CHAPTER SIX

RESULTS AND DISCUSSION

6.1 Introduction

This chapter includes;

(1) The performance evaluation and analysis of the developed ANN.

(2) The parametric study based on the developed ANN model.

6.2 Performance of ANN Model:

The performance of the trained and tested neural networks was monitored during the training and testing process for the present model.

6.2.1 Training of the ANN Model

The ANN model was trained using 164 different high strength concrete mix design data HSC (see appendix B). The performance of the trained neural networks was monitored during the training process, the sum of mean squared error (MSE) over all the training data which was 10.67 for the present model.

The predicted compressive strength obtained from the trained ANN model was compared with the experimental compressive strength by plotting the data in Figure (6.1). It is obvious that the predicted and experimental compressive strengths were strongly correlated with a linear relationship. The training data are much closer to the experimental data with the coefficient of determination of 0.9592; therefore, the training process seems very accurate. It has also been found

That the percentage relative error of the training process ranges from (-18.16% to 22.87%) (calculated based on the predicted and experimental compressive strength values) which shows the higher degree of accuracy of the network pattern.

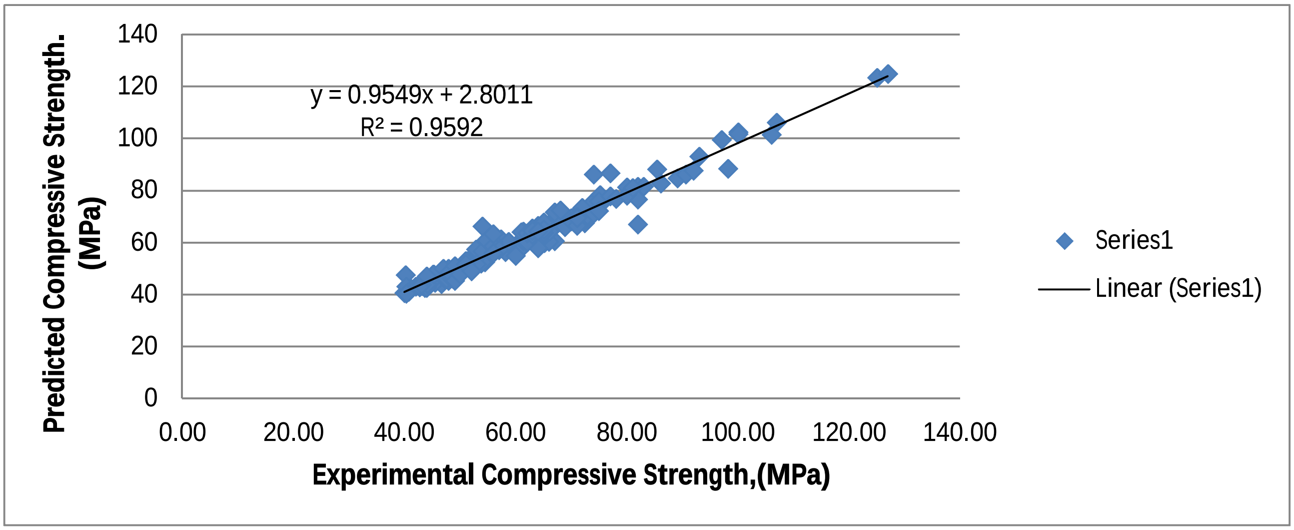

Figure (6.1): Correlation Between (f_{cu}) experimental. With (f_{cu}) predicted. Results of ANN Model for Training Set.

6.2.2 Testing of the ANN Model

After the training process, the ANN model was tested for validation using another set of data 29 different high strength concrete mix design data HSC Table (6.1). The experimental data used for the testing process were not the same one used in the training process. The mix proportioning and strength data used in the testing or validation process are presented in Table (6.1). The experimental compressive strength data and the predicted compressive strength values obtained from the ANN model during the testing process are presented as well in Table (6.1).

The predicted compressive strength obtained from the tested ANN model was compared with the experimental compressive strength by plotting the data in Figure (6.2). It is obvious that the predicted and experimental compressive strengths were strongly correlated with a linear relationship. The testing data are much closer to the experimental data with the coefficient of determination of 0.9102; therefore, the testing process seems very accurate.

In the testing phase, the relative error was calculated to determine the accuracy of the validation process. The values of the relative errors are given in Table (6.1). It is evident that the relative error in the testing process ranged from (-20.22% to 14.87%). The relative error indicates that the error was significantly low.

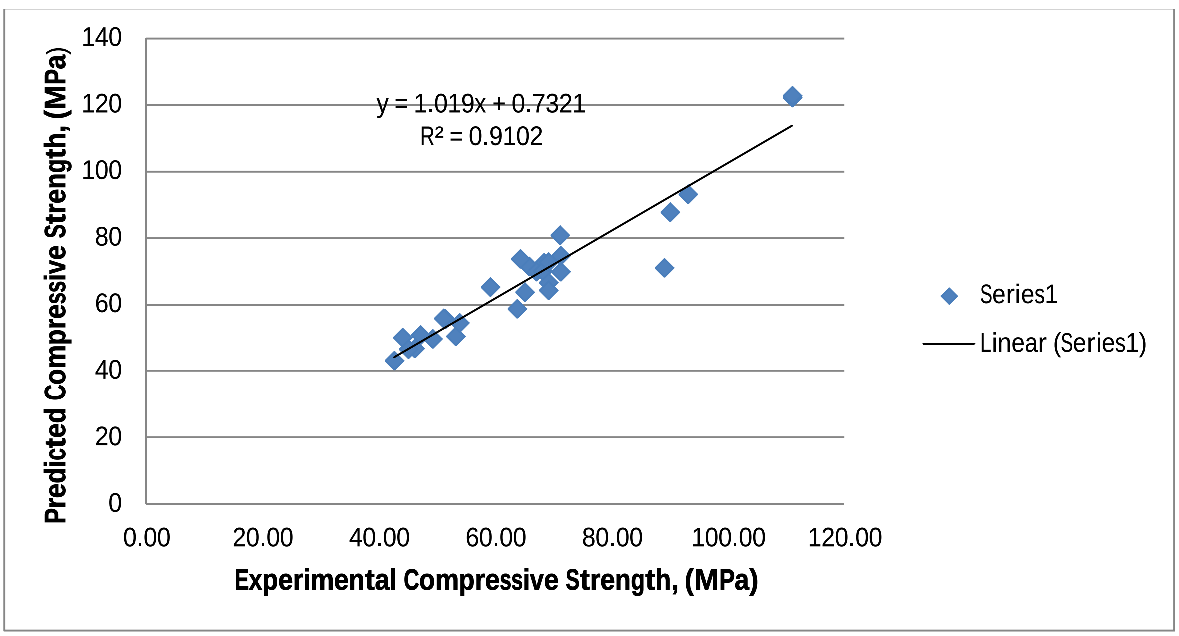

Figure (6.2): Correlation Between (f_{cu}) experimental. With (f_{cu}) predicted. Results of ANN Model for Testing Set.

Table (6.1) Statistics of Error Analysis for Testing Set.

S/N	Main Components + Additives							Compressive Strength MPa		Error	
	Cement Kg/m^3	Silica fume Kg/m^3	Fly ash Kg/m^3	Water Kg/m^3	Course Aggregate Kg/m^3	Sand Kg/m^3	Super plasticizer Liter/m^3	Experimental Result	Predicted Results	Square Error	Relative Error %
1	543.31	28.58	0.00	173.86	1171.80	599.81	8.83	63.70	58.69	25.12	(7.87)
2	475.00	0.00	0.00	209.00	1168.50	565.25	0.00	53.10	50.45	7.02	(4.99)
3	425.00	0.00	0.00	178.50	1049.75	416.50	0.00	51.30	55.63	18.79	8.45
4	425.00	0.00	0.00	191.25	1139.00	463.25	0.00	49.10	49.71	0.37	1.24
5	450.00	0.00	0.00	189.00	1102.50	441.00	0.00	53.70	54.57	0.75	1.62
6	436.00	76.65	0.00	143.88	1044.00	773.00	5.11	71.11	69.88	1.52	(1.74)
7	505.00	0.00	60.00	196.95	1030.00	630.00	0.00	65.00	63.80	1.44	(1.85)
8	467.00	46.70	0.00	182.13	1235.00	577.00	0.00	65.77	71.38	31.52	8.54
9	467.00	58.38	0.00	182.13	1235.00	563.00	0.00	64.24	73.79	91.24	14.87
10	424.00	53.00	53.00	148.40	1040.00	767.00	2.20	68.30	72.63	18.78	6.35
11	397.00	80.00	53.00	150.86	1040.00	767.00	2.20	71.10	74.65	12.58	4.99
12	382.50	0.00	67.50	191.25	937.00	375.00	0.00	46.10	46.82	0.52	1.57
13	382.50	0.00	67.50	198.90	899.00	436.00	0.00	42.50	43.25	0.56	1.76
14	550.00	60.00	0.00	152.00	1120.00	620.00	19.00	89.00	71.00	323.84	(20.22)
15	500.00	30.00	0.00	135.00	1100.00	700.00	19.00	90.00	87.73	5.15	(2.52)
16	500.00	30.00	0.00	135.00	1100.00	700.00	14.00	93.00	93.13	0.016	0.14
17	500.00	0.00	0.00	200.00	1124.00	613.00	3.00	44.00	50.18	38.24	14.05
18	336.00	0.00	0.00	181.46	986.00	817.00	3.00	45.00	46.72	2.96	3.82
19	337.00	0.00	118.00	198.57	1023.00	753.00	10.00	47.00	50.88	15.05	8.26
20	297.00	0.00	121.00	171.72	1054.00	778.00	10.00	51.00	55.95	24.46	9.70
21	436.00	59.00	0.00	151.70	1044.00	773.00	5.00	67.00	69.91	8.46	4.34
22	530.00	80.00	53.00	150.00	1040.00	767.00	19.00	68.00	70.01	4.05	2.96
23	530.00	53.00	0.00	150.00	1040.00	767.00	19.00	69.00	66.56	5.94	-3.53

24	530.00	37.00	51.00	158.48	1037.00	775.00	18.00	69.00	64.37	21.42	(6.71)
25	505.00	76.00	53.00	142.92	1040.00	767.00	19.00	69.00	72.87	14.96	5.61
26	530.00	106.00	0.00	179.60	1037.00	594.00	3.00	71.00	80.85	97.08	13.88
27	481.00	31.00	0.00	164.05	1044.00	662.00	10.00	59.00	65.24	38.92	10.57
28	520.00	0.00	0.00	126.69	1120.00	620.00	18.00	111.00	122.14	124.19	10.04
29	550.00	60.00	0.00	122.00	1120.00	620.00	19.00	111.00	122.81	139.56	10.64
								∑ Mean Square Error		37.05	

Max Square Error	**323.84**	**Max Error %**	**14.87**
Min Square Error	**0.02**	**Min Error %**	**-20.22**
Arith. Mean	**37.05**	**Arith. Mean**	**3.24**
St. Dev.	**66.79**	**St. Dev.**	**7.68**

6.3 Parametrical Analysis Based on the ANN Results

Once an ANN is trained, the knowledge learned can be expressed in terms of the relations between the variables and the output. It can then be assessed and rigorously investigated. Well-established relations can be used to verify and validate the ANN during development and the ANN can then be used to shed light on variables of lesser influence. Assessing the knowledge learned by ANNs in this way can help in changing the black box image of ANNs.

The trained neural network model was utilized to carry out a parametric study to evaluate the effect of all influencing parameters (input parameters) on the compressive strength of High Strength Concrete. The parametric studies were performed by varying one input parameter and all remaining input parameters are set to constant values.

The ANN is used to study the impact of factors influencing compressive strength such as; cement, water/cement ratio, silica fume, super plasticizer, fly ash percentage and silica fume percentage.

6.3.1 Influence of Cement Content on the Compressive Strength

Figure (6.3) presents predicted compressive strength versus cement content for mixes with constant material proportions as shown in table (6.2). Cement and water contents were changed and their effect was detected. It seems clear that when the cement content increases the compressive strength increases as well, because when the cement content increases, w/c ratio will decrease, then the compressive strength will increase. When the water content changed from 135 to 150 kg/m^3 the compressive strength decreased, because w/c ratio increased. It was also observed that while the water content changed from 150 to 170 kg/m^3, the strength got dropped. This is completely compatible with what mentioned in chapter two, see figure (2.1).

Table (6.2): Mix Proportions for Predicted Compressive Strength versus Cement Content (1 m^3).

Silica Fume K/m^3	Fly Ash Kg/m^3	Coarse Aggregate Kg/m^3	Sand Kg/m^3	Super Plasticizer Liter/m^3
0.00	0.00	1200.00	600.00	0.00

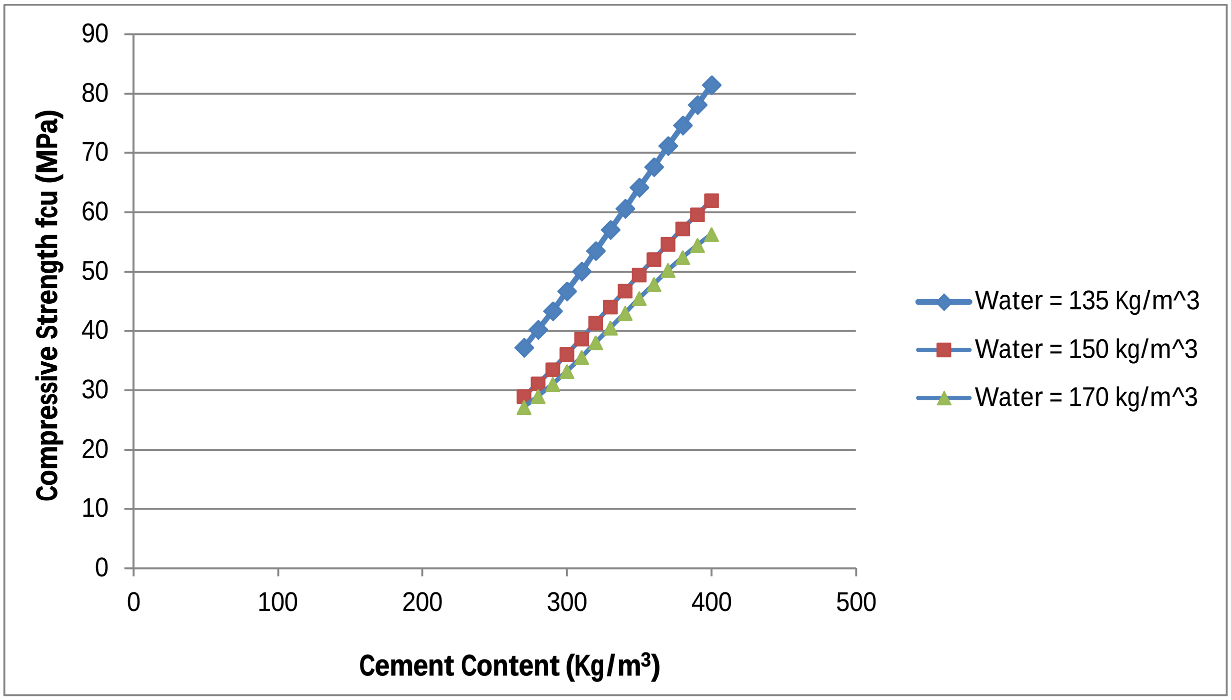

Figure (6.3): Influence of Cement Content on the Compressive Strength of High Strength Concrete.

6.3.2 Influence of Water/cement Ratio on the Compressive Strength

Figure (6.4) presents predicted compressive strength versus water/ cement ratio for mixes with constant material proportions as shown in table (6.3). Cement content and water/cement ratio were changed and their effect was detected. It seems clear that when the water/cement ratio increases the compressive strength decreases. While the cement content changed from 400 to 350 kg/m^3, the compressive strength decreased, because w/c ratio increased. It was also observed that while the cement content changed from 350 to 300 kg/m^3 the compressive strength decreased as well. This is completely compatible with which mentioned in chapter two, see figure (2.1).

Table (6.3): Mix Proportions for Predicted Compressive Strength versus Water/cement Ratio (1 m^3).

Silica Fume kg/m^3	Fly Ash kg/m^3	Coarse Aggregate kg/m^3	Sand kg/m^3	Super Plasticizer $Liter/m^3$
0.00	0.00	1200.00	600.00	0.00

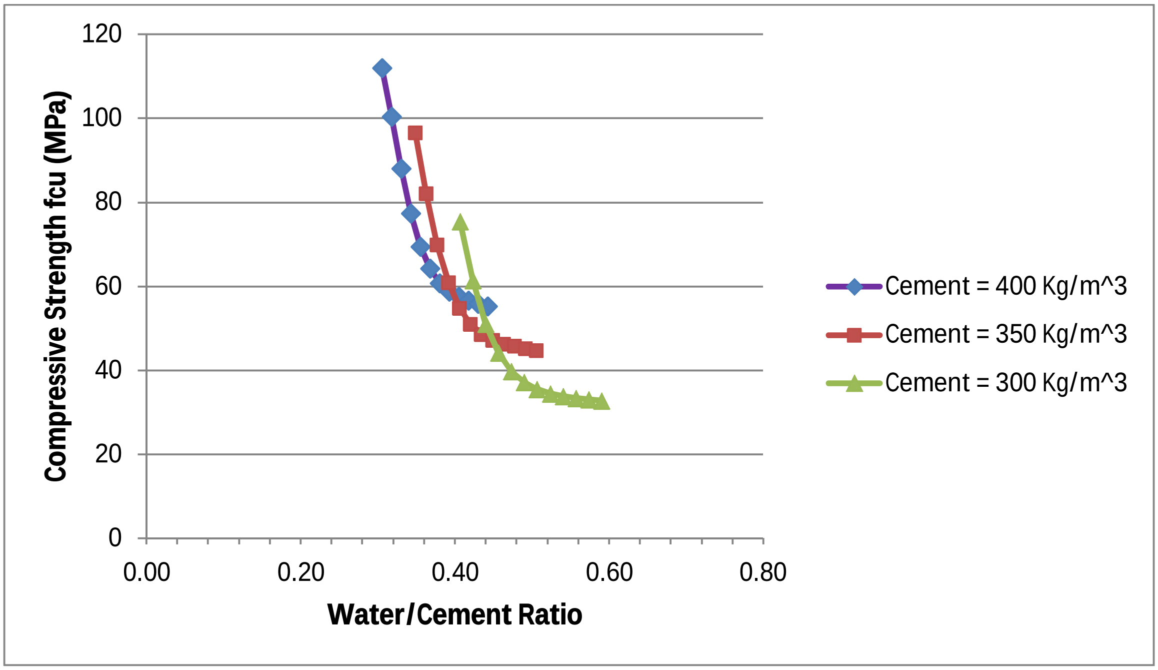

Figure (6.4) Influence of Water/Cement ratio on the Compressive Strength of High Strength Concrete.

6.3.3 Influence of Silica Fume Content on the Compressive Strength

Figure (6.5) presents predicted compressive strength versus silica fume content for mixes with constant material proportions as shown in table (6.4). Cement and silica fume were changed and their effect was detected. It was observed that compressive strength increased with increase of silica fume content, this is logical; because of the high pozzolanic nature of the silica fume and its void filling ability

(Amudhavalli and Mathew, 2012). It was observed that the strength at cement content 400 kg/m^3 is greater than strength at cement content 350 kg/m^3, and the strength at cement content 350 kg/m^3 is greater than the strength at 300 kg/m^3 of cement.

Table (6.4): Mix Proportions for Predicted Compressive Strength versus Silica Fume Content (1m^3)

Water Kg/m^3	Fly Ash Kg/m^3	Coarse Aggregate Kg/m^3	Sand Kg/m^3	Super Plasticizer Liter/m^3
150.00	0.00	1200.00	600.00	0.00

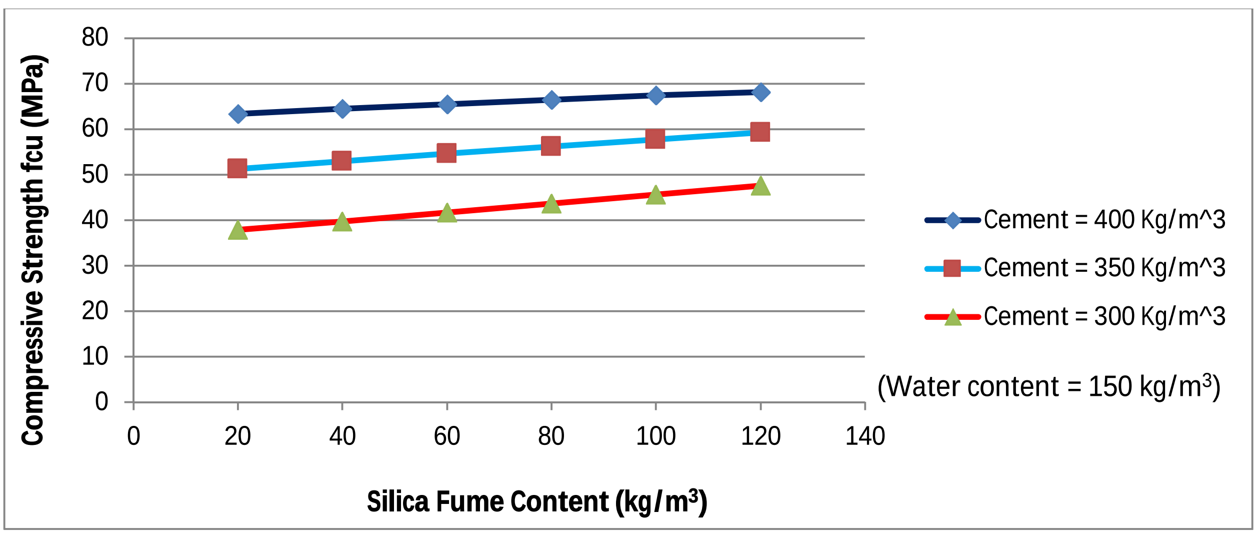

Figure (6.5): Influence of Silica fume Content on the Compressive Strength of High Strength Concrete.

6.3.4 Influence of Super plasticizer Content on the Compressive Strength

Figure (6.6) presents predicted compressive strength versus Super plasticizer content for mixes with constant material proportions as shown in table (6.5). Water and super plasticizer contents were changed and their effect was detected. The super plasticizer influences the strength indirectly, to achieve a higher strength by decreasing the water/cement ratio at the same workability (Neville, 2002) , it was observed that the strength at water content 135 kg/m^3 ,w/c ratio 0.34 is greater than strength at water content 150 kg/m^3 ,w/c ratio = 0.38, and the strength at water content150 kg/m^3,w/c ratio =0.38 is greater than the strength at water content 170 kg/m^3,w/c ratio = 0.42, when w/c ratio increase the strength decreases (Neville, 2002). It was also observed that the use of super plasticizer has an optimum amount after which the strength will decline.

Table (6.5): Mix Proportions for Predicted Compressive Strength versus Super Plasticizer Content (1 m^3).

Cement Kg/m^3	Silica Fume Kg/m^3	Fly Ash Kg/m^3	Coarse Aggregate Kg/m^3	Sand kg/m^3
400.00	00.00	00.00	1200.00	600.00

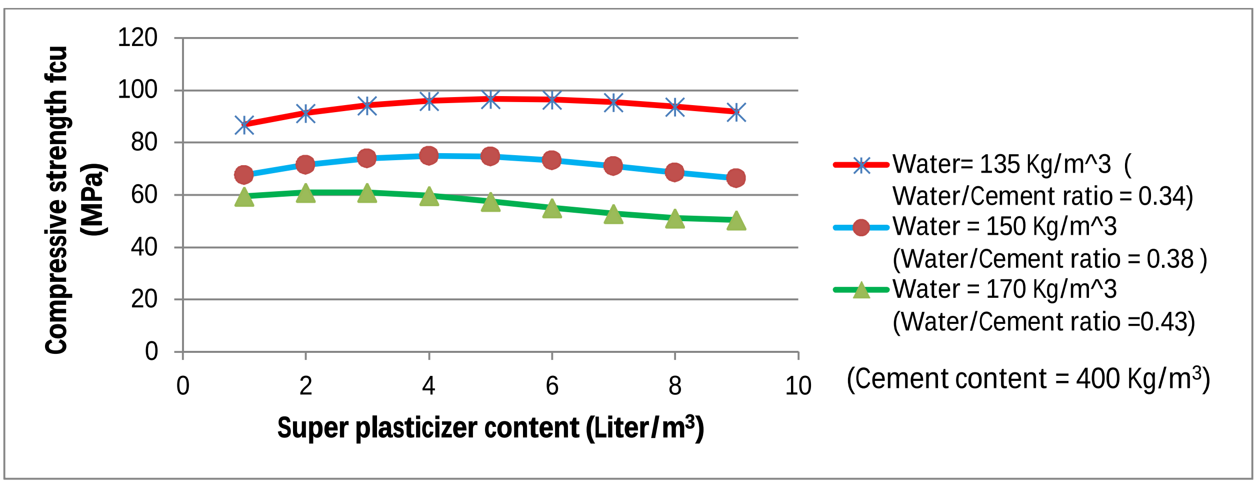

Figure (6.6): Influence of Super Plasticizer Content on the Compressive Strength of High Strength Concrete.

6.3.5 Influence of Replacing Cement with Fly Ash on the Compressive Strength

Figure (6.7) presents predicted compressive strength versus fly ash percentages for mixes with constant material proportions as shown in Table (6.6). Fly ash percentage and cement content were changed and their effect was detected. From the figure it can be observed that 0 % replacement of cement by fly ash was the optimum value at which the strength reached its peak at 28 days of curing. It is observed that the compressive strength decreased when 10% replacement of cement by fly ash was used. It can be observed that the strength is dropping with the increase fly ash percentage (at early age). This is completely compatible with what mentioned in chapter three, see figure (3.2). It was also observed when 400 kg/m^3 of cement is used; the strength reached greater value than when 350 kg/m^3 and 300kg/m^3 of cement were used respectively.

Table (6.6): Mix Proportions for Predicted Compressive Strength versus Fly Ash Percentage (1 m^3).

Water Kg/m^3	Silica Fume Kg/m^3	Coarse Aggregate Kg/m^3	Sand Kg/m^3	Super Plasticizer Liter/m^3
115	0	1200	600	0

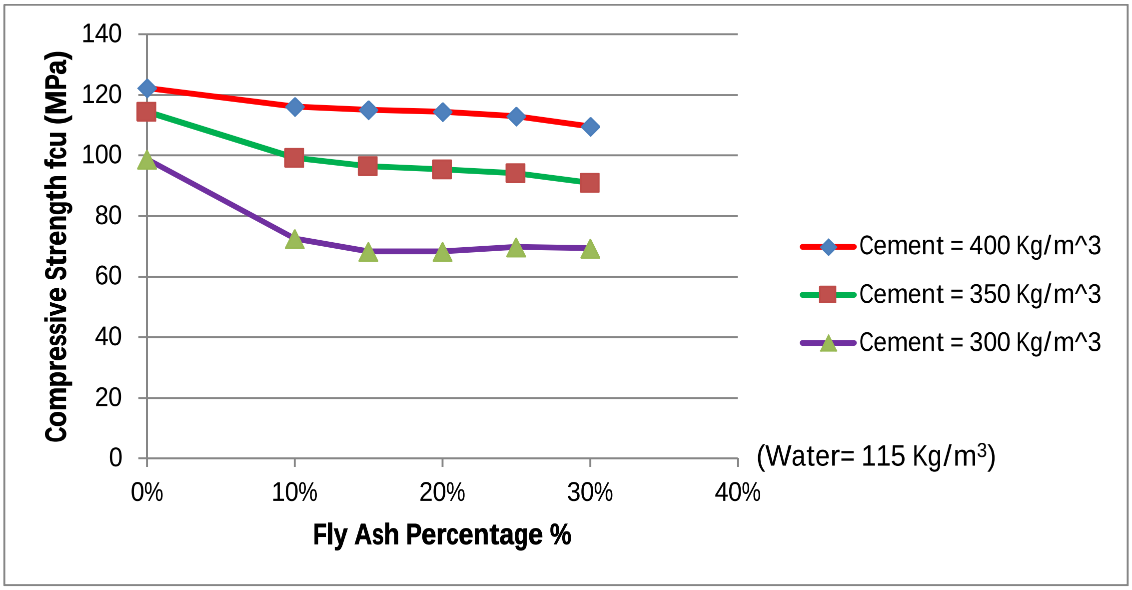

Figure (6.7): Influence of Replacing Cement with Fly Ash on the Compressive Strength.

6.3.6 Influence of Replacing Cement with Silica Fume on the Compressive Strength

Figure (6.8) presents predicted compressive strength versus silica fume percentages for mixes with constant material proportions as shown in table (6.7). Silica fume percentage and cement content were changed and their effect was detected. It has been seen that when cement is replaced by silica fume the compressive strength increases. 10% replacement of cement by silica fume gives greater compressive strength as compared to 0% replacement. It can be observed that the strength is rising with the increase silica fume percentage. It is also observed that when 400 kg/m^3 of cement was used, the strength reached greater value than using 350 kg/m^3 and 300 kg/m^3 of cement respectively.

Table (6.7): Mix Proportions for Predicted Compressive Strength versus Silica Fume Percentage (1m³).

Water Kg/m³	Fly Ash Kg/m³	Coarse Aggregate Kg/m³	Sand Kg/m³	Super Plasticizer Liter/m³
150	0	1200	600	0

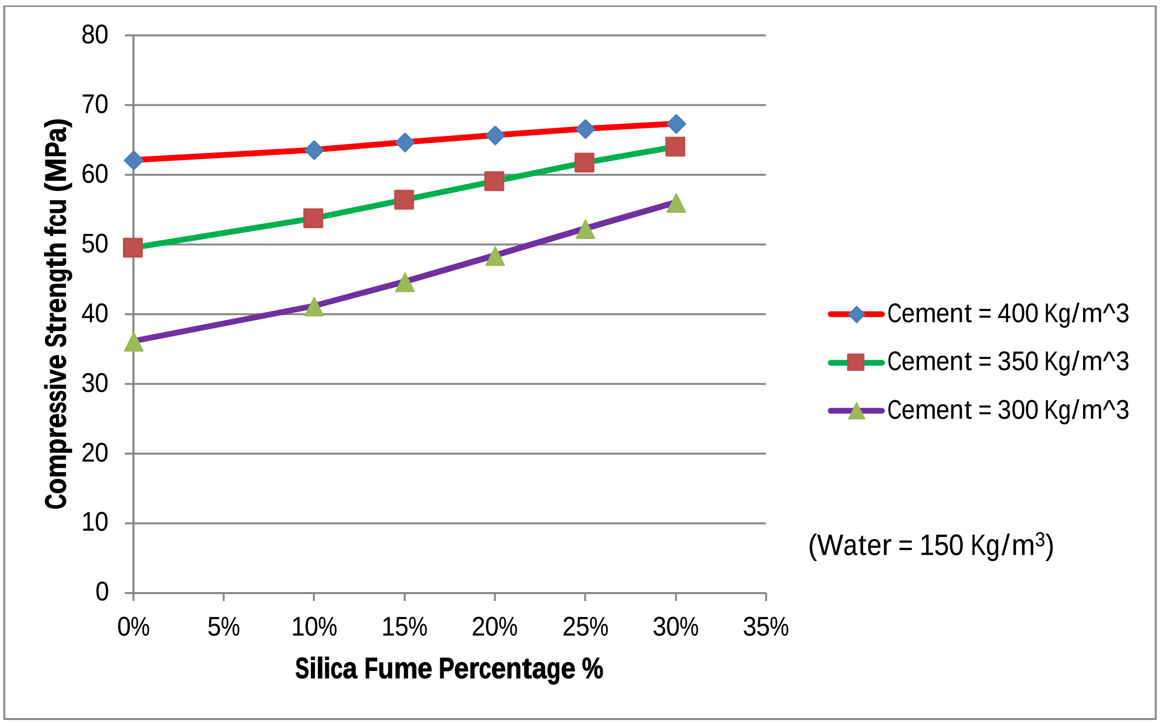

Figure (6.8): Influence of Replacing Cement with Silica Fume on the Compressive Strength.