Karaelmas Science and Engineering Journal
Journal home page: https://dergipark.org.tr/tr/pub/karaelmasfen
DOI: 10.7212/karaelmasfen.1101186

Research Article
Received / Geliş tarihi : 10.04.2022
Accepted / Kabul tarihi : 10.05.2022

Effects of Basalt Fibre Utilization on Durability and Mechanical Properties of SIFCON

Bazalt Lif Kullanımının SIFCON'un Dayanıklılık ve Mekanik Özelliklerine Etkisi

Zeynep Algın*, Erdal Özbebek, Sümeyra Gerginci, Kasım Mermerdaş

Harran University, Engineering Faculty, Civil Engineering Department, Sanliurfa, Turkey

Abstract

The basalt fibre utilisation in Slurry Infiltrated Fibre Concrete (SIFCON) production has been studied to investigate how the durability and mechanical properties of SIFCON are affected by the basalt fibre replacement with steel fibre. Steel fibre with a length of 30 mm and the basalt fibre having a length of 24 mm are used in the SIFCON mixtures with the replacement ratios of 0%, 25%, 50%, 75% and 100% by volume. The extensive laboratory studies have been conducted to specify compressive strength, flexural strength, sorptivity, water absorption, acid attack and Bohme abrasion resistance in terms of the basalt fibre replacement variation. The results reveal that the increment in basalt fibre replacement ratio decreases the compressive strength and the capillary water absorption while increasing the water absorption values. No significant change in the flexural strength is observed up to 50% basalt fibre utilisation and lower weight loss values are specified in this range for the SIFCON samples exposed to acid solution. The highest Bohme abrasion resistance is identified for samples having the basalt fibre replacement ratio of 25%. The results signify that the basalt fibre utilisation provides advantages considering the variations in flexural strength, physical and chemical degradation.

Keywords: Abrasion resistance, Acid attack, Basalt fibre, Permeability, SIFCON, Strength

Öz

Bu çalışmada SIFCON üretiminde çelik lif yerine bazalt lif kullanımının SIFCON'un dayanıklılık ve mekanik özelliklerini nasıl etkilediği araştırılmıştır. SIFCON numunelerinde, 24 mm uzunluğundaki bazalt lif hacimce %0, %25, %50, %75 ve %100 oranlarında 30 mm uzunluğundaki çelik lif ile yer değiştirilerek kullanılmıştır. SIFCON numunelerinin dayanıklılık ve mekanik özelliklerini belirlemek için basınç dayanımı, eğilme dayanımı, su emme, kılcal su emme, asit saldırısı ve Böhme aşınma direnci deneyleri yapılmıştır. Sonuçlar, bazalt lifin yer değiştirme oranındaki artışla SIFCON numunelerinin su emme değerinin arttığını, basınç dayanımı ve kılcal su emme değerlerinin ise azaldığını göstermiştir. %50 oranına kadar bazalt lif kullanımı, SIFCON numunelerinin eğilme dayanımı sonuçlarında önemli bir değişikliğe neden olmamıştır. Asit çözeltisine maruz bırakılan SIFCON numuneleri için %50 oranına kadar bazalt lif içeren numunelerde elde edilen ağırlık kaybı değerlerinin daha düşük olduğu belirlenmiştir. En yüksek Böhme aşınma direnci %25 oranında bazalt lif içeren SIFCON numunelerinde elde edilmiştir. Sonuç olarak, eğilme dayanımı, fiziksel ve kimyasal aşınma deneylerindeki değişimler göz önüne alındığında SIFCON üretiminde bazalt lif kullanımı avantaj sağlamaktadır.

Anahtar Kelimeler: Aşınma direnci, Asit saldırısı, Bazalt lif, Geçirimlilik, SIFCON, Dayanım

1. Introduction

The conventional concrete with high-volume steel fibre is not suggested in practical concrete design due to the reduction in workability occurs in concrete mixture incorporated with high-volume steel fibre utilisation targeting to attain higher ductility, flexural, compressive and tensile strength values (Akçaözoğlu and Kıllı 2021). On the other hand, much higher steel fibre utilisation is possible with Slurry Infiltrated Fibre Concrete (SIFCON) technique (i.e. 5-30% by volume), which was first developed by Lankard (Lankard 1984, Lankard and Newell 1984). SIFCON is produced by the special slurry poured into fibre, which contains the mixture of cement, fine sand, silica fume, water and super plasticizer (e.g. (Wang and Maji 1994, Tabak 2004). Since

*Corresponding author: zyilmaz@harran.edu.tr

Zeynep Algın orcid.org/0000-0001-7004-8403
Erdal Özbebek orcid.org/0000-0001-9035-9815
Sümeyra Gerginci orcid.org/0000-0001-5912-7311
Kasım Mermerdaş orcid.org/0000-0002-1274-6016

high-volume fibre and fine material are used in the slurry, the SIFCON matrix provides superior flexural strength, toughness and subsequently higher ductility properties (e.g. (Yazıcı et al. 2010, Beglarigale et al. 2014, Elavarasi and Mohan 2016)).

The extensive compressive and tensile strength tests to determine the mechanical properties of SIFCON samples containing 4-10% hooked steel fibre have been conducted by the previous studies which reveal that tensile strength and fracture toughness of samples are improved with the increment in fibre content (e.g. (Wecharatana and Lin 1992, Yan et al. 2002)). Although no substantial change in compressive strength variation is observed in this increasing range of fibre content by Wecharatana and Lin (1992), Yan et al. (2002) states otherwise by referring to the significant increases in compressive and flexural strength values (especially in fracture toughness). The highest compressive and flexural strength results are obtained from the samples having the fibre content of 10% as 127.8 MPa and 78.7 MPa, respectively. It is highlighted that the cracks formed on the side surfaces of the sample beams are distributed more homogeneously in the cases of the fibre amount is increased. Sharma and Singh (2008) concludes that the best compressive strength performance is identified in the samples having the fibre content of 8% based on the results obtained from samples with the fibre content range of 0-9%. The observed reduction in the compressive strength values obtained from the samples having the fibre content of 9% is attributed to the prevention of free and uniform spreading of the cement slurry through the utilised high-volume fibre which leads to many voids in fibre matrix. It is highlighted that the compressive and flexural strength values are decreased due to the difficulty of passing mortar through the fibre matrix because of these resulting voids.

Giridhar and Rao (2015) examined the effect of steel fibre utilisation on the mechanical properties of SIFCON in terms of compressive, flexural and tensile strength values obtained from the samples having the steel fibre content of 4-8%, among which the highest compressive, flexural and splitting tensile strength values are attained from the samples produced with 8% steel fibre content. The coinciding results are also obtained from the studies conducted by Soylu and Bingol (2019). The maximum compressive and flexural strength are obtained from the 28-day samples produced with a fiber volume of %8, as 80.12 MPa and 35.85 MPa respectively. Tuyan and Yazici (2012) investigated the mechanical properties of SIFCON produced by steel fibre with hook-end and smooth shapes, and the bond between fibre and matrix. It is revealed that the adherence is increased with the appropriate curing conditions and the increment in the strength of matrix and the fibre diameter. It is also stated that the bonding ability of the hook-end fibre is superior to that of the smooth fibre. It is underlined that as the fibre embedded length is increased, the toughness is improved with the surge in the adherence ability.

Ipek et al. (2014) investigated the flexural strength and fracture toughness of SIFCON samples produced with the steel fibre having the length of 35 mm and 60 mm. It is revealed that while the strain capacity of the samples with steel fibre having the length of 60 mm is higher, the maximum tensile capacity (47.06 MPa) of the samples produced by using steel fibre combination having the length of 35 mm and 60 mm is higher. Yardimci et al. (2007) produced SIFCON samples using single or combined steel and synthetic fibre content of up to 12%. These samples were cured under low steam pressure at 80°C for 24 hours. The highest flexural strength (62 MPa) is obtained from the samples containing 12% steel fibre and the highest flexural toughness value (103367 Nmm) is attained from the samples with 9% steel and 3% synthetic fibre contents. The combined effect of steel and polypropylene fibre on the physical and mechanical properties of SIFCON was investigated by Canbay (2014). It is indicated that steel fibre is more effective on the mechanical properties of samples than that of polypropylene fibre. The compressive strength test results of SIFCON containing 100% steel fiber, 50% steel fiber-50% polypropylene fiber and 100% polypropylene fiber are obtained as 141.29, 110.38 and 108.73 MPa, and flexural strength results are obtained as 32.95, 19.21 and 15.60 MPa, respectively. Although polypropylene fibre has lower strength compared to steel fibre, it is suggested that polypropylene fibre would be superior to be used where corrosion risk is higher.

The performance assessment of conventional reinforced concrete and SIFCON has been evaluated in terms of the results obtained from compressive, flexural, tensile strength and abrasion tests by Vijayakumar and Kumar (2017). In this study, the SIFCON samples were produced with the glass fibre content of 1% and the steel fibre contents in the range of 5-11%. The highest compressive and flexural strength values are 36.98 MPa and 5.52 MPa in SIFCON samples containing 1% glass fiber and 9% steel, respectively. It is revealed that SIFCON provides superior performance compared to that of normal reinforced concrete. It is underlined that the highest performance is attained from the samples having the steel fibre content of 9%, higher the fibre content is more difficult for mortar to settle, which adversely affects the results. Ipek and Aksu (2019) investigated the combined effect of steel and polypropylene fibre blends. The highest flexural strength values obtained from fully fibre-filled beam samples are attained as 44 MPa and 41 MPa from the samples having the steel fibre combined lengths of 60 mm and 35 mm, and the combined lengths of 60 mm steel and 50 mm polypropylene fibre, respectively. It is highlighted that the combined polypropylene and steel fibre utilisation improves flexural strength and fracture toughness. The polypropylene fibre provides significant advantages in terms of its unit weight and cost compared to steel fibre.

The reason of basalt fiber preferred to be used in SIFCON applications in the presented study is not just because it is an environmental-friendly material and it has a superior characteristic as higher tensile strength properties, it also overcomes the drawbacks such as corrosion and higher weight of steel fibre that could be more critical in some specific SIFCON applications. Although several researches in the literature present the effect of steel and polypropylene fibre on the mechanical properties of SIFCON, it is the first time in the literature (to the best of the authors' knowledge), the basalt fibre utilisation is considered in the production of SIFCON and presented in this paper. The durability and mechanical properties of SIFCON incorporated with basalt fibre having various volumetric replacement ratios of steel fibre are investigated in this presenting research and some substantial conclusions are drawn.

Table 1. Chemical composition and physical properties of cement and silica fume.

Chemical properties	Portland cement	Silica fume
CaO	63.52	2.06
SiO_2	19.54	91.92
Al_2O_3	4.47	0.42
Fe_2O_3	2.94	0.20
MgO	1.27	3.28
SO_3	2.73	0.83
K_2O	0.90	2.58
Na_2O	0.14	0.55
Loss on ignition (%)	3.92	1.68
Physical properties		
Specific gravity	3.12	2.2
Blaine fineness (m^2/kg)	384	20000

2. Materials and Methods

2.1. Materials

In this study, the silica fume which is obtained from Eti Elektrometalurji Inc. in Turkey and CEM I 42.5R type of Portland cement are used. The physical properties and chemical compositions of Portland cement and silica fume are given in Table 1.

CEN standard sand complying with TS EN 196-1 (2016) was used to prepare SIFCON mixtures. Standard sand is produced by Limak Trakya Cement Factor in Turkey. The sieve analysis results of sand having the specific gravity of 2.6 are given in Table 2. The polycarboxylic-ether based superplasticizer (SP) having the specific gravity of 1.10 was utilised.

KMX 55/30 BL type of steel fibre having hooks on both ends obtained from Kemerli Metal Industry and Trade Inc. were used, which are of the length of 30 mm, the diameter of 0.55 mm and the specific gravity of 7.18. The basalt fibre was procured from Spinteks Textile Construction Industry and Trade Inc., which are having the length of 24 mm, the diameter of 14 microns, and the specific gravity of 2.78. The close view images of steel and basalt fibre used in the presented study are given in Figure 1.

2.2. Detail of Mixes and Preparation

Although there is no standard for SIFCON slurry mixes at present, the slurry must have a sufficient level of fluidity to pass through the fibre without snagging to attain a void-free structure. The water/cement (w/c) ratio of the SIFCON slurry prepared in this study was specified as 0.3, the content of binder was designated as 1000 kg/m^3, and the silica fume was incorporated as 10% of the binder. It is stated by the previous researchers that the mini-flow diameter of SIFCON slurry should be approximately 38 cm

Table 2. Sieve analysis results of sand.

Sieve size (mm)	2.00	1.60	1.00	0.50	0.16	0.08
Percentage passing (%)	0.00	6.37	33.47	67.18	86.92	99.33

for adequate workability for the utilization of steel fiber (e.g. (Ipek et al. 2014, Ipek and Aksu 2019)). In this study, the mini-flow test was carried out as per TS EN 1015-3/A2 (2000) on the trial mixtures using various superplasticizer ratios. Accordingly, the amount of superplasticizer required in the mixture for the flow diameter of 38±1 cm was specified as 1.4% of the binder (see Figure 2A). In addition, the mini V-funnel test shown in Figure 2B was conducted and the flow time for SIFCON slurry was obtained as 3.21 s. The mix proportions for the SIFCON slurry used in this study are given in Table 3.

In the mixing procedure for the SIFCON slurry, initially, the cement and silica fume as a binder were mixed, then sand was added and mixed until a uniform distribution was attained. Then, two-thirds of the water was added to the mixture and mixed, and finally, the remaining water mixed with the superplasticizer was added into the mixture and mixed for another 2-3 minutes.

The fibre rate of 6.8% by volume was used in the production of all SIFCON samples. The total number of 5 SIFCON mixtures have been produced with the rates of fibre which are 100% steel fibre (control), 75% steel fibre and 25% basalt

Table 3. Mixing ratios for SIFCON slurry in 1 m^3.

Materials	Amount (kg)
Cement	900
Silica fume	100
Sand	919
Water	300
Superplasticizer	14

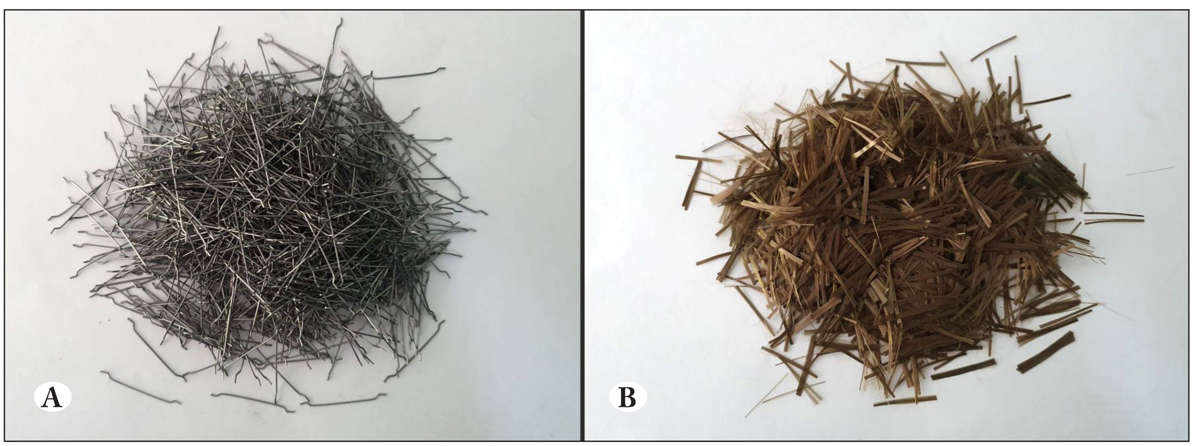

Figure 1. Fibre used in the production of SIFCON **(A)** steel fibre **(B)** basalt fibre.

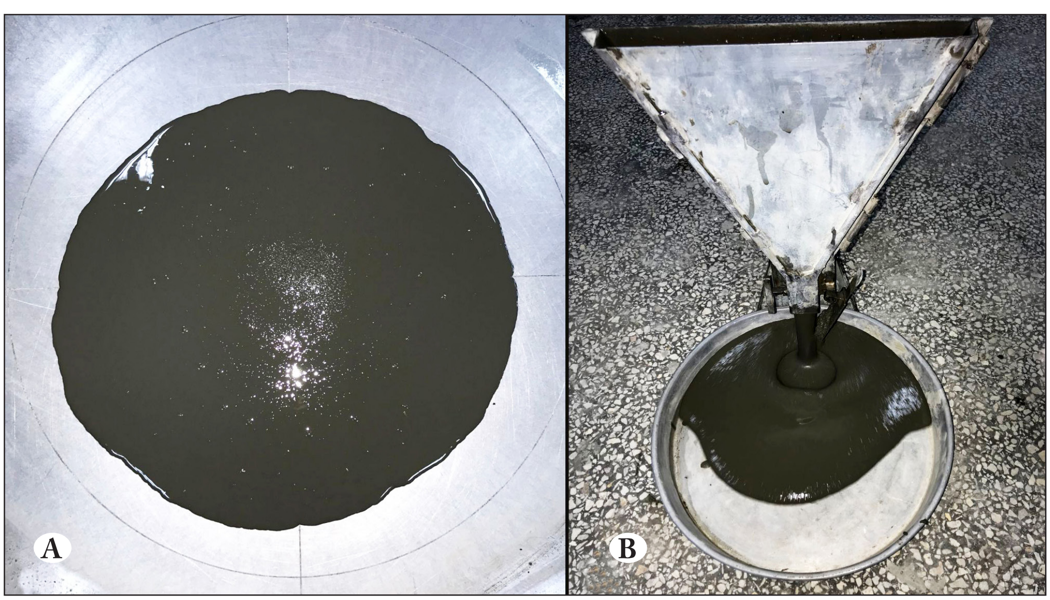

Figure 2. Flowability of SIFCON slurry **(A)** mini slump-flow **(B)** mini V-funnel.

fibre, 50% steel fibre and 50% basalt fibre, 25% steel fibre and 75% basalt fibre, and finally 100% basalt fibre. Several studies in the literature suggest considering the multi-layer method for the production of SIFCON samples in order to attain a homogeneous fibre distribution at every point of the mould and to allow the slurry fully flowing through the fibre (Abdalay et al. 2019, Ali 2018, Khamees et al. 2020, Alcan and Bingol 2019, Bajpai and Chandak 2018). Therefore, in the present study, the three-layer technique was used in the production of SIFCON samples. In this method, after one-third of the total fibre volume was randomly placed in the mould, the SIFCON slurry was then poured into the mould for slightly covering the fibre placed in the mould, and similarly, the process was repeated for the other two layers. After 24 hours of casting, the cube and beam specimens were demoulded and cured in water until the day of experiment was conducted.

2.3. Testing

The testing programs were designed to identify how the basalt fibre replacement ratios affect the durability and mechanical properties of SIFCON. Accordingly, compressive strength, flexural strength, sorptivity, water absorption, acid attack and Bohme abrasion tests were conducted. Compressive strength values for 7, 14 and 28-day samples were determined using 3 cube sample sets having the dimensions of 50x50x50 mm obtained from each SIFCON mixture according to ASTM C109/C109M-20 (2020). In order to identify the flexural strength values, the three-point flexural tests were carried out complying with ASTM C348-18 (2018) standard on three beam samples having the dimensions of 40x40x160 mm cured up to 7 and 28 days for each mixture.

The sorptivity test was performed on 28-day cured cube samples having the dimensions of 50x50x50 mm, which were initially dried to obtain the constant weight in the oven and then kept in ambient temperature to cool them down. The side surfaces of samples were covered with waterproof tape in order to allow the capillary absorption only from the bottom surface. After measuring the mass, they were placed into the container which was filled with enough water to just cover the bottom surface. In order to obtain the mass gained at different time intervals (i.e. 1, 4, 9, 16, 25, 36, 49 and 64 minutes) the samples were removed out of the container, surface dried and weighed. Accordingly, the sorptivity values were specified considering the slope of regression curve based on the relationship between the amount of water absorbed from the unit surface area and the square root of elapsed time. The water absorption test was performed using 28-day cured cube samples having the dimensions of 50x50x50 mm complying with ASTM C642-21 (2021). The saturated surface dry weight (W_{ssd}) of the SIFCON samples were measured and then the samples were dried in an oven until attaining a constant weight. After the dry weight (W_d) measurement of the samples, the water absorption ratios of SIFCON samples were calculated using the equation as follows.

$$WA = \frac{W_{ssd} - W_d}{W_d} \times 100 \qquad \text{(Eq. 1)}$$

The performance of SIFCON samples against acid attack was identified by examining the change in weight, compressive and flexural strength values. The cube and prism samples having the dimensions of 50x50x50 mm and 40x40x160 mm cured in water for 28 days were placed in a solution with 7% H_2SO_4 (acid) concentration after the curing time is ended. Another set of samples from each mixture was kept in water to identify the acid effect by comparison. The solution was renewed every 20 days due to the change in the concentration of the acid solution in which the samples were kept. During this acid solution change, the surface of samples was cleaned, dried and their weights were measured. Compressive and flexural strength tests were applied to the samples exposed to H_2SO_4 solution for 90 days and samples kept in water.

Bohme test complying with TS 2824 EN 1338 (2005) was carried out to determine the abrasion resistance of SIFCON samples. The cube samples with a size of 71±1.5 mm were used in this experiment. The 28-day cured samples were dried in the oven until attaining the constant weight. Then the measurements of weight and dimensions of the samples were undertaken. The samples were placed in a clamp and an axial force of 294 ± 3 N was applied. After placing 20 g of standard abrasive grain on the test track, the sample was subjected to 22 revolutions which is referred as a cycle. After each cycle, the disc and the contacted face of the sample were cleaned and the sample was rotated by 90° around its vertical axis. After each 4 cycle-set the dimensions and weight of the sample were measured. After the test was repeated 16 cycle-set, the total volume loss was determined using the equation as follows.

$$\Delta V = \frac{\Delta m}{\rho} \qquad \text{(Eq. 2)}$$

ΔV = is volume loss after 16 cycle-set (measured from mass), cm^3

Δm = is mass loss after 16 cycle-set, g

ρ = is volume bulk density of the sample g/cm^3

3. Results and Discussion

The flexural strength tests were performed on the 7-day and 28-day water cured SIFCON samples having the basalt fibre replacement ratios of 0%, 25%, 50%, 75% and 100%. Figure 3 indicates the variation of flexural strength values in terms of the basalt fibre replacement ratios. Figure 3 shows that the flexural strength values from the 7-day cured samples are in the range of 23-33 MPa and the results from the 28-day cured samples are in the range of 26-36 MPa. The flexural strength values from the 7-day cured samples with the basalt fibre replacement ratios of 0, 25, 50, 75 and 100% were obtained approximately as 33, 32, 32, 31 and 24 MPa, respectively. The flexural strength results from the 7-day cured samples reveal that using basalt fibre replacement ratios up to 75% insignificantly affect the flexural strength of SIFCON samples. However, Figure 3 indicates that using 100% basalt fibre replacement ratio reduces the flexural strength of the 7-day cured samples by approximately 28% compared to the samples produced with 100% steel fibre (control). The flexural strength values from the 28-day cured samples having the basalt fibre replacement ratios of 0, 25, 50, 75 and 100% were obtained approximately as 36, 35, 34, 32 and 26 MPa, respectively. Figure 3 shows that using basalt fibre replacement ratios up to 50% insignificantly affect the flexural strength values from the 28-day cured samples. However, the flexural strength results from the 28-day cured sample having 75 and 100% basalt fibre replacement ratios are reduced by approximately 12% and 27% compared to the samples produced with 100% steel fibre, respectively.

The research conducted by Ipek and Aksu (2019) has revealed the similar results compared to the results obtained in the presented study. It is highlighted in their study that the highest flexural strength values attained in the fully fibre-filled beam samples are specified as 44 MPa and 41 MPa, respectively, for the samples having the combination of equal volume steel fibre having the lengths of 60 mm and 35 mm, and for the samples having the combination of steel fibre having the length of 60 mm (66% of total fiber volume) and polypropylene fibre having the length of 50 mm (33% of total fiber volume).

Figure 4 shows the compressive strength results from the SIFCON samples, which are obtained at the curing ages of 7, 14 and 28 days. The results from the samples with 100% steel fibre (i.e. the basalt replacement ratio of 0%) for all curing ages are within the range of 46-86 MPa. Figure 4 indicates that the compressive strength results vary as 86, 68, 55, 38 and 29 MPa for the samples having the basalt fibre replacement ratios of 0, 25, 50, 75 and 100% at the curing age of 28-day, respectively. Figure 4 shows that the compressive strength results are reduced with the increase in basalt fibre replacement ratio for all curing ages. The percentage reductions in compressive strength for 7-day cured samples are about 22%, 44%, 56% and 56%, for 14-day cured samples are about 18%, 40%, 58% and 62%, for 28-day cured samples are about 20%, 35%, 56% and 66% (for the basalt replacement of 25%, 50%, 75% and 100%), respectively. When the compressive strength values in Figure 4 are compared in terms of the curing time, the rate of increment corresponding to the same replacement ratios gradually decreases with an increase in basalt fibre content.

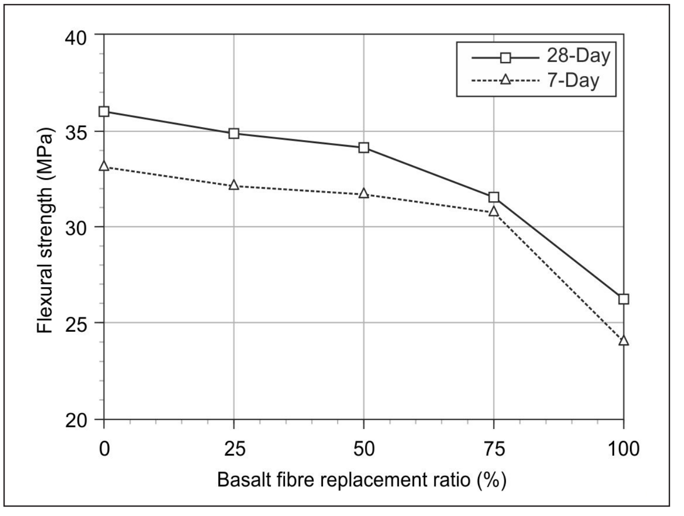

Figure 3. The variation of flexural strength values in terms of the basalt fibre replacement ratios.

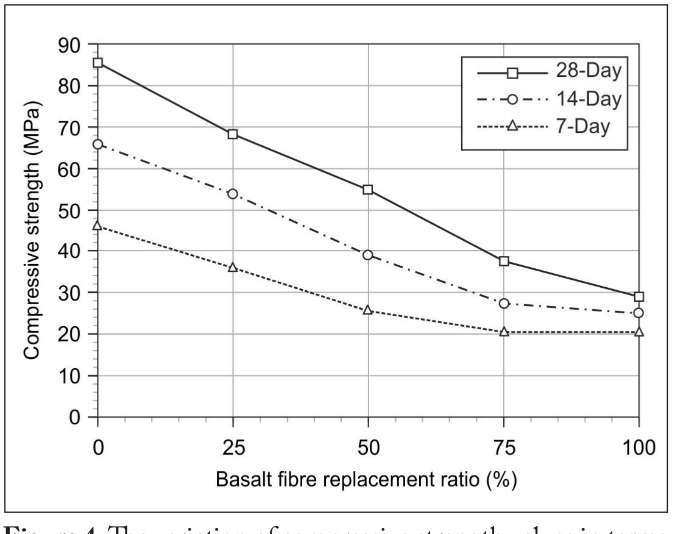

Figure 4. The variation of compressive strength values in terms of the basalt fibre replacement ratios.

The difference in compressive strength results for 7, 14 and 28-day cured samples with 100% basalt fibre replacement ratio are minimal compared to the results obtained from the samples having lower replacement ratios. Since basalt fibre is of lower density than that of steel fibre, the quantity of basalt fibre is higher than the steel fibre volumetrically replaced. Since the agglomeration of the basalt fibre occurs in the samples with high replacement ratio, the compressive strength result dramatically reduces due to non-uniformity of the sample, which is attributed to the non-infiltration of cement slurry through the basalt fibre. This outcome of the presented study also coincides with the comments made by Zhang et al. (2020) investigated the mechanical properties of reactive powder concrete (RPC) using steel and basalt fibers. Zhang et al. (2020) reveals that as the amount of steel fiber used is high, the excessive amount of basalt fiber causes adverse effects such as entanglement and agglomeration of the fibers. Accordingly, the contact interface decreases between the fiber and the cementitious material, resulting in a weakening of the bond between the fiber and the cement slurry. This subsequently affects the compactness of the RPC matrix, increases the internal defects, reduces the effective internal bearing contact surface area of the RPC material and makes harder to improve the mechanical properties.

Figure 5 shows the variation of water absorption results obtained from 28-day cured samples in terms of the basalt fibre replacement ratios, which fall within the range of 2.6-3.2 %. Figure 5 indicates that the water absorption values slightly increase with the increment in the basalt fibre replacement ratio, which are about 3%, 13%, 13% and 22% for the basalt ratio of 25%, 50%, 75% and 100%, respectively. The sorptivity values obtained from the SIFCON samples are given in Figure 6 which demonstrates that the results vary in the range of 0.0225-0.015 mm/min$^{1/2}$. Figure 6 shows that the sorptivity coefficients reduce with an increase in the basalt fibre replacement ratio. The percentage reduction in sorptivity result is about 9%, 28%, 25% and 33% for the basalt replacement ratios of 25%, 50%, 75% and 100%, respectively. The capillarity and permeability properties of concrete defer widely depending on the void structure of concrete, which vary in terms of both the continuity and the ratio of voids along with the voids' size variation. Sorptivity depends on the amount of continuous capillary voids in the concrete (viz. total capillary void volume) and their size. Accordingly it is observed in this study that the increase in water absorption capacity and the reduction in the sorptivity occur due to the increase in basalt fiber content of SIFCON since the basalt fibre utilization increases the void size and ratio in the vicinity of fiber, which restrains the flow of cement slurry through the fiber properly. Figure 7 indicates the correlation between the sorptivity and the water absorption results obtained from the SIFCON samples. The coefficient of determination level (the R^2 value) for this correlation is also considerably high as 0.98. Bankir, MB (2020) has obtained a similar relationship between the results of the water absorption test and the sorptivity test compared to that of the presented study. It is specified that the capillary water absorption coefficient was low in concretes having high water absorption capacity. This is explained by the bridging effect of the fibers, the movement of water in the fiber line and the number of voids encountered in the concrete.

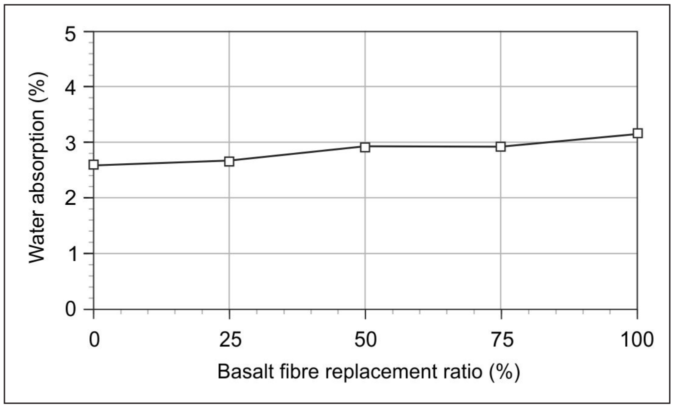

Figure 5. The variation of water absorption values in terms of the basalt fibre replacement ratios.

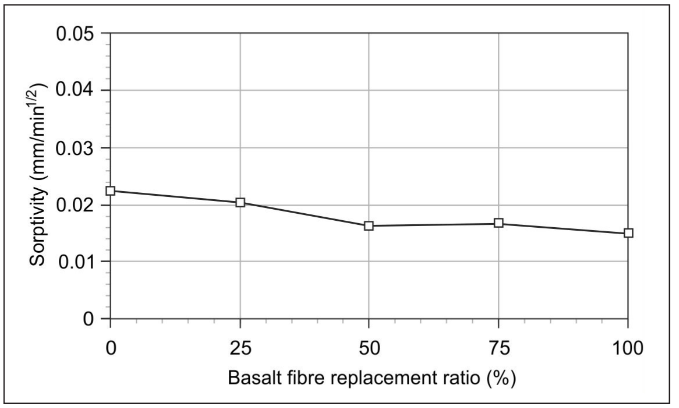

Figure 6. The variation of sorptivity values in terms of the basalt fibre replacement ratios.

The flexural strength results from the SIFCON samples immersed in 7% sulfuric acid solution and kept in water are shown in Figure 8. This figure also indicates the resulting percentage reduction in the strength values. It demonstrates that for the samples immersed in the aggressive acid solution at 90 days, the flexural strength values are reduced compared to the samples kept in water at the same period. The results from the samples kept in water are in the range of 28-39 MPa, while the flexural strength values from the samples exposed to the sulfuric acid solution are in the range of 20-37 MPa. Figure 8 implies that the results from the samples exposed to acid solution are reduced with an increase in the basalt fibre replacement ratio. The flexural strength values from the samples exposed to acid solution and having the basalt fibre contents of 0%, 25%, 50%, 75% and 100% are reduced approximately by 6%, 12%, 17%, 21% and 30% compared to that of the samples kept in water corresponding to the same basalt fibre replacement ratio, respectively.

The compressive strength results of SIFCON samples immersed in 7% sulfuric acid solution and kept in water are shown in Figure 9. This figure also indicates the resulting percentage reduction in the strength values. It demonstrates that the compressive strength values from the samples immersed at 90 days in aggressive sulfuric acid solutions are reduced comparing with the samples kept in water at the same period. The results from the samples kept in water are in the range of 52-107 MPa, while the compressive strength values from the samples exposed to the sulfuric acid solution are in the range of 11-43 MPa. Figure 9 shows that the results from the samples exposed to acid solution are reduced with an increase in the basalt fibre replacement ratio. The results from the samples exposed to acid solution and having the basalt fibre replacement ratios of 0%, 25%, 50%, 75% and 100% are reduced approximately by 60%, 72%, 72%, 77% and 78% compared to that of the samples kept in water corresponding to the same basalt fibre replacement ratio, respectively.

Figure 10 shows the time-dependent weight loss results of the SIFCON samples exposed to acid solution. The weight loss values of the samples are in the range of 0-45%. Figure 10 indicates that the weight loss surges by an increase in the exposure time. The weight loss results from the samples containing the basalt fibre replacement ratios of 0% 25% and 50% vary in the range of 0-15%, while the weight loss results from the samples having the basalt fibre replacement ratios of 75% and 100% are diversified within the range of 8-45%. This variation is attributed to the increase of voids in SIFCON owing to the basalt fibre utilisation at a higher rate, accordingly, the acid solution penetrates into the internal structure and subsequently causes more deterioration in the sample.

Figure 11 indicates the variation of Bohme abrasion test results obtained from 28-day cured SIFCON samples in

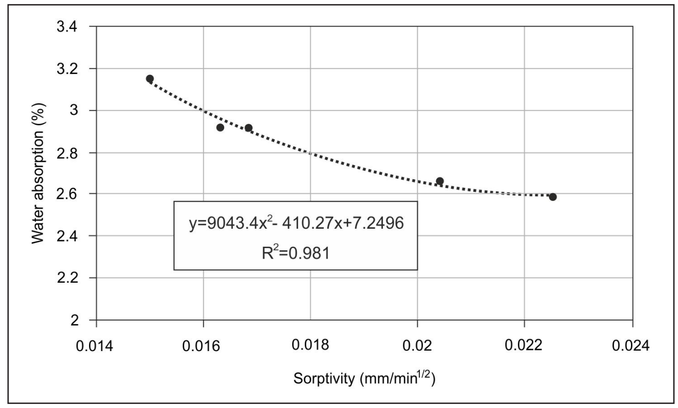

Figure 7. Correlation between sorptivity and water absorption values.

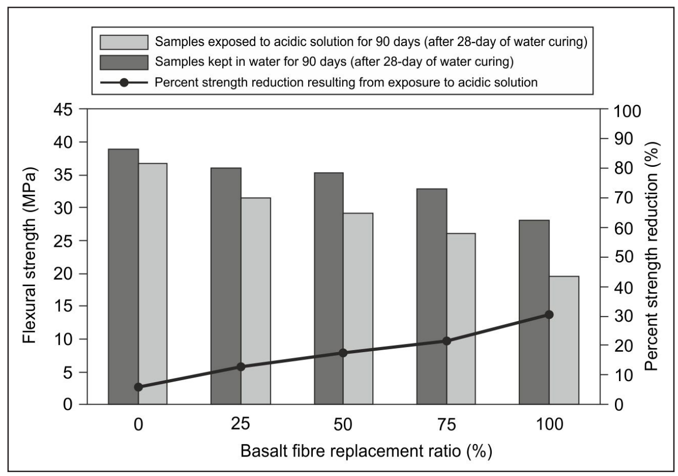

Figure 8. The flexural strength values from the samples exposed to acid solution and kept in water, and the percent strength reduction variation.

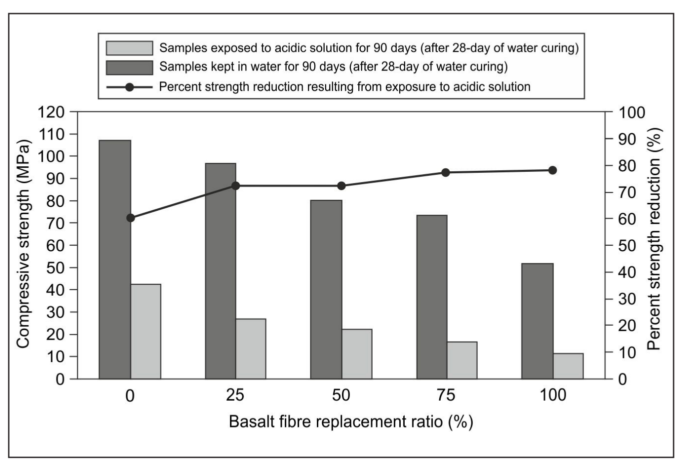

Figure 9. The compressive strength values from the samples exposed to acid solution and kept in water, and the percent strength reduction variation.

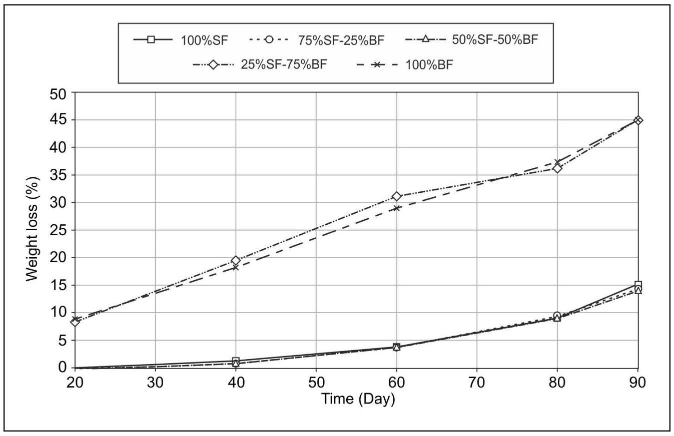

Figure 10. The time-dependent weight loss variation of SIFCON samples exposed to acid solution.

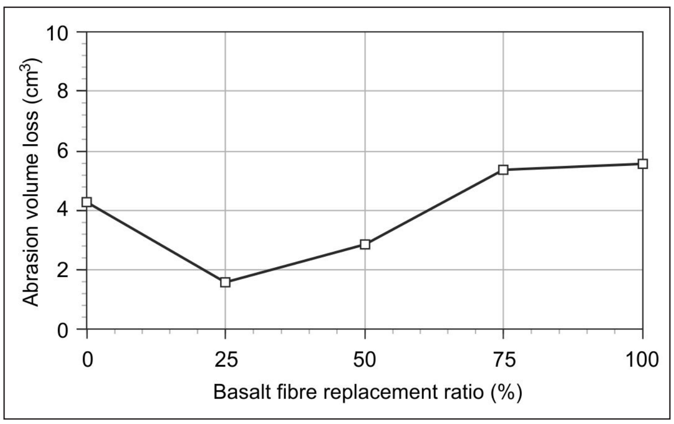

Figure 11. Variation of abrasion loss values for the SIFCON samples in terms of the basalt fibre utilisation ratios.

terms of the basalt fibre replacement ratios. The abrasion loss values of samples are in the range of 1.6-5.6 cm^3. Figure 11 shows that the abrasion loss is reduced up to the basalt fibre replacement ratio of 50%. The percentage reduction in abrasion loss are about 63% and 33% for the basalt fibre replacement ratios of 25% and 50%, respectively. The percentage increases in abrasion loss from the samples having the basalt fibre replacement ratios of 75% and 100% are about 26% and 31%, respectively.

Atis et al. (2009) states that there is a stronger relationship between surface abrasion and flexural strength rather than compressive strength. This outcome also coincides with the results from the presenting research, in which it is observed that the compressive strength values from the SIFCON samples are reduced with an increase in the basalt fibre replacement ratio, unlike the flexural strength value obtained from 28-day cured samples up to the replacement ratio of 50% (see Figure 3). This signifies that abrasion resistance is more related to flexural strength rather than compressive strength.

Considering the abrasion volume loss results obtained from the Bohme abrasion test, it is observed that the basalt fibre replacement ratio of up to 50% leads to a reduction in the abrasion volume loss. Since the abrasion is referred to the breaking off the particles from the sample body resulting from the frictional forces caused by the abrasive material or impact forces from the rolling action, it causes the tensile stresses exceeding the corresponding strength of the material subjected to abrasion. It is demonstrated that the fibre act as the crack inhibitors in concrete, which improve the tensile strength and toughness of the samples, and accordingly reduce the abrasion damage. The samples, in which steel and basalt fibre combination is used, demonstrate a superior performance than the samples containing only steel fibre or basalt fibre per se. Thus, a suitable steel and basalt fibre combination provides higher abrasion resistance. In the case of a combined utilisation of macro and micro-fibre, micro-cracks are initially surrounded micro-fibre which delay the coalescence of cracks in the cement paste and mortar phase, and subsequently increase the apparent tensile strength in these phases. Then, the increased stress is transferred to macro-fibre by bridging the micro-cracked region. Thus, convergence and coalescence of cracks are delayed. Accordingly, the utilisation of basalt fibre up to 50% prevents the separation of concrete particles from the sample body due to the friction forces caused by the abrasive material.

4. Conclusion

The following conclusions may be drawn based on the findings from the presented experimental study.

- The flexural strength results from 7-day cured samples reveal that using basalt fibre replacement ratios up to 75% insignificantly affect the flexural strength of SIFCON samples. However, using 100% basalt fibre replacement ratio reduces the flexural strength of 7-day cured samples by approximately 28% compared to the samples produced with 100% steel fibre (control). In the case of 28-day cured samples, using basalt fibre replacement ratios up to 50% also insignificantly affect the flexural strength values. However, the flexural strength results from 28-day cured samples having 75 and 100% basalt fibre replacement ratios are reduce by approximately 12% and 27% compared to the sample produced with 100% steel fibre, respectively.

- The compressive strength reduces with the increase in basalt fibre replacement ratio for all curing age. When the compressive strength values are compared depending on the curing time, the rate of increment corresponding to the same replacement ratios gradually is reduced with an increase in basalt fibre content. The difference in compressive strength results for 7, 14 and 28-day cured samples with 100% basalt fibre replacement ratios are minimal compared to the results obtained from the samples having lower replacement ratios. Since basalt fibre are of lower density than that of steel fibre, the quantity of basalt fibre is higher than the steel fibre volumetrically replaced. Since the agglomeration of the basalt fibre occurs in the samples having high replacement ratio, the compressive strength results are dramatically reduced due to non-uniformity of the sample, which is attributed to the non-infiltration of cement slurry through the basalt fibre.
- The water absorption values are slightly increased with an increment in the basalt fibre replacement ratio due to the increase in the number of pores within the interior structure.
- The sorptivity coefficients are reduced with an increase in the basalt fibre replacement ratio. There is a strong correlation between the sorptivity and the water absorption results obtained from the SIFCON samples.
- The weight loss results from the samples containing the basalt fibre replacement ratios of 0% 25% and 50% vary in the range of 0-15%, while the weight loss results from the samples having the basalt fibre replacement ratios of 75% and 100% diversify in the range of 8-45%. This variation is attributed to the increase of voids in SIFCON owing to the basalt fibre utilisation at a higher rate, the acid solution penetrates into the internal structure and subsequently causes more deterioration in the sample.
- The abrasion loss is reduced up to the basalt fibre replacement ratio of 50%. The percentage reduction in abrasion loss are about 63% and 33% for the basalt fibre replacement ratios of 25% and 50%, respectively. The percentage increases in abrasion loss from the samples having the basalt fibre replacement ratios of 75% and 100% are about 26% and 31%, respectively. This signifies that a suitable steel and basalt fibre combination provides the highest abrasion resistance.

4. References

Abdalay, N.M.A., Zeini, H.A., Kubba, H.Z. 2019. Effect of impact load on SIFCON. Global Journal of Researches in Engineering, 19:17-27.

Akçaözoğlu, K., Kıllı, A. 2021. The effect of curing conditions on the mechanical properties of SIFCON. Revista de la Construcción, 20:37-51. https://doi.org/10.7764/RDLC.20.1.37

Alcan, H.G., Bingol, A.F. 2019. Examining SIFCON's mechanical behaviors according to different fiber and matrix phase. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 43:501–507. https://doi.org/10.1007/s40996-018-00227-x

Ali, M.A. 2018. Properties of slurry infiltrated fiber concrete (SIFCON). Ph.D. Thesis, Department of Building and Construction Engineering of the University of Technology.

ASTM C109/C109M-20. Standard test method for compressive strength of hydraulic cement mortars (Using 2-in. or [50-mm] cube specimens), West Conshohocken, PA, 2020.

ASTM C348-18. Standard test method for flexural strength of hydraulic-cement mortars, West Conshohocken, PA, 2018.

ASTM C642-21. Standard test method for density, absorption and voids in hardened concrete, West Conshohocken, PA, 2021.

Atis, C., Karahan, O., Ari, K., Sola, Ö.C., Bilim, C. 2009. Relation between strength properties (flexural and compressive) and abrasion resistance of fiber (steel and polypropylene)-reinforced fly ash concrete. Journal of Materials in Civil Engineering, 21:402-408. http://dx.doi.org/10.1061/(ASCE)0899-1561(2009)21:8(402)

Bajpai, A., Chandak, R. 2018. Experimental studies on slurry infiltrated fibrous concrete (SIFCON). International Journal for Technological Research İn Engineering, 5:3180-3183.

Bankir, M.B. (2020). Investigation of mechanical and durability properties of hybrid fiber concretes and performance optimization. Ph.D. Thesis, Iskenderun Technical University Engineering and Science Institute, 168 p. (In Turkish)

Beglarigale, A., Yalçınkaya, Ç., Keskinateş, M., Yazıcı, H. 2014. The influence of fiber-matrix bond characteristics on tensile performance of SIFCON. 11th International Congress on Advances in Civil Engineering, Istanbul, Turkey.

Canbay, M. 2014. The effect of steel and polypropylene fibers as combination and single use SIFCON. M.Sc. Thesis, Sakarya University The Graduate School of Natural and Applied Sciences, 91 p. (In Turkish)

Elavarasi, D., Mohan, K.S.R. 2016. Performance of slurry infiltrated fibrous concrete (SIFCON) with silica fume. International Journal of Chemical Sciences, 14:2710-2722.

Giridhar, R., Rao, P.R.M. 2015. Determination of mechanical properties of slurry infiltrated concrete (SIFCON). International Journal for Technological Research in Engineering, 2:1366-1368.

Ipek, M., Aksu, M. 2019. The effect of different types of fiber on flexure strength and fracture toughness in SIFCON. Construction and Building Materials, 214:207–218. https://doi.org/10.1016/j.conbuildmat.2019.04.055

Ipek, M., Aksu, M., Yılmaz, K., Uysal, M. 2014. The effect of pre-setting pressure on the flexural strength and fracture toughness of SIFCON during the setting phase. Construction and Building Materials, 66:515–521. https://doi.org/10.1016/j.conbuildmat.2014.04.107

Khamees, S.S., Kadhum, M.M., Alwash, N.A. 2020. Effects of steel fibers geometry on the mechanical properties of SIFCON concrete. Civil Engineering Journal, 6:21-33. http://dx.doi.org/10.28991/cej-2020-03091450

Lankard, D.R. 1984. Properties, applications: slurry infiltrated fiber concrete (SIFCON). Concrete International, 6:44-47.

Lankard, D.R., Newell, J.K. 1984. Preparation of highly reinforced steel fiber reinforced concrete composites. Fiber Reinforced Concrete–International Symposium, SP-81, American Concrete Institute, pp. 287-306.

Sharma, H.K., Singh, V.P. 2008. Performance characteristics SIFCON plates. 2nd IASME/WSEAS International Conference on GEOLOGY and SEISMOLOGY (GES'08), pp. 149-154, Cambridge, UK.

Soylu, N., Bingöl, A.F. 2019. Research on effect of the quantity and aspect ratio of steel fibers on compressive and flexural strength of SIFCON. Challenge Journal of Structural Mechanics, 5:29-34. https://doi.org/10.20528/cjsmec.2019.01.004

Tabak, V. 2004. Effect of fiber aspect ratio and fiber volume variation on mechanical properties of steel concrete. M.Sc. Thesis, Dokuz Eylül University the Graduate School of Natural and Applied Sciences, 148 p. (In Turkish)

TS 2824 EN 1338. Concrete paving blocks-Requirements and test methods. Turkish Standards Institute, 2005.

TS EN 1015-3. Methods of test for mortar for masonry - Part 3: Determination of consistence of fresh mortar (by flow table). Turkish Standards Institute, 2000.

TS EN 196-1. Methods of testing cement - Part 1: Determination of strength. Turkish Standards Institute, 2016.

Tuyan, M., Yazici, H. 2012. Pull-out behavior of single steel fiber from SIFCON matrix. Construction and Building Materials, 35:571-577. https://doi.org/10.1016/j.conbuildmat.2012.04.110

Vijayakumar, M., Kumar, P.D. 2017. Experimental investigation on SIFCON with using different type fibers. International Journal of Scientific Research in Civil Engineering, 2:1-4.

Wang, M.L., Maji, A.K. 1994. Shear properties of slurry ınfiltrated fiber concrete (SIFCON). Construction and Building Materials, 8:161-168. https://doi.org/10.1016/S0950-0618(09)90029-0

Wecharatana, M., Lin, S. 1992. Tensile properties of high performance fiber reinforced concrete. High Performance Fiber Reinforced Cement Composites, London, pp. 248-258.

Yan, A., Wu, K., Zhang, X. 2002. A quantitative study on the surface crack pattern of concrete with high content of steel fiber. Cement and Concrete Research, 32:1371-1375. https://doi.org/10.1016/S0008-8846(02)00788-3

Yardımcı, M.Y., Yiğiter, H., Aydın, S., Yazıcı, H. 2007. Flexural performance of steam cured SIFCON produced with steel and synthetic-macro fibers. 3rd International Symposium on Sustainability in Cement and Concrete, pp. 681-690, Istanbul, Turkey.

Yazıcı, H., Aydın, S., Yiğiter, H., Yardımcı, M.Y., Alptuna, G. 2010. Improvement on SIFCON performance by fiber orientation and high-volume mineral admixtures. Journal of Materials in Civil Engineering, 22:1093-1101. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000114

Zhang, Y., Liu, J., Wang, J., Wu, B. 2020. Effect of hybrid steel-basalt fiber on behaviors of manufactured sand RPC and fiber content optimization using center composite design. Advances in Civil Engineering, Article ID 8877750, 17 p. https://doi.org/10.1155/2020/8877750