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State of Art: Behavior of High-Strength Concrete with and Without Steel Fiber Reinforcement

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Abstract: Steel fibered high-strength concrete (SFHSC) has emerged as a widely utilized material in structural engineering due to its superior durability and aesthetic benefits. Its strength enhances structural performance, making it particularly valuable in dynamic loading conditions. Extensive research has been conducted to optimize fiber content, identify suitable fiber types, and integrate SFHSC with conventional reinforcement to improve ductility and mitigate macro-crack propagation. Additionally, composite two-layer beams combining SFHSC with normal-strength concrete offer cost-effective solutions for new constructions and retrofitting applications. Recent experimental studies have provided valuable insights into SFHSC properties, existing design codes, and potential advancements in modern structural engineering. [1].

Keywords: steel, fiber, strength, concrete, SFHSCs.

Introduction

Concrete consists of aggregate, cement, water, and optional additives, chosen based on the project's needs. It hardens over time, with its strength influenced by the materials used and the mixing process.

Admixtures enhance concrete properties, such as performance, setting time, and strength, while minimizing issues like drying and segregation. Maintaining quality during mixing, transporting, pouring, and curing is crucial, especially in varying weather conditions.

Additives, including chemical admixtures and supplementary materials, can improve fresh and hardened concrete. For instance, steel fibers can be mixed in after the other components, requiring at least 5 minutes of high-speed mixing to ensure proper distribution and workability.

In recent years, construction projects, particularly in China, have increased rapidly, requiring high-quality materials for durability. Ultra-high-performance concrete (UHPC) meets these needs, and incorporating steel fibers enhances its strength. While steel fibers in UHPC are typically spread randomly, optimal reinforcement occurs when they align with the direction of tensile stress.

In 1984, Shen used a magnetic field to align steel fibers in concrete beams. Chen later confirmed that this method significantly increases the concrete's strength compared to randomly placed fibers [2,3].

Steel fibered high-strength concrete (SFHSC) is popular in construction for its strength and aesthetics. Regular concrete was brittle with low tensile strength, leading to the use of steel bars in reinforced concrete (RC) to enhance its performance under bending forces. Recent research focuses on increasing concrete's compressive strength for lighter, more cost-effective building designs. The use of fibers to enhance weak materials dates back to ancient Egyptian and Babylonian times [4]. Fibers enhance reinforced concrete by filling cracks and improving flexibility and energy absorption. They increase bending strength, impact resistance, tensile strength, and toughness [5].

Fiber reinforcement can be placed randomly or in specific locations within composite structures, such as beams of two layers [5,6] or high-strength concrete columns encased in fiber-reinforced concrete [7]. For nearly 90 years, different types of fibers—such as steel, textile, organic, and glass—have been used to improve the performance of concrete [8]. Understanding fiber-reinforced concrete stretching is crucial for Design. It depends on factors like fiber shape, quantity, bonding with concrete, concrete strength, shrinkage, and fiber orientation [9]. Researchers evaluate fiber effectiveness using experimental and numerical methods, including impact, compression, tension, and bending tests [10].

Mu and his team developed a solenoid coil that aligns steel fibers using the principle that a compass points north in a magnetic field. This magnetic force causes the fibers to rotate and align with the magnetic lines, achieving an orientation efficiency factor of 0.96 [11,12]. Researchers have looked into two steel fiber reinforced concrete types: annularly aligned and full-field aligned [14].

Several studies have examined the impact of adding fiber to concrete, focusing on strength, toughness, ductility, crack resistance, and durability [15, 16]. Studies have examined how different fibers and concrete mixtures affect various concrete formulations [17,18]. Research has explored how fiber direction impacts material strength and the effects of aggregate types and curing methods on production costs and mechanical properties [19,20]. Steel fiber-reinforced concrete is gaining popularity for its beneficial properties and is used in airport pavements, earthquake-resistant structures, tunnels, bridges, and hydraulic systems [21]. Fiber-reinforced high-strength concrete is used not only for building new structures but also for strengthening older ones [22]. New nondestructive testing methods (NDT) allow researchers to better assess the properties of concrete [23]. Methods like electrical resistivity measurements and X-ray imaging help us check how fibers are spread out and oriented [21]. Acoustic emission techniques monitor early cracking in fiber-reinforced mortars and analyze the bending of fiber-reinforced concrete elements [22, 23]. Interest in nondestructive testing of fiber-reinforced concrete is growing for two reasons. First, quality management systems require precise checks of material properties during production and construction. Second, researchers are developing tools for in-depth material analysis beyond surface inspections, as standard bulk measurements often fail to reveal internal conditions. This has created a demand for detailed meso-scale modeling of material properties instead of broader macro-scale evaluations [24,25].

This paper examines recent studies on SFHSC, emphasizing the materials used and the properties of fresh and hardened concrete for effective Design. It highlights durability aspects and performance under various loads, while also analyzing design standards and regulations about experimental results, showcasing promising applications for SFHSC in modern construction.

Research significance

Adding steel fibers to concrete enhances its strength and performance, particularly against cracking. Concrete is strong under pressure but weak in tension, making it vulnerable to cracking from stress or temperature changes. Steel fibers act as reinforcements within the concrete, preventing cracks and controlling their growth.

One significant advantage of steel fibers is that they maintain concrete's strength even after cracking, as the fibers help absorb stress and keep the structure stable. They also improve durability, making the concrete more resistant to wear and environmental changes, extending its lifespan.

Overall, incorporating steel fibers significantly strengthens concrete, enhancing its performance and durability for demanding applications like industrial floors, parking lots, and tunnels.

Effect of steel fiber orientation on mechanical properties

The positioning of steel fibers is crucial for the strength and durability of ultra-high-performance concrete (UHPC). UHPC consists of a matrix with short, randomly distributed steel fibers that do not run continuously. Their position, length, and bond with the matrix matter greatly.

When cracks occur, the steel fibers pull out rather than break, provided their length (lf) is shorter than a critical length (lfcr). This behavior impacts the overall strength and durability of fiber-reinforced UHPC [3].

The steps to implement the test

1 - I conducted the sieve analysis process according to the Iraqi specification for both sand and gravel, according to tables 1 and 2.

Table 1 (Sieve analysis of gravel)

Sieve number	Empty sieve weight(g)	Weigh the sieve with the remainder	Weight of residue on each sieve	Remaining percentage	Accumulated percentage	Passage rate
37.5 mm	493	493	0	0	0	100
20 mm	643	643	0	0	0	100
10 mm	544	1060	516	51.6	51.6	48.4
5 mm	511	992	481	48.1	99.7	0.3
pan	303	309	6	0.6	100	0

Table 2 (Sieve analysis of sand)

Sieve number	Empty sieve weight(g)	Weigh the sieve with the remainder	Weight of residue on each sieve	Remaining percentage	Accumulated percentage	Passage rate
9.5 mm	544	544	0	0	0	100
4.75 mm	511	545	34	3.4	3.4	96.6
2.36 mm	482	544	62	6.2	9.6	90.4
1.18 mm	458	555	97	9.7	19.3	80.7
0.6 mm	428	557	129	12.9	32.2	67.8
0.3 mm	423	754	133	33.1	65.3	34.7
0.15 mm	400	673	273	27.3	92.6	7.4
pan	194	278	84	8.4	100	0

2- The unadded concrete mix is prepared from ideal samples of materials. We take samples of cement, gravel, and sand, then weigh each sample where the weight of cement is (4.418 kg), the weight of sand is (6.627 kg), and the weight of gravel is (13.25 kg).

3 - We mix the dry materials (cement, sand, and gravel) until the mixture becomes homogeneous, according to figures 1 and 2.

Figure 1 (cement mixing) Figure 2 (sand mixing)

4 - We add distilled water to the concrete mixture and turn on the mixer.

5 - We grease the mold before placing the concrete mixture, then place the mixture in the cubes in three layers. Each layer is stacked with 25 blows to remove air bubbles from the sample.

6 – Preparing the concrete mixture with steel fiber and superplasticizer as shown in Figure 3.

Figure 3 (steel fiber)

7 - Place the mixture in the cubes in three layers. Each layer is stacked with 25 blows to remove air bubbles from the sample.

8- Leave the samples for 24 hours as shown in figure 4, and then place them in the treatment tanks.

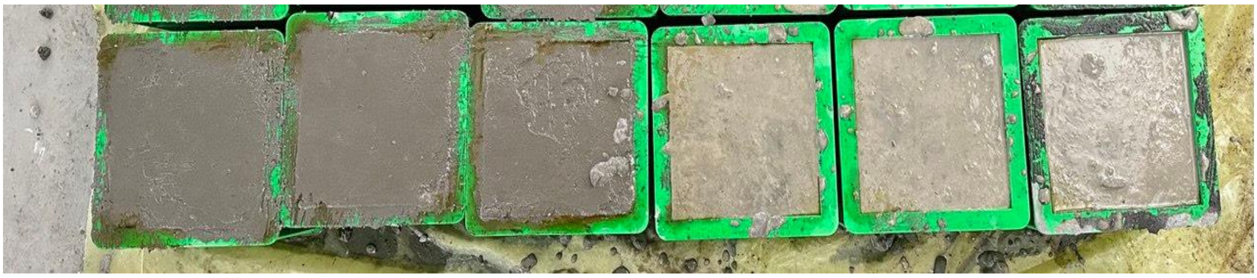

Figure 4 (cement cubes)

Concrete mix design

Volume of cubic = 0.15 * 0.15 * 0.15

= 0.00337 * 6

= 0.0202

cement contect from w/c , w/c =0.45

(w/c is water cement ratio)

C = 8.83 kg (cement)

S = 13.25 kg (sand)

G = 26.5 kg (gravel)

w = 3800 ml (water)

steel fiber = 0.75%

Superplasticizer = 22 ml

The concrete cubes were put in the compressive strength device, and the compressive strength was measured according to Figure 5.

Strength without steel fiber

1- 31.5MPa

2- 31 MPa

3- 30 MPa

Figure 5 (Compression resistance device).

Strength with steel fiber

1- 40 MPa

2- 40 MPa

3- 39 MPa

Figure 5 (Compression resistance device).

Conclusion

This study examines how steel fibers enhance the mechanical properties of concrete, particularly its tensile and bending strength. Results indicate that steel fibers reduce cracking early and later, improving the concrete's load-bearing capacity after cracking and overall durability. The random fiber distribution helps manage dynamic loads and minimizes shrinkage-related issues.

Tests showed that concrete cubes with steel fibers were stronger than regular ones, primarily due to improved bonding between particles. Therefore, steel fiber reinforced concrete is advantageous for structures requiring high performance, longevity, and reduced maintenance.

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