SIFCON ile Üretilen Beton Yolların Bazı Mekanik Özelliklerinin Optimizasyonu

Osman Ünsal BAYRAK*[1] , Muhammed Ziya BİNGÖL[1], Halim Ferit BAYATA[2]

[1]Atatürk University, Civil Engineering Department, Erzurum, Turkey.
[1]Atatürk University, Civil Engineering Department, Erzurum, Turkey.
[3] Erzincan Binali Yıldırım University, Civil Engineering Department, Erzincan, Turkey.

Öz

Son zamanlarda geliştirilen kompozit bir malzeme olan çimento bulamacı emdirilmiş lifli beton (SIFCON), inşaat mühendisliği alanında çok popüler malzemelerden biri olmuştur. Yüksek dayanımlı betonlardan en önemli farkı kırılma sırasında sünek davranış göstermesidir. Bu çalışmada SIFCON'un rijit kaplama olarak kullanımı araştırılmıştır. Deneyler, L_{16} ortogonal dizi tekniği kullanılarak her biri dört seviyeli dört faktör ile tasarlanmıştır. Faktörler ve seviyeleri 40, 55, 65, 80 lif görünüm oranı, %3, %6, %9, %12 lif hacmi, 0,30, 0,35, 0,40, 0,45 su/çimento oranı ve %0, %5, %10, %15 silis dumanı oranıdır. Deney sonuçları Taguchi yöntemi ile varyans analizi (ANOVA) tekniği kullanılarak değerlendirilmiştir. ANOVA'ya göre, beton kaplamaların basınç ve eğilme mukavemetinde en önemli rolü lif görünüm oranı (L/d) oynamıştır. Ayrıca basınç mukavemeti için optimum koşullar 55 (L/d), %3 lif oranı, 0.45 su / bağlayıcı oranı ve %5 SD oranı, eğilme mukavemeti için 80 L/d, %12 lif oranı, 0.45 su / bağlayıcı oranı ve %5 SD oranı olarak bulunmuştur. Optimum koşullarda 145.72 MPa ve 31.58 MPa'lık maksimum basınç ve eğilme dayanımı elde edilmiştir.

Anahtar Kelimeler: Beton Yollar, SIFCON, Çelik Lif, Taguchi Metodu

Optimization of the Some Mechanical Properties of Concrete Pavements Produced with SIFCON

Abctract

Slurry Infiltrated Fiber Reinforced Concrete (SIFCON) is one of the recently developed composite material became a very popular material in civil engineering. The difference between high strength concrete (HSC) and SIFCON is the ductile behavior at failure. In this study, usage of SIFCON as a rigid pavement is investigated. The experiments were designed according to Taguchi method using orthogonal array technique in an L16 array with four factors with four levels each. The factors and their levels are 40, 55, 65, 80 fiber aspect ratio, 3%, 6%, 9%, 12% fiber volume, 0,30, 0,35, 0,40, 0,45 water/cement ratio (w/c) ratios and 0%, 5%, 10%, 15% silica fume ratio. Analysis of variance technique (ANOVA) was used for analyzing the test results. According to the ANOVA, the fiber aspect ratio (L/d) plays a significant role in compressive and flexural strength. Moreover, the optimum conditions were found to be 55 fiber aspect ratio, 3% fiber content, 0.45 w/c ratio and 5% SF ratio for compressive strength and 80 fiber aspect ratio, 12% fiber content, 0.45 w/c ratio and 5% SF ratio for flexural strength. Maximum compressive and flexural strength of 145.72 and 31.58 MPa was obtained under the optimum conditions respectively.

Keywords: Concrete Pavements, SIFCON, Steel Fiber, Taguchi Method

1. Introduction

Concrete roads are rigid pavements that are more environmentally friendly compared to flexible pavements and have a long service life and resistance to heavy vehicle loads. Although it has many advantages, concrete which is a brittle material, is generally poor in terms of fatigue strength, abrasion resistance, flexural strength, load carrying capacity after cracking (Mehta, 1986; Neville, 1995). Particularly dynamic wheel

loads cause cracks in the corner and the edge of concrete with low flexural strength and these cracks spread easily. Adding fiber to the concrete can increase ductility and energy absorption capacity of concrete (Lee, 2017; Lee et al., 2017). Random and uniformly distributed steel fibers in concrete cause decrease significantly the formation of cracks in the concrete. ACI Committee 544 (ACI, 1996) reported that the addition of steel fibers in a concrete matrix improves all mechanical properties of concrete, especially durability, tensile strength and toughness (Musmar, 2013). Hence, concrete with high ductility level is obtained by increasing the strain capacity of the concrete and energy absorption capacity.

SIFCON is a special type of high-performance composite material. It was developed by Lankard in New Mexico Engineering Research Institute in 1984 (Lankard, 1984; Lankard and Newell, 1984). The fiber content in conventional fiber concrete is limited to 3% by volume, while 5-30% can be attained in SIFCON depending on the geometric properties of the fiber used (Tuyan ve Yazıcı, 2012; Beglarigale et al., 2016). Steel fibers are placed into a formwork and then flowable slurry (cement, water, silica fume, very fine sand and superplasticizer) infiltrated to coat the fibers. In SIFCON the fiber content and the fiber geometric properties influence the void size between fibers and thus the fineness of the slurry (Abdou et al., 1989). The main differences that distinguish SIFCON from steel fiber concretes are its high fiber content and the matrix of the slurry is composed of very thin materials. These two phenomena give the SIFCON superior flexural strength, toughness and ductility. SIFCON has been used in many applications such as pavement repairs, repair of bridge structures, safe vaults, defense structures, repair, and reinforcement works (Rao et al., 2010; Tuyan and Yazıcı, 2012).

In a concrete mix design, when the number of mix variables increases, the number of experiments also increases. Hence, the quantity of materials, money and time increases in the traditional design of experiments. The Taguchi method can be used to decrease the number of experiments for such experimental studies. One of the advantages of the Taguchi method over the traditional experimental design is keeping the experimental cost at a minimum level.

Flexural strength is one of the most important parameters in concrete pavement design. In this study, the effect of aspect ratio (height/thickness), fiber content, w/c ratio and silica fume (SF) content on the compressive and flexural strength of the SIFCON were investigated. This experimental work was designed to obtain the optimum working conditions of the parameters which affect the flexural and compressive strength, using the Taguchi method.

2. Materials and Method

In this study, Portland cement (CEM I 42.5 R) was used. The pozzolanic material is required for filling the voids of micro-particulates in the binder paste. This pozzolanic material contributes the binder paste strength by its pozzolanic reaction (Richard and Cheyrezy, 1995; Chan and Chu, 2004; Hinislioglu and Bayrak, 2004). Therefore, SF obtained from Electro Metallurgy Enterprise was used in this study. The physical and chemical properties of the cement and SF are summarized in Table 1.

Table 1. Chemical and physical properties of PC and SF

Component		PC (%)	SF (%)
Unit volume weight (g/mL)		3.13	–
Specific surface (cm^2/g)		3690	–
Specific gravity		3.12	–
Initial setting time (min)		130	–
Final setting time (min)		195	–
Volume expansion (mm)		1	–
Compressive Strength (MPa)	2 days	23.5	–
	7 days	35.3	–
	28 days	47.0	–
Flexural Strength (MPa)	2 days	5.0	–
	7 days	6.2	–
	28 days	7.7	–
SiO_2		19.94	85 – 95
Al_2O_3		5.28	1.0 – 3.0
Fe_2O_3		3.45	0.5 – 1.0
CaO		62.62	0.8 – 1.2
MgO		2.62	1 – 2
SO_3		2.46	–
LOI		1.99	0.5 – 1,0
Na_2O		0.23	2.18
K_2O		0.83	–
Cl		0.0107	–
Undetermined		0.08	–
Total		100	–
Free CaO		0.51	–
Insoluble residue		0.70	–
Fe_2O_3		3.45	–

Portland cement (CEM I 42.5 R) was added as the basic cementitious material. The dosage was kept constant at 800 kg/m3. SF was added as partial replacement of the cement at levels of 0%, 5%, 10% and 15%. The w/c ratios were 0.30, 0.35, 0.40 and 0.45. The dosage level of polycarboxylate based superplasticiser was slightly adjusted for mixes to maintain the adequate workability. Steel fibers (Figure 1) with hooked-end were used at levels of 3%, 6%, 9% and 12% with four different aspect ratios (L/d) of 40, 55, 65 and 80. The physical and mechanical properties of the fibers are presented in Table 2.
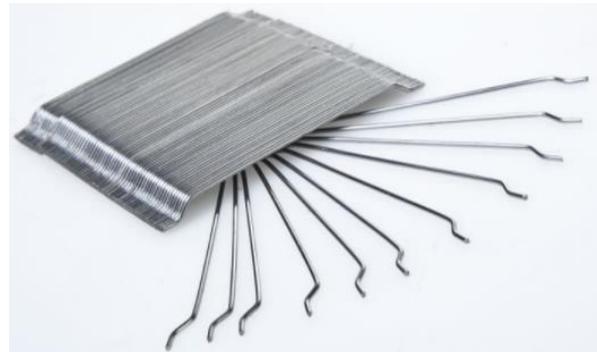

Figure 1. Hooked-end steel fibers

Table 2. Properties of Hooked-end steel fibers

Fiber Type	KMX (L/d) 40/30	KMX (L/d) 55/30	KMX (L/d) 65/35	KMX (L/d) 80/60
Length (L) (mm)	30	30	35	60
Diameter (d) (mm)	0,75	0,55	0,55	0,75
Aspect ratio (L/d)	40	55	65	80
Min. Tensile Strength (N/mm^2)	1200	1500	1500	1200

Two 150 x150 x 150 mm cube and 7 x 7 x 28 mm beams were cast for each mix. The specimens were demolded after 24 h and stored in a water tank at 21±1°C until tested at 28 days. Then the compressive and flexural strengths of each specimen were determined.

2.1. Experimental approach

In full factorial experiment design, one factor is varied while all other factors are kept constant. The number of experiments will increase as the factors and levels in the design of the experiment increase. Therefore, it will not be possible to perform such a design in practice. Moreover, if interactions between the parameters are present, the optimum condition obtained from the conventional experimental design may not be the actual optimum. The fractional factorial experiments using an orthogonal array were investigated and developed by Taguchi. The linear graph developed by Taguchi is useful to scientists and engineers to design and analyze the experimental data without having the basic knowledge of factorial design (Taguchi, 1962; Roy, 1990; Hinislioglu and Bayrak, 2004; Bayrak and Hinislioglu, 2017).

The experiments were designed according to the orthogonal array technique. Factors and their levels were selected based on the literature review on the subject. Four factors with four levels each have been taken for experimental design. The L_{16} orthogonal array was selected according to Taguchi Method (Table 3).

Table 3. Factors and their levels

Factors	Levels			
	1	2	3	4
(A) Aspect ratio (L/d)	40 (A$_1$)	55 (A$_2$)	60 (A$_3$)	80 (A$_4$)
(B) Fiber Ratio (%)	3 (B$_1$)	6 (B$_2$)	9 (B$_3$)	12 (B$_4$)
(C) w/c	0.30 (C$_1$)	0.35 (C$_2$)	0.40 (C$_3$)	0.45 (C$_4$)
(D) SF Ratio (%)	0 (D$_1$)	5 (D$_2$)	10 (D$_3$)	15 (D$_4$)

The experiments were carried out based on the L_{16} orthogonal array by the Taguchi method Table 4.

Table 4. L_{16} orthogonal array

Experiment Number	Aspect ratio (L/d)	Fiber Ratio (%)	W/C	SF %)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

The numbers in Table 4 represent the levels of each factor for the related experiment. The order of experiments was carried out randomly to avoid noise sources which had not been initially considered and affect the results in a negative way. The test results were calculated based on the quality characteristic of "the bigger the best" by equation 1.

$$S/N_L = -10Log\left[\frac{1}{n}\sum_1^n \frac{1}{Y_i^2}\right] \tag{1}$$

Here, S/N is the performance statistics, defined as the signal to noise ratio (S/N unit: dB), n is the number of the repetition for each experiment and Y_i is the performance value of the ith experiment.

The levels of factors that maximize the S/N were optimum. However, in the Taguchi method, the experiment corresponding to the optimum working conditions might not have been done during the whole period of the experimental stage. In such cases, the performance value corresponding to the optimum working conditions can be predicted by the balanced character of the orthogonal array using the following equation:

$$Y_i = \mu + X_i + e_i \tag{2}$$

where μ is the overall mean of the performance value, X_i is the fixed effect of the factor level combination used in the ith experiment and e_i is the random error in the ith experiment. Because Equation (2) is a point estimation, which is calculated by using experimental data in order to determine whether results of the confirmation experiments are meaningful or not, the confidence interval must be evaluated. The confidence interval at the chosen error level may be calculated by the following equation:

$$CI = \mu \pm \sqrt{\frac{F(1,n_2)}{N_e}} \tag{3}$$

where μ is the overall mean of the performance value at optimum conditions, F is the value of the F table, Ne is the effective number of repetition in confirmation analysis (Hinislioglu and Bayrak, 2004, 2005; Bayrak and Hinislioglu, 2017).

3. Results and Discussion

The compressive and flexural strengths obtained from experiments are given in Table 5 together with their equivalent S/N values (Bingöl, 2017).

Table 5. Orthogonal array for L_{16} with test results

Experiment Number	Aspect ratio (l/d)	Fiber Ratio (%)	w/c	SF (%)	Compressive Strength		Flexural Strength	
					Test Results (MPa)	Performance Statistics (S/N)	Test Results (MPa)	Performance Statistics (S/N)
1	A_1	B_1	C_1	D_1	60.23 59.15	35,518	6.85 7.60	17.177
2	A_1	B_2	C_2	D_2	50.95 51.49	34,189	10.14 11.75	20.784
3	A_1	B_3	C_3	D_3	63.33 62.48	35,974	11.25 10.26	20.632
4	A_1	B_4	C_4	D_4	53.79 52.74	34,529	15.21 14.38	23.401
5	A_2	B_1	C_2	D_3	80.46 78.51	38,006	18.45 17.62	25.122
6	A_2	B_2	C_1	D_4	78.06 77.19	37,800	20.17 20.95	26.260
7	A_2	B_3	C_4	D_1	60.15 59.11	35,509	19.76 18.52	25.639
8	A_2	B_4	C_3	D_2	74.84 72.67	37,356	22.45 22.17	26.970
9	A_3	B_1	C_3	D_4	71.04 70.59	37,003	18.92 18.66	25.479
10	A_3	B_2	C_4	D_3	58.52 59.10	35,389	23.52 22.75	27.285
11	A_3	B_3	C_1	D_2	43.76 44.24	32,869	21.76 22.01	26.803
12	A_3	B_4	C_2	D_1	24.49 23.79	27,655	17.24 18.21	24.972
13	A_4	B_1	C_4	D_2	63.15 61.76	35,911	25.27 24.62	27.939
14	A_4	B_2	C_3	D_1	20.24 21.42	26,374	16.15 17.14	24.426
15	A_4	B_3	C_2	D_4	14.49 15.21	23,435	19.53 18.64	25.614
16	A_4	B_4	C_1	D_3	21.28 19.52	26,193	26.25 27.02	28.509
					Average	**33,357**		**24.813**

An example calculation of S/N (the first S/N alue of compressive strength) is as follows.

$$\frac{S}{N} = -10 Log\left(\frac{1}{2}\left(\frac{1}{60.23^2} + \frac{1}{59.15^2}\right)\right)$$
$$= 35.518$$

All results can be converted to S/N with the same method. After calculating all S/N values, the optimum conditions can be obtained by using average S/N effects. The average S/N effects for compressive and flexural strength are given in Table 6.

Table 6. Average S/N effects of compressive and flexural strength

Level	Compressive Strength				Flexural Strength			
	Aspect ratio (l/d)	Fiber Ratio (%)	w/c	SF (%)	Aspect ratio (l/d)	Fiber Ratio (%)	w/c	SF (%)
1. Level	35.052	36.609	33.095	31.264	20.498	23.929	24.687	23.053
2. Level	37.168	33.438	30.821	35.081	25.998	24.689	24.123	25.624
3. Level	33.229	31.947	34.176	33.890	26.135	24.672	24.376	25.387
4. Level	27.978	31.433	35.335	33.191	26.622	25.963	26.066	25.188

Table 6 was calculated according to the Table 5. For instance, in Table, let us choose the first level of the aspect ratio for compressive strength. The first level of aspect ratio (L/d=40) was used in the first, second, third and fourth experiments (Table 4 and 5). The average of the S/N values of these experiments was calculated and the value of 35.052 was written in Table 6. Likewise, the first level of SF was used in the experiment number of 1, 7, 12 and 14. Therefore, the mean effect of SF on the compressive strength (31.264) was obtained by taking the average of the S / N values of the experiments with numbers 1, 7, 12 and 14. All data were calculated according to the above calculation method.

In Table 6, the level which has the maximum average S/N effect is the optimum level of that factor. Thus, the optimum conditions determined from Table 6 for compressive and flexural strength were demonstrated in Figure 2 and 3.
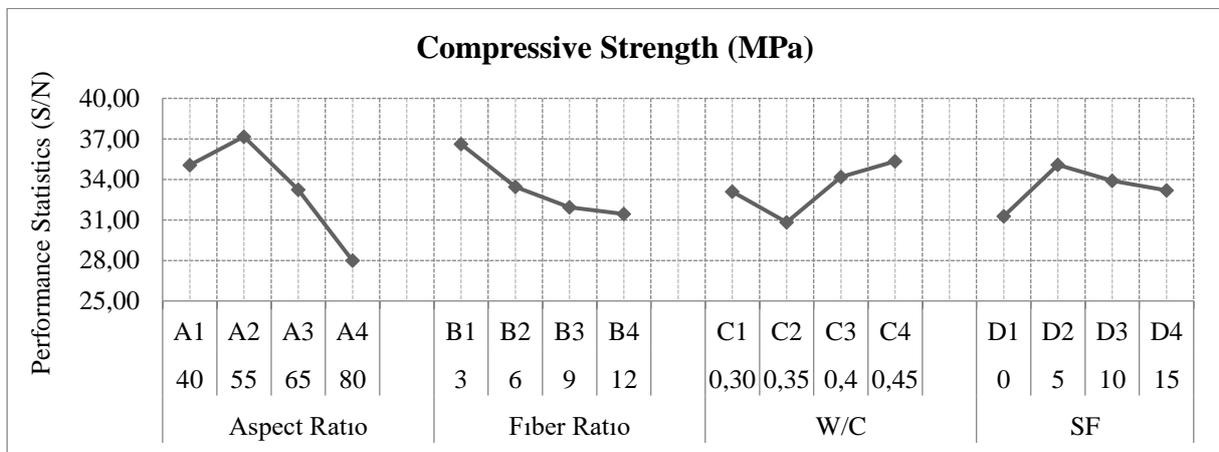

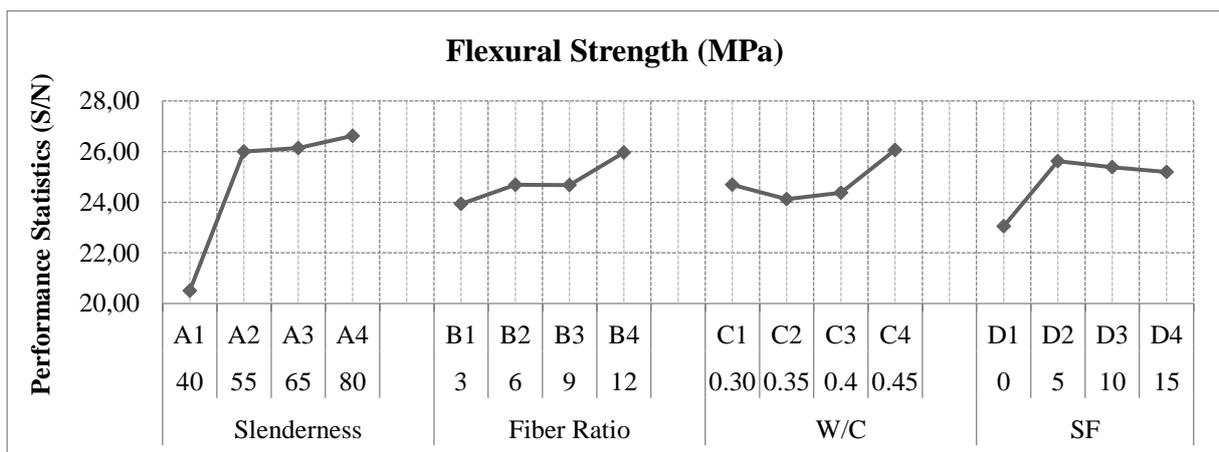**Figure 2.** The effect of parameters on S/N for compressive strength

Figure 3. The effect of parameters on S/N for flexural strength

3.1. Evaluation of Analysis of Variance (ANOVA)

The quantities such as the degree of freedom (DOF), the sum of squares etc. can be calculated by ANOVA (Table 7 and 8). Moreover, the relative significance of each factor can also be calculated by ANOVA.

Table 7. The ANOVA table for compressive strength

Factors	DOF	Sums of Squares	Variance	F-Ratio	Pure Sum	Percent (P)
(A) Aspect ratio	3	185.380	61.793	34.752	180.052	54.43
(B) Fiber Ratio	3	65.100	21.700	12.198	59.772	18.07
(C) W/C	3	44.329	14.776	8.298	39.001	11.79
(D) SF	3	30.660	10.220	5.738	25.332	7.66
Error	3	5.328	1.776			8.05
Total	15	330.797				100.00

Table 8. The ANOVA table for flexural strength

Factors	DOF	Sums of Squares	Variance	F-Ratio	Pure Sum	Percent (P)
(A) Aspect ratio	3	100.155	33.385	75.347	98.464	72.23
(B) Fiber Ratio	3	8.554	2.851	7.638	6.863	5.04
(C) W/C	3	9.011	3.004	3.770	7.320	5.37
(D) SF	3	16.901	5.634	15.990	15.210	11.16
Error	3	1.691	0.564			6.20
Total	15	136.311				100.00

These quantities were calculated for compressive strength as follows.

Step 1. The sum of all S/N results (Table 5):

$$T = 35.518 + 34.189 + 35.974 + \cdots. + 26.193 = 533.708$$

Step 2. Correction factor:

$$CF = \frac{T^2}{n} = \frac{533.708^2}{16} = 17802.8$$

where n is the total number of experiments.

Step 3. Total sum of squares

$$S_T = \sum_{i=1}^{16} y_i^2 - CF$$
$$= (35.518^2 + 34.189^2 + \cdots. + 26.193^2) - 17802.8$$
$$= 330.8$$

Step 4. Sum of squares of factors

$$S_{Ai} = \frac{S_1^2}{N_{A1}} + \frac{S_2^2}{N_{A2}} + \frac{S_3^2}{N_{A3}} + \frac{S_4^2}{N_{A4}} - CF$$

$$A_1 = A_{11} + A_{12} + A_{13} + A_{14}$$
$$= 35.518 + 34.189$$
$$+ 35.974 + 34.529$$
$$= 140.21$$

$$A_2 = A_{21} + A_{22} + A_{23} + A_{24}$$
$$= 38.006 + 37.800$$
$$+ 35.509 + 37.356$$
$$= 148.67$$

NA_1, NA_2... = 4 (total number of experiments in which factor A1, A2... is present)

$$S_A = \frac{\sum_1^4 A_i^2}{4} - S_T$$
$$= \frac{140.21^2 + 148.67^2 + \cdots}{4}$$
$$- 330.8 = 185.38$$

Step 5. Variance

$$V_A = \frac{S_A}{DOF_A} = \frac{185.38}{3} = 61.79$$

Step 6. Pure sum of squares

$$S_A' = S_A - (V_e x DOF_A)$$
$$= 185.38 - (1.776 x 3)$$
$$= 180.05$$

here *Ve* is the variance of error, DOFA is the degree of freedom of parameter A

Step 7. Percentage contribution of parameters

$$P_A = \frac{S_A'}{S_T} = \frac{180.05}{330.8} = 0.5443 \cong 54.53\%$$

3.2 Estimating the Expected Performance (S/N) at Optimum Conditions

The optimum conditions were calculated according to quality characteristics of "the bigger the better". As mentioned above, the optimum conditions for compressive strength and flexural strength are A_2, B_1, C_4 and D_2 (Table 9) and A_4, B_4, C_4 and D_2 (Table 10) respectively. However, it can be seen from Table 5 that an experiment corresponding to optimum conditions was not performed during experimental work. Thus, the compressive and flexural strengths in the optimum conditions should be both estimated by equation 2 and verified by a confirmation experiment.

Table 9. The optimum conditions for compressive strength and prediction performance

Factors	Level	Contribution to the S/N
(A) Aspect ratio	**A₂ (55)**	3.811
(B) Fiber Ratio	**B₁ (3%)**	3.253
(C) W/C	**C₄ (0.45)**	1.978
(D) SF	**D₂ (5%)**	1.724
Total contribution of all factors (S/N)		10.766
The average performance statistics (S/N)		33.357
The expected value at optimum conditions (S/N)		44.122
Confirmation test results (S/N) / (MPa)		43.270 / 145.72
Confidence interval (α=95%) (S/N)		41.674 - 46.571

Table 10. The optimum conditions for flexural strength and prediction performance

Factors	Level	Contribution to the S/N
(A) Aspect ratio	**A$_4$ (80)**	1.809
(B) Fiber Ratio	**B$_4$ (12%)**	1.150
(C) W/C	**C$_4$ (0.45)**	1.253
(D) SF	**D$_2$ (5%)**	0.811
Total contribution of all factors (S/N)		5.022
The average performance statistics (S/N)		24.813
The expected value at optimum conditions (S/N)		29.835
Confirmation test results (S/N) / (MPa)		29.98 / 31.58
Confidence interval (α=95%) (S/N)		28.456 - 31.22

The expected value of 44.123 at optimum conditions for compressive strength was calculated using equation 2 (Table 9).

$$Exp.\,value = 33.357 + (37.168 - 33.357)$$
$$+ (36.609 - 33.357)$$
$$+ (35.335 - 33.357)$$
$$+ (35.081 - 33.357)$$
$$= 44.122$$

Then the confirmation experiment was performed at the optimum conditions and average of 145.72 MPa (43.270 S/N) compressive strength was obtained. Since this value is a point estimation, it should be determined whereas the results of the confirmation experiments are meaningful in a confidence interval of 95% using equation 3.

$$CI = 44.122 \pm \sqrt{\frac{10.128 x 1,776}{3}}$$
$$= 44.122 \pm 2.448$$

Since the result of confirmation experiment was between confidence interval, it can be said that the experimental results are meaningful at 95% confidence level.

3.3. Effect of Aspect ratio

The effect of aspect ratio on compressive and flexural strength is demonstrated in Figure 2 and 3, respectively. The aspect ratio was obtained as the most important factor in concrete mix design for both compressive and flexural strengths (Table 9 and 10). Karadelis and Lin (Karadelis and Lin, 2015) indicated that the fiber aspect ratio has a remarkable influence on flexural performance. Wang et al. (Wang et al., 2010) emphasized that the effect of aspect ratio on mechanical properties of steel fiber reinforced concrete (SFRC) is significant and there is an optimal value for strength indexes in each concrete series. Therefore, the 2nd level of 55 aspect ratio maximized the compressive strength (Figure 2 and Table 9). Bayramov et al. (Bayramov et al., 2004) performed a compressive and splitting tensile test for SFRC specimens. They concluded that the compressive strength increases with the increase in the aspect ratio. However, compressive strength declines when aspect ratio rises from 65 to 85. Wang et al (Wang et al., 2010) concluded that although higher fiber aspect ratio induces lower compressive strength, the toughness and peak strain of SFRC increase. Similar results were obtained by Eren and Çelik (Eren and Celik, 1997). From the compressive strength results it is clear that increasing the

aspect ratio decreases the workability, hence it causes difficulties in achieving good compaction of SIFCON matrix. Recent studies indicated that flexural strength increases with increasing aspect ratio (Yazıcı vd., 2007; Teng et al., 2008). Therefore, the 4th level of 80 aspect ratio maximized the flexural strength (Figure 3 and Table 10).

3.4. Effect of fiber ratio

The 1st level of fiber ratio maximized the compressive strength (Figure 2 and Table 9). Farnam et al. compared SIFCON with high strength concrete (HSC) and high-performance fiber reinforced concrete (HPFRC) under confining pressure. They indicated that adding steel fiber up to 5% has a considerable effect on increasing triaxial compressive strength and adding more fiber has a small effect (Farnam et al., 2010). Similarly, in this study, a decrease in the compressive strength was observed as the fiber ratio increased. This is mainly due to the increase in voids because of segregation.

Using fiber in concrete increases both flexural strength and energy absorption capacity (Lankard, 1985; Ipek vd., 2014; Lee, 2017; Lee et al., 2017). Therefore, the 4th level of (12%) fiber ratio maximized the flexural strength (Figure 3 and Table 10).

3.5. Effect of w/c ratio

The effect of w/c on compressive and flexural strength are shown in Figure 2 and 3 respectively. From the test results, it can be seen that 0.45 w/c ratio maximizes both compressive and flexural strength. It is well known that as w/c ratio decreases the strength increases. Here, 0.30 w/c ratio is expected to maximize the strength. However, despite the benefits of fiber reinforcement, fiber can affect the workability of fresh concrete significantly. Moreover, concrete with mineral admixtures needs more water than others. Since, SF is extremely fine powders,

the maximum compressive and flexural strength was obtained at 0.45 w/c ratio.

3.6. Effect of SF

Test results demonstrated that 5% SF replacement maximizes both compressive and flexural strength. It is known that adding mineral admixtures increase mechanical properties of concrete (Hinislioglu and Bayrak, 2004; Shah and Ribakov, 2011). However, very finely divided supplementary materials such as SF can have a very strong negative effect on water demand (Ikpong and Okpala, 1992; Erdoğan, 1997). Hence, workability reduces with increase in SF content.

4. Conclusion

Concrete pavements have been widely used in many countries due to its high load carrying capacity and low maintenance cost. The mission of concrete in a rigid pavement is to conduct the severe wheel load to the subgrade without any deformation. Passing a wheel load through the rigid pavement causes the compressive and flexural stresses. In this study, SIFCON which has high flexural strength was investigated as a rigid pavement. The Taguchi method was used for evaluating and optimization of four parameters each has four levels. The following conclusions can be drawn from this study:

- The optimum compressive strength was achieved by the second level of slenderness (55), the first level of fiber ratio (3%), the fourth level of w/c (0.45) and the second level of SF ratio (5%).

- The optimum flexural strength was achieved by the fourth level of slenderness (80), the fourth level of fiber ratio (12%), the fourth level of w/c (0.45) and second level of SF ratio (5%).

- The compressive strength of 145.72 MPa was obtained with 55 aspect ratio in optimum conditions.

- Reduction in compressive strength was determined as fiber aspect ratio (L/d) increases.

- Reduction in compressive strength was determined as fiber volume increases.

- The aspect ratio (L/d) was determined as the most effective parameter on both compressive and flexural strength.

- The flexural strength of 31.58 MPa was obtained with 80 aspect ratio in optimum conditions.

- The increment in compressive strength was determined as fiber volume increases.

- It was determined that the most and less effective parameter on both compressive and flexural strengths were the aspect ratio and SF content respectively.

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