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Research Paper

Developing a new model to predict compressive strength of self-compacting concrete modified with silica fume under different curing periods

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ABSTRACT

This study develops a nonlinear predictive model to estimate the compressive strength (σ_c) of self-compacting concrete (SCC) modified with silica fume (SF) based on water-to-cement ratio (w/c), SF content, and curing time (t). A comprehensive dataset of over 225 experimental results from the literature was collected, covering w/c ratios from 0.23 to 0.62, silica fume replacement levels up to 20%, and curing periods up to 90 days. The proposed nonlinear model was calibrated and validated using statistical performance indicators, including the coefficient of determination (R^2) and root mean square error (RMSE). Results show a strong agreement between predicted and experimental compressive strength values, confirming the model's high accuracy and reliability in capturing the nonlinear behavior of SCC. Findings indicate that curing time has the most significant impact on compressive strength development, followed by water-to-cement ratio, while silica fume content has a moderate effect within the studied range. Overall, the proposed model offers a robust and accurate tool for predicting the compressive strength of SF-modified SCC across different mix proportions and curing conditions.

1 Introduction

As a developed concrete technology in the civil engineering field, self-compacting concrete (SCC) can consolidate and fill forms under its own weight without vibration; it is highly spouted, homogeneous, and stable. The prototype method was first suggested by Japanese researchers [1]. Properly proportioned SCC should exhibit adequate stability to avoid blockage of concrete during flow as well as separation of material constituents [2]. SCC generally uses higher binder content than traditional concrete, resulting in a higher build cost. In addition, the output of the SCC needs a high amount of cement, for which the advised cement content is 400-600 kg/m3 in EFNARC [3]; and 386-475 kg/m3 in ACI 237R [4] standards, which generate high quantities of CO2 emissions and contribute to environmental pollution. Increasing the volume of additional cementation materials, such as ground granulated blast-furnace slag (GGBS), fly ash (FA), and silica fume (SF),

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in concrete has been shown to reduce CO2 emissions. The engineering benefits of using supplementary cementing materials (SCM) mainly resulted from their fine particle size and pozzolanic reactivity [5]. Some researchers have focused on SCC with low binder content, particularly its mixing design. Material exchange has been one of the most effective measures to reduce the environmental impact of concrete. Adding SF has also been shown to improve the impact resistance of concrete and increase the cohesion between the aggregate and the cement matrix in concrete mixtures. Note that using SF in concrete showed a growth in its modulus of elasticity, but this increase was lower than that observed in compressive strength. SCC mixed with 15% SF as a replacement for cement was experimentally analyzed in concrete and showed that SF can fill the Nanometric gap in a cement matrix, thereby producing a denser structure and, in turn, increasing compressive strength. SF advanced bond between aggregate–matrix, obtained from the establishment of lower pore content, gives high-ranking values of concrete compressive strength, at the same time.

Silica fume is regarded as one of the extremely effective supplementary cementing materials to get the self-compacting characteristic of concrete, which is estimated by the method of slump flow, U-box, V-funnel, and L-box tests. Use of mineral admixtures slightly increased the slump flow time T50, particularly in the silica fume-included SCC.SF improves the mechanical properties of concrete, especially the compressive strength (σ_c) of the mixtures. Workability outcomes of fresh mixtures display that adding mineral admixtures (SF) increases the V-funnel and T50 times and increases the super-plasticizer exhaustion. The slump flow decreases as SF increases [6].Silica fume reduced the workability and improved the fresh properties of SCCs. The influence of the curing method on the compressive strength, splitting tensile strength, and flexural strength of SCC showed that water-cured samples achieved higher concrete compressive strength, splitting tensile strength, and flexural strength than air-cured samples by around 11%, 10%, and 11%, respectively. Curing conditions (curing time) of concrete have been shown to have a greater influence on the degree of cement hydration [7].Curing conditions influence mechanical properties; for SCC with silica fume, values across all curing periods and conditions increase. The tests also noted that SCC gave high early concrete compressive strength. In this research, the effect of SF on SCC was considered, and the compressive strength of SSC modified with SF was evaluated as a function of w/c, curing time, and SF content (%) until 90 days. Modeling for compressive strength was performed for different curing times. The Vipulanandan correlation model [8,9,10] has been used to get the compressive strength quality of SCC modified with SF. Also, a statistical analysis of the properties of SCC and SF-modified SCC was performed.

To address the limitations identified in previous studies, this research focuses on developing a generalized predictive approach for estimating the compressive strength of silica fume-modified self-compacting concrete (SCC). The main issue is the lack of a reliable nonlinear model capable of accurately capturing the combined effects of water-to-cement ratio, silica fume content, and curing time across a wide range of experimental conditions, supported by a large consolidated dataset. Therefore, the central research question is whether a nonlinear regression-based model can effectively predict the compressive strength of SCC with silica fume, using these key influencing parameters. To answer this, more than 225 experimental data points were gathered from published literature, covering different mix proportions and curing periods. Using this dataset, a nonlinear predictive model was developed to estimate compressive strength based on water-to-cement ratio, silica fume content, and curing time. The model's performance and reliability were evaluated with statistical indicators like the coefficient of determination (R^2) and root mean square error (RMSE) to confirm its accuracy and practical use in engineering.

2 Objectives

The general purpose of this research was to quantify the compressive strength behavior of SF-modified SCC using more than 225 datasets collected from prior research. The specific objectives are:

a) Statistical variation of the compressive strength, tensile strength, w/c, SF content and curing time of concrete, curing time adjusted with SF.

b) To evaluate the influence of w/c, curing time, slump flow, and SF content on the compressive strength of SCC with and without SF using the nonlinear model.

c) To give equations for predicting the compressive strength of SCC with or without SF.

3 Materials and methods

3.1 Data collection

This study examined the fundamental properties of SCC enhanced with silica fume; the behavior of SCC was evaluated based on compressive strength. Tables 1 and 2 list the properties of SCC and SCC modified with SF.

Table 1- Properties of SCC not modified with SF collected from the literature

Reference	w/c ratio	Curing time (day)	Slump flow (mm)	Compressive strength, σ_c (MPa)	Tensile strength, σ_t (MPa)	Flexural strength, σ_f (MPa)
Gesoğlu et al. [11]	0.4 – 0.62	28	670-730	60– 78	--	--
Wongkeo et al. [12]	0.3 – 0.62	3,7, 28,90	650	18– 84	--	
Leung et al. [13]	0.4 – 0.6	28	650	38– 61	--	--
Ghanooni et al. [14]	0.40	28 - 90	680-720	60 – 69		
Ardalan et al. [15]	0.4 – 0.62	7, 28,90	640-650	18 – 47	--	--
Esfandiari et al. [6]	0.4 – 0.62	28, 90	593-733	3– 47	--	--
Sasanipour et al. [16]	0.40-0.43	28 - 90	575-670	29 – 43	--	--
Liu et al. [17]	0.30 – 0.60	3,7, 28	690	26– 53	3.9	3.3
Notes	Changed From 0.30 to 0.60	Up to 90 days of curing	Changed From 575 to 733	Changed From 18 to 75MPa	Changed From 3 to 3.9 MPa	Changed From 3 to 3.3 MPa

Table 2- Properties of SCC modified with SF collected from the literature

Reference	w/c ratio	SF (%)	Curing time (day)	Slump tests flow (mm)	Compres-sive strength, σ_c (MPa)	Tensile strength, σ_t (MPa)	Flexural strength, σ_t (MPa)
Gesoğlu et al. [11]	0.4 – 0.62	5-23	28	650-720	44– 76.1	--	--
Turk and Karatas [18]	0.30 – 0.5	10-23	3, 28	701-708	58– 67	4– 5	--
Wongkeo et al. [12]	0.3 – 0.62	3.76-23	3,7, 28,90	650	18– 100		
Ghanooni et al. [14]	0.40	9-23	28 - 90	660-710	32 – 63		
Leung et al. [13]	0.4 – 0.6	7-23	28	650	64– 75	--	--
Ardalan et al. [15]	0.4 – 0.62	9-23	7, 28,90	650	46 – 55	--	--
Sanjay and Keshava Murty [19]	0.4	10-20	3, 28	682-695	16 – 34	3 – 4	--
AbdelAleem and Hassan [20]	0.40 – 0.6	10-23	28	660-730	27– 81	2– 8	3-11
Liu et al. [17]	0.3– 0.60	6	3,7, 28	645-680	23 – 62	3 – 7	3 – 6
Esfandiari et al. [6]	0.4 – 0.62	5-23	28, 90	692-769	10–48	--	--
Sasanipour et al. [16]	0.40-0.43	9	28 - 90	600-628	25 – 58	--	--
Notes	Changed from 0.30 and 0.60	Changed from 3.76% to 23%	Up to 90 days of curing	Changed from 645 and 769	Changed from 18 to 75 MPa	Changed from 2 MPa to 7.2 MPa	Changed from 3 MPa to 10.5 MPa

The dataset used in this research was compiled from a broad range of previously published experimental studies to ensure enough variability in mix proportions and material characteristics. Tables 1 and 2 summarize the collected data for normal SCC and silica fume-modified SCC, respectively. As shown, the database includes variations in water-to-cement ratio, silica fume replacement level, curing time, and related mechanical properties such as compressive strength, and when available, tensile and flexural strengths. The water-to-cement ratio ranges from 0.23 to 0.62, silica fume content varies up to 20%, and curing periods extend up to 90 days, providing a solid basis for model development and validation. The SCC mixtures in the database generally consist of ordinary Portland cement, fine and coarse aggregates, water, and chemical admixtures like high-range water reducers (superplasticizers), viscosity-modifying agents, and air-entraining admixtures to achieve self-compacting properties. Additionally, silica fume is used as a supplementary cementitious material to improve microstructure densification and increase compressive strength. The data collected reflect different material sources and mix designs reported in the literature, enhancing the overall reliability and versatility of the proposed predictive model.

3.2 Modelling

3.2.1 Vipulanandan correlation model

The mechanical behaviour of SCC improved with SF, as predicted by the Vipulanandan correlation model [8–10]. To describe the nonlinear relationship between the compressive strength of self-compacting concrete (SCC) modified with silica fume (SF) and the influencing parameters, a Vipulanandan correlation-based model was used. This model has been widely applied to cementitious materials because of its ability to capture nonlinear behaviour and interactions among mix parameters with good accuracy and stability. In this study, the Vipulanandan model is used to represent the dependence of compressive strength on key variables such as water-to-cement ratio, silica fume content, and curing time, based on the behaviour observed in the experimental dataset. The general form of the model can describe both the initial rapid change and the gradual stabilization of mechanical properties as input variables increase.

Based on the visitation of the collected data, the following relation was suggested:

$$Y = Y_o + \frac{X}{(H+I*X)} \quad (1)$$

Where:

Y = Concrete behaviour (dependent variable), i.e., compressive strength (σ_c).

Y_o, H, and I = model parameters, X = Concrete behaviour (independent variables), i.e., curing time (t).

3.2.2 Comparison of model predictions

To compare the model forecasting, statistical quantification like the coefficient of determination (R2) and root mean square error (RMSE) were applied and quantified as follows:

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

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (y_i-x_i)^2}{N}} \quad (3)$$

Where:

yi = experimental value. xi = forecasted value from the model. $\bar{y}$ =mean of the real test values. $\bar{x}$= mean of measured values, and N is the number of data.

3.2.3 Nonlinear model (NLM) for compressive strength

The influence of water-to-cement ratio (w/c), curing time (t), and percentage of silica fume (SF) on the σ_c and σ_t of SCC could be modelled as follows

a- Compressive strength of SCC (with 0% of SF)

$$\sigma_c = a \left(\frac{W}{C}\right)^b (t)^c 4(a)$$

b- Compressive strength of SCC improved with SF.

$$\sigma_c = a\left(\frac{W}{C}\right)^b (t)^c + d\left(\frac{W}{C}\right)^e (t)^f (SF)^g \quad 4(b)$$

Based on test data collected from various studies, the model parameters in Eqs. 4(a) and 4(b) were gained from multiple regression analysis using the least square method, as shown in Tables 3 and 4.

Table 3(a) - Statistical analysis for the properties of SCC not modified with SF

Variable	No. of Data	Mean	StDev	CoefVar	Minimum	Maximum	Curing time
Compressive Stress (MPa)	12	23.83	6.29	26.41	14.00	35.00	3 days
Compressive Stress (MPa)	28	29.96	7.63	25.47	18.00	45.00	7 days
Compressive Stress (MPa)	66	41.70	10.17	24.40	15.50	55.00	28 days
Compressive Stress (MPa)	49	48.50	10.41	21.46	26.70	75.00	90 days
W/C %	66	0.4043	0.1008	24.94	0.2338	0.6275	
Silica Fume %	66	0.00	0.00	*	0.00	0.00	
Flow Slump tests mm	66	658.82	33.57	5.10	575.00	733.00	

Table 3(b) - Statistical analysis for the properties of SCC modified with SF

Variable	Total Count	Mean	StDev	CoefVar	Minimum	Maximum	Curing time
Compressive Stress (MPa)	87	25.377	5.906	23.27	13.000	40.000	3 days
Compressive Stress (MPa)	74	36.99	6.80	18.37	18.00	48.00	7 days
Compressive Stress (MPa)	101	44.45	10.28	23.13	18.00	55.00	28 days
Compressive Stress (MPa)	74	54.10	13.71	25.34	27.00	73.00	90 days
Tension Stress (MPa)	32	3.864	1.250	32.36	2.180	7.200	28 days
Flexural Stress (MPa)	19	6.019	1.613	26.79	3.600	10.460	28 days
W/C %	101	0.4015	0.1029	25.64	0.2717	0.6478	
Silica Fume %	101	9.481	4.632	48.85	3.763	22.971	
Flow Slump tests mm	101	670.86	34.60	5.16	600.00	769.00	

Table 3(c) - Summary statistical analysis for the properties of SCC

	Statistical parameters	w/c %	Compressive strength, σ_c (MPa)	Tensile strength, σ_t (MPa)	Tensile strength, σ_t (MPa)	Slump flow (mm)
Concrete	No. of data	66	66	0	0	66
	Range	0.23 –0.62	14 – 75	--	–	575-733
	Mean	0.40	48.50	--	--	658.82
	Std. deviation	0.1	10.41	--	--	33.57
	COV (%)	24.94	21.46	--	--	5.10
Concrete + SF	No. of data	101	100	32	19	100
	Range	0.27 – 0.64	13 - 73	2– 8	3.0 – 11	600-769
	Mean	0.40	25.37--53.86	3.92	5.95	670.85
	Std. deviation	0.10	5.77-13.49	1.28	26.5	34.42
	COV (%)	25.75	22.75-25.06	35.43	27.3	5.13

Table 4- Model parameters for compressive strength up to 90 days

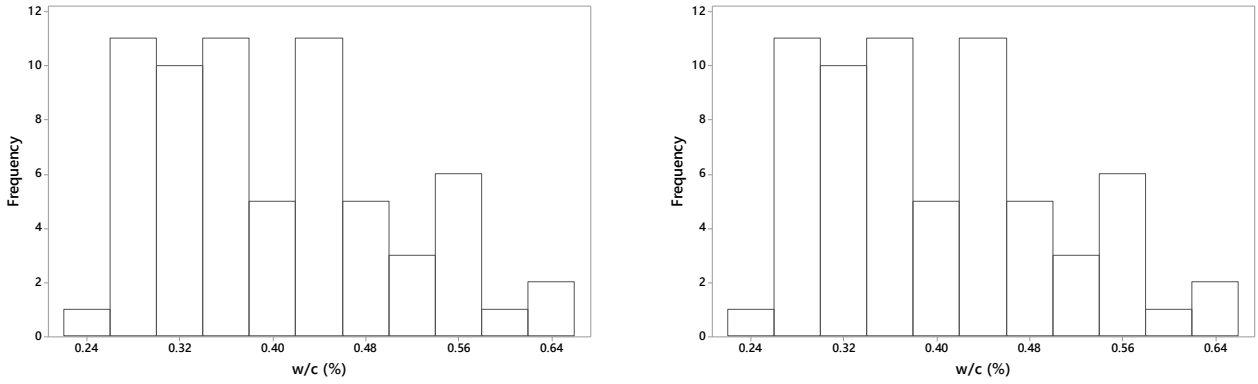
			Non-linear model parameter										
	Depended variables (Y-axis)	**Indepen-dent variable (X-axis)**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**RMSE (MPa)**	**R^2**	**No. of data**	**Fig No**
Concrete	Compressive Strength σ_c (MPa) SCC %0 SF (MPa)	w/c , curing time,	9.4	-0.56	0.26	-	-	-	-	1.96	0.96	50	9a
Concrete + SF	Compressive Strength σ_c (MPa) SCC modified by SF	w/c, curing time	9.4	-0.56	0.26	1	-0.1	0.54	0.15	2	0.98	64	9b
	Compressive Strength σ_c (MPa) , SCC from 0-20% SF	w/c , curing time, SF 0-20 %	9.4	-0.56	0.26	1	-0.1	0.54	0.15	2	0.98	120	9c

4 Results and analysis

4.1 Statistical analysis

(a) w/c ratio

Based on the total of 66 water-cement ratio (w/c) data for the SCC obtained from the literature shown in Table 1, the w/c for the SCC was changed from 0.23 to 0.62 with a Mean of 0.40, the Standard deviation (STDEV) of 0.10, and the coefficient of variation (COV) of 24.9%. About 97% of the total w/c was varied from 0.3 to 0.5 as shown in Fig.1 (a), corresponding to the total of 101 w/c data for the SCC modified with SF collected from the literature Table 2, the w/c for the SCC modified with SF was changed from 0.27 to 0.64 with a Mean of 0.40, the Standard deviation (STDEV) of 0.10 and Coefficient of variation (COV) of 25.64%. About 87% of the total w/c of SCC modified with SF also ranged from 0.3 to 0.5, as shown in Fig.1 (b). Most of the SCC with low w/c high-range superplasticizers were used to obtain suitable workability.



(a) (b)

Fig. 1- Histogram of water to cement ratio (w/c) for SCC modified with silica fume (a) 0% SF, (b)SF up to 20%

(b) Silica fume

According to the 101 data on silica fume percentage used to modify concrete, SF% ranged from 3.76% to 23% (by dry weight of cement), with a mean of 9.48%, a standard deviation of 4.63%, and a COV of 50.1%. Fig. 2 shows that almost 65% of the total SF was changed from 5% to 15%, and 19% of the total SF was less than 5%.

(c) Slump flow

Based on a total of 66 data points on slump flows for SCC mixes obtained from the literature, the results are presented in Table 1. One can find that the slump flow for SCC varied between 575 mm and 733 mm, with a Mean of 658.88, a Standard deviation (STDEV) of 33.57, and a Coefficient of variation (COV) of 5.10%, as shown in Table 3(a). About 80% of the total of slump flow varied from 600 mm to 700 mm, as shown in Fig.3. Corresponding to the total of 101 data slump flow for the SCC modified with SF collected from the literature Table 3(b), the slump flow for the SCC modified with SF was changed from 600 mm to 769 mm with a Mean of 670.90 mm, the standard deviation (STDEV) of 34.10 and coefficient of variation (COV) of 5.16% as illustrated also in Table 3(b). Approximately 83% of the total slump flow of SCC modified with SF was increased from 600 mm to 700 mm, as shown in Fig. 3.

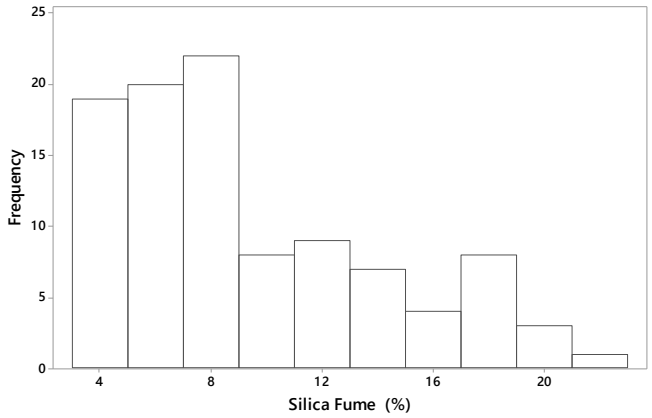


Fig. 2- Histogram of percentages of silica fume (SF) up to 20% used to modify SCC

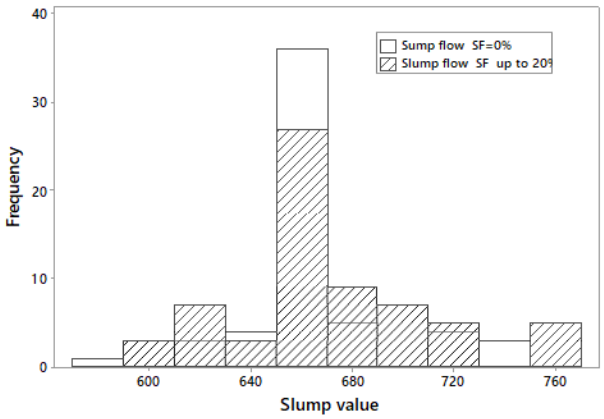


Fig. 3- Histogram of slump flow of SCC modified with silica fume, 0% SF, and SF up to 20 %

4.2 Mechanical properties

4.2.1 Compressive strength

(a) SCC (without SF)

A total of 66 datasets on the compressive strength of SCC were collected from the literature for mixes tested at curing times of 3, 7, 28, and 90 days, and the results are given in Table 1. The compressive strength (σ_c) was changed from 14 to 75 MPa with a mean of 23.83, 29.96, 41.70, and 48.50 MPa, the standard deviation (STDEV) 6.29, 7.63, 10.17, and 10.41 MPa, and COV of 26.41 %, 25.47%, 24.4 % and 21.64 % for 3, 7, 28, and 90 days curing time, respectively. From Fig. 4 (a), for the compressive strength (σ_c), up to 3 days of curing based on 12 data, 75% of the compressive strength was from 15 to 30 MPa, while 17 % of the data was more than 30 MPa and 8% of the data was less than 15 MPa as shown in Fig. 4 (a), up to 7 days of curing based on 28 data 78% of the compressive strength was from 20 to 40 MPa, while 10% of the data was more than 40 MPa and 12% of the data was less than 20 MPa as shown in Fig. 4 (b), up to 28 days of curing based on 66 data 65 % of the compressive strength was from 30 to 50 MPa, while 36% of the data was more than 50 MPa and 4% of the data was less than 30 MPa as shown in Fig. 4(c), and up to 90 days of curing based on 49 data 70% of the compressive strength was from 40 to 60 MPa, while 14% of the data was more than 60 MPa and 16 % of the data was less than 40 MPa as shown in Fig. 4 (d).

(b) SCC modified with SF

A total of 101 data points on the compressive strengths of SCC were collected from the literature, and the results for curing times of 3, 7, 28, and 90 days are given in Table 1. The compressive strength (σ_c) was changed from 13 to 73 MPa with a mean of 25.37, 37, 44.45, and 54.10 MPa, the standard deviation (STDEV) 5.9, 6.80, 10.28, and 13.71 MPa, and COV of 231.3%, and 25.34% for 3, 7, 28 and 90 days curing time, respectively. From the Fig. 4(e), for the compressive strength (σ_c) up to 3 days of curing based on 42 data, 83% of the compressive strength was from 15 to 30 MPa, while 14%

of the data was more than 30 MPa and 3% of the data was less than 15 MPa as showed in Fig. 5(a), up to 7 days of curing based on 29 data 65% of the compressive strength was from 20 to 40 MPa, while 31% of the data was more than 40 MPa and 4% of the data was less than 20 MPa as shown in Fig. 5(b), up to 28 days of curing based on 101 data 42% of the compressive strength was from 30 to 50 MPa, while 45% of the data was more than 50 MPa and 13% of the data was less than 30 MPa as shown in Fig. 5(c), and up to 90 days of curing based on 52 data 44% of the compressive strength was from 40 to 60 MPa, while 42% of the data was more than 60 MPa and 14% of the data was less than 40 MPa as shown in Fig. 5(d).

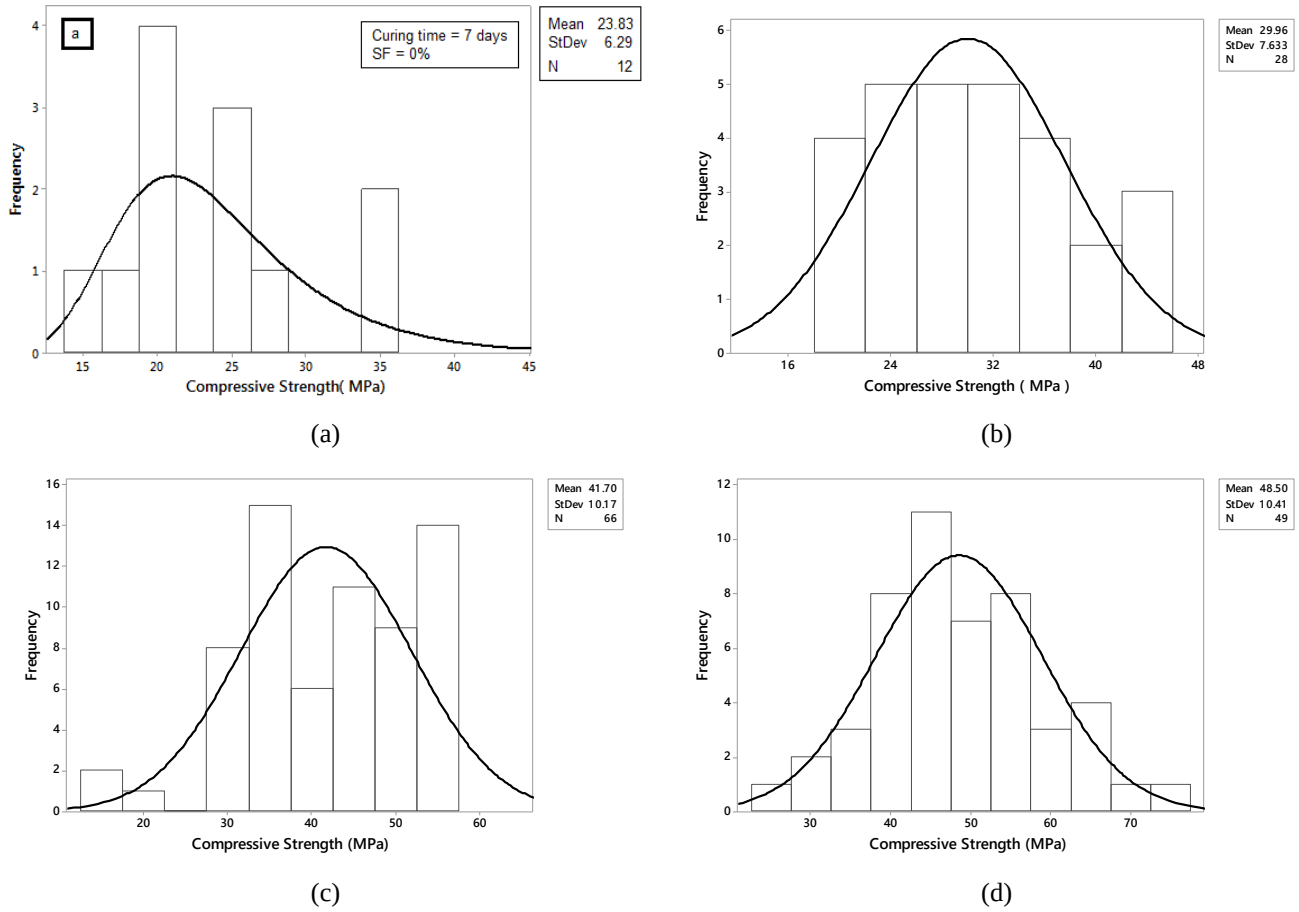


Fig. 4- Histogram of compressive strength of SCC without silica fume (SF) (a) 3 days, (b) 7 days, (c) 28 days, (d) 90 days curing time with 0% SF

4.2.2 Tensile strength (σ_t) of SCC modified with SF

Based on 32 tensile strengths (σ_t) data for SCC modified with SF collected from the literature Table 2, the tensile strength (σ_t) of concrete modified with silica fume was varied between 2.18 to 7.2 MPa with a mean of 3.86 MPa, standard deviation (STDEV) 1.25 MPa and COV of 32.36% as in Table 3(b), from the Fig. 6, for the tensile strengths (σ_t) up to 28 days of curing based on 32 data 81% of the tensile strengths (σ_t) was from 2.5 to 5 MPa, while 12 % of the data was more than 5 MPa, and 7 % of the data was less than 2.5 MPa.

4.2.3 Flexural strength (σ_f)of SCC modified with SF

Based on 19 flexural strengths (σ_f) data for SCC modified with SF collected from the literature, the results are given in Table 2. Flexural strength (σ_f) of concrete modified with silica fume was varied between 3 to 11 MPa with a mean of 6 MPa, standard deviation (STDEV) of 1.61 MPa, and COV of 26.79% as in Table 3(b). From Fig. 7, for the flexural strengths (σ_f) up to 28 days of curing based on 9 data, 78% of the tensile strengths (σ_f) were from 4 to 8 MPa, while 11% of the data were more than 8 MPa, and 11% of the data were less than 4 MPa.

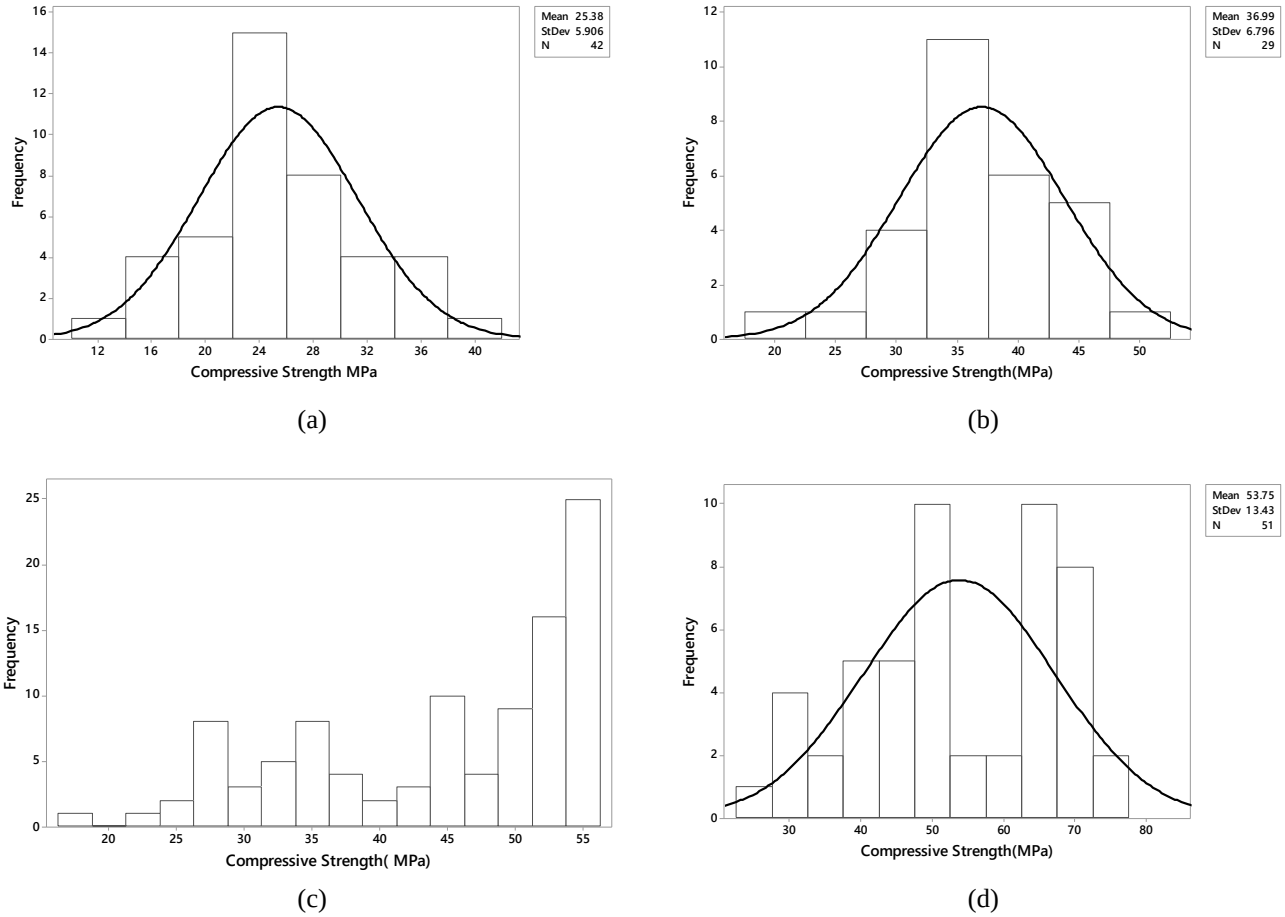


Fig. 5- Histogram of compressive strength for SCC modified with silica fume (SF) (a) 3 days, (b) 7 days, (c) 28 days, (d) 90 days curing time with SF up to 20% in the literatures

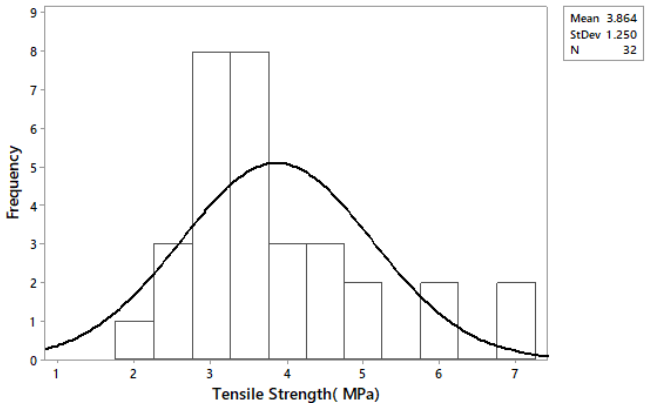


Fig. 6- Histogram of tensile strength for self-compacting concrete modified with silica fume (SF), up to 20% for 28 days curing time in the literature

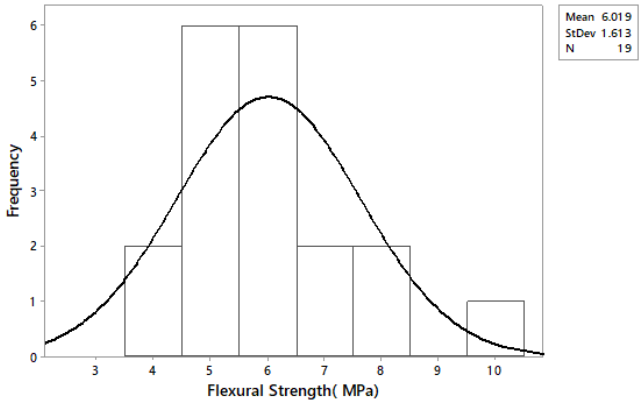


Fig. 7- Histogram of flexural strength for self-compacting concrete modified with silica fume (SF), SF up to 20% for 28 days curing time in the literature

5 Property correlation

5.1 Relationship between compressive strength (σ_c) and water-to-cement ratio (w/c) of SCC

A total of 132 data on the compressive strength (σ_c) of SCC up to 90 days of curing were gathered from the literature, and the property relationship was investigated. The inverse relation between the compressive strength and w/c for SCC with and without SF is shown in Fig. 8.

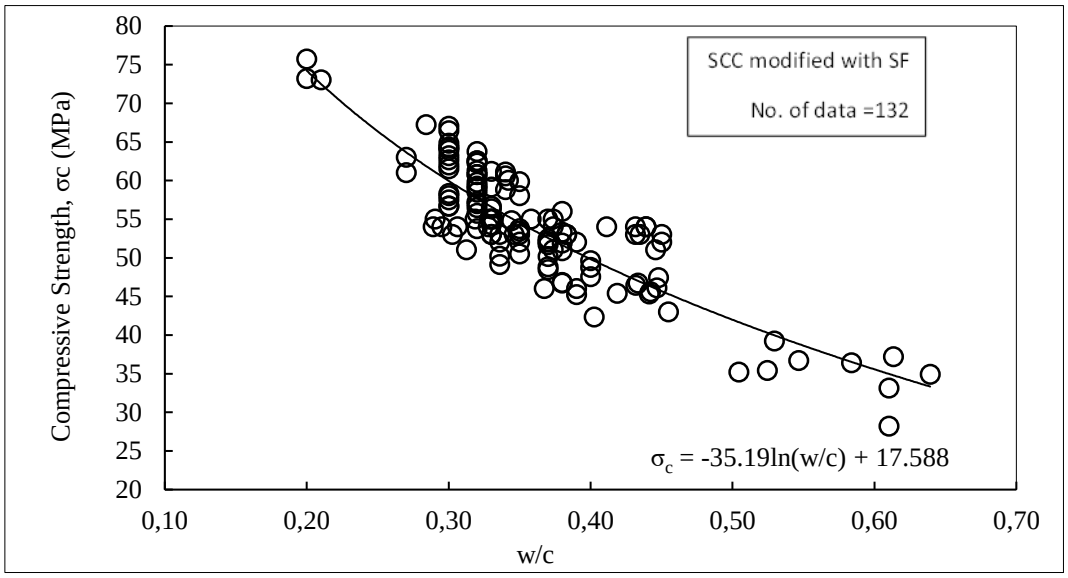


Fig. 8- Correlation between water-to-cement ratio and compressive strength of self-compacting concrete modified with silica fume up to 20%

5.2 Relationship between measured and predicted of compressive strength of SCC not modified by SF

Because the relation between the compressive strength(σ_c), w/c, and curing time (t) was observed only in 28 days, it's not adequate, so the compressive strength (σ_c)was correlated to the independent variables of w/c and curing time using a nonlinear relationship Eq. 5(a). Based on the model parameters, the influence of w/c was greater than that of curing time on the rise and fall in compressive strength. The model parameters were obtained from an overall of 50 data points gathered from the literature, as shown in Fig. 9(a). The Vipulanandan correlation model uses parameters R2, RMSE, and the number of data points, which are summarized in Table 4. One can obtain the following equation

$$\sigma_c = \frac{9.40*t^{0.26}}{W/C^{0.56}} \tag{5a}$$

No. of data = 50, R^2 = 0.96, RMSE =1.96 MPa

5.3 Relationship between measured and predicted compressive strength of SCC modified by SF

Overall, 64 data points collected from the literature, the relation between measured and predicted compressive strength was developed as illustrated in Fig. 9(b).From the model parameters, the effect of curing time was more pronounced than w/c on the rise and fall of compressive strength in the term model, including SF, while SF slightly influenced compressive strength. The model parameters, R^2, RMSE, and number of data are summarized in Table 4. One can obtain the following equation

$$\sigma_c = \frac{9.4*t^{0.26}}{w/c^{0.56}} + \frac{t^{0.54}*SF^{0.15}}{w/c^{0.1}} \tag{5b}$$

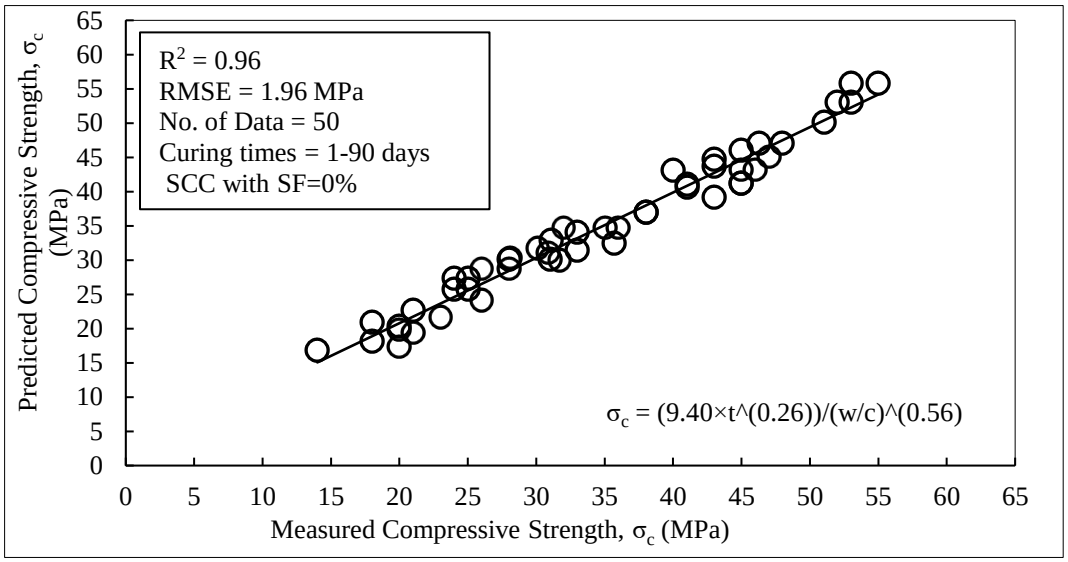
No. of data = 64, R^2 = 0.98, RMSE=2 MPa

5.4 Relationship between measured and predicted compressive strength of SCC modified by SF from 0% to 20%

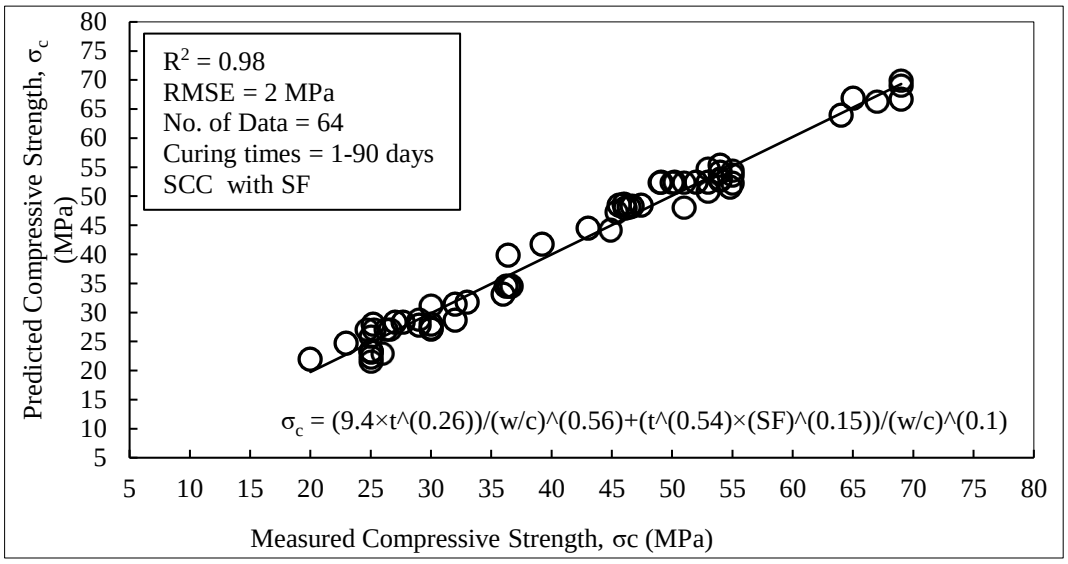
Overall, 120 data points gathered from the literature show the relation between measured and predicted compressive strength, as illustrated in Fig. 9(c). Based on the model parameters, the effect of curing time was more significant than w/c ratio on the increase and decrease of compressive strength, with the model including SF, although SF has only a slight influence on compressive strength. The model parameters, R2, RMSE, and the number of data points, are summarized in Table 4. One can derive the following equation.

$$\sigma_c = \frac{9.4*t^{0.26}}{w/c^{0.56}} + \frac{t^{0.54}*SF^{0.15}}{w/c^{0.1}} \tag{5c}$$

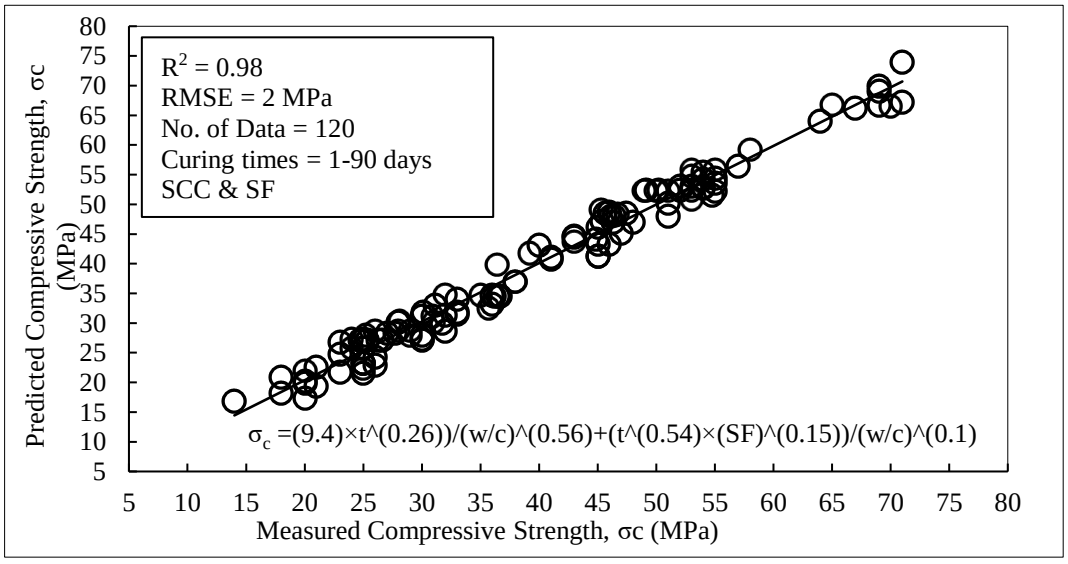
No. of data = 120, R^2 = 0.98, RMSE =2 MPa



(a)



(b)



(c)

Fig. 9- Comparison between measured and predicted compressive strength of SCC modified with SF (a) 0% SF, (b) SF up to 20%, and (c) SF ranged 0% to 20% for 1 to 90 days curing time

6 Conclusions

The main focus of this research was to determine the influence of silica fume, w/c, and curing time on the compressive strength of SCC. Based on data gathered from the papers and limited test data from the researcher's past studies, methodical models were developed, the following conclusions are developed:

Range w/c for the SCC moderated with SF was 0.4, while the range of the w/c was between 0.5 - 0.65%.

Based on the data gathered from the literature, the most common admixture used in SCC was silica fume.

Based on the statistical analysis, the most common percentage of SF used in SCC was 10%, and the range was from 5% to 20%. Even though a high range of SF was used for SCC, a low increase in the compressive strength of SCC was observed.

In this study, linear correlation between the variables was found to be weak or insufficient to describe the complex behaviour of SCC. However, this does not imply independence between variables. Instead, the relationship between compressive strength and the influencing parameters is strongly nonlinear, thereby justifying the development and application of the proposed nonlinear regression model.

Based on the model parameter, the effect of curing time was more efficient than w/c on the rising and lowering compressive strength in terms of the model, which includes SF, while the SF slightly influences compressive strength on SCC.

Added Limitations and Future Research

The study has some limitations due to the use of secondary data from previously published literature, which may introduce variability due to differences in materials, testing standards, and curing conditions. Future research should validate the proposed model using controlled experimental datasets and extend the modelling approach to include additional supplementary cementitious materials. Additionally, incorporating advanced machine learning techniques could further enhance prediction accuracy and generalization.

Declaration of AI and AI-Assisted Technologies in the Writing Process

The authors used OpenAI ChatGPT-4o to enhance readability while preparing this work. They thoroughly reviewed and edited all content generated by these tools and take full responsibility for the final version of the published article.

REFERENCES

[1]- H. Okamura, M. Ouchi, Self-compacting concrete. J. Adv. Concr. Technol., 1(1) (2003) 5-15. https://doi.org/10.3151/jact.1.5

[2]- A. Mechaymech, J.J. Assaad, Stability of Self-Consolidating Concrete Containing Different Viscosity Modifiers. Civil Eng. Infrastruct. J., 52(2) (2019) 245-263. https://doi.org/10.22059/ceij.2019.262859.1502

[3]- EFNARC, Specification and Guidelines for Self-Compacting Concrete. European Federation for Specialist Construction Chemicals and Concrete Systems, Farnham, UK, 2002.

[4]- ACI Committee 237, Self-consolidating concrete, ACI 237R-07. American Concrete Institute, Farmington Hills, 2007.

[5]- A.H. Bhat, J.A. Naqash, S.U. Islam, T. Habib, Compressive Strength and Microstructural Properties of Sustainable Concrete Containing Nanosilica, Alccofine and Metakaolin. Civil Eng. Infrastruct. J., 57(1) (2024) 1-15. https://doi.org/10.22059/CEIJ.2023.348240.1866

[6]- J. Esfandiari, P. Loghmani, Effect of perlite powder and silica fume on the compressive strength and microstructural characterization of self-compacting concrete with lime-cement binder. Measurement, 147 (2019) 106846. https://doi.org/10.1016/j.measurement.2019.07.074

[7]- D.P. Bentz, Three-dimensional computer simulation of Portland cement hydration and microstructure development. J. Am. Ceram. Soc., 80(1) (1997) 3-21. https://doi.org/10.1111/j.1151-2916.1997.tb02785.x

[8]- C. Vipulanandan, A.S. Mohammed, Hyperbolic rheological model with shear stress limit for acrylamide polymer modified bentonite drilling muds. J. Pet. Sci. Eng., 122 (2014) 38-47. https://doi.org/10.1016/j.petrol.2014.08.004

[9]- A.S. Mohammed, Vipulanandan models to predict the electrical resistivity, rheological properties and compressive stress-strain behavior of oil well cement modified with silica nanoparticles. Egypt. J. Pet., 27(4) (2018) 1265-1273. https://doi.org/10.1016/j.ejpe.2018.07.001

[10]- A.S. Mohammed, W. Mahmood, Statistical Variations and New Correlation Models to Predict the Mechanical Behavior and Ultimate Shear Strength of Gypsum Rock. Open Eng., 8 (2018) 213-228. https://doi.org/10.1515/eng-2018-0026

[11]- M. Gesoğlu, E. Güneyisi, E. Özbay, Properties of self-compacting concretes made with binary, ternary, and quaternary cementitious blends of fly ash, blast furnace slag, and silica fume. Constr. Build. Mater., 23(5) (2009) 1847-1854. https://doi.org/10.1016/j.conbuildmat.2008.09.015

[12]- W. Wongkeo, P. Thongsanitgarn, K. Ngamjarurojana, A. Chaipanich, Compressive strength and chloride resistance of self-compacting concrete containing high level fly ash and silica fume. Mater. Des., 64 (2014) 261-269. https://doi.org/10.1016/j.matdes.2014.07.042

[13]- H.Y. Leung, J. Kim, A. Nadeem, J. Jaganathan, M.P. Anwar, Sorptivity of self-compacting concrete containing fly ash and silica fume. Constr. Build. Mater., 113 (2016) 369-375. https://doi.org/10.1016/j.conbuildmat.2016.03.071

[14]- M. Ghanooni-Bagha, M.A. Shayanfar, A.A. Shirzadi-Javid, H. Ziaadiny, Corrosion-induced reduction in compressive strength of self-compacting concretes containing mineral admixtures. Constr. Build. Mater., 113 (2016) 221-228. https://doi.org/10.1016/j.conbuildmat.2016.03.046

[15]- R.B. Ardalan, A. Joshaghani, R.D. Hooton, Workability retention and compressive strength of self-compacting concrete incorporating pumice powder and silica fume. Constr. Build. Mater., 134 (2017) 116-122. https://doi.org/10.1016/j.conbuildmat.2016.12.090

[16]- H. Sasanipour, F. Aslani, J. Taherinezhad, Effect of silica fume on durability of self-compacting concrete made with waste recycled concrete aggregates. Constr. Build. Mater., 227 (2019) 116598. https://doi.org/10.1016/j.conbuildmat.2019.07.324

[17]- X. Liu, L. Wu, X. Yang, H. Wei, Properties of self-compacting lightweight concrete reinforced with steel and polypropylene fibers. Constr. Build. Mater., 226 (2019) 388-398. https://doi.org/10.1016/j.conbuildmat.2019.07.306

[18]- K. Turk, M. Karatas, Abrasion resistance and mechanical properties of self-compacting concrete with different dosages of fly ash/silica fume. Indian J. Eng. Mater. Sci., 18(1) (2011) 49-60.

[19]- S.J. Sanjay, M. Keshava Murty, Experimental studies on self compacting concrete with partial replacement of cement and sand by granite waste and foundry sand. Int. J. Creat. Res. Thoughts, 5(4) (2017) 311-318.

[20]- B.H. AbdelAleem, A.A. Hassan, Development of self-consolidating rubberized concrete incorporating silica fume. Constr. Build. Mater., 161 (2018) 389-397. https://doi.org/10.1016/j.conbuildmat.2017.11.146