

# Investigation of Some mechanical properties of Slurry Infiltrated Fibrous Concrete (SIFCON) Under Different Curing Times

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**Abstract.** This paper attempts to study the mechanical performance and durability of slurry infiltrated fibrous concrete (SIFCON) made using a liquid infiltration method with carbon and Basalt fibers in different curing environments. The high-performance cementitious composite through the innovative process, in which attached fibers are pre-positioned in the mold and subsequently infiltrated with liquid mixture, possesses special properties that enable its much stronger flexibility and durability as against standard concrete. Ordinary Portland cement (Type I), fine sand, fly ash (30% as replacement of fine aggregate) basalt fibers and carbon were used in the study with high-range water-reducing admixture. Workability was determined by means of tests of slump and flow, whereas the compressive, flexural and splitting strengths at 7, 28 and 56 days were tested. Results showed that basalt fibers enhanced the early-age strength, but their effect was limited in the long term. Carbon fibers significantly improved compressive and splitting strengths, with optimal performance at 3-5% fiber content. Blends containing a combination of carbon and basalt fibers exhibited synergistic effects, achieving compressive strength 69% higher than conventional concrete and splitting strength nearly five times higher. Fly ash addition improved matrix density and bond strength, particularly with increasing age. In general, the results confirm the importance of the type and percentage of fibers, as well as the curing time, in the performance of SIFCON concrete. Using a combination of different types of fibers and extending the curing time provides the best balance between strength, flexibility, and durability.

**Keywords.** SIFCON ,Carbon fiber, Basalt fiber ,Fly ash, Curing time ,Compressive strength Splitting tensile strength, Flexural strength, Workability.

## 1. Introduction:

Concrete is the most common structural material as it is strong, durable and versatile. Nonetheless, conventional concrete possesses some inherent limitations including the brittleness of concrete and its low tensile strength leading to cracking and failure under service loads such as dynamic loading or extreme loads. To overcome these drawbacks, special high-performance cementitious composites have been developed and one of them is Slurry Infiltrated Fibrous Concrete (SIFCON) which possesses excellent ductile, impact resistance and energy absorption properties. Contrary to ordinary fiber

reinforced concrete in which random orientation fibers are mixed up with the concrete matrix, SIFCON is prepared by pre-forming an extremely dense volume of fibers within a mold and saturated by highly workable cementitious slurry that passes among many gaps of the loose fibers, leading to more homogeneous distribution pattern of reinforcing material throughout the entire matrix and achieving higher mechanical properties [1].

Properties of SIFCON can be considerably affected by the fiber type, matrix formulation and curing condition. In the latter of these, the choice of fiber is an essential step in determining the mechanical response of composite materials. During the past years carbon fibers and basalt fibers have attracted more and more attention for their excellent mechanical properties, good performances of durability. CFR composites have excellent strength-to-weight ratio, corrosion resistance and its good fatigue properties makes the material suitable for structural applications requiring long-life performance [2]. Basalt fibers extracted from volcanic rock have on the other hand, high thermal resistance and good tensile strength as well as being environmentally friendly and can therefore substitute for synthetics [3]. The simultaneous addition of carbon and basalt fibers into a SIFCON, generating a synergistic effect of strength and toughness, may also have been the cause.

The partial substitution of cement by supplementary cementing materials (SCM), as for example fly ash, is also an important issue in SIFCON's performance. Fly ash, another by product of power plant using coal combustion, is also commonly used in concrete because of its pozzolanic characteristic contributing to improving durability, reducing heat of hydration and developing strength with time [4]. Partially replacing the cement with fly ash not only increases both mechanical strength and durability of SIFCON, it also helps to minimize the carbon foot print due to reduction in production of cement which is harmful for environment and promote sustainable construction.

Curing time is another crucial aspect that affects the microstructure and mechanical properties of cementitious materials. The hydration process in concrete is time-dependent, and the strength development of SIFCON varies with different curing durations. Extended curing periods allow for better hydration and densification of the matrix, leading to improved mechanical properties, while insufficient curing may result in weaker bonds between fibers and the cementitious matrix [5]. Understanding how different curing durations influence the characteristics of SIFCON is essential for optimizing its performance in various construction applications.

This research is focusing on mechanical and durability performances of SIFCON with carbon and basalt fibers using fly ash as a partial replacement of cement. In addition, the influence of variation in curing time on the performance of the composite will be studied. Through the investigation of these aspects, the study aims to facilitate and foster high-performance FRC development as well as casting a light on maximizing SIFCON for practical engineering utilization.

This research explores the complex properties and behavior of SIFCON, a high strength fiber-reinforced which under constant curing durations. It is of particular importance because it attempts to incorporate two advanced fibers—carbon and basalt fibers—that can be incorporated into the SIFCON matrix in order to understand how they affect mechanical properties as well as durability. SIFCON is a novel composite material with high strength, toughness and crack resistance, enjoying broad prospects of application in damage tolerance structures under extreme conditions (e.g. seismic areas, military buildings and industrial slabs). The present work is aimed at developing a deep insight into the influence of curing time on the properties of SIFCON with carbon and basalt fibers towards its optimal utilization as construction material.

The importance of this study is to meet the growing demand for durable and environmentally friendly construction materials. By examining the impact of curing period on SIFCON, this paper aims at

finding out optimal curing conditions to enhance material behavior. Furthermore, the use of carbon or basalt fibers with high tensile strength and corrosion resistance may find a way to improve the mechanical properties of SIFCON. The findings of this research will provide useful information for practicing engineers as well as researchers in the area of advanced concrete technology, thus leading to more efficient producing and implementation of sustainable construction.

Yu Yang, Changhao Xin, Yidan Sun, Jun Chen and Pingfei Liang (2024) [6] Concrete made with coal tailings has lower strength and durability than ordinary concrete, but adding basalt fibers (BF) and polypropylene fibers (PPF) can significantly improve its performance. A 0.1% content of hybrid fibers is considered optimal, enhancing the mechanical strength, stiffness, strain energy, and energy dissipation under uniaxial compression. BF strengthens the bond with the concrete matrix, while PPF helps control crack propagation, thus improving ductility and durability [6]. Gunasekaran Murali, Sallah R. Obaid, Karar Al-Lami, Nikolai Ivanovich Vatin, and others et al, (2023) The materials used included ordinary Portland cement, fine and coarse sand, a liquid admixture (0.4-0.5% by weight of cement), polypropylene fibers, hooked-end steel fibers, and a nanomaterial: multi-walled carbon nanotubes (MWCNTs, 97% purity, 2-10  $\mu\text{m}$  length, 10-15 nm diameter, 250-270  $\text{m}^2/\text{g}$  surface area), added at 0.1% of the cement weight [7]. Luma et al., (2024) The study also discussed utilization of a quantity of cement replacement by different materials like silica fume and fly ash, with variation in steel fiber content over workability, density, compressive strength, flexural strength and energy absorption. In addition, the study investigated the response of SIFCON when exposed to different environmental attacks like sulfate, acid and high temperature [8]. Nadia M. et al., (2019) investigated the mechanical responses and impact characteristics of steel fiber on (SIFCON) in comparison to normal concrete. This concrete mixture was manufactured from 10% silica fume, 20% Class F Fly ash and 6% fine steel fibers (all by volume), as well as regular Portland cement (Krasta), Turkish fly ash and a liquid admixture (BASF Glenium 54). A Procedure for Casting in Two Layers to Obtain a Uniform Fiber Distribution. Tests, conducted according to ASTM and BS standards. The synergistic effect of the steel fibers, silica fume, and fly ash was the primary factor contributing to the improved performance of this concrete. [9]. (Mini Soman, et al 2012) In this study, chemical properties of fly ash were studied by providing the constituents and its percentage. Physical properties also mentioned like Fineness residue, Moisture content, Soundness. 20, 30, 40, 50, 60 % of cement replaced with fly ash. From results, it was observed that the minimum replacement of cement by fly ash could be 50% without affecting on its hardened and fresh properties. Four beams casted under reinforcement for two beams and the other two balanced reinforcement [10], (Dr. K.V. Ramesh et al. 2016): conducted an experimental study on normal concrete and concrete with partial cement replacement using fly ash at (30%, 40%, and 50%). The fly ash mixes turned orange-red. And surface cracks appeared at 600°C and became more visible at 800°C, while no visible cracks noted below 400°C. The weight loss decreased with higher fly ash content. The compressive strength decreased with increasing temperature and fly ash content. Peak strength was observed at 7 days for the normal mix and at 28 days for the C70 and F30 mixes [10].

## 2. Materials

2.1 Binding materials : Cement used in this study is ordinary portland cement ( Tasluja)( portland cement Type I )

- Grade strength: CEM I 42.5 R — meaning it is a high early strength cement (the “R” stands for “rapid/early strength”).
- Standards compliance: Complies with Iraqi Standard IQ.S 5:1984 – Type I

Also complies with European standard EN 197-1:2011 for CEM I 42.5 R cement , chemical and physical properties of cement shown in Table 1 and Table 2.

Table 1. Physical properties of Portland cement[11][12] .

Test	Requirments	Results
Finess specific surface(m2/Kg)	260 Minimum	317
Setting Time ( minutes)	-	-
Initial	45 Minimum	190
Final	375 Minimum	255
Soundness Autoclave Expansion (%)	0.8 Maximum	0.04
Compressive strength 50 mm Mortar Cubes (Mpa)	-	-
3 days	12 Minimum	19
7 days	19 Minimum	24
28 days	Not Applicable	34.1

Table 2. Chemical characteristics of Portland cement using XRF technique

IR—Insoluble Residue; XRF—X-ray Fluorescence[11][12].

Compostion	Requirments	(%)
SiO2	No limit	21
IR	5% Max	0.28
Al2O3	No limit	5
Fe2O3	No limit	3.8
CaO	No limit	63.4
MgO	6% Max	2.3
SO3	3.5% Max	2.5
Na2O	Nolimit	0.22
K2O	No limit	0.5
LOI	3% Max	1.6
C3S	No limit	45.2
C2S	No limit	26
C3A	No limit	7
C4AF	No limit	11.4

2.2 Fine aggregate : In this study, standard sand sourced from the Iraqi Geological Survey under the Ministry of Industry and Mining was employed. The size distribution of particle and harmful materials for the sand is detailed in Table 3 and Table 4. Upon analysis of its gradation, it was found to conform to the specified grading criteria outlined in the ASTM C778 standard [13].

Table 3. Red Sand Test Result

Sieve Size(mm)	Percentage passing(%)	Iraqi Specification Limits No.45(1984)_Zone 2
10.00	100.00	100
4.75	92.70	90_100

2.36	79.65	75_100
1.18	68.60	55_90
0.60	52.60	35_59
0.30	27.40	8_30
0.15	2.65	0_10

Table 4. Red sand test of Harmful Materials.

Test	Result	Specification Limit
Sulfate salts % (SO <sub>3</sub> )	0.37	0.5 max

2.3. Fly ash : Fly ash (FA) is a fine powder recovered from the flue gases of coal-fired power plants (shown in Fig . 1 c). It is a widely used pozzolan in concrete due to its ability to improve workability, reduce heat of hydration, and enhance durability[14]. Fly ash class F used in this study , all chemical characteristics shown in Table 5 below.

Table 5. Chemical characteristics of Turkish FA .

Oxides	%
SiO <sub>2</sub>	58.7
Fe <sub>2</sub> O <sub>3</sub>	7.43
CaO	3.73
MgO	0.15
SO <sub>3</sub>	0.12
Al <sub>2</sub> O <sub>3</sub>	21.13
Loss of Ignition (LOI)	2.46

2.4. Basalt fiber : Basalt fiber is a mineral-based fiber derived from molten basalt rock. It is known for its high strength, thermal stability, and resistance to chemical corrosion, making it an ideal material for use in high-performance applications [15], all production properties shown below in Table 6.

basalt fiber used in this study chopped strands with 10 mm length ( Shown in Fig 1.b )

Table 6. Basalt fiber production properties.

Item	Unit	Standard Value
Line Density	Tex	±8
Filament Diameter	Filament Diameter	16 um
Moisture	%	≤0.2
Tensile Strength	Mpa	≥3550
Elastic Modulus	Gpa	≥40

Break Strength	N/tex	≥0.4
Tensile Rate Of Break	%	≤3.1

Apperance : No stains, impurities, hairiness and other defects; uniform color, dark brown, rich in metallic luster .

2.5. Carbon fiber : Carbon fiber is a lightweight, high-strength material composed of thin strands of carbon atoms bonded together in a crystalline structure. It is known for its exceptional tensile strength, stiffness, and corrosion resistance, making it an ideal material for use in high-performance applications [16]. carbon fiber used in this study with 8mm length ( Shown in Fig .1 a)



Figure 1 a) Carbon fiber

b) Basalt fiber

c) Fly ash class F

#### 2.6. Mixing water

Potable water of the laboratory has been used for mixing the SIFCON slurry matrix, reference mix, and curing of specimens.

2.7. superplasticizer : Its considered as chemical admixture , which is High range water reducind admixrure ( HRWR) that increase workability and reduce the water content and improve performance of cementitious materials . the superplasticizer used is (Sika® ViscoCrete®-180 GS ) , high range water reducing , Retarding , Slump retaining and super plasticizing admixture for Concrete & Mortar utilizing Sika’s ‘ViscoCrete®’ polycarboxylate polymer technology ( 3rd Generation).

**3. Preperation of slurry :** The SIFCON mortar matrix production process is as follows: The molds used for sample production were cleaned and coated with oil to facilitate demolding. Cement and fine aggregate were mixed in a 1:2 ratio [17] (with 30% of the cement weight replaced by fly ash, which is the recommended optimal cement replacement ratio [18]) in dry form. Water and the superplasticizer were then added to the dry mixture. The entire mortar mixture was mixed for at least two minutes in a rotary mixer to ensure proper mixing of the mortar matrix.

#### 4. Test for fresh SIFCON matrix

A) Determination of Flow time : This test used to determine the flow time of slurry matrix by using Mini V funnel ( See Fig 2.b) ,The result Shown in Table 7.

B) Determination of Slump flow : The apparatus used to measure the flow and viscosity of mortar (shown in Fig 2.a ). In this test, the spread diameter of the mortar is measured in two perpendicular directions horizontal D1 and vertical D2.The average value is reported as the slump-flow. A truncated cone mold is placed precisely at the center of a 100 mm diameter graduated circle[19].

By using Slump flow test equation =  $\frac{D1+D2}{2}$  , Result shown in Table 7 below.

Table 7. Fresh tests results.

Mini Slump flow	Result	Mini V _funnel	Result
avarage diameter	225	Time of flow	7 Sec



**Figure 2. a)** Mini slump\_flow test.      **b)** Mini\_V\_funnel test



**Figure 3 a)** Casting      **b)** Curing of SIFCON .

## 5. Results and discussion:

### 5.1 Compressive Strength Results :

The compressive of SIFCON improved at low fiber content 1\_3% volumetric ratio which showed about 25% increase compared to reference concrete ( 0% fiber, 0% fly ash) at early ages but control concrete achieved higher compressive strength over basalt SIFCON at 56 days. However , at high fiber volumetric ratio 5\_7% compressive strength decrease due to fiber agglomeration and formation of microcracks [20][21].SIFCON with carbon fiber 1% showed lower compressive strength compared to control concrete . At 3\_5% fiber content , significant improve in SIFCON strength reaching up to 45.36 Mpa at 56 days which is 30% over plain concrete . But at 7% fiber ratio results showed no significant improve in compressive strength .The hybridization for the two types of fiber showed significant improvement at all ages . The 5% fiber ratio reached best result with 69% increase in compressive strength compared to control .At 7% fiber ratio , notes reduction in strength due to agglomeration of fiber [22] . 30% fly ash replacement by weight of cement increase long term strength by improved strength at later ages [23].Samples of compression strength is 100x100x100mm according to ASTM C109/C109M.(The results shown in Fig .4).

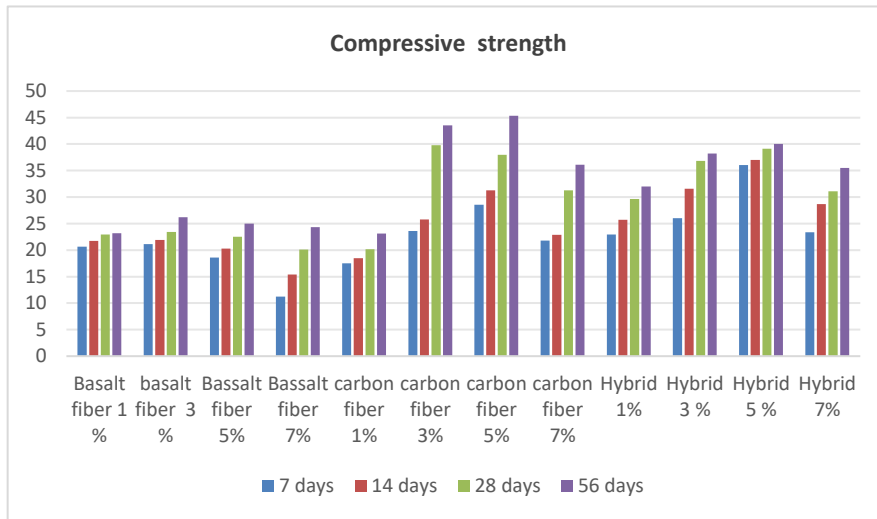


Figure 4 . Compression strength test results with Curig time.

5.2. Splitting tensile strength test :

The splitting tensile strength of SIFCON significantly improved with basalt fiber addition at all curing ages [24] compared to control concrete 1.178 Mpa at 56 days . The optimal ratio of SIFCON which showed higher splitting tensile at 3% fiber ratio reaching 4.79 Mpa which 307% higher than plain concrete[25] . At higher fiber ratios 5\_7 % , showed slight reduction in strength due to fiber clustering and void formation[21][25] .Over all basalt fiber improved significantly the crack bridging ,durability and bond strength .SIFCON with carbon fiber showed significant enhancement the splitting tensile at all curing ages by 313% compared to plain concrete. Carbon fiber improving crack bridging , prevent propagation , load resistance and enhance durability[26]. The optimum fiber content 3\_5% ratio, which achived 4.9 Mpa at 56 days. At higher content of fiber 7% ratio ( See Fig. 6 ) , the strength slightly reduced because poor workability cause void formation [27]. The combining of hybrid fiber (basalt and carbon) significantly enhance splitting tensile at all ages[28]. Hybridization in SIFCON gives outperform in splitting over the sigle fiber mix because the balace between two types of fibers (stiffness,load transfer of carbon and crack resistance ,durability of basalt ) .Highest splitting tensile recorded 6.7Mpa at 5\_7% fiber ratio which higher by 5 times over control. 30% fly ash replacement improving workability of slurry and bonding of fiber\_matrix by filling microvoids and enhacing viscosity[29]. This test using cylinders with 100mm diameter and 200mm length according to ASTM C39/C39M.Test shown in Fig .5



Figure 5. Splitting tensile strength test .

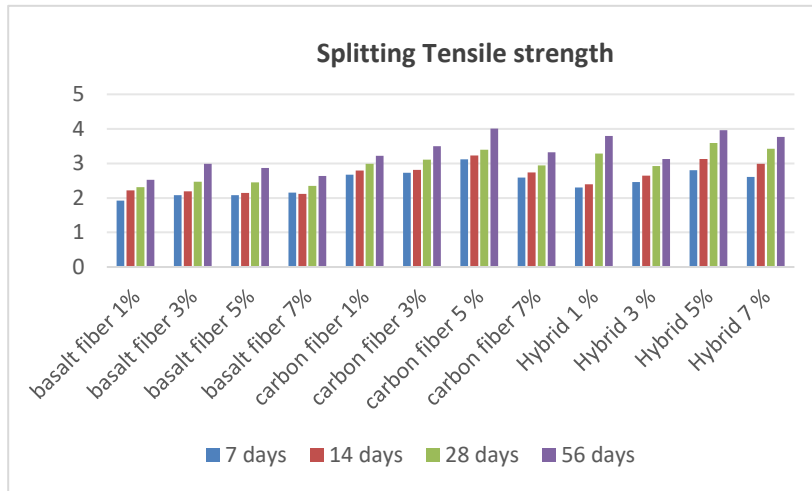


Figure 6. Splitting tensile strength test results with Curing time .

### 5.3 Flexural strength :

SIFCON flexural strength increased significantly due to addition of fly ash 30% cause cement hydration and pozzalanic activity which forms C-S-H gel (glue of cement) [30]. At early age SIFCON showed lower strength but improved at later ages by densify the matrix. SIFCON with basalt fiber with 5% volume ratio achieved 8.03Mpa which is 108% enhancing over the control mix considered as best ratio [24]. This attributed to ability of basalt fiber to control crack propagation and increase stiffness [20]. But at higher content 7% led to reduce flexural strength slightly due to fiber agglomeration [28]. SIFCON with carbon fiber enhance flexure strength even higher than basalt fiber reaching to 9.98 Mpa about 160% increase over control mix ( See Fig. 8) . This due to the high tensile strength and stiffness of carbon fiber [31]. The hybrid fiber gives the best results which strength reached to 10.7 Mpa which about 2.9 times higher than control mix .This attributed to synergistic effect of basalt with carbon fibers caused improve ductility. Flexural strength carried out by using (100x100x400mm) prisms which according to C78/C293 . The test shown in Fig. 7



Figure 7. Flexural strength test was carried out in Mustansiriyah university, college of engineering

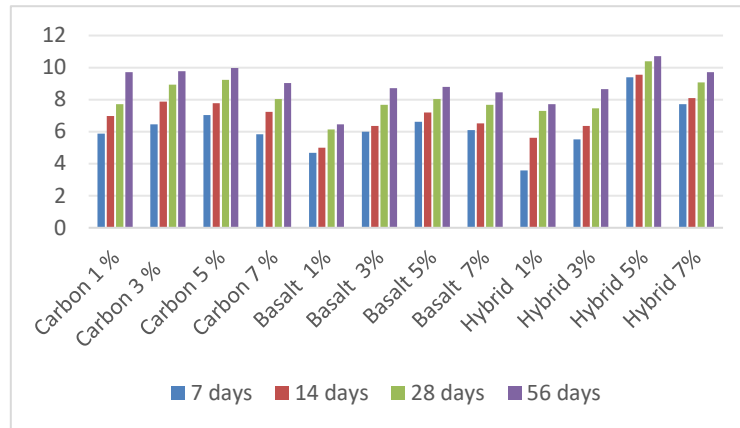


Figure 8 . Flexural strength test results with Curing time.

## 6. Conclusion

1. Compressive strength of basalt increased by 25% at early ages by adding 3\_5% which is optimum ratio, basalt fiber improve strength by crack bridging but at excessive content 7% strength reduced due to agglomeration. Carbon fiber achieved significant improve in compressive strength compared to reference concrete by 30% at 3\_5% ratio .
2. Basalt fiber improved splitting tensile by 307% at ratio 3\_5% which consider as optimum ratio , but increasing fiber content cause reduce in strength due to uneven distribution and clustering .Basalt fiber improved splitting tensile by 307% at ratio 3\_5% which consider as optimum ratio , but increasing fiber content cause reduce in strength due to uneven distribution and clustering .Hybrid fiber gives best result of splitting test by increasing 497% over plain concrete .Carbon fiber also enhanced splitting strength over plain concrete at 3\_7%.
3. Flexural strength test of SIFCON with basalt fiber showed higher improvement compared to plain concrete at early ages (7 and 14 days) and increased with increasing curing time and fiber content and reduced at excessive fiber ratio .Same for carbon fiber which showed superior crack bridging by 160% over control mix but at 7% fiber ratio reduced . Best results was at SIFCON with hybrid fibers (basalt +carbon0 at 5% volumetric ratio .
4. Fly ash replacement improve matrix densifications and fiber matrix bonding also improve workability of slurry . This type of SIFCON consider as light weight concrete and eco\_friendly.
5. Hybrid fiber results showed higher improvement than single mix .

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