7th Conference on Sustainability in Civil Engineering (CSCE'25)
(An International Conference)
Department of Civil Engineering
Capital University of Science and Technology, Islamabad Pakistan

AN OVERVIEW OF THE EFFECTS OF STEEL FIBER REINFORCED COMPOSITES ON FLEXURAL CRACKING IN CONCRETE

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Abstract- Cement concrete is the most widely used construction material globally, attributed to its excellent workability and moldability. However, its inherently low tensile strength, minimal ductility, and high susceptibility to cracking limit its application without reinforcement. These deficiencies often result in the formation of internal microcracks that compromise the material's structural integrity. As modern civil engineering structures demand higher performance and durability, conventional concrete must be enhanced to meet these evolving requirements. The incorporation of various fiber types into concrete mixtures has shown promising improvements in mechanical performance, durability, and serviceability. Among these, Steel Fiber Reinforced Concrete (SFRC) has demonstrated exceptional crack resistance and control. SFRC significantly improves tensile strength of concrete under flexural loading, by bridging cracks and preserving the integrity of the matrix even after extensive cracking. This paper provides an overview of the effectiveness of steel fiber composites in enhancing the structural behavior of concrete, with a focus on mitigating flexural cracking.

Keywords- Concrete Durability, Flexural Cracking, Steel Fiber Reinforced Concrete (SFRC), Tensile Strength Enhancement.

1 Introduction

Concrete is vulnerable to cracking due to various factors. These include foundation settlement, temperature changes, flexural stresses from bending, excessive loading, shrinkage during curing, and reinforcement corrosion [1]. Early-age plastic shrinkage cracks often occur during the curing stage. In contrast, map and hairline cracks typically result from temperature variations or drying shrinkage [2]. Cracks can reduce the durability and performance of concrete structures. To prevent them, engineers use several methods. These include proper mix design, installation of control joints, fiber or steel reinforcement, careful curing, and avoiding overloads [3]. With effective construction practices, the service life of concrete can be extended, and the likelihood of cracking can be reduced [4].

Steel Fiber Concrete (SFC) is a composite made by adding steel fibers to cement, aggregates, and water. Plain concrete is brittle and weak in tension. It tends to crack under bending or flexural stresses [5]. Steel fibers help control these cracks. They are randomly distributed in the mix and act as internal reinforcement. After cracking begins, the fibers bridge the cracks and provide ductility. This improves the toughness of concrete, which refers to the energy absorbed after peak load [6][7]. Fibers help the concrete resist sudden failure by increasing its energy absorption capacity [8]. Although there are cheaper alternatives, the performance benefits of steel fibers make them valuable in structural applications.

Steel fibers are not a replacement for main reinforcement bars. However, they improve crack resistance and reduce deflection in structural elements [9][10]. When added to the concrete matrix, the fibers act as stiff inclusions. They help resist serviceability issues like crack widening and excessive bending. Fibers can be distributed in three dimensions throughout the concrete. This is useful for general reinforcement. In some cases, they can also form a two-dimensional tensile layer over steel reinforcement [11][12]. The research significance is to improve shear resistance and help control crack growth [13]. As a result, steel fiber reinforced concrete is increasingly used in beams, slabs, pavements, and other load-bearing elements.

2 Structural Cracking and Flexural Failure

Several researchers have studied the types, causes, and control methods of cracks in concrete structures [14]. One common area of focus is surface cracking, which is important for civil engineers to understand due to its impact on durability and appearance [1]. Studies have identified various reasons for concrete cracking and methods to evaluate them, including tools like crack compactors and ultrasonic testing [15]. The paper *Building Cracks: Causes and Remedies* highlights that cracks can have both direct and indirect consequences. While cracks may not always be the immediate cause of structural failure, they often contribute to conditions that lead to it [16]. Researchers have also provided classifications of cracks along with their causes and possible remedies. In one study, visual inspection was used effectively to identify and categorize cracks in an institutional building, demonstrating how such evaluations can support maintenance and repair decisions [17].

A specific type of fracture known as flexural crack commonly forms in reinforced concrete elements such as beams and slabs due to bending or flexural stresses [18]. Figure 1 illustrates flexural cracks in a reinforced concrete beam. These cracks occur because concrete is inherently strong in compression but weak in tension. When a beam is subjected to bending, the top fibers experience compression, while the bottom fibers are placed in tension [19]. If the tensile stress in the tension zone exceeds the concrete's tensile strength, cracks begin to form typically starting at the bottom and moving vertically upward [20]. Flexural cracks most often appear at mid-span, where bending moments are greatest. Contributing factors include excessive loading, poor or insufficient reinforcement, substandard concrete quality, improper curing, long spans, and inadequate structural design. Understanding the stress behavior of concrete is essential for identifying, controlling, and preventing flexural cracking in structural elements.

Figure 1: Flexural cracks in a reinforced concrete b*eam [30]*

3 Governing Parameters Influencing Flexural Cracking

Flexural cracking in concrete mainly occurs because it is strong in compression but weak in tension. When a structural element bends, the tension at the bottom may exceed the concrete's capacity, leading to cracks [1]. A low modulus of elasticity in concrete allows greater deflections under load, which increases the likelihood of cracking due to higher strain levels [14]. Creep, which is the slow deformation under long-term loading, also contributes by increasing deflection over time. Shrinkage, especially during drying, creates internal tensile stresses that can further promote cracking [2-4].

Poor bonding between the concrete and reinforcement reduces the reinforcement's effectiveness in handling tensile forces [7]. Internal flaws like voids and weak zones can concentrate stress and trigger cracks. These factors combined make concrete vulnerable to flexural failure [18]. As shown in Table 1, properties of steel fibers significantly enhance the performance of concrete. They improve tensile and flexural strength, increase ductility, and help control cracks by bridging micro-cracks and absorbing energy. This results in better durability and reduced cracking under flexural stress [5-8].

Table 1 Properties of Steel Fibers [21]

Property	Typical Values / Description
Tensile Strength	280–990 MPa
Young's Modulus	~200 GPa
Poisson's Ratio	~0.30
Ultimate Elongation	~3.6%
Specific Gravity	~7.86
Fiber Dimensions	Diameter: 0.25–0.75 mm
Aspect Ratio	20-100
Fiber Dosage	5% use in volume
Fiber Length	2" in length
W/C Ratio	0.5% w/c ratio
Compressive Strength Gain	Increased by 14–32% with steel fiber inclusion
Splitting Tensile Strength	Increased up to 77%
Flexural Strength	Increase of 6–69% depending on fiber shape and dosage
Ductility and Toughness	Enhanced; fibers delay crack growth and increase energy absorption
Impact Resistance	Significantly improved compared to conventional concrete
Crack Control	Fibers bridge micro-cracks, reducing crack widths and propagation
Fiber Shapes	Hooked-end, straight, crimped, corrugated – affect performance
ASTM A820 Fiber Types	Type I: Cold-drawn, Type II: Cut sheet, Type III: Melt- extracted, Type IV: Mill cut, Type V: Modified wire

4 Fiber Shortlisting for Crack Control

To improve concrete's flexural strength and prevent it from cracking, several fibers are used, each with unique benefits. Steel fibers are the most efficient method of enhancing flexural strength and fracture resistance because they disperse tensile stress and bridge cracks. This increases the concrete's ductility and decreases the likelihood that it will shatter when bent [22-23]. Polypropylene fibers primarily prevent shrinkage fractures by reducing internal stresses during the early curing phase, even though they don't significantly boost flexural strength [24]. Glass fibers provide corrosion resistance and flexural strength, making them suitable for severe environments even though their tensile strength is inferior to that of steel [25]. The durability and corrosion resistance of basalt fibers are well known, and they improve flexural strength and crack resistance in harsh environments [26]. Carbon fibers are ideal for high-performance concrete because of their exceptional flexural strength and fatigue resistance, despite their higher cost [27]. Nylon fibers can improve impact resistance and reduce shrinkage fractures, although having a slight effect on flexural strength [28]. When selecting these fibers, the specific needs of the project such as strength, durability, and environmental exposure are taken into account.

Figure 2: Steel Fibers in concrete matrix [31]

Figure 2 illustrates steel fibers embedded in the concrete matrix, highlighting their role in improving tensile properties and fracture resistance. Steel fibers act as internal reinforcement, distributing tensile stresses more evenly throughout the concrete. They bridge flexural cracks that develop under bending stress, significantly increasing the concrete's resistance to bending and preventing fractures from spreading. This greatly enhances the concrete's ductility, allowing it to deform more without cracking. Additionally, steel fibers limit shrinkage cracks and prevent large fractures by reducing internal tensile strains during drying and curing. They serve as barriers restricting concrete mobility during drying shrinkage, lowering the risk of early-stage cracking. Overall, steel fibers improve toughness, impact resistance, and post-cracking behavior, making concrete more durable and resistant to cracking over time [22-23, 29].

Table 2 Comparison of fiber type [21]

Fiber Type	Mechanical Properties Enhanced	Shrinkage Control	Workability Impact
Straight	Tensile strength, flexural strength, Compressive strength, toughness, ductility	Moderate to good	Usually manageable, but decreases with increasing aspect ratio and volume
Crimped	Mechanical anchorage, flexural strength, toughness	Good	Adequate reduction in slump as compared to plain concrete
Hooked-End	Flexural strength, tensile strength, toughness, impact resistance, pull-out resistance	Effective in reducing plastic shrinkage and micro-cracks, and most efficient for drying shrinkage control	Adequate reduction in slump, but generally less than RTSF at similar dosages

Table 2 illustrates that fiber may effectively increase the mixture's ability to regulate cracks, which will lower the breadth and length of cracks. Furthermore, steel fiber-reinforced concrete (SFRC) has superior mechanical properties, including fatigue resistance, impact resistance, and shear and flexural strength. Concise overview of how different steel fiber forms influence concrete properties is provided.

5 Conclusion

In conclusion, this study highlights the importance of improving concrete performance through fiber reinforcement to reduce flexural cracking. The following key points summarize the findings:

1. Several factors, including foundation settlement, temperature changes, excessive loading, curing shrinkage, and reinforcement corrosion, influence concrete cracking. Early-age plastic cracks and later-stage map or hairline cracks are common in poorly managed concrete.
2. Flexural cracks typically occur in the tension zone of beams and slabs when bending stresses exceed the concrete's limited tensile strength. These cracks compromise structural capacity and durability, especially in elements exposed to repeated or sustained loads.
3. Steel fibers significantly enhance concrete's performance by improving tensile and flexural strength, delaying crack formation, and bridging micro cracks. This increases the concrete's energy absorption and resistance to crack propagation under flexural loading.
4. The inclusion of steel fibers also contributes to improved ductility, impact resistance, and post-cracking behavior. As a result, structures reinforced with steel fibers demonstrate increased durability, reduced maintenance needs, and better long-term performance under flexural stress.

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