Polytechnic Journal

Polytechnic Journal

Volume 8 | Issue 3 Article 11

11-1-2018

VALIDATION OF FERET REGRESSION MODEL FOR FLY ASH BASED GEOPOLYMER CONCRETE

Peshkawt Yaseen Saleh DOLAMARY
Ph.D.Student,HasanKalyoncuUniversity,CivilEngineeringDepartment,Gaziantep,Turkey

Dilshad Kakasor JAF
Assistance Prof. Dr. Salahaddin University, Civil Engineering Department, Erbil, Iraq

Mohamed Moafak ARBILI
AssistanceLecturer,Erbilpolytechnicuniversity,Chomantechnicalinstitute,Erbil,Iraq

Mehmet KARPUZCU Mr.
Prof.Dr.HasanKalyoncuUniversity,CivilEngineeringDepartment,Gaziantep,Turkey

How to Cite This Article

Saleh DOLAMARY, Peshkawt Yaseen; JAF, Dilshad Kakasor; ARBILI, Mohamed Moafak; and KARPUZCU, Mehmet Mr. (2018) "VALIDATION OF FERET REGRESSION MODEL FOR FLY ASH BASED GEOPOLYMER CONCRETE," *Polytechnic Journal*: Vol. 8: Iss. 3, Article 11.
DOI: https://doi.org/10.25156/ptj.2018.8.3.310

VALIDATION OF FERET REGRESSION MODEL FOR FLY ASH BASED GEOPOLYMER CONCRETE

Abstract

This paper dealt with the statistical analysis to find the best fit equation predicts compressive strength of geopolymer concrete (GPC) from mixture proportion, where the compressive strength is one of the desired and required properties of hardened concrete. The main concept of finding the equation is derived from the Feret Model, all the factors that effects on the compressive strength of geopolymer concrete and related to the ingredient materials are listed. A regression analysis has been done to new model to find the empirical constant of the best fit equation with a highest coefficient of determination 0.943 and lowest loss function expressed by residual mean squares. Statistical analysis showed that the new model is applicable to geopolymer concrete. The developed equation was validated with the experimental results.

Polytechnic Journal: Vol.8 No.3 (Aug 2018): Pp: 173-189
http://epu.edu.krd/ojs/index.php/Journal
https://doi.org/10.25156/ptj.2018.8.3.310

VALIDATION OF FERET REGRESSION MODEL FOR FLY ASH BASED GEOPOLYMER CONCRETE

Peshkawt Yaseen Saleh DOLAMARY[1], Dilshad Kakasor JAF[2], Mohamed Moafak ARBILI[3], Mehmet KARPUZCU[4]

[1]*Ph.D. Student, Hasan Kalyoncu University, Civil Engineering Department, Gaziantep, Turkey*

[2] *Assistance Prof. Dr. Salahaddin University, Civil Engineering Department, Erbil, Iraq*

[3]*Assistance Lecturer, Erbil polytechnic university, Choman technical institute, Erbil, Iraq*

[4] *Prof. Dr. Hasan Kalyoncu University, Civil Engineering Department, Gaziantep, Turkey*

ABSTRACT

This paper dealt with the statistical analysis to find the best fit equation predicts compressive strength of geopolymer concrete (GPC) from mixture proportion, where the compressive strength is one of the desired and required properties of hardened concrete. The main concept of finding the equation is derived from the Feret Model, all the factors that effects on the compressive strength of geopolymer concrete and related to the ingredient materials are listed. A regression analysis has been done to new model to find the empirical constant of the best fit equation with a highest coefficient of determination 0.943 and lowest loss function expressed by residual mean squares. Statistical analysis showed that the new model is applicable to geopolymer concrete. The developed equation was validated with the experimental results.

Key words: ***Statistical Analysis, Geopolymer Concrete, Feret Model, SPSS.***

1. INTRODUCTION

Geopolymers, an alternate class of binders which is a cementless one has emerged in the recent decades to replace cement. Geopolymers invented by Joseph Davidovits in 1978 were initially developed to serve as a fire resistant material, but it has now gained momentum as an effective alternate to cementitious binders to limit greenhouse gas emissions.

Geopolymer is a kind of inorganic polymer produced by the reaction of aluminosilicate materials with alkaline solutions (Kong et al., 2007, Damtoft et al., 2008). Geopolymers have shown many excellent properties such as high early strength, good resistance against acid and sulfate attacks, and good performance in high temperature (Wang et al., 1995, Hardjito et al., 2004, Bakharev, 2005a, Hu et al., 2008, Kong and Sanjayan, 2008). One remarkable point about geopolymer is elimination of cement usage (Van Deventer et al.), and 44-64% reduction of greenhouse gas emission (McLellan et al., 2011). Besides, some of wastes and by-products such as fly ash and blast furnace slag are appropriate sources of aluminosilicate which are used to produce geopolymer (Olivia and Nikraz, Lloyd and Rangan, 2010). As geopolymers made from mentioned materials need less amount of sodium silicate to be activated, they have lower environmental impact in comparison to other types of geopolymers as a binder (Habert et al., 2011).

Regression Analysis is a statistical technique used for assessing the relationship between the outcome (known as the Dependant variable) and the predictors (known as the Independent variables). Also regression is the most widely used technique for prediction and forecasting. Regression Analysis helps to understand the variance in the dependant variable due to one or more independent variables. In other words, it shows the impact of each independent variable on the dependant variable. (Palmer et al., 2009).

Typically regression analysis can be performed for one or more of the three purposes:

- To predict the value of the dependant variable provided some data is available on the independent variables
- To identify the effect of the Independent Variables (IV's) on the Dependant Variables (DV's) or model the relationship between the variables and
- For testing of Hypothesis

In this study regression analysis was used for identifying the relationship between the variables, molarity, mix ratio and density on compressive strength of geopolymer concrete. Compressive strength was taken as the dependant variable and molarity, mix ratio and density were taken as the independent variables as shown in experimental procedure.

2. EXPERIMENTAL PROCEDURE

In the research facility, prepared all material expected to geopolymer solid. The fly ash and the aggregates with a little extra water were first mixed together dry in a pan mixer for about three minutes as it is shown that in saturated-surface-dry (SSD) condition, the aggregates had been prepared. We mixed the alkaline liquid with dry mixture in the mixer step by step .Then super plasticizer mixed with remaining extra water. After then mixed in the pan component the mixing continued usually for another four minutes. By the normal methods prepared in the case of Portland cement concrete, the fresh concrete had been compacted. After casting cubes, putting another location in the laboratory for (24) hours to take rest period the laboratory temperature is between (20 -25) C^o. After than those cubes putting in the oven for (24) hours at temperature 70 C^o. The specimens, that were tested, are (150*150*150) mm cubes .In every length 3 tests were tried for every blend and the normal outcomes were taken from these three tried examples. Add up to number of molds were 570 molds. They were made of iron. The inside parts of each form were secured by a sticker or hostile to consume nylon to disallow solidly adheres to the shape.

2.1. DATA ANALYSIS

Compressive strength depends on various parameters like the quality and quantity of its ingredients and its fresh properties. From the list of variables select (fall) to represent the strength of concrete.(from result of experimental study shown in the Table 1)

The virables condecte from totale solied (Solids Na_2Si, Vol of Na_2SiO, Solid NaOH, Vol of NaOH), water (water, Na_2SiO_3, NaOH), fine aggergate, coarse aggregate and Maximum Paste thickness (MPT). For depent virable the compessive strenght was used for (3day,7 day, 28 day, 56 day and 91 day)

3. RUSULT OF EXPERIMENTAL STUDY

Table 1 the show result the fall (compressive study) from the laboratory result

Table 1 experimental result

group	Mix	Fall (Compressive strength, Mpa)				
		3 Day	7 Day	28 Day	56 Day	91 Day
1	1	45.15	46.54	47.55	48.81	49.50
	2	40.72	41.93	42.85	44.00	44.69
	3	35.55	37.48	38.83	39.86	40.19
	4	29.89	31.10	32.20	33.06	33.81
	5	22.00	22.57	24.04	24.67	25.04
2	6	43.53	44.96	46.15	47.35	48.21
	7	39.10	40.43	41.40	42.47	43.04
	8	33.93	35.26	36.07	37.03	37.89
	9	28.27	29.47	30.73	31.54	32.26
	10	20.38	21.26	22.27	22.85	23.70
3	11	42.07	43.69	44.66	45.69	46.38
	12	37.50	39.09	40.30	41.10	42.03
	13	32.31	33.71	34.81	35.64	36.25
	14	26.72	28.05	29.29	29.97	31.05
	15	18.68	19.77	20.91	21.54	22.21
4	16	40.63	41.99	42.86	44.02	45.06
	17	35.95	37.82	38.73	39.60	40.89
	18	30.73	32.30	33.47	34.36	35.09
	19	25.38	26.71	27.95	28.69	29.58
	20	17.23	18.47	19.76	20.30	21.04

3.1. RUSULT OF REGRESSION ANALYSIS

Table 2, 3 and 4 show the result obtained from statistical analysis by using SPSS software. This analysis was done based on the experimental results of various concrete mixes. The relationship between variables is demonstrated as follows.

$\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c}, \boldsymbol{d},$ Are empirical constants from the regression analysis of the experimental results, their values are estimated statistically using nonlinear curve estimation from the software package SPSS-version-22

Table 2, Iteration History[b]

Iteration Number[a]	Residual Sum of Squares	Parameter			
		a	b	c	d
1.0	118116.358	1.000	1.000	1.000	1.000
1.1	2.605E+44	106.021	94.775	-114.563-	-35.199-
1.2	1.435E+43	5.754	-45.664-	5.356	-19.695-
1.3	38300.817	1.660	-3.503-	1.889	-.413-
2.0	38300.817	1.660	-3.503-	1.889	-.413-
2.1	23001.682	1.823	-3.751-	2.438	-.498-
3.0	23001.682	1.823	-3.751-	2.438	-.498-
3.1	15992.681	2.159	-3.829-	3.496	-.399-
4.0	15992.681	2.159	-3.829-	3.496	-.399-
4.1	14698.610	2.871	-3.214-	3.345	-.240-
5.0	14698.610	2.871	-3.214-	3.345	-.240-
5.1	16999.556	4.411	-2.381-	1.554	-.209-
5.2	14205.314	3.241	-3.107-	3.022	-.219-
6.0	14205.314	3.241	-3.107-	3.022	-.219-
6.1	13732.666	3.894	-2.788-	2.365	-.213-
7.0	13732.666	3.894	-2.788-	2.365	-.213-
7.1	13458.604	5.245	-2.246-	1.475	-.217-
8.0	13458.604	5.245	-2.246-	1.475	-.217-
8.1	12249.797	5.964	-2.185-	1.347	-.231-
9.0	12249.797	5.964	-2.185-	1.347	-.231-
9.1	11699.159	7.282	-1.799-	1.015	-.228-
10.0	11699.159	7.282	-1.799-	1.015	-.228-
10.1	11319.142	9.956	-1.224-	.599	-.229-
11.0	11319.142	9.956	-1.224-	.599	-.229-
11.1	9714.724	12.667	-.917-	.456	-.235-
12.0	9714.724	12.667	-.917-	.456	-.235-
12.1	9563.240	18.080	-.208-	.238	-.231-
13.0	9563.240	18.080	-.208-	.238	-.231-
13.1	7715.976	20.808	-.173-	.218	-.237-
14.0	7715.976	20.808	-.173-	.218	-.237-
14.1	7067.196	25.845	.284	.158	-.232-

15.0	7067.196	25.845	.284	.158	-.232-
15.1	6301.173	31.296	.577	.113	-.229-
16.0	6301.173	31.296	.577	.113	-.229-
16.1	5674.666	42.197	1.184	.067	-.223-
17.0	5674.666	42.197	1.184	.067	-.223-
17.1	4525.453	53.109	1.521	.046	-.219-
18.0	4525.453	53.109	1.521	.046	-.219-
18.1	4113.816	74.931	2.254	.024	-.209-
19.0	4113.816	74.931	2.254	.024	-.209-
19.1	2806.495	96.763	2.635	.016	-.202-
20.0	2806.495	96.763	2.635	.016	-.202-
20.1	2662.956	140.424	3.465	.009	-.189-
21.0	2662.956	140.424	3.465	.009	-.189-
21.1	1507.950	162.260	3.566	.007	-.185-
22.0	1507.950	162.260	3.566	.007	-.185-
22.1	1235.565	205.927	4.113	.006	-.177-
23.0	1235.565	205.927	4.113	.006	-.177-
23.1	918.559	249.597	4.471	.005	-.170-
24.0	918.559	249.597	4.471	.005	-.170-
24.1	879.808	336.937	5.166	.004	-.160-
25.0	879.808	336.937	5.166	.004	-.160-
25.1	524.620	380.608	5.322	.004	-.156-
26.0	524.620	380.608	5.322	.004	-.156-
26.1	504.260	467.950	5.806	.003	-.150-
27.0	504.260	467.950	5.806	.003	-.150-
27.1	435.296	511.621	5.956	.003	-.147-
28.0	435.296	511.621	5.956	.003	-.147-
28.1	431.197	546.422	6.097	.003	-.145-
29.0	431.197	546.422	6.097	.003	-.145-
29.1	430.635	545.565	6.088	.003	-.145-
30.0	430.635	545.565	6.088	.003	-.145-
30.1	430.635	545.707	6.089	.003	-.145-
31.0	430.635	545.707	6.089	.003	-.145-
31.1	430.635	545.698	6.089	.003	-.145-

Derivatives are calculated numerically.

a. Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b. Run stopped after 65 model evaluations and 31 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Table 3, Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
a	545.698	42.554	461.414	629.983
b	6.089	.177	5.739	6.438
c	.003	.001	.002	.004
d	-.145-	.015	-.174-	-.116-

Table 4, Correlations of Parameter Estimates

	a	b	c	d
A	1.000	.977	-.093-	.129
B	.977	1.000	.059	.000
C	-.093-	.059	1.000	.000
D	.129	.000	.000	1.000

Figure 1 shows Predicted versus measured values of the compressive strength. This is a graph of measured compressive strength in the data and the strength as predicted by the modified Feret model. Ideally, all the points fall on the diagonal line, which indicates a high corrleation.

$\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c}, \boldsymbol{d},$ Are empirical constants from the regression analysis of the experimental results, their values are estimated statistically using nonlinear curve estimation from the software package SPSS-version-22. The program used quasai-Newton method for the best fit equation with the highest coefficient of determination R2 = 0.943 and Lowest loss function expressed by the residual mean squares=3.763. Table (2 and 3) showing statistical analysis taken as the output of the program, lower and upper bound values of the estimated parameters and ANOVA table are shown.

$$\boldsymbol{a} = \mathbf{545.698}\ , \quad \boldsymbol{b} = \mathbf{6.089}\ , \qquad \boldsymbol{c} = \mathbf{0.003}\ , \qquad \boldsymbol{d} = \mathbf{-0.145}$$

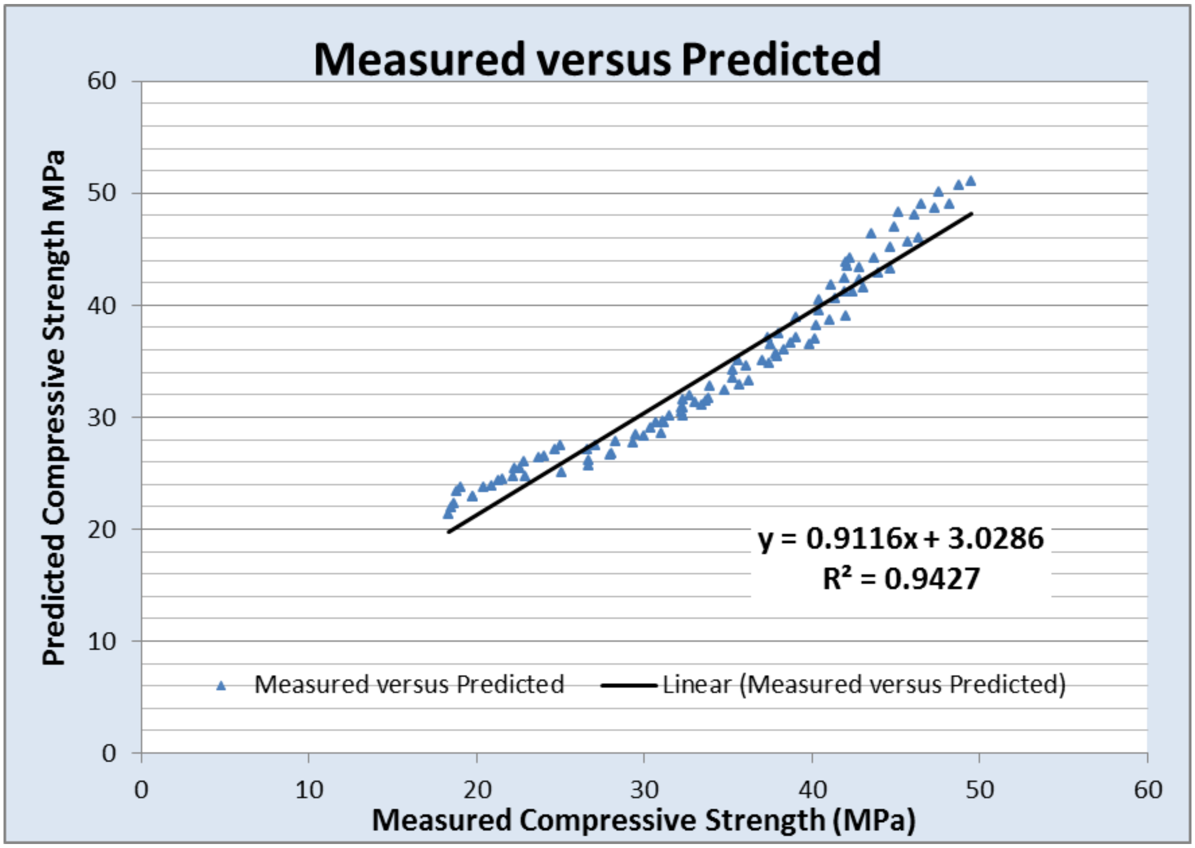

Figure 1. Illustrait Predicted versus measured compressive strength of geopolymer concrete (GPC)

The figuers 2,3,4,5 and 6 shows the results of predicted and laboratoray compressive strength at different ages of conceret.

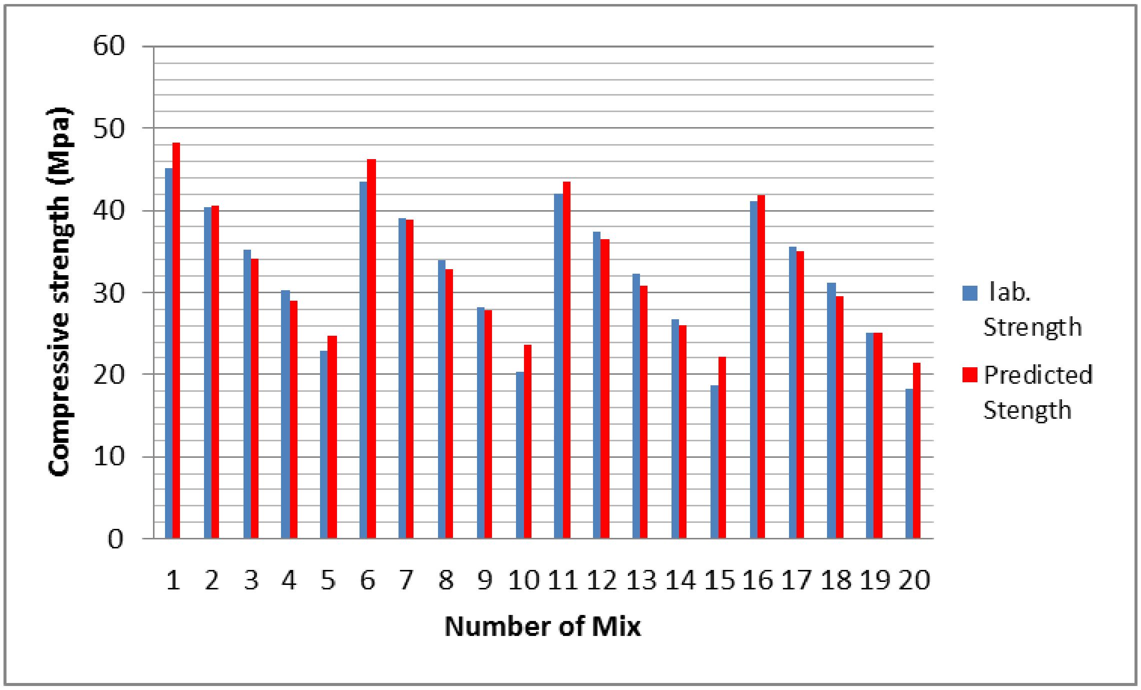

Figure 2. Illustrait the results of predicted and laboratoray compressive strength at 3days

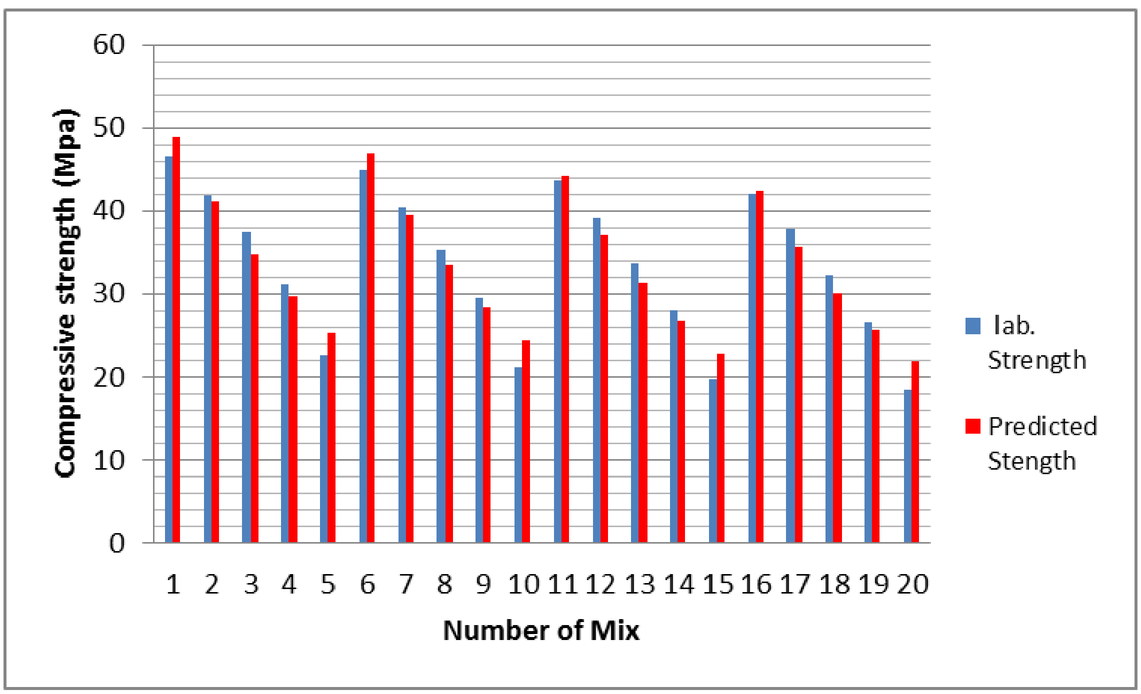

Figure 3. Illustrait the results of predicted and laboratoray compressive strength at 7 days

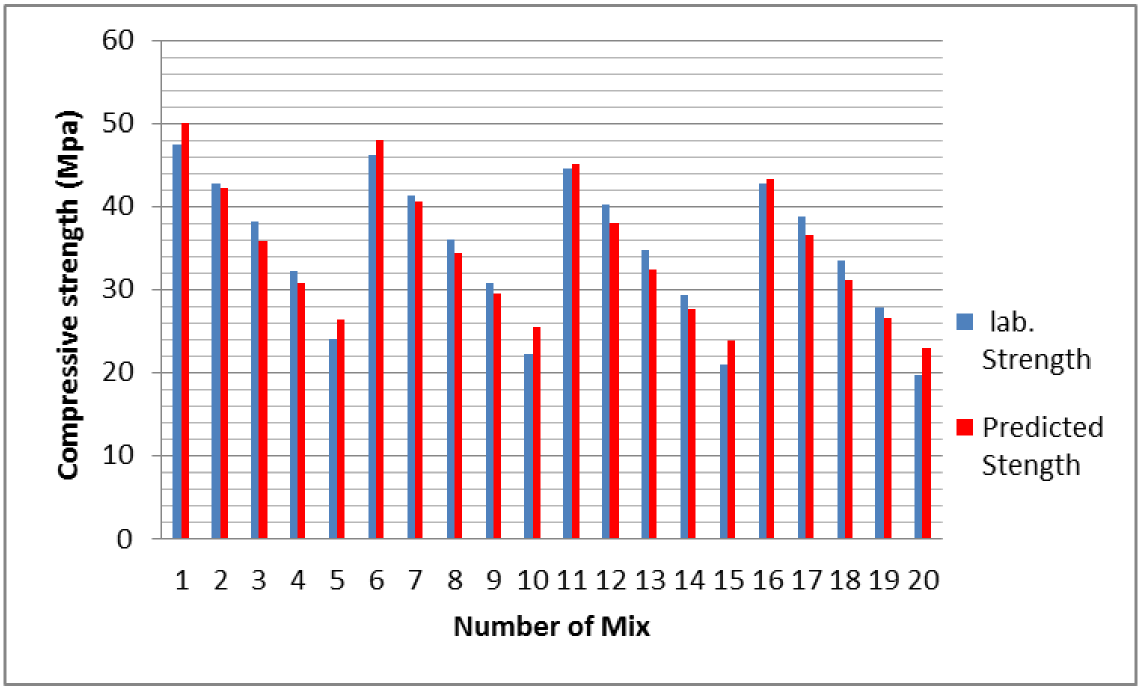

Figure 4. Illustrait the results of predicted and laboratoray compressive strength at 28 days

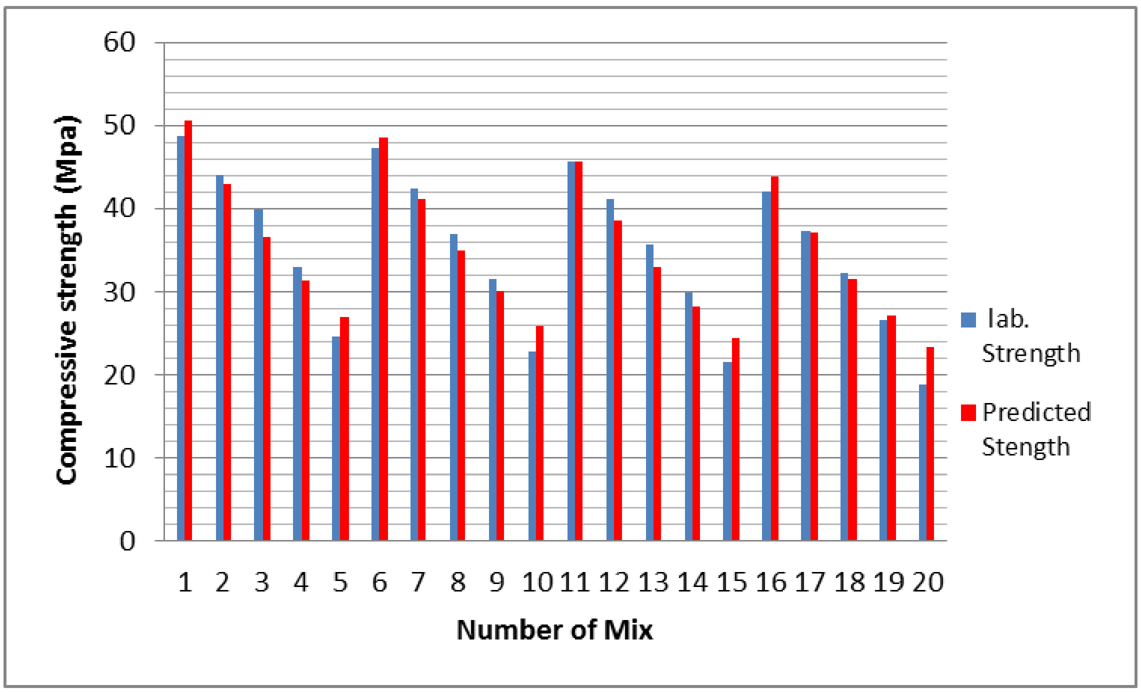

Figure 5. Illustrait the results of predicted and laboratoray compressive strength at 56 days

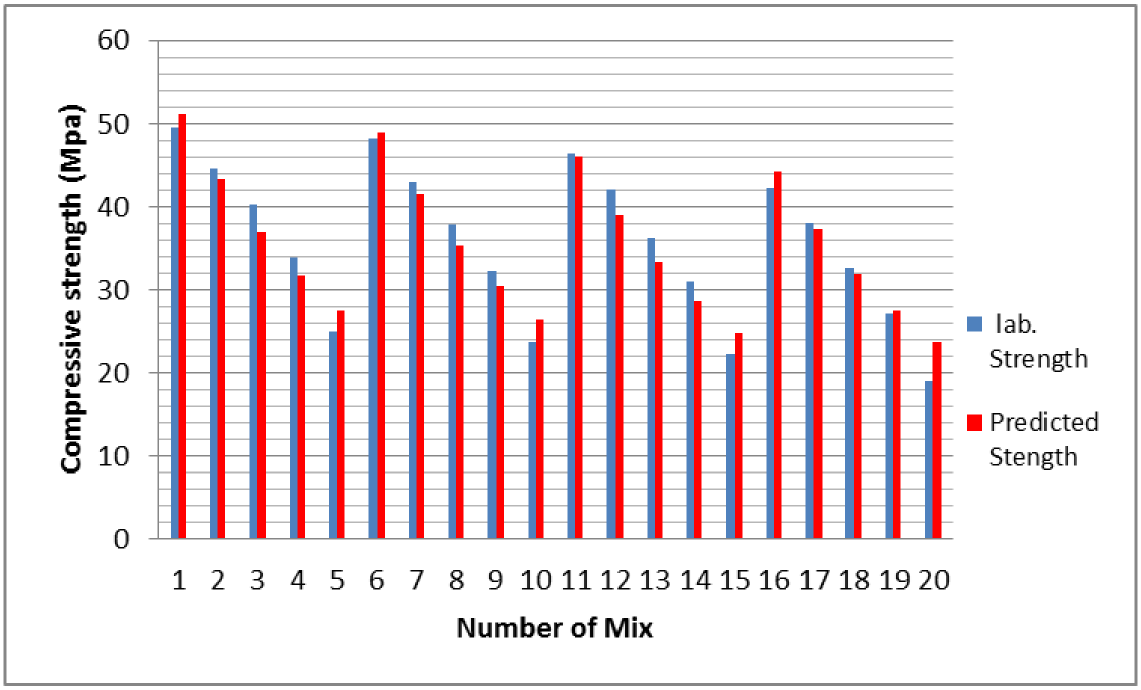

Figure 6. Illustrait the results of predicted and laboratoray compressive strength at 91 days

3.2.FERET MODEL AND VALIDATION

3.2.1. Modified Feret Model

Some of the most important previous models that predicts compressive strength of conventional concrete were developed, one of these models found out by Feret in 1897 predicts compressive strength of conventional concrete from the concentration of cement in cement paste, the model developed by F.d. Larrard in the nineteenth of the last century to include maximum paste thickness around aggregate particles and the effect of age of conventional concrete. This is the most important model for the mixture proportion of concrete.

The experimental results from (table 1) indicated that there is a strong relationship between the compressive strength of geopolymer concrete and the geopolymer binder concentration. Presently, this relation expressed using modified Feret's Model as follows;

$$\boldsymbol{fc(t) = a * \left[d(t) + \left(\frac{V_{gs}}{V_{gs}+V_{tw}} \right)^{b} \right] * MPT^{d}} \qquad \text{Eq(1)}$$

$$MPT^{d} = D * \left(\sqrt[3]{\frac{g*}{g}} - 1\right) \qquad \text{Eq}(2)$$

$$g = V_{CA} + V_{FA} \qquad \text{Eq}(3)$$

$$g* = \frac{\text{Bulk density of combined aggregate} * \text{Weight fraction}}{\text{Specific gravity}} \qquad \text{Eq}(4)$$

$d(t)$: the kinetics parameter at age t. It is supposed to be a characteristic of the geopolymer binder. This can be determined from the following equation

t : the age of geopolymer concrete, age would be considered at the time after placing the geopolymer concrete in the molds.

V_{gs} : volume of geopolymer solid (The sum of Volume of fly ash , volume of sodium silicate solid and volume of sodium Hydroxide flakes).

V_{tw}: total Volume of water (Volume of water used for NaOH solution , Volume of Water in sodium silicate solution and Volume of extra water).

MPT : the distance between aggregates which is called Maximum Paste thickness this can be determined by the equation (2).

D : Maximum size of aggregate (mm)

g^*: is equal to the packing density of the aggregate, considered as a granular mix.

g : is the aggregate volume in a unit volume of concrete. Aggregate volume determined by the equation(3).

a, b, c, d : are empirical constants from the regression analysis of the experimental results, their values are estimated statistically using nonlinear curve estimation from the software package SPSS-version-22

3.2.2. Validation Feret Model

We take an example to calculate the parameters of the modified model:

Suppose age of GPC = 7 days, Total amount of aggregate (Coarse and Fine) = 1230 + 620 = 1890 kg/m^3, Maximum size of aggregate =19.0 mm, Fly Ash content = 400 kg/m^3, Volume of fly ash = 400 / 2.2 = 181.81 L, Alkaline liquid to fly ash ratio Alk/Fly Ash = 0.45 , Alkaline liquid = 0.45*400 = 180 kg/m^3, Na_2SiO_3 / NaOH = 2.5, Then Na_2SiO_3 Solution = 128.5 and NaOH Solution = 51.5 kg [Molarity NaOH = 12]. The water utilized for making NaOH Solution = 0.639 * 51.5 = 32.91 kg, Solid Mass of NaOH flakes = 0.361 * 51.5 = 18.59 kg, Volume of NaOH solids = 18.59 / 2.13 = 8.73 L, The water utilized for making Na_2SiO_3 Solution = 0.559 * 128.5 = 71.83 kg, Solid weight of Na_2SiO_3 = 0.441*128.5 = 56.67, Solid Volume of Na_2SiO_3 = 56.67 / 2.4 = 23.61, Total volume of solids = Volume of fly ash + Volume of NaOH flakes + Solid Volume of Na_2SiO_3, Total volume of solids = 181.81 + 8.73 + 23.61 = 214.15 L, Total volume of water = Volume of water in NaOH + Volume of water in Na_2SiO_3 + Volume of extra water added

Consider volume of extra water added = 30 kg/m3, Total volume of water V_{tw} = 32.91 + 71.83 + 30 = 134.74 kg, Total volume of SolidsV_{gs} = 214.15, D (t) = 0.003* Log (7) = 0.0025

$$MPT^d = 19 * \left(\sqrt[3]{\frac{0.78 *}{0.704}} - 1 \right) = 0.65$$

Substitute in the modified Ferret equation

$$fc(7) = 545.698 * \left[0.0025 + \left(\frac{214.15}{214.15 + 134.74} \right)^{6.089} \right] * 0.65^{-0.145}$$

$fc(7) = 31.2\ MPa$ Compared to Actual strength 33.71 Mpa from (table 1)

The obtained value was valid for the equation above.

4. CONCLUSIONS

The conclusions of the study it can be summarized as follows.

- New model derived from Feret model to predict compressive strength of Geopolymer concrete, Solid material includes, fly ash and alkaline solution, while total water in the binder, water from alkaline solution plus extra water if added in experimental study.
- A regression analysis has been done to new model to find the empirical constant of the best fit equation with a highest coefficient of determination 0.943 and lowest loss function expressed by residual mean squares. Statistical analysis showed that new model is applicable to geopolymer concrete.
- The obtained value from Feret Model was valided the experimantal study.

REFERENCES

1. Arbili, M. M. Ghaffoori, F., Mermerdaş, K., (2016). Statistical analysis of the performance of the soft computing based prediction model for shrinkage of concrete including mineral admixtures. *ZANCO Journal of Pure and Applied Sciences*, 28 (2).
2. Damtoft, J. S., Lukasik, J., Herfort, D., Sorrentino, D. & Gartner, E. M. (2008). “Sustainable development and climate change initiatives.” Cement and Concrete Research, 38, 115-127
3. De Larrard, F. (2014). Concrete mixture proportioning: a scientific approach. CRC Press.
4. Feret, R. (1897). Etude sur la constitution intime des mortiers hydrauliques. Bulletin de la Societe d'Encouragement pour 1'Indutrie Nationale, 96, 1591-1625.
5. Kong, D. L. Y. & Sanjayan, J. G. (2008). “Damage behavior of geopolymer composites exposed to elevated temperatures.” Cement and Concrete Composites, 30, 986-991.

6. Kong, D. L. Y., Sanjayan, J. G. & Sagoe-crentsil, K. (2007). “Comparative performance of geopolymers made with metakaolin and fly ash after exposure to elevated temperatures.” Cement and Concrete Research, 37, 1583-1589.
7. Mermerdaş, K., & Arbili, M. M. (2015). Explicit formulation of drying and autogenous shrinkage of concretes with binary and ternary blends of silica fume and fly ash. Construction and Building Materials, 94, 371-379.
8. Mclellan, B. C., Williams, R. P., Lay, J., Van riessen, A. & Corder, G. D. (2011). “Costs and carbon emissions for geopolymer pastes in comparison to ordinary portland cement.” Journal of Cleaner Production, 19, 1080-1090.
9. Nazari, A. & Riahi, S. (2012). “Experimental investigations and ANFIS prediction of water absorption of geopolymers produced by waste ashes.” Journal of Non-Crystalline Solids, 358, 40-46.
10. Nazari, A., Bagheri, A. & Riahi, S. (2011). “Properties of geopolymer with seeded fly ash and rice husk bark ash.” Materials Science and Engineering A, 528, 7395-7401.
11. Nazari, A., Khanmohammadi, H., Amini, M., Hajiallahyari, H. & Rahimi, A. (2012a). “Production geopolymers by Portland cement: Designing the main parameters’ effects on compressive strength by Taguchi method.” Materials and Design, 41, 43-49.
12. Nazari, A., Riahi, S. & Bagheri, A. (2012b). “Designing water resistant lightweight geopolymers produced from waste materials.” Materials and Design, 35, 296-302.
13. Olivia, M. & Nikraz, H.(2012). “Properties of fly ash geopolymer concrete designed by Taguchi method.” Materials and Design, 36, 191-198.
14. Pan, Z. & Sanjayan, J. G. (2012). “Factors influencing softening temperature and hot-strength of geopolymers.” Cement and Concrete Composites, 34, 261-264.

15. Palmer, P. B., & O'connell, D. G. (2009). Regression analysis for prediction: understanding the process. Cardiopulmonary physical therapy journal, 20(3), 23.
16. Rattanasak, U. & Chindaprasirt, P. (2009). “Influence of NaOH solution on the synthesis of fly ash geopolymer.” Minerals Engineering, 22, 1073-1078.
17. Riahi, S., Nazari, A., Zaarei, D., Khalaj, G., Bohlooli, H. & Kaykha, M. M. (2012). “Compressive strength of ash-based geopolymers at early ages designed by Taguchi method.” Materials and Design, 37, 443-449.
18. Second International Confrance on Sustainable Construction Materials and Technologies. (2010). Geopolymer Concrete with Fly Ash. Lloyd, N. A. & Rangan, B. V.
19. Thaarrini, J. Venkatasubramani, R. Murali, K. Development of a Statistical Model for Strength Prediction of BA-GGBFS-FS Geopolymer Concrete Paver Blocks. *Asian Journal of Research in Social Sciences and Humanities* Vol. 6, No. 6, June 2016, pp. 1514-1526.
20. Van deventer, J. S. J., Provis, J. L. & Duxson, P. (2011) “Technical and commercial progress in the adoption of geopolymer cement.” Minerals Engineering.
21. Wang, S.-D., Pu, X.-C., Scrivener, K. L. & Pratt, P. L. (1995). “Alkali-activated slag cement and concrete: a review of properties and problems.” Advances in Cement Research, 7, 93-102.
22. Xu, H. & Van deventer, J. S. J. (2000). “The geopolymerisation of alumino-silicate minerals.” International Journal of Mineral Processing, 59, 247-266.