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Study of Fiber-Reinforced Self-Compacting Concrete with Fibers

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ABSTRACT

The present study aims to compare the mechanical characteristics of self-consolidating concrete (SCC) reinforced with different fiber types and varying fiber contents. Glass fiber, carbon fiber, and basalt fiber of 12 mm length were incorporated at volume fractions of 0.0%, 0.1%, 0.15%, 0.2%, 0.25%, and 0.3%. The experimental program was carried out in two phases. In the first phase, an SCC mix design was developed for M30 grade concrete. In the second phase, fresh properties of SCC were evaluated, followed by an investigation of hardened mechanical properties, toughness, fracture energy, and sorptivity. To further assess employed to study the hydration products and the interfacial bonding between fibers and the cementitious matrix. The findings provide insights into the comparative performance of different fibers in enhancing SCC properties, highlighting their potential in improving durability and structural efficiency.

Keywords: Fiber Reinforcement, Glass Fiber, Carbon Fiber, Basalt Fiber, compressive strength, concrete

1. Introduction

The Self-Compacting Concrete (SCC) represents one of the most remarkable advancements in construction material technology. Developed initially in Japan in 1986 by Prof. H. Okamura, SCC was introduced to address challenges associated with conventional concrete, particularly the issues of vibration, compaction, and placement in congested reinforcement zones. Unlike normal concrete, SCC possesses the unique ability to flow under its own weight, completely filling the formwork and encapsulating reinforcement without the need for external vibration or mechanical compaction. This revolutionary property has significantly improved construction practices, ensuring higher productivity, better surface finishes, reduced labor requirements, and enhanced durability.

The composition of SCC is similar to conventional concrete, comprising cementitious binders, fine and coarse aggregates, water, and admixtures. However, SCC requires a higher content of fines, the use of superplasticizers, and sometimes viscosity-modifying agents to ensure the necessary rheological properties. The Bureau of Indian Standards (BIS) has not yet established a standardized mix design method for SCC, and hence extensive research and experimental trials have been conducted globally to optimize mix proportions.

In comparison with conventional concrete, SCC exhibits superior characteristics such as improved compaction, better bond strength, enhanced durability, and more uniform quality. While its modulus of elasticity is slightly lower due to higher paste content, SCC demonstrates excellent resistance to segregation, higher fire resistance, and improved surface finishes. Consequently, SCC has found extensive application in precast elements, bridges, tunnels, high-rise structures, and other critical infrastructure projects where quality control and durability are of utmost importance.

Despite its numerous advantages, SCC, like traditional concrete, remains inherently brittle with limited tensile strength. This brittleness often leads to crack initiation and propagation under tensile and flexural stresses, restricting its structural applications. To overcome this limitation, fiber reinforcement has emerged as an effective solution, enhancing toughness, ductility, and fracture resistance.

2. Literature Review

The Fiber Reinforced Self-Compacting Concrete (FRSCC) is an innovative material that combines the self-consolidating ability of SCC with the crack-bridging and strengthening effects of fibers. Fibers provide resistance against micro- and macro-crack propagation, significantly improving post-cracking behavior and overall mechanical performance. The mechanisms of debonding, sliding, and pull-out of fibers contribute to the bridging effect, which increases fracture toughness and energy absorption capacity of the composite.

Among the various fibers investigated, glass, basalt, and carbon fibers have shown considerable promise. Glass fibers are cost-effective and easy to disperse, basalt fibers offer excellent chemical resistance and superior thermal stability, while carbon fibers provide exceptional strength, durability, and crack resistance Self-compacting concrete (SCC) has continued to evolve from a specialty material to a mainstream solution for congested reinforcement and high-quality finishes. Recent work underscores that the rheology of SCC is highly sensitive to fines content and admixture synergy; adding discrete fibers modifies flow and segregation resistance, necessitating careful dosage optimization to preserve self-compactability (typically verified via slump-flow, V-funnel, L-box, and sieve stability). Contemporary reviews confirm that fibers improve post-cracking behavior and durability, but with a trade-off in workability proportional to volume fraction and aspect ratio[2,3].

Self-Compacting Concrete (SCC) is a highly flowable, non-segregating concrete that can spread under its own weight, fill formwork, and encapsulate reinforcement without any need for mechanical vibration[4]. This technology revolutionized concrete construction by ensuring better compaction in complex formworks, reducing labor costs, minimizing noise pollution, and improving the working environment. The key to achieving self-compatibility lies in a carefully designed mix proportion with a high powder content, low water-to-binder ratio, and the use of modern high-range water-reducing admixtures (HRWR) or superplasticizers (SP)[5].

The incorporation of fibers invariably affects the rheology of SCC. Fibers increase the surface area in the mix and can interlock, leading to increased internal friction and reduced flowability. The extent of this reduction depends on the fiber type, geometry, and dosage.

Glass Fibers (GF): Known for high tensile strength and good alkali resistance (in the case of AR-glass fibers). However, they can be susceptible to degradation in the high-pH environment of cement paste if not properly coated, potentially leading to long-term strength loss.

Basalt Fibers (BF): Extruded from molten basalt rock, these fibers offer excellent tensile strength, high elastic modulus, good chemical resistance, and superior temperature stability compared to E-glass fibers. They are often considered a more environmentally friendly alternative to carbon fibers.

Carbon Fibers (CF): Possess the highest specific strength and modulus of elasticity among common fibers, leading to significant improvements in flexural strength and stiffness. They are also electrically conductive and chemically inert. Their main drawback is high cost, which often limits their use to specialized application[6].

The fresh properties of SCC are characterized by three essential properties: flowability (filling ability), passing ability (to flow through tight openings like reinforcement bars without blocking), and segregation resistance (stability). These are typically evaluated using the slump flow test, V-funnel test, and L-box test, respectively, as per EFNARC (2005) guidelines. The effect of fibers on compressive strength is generally less pronounced and can be variable. While fibers provide confinement and can delay the lateral expansion of the concrete under compression, a high fiber content can introduce voids and defects, potentially negating any benefits. Most studies report a marginal increase or a slight decrease in compressive strength with fiber addition [7].

3. Objectives

The primary objective of this study is to design an M30 grade SCC mix and investigate the effect of incorporating chopped glass, basalt, and carbon fibers of 12 mm length in varying volume fractions (0.0%–0.3%). The research focuses on both fresh and hardened properties of FRSCC. Fresh properties include flowability, passing ability, and segregation resistance, measured using standard SCC tests such as slump flow, V-funnel, and L-box. Hardened properties to be evaluated are compressive strength conducted to assess the interfacial bond and hydration products in fiber-reinforced mixes. Incorporation of different fibers into SCC at varying dosages and evaluation of their mechanical performance.

4. Experimental Program

The experimental program aimed to investigate the mechanical and fracture properties of M30-grade self-compacting concrete (SCC) reinforced with chopped glass (GFC), basalt (BFC), and carbon (CFC) fibers. Fibers, each 12 mm long, were incorporated at volume fractions of 0.0% (control), 0.1%, 0.15%, 0.2%, 0.25%, and 0.3%. The SCC mix was designed as per EFNARC 2005 guidelines, incorporating silica fume and a superplasticizer.

The fresh properties of each mix, including flowability (slump flow, T50), passing ability (L-Box), and viscosity (V-Funnel), were rigorously tested to ensure they met SCC criteria. For hardened properties, a total of 186 specimens—including cubes (150mm), cylinders (150x300mm), and prisms (100x100x500mm)—were cast. These were tested at 7 and 28 days for compressive strength, split tensile strength, flexural strength, ultrasonic pulse velocity (UPV), and fracture energy using notched beams under three-point bending.

5. Result and Discussion

The incorporation of fibers significantly influenced both the fresh and hardened properties of the SCC. Fresh properties, particularly slump flow, decreased with increasing fiber content, with carbon fiber (CFC) exhibiting the most substantial reduction (63.88% at 0.3%) due to its high water absorption, making mixes beyond 0.2% unsuitable for SCC. Glass fiber (GFC) showed the least impact on workability.

Regarding hardened properties, an optimal fiber dosage was identified for each type, maximizing mechanical performance. Basalt fiber (BFC) at 0.25% volume fraction yielded the highest 28-day compressive strength (61.4 MPa, a 50.16% increase over plain SCC) and a 61.74% increase in flexural strength. Carbon fiber (CFC) at 0.15% provided the greatest enhancement in flexural strength (12.32 MPa, a 67.16% increase) and a 47.6% increase in compressive strength. Glass fiber (GFC) at 0.2% showed more modest improvements, with a 15.21% increase in compressive strength and a 36.77% increase in flexural strength..

6. Conclusions

This study conclusively demonstrates that basalt, glass, and carbon fibers significantly enhance the mechanical and fracture properties of SCC when used at optimal dosages (0.25% for basalt, 0.2% for glass, and 0.15% for carbon). While carbon fiber yielded the highest strength improvements, its detrimental effect on workability and high cost are limiting factors. Basalt fiber offered an excellent balance, providing superior strength, enhanced ductility, low sorptivity, and satisfactory fresh properties, making it the most viable and cost-effective option for producing high-performance Fiber-Reinforced Self-Compacting Concrete (FRSCC) for structural applications.

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