification factors, the multi-linear regression model takes into account the variables influencing concrete strength hence the slight deviation.

The Multi-linear regression model and the British Standard prediction curve were observed to deviate from the American Concrete Institute prediction curve by a bigger margin. This could be explained by the difference in mix design procedures in place that vary from the BS codes.

IV. CONCLUSION

For a long time, concrete strength gain over time was based on water-cement ratio, without regard to the physical and chemical composition of the various fine aggregate materials used in making concrete.

Though British Standard gives modification factors for concrete strength gain over time, the criteria and conditions used to define the same is not articulated.

Researchers have attempted to give corresponding formulae for concrete strength prediction relying on water-cement ratio and the assumption that concrete strength at 7 and 28 days is factual to an extent of employing the use of the observed results in the created formulae for the prediction of concrete strength which is certainly erroneous.

Shetty and Neville note that physical and chemical properties of aggregates have an impact on concrete strength but no studies have shown how these properties have impacted on strength gain.

Modification of Abram's model into a multi-linear regression that incorporates constituent parameters of aggregates not limited to physical but also extends to incorporate chemical properties has been used. The proposed modified model carries the form $f = b1 + b2\, w/c + b3\, FA + b4\, CA + b5\, W + b6\, C + b7\, SiO + b8\, Al2O3 + b9\, S\&C$.

In the case of fine aggregate materials mined from Mwingi, Machakos, Kajiado, Naivasha and Mlolongo, multi-linear regression models were done at 7,14, 28, 56, 112 and 180 days and yielded equations 10-15 with satisfactory coefficients of determination (CODs). Due to the fact that these models have been formulated from different samples obtained from different parts of Nairobi metropolitan, they would fairly form reliable prediction models for any other sands in Nairobi metropolitan for water-cement ratio of 0.52 and class 30 concrete.

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