

MODELING THE BEHAVIOUR OF CHEMICAL RESISTANT CONCRETE MODIFIED WITH FLY ASH UNDER DIFFERENT PH ENVIRONMENTS

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ABSTRACT

Concrete is the main building unit used in infrastructure and buildings, including dams, swages, and sewage pipes. The main problem in the concrete used in the sewerage pipe or the water treatment system is the erosion when concrete becomes subjected to different pHs. This study's objective is to evaluate and model the effects of various pHs on plain concrete and concrete modified with fly ash. Water to cement ratio and time of curing were taken as independent variables in the experiment. The main dependent variables are the strengths of compression and tensile of the concrete. From the over 900 data collected, the w/c was ranged between 0.3-0.5. The compression strength varied from 0-88.6 MPa and tensile strength ranged from 0.5-5 MPa. Direct correlations between compression strength and w/c, curing time, pH value and fly ash percentage were not found. From the Nonlinear Model (NLM) parameters, fly ash percentage has a positive effect on the concrete resisting the different pH values. However, FA% content should not exceed 25% because it will cause the cement to lose its bonding qualities. FA might reduce the rate of penetration of the chemicals and make the concrete resist the chemicals to penetrate further into the interior of the concrete.

KEYWORDS: Concrete; pH; fly ash; chemical resistant; erosion

1. INTRODUCTION

Concrete has been one of the main components in buildings and constructions for centuries. Concrete's mechanical properties, high compression strength, durability, high stiffness, cost-efficient and easily manufactured and fabricated, make it the perfect medium for constructing (Burhan, 2019, p. 1). Over the years, concrete has seen development in its composition depending on its application and use. Depending on the concrete's strength, weight, thermal capacity or chemical resistance, concrete has different mixes that are designed for use (Li, 2018, p. 23-24). Typically, concrete is a mixture that is heterogeneous of cementation materials, , fine aggregate, gravel, rocks, coarse aggregate, sand, and water in the mixing hydration part or/ and curing part, and admixtures (Sathawanea, 2013, p. 36). Concrete has an isolation property making it durable toward fire, pollution, sunlight, and dust.

Normal concrete is a mix of cement, water, fine and coarse aggregate, and it has an average compressive strength of 25 MPa but can reach 40 or 50 MPa (Qadir, 2019, p. 1). In modern

research, it was found that cement and producing cement is polluting the environment with massive CO² production and pollution that it courses during manufacturing (Oner, 2007, p. 505). Therefore, other cementation materials such as fly ash are substituting the cement not only to reduce the cement usage for less ecological harm but also to improve its properties such as mechanical properties, durability, and hydration (Huang, 2013, p. 71).

The mixing of cement and fly ash will cause a pozzolanic reaction by binding free silica and Ca(OH)² (Aydın, 2007, p. 717). The most utilized waste material of coal combustion products is fly ash due to its benefits. Fly ash has a high aluminous and siliceous content (Kaniraj, 2003, p. 539). Fly ash has a higher percentage of SO⁻² which makes the concrete be hydrated with less water to cement or water to binder ratio (Torii, 1994, p. 362). Many studies show that the controlled adding of FA for substituting cement will increase the compression strength of the concrete (Kumar, 2000, p. 347). Tensile strength increases with the addition of FA to the concrete (Atis, 2004, p. 1117). Also, the most expensive material in concrete production is cement, and FA

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is a waste and recycled material, therefore using FA will reduce the cost. Using fly ash is an environmental benefit as well. The active hydration level will make the concrete early age and improves the workability as well.

Concrete is used in many applications, and it is exposed to a lot of environmental factors, such as high heat, freezing and thawing and aggressive chemicals. The concrete will be weaker and less durable due to these factors, so additives and new mix designs are added to make the concrete resist these harsh environments. Fly ash in concrete has shown that it reduces the voids of the concrete and decreases the external materials such as the wastewater, acids, and harmful materials to penetration into it (Chalee, 2010, p. 1242). Therefore, when there is a chemical attack on the concrete from swages wastewater or chemical wastes, the concrete that contains fly ash theoretically will have less damage than concrete not containing fly ash because the fly ash will modify the chemical composition of the concrete, which will lead the reduction the voids and micro-cracks, increase the bond of the materials, and reduce the disintegration (Li, 2018, p. 24). In this review, data from 33 papers have been reviewed and collected to study the concrete's tensile and compression strength with many percentages of

fly ash and being subjected to many pH values, from neutral 7 to nearly 0 and 14, extreme pH values. The curing time was up to 28 days. Throughout 16 countries various percentages of FA were used to test the true effect of FA on concretes properties.

The study aims to study the compression and tensile strength of concrete with FA from 990 literature data. The first objective is water to cement ratio, fly ash content, curing time, pH exposer, compressive strength, and tensile strength statistical difference. The second is the effects of the independent variables which are: the water to cement ratio, time of curing, FA content, and curing pH on the dependent variables, compressive strength, and tensile strength by utilizing NLM. The final objective is to relate between the compressive strength and tensile strength.

2. MATERIALS & METHODS

2.1 Collection of data

The mechanical behavior, compressive strength, and tensile strength, of concrete with FA cured in different pH values were the main focus of this study. Table 1 displays the plain concrete and modified concrete properties.

Table (1): Literature's concrete properties modified with fly ash

Ref	Country	FA%	W/C	Time of curing, t (days)	Comp strength, σ_c (MPa)	Tens strength, σ_t (MPa)
1	Malaysia	0 - 100	0.4-0.59	28	21-29	-
2	Turkey	0 - 70	0.28-0.34	1, 3, 7, 28	1.76-66.55	1.81-4.2
3	Turkey	0 - 70	0.4	1, 3, 7, 28	4.3-58.5	2.5-4.5
4	Australia	0 - 60	0.35	7, 14, 28	18.07-35.37	-
5	China and Lithuania	0	0.33	7, 28	22.3-48.6	-
6	Hong Kong	0 - 35	0.45-0.55	1, 4, 7, 28	5.9-66.8	0.49-3.43
7	Germany	0 - 25	0.5	28	-	4.1-5
8	Japan	0	0.4-0.58	7, 14, 28	24-62.1	-
9	Iran	0 - 20	0.3675	7, 28	21.6-36.34	2.3-3.35
10	Turkey	0	0.6-1.2	7, 14, 28	9.2-40.4	-
11	India	0	0.45	28	23.53-27.83	2.37-3.43
12	Portugal	0	0.4-0.57	7, 28	29.5-65.4	-
13	India	0 - 30	0.44	7, 14, 28	32.89-45.78	4.1-4.38
14	Australia	0 - 60	0.4075	3, 7, 28	4-27.5	-
15	India	15 - 35	0.41-0.44	7, 28	22.78-35.19	1.55-2.4
16	Australia	18.3	0.35	1, 7, 28	40-62	-
17	India	62 - 67	0.4-0.6	28	31.7-46.02	-
18	Canada	0	0.4	1, 3, 7, 28	20.9-36.4	2.7
19	China and Canada	0	0.5	3, 7, 28	30.91-41.05	2.61-2.68

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20	Taiwan	0 - 80	0.24-0.72	1, 3, 7, 28	1-47.5	-
21	China	0 - 60	0.5	28	35.6-47.5	-
22	China and US	0 - 40	0.31	28	20.1-34.5	-
23	Thailand, Japan	0 - 30	0.45	3, 7, 28	31-59	-
24	India	0-85	0.22-0.79	28	14.64-87	-
25	Turkey	0-70	0.28-0.39	1, 3, 7, 28	0-70.3	1.3-4.59
26	Australia, USA, Germany	0-20	0.45	3, 7, 14, 28	23.51-54.19	-
27	Japan	0-50	0.37-0.56	28	15-41	-
28	India	0-20	0.38	28	35-39	-
29	India	0-50	0.42	7, 28	24.8-51.27	-
30	Thailand	0-50	0.45-0.65	28	16.6-50.4	-
31	India	0-30	0.4	28	18-33	-
32	Australia	0-100	0.3-0.4	28	0-66	-
33	India	0	0.25-0.45	28	34-88.6	-
Remarks	16 countries	Ranged from 0% to 100%	Ranged from 0.22 to 1.2	Ranged from 1 day to 28 days	Ranged from 0 MPa to 88.6 MPa	Ranged from 0.49 MPa to 5 MPa

2.2 Data modeling

2.2.1 Model of Vipulanandan correlation

The Vipulanandan correlation model was used to predict the values of concrete modified with fly ash's mechanical properties. The following relationship was proposed based on the collected data:

$$Y = Y_0 + \frac{X}{A + (BX)} \quad \text{----- (1)}$$

Tensile strength is Y, dependent variable. Model parameters are Y₀, A and B. Compressive strength is X, the independent variables.

2.2.2 Model predictions comparison

Statistical quantification such as coefficient of determination (R²) and the root mean square error (RMSE) were found as follows:

$$R^2 = \left(\frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2} \times \sqrt{\sum_i (y_i - \bar{y})^2}} \right)^2 \quad \text{----- (2)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (y_i - \hat{y}_i)^2}{N}} \quad \text{----- (3)}$$

Experimental values are Y_i, x_i, \bar{y} , \bar{x} , N. Table 2 shows the values of the experimental, model of predicted value, actual test values and calculated values' mean, data amount, respectively.

Table (2): Properties of plain concrete and concrete with FA statistical analysis

Statistical Parameters	W/C	FA%	Comp strength (σ)	Tensile strength (σ _t)	
			(MPa) (until 28 days)	(MPa) (until 28 days)	
Cement Concrete	No. of data	277	-	268	62
	Range	0.22 - 1.2	-	0 - 88.6	1.21 - 5
	Mean (μ)	0.49	-	37.27	2.96
	Std. deviation (σ)	0.15	-	15.63	0.93
	COV (%)	30.59	-	41.94	31.51
Cement Concrete modified with fly ash	No. of data	531	531	528	113
	Range	0.24 - 0.66	10-100	0 - 86.41	0.49 - 4.75
	Mean (μ)	0.42	36.19	30.34	2.37
	Std. deviation (σ)	0.074	20.23	13.25	1.115
	COV (%)	17.56	55.9	43.68	46.99

2.3 Nonlinear model for compressive strength (NLM)

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The evaluations were for the influence of water to cement ratio (w/c), time of curing (t), FA percentage, and pH on concrete's compression and tensile strength:

(i) Concrete (with 0% of FA) and pH = 7 maximum compressive stress

$$\sigma_c = a(w/c)^b(t)^c \text{----- (4)}$$

(ii) Concrete (with 0% of FA) and pH ≠ 7 maximum compressive stress

$$\sigma_c = a(w/c)^b(t)^c + d(w/c)^e(t)^f(pH)^g \text{----- (5)}$$

(iii) Concrete (with 0% < FA ≤ 25%) and pH = 7 maximum compressive stress

$$\sigma_c = a(w/c)^b(t)^c + d(w/c)^e(t)^f(FA)^g \text{----- (6)}$$

(iv) Concrete (with 25% < FA ≤ 50%) and pH = 7 maximum compressive stress

$$\sigma_c = a(w/c)^b(t)^c + d(w/c)^e(t)^f(FA)^g \text{----- (7)}$$

(v) Concrete (with 50% < FA ≤ 100%) and pH = 7 maximum compressive stress

$$\sigma_c = a(w/c)^b(t)^c + d(w/c)^e(t)^f(FA)^g \text{----- (8)}$$

(vi) Concrete (with 0% < FA ≤ 25%) and pH ≠ 7 maximum compressive stress

$$\sigma_c = a(w/c)^b(t)^c + d(w/c)^e(t)^f(FA)^g + h(w/c)^i(t)^j(FA)^k(pH)^l \text{----- (9)}$$

(vii) Concrete (with 25% < FA ≤ 50%) and pH ≠ 7 maximum compressive stress

$$\sigma_c = a(w/c)^b(t)^c + d(w/c)^e(t)^f(FA)^g + h(w/c)^i(t)^j(FA)^k(pH)^l \text{----- (10)}$$

(viii) Concrete (with 50% < FA ≤ 100%) and pH ≠ 7 maximum compressive stress

$$\sigma_c = a(w/c)^b(t)^c + d(w/c)^e(t)^f(FA)^g + h(w/c)^i(t)^j(FA)^k(pH)^l \text{----- (11)}$$

The model parameters are a, b, c, d, e, f, g, h, i, j, k and l that were gotten from numerous lapse analysis with the method of least square from the collected data as shown in Tables 3.

Table (3): Nonlinear Model parameters for compression strength

Dep Variables (Y-axis)	In-dep Variable (X-axis)	a	b	c	d	e	F	g	h	i	j	k	l	RMSE (MPa)	R ²	Data No.	Fig no.
Concrete	Comp strength of concrete (with 0% of FA) and pH = 7	10.99	-0.99	0.22										6.38	0.81	181	Fig 9.
	Comp strength of concrete (with 0% of FA) and pH ≠ 7	10.99	-0.99	0.22	-9.54	-0.08	0.27	-0.79						7.51	0.81	64	Fig 10.
Concrete with FA	Comp strength of concrete (with 0% < FA ≤ 25%) and pH = 7	10.99	-0.99	0.22	0.20	-0.60	0.18	0.20						3.22	0.86	116	Fig 11.
	Comp strength of concrete (with 25% < FA ≤ 50%) and pH = 7	10.99	-0.99	0.22	-15.96	-0.89	0.18	-0.38						5.33	0.80	91	Fig 12.
	Comp strength of concrete (with 50% < FA ≤ 100%) and pH = 7	10.99	-0.99	0.22	-1.01	-1.35	0.11	0.41						4.38	0.81	62	Fig 13.
	Comp strength of concrete (with 0% < FA ≤ 25%) and pH ≠ 7	10.99	-0.99	0.22	0.20	-0.60	0.18	0.20	-2.00	-0.29	1.77	-1.18	-0.33	3.84	0.82	23	Fig 14.
	Comp strength of concrete (with 25% < FA ≤ 50%) and pH ≠ 7	10.99	-0.99	0.22	-15.96	-0.89	0.18	-0.38	-0.02	-2.08	0.67	0.69	-0.49	1.69	0.83	25	Fig 15.
	Comp strength of concrete (with 50% < FA ≤ 100%) and pH ≠ 7	10.99	-0.99	0.22	-1.01	-1.35	0.11	0.41	-14.4	-26.18	1.85	-8.26	-2.95	2.83	0.86	14	Fig 16.

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3. RESULTS, DISCUSSION AND ANALYSES

3.1 The analysis of the statistics

3.1.1 Water to cement ratio, (w/c)

From the literature, 277 data of w/c were of plain concrete, which had the w/c ranged between 0.22 and 1.2, a mean of 0.49, coefficient of variation (COV) of 30.59% and the standard deviation of 0.15 as shown in Table 2. The w/c

data ranging between 0.3 and 0.5 compiled 70% of total data. Based on the 531 water to cement ratio data shown in Table 2, the water to cement ratio had a mean of 0.42, SD of 0.074, COV of 17.56% and ranged from 0.24 to 0.66. Also, as shown in Figure 1, more than 70% of overall water to cement ratio of concrete with FA was between 0.3 and 0.5.

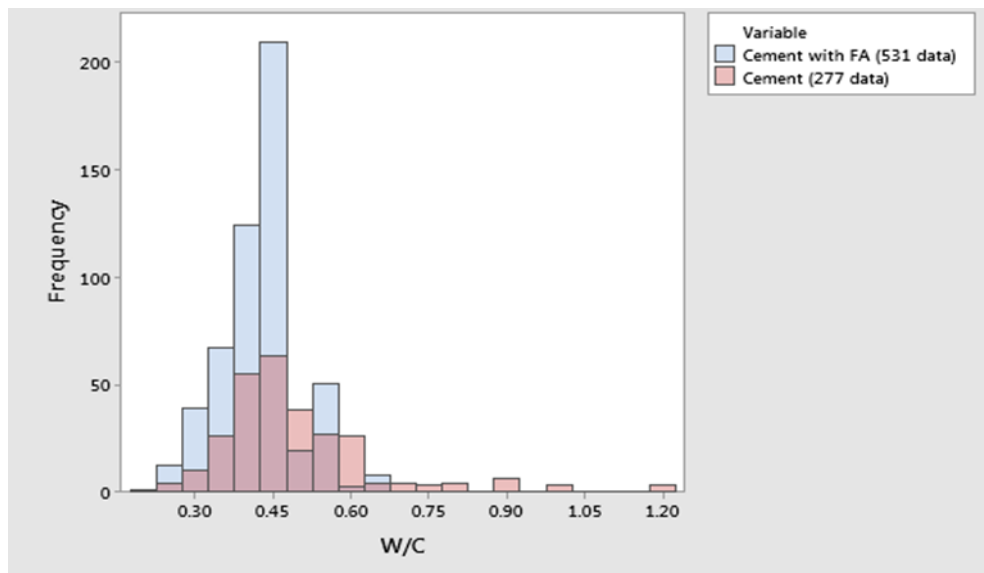
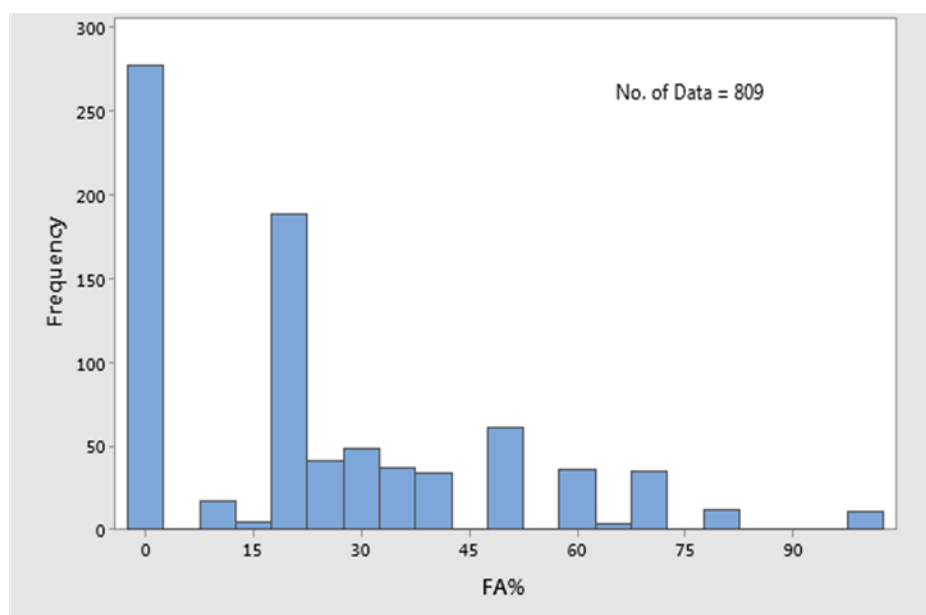


Fig. (1): Histogram of Frequency of W/C corresponding to cement and cement with FA

3.1.2 Fly Ash (FA%)

According to the overall 531 data of FA percentages that were used to modify concrete, FA percentages were changing from 10% to 100%, the mean 36.19%, COV of 55.9%, and SD

of 20.23% demonstrated in Table 2. 58% of the FA ranged from 15%-30%. Moreover, only 30% of the total FA percentage data was above 50% FA content shown in Figure 2.



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Fig. (2): Histogram of FA percentages

3.2 Mechanical properties

3.2.1 Maximum compressive stress (σ_c)

3.2.1.1 Concrete with 0% FA

From 268 data concrete's compressive strengths gathered from the literature, shown in Table 1, σ_c ranged between 0 and 88.6 MPa,

37.27 MPa mean value, SD of 15.63 MPa and COV of 41.94%, summarized in Table 2. The histogram shows 55% of the compressive strength ranged from 20-45 MPa. 25% of the data was more than 50 MPa, and 20% of the data was fewer than 20 MPa, shown in Figure 3.

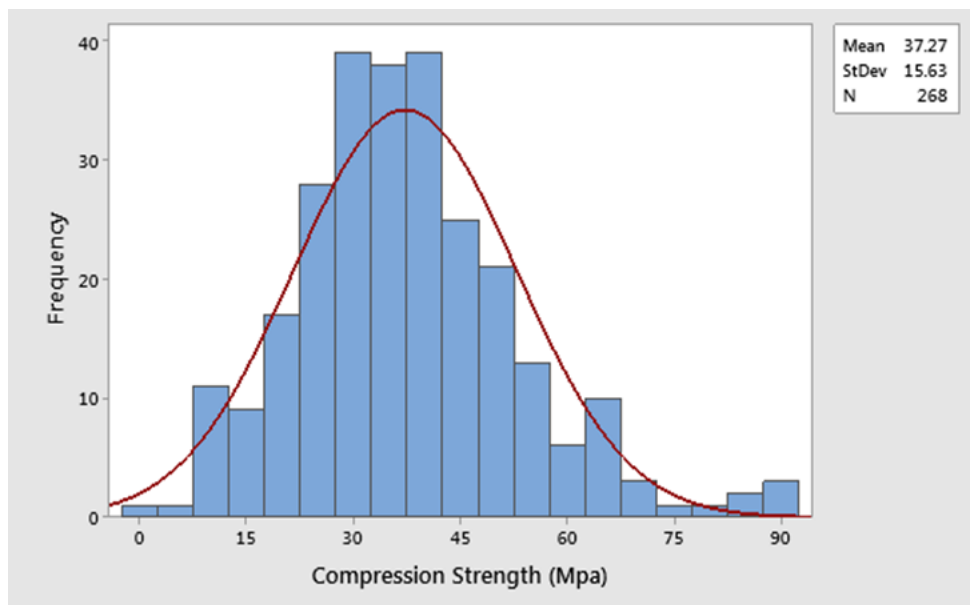


Fig. (3): Histogram of Compression Strength without FA

3.2.1.2 Concrete with FA

Referring to 528 data of concrete with FA's ultimate compressive stress collected, Table 2, σ_c varied between 0 and 86.41 MPa 30.34 MPa mean value, SD of 13.25 MPa and 43.68% COV. The histogram of σ_c for concrete with fly ash

cured for up to 28 days, 56% of the data ranged between 20- 45 MPa. 30% of the data had a value higher than 50 MPa, and 14% of the data had a value of less than 20 MPa, demonstrated in Figure 4.

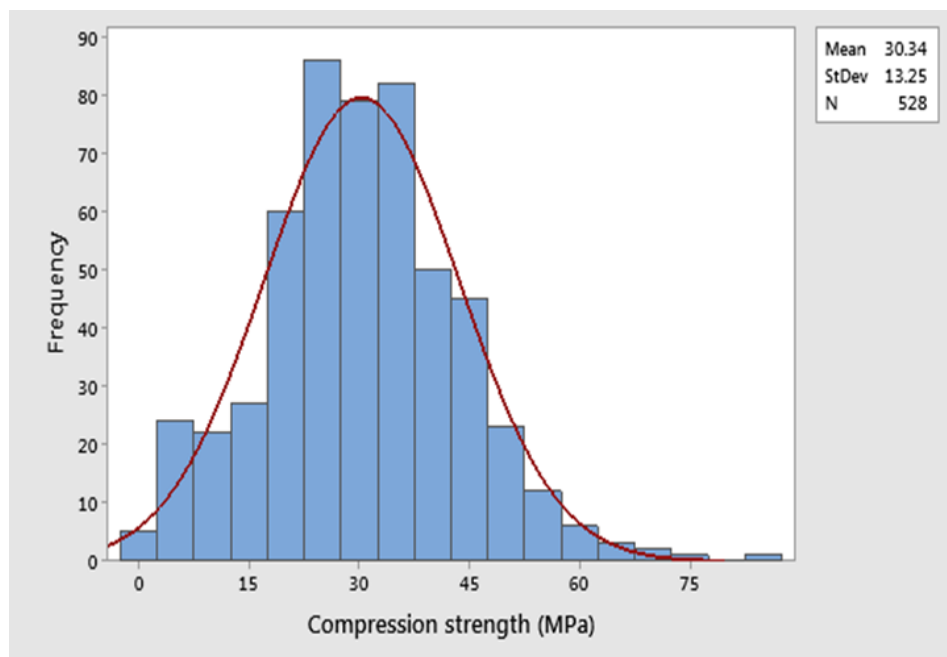


Fig. (4): Histogram of Compression Strength with FA

3.2.2 Tensile strength (σ)

3.2.2.1 Concrete (with 0% FA)

62 tensile strengths data of plain concrete were gathered in Table 1. The tensile strength varied from 1.21 to 5 MPa with 2.96 MPa mean value, COV of 31.51%, and 0.93 MPa SD value, as in Table 2.

3.2.2.2 Concrete modified with FA

113 tensile strengths data of concrete with FA were composed of the literature, Table 2. The tensile strength of concrete with fly ash varied between 0.49- 4.75 MPa, 2.37 MPa mean, SD of 1.115MPa and 46.99% COV, displayed in Table 2.

3.3 Property correlations

3.3.1 Compressive strength' relationship with water to cement ratio, curing time, pH level and FA% of concrete

793 data of concrete's optimum compression stress that was cured up to 28 days was gathered from literature and relationships' properties were examined between the compressive strength, FA content, pH value and water to cement ratio. Poor or non-existing relationships were detected between compressive strength and FA%, pH and water to cement ration that was cured up to 28 days, presented in Fig.5, 6, 7, 8.

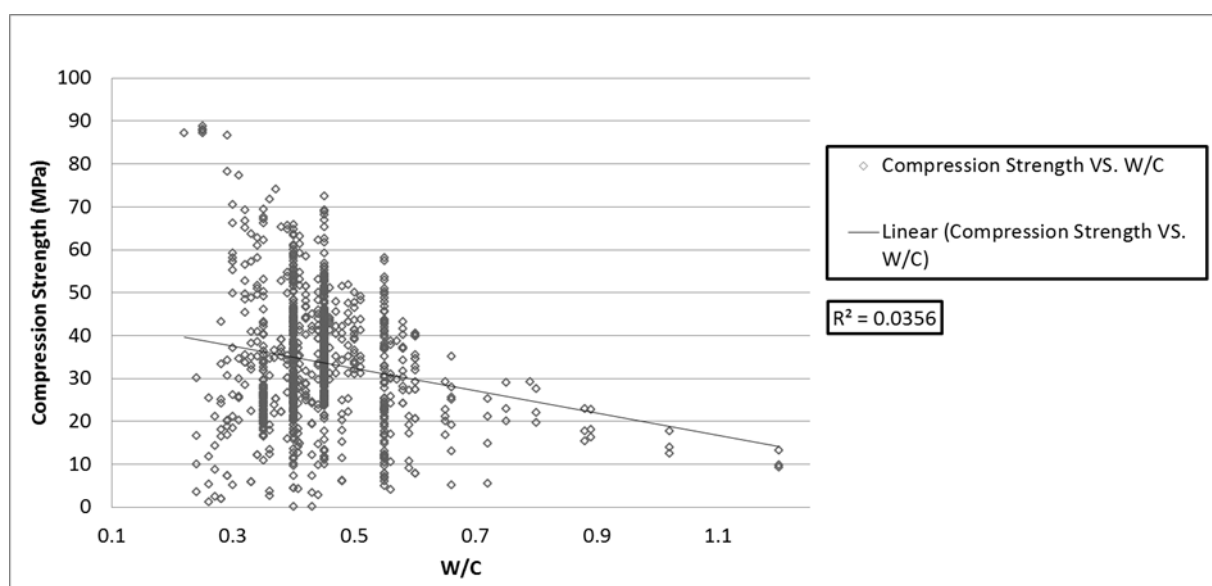


Fig. (5): Compression Strength vs. W/C

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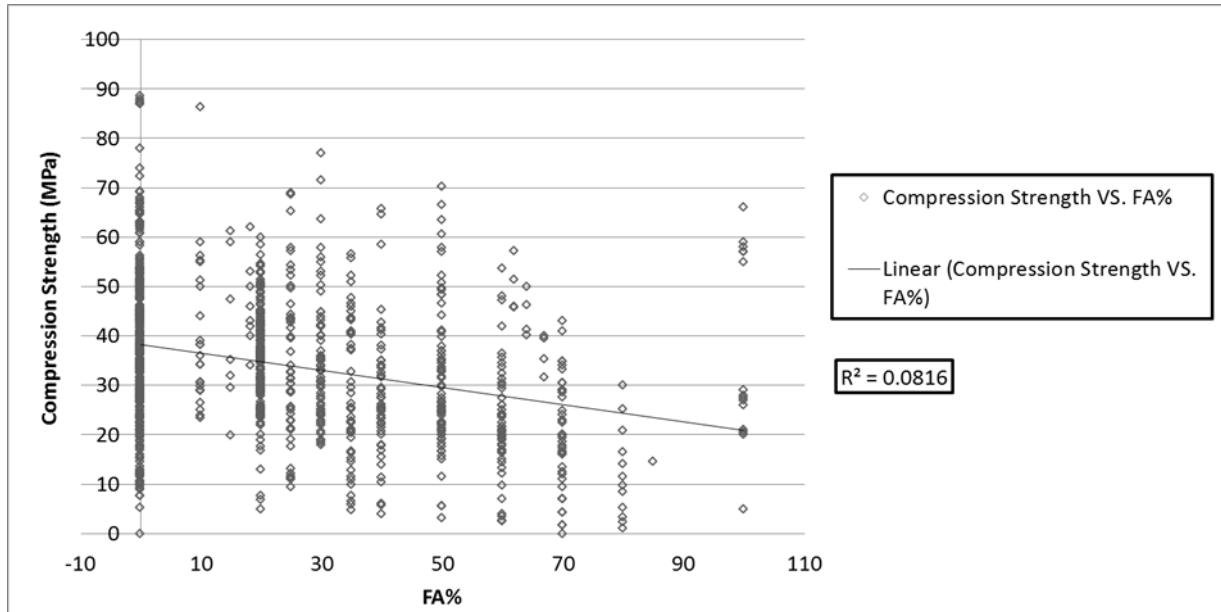


Fig. (6): Compression Strength vs. FA%

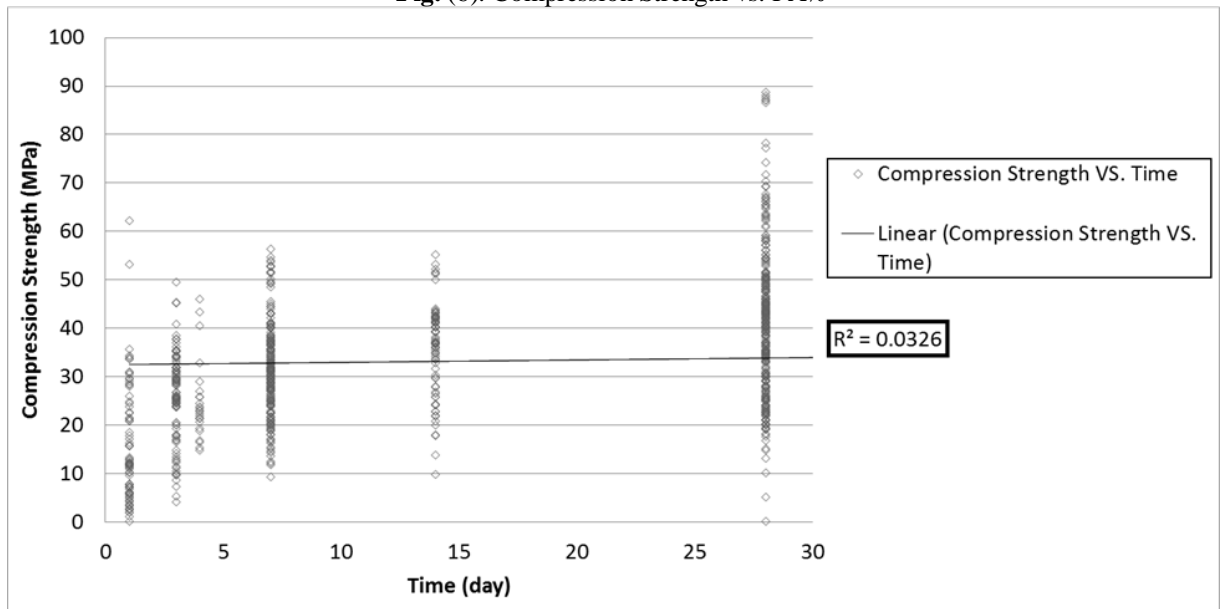


Fig. (7): Compression Strength vs. Curing time

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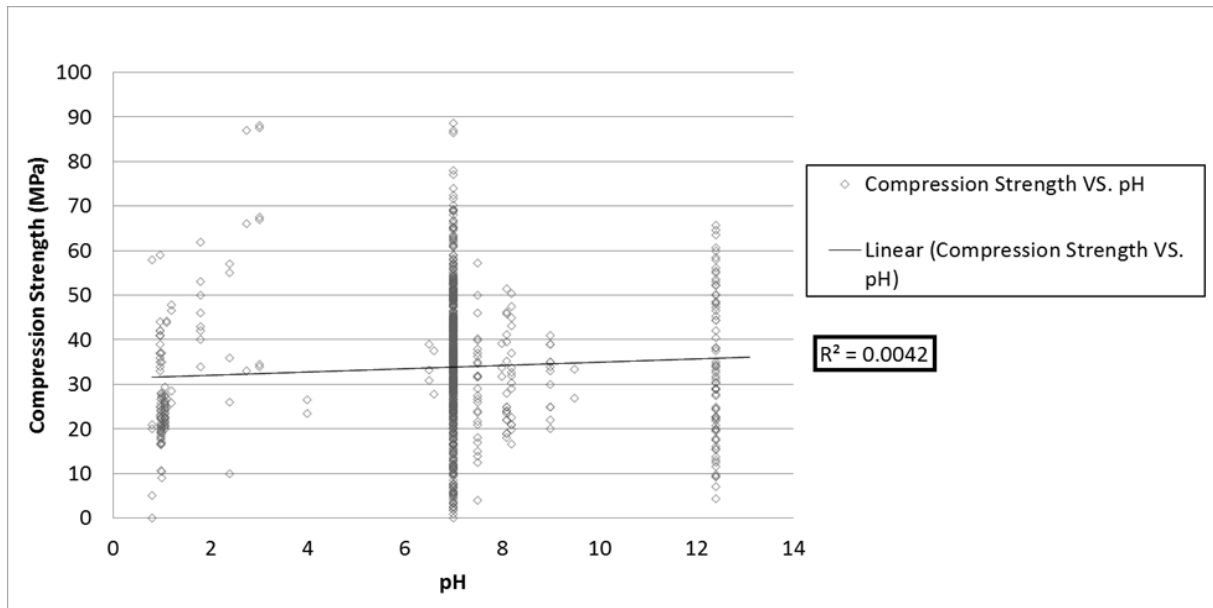


Fig. (8): Compression Strength vs. pH

3.3.2 Measured compressive strength and predicted compressive strength relationship

Because no relative correlation between the compressive strength, curing time, pH, FA%, and water to cement ratio was detected, the max compressive stress was related to pH value, FA%, water to cement ratio and curing period as independent variables via a nonlinear correlation. The parameters of the relationships were gained

with the least square method that uses multiple regression analyses.

The main observation was that the w/c ratio has the highest effect on compression strength. Table 3 summarizes the R², parameters, RMSE and the amount of data. measured and calculated compressive strength had decent relations, shown in Figures 9, 10, 11, 12, 13, 14, 15, 16.

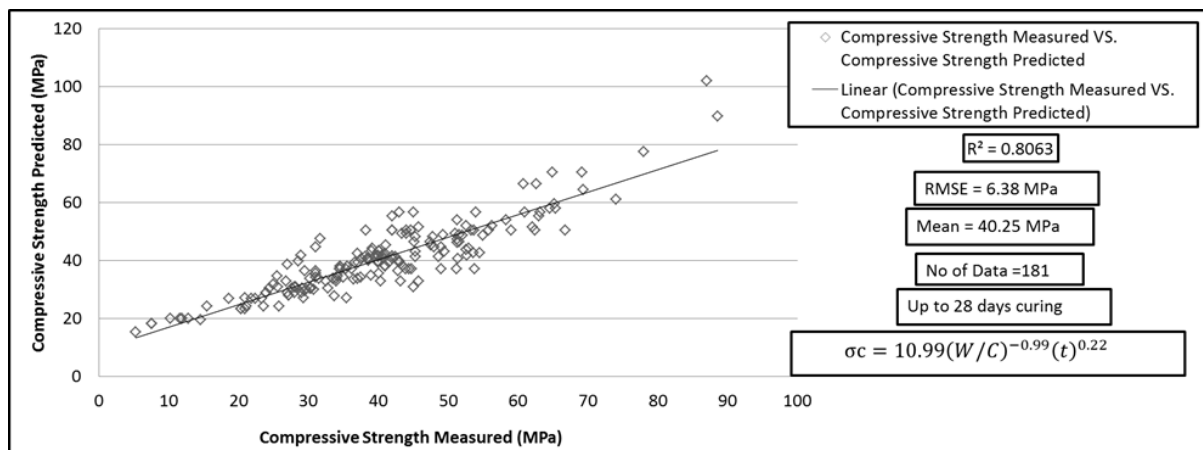


Fig. (9): Concrete (with 0% of FA) and pH = 7 maximum compressive stress

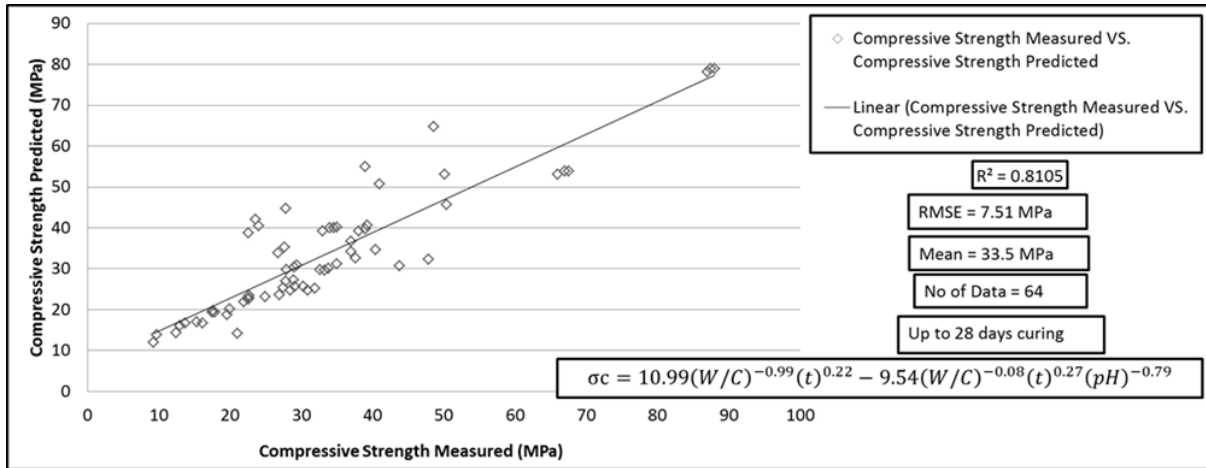


Fig. (10): Concrete (with 0% of FA) and pH ≠ 7 maximum compressive stress

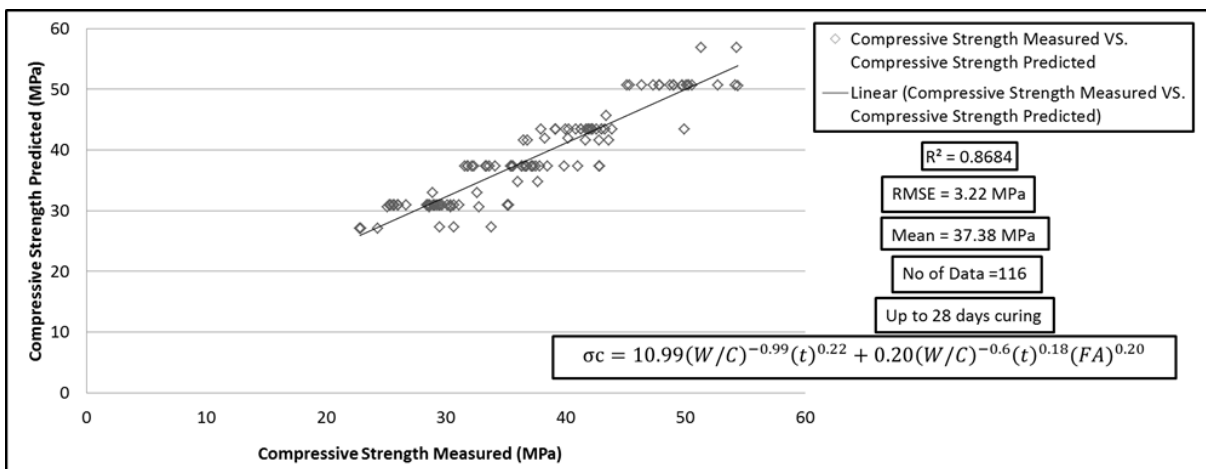


Fig. (11): Concrete (with 0% < FA ≤ 25%) and pH = 7 maximum compressive stress

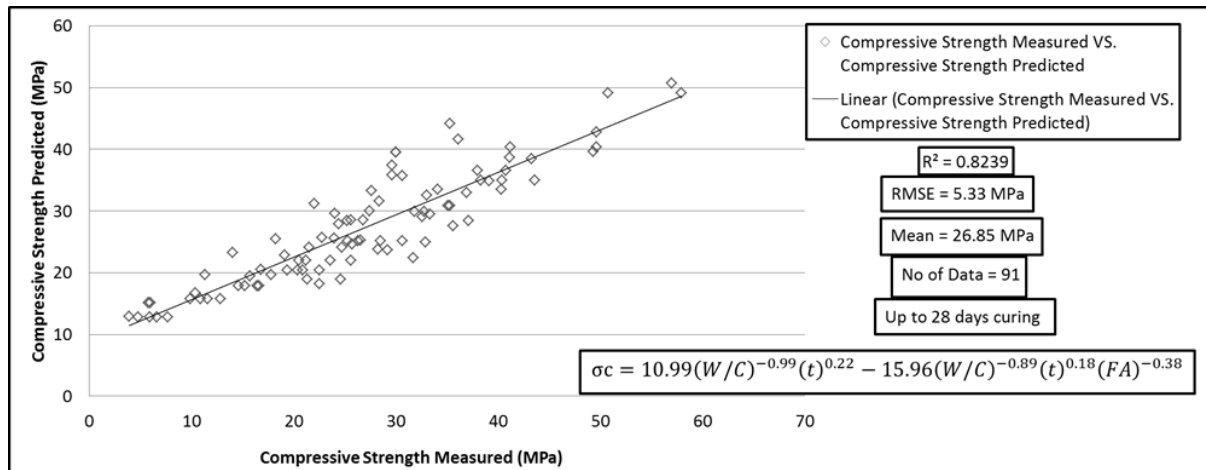


Fig. (12): Concrete (with 25% < FA ≤ 50%) and pH = 7 maximum compressive stress

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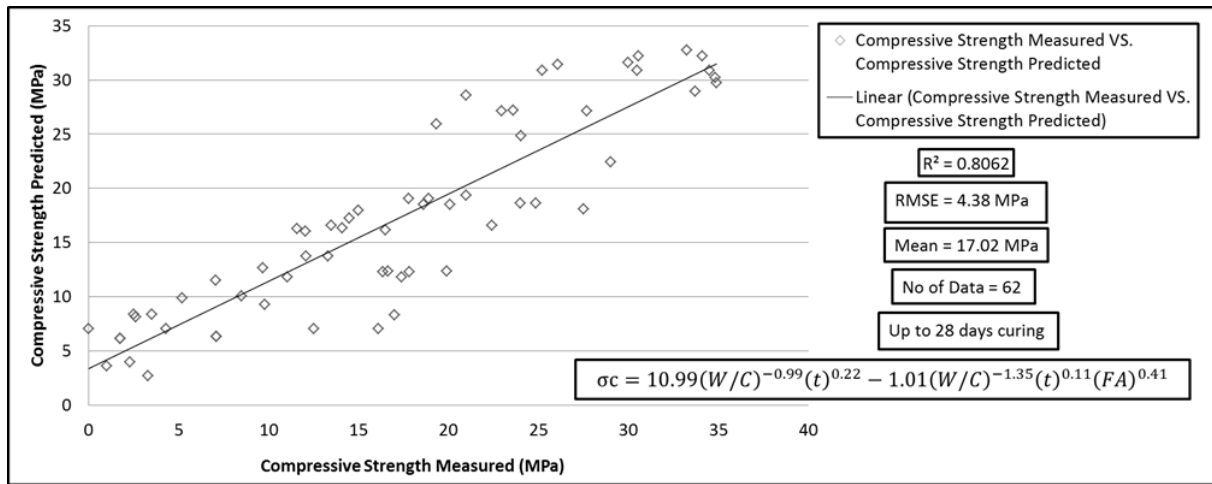


Fig. (13): Concrete (with 50% < FA ≤ 100%) and pH = 7 maximum compressive stress

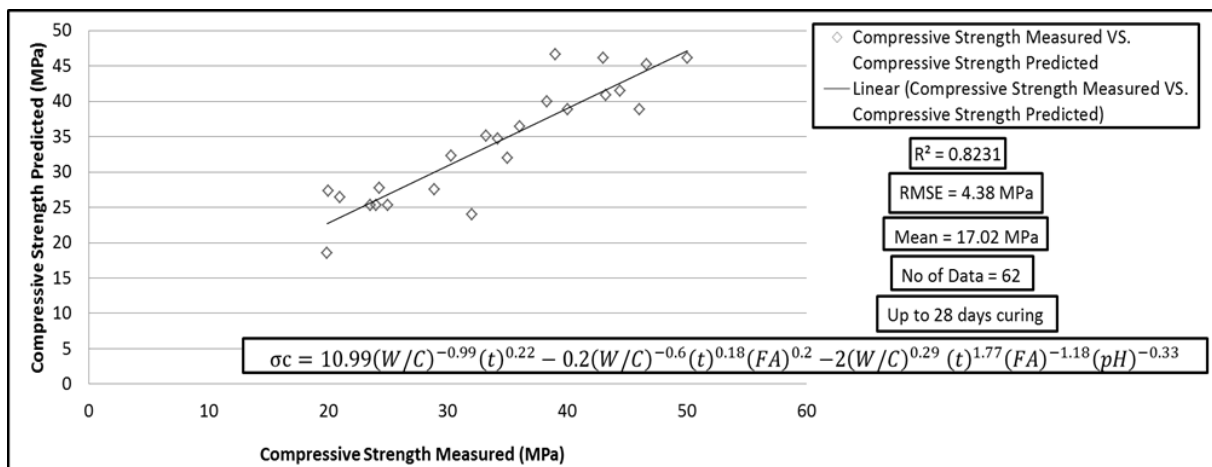


Fig. (14): Concrete (with 0% < FA ≤ 25%) and pH ≠ 7 maximum compressive stress

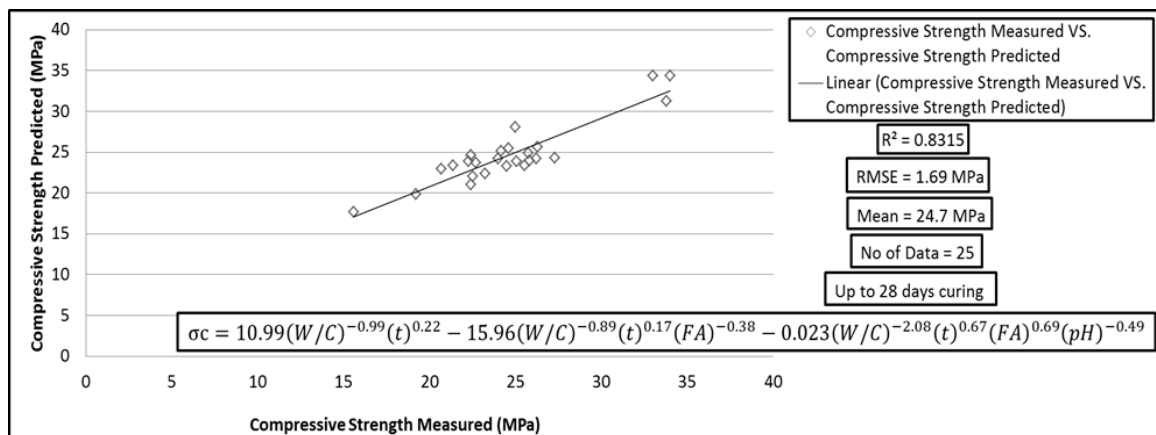


Fig. (15): Concrete (with 25% < FA ≤ 50%) and pH ≠ 7 maximum compressive stress

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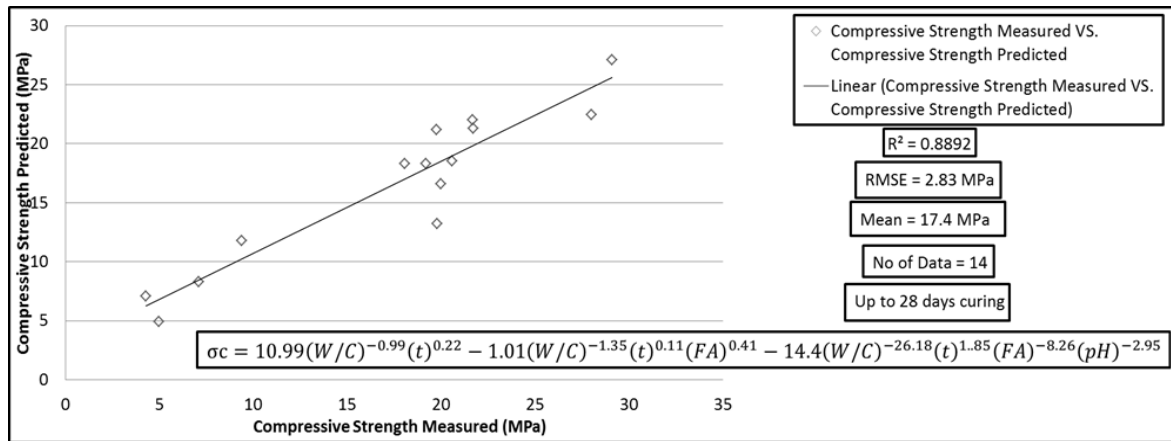


Fig. (16): Concrete (with 50% < FA ≤ 100%) and pH ≠ 7 maximum compressive stress

3.3.3 Compressive strength and tensile strength correlation

The model of the Vipulanandan correlation was utilized for relating between tensile and compression strength, Figure 17. The model showed a great relation between tensile measured

and predicted as long as with compression vs tensile graph, making R² be 0.99, Fig.18. Using the value of compressive strength, the tensile can be calculated with the equation below.

$$\sigma_t = 0.083 + \frac{\sigma_c}{10.59 + (0.095 * \sigma_c)} \quad (12)$$

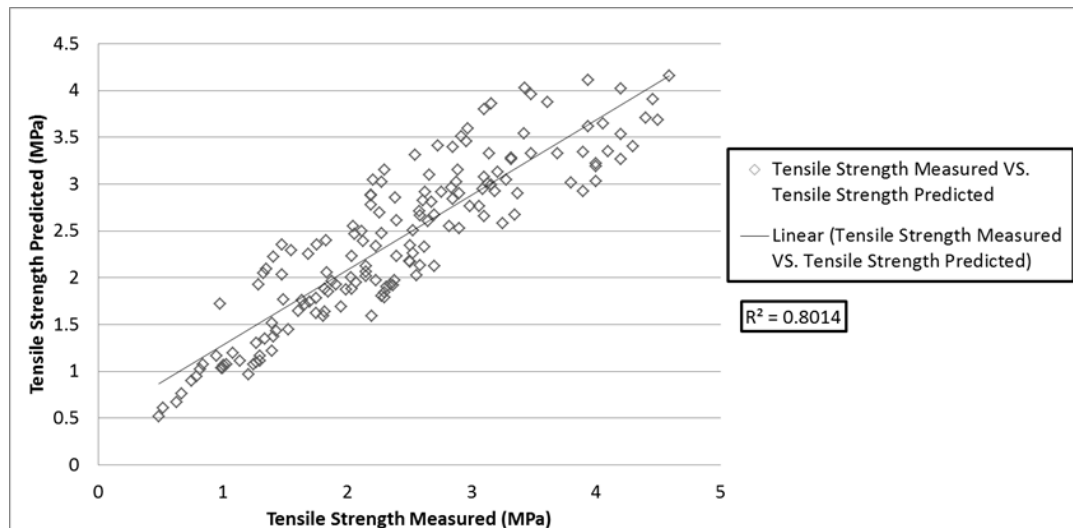


Fig. (17): Tensile strength measured vs. predicted

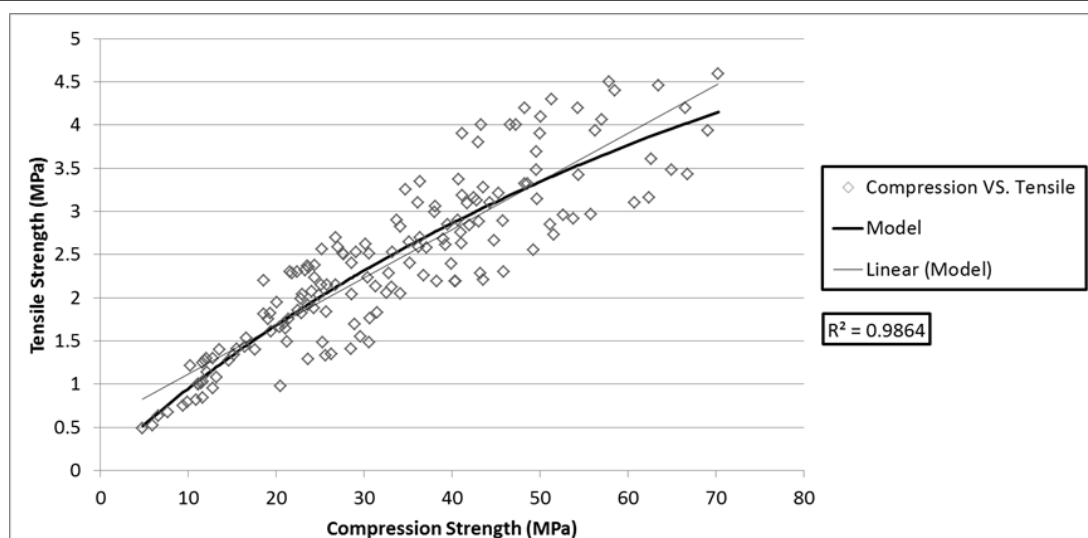


Fig. (18): Compression strength vs. Tensile strength and tensile model

3. CONCLUSION

This study's purpose was to know how different pHs of curing liquid will affect concrete, also to see if adding FA will make the concrete more durable and resistive to these pH harsh environments. The water to cement or binder ratio and curing time are major parameters in any concrete application to understand the full picture of what this concrete is supposed to do and what are the expectations. From many references, literature was collected to develop relationships, models, and formulas. The main conclusions were; correlations were not found between compressive strength water to cement ratio, curing time, pH and Fly ash percentage, more does not mean more when it comes to FA% in concrete because it will lead the concrete to lose its bonding properties, lower FA% had better performance; the higher fly ash percentage weakened the concrete. The best W/C ratio is 0.35-0.45. The Nonlinear model parameters show that water to cement ratio has the most effect on concrete's strength, then curing time than any FA% in small quantities. Overall, according to the parameters and the data observation, FA has a role in making concrete have better resistance to high and low pHs.

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