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Experimental Investigation of Some Mechanical and Physical Properties of SIFCON Concrete Incorporating Bauxite as a Mining-Derived Waste Material

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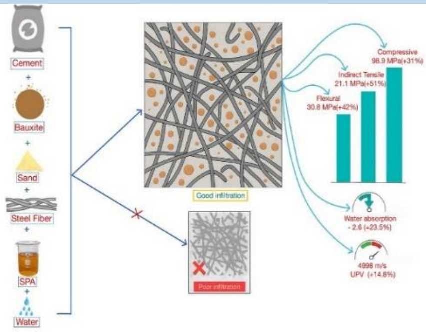
Abstract: This study performs an assessment of the mechanical and physical behavior of slurry-infiltrated fibrous concrete (SIFCON) with a combination of thermally activated bauxite waste that can be used as a partial replacement for cement. Bauxite substitution of 10, 20, and 30 % was used with steel fiber content of 8, 16, and 24 % to come up with twelve mixtures. The findings indicate that the MS2 mixture (20 % bauxite, 16 % steel fibers) performed better and showed a compressive, tensile, and flexural strength of 98.9 Mpa, 21.1 Mpa, and 30.8 Mpa, which are an increment of 31.3 %, 51.4 %, and 42.6 %, respectively, over the reference mix. The water absorption dropped by 23.5%, and the ultrasonic pulse velocity rose to 4998 m/s, which means it has a denser and more homogeneous matrix. Conversely, the 24% fiber mix combinations showed a loss of performance due to the clustering effect of the fibers as well as low slurry infiltration. The prediction equation for compressive strength based on UPV and rebound number had very good statistical accuracy with R2 = 0.93. Overall, based on these findings, it appears that the thermally activated bauxite waste can be an excellent source for supplementary cementitious materials for SIFCON with added advantages based on performance as well as sustainability.



Keywords: SIFCON, bauxite waste, hooked-end steel fiber, mechanical properties, water absorption, pozzolanic activity, mining waste, fiber-reinforced concrete.

Introduction

The ever-increasing demands on the construction sector have led to research and developments into new materials and methods that will optimize the performance capabilities of these structures and also improve sustainability. One major recent development in Fiber Reinforced Concrete technologies is Slurry Infiltrated Fiber Concrete (SIFCON), which uses a special composition involving infiltration with large volumes of fibers pre-placed in a mold with a flowing cement slurry [1, 2]. It presents a new method for developing a more efficient and superior concrete with better tensile strength and ductility compared with regular concrete [3, 4].

Consequently, the rising issue pertaining to green buildings has seen research trends shift towards using waste materials and mining materials within concrete. This contributes towards addressing an environmental issue regarding waste materials, aside from resource conservation and cost savings within the construction sector [5]. Among different waste materials, bauxite, which is commonly recognized as a chief ore used to extract aluminum, produces a remarkable quantity of byproducts within mining and processing operations [6]. Employing waste materials from bauxite in concrete is a promising avenue for sustainable construction, while at the same time potentially enhancing some material properties.

Bauxite residues possess certain physical and chemical properties that can positively affect concrete properties. The high alumina content and pozzolanic activity of certain bauxite fractions suggest their potential to increase concrete durability and strength gain [7]. However, the addition of bauxite residue to SIFCON systems requires an in-depth study to uncover the mechanisms of interaction and their effects on the properties of the final composite material.

Although there is a great literature available on SIFCON and on the applications of different industrial by-products in cementitious systems, there is no previous research on the use of thermally treated bauxite mining waste in SIFCON matrices. The distinctive mineralogical structure and possible pozzolanic properties of bauxite are that it has the potential to considerably affect SIFCON densification, microstructural refinement, and mechanical performance. Still, this relationship has not experimentally investigated yet. Thus, the present research fills this gap by analyzing various levels of bauxite replacement systematically and their interaction with high-volume steel fibers. The hypothesis is that adding thermally treated bauxite waste at controlled levels of replacement (10-30 %) into SIFCON will lead to enhanced mechanical/durability performance because of higher packing density, lower porosity, and higher pozzolanic activity.

This study investigated the physical and mechanical properties of SIFCON with bauxite as the mining waste material. This study evaluated the practicability of utilizing bauxite waste

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as a supplementary cementitious material or aggregate replacement in SIFCON systems, considering compressive strength, tensile strength, flexural behavior, durability, and Non-destructive testing. The findings of this study will contribute to the pool of available information on sustainable concrete technology and provide information on the utilization of waste materials from mines in high-performance fiber-reinforced concrete systems.

Literature Review

Slurry Infiltrated Fiber Concrete (SIFCON)

SIFCON technology was originally developed by Lankard in the 1980s as an extremely advanced fiber-reinforced concrete system to overcome the limitations of conventional fiber-reinforced concrete [8]. The fundamental concept of SIFCON is to pre-place high-volume fibers (generally 5-20% by volume) in a mold and subsequently infiltrate them with a pressure- or vibratory-flowing cement-based slurry [9, 10]. The manufacturing process ensures an aligned fiber distribution and superior fiber-matrix interaction, leading to improved mechanical properties.

Naaman and Homrich [11] investigated the tensile properties of SIFCON and tested the impact of matrix composition and fiber properties. They found that SIFCON reaches tensile strengths of up to 28 MPa at 1–2% strain and created a model for the prediction of stress-strain response from compressive strength and fiber parameters.

An experimental study on SIFCON, with special emphasis on its static and cyclic loading flexural characteristics, under flexure, shear, and tension loading conditions, was performed by Balaguru et al. [12]. It examined various parameters like length (30-60 mm), volume percentage (4-12%), and admixture of silica fumes and sand with cement slurry. It indicated that with SIFCON, a maximum strength of 68.9 MPa can be achieved under flexure, 27.6 MPa under shear, and 13.8 MPa under tension. The high ductility under all loading conditions and added benefits due to silica fumes and acceptable addition rates for sand were also outlined.

Bauxite and Mining Waste Utilization in Concrete

Bauxite, which contains aluminum hydroxide minerals like gibbsite, boehmite, and diaspore, is the most prominent ore for aluminum extraction [13]. Bauxite mining and refining result in large generation rates of waste materials, which include tailings and red mud, and are considerable because of their high pH and heavy metal composition [14].

Several recent works have also examined bauxite-based materials as concrete components. The pozzolanic and hydraulic properties of raw and thermally activated bauxite have been analyzed as an admixture for the production of alternative binders for construction. Although bauxite mining shows low CO2 emission intensities (3-5 kg CO2e/t), traditional bauxite usage for aluminum and cement production shows very high carbon intensities. The pozzolanic activity of bauxite increases with heating and at temperatures above 550°C. At 550°C, its reaction rate benefits from a high surface area and an amorphous form rich in aluminum. The thermal treatment at 700-800°C increases late-stage reaction rates because of the production of amorphous alumina and metakaolin due to boehmite and kaolinite decomposition. Bauxite shows high pozzolanic and mechanical activity due to its advantageous mineral composition and surface area.

Azevedo et al. [16] made a comprehensive examination of bauxite tailings from Pará, Brazil, with the intention of identifying opportunities for using these tailings in the production of construction materials. By applying methods that include XRF, XRD, SEM/TEM-EDS, BET surface area measurement, and pozzolanicity analysis, it was determined that these tailings were aluminosilicate materials with high amorphous phases. According to these findings, bauxite tailings have specific uses as pozzolan, binder for alkali-activated materials, and plasticity modifier in red ceramic production. Bauxite tailings can thus be recommended as a sustainable alternative in bauxite mining.

The benefits associated with utilizing bauxite waste materials within concrete have been documented by several authors. A review on the utilization of bauxite residue, commonly known as red mud, within cementitious materials and special concrete as a method for promoting energy savings, lowering carbon emissions, and waste production within the construction industry was offered by Wang et al. [17]. The global attributes and red mud utilization, as well as joint utilization with multisolid waste, were included within the review as they relate to modern developments and associated environmental influences. The review integrates various associated problems and future directions within multi-solid waste systems incorporating red mud.

Waste Material Integration in Fiber-Reinforced Concrete Systems

The issue of waste materials being introduced into fiber-reinforced cement systems has lately garnered considerable interest [18-20]. A review on the utilization of industrial waste materials, metakaolin, fly ash rejects, glass powder, and palm oil fuel ash for making green ultra-high-performance fiber-reinforced cementitious composites (UHPFRCCs) has been conducted thoroughly in [21]. It was revealed that these materials have the potential to reduce waste and lower emissions of greenhouse gases created during cement production, and at the same time can reduce costs, thereby making concrete more environmentally friendly [19, 20].

There have been very limited studies on the use of industrial waste materials as components in SIFCON. The findings have shown promise. Frazao et al. [22] conducted research on the use of recycled steel fibers (RSF), an eco-friendly alternative to industrial steel fibers (ISF), for concrete production. The findings revealed that RSF has the potential to provide comparable strength and a greatly reduced environmental impact.

The challenges associated with the integration of waste materials into fiber-reinforced systems include the potential disruption of fiber distribution, altered rheological behavior of the slurry, and altered bond properties [23]. Successful integration without compromising the inherent advantages of fiber reinforcement requires appropriate characterization and optimization of waste material properties.

In order to better synthesize the reviewed literature and to clearly situate the current study in the current body of research, the following condensed comparison summary indicates the key contributions and gaps of previous research on SIFCON, the use of bauxite waste, and the use of waste-based fiber-reinforced composite. This overview has shown that despite all the research directions, which have remained independent of each other, no research has incorporated thermally treated bauxite waste into SIFCON systems, especially when high volumes of steel fibers are used. Table 1 provides a brief comparison of the corresponding research spheres and the gap focused on by the present work.

Table (1): Condensed Comparison of Related Studies and Identified Research Gap.

Research Area	Main Findings	Identified Gap
SIFCON mechanical behavior	High tensile, flexural, and energy absorption performance; sensitive to fiber distribution and slurry rheology	No incorporation of pozzolanic waste materials into SIFCON matrices
Bauxite waste in cementitious materials	Demonstrated pozzolanic activity, reduced porosity, improved strength after thermal activation	No evaluation within high-fiber composites, such as SIFCON
Industrial waste in	Enhanced sustainability and improved mechanical	Findings not transferable to

Research Area	Main Findings	Identified Gap
FRCC/UHPFRC	performance across various waste additives	slurry-infiltrated systems with very high fiber volumes
Sustainability-focused studies on red mud and mining waste	Highlighted environmental benefits and reuse potential of bauxite residues	Lacked experimental validation in structural composites or SIFCON
Recycled steel fiber concrete	Comparable performance to conventional fibers with environmental advantages	Did not examine binder modifications or integration with bauxite waste

Research Gaps and Opportunities

Although significant work has been conducted on SIFCON and waste material utilization in concrete, very few studies have specifically focused on the utilization of bauxite waste materials in SIFCON systems. The unique nature of bauxite, including its composition and potential pozzolanic characteristics, necessitates careful exploration of high-performance fiber-reinforced concrete systems.

The processes involved in bauxite waste materials and fiber/matrix systems should be clearly understood with regard to optimizing ratios and variables. Additionally, the suitability and applicability of SIFCON with bauxite waste materials should be carefully considered with regard to its performance and longevity.

The variability associated with the use of different fractions of bauxite waste materials (fine grains, coarse grains, and calcined materials) in SIFCON mixtures can offer scope for optimizing properties and meeting the target performance. Moreover, working on guidelines and optimization methods for bauxite-based SIFCON would enable feasible implementation within building structures.

Materials and Methods

Materials

Ordinary Portland Cement (OPC) from the Tasluja Cement Factory was used in this study because of its availability and compatibility with SIFCON. It had a specific gravity of 3.15 and fineness of 320 m^2/kg. The chemical composition was confirmed by XRD at Baghdad University and met ASTM C150 [24] standards, ensuring the strength and durability of the cement. As listed in Table 2, chemical analysis of the cement further verified its compliance with the required specifications.

Table (2): OPC Chemical analysis.

Component	Results
SiO_2 %	20
Al_2O_3 %	4.2
Fe_2O_3 %	2.3
CaO %	63
MgO %	2.7
SO_3 %	2.6
Na_2O %	2.4
K_2O %	0.7
Others %	0.8
Ignition loss %	1.5

Bauxite mining waste, collected from a local site, was thermally treated at 750°C to enhance its pozzolanic activity and then finely ground to increase its surface area and reactivity. The decision to use 750°C to calcinate the bauxite waste is informed by the fact that the primary alumina-bearing phases, especially gibbsite and boehmite, dihydroxyl, and convert into highly reactive amorphous alumina in the 700-800°C range. This conversion is reported to improve pozzolanic reaction and increase the reactivity of aluminosilicate residues with calcium hydroxide and thus densify the matrix. However, with regard to this, the optimum temperature of 750°C was chosen because it had the capability to achieve maximum reactivity without the possibility of sintering at a higher temperature [15]. This enhances the performance of pozzolanic additives. The waste with the potential for improving concrete properties was selected due to its specific gravity ranging from 2.5 to 2.8 and an optimal size distribution. Its pozzolanic activity was evaluated using ASTM C311 [25], and its chemical and physical properties were tested to ensure compliance with ASTM C618 [26] standards. Figure 1a displays the material, and Tables 3–5 present its physical and chemical properties and the corresponding ASTM C618 [26] requirements.

Table (3): Physical Properties of Bauxite Mining Waste.

Bauxite Mining Waste Properties	Results
Surface area m^2/g	0.421
Nature of material	Powder
Specific gravity	2.63
Color	brown light powder

Table (4): Chemical Analysis of Bauxite Mining Waste by XRD.

Chemical Content	Results
SiO_2 (Silicon Dioxide)	15.9
Al_2O_3 (Aluminum Oxide)	49.2
Fe_2O_3 (Iron Oxide)	18.4
CaO (Calcium Oxide)	7.7
MgO (Magnesium Oxide)	2.2
K_2O (Potassium Oxide)	1.01
SO3 (Sulfur Trioxide)	0.87
TiO_2 (Titanium Dioxide)	2.22
Others	0.2
LOI (Loss on Ignition)	2.3

Table (5): ASTM C618 [26] Requirements of Raw or Calcined Natural Pozzolan.

Items	ASTM C618 [26] Requirement	Results
$SiO_2+Al_2O_3+Fe_2O_3$(%) min	70	83.5
SO_3 (%) max	5	0.87
Loss of Ignition (%) max	6	2.3
Moisture content (%) max	3	0.93

Fine aggregates (sand) were sourced from the AL-Okhadir zone, where sand exhibits size variation. To ensure proper infiltration in the SIFCON slurry and prevent fiber agglomeration, sand was sieved using a 1.18 mm mesh to obtain finer particles. The sand grading and analysis, shown in Table 6, complied with the Iraqi Specification No. 45/2021 [27], and its properties, presented in Table 7, were verified through testing at the Al-Nahrain University Central Laboratory.

Table (6): The Gradient Experiment for Sand.

Iraq specification No.45/2021 [27] Zone (2)	Passing the cumulative sample (%)	Mesh Size (mm)
100	100	10
90-100	93.1	4.75
75-100	78.52	2.36
55-90	63.48	1.18
35-59	46.33	0.6
8-30	17	0.3
0-10	0.09	0.15

Table (7): The Characteristics of Used Sand.

Sand Properties	Results	Iraq specification No.45/2021 [27]
Specific gravity	2.7	------
Absorption (%)	0.65	------
Bulk density(kg/m^3)	1684	------
Modulus of fineness	3.01	------
SO3 content (%)	0.32	≤ 0.5%

A highly efficient superplasticizer, Sika® ViscoCrete®-180 GS, was procured from Sika Iraq and used in this research. It acts as a set retarding and high-range water-reducing admixture meant for use with concrete and mortar. The admixture satisfied the criteria set forth by ASTM C494/C494M-17 [28] standards, specifically criteria for Type G. Figure 1c shows a picture of a superplasticizer. Technical specifications are shown in Table 8.

Table (8): The Technical Properties of (SPA) (Sika® ViscoCrete®-180 GS).

Technical Characteristics	Values
Chemical Composition	aqueous solution of modified polycarboxylates
Color	light brownish appearance
Specific Gravity	1.070 ± 0.02 g/cm³
pH	4-6

The Bauxite SIFCON concrete in this study was reinforced with hooked-end steel fibers supplied by Atlas Company (Turkey), as shown in Figure 1b. These fibers had a diameter of 0.7 mm and a length of 35 mm and conformed to ASTM A820/A820M-04 [29] standards. The technical specifications and chemical compositions of these materials are listed in Tables 9 and 10, respectively. Distilled water with a neutral pH was used for mixing to ensure consistent hydration and to comply with ASTM C1602 [30].

Table (9): The Technical Properties of Hooked-End Steel Fiber

Technical Properties	Value
Shape	Hooked End
Density (kg/m^3)	7800
Tensile strength (MPa)	1100
Appearance	Grey No-copper cover
Diameter(d) mm	0.7
Length (l) mm	35
Aspect ratio(l/d)	50

Table (10): The Chemical Analysis of Hooked-End Steel Fiber

Fiber Composition %	Elements
91.8	Fe
2.92	Si
0.26	Mn
0.05	Cr
0.67	Mo
1.51	Cu
1.85	C
0.78	Ni
----	P
0.05	Al
0.04	Mg
0.07	Ti


a
b
c

Figure (1): The materials used a) Bauxite mining waste, b) Hooked End Steel Fibers, c) Superplasticizer, Sika® ViscoCrete® 180 GS

Mixing Procedure

The mixing technique adopted ensured uniformity and consistency. Dry materials (cement, bauxite waste, and sand) were mixed mechanically for a period of 2 minutes. Distilled water and a superplasticizer were added incrementally, and mixing took an additional 3 minutes. This process produced a bauxite-concrete paste, ready for casting Bauxite SIFCON. Figure 2a shows the mixer used to prepare the slurries.

Production of Bauxite Concrete

Bauxite SIFCON was produced using one of three casting techniques. The single-layer technique involves preplacing all the fibers in the mold and then pouring the slurry to cover them. The three-layer technique divides the fibers into three equal portions, each of which is pre-placed and sequentially covered with a slurry until the mold is filled. The immersion technique, shown in Figure 2c, involves filling the mold one-third at a time with slurry, immersing the fiber into it, and repeating the process until it is full. All methods use a vibrating table to improve the fiber distribution and homogeneity, with the immersion technique considered the most effective (Parameswaran et al., 1993) [31].

Curing

After casting, the Bauxite SIFCON concrete samples were demolded after 24 h and cured in a laboratory oven at 40°C for 24 h to promote better chemical reactivity under controlled conditions. The rationale of using a 40°C early-age curing regime is due to its capacity to speed up pozzolanic reactions and advance early formation of binding phases within aluminosilicate-based cementitious systems. Such mild thermal treatment at this temperature increases the densification of the matrix without losses of moisture or thermal cracking, and has been extensively used in studies of geopolymer and SIFCON-based composites to enhance early microstructural maturation [32]. Subsequently, the samples were kept outdoors for 27 days at temperatures ranging from 25 to 35 °C. Figure 2b shows the samples during the curing process.


a
b
c

Figure (2): a) The mixer used to prepare bauxite-concrete slurry, b) Samples during exposure to the curing process, c) Bauxite SIFCON concrete cast by (immersed technique)

Test Procedures

The experimental tests conducted on Bauxite SIFCON included flowability, compressive, tensile, flexural, and surface strength assessments. The Flow Table Test (Figure 3), following ASTM C230 [33], evaluated the workability using a 25 cm diameter table, Abram's cone, and tamping rod. Fresh SIFCON slurry was placed and tamped in two layers before lifting the cone and dropping table 15 times, after which the final spread was measured. The Compressive Strength Test (Fig. 4a) was conducted on 100×100×100 mm samples at 28 days as per EN 12390-3 [34] with a 2000 kN hydraulic press. The Indirect Tensile Test, or splitting strength test (Fig. 4b), was conducted as per ASTM C496 [35] on 150 mm×300 mm samples with a 3500kN loading capacity press. The Bending Strength Test, or flexural strength as per ASTM C78 [36] with two-point loading, was conducted on 100×100×400 mm prismatic samples with a 3500kN loading capacity press. Based on the position of failure, the rupture modulus was determined. Finally, a water absorption test as per ASTM C642 [37] was performed on the samples to ascertain the porosity. A 100×100×100 mm sample was oven-dried at 100-110°C for at least 24 h, or until a stable weight. Water at 21°C with a 24 h immersion period followed. The weight at this stage was measured, and then the water absorption percentage was calculated based on the weight difference.

Non-Destructive testing included the Ultrasonic Pulse Velocity Test, as specified by ASTM C597 [38] and conducted at 54 kHz, also known as UPV, and the Rebound Number Test, as per ASTM C805 [39] guidelines, which determined surface strength via multiple readings on cubic samples using a Schmidt Hammer. The density was calculated by volume and weight as per BS 12390-7 [40]. Finally, the Curve Expert Professional 2.7.3 program was used to correlate the non-destructive (UPV and Rebound Number) results with compressive strength.

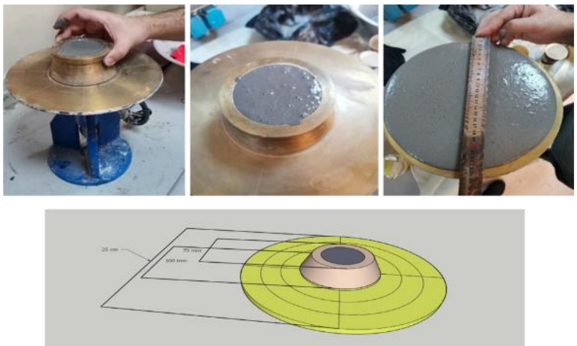

Figure (3): Flow table test.

Figure (4): Experimental Tests Conducted: (a) Compressive Strength, (b) Indirect Tensile Strength, (c) Flexural Strength.

Mix Design

Two mixed designs were prepared. The first aimed to determine the optimum flow table results (i.e., the optimum SPA percentage), whereas the second, formulated based on the identified optimum, was used as a reference to evaluate the mechanical properties. Theoretical and experimental evidence support the selection of the bauxite replacement levels between 10 and 30 %. Previous research on calcined aluminosilicate pozzolans shows that substantial pozzolanic performance is typically seen at replacement levels above 10% of the overall cement volume, with lower contents contributing little to secondary hydration and refinement of the matrix [15]. Conversely, initial experiments in the current study revealed that above 30 % replacement levels had a negative impact on slurry rheology, decreasing flowability and limiting fiber infiltration, which are essential demands of high-quality SIFCON production. The 10-30 % range was, therefore, found to be the best range to combine reactivity, slurry workability, and total composite integrity, which aligns with prior results concerning the performance of pozzolanic materials [16].

Table (11): Trial mixtures design for bauxite SIFCON.

Mix.	Cement	Sand	Water	SPA (%) by wt. of cement	Flow Table Test results
	Kg/m^3				
GRF	885	885	265.5	1.2	20.9 cm
GR1	885	885	265.5	1.3	21.4 cm
GR2	885	885	265.5	1.35	22.6cm
GR3	885	885	265.5	1.4	23.9 cm
GR4	885	885	265.5	1.15	19.3 cm

Table 11 and Figure 5 present the flow table test results for the Bauxite SIFCON mixes with varying SPA percentages. The reference mix (GRF) with 1.2% SPA, based on (Manolia Abed Al-Wahab Ali) (2018) [41], was used as the baseline. Among the tested mixes, GR2 with 1.35% SPA demonstrated optimal flowability, ensuring proper matrix infiltration without any segregation. Lower SPA contents (1.2%, 1.3%, and 1.15%) resulted in reduced workability, risking poor fiber-matrix bonding, whereas the highest content (1.4%) caused excessive fluidity, increasing the risk of segregation. Consequently, GR2 was selected for further mechanical evaluation (Table 12).

To enhance the comprehension and easier interpretation of the mixture design, a description of the nomenclature that is adopted to classify the SIFCON mixtures is given in Table 13. The labels show the replacement level of bauxite and the volume fraction of fiber chosen in every mix. This classification system aids in uniform referring, and the comprehension of the following tables and figures becomes even more readable.

Table (13): Bauxite replacement level and fiber volume fraction adopted in each mix bauxite SIFCON.

Symbol	Meaning	Description
GF	Reference mix	Contains no bauxite replacement; used as a control for fiber-only effects
LS	Low bauxite	Mixtures with 10% bauxite replacement
MS	Medium bauxite	Mixtures with 20% bauxite replacement
HS	High bauxite	Mixtures with 30% bauxite replacement
FS	Fiber series	Mixtures designed to isolate the effect of increasing fiber volume (8%, 16%, 24%) without bauxite replacement

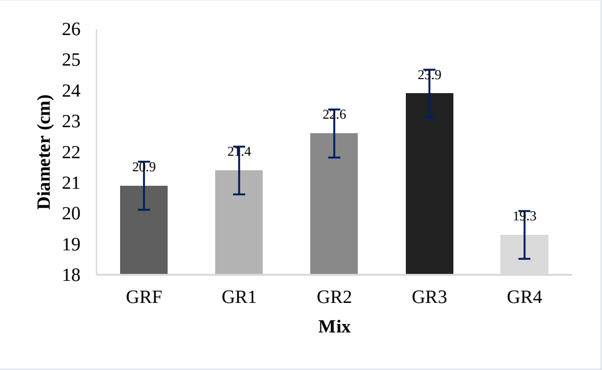

Figure (5): Flow table test results.

Table (12): Bauxite SIFCON mixtures design.

Mix	Slurry (Kg/m³)				Bauxite (Kg/m³)			Hooked End Steel Fiber (Kg/m³)		
	Cement	Sand	Water	SPA 1.35%	10% Rep.	20% Rep.	30% Rep.	8%	16%	24%
GF1	885	885	265.5	11.95	----	----	----	70.8	----	----
GF2	885	885	265.5	11.95	----	----	----	----	141.6	----
GF3	885	885	265.5	11.95	----	----	----	----	----	212.4
LS1	796.5	885	265.5	11.95	88.5	----	----	70.8	----	----
LS2	708	885	265.5	11.95	----	177	----	70.8	----	----
LS3	619.5	885	265.5	11.95	----	----	265.5	70.8	----	----
MS1	796.5	885	265.5	11.95	88.5	----	----	----	141.6	----
MS2	619.5	885	265.5	11.95	----	177	----	----	141.6	----
MS3	885	885	265.5	11.95	----	----	265.5	----	141.6	----
HS1	796.5	885	265.5	11.95	88.5	----	----	----	----	212.4
HS2	708	885	265.5	11.95	----	177	----	----	----	212.4
HS3	619.5	885	265.5	11.95	----	----	265.5	----	----	212.4

Results and Discussions

Compressive Strength

Figure 6 shows the compressive strength results of the Bauxite SIFCON mixtures. The MS2 mix achieved the highest strength at 98.9 MPa (31.34% increase, as shown in Figure 7) owing to the combined effects of 20% bauxite and 16% hooked-end steel fiber, which enhanced matrix densification and crack resistance [42]. The LS2 mix also showed a notable improvement (87.5 MPa, 25.35%) owing to the pozzolanic activity of bauxite and the improved microstructure of the mixture [43, 44].

However, higher fiber contents in the FS mixes (24%) led to mixed results—FS2 (86.3 MPa, 25.75%) and FS3 (85.9 MPa, 18.31%)—as excessive fibers hindered the slurry infiltration and created voids [45, 46]. In comparison, GF2 (75.3 MPa, 7.89%) and GF3 (72.6 MPa, 4.01%), which lacked bauxite, showed limited improvement, indicating that the fibers alone provided modest strength gains.

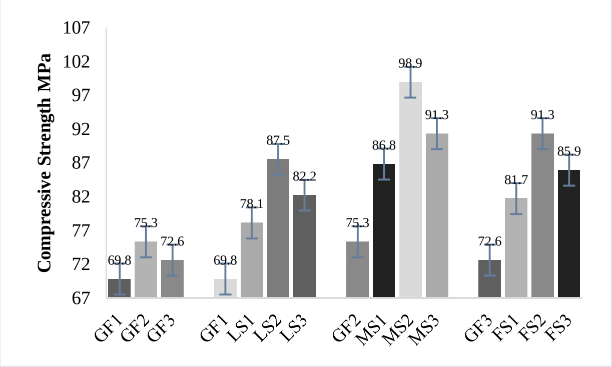

Figure (6): Compressive Strength Results for Bauxite SIFCON Concrete Mixtures.

Figure (7): Percentage Increase % in Compressive Strength for Bauxite SIFCON Concrete Mixtures.

Indirect Tensile Strength

Figures 8 and 9 present the results of the Indirect Tensile Strength Test. All mixes showed improvements over the reference mix (GF1 = 12.3 MPa), confirming the positive effect of bauxite and hooked-end steel fibers on the tensile strength.

The MS2 mix exhibited the highest tensile strength (21.1 MPa), marking a 51.36% increase owing to the synergistic effect of 20% bauxite and 16% steel fibers, which enhanced matrix interconnectivity and crack resistance through mechanical anchorage [42].

FS2 (18.7 MPa, 41.66%) and LS2 (17.1 MPa, 39.02%) also demonstrated significant gains, validating the benefits of moderate fiber and bauxite levels in improving toughness and energy dissipation [47].

However, the performance declined at higher fiber volumes. FS3 (18.1 MPa) and MS3 (20.2 MPa) showed lower improvements than MS2, likely due to hindered slurry infiltration and weak bonding from fiber overcrowding, which reduced the tensile efficiency[47, 48].

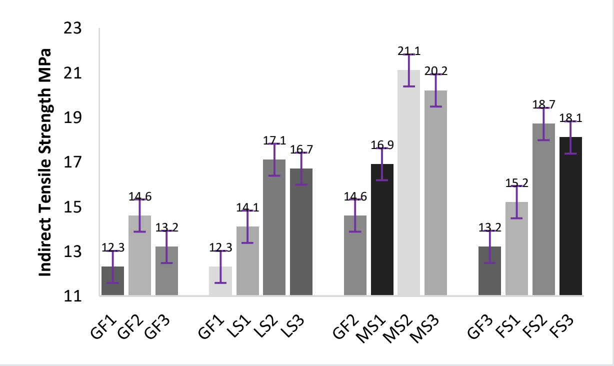

Figure (8): Indirect tensile results for bauxite SIFCON concrete mixtures

Figure (9): Percentage increase in indirect tensile for bauxite SIFCON concrete mixtures

Bending Strength

Figures 10 and 11 show that all Bauxite SIFCON mixes exhibited improved flexural strength compared to the reference (GF2 = 21.6 MPa), with the MS2 mix achieving the highest value of 30.8 MPa (42.59% increase) owing to the optimal combination of 20% bauxite and 16% hooked-end steel fibers, which enhanced crack bridging and mechanical interlock [42]. MS3 (29.6 MPa, 37.03%) and FS2 (25.7 MPa, 31.12%) also showed notable improvements, confirming the effectiveness of moderate fiber content. LS2 (22.4 MPa, 30.99%) and LS3 (21.3 MPa, 24.56%) demonstrated that bauxite alone contributes to matrix cohesion and reduces brittleness [49]. However, the excessive fiber content (24%) in FS3 and MS3 resulted in reduced gains owing to hindered slurry infiltration and non-uniform fiber distribution, which compromised the flexural performance. The three main processes can be attributed to the interaction that underlies the improved mechanical performance of the bauxite-SIFCON mixtures, most prominently the MS2 mix. The thermally activated bauxite is first introduced to add reactive fine particles of aluminosilicate, which increase the packing density and decrease the pore continuity to create a more compact matrix. Second, the pozzolanic reaction between calcium hydroxide and amorphous alumina phases produces further C–A–H and C–S–H gels, which leads to the development of strength and durability. Third, the hooked-end steel fibers also provide superior crack bridging and load transfer by means of effective fiber-matrix lock-up. In large fiber volumes (e.g., 24%), fiber clustering constrains slurry infiltration and forms voids, which reduces the total efficiency. The combination of these mechanisms allows explaining the better performance at medium fiber contents and the decrease at high volumes, which are consistent with previous findings on high-performance fiber-reinforced composites [3, 43].

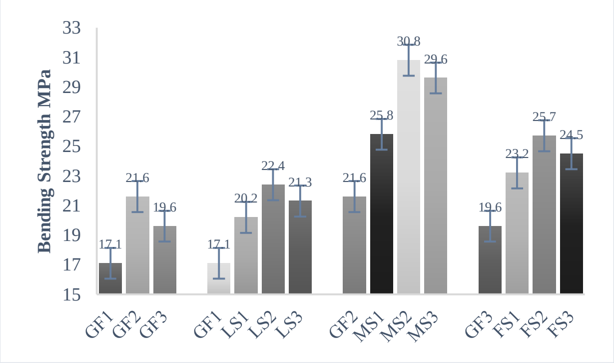

Figure (10): Bending strength results for bauxite SIFCON concrete mixtures.

Figure (11): Percentage increase % in bending strength for bauxite SIFCON concrete mixtures.

Failure Mode Analysis

It should be pointed out that the finer characterization of microstructure was not within the scope of the present experimental program in terms of SEM, XRD, or pore structure study. To this end, the mechanisms of improvement in the packing, pozzolanic contribution, and fiber-matrix interlock systems of the mechanistic interpretations discussed are not made based on the micro-scale behavioral indicators, but on the observed macro-scale behavioral changes in the mechanical and durability tests. The discussion has been narrowed down to avoid overinterpretation so that all the explanations given are consistent with already experimentally tested data.

However, the fracture surface observations made qualitatively were helpful in gaining an insight into the fracture mechanisms that controlled the behavior of the bauxite-SIFCON mixtures. The compressive failure of the reference and low-fiber mixes had a relatively brittle crushing behavior with slight sideways cracking. Contrarily, mixtures with 16 percent steel fibers showed slower, pseudo-ductile failure with observable crack-bridging behavior and load transfer, as is expected of fibers with hooked ends. Tensile and flexural specimens were observed to exhibit fiber pull-out and partial fiber rupture, which is a sign of correct fiber-matrix interaction. With increasing volumes of fiber (24 %), localized fiber concentration also led to heterogeneous stress distribution, reduced uniformity of crack propagation, and reduced fiber pull-out resistance, which is again in agreement with the observed drop in mechanical performance. The obtained results correspond with the failure mode that is usually observed with high-performance fiber-reinforced cementitious composites [3, 43].

It is also recommended that future studies should use SEM and XRD as part of the research to support the hypothesized microstructural changes and also shed more light on the mechanisms of interaction between thermally activated bauxite particles and SIFCON matrix.

Water Absorption

Figures 12 and 13 present water absorption results for various Bauxite SIFCON mixes compared to reference mixes GF1, GF2, and GF3. GF2 (3.4% absorption) was used as the primary benchmark. Despite its medium fiber content, GF2 outperformed GF1 (4.2%) and GF3 (3.7%), suggesting a non-linear relationship between fiber volume and permeability, likely due to matrix densification. The bauxite-replaced mixes showed significant improvement. At 20% bauxite replacement, LS2, MS2, and FS2 achieved the highest reductions (-21.42%, -23.5%, -21.62%), attributed to the low porosity and high density of bauxite [50], further enhanced by SPA and fiber reinforcement [51]. Mixes with 30% bauxite showed slightly lower but still notable reductions (-16.21% to -17.64%), whereas 10% bauxite mixes achieved moderate improvements (-9.52% to -11.76%), indicating that even small bauxite additions enhance water resistance when combined with proper fiber content.

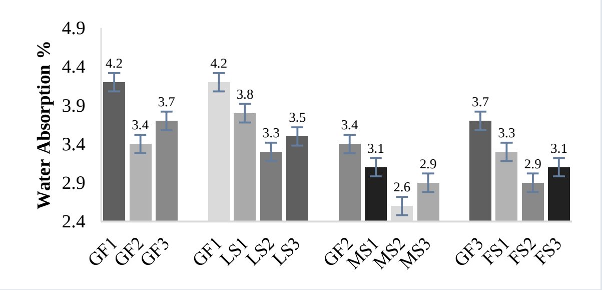

Figure (12): Water Absorption Results for Bauxite SIFCON.

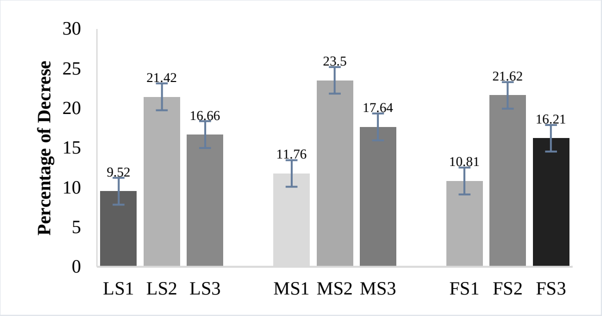

Figure (13): Percentage of Decrease in Water Absorption Values for Bauxite SIFCON.

Non-destructive testing

Longitudinal Pulse Velocity (Vl)

Figures 14 and 15 illustrate that the MS2 mix had the greatest longitudinal pulse velocity with a value of 4998 m/s, registering an increase of 14.84% compared with the control mix GF2, reflecting better internal denseness and uniformity [51]. The reason for this improvement is primarily due to the optimal contribution from 16% steel fibers, which enhances matrix uniformity and pulse transmission. Conversely, higher fiber percentages (24% in FS3 mix) caused a drop in pulse velocity due to inadequate fiber distribution and voids [45, 46]. Bauxite percentage caused a marginal reduction in velocity values among various mix designs (MS3 vs. MS2, FS3 vs. FS2, and LS3 vs. LS2).

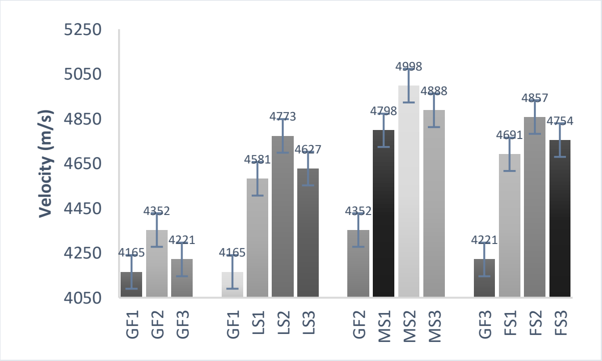

Figure (14): Longitudinal Velocity Results (m/s) for Bauxite SIFCON.

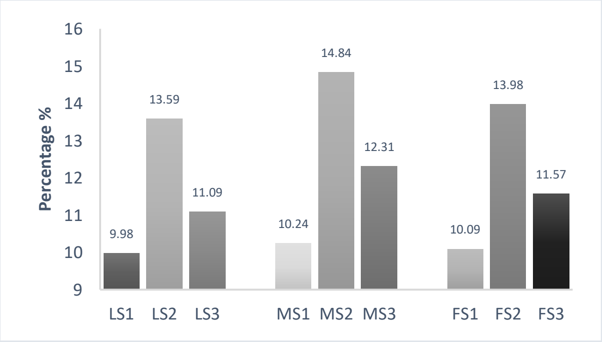

Figure (15): Longitudinal Velocity Enhanced Percentage for Bauxite SIFCON.

Shear Pulse Velocity

Figures 16 and 17 illustrate the results of the shear pulse velocity that was obtained for the samples.

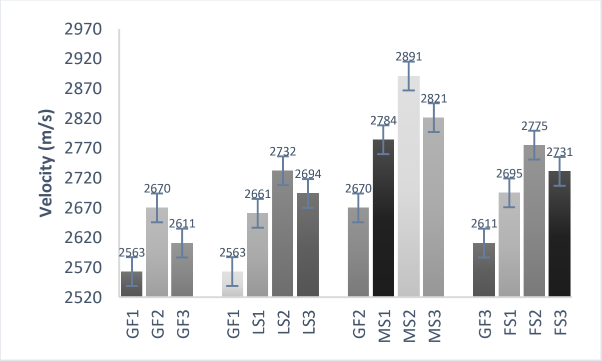

Figure (16): Shear Pulse Velocity for Bauxite SIFCON.

Figure (17): Shear Pulse Velocity Enhanced Percentage for Bauxite SIFCON.

Rebound Number (Schmidt Hummer) Test

The rebound numbers on these tests (Figures 18 and 19) show considerable variation among the concrete mix designs, mainly due to the addition and amount of steel fibers. Concrete mix designs with added steel fibers, as seen with MS2, FS2, and HS2, demonstrate higher rebound numbers because their surface hardness increases due to the higher hardness value of the steel fibers relative to that of the cementitious matrix [53]. Yet, higher amounts of steel fibers, as seen with FS3 and MS3, with 24%, can sometimes decrease rebound numbers because the concrete slurry infiltration becomes difficult at higher levels of added steel fibers, thus causing voids and surface irregularities that affect surface homogeneity and hardness [54].

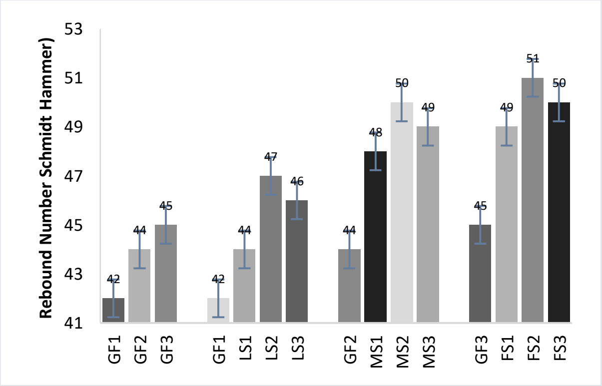

Figure (18): Rebound Number for Bauxite SIFCON.

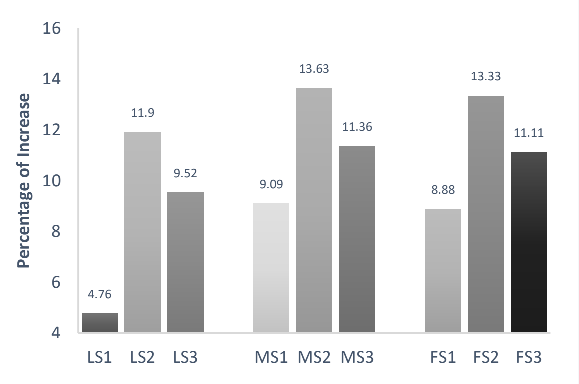

Figure (19): Percentage of Increasing Rebound Number Values for Bauxite SIFCON.

Density

The result for the density test (Figures 20 and 21) clearly identifies that with an increase in steel fibers, the density of mixtures will increase. It occurs due to higher density values for steel fibers (approx. 7800 kg/m³) compared with mortar components [55]. The mixtures with low and moderate steel fibers, naming LS1-LS3 and MS1-MS2, showed an increase in density with a maximum increase of 13.2% and 9.88% for mixtures LS3 and MS2, respectively. But mixtures with high steel fibers, naming FS1-FS3, showed maximum increases with 14.47% for FS3. Though it is lower compared with theoretical predictions because of slurry and uneven distribution for high proportions beyond 16-18%, leading to possible generation and presence of voids as well as lowering uniformity [52].

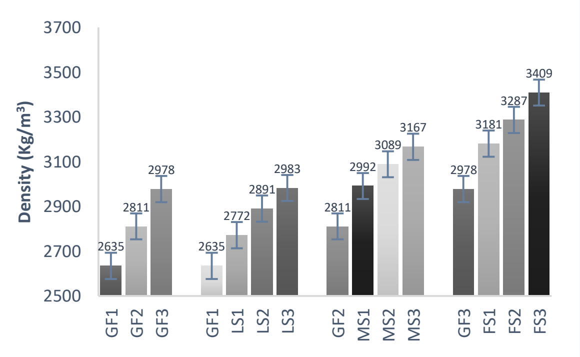

Figure (20): Density test results of SIFCON mixes.

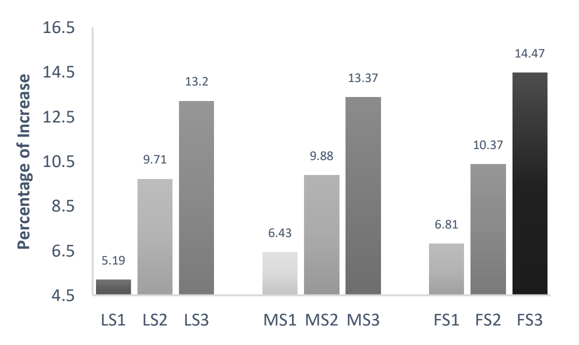

Figure (21): Percentage increase of SIFCON mixes.

Logical Relationship between (RN and UPV) and Compressive Strength

Figure 22 illustrates the relationship of the Bauxite SIFCON concrete compressive strength, which can be found using the following equation:

$$Compressive\ Strength\ MPa = a1 + a2 \cdot R + a3 \cdot U - a4 \cdot R^2 + a5 \cdot R \cdot U - a6 \cdot U^2 + a7 \cdot R^3 - a8 \cdot R^2 \cdot U + a9 \cdot R \cdot U^2 - a10 \cdot U^3$$

Where;

R: Rebound Number

U: ultrasonic pulse velocity in km/s (i.e., UPV / 1000)

a1 = -7215.613246

a2 = 134.041517

a3 = 3493.704810

a4 = 11.892137

a5 = 182.462980

a6 = 1707.536055

a7 = 0.585208

a8 = 15.127693

a9 = 132.601375

a10 = 318.874891

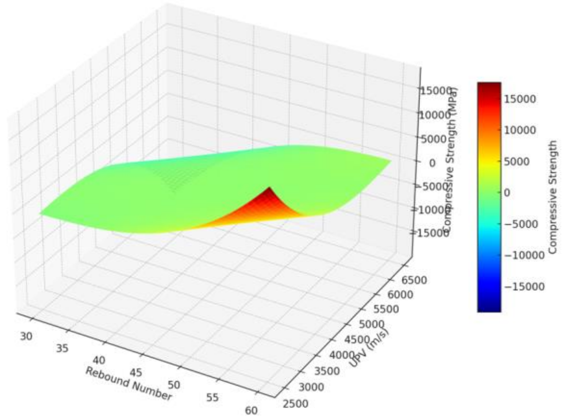

Figure (22): Logical relationships between compressive strength and RN, UPV.

The statistical indicators to assess the strength and predictive validity of the suggested multivariate model to predict compressive strength with respect to UPV and rebound number were the computation of the coefficient of determination (R^2) and the root mean square error (RMSE). The R^2 of the model was 0.93, and it shows that the model is highly correlated between the predicted compressive strengths and the experimentally measured compressive strengths. The values of RMSE were found to be 2.41 MPa, which represents a small error in prediction as compared to the strength range of the mixtures. The results obtained validate the fact that the model developed herein offers a valid prediction of compressive strength based on the non-destructive testing parameters, in line with the recommendations in non-destructive evaluation studies [10].

Environmental and Sustainability Considerations

The addition of bauxite waste that has been thermally activated to the SIFCON matrix not only leads to improved mechanical and durability performance but also to significant environmental advantages. The partial substitution of cement with 10-30% bauxite leads directly to a decrease in cement use and also to a decrease in the CO^2 emissions produced during the manufacture of clinkers, as the carbon intensity of cement production is great [17]. This helps in creating a smaller environmental footprint and is in line with the worldwide trends of green construction materials. Moreover, bauxite mining residues have been used as an auxiliary cementitious material, which contributes to increased waste valorization, the reduction of the challenge in waste disposal, and the environmental load linked to the long-term storage of bauxite mining residues [16]. Though the scope of the present study did not allow conducting a full life-cycle assessment, the qualitative results, such as the decreased cement demand, the advantageous reuse of industrial waste, reduced dependence on virgin raw materials, etc., demonstrate the potential of bauxite-modified SIFCON as a more environmentally friendly alternative to the conventional systems.

Conclusions

The paper gives a novel understanding of the effects of thermally activated bauxite waste and different proportions of steel fiber on the structural performance and sustainability of SIFCON. The key conclusions can be summarized as follows:

1. The bauxite waste that was thermally activated was found to have a great impact on the SIFCON functioning when added at mid-levels. The MS2 (20% bauxite, 16% steel fibers) had the greatest mechanical capacities of 98.9 Mpa compression, 21.1 Mpa tension, and 30.8 Mpa flexure.
2. The use of bauxite minimized water absorption by almost 23.5 percent and maximized UPV to 4998 m/s, which proved a significant enhancement of microstructural compactness and general endurance.
3. The consistency in decline of mechanical performance due to 24% fiber content in all levels of bauxite was mainly because the fiber agglomeration and poor slurry infiltration happened, and it is important to pay attention to the volume of fiber to ensure uniformity of the structure.
4. The predictive model that was developed between compressive strength, UPV, and rebound number was found to correlate very well ($R^2 = 0.93$), which shows that non-destructive testing is an accurate tool in order to predict SIFCON strength in practice.
5. Sustainably, the fact that the partial replacement of cement and bauxite waste has quantifiable environmental benefits, such as the decrease in cement demand and the useful re-utilization of mining residues, can help to promote low-carbon and resource-efficient composite technologies.
6. It is suggested that further studies that include the use of SEM, XRD, and pore structure would be necessary to confirm the proposed microstructural processes and understand bauxite-cement interactions in fiber-based matrices better.

Disclosure statement

- **Ethics approval and consent to participate:** Not applicable
- **Consent for publication:** Not applicable
- **Availability of data and materials:** The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.
- **Author's contribution:** The authors confirm contribution to the paper as follows: study conception and design: Hiba Tarek Mezher and Hojjat Hosseinzadeh Gharehgheshlagh; experimental work, data collection, and analysis: Hiba Tarek Mezher; validation and supervision: Hojjat Hosseinzadeh Gharehgheshlagh and Aref Alipour; manuscript drafting and revision: Hiba Tarek Mezher and Aref Alipour. All authors reviewed the results and approved the final version of the manuscript.

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References

1] Lankard DR. Slurry Infiltrated Fiber Concrete (SIFCON): Properties and Applications. MRS Online Proc Libr. 1984;42(1):277-86. https://doi.org/10.1557/PROC-42-277

2] Abdulbaqi D., Abdulrehman M. Some properties of SIFCON made by reactive powder. Al-Rafidain J Eng Sci. 2024;2(1):256-264. https://doi.org/10.61268/8zcb6d70

3] Naaman A. Fiber reinforced concrete: five decades of progress. 2018. https://doi.org/10.21452/bccm4.2018.02.01

4] Abdulrehman MA, Kasim SR, Eweed KM, Razak KA. A critical review of mechanical, physical and durability properties of slurry infiltrated fibrous concrete (SIFCON). In: Annales de Chimie - Science des Materiaux. International Information and Engineering Technology Association (IIETA); 2024.

https://doi.org/10.18280/acsm.480602

5] Mehta PK. Greening of the concrete industry for sustainable development. Concrete Int. 2002;24(7):23-8. https://ecosmartconcrete.com/docs/trmehta02.pdf

6] Gräfe M, Power G, Klauber C. Bauxite residue issues: III. Alkalinity and associated chemistry. Hydrometallurgy. 2011;108(1):60-79. https://doi.org/10.1016/j.hydromet.2011.02.004

7] Lemougna PN, Wang K, Tang Q, Cui X. Study on the development of inorganic polymers from red mud and slag system: Application in mortar and lightweight materials. Construction Build Mater. 2017;156:486-95. https://doi.org/10.1016/j.conbuildmat.2017.09.015

8] David RL, Jeffrey KN. Preparation of highly reinforced steel fiber reinforced concrete composites. ACI Symp Publ. 1984;81. https://doi.org/10.14359/6456

9] Joseph RH, Antoine EN. Stress-strain properties of SIFCON in compression. ACI Symp Publ. 1987;105.

https://doi.org/10.14359/2172

10] Abbas AS, Abdulrehman MA. Use of non-destructive testing to estimate the properties of geopolymer SIFCON concrete. In: AIP Conference Proceedings. AIP Publishing LLC; 2024.

https://doi.org/10.1063/5.0211170

11] Antoine EN, Joseph RH. Tensile stress-strain properties of SIFCON. ACI Mater J. 1989;86(3). https://doi.org/10.14359/2443

12] Balaguru P, John K. Mechanical properties of slurry infiltrated fiber concrete (SIFCON). ACI Symp Publ. 1987;105. https://doi.org/10.14359/2154

13] Stoops G, Marcelino V. Lateritic and bauxitic materials. In: Stoops G, Marcelino V, Mees F, editors. Interpretation of Micromorphological Features of Soils and Regoliths. 2nd ed. Elsevier; 2018. p. 691-720. http://doi.org/10.1016/B978-0-444-63522-8.00024-3

14] Power G, Gräfe M, Klauber C. Bauxite residue issues: I. Current management, disposal and storage practices. Hydrometallurgy. 2011;108(1):33-45. https://doi.org/10.1016/j.hydromet.2011.02.006

15] Alelweet O, Pavia S. Pozzolanic and hydraulic activity of bauxite for binder production. J Build Eng. 2022;51:104186.

https://doi.org/10.1016/j.jobe.2022.104186

16] de Azevedo ARG, Marvila MT, de Oliveira MAB, Umbuzeiro CEM, Huaman NRC, Monteiro SN. Perspectives for the application of bauxite wastes in the development of alternative building materials. J Mater Res Technol. 2022;20:3114-25.

https://doi.org/10.1016/j.jmrt.2022.08.092

17] Wang J, Liu X, Zhang Z, Liu Y. Synergistic utilization, critical mechanisms, and environmental suitability of bauxite residue (red mud) based multi-solid wastes cementitious materials and special concrete. J Environ Manage. 2024;361:121255.

https://doi.org/10.1016/j.jenvman.2024.121255

18] Abdulbaqi DA, Abdulrehman MA. Study some mechanical properties of SIFCON concrete containing of slag. In: AIP Conference Proceedings. AIP Publishing LLC; 2024. https://doi.org/10.1063/5.0239459

19] Nawar MT, Hama SM. A review of the combined effect of recycled steel fibers and waste nano glass on the technical performance of self-compacting concrete. An-Najah Univ J Res A (Nat Sci). 2025;40(1):77-84. https://doi.org/10.35552/anujr.a.40.1.2446

20] Abduljaleel MT, Al-Hadithi AI. Flexural performance of SCC beams reinforced with GFRP rebars containing EPS and waste plastic fibers. An-Najah Univ J Res A (Nat Sci). 2025;40(4). https://doi.org/10.35552/anujr.a.a2695

21] Aldahdooh MA. Utilization of by-product materials in ultra high-performance fiber reinforced cementitious composites. In: Cement Based Materials. IntechOpen; 2018. https://doi.org/10.5772/intechopen.74376

22] Frazão C, Barros J, Bogas JA, García-Cortés V, Valente T. Technical and environmental potentialities of recycled steel fiber reinforced concrete for structural applications. J Build Eng. 2022;45:103579. https://doi.org/10.1016/j.jobe.2021.103579

23] Onyelowe KC, Kamchoom V, Ebid AM, Hanandeh S, Polo SMZ, Silva VFN, Murillo ROS, et al. Evaluating the strength of industrial wastes-based concrete reinforced with steel fiber using advanced machine learning. Sci Rep. 2025;15(1):8082.

https://doi.org/10.1038/s41598-025-92194-3

24] ASTM International. C150/C150M-20: Standard specification for Portland cement. West Conshohocken (PA): ASTM International; 2020. https://doi.org/10.1520/C0150_C0150M-20

25] ASTM International. C311-07: Standard test methods for sampling and testing fly ash or natural pozzolans for use in Portland-cement concrete. West Conshohocken (PA): ASTM International; 2007. https://doi.org/10.1520/C0311-07

26] ASTM International. C618-19: Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. West Conshohocken (PA): ASTM International; 2019. https://doi.org/10.1520/C0618-19

27] Central Organization for Standardization and Quality Control. Iraqi Specification No. 45/2021: Aggregates used in concrete and construction. Baghdad (Iraq): COSQC; 2021. https://iraqi-standards.org/Home/st_dep_tab

28] ASTM International. C494/C494M-17: Standard specification for chemical admixtures for concrete. West Conshohocken (PA): ASTM International; 2017. https://doi.org/10.1520/C0494_C0494M-17

29] ASTM International. A820/A820M-04: Standard specification for steel fibers for fiber-reinforced concrete. West Conshohocken (PA): ASTM International; 2006. https://doi.org/10.1520/A0820_A0820M-04

30] ASTM International. C1602/C1602M-18: Standard specification for mixing water used in the production of hydraulic cement concrete. West Conshohocken (PA): ASTM International; 2018. https://doi.org/10.1520/C1602_C1602M-22

31] Parameswaran V, Krishnamoorthy TS, Balasubramanian K, Gangadar S. Studies on slurry-infiltrated fibrous concrete (SIFCON). Transp Res Rec. 1993;1382. https://trid.trb.org/View/377852

32] Akçaözoğlu K, Kıllı A. The effect of curing conditions on the mechanical properties of SIFCON. Revista De La Construcción. Journal of Construction. 2021;20(1):37–51. https://doi.org/10.7764/RDLC.20.1.37

33] ASTM International. C230/C230M-14: Standard specification for flow table for use in tests of hydraulic cement. West Conshohocken (PA): ASTM International; 2014. https://doi.org/10.1520/C0230_C0230M-14

34] European Committee for Standardization. EN 12390-3:2019: Testing hardened concrete – Part 3: Compressive strength of test specimens. Brussels (Belgium): CEN; 2019. https://standards.cencenelec.eu/ords/f?p=CEN:110:::::FSP_PROJECT,FSP_ORG_ID:64409,6087&cs=150BABA867BBED12622E6FFBB5024034E

35] ASTM International. C496/C496M-17: Standard test method for splitting tensile strength of cylindrical concrete specimens. West Conshohocken (PA): ASTM International; 2017. https://doi.org/10.1520/C0496_C0496M-17

36] ASTM International. CASTM C78/C78M-22: Standard test method for flexural strength of concrete (using simple beam with third-point loading). West Conshohocken (PA): ASTM International; 2022. https://doi.org/10.1520/C0078_C0078M-22

37] ASTM International. C642-13: Standard test method for density, absorption, and voids in hardened concrete. West Conshohocken (PA): ASTM International; 2013. https://doi.org/10.1520/C0642-13

38] ASTM International. C597-16: Standard test method for pulse velocity through concrete. West Conshohocken (PA): ASTM International; 2016. https://doi.org/10.1520/C0597-16

39] ASTM International. C805: Standard test method for rebound number of hardened concrete. West Conshohocken (PA): ASTM International; 2008. https://doi.org/10.1520/C0805_C0805M-18

40] British Standards Institution. BS 12390-7: Testing concrete. Method for determination of density of hardened concrete. London (UK): British Standards Institution; 2019. https://knowledge.bsigroup.com/products/testing-hardened-concrete-density-of-hardened-concrete-2

41] Manolia AA, Shakir AS, Qais JF. The effect of fiber and mortar type on the freezing and thawing resistance of slurry infiltrated fiber concrete (SIFCON). IOP Conf Ser Mater Sci Eng.

2018;454(1):012142. https://doi.org/10.1088/1757-899X/454/1/012142

42] Donnini J, Lancioni G, Chiappini G, Corinaldesi V. Uniaxial tensile behavior of ultra-high performance fiber-reinforced concrete (UHPFRC): Experiments and modeling. Compos Struct. 2021;258:113433. https://doi.org/10.1016/j.compstruct.2020.113433

43] Tangpagasit J, Cheerarot R, Jaturapitakkul C, Kiattikomol K. Packing effect and pozzolanic reaction of fly ash in mortar. Cem Concr Res. 2005;35(6):1145-51. https://doi.org/10.1016/j.cemconres.2004.09.030

44] Gong J, Chou K, Huang ZY, Zhao M. A quantitative study on packing density and pozzolanic activity of cementitious materials based on the compaction packing model. IOP Conf Ser Mater Sci Eng. 2014;62(1):012013. https://doi.org/10.1088/1757-899X/62/1/012013

45] Akçaözoğlu K, Kıllı A. The effect of curing conditions on the mechanical properties of SIFCON. Rev Constr. 2021;20(1):37-51. https://doi.org/10.7764/rdlc.20.1.37

46] Alrubaie M, Hameed D, Salih S, Habeeb G, Abbas W. Slurry infiltrated fiber concrete as sustainable solution for defected buildings. Eng Technol J. 2019;37(1C):132-8. https://doi.org/10.30684/etj.37.1C.21

47] Bentur A, Mindess S. Fibre reinforced cementitious composites. Boca Raton (FL): CRC Press; 2006. https://doi.org/10.1201/9781482267747

48] Naaman AE. Engineered steel fibers with optimal properties for reinforcement of cement composites. J Adv Concr Technol. 2003;1(3):241-52. https://doi.org/10.3151/jact.1.241

49] Ghalehnovi M, Roshan N, Hakak E, Shamsabadi EA, de Brito J. Effect of red mud (bauxite residue) as cement replacement on the properties of self-compacting concrete incorporating various fillers. J Clean Prod. 2019;240:118213.

https://doi.org/10.1016/j.jclepro.2019.118213

50] Alameri IA, Oltulu M. The physico-mechanical properties of concrete with red-mud at high temperatures. CJCRL. 2020;11(4):10. https://doi.org/10.20528/cjcrl.2020.04.001

51] Behbahani HJ, Nematollahi B, Farasatpour M. Steel fiber reinforced concrete: a review. 2011. http://dl.lib.mrt.ac.lk/handle/123/9505

52] Ferrara L, Park Y, Shah SP. A method for mix-design of fiber-reinforced self-compacting concrete. Cem Concr Res. 2007;37(6):957-71. https://doi.org/10.1016/j.cemconres.2007.03.014

53] Neville AM. Properties of concrete. 4th ed. London; 1995. https://trid.trb.org/View/454875

54] Wang Z, Li H, Zhang X, Chang Y, Wang Y, Wu L, Fan H. The effects of steel fiber types and volume fraction on the physical and mechanical properties of concrete. Coatings. 2023;13(6):978. https://www.mdpi.com/2079-6412/13/6/978

55] Song PS, Hwang S. Mechanical properties of high-strength steel fiber-reinforced concrete. Constr Build Mater. 2004;18(9):669-73. https://doi.org/10.1016/j.conbuildmat.2004.04.027