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Performance Analysis of Self-Compacting Concrete Modified with Fiber for Enhanced Fracture Resistance

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Abstract: *The fibers employed in this research include chopped glass fibers, carbon fibers and basalt fibers, each with a length of 12 mm, incorporated at volume fractions of 0.0%, 0.1%, 0.15%, 0.2%, 0.25% and 0.3%. The study was conducted in two phases: first, developing an M30 grade SCC mix design and second incorporating the selected fibers to assess their impact on fresh and hardened properties. Results indicate significant improvements in overall performance with fiber addition. Carbon fiber-reinforced SCC demonstrated superior mechanical properties but reduced fresh workability due to higher water absorption whereas glass fiber-reinforced SCC exhibited the best performance in the fresh state. Basalt fiber-reinforced SCC achieved an optimal balance of performance and cost emerging as the most practical option for improving overall SCC quality.*

Keywords: Self-Compacting Concrete, Fiber Reinforcement, Basalt Fiber, Scanning Electron Microscopy

I. INTRODUCTION

Concrete has remained the cornerstone material of the construction industry due to its versatility, durability & cost-effectiveness. Conventional concrete requires significant vibration and compaction efforts during placement which can lead to problems as segregation, honeycombing and inadequate consolidation in heavily reinforced sections. To overcome these limitations, the concept of Self-Compacting Concrete (SCC) was introduced in the late 20th century revolutionizing modern construction practices.

SCC is characterized by its ability to flow and compact under its own weight without the need for mechanical vibration, resulting in uniform distribution superior surface finish and improved structural integrity. Its high workability and ease of placement have made SCC widely applicable in complex structural elements precast components and densely reinforced zones where conventional concreting poses challenges.

Self-Compacting Concrete

Self-compacting concrete was originally developed in Japan and Europe. It is a concrete that is able to flow and fill every part of the corner of the formwork even in the presence of dense reinforcement purely by means of own weight and without the need of for any vibration or other type of compaction. The growth of Self Compacting Concrete by Prof. H.Okamura in 1986 has caused a significant impact on the construction industry by overcoming some of the difficulties related to freshly prepared concrete.

Fiber Reinforced Self-Compacting Concrete

There is an innovative change in the Concrete technology in the recent past with the accessibility of various grades of cements and mineral admixtures. However there is a remarkable development some complications quiet remained. These problems can be considered as drawbacks for this cementatious material when it is compared to materials.

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Considering it, researchers have focused on studied the strength and durability aspects of fiber reinforced SCC which are:

1. Glass fibers
2. Carbon fibers
3. Basalt fibers
4. Polypropylene fibers

Objective of Study

1. To assess how different types and proportions of fibers influence compressive, tensile and flexural strength of self-compacting concrete.
2. To determine improvements in fracture energy, crack propagation resistance and post-cracking toughness compared to conventional SCC.
3. To investigate the effect of fiber inclusion on fresh properties of SCC.

II. REVIEW OF LITERATURE

Anonymous (2024) presents a detailed investigation into the performance of self-compacting fiber reinforced concrete (SCFRC) incorporating e-waste fibers when subjected to elevated temperatures. The research addresses two critical aspects: sustainable utilization of electronic waste and enhancement of concrete's fracture resistance under thermal stress. The experimental program involved developing SCFRC mixes with varying percentages of e-waste fibers, followed by evaluation of fresh properties through slump flow and L-box tests to ensure self-compacting characteristics.

Rao, Vipin (2023) Results revealed that steel fibers significantly improved the fracture energy, load carrying capacity and ductility of SCC providing superior crack bridging compared to plain SCC. The DIC method enabled precise tracking of strain localization and crack width evolution offering insights into the progressive damage mechanism and fiber-matrix interaction. Study demonstrated that the addition of steel fibers altered the failure mode from brittle to pseudo-ductile thus increasing structural safety margins.

Saba et al. (2021) the paper compiles research findings on the influence of steel fiber type, geometry and dosage on both fresh and hardened properties of SCC. It highlights that steel fibers significantly enhance tensile and flexural strengths, energy absorption capacity and post-cracking toughness thereby mitigating the inherent brittleness of SCC. The review also examines the effect of fiber inclusion on rheological properties as slump flow, viscosity and segregation resistance identifying dosage thresholds where workability is maintained.

Sadrmomtazi A., Haghighat Gashti S. & Tahmouresi B. (2020) study aims to evaluate the residual performance of SCC modified with various fiber types, including steel and polypropylene fibers when subjected to elevated temperatures up to 800 °C. Experimental work involved preparing FR-SCC mixes with different fiber dosages testing fresh properties to ensure self-compacting behavior and exposing hardened specimens to controlled heating cycles followed by cooling.

Mustapha Abdulhadi, et al. (2012) the author prepared M30 grade concrete and added polypropylene fiber 0% to 1.2% volume fraction by weight of cement and tested the compressive and split tensile strength and obtained the relation between them. This paper the mechanical attributes of a self-compacting concrete with low, medium and high-fiber contents of macro polyolefin fibers are considered. Their fracture behavior is compared with a manifest self-compacting concrete and also with a steel fiber-reinforced self-compacting concrete.

III. METHODOLOGY

This Methodology is to mix design of SCC of grade M30 and to investigate the effect of inclusion of chopped basalt fiber, glass fiber & carbon fiber on fresh properties and hardened properties of SCC. Fresh properties comprise flow ability, passing ability, and viscosity related segregation resistance. Hardened properties to be studied are compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, Ultrasonic pulse velocity and fracture energy.

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Fiber-reinforced self-compacting concrete uses the flow ability of concrete in fresh state to improve fiber orientation and in due course enhancing toughness and energy absorption capacity. In the past few years there has been a boost in the development of concretes with different types of fibers added to it. In the present work the mechanical properties of a self- compacting concrete with chopped Basalt, glass & Carbon fiber of length 12mm added in various proportions will be studied in fresh and hardened state. With the help of scanning electron microscope (SEM) the microstructure of fibered concrete was also studied.

The fracture energy behavior is one parameter that is very useful in calculating the specific fracture energy GF is by means of a uniaxial tensile test, where the complete stress-deformation curve is measured.

The present studies are designed at making standard grade (M30) fiber reinforced SCC with glass fibers, basalt fibers & carbon fibers and study their mechanical & structural behavior.

- Mix Design of self-compacting concrete of M30 grade.
- Mixing of SCC and determination of its fresh properties in terms of flowability, passing ability and segregation resistance by using Slump flow,V-funnel and L-box apparatus .
- Casting of standard specimens to determine compressive, tensile, flexural strengths and fracture energy.
- Mixing of SCC impregnated with different fibers in different dosages and determination of their fresh properties in terms of flow-ability, passing ability and segregation resistance by using Slump flow, V-funnel and L-box apparatus.
- Casting of standard specimen to determine compressive, tensile, flexural strengths and fracture energy incorporating glass fiber, basalt fiber and carbon fiber of different volume fraction ranging from 0.1% to 0.3%.
- Testing of standard specimens for strength determination after 7days and 28 days.
- Sorptivity test for determination of absorption capacity of SCC cubes reinforced with different fibers after 28 days.
- Study of micro structures by SEM of SCC reinforced with different fibers at different ages.

IV. RESULT AND DISCUSSION

Preparation of SCC and FRSCC and Studies on Fresh and Hardened Properties

The first stage of investigations was carried out to develop SCC mix of a minimum strength M30 grade using silica fume and chemical admixtures, and to study its fresh and hardened properties. For developing SCC of strength M30 grade, the mix was designed based on EFNARC 2005 code using silica fume as mineral admixture. Finally SCC mixes which yielded satisfactory fresh properties and required compressive strength were selected and taken for further investigation. In the second stage of investigation SCC with different fiber contents with different volume fraction were mixed. The mix proportions are shown in table.

Mix Proportions and Fiber Content

The number of trial mixes was prepared in the laboratory and satisfying the requirements for the fresh state given by EFNARC 2005 code. The present work involved preparation of M30 grade SCC and to study its behavior when different types of fibers were added to it. Plain SCC of M30 grade was prepared using silica fume as mineral admixture with sika viscocrete as admixture.

Table-1 Description of Mixes

Designation	Fiber content (%)	Description
PSC	0.0%	Plain self-compacting concrete
BFC-1	0.1%	0.1% Basalt fiber reinforced SCC
BFC-1.5	0.15%	0.15% Basalt fiber reinforced SCC
BFC-2	0.2%	0.2% Basalt fiber reinforced SCC
BFC-2.5	0.25%	0.25% Basalt fiber reinforced SCC
BFC-3	0.3%	0.3% Basalt fiber reinforced SCC
GFC-1	0.1%	0.1% Glass fiber reinforced SCC
GFC-1.5	0.15%	0.15%Glass fiber reinforced SCC
GFC-2	0.2%	0.2% Glass fiber reinforced SCC

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GFC-2.5	0.25%	0.25% Glass fiber reinforced SCC
GFC-3	0.3%	0.3% Glass fiber reinforced SCC
CFC-1	0.1%	0.1% Carbon fiber reinforced SCC
CFC-1.5	0.15%	0.15% Carbon fiber reinforced SCC
CFC-2	0.2%	0.2% Carbon fiber reinforced SCC

Hardened Properties

To compare the various mechanical properties of the FRSCC mixes the standard specimens were tested after 7 days and 28 day of curing. The results are summarized.

Table-2 Hardened Concrete Properties of SCC and FRSCC

Mixes	7-Day compressive strength (MPa)	28-days compressive strength (MPa)	28-days split tensile strength (MPa)	28-days flexural strength (MPa)
PSC	33.185	40.89	4.1	7.37
BFC-1	31.11	38.67	3.11	7.84
BFC-1.5	34.22	49.77	4.95	11.4
BFC-2	37.77	50.99	5.517	11.78
BFC-2.5	45.48	61.4	4.52	11.92
BFC-3	20.89	32.89	4.24	7.54
GFC-1	24.88	40.89	2.97	7.44
GFC-1.5	33.77	46.19	4.81	9.74
GFC-2	32.89	47.11	4.95	10.08
GFC-2.5	31.55	45.33	3.96	9.46
GFC-3	23.55	39.11	3.678	8.32
CFC-1	24.44	42.22	3.82	7.52
CFC-1.5	43.11	62.22	5.23	12.32
CFC-2	40.89	55.2	4.52	10.54

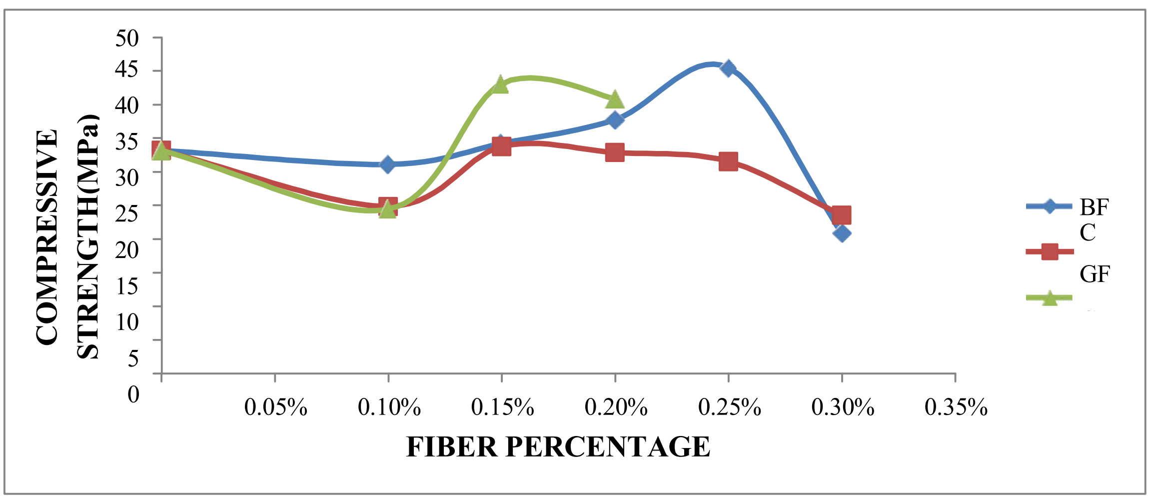

Figure-1 Comparison of Different Percentages of Fiber Mixes with 7 days Compressive Strength

The graph shows the optimum fiber content for maximum strength in mixes with different fibers. The maximum strength of 43.11MPa was observed with 0.15% carbon fiber content, 45.48 MPa was observed with 0.25% basalt fiber

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content and 33.77 MPa was observed with 0.15% glass fiber content. The highest 7-day compressive strength was observed for mix with 0.25 % basalt fiber and lowest for mix with 0.3% basalt fiber.

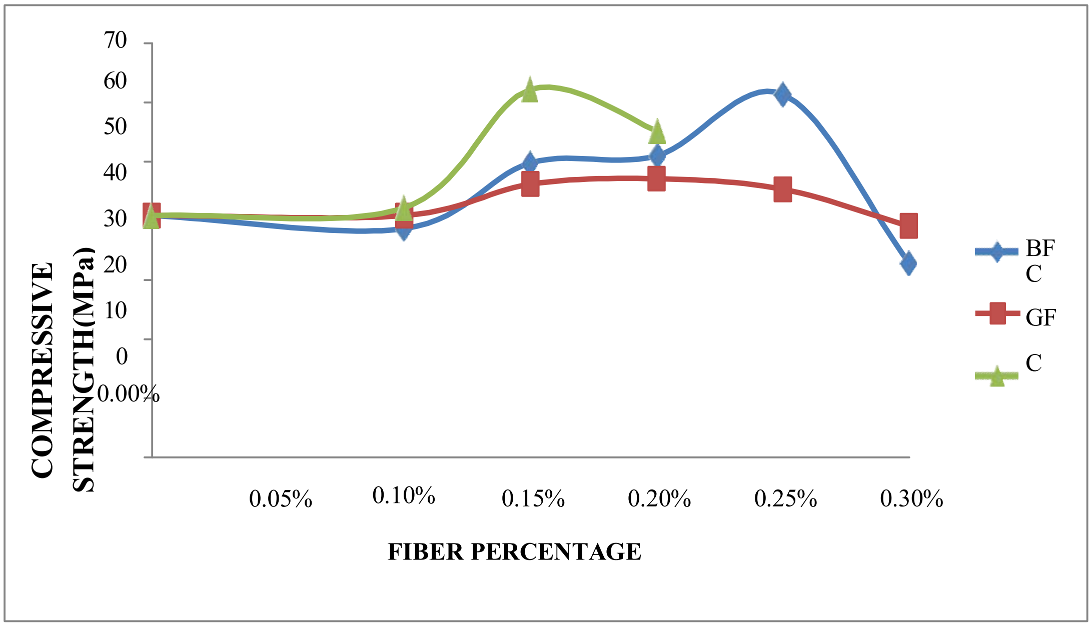

Figure-2 Comparison of Different Percentages of Fiber Mixes with 28 days Compressive Strength

The figure shows the optimum fiber content in mixes with different fibers. The maximum strength of 61.4 MPa was observed with 0.25% basalt fiber content, 60.35 MPa was observed with 0.15% carbon fiber content and 47.11 MPa was observed with 0.2% glass fiber content. Highest 28-days compressive strength was observed for mix with 0.25%basalt fiber & lowest for mix with 0.3% basalt fiber. Results indicated that the inclusion of fibers significantly influenced the compressive strength of the concrete mixes. These findings suggest that fiber content exists for diminish reverse due to fiber agglomeration and increased voids in the concrete matrix.

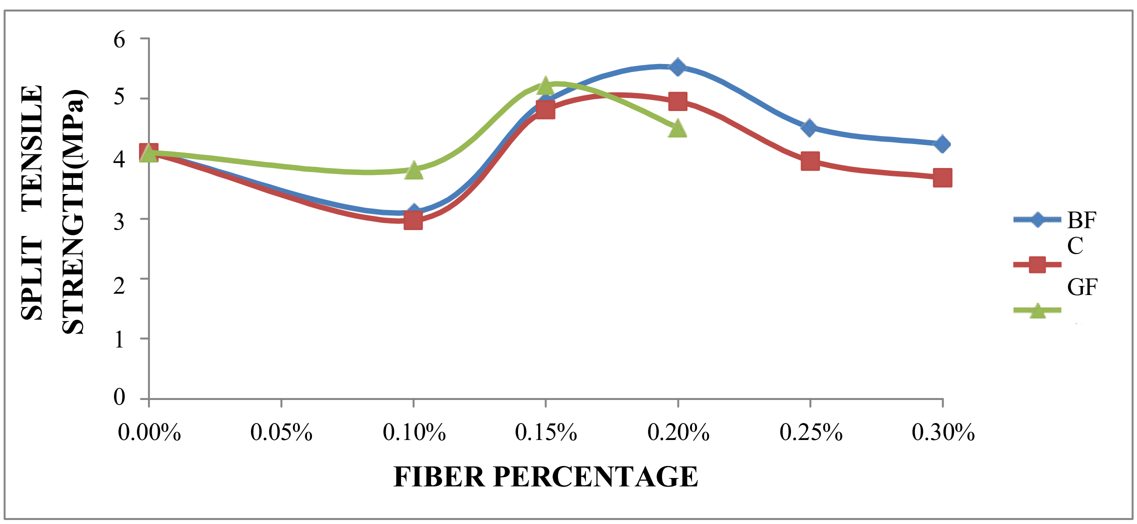

Figure-3 Comparison of Different Percentages of Fiber Mixes with 28 days Split Tensile Strength

The Figure shows the optimum fiber content in mixes with different fibers. The maximum strength of 5.517MPa was observed with 0.2% basalt fiber content, 5.23MPa was observed with 0.15% carbon fiber content and 4.95MPa was

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observed with 0.2% glass fiber content. The highest 28-days split tensile strength was observed for mix with 0.2%basalt fiber and lowest for mix with 0.1% glass fiber.

This trend signifies that basalt fibers provide superior bonding and crack-bridging properties, contributing to higher tensile capacity while carbon and glass fibers also improve strength but to a comparatively lesser extent to maximize tensile strength without compromising workability or matrix integrity.

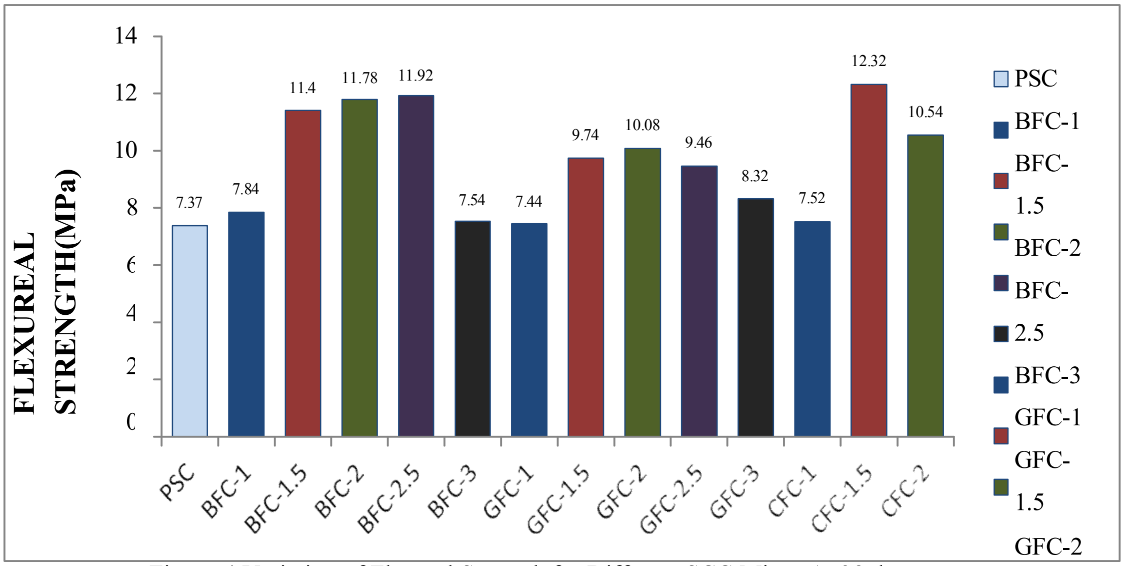

Figure-4 Variation of Flexural Strength for Different SCC Mixes At 28 days

V. CONCLUSION

From the present study the following conclusions can be drawn

Carbon fiber addition more than 2% made mix harsh which did not satisfy the aspects like slump value, T50 test required for self-compacting concrete. Addition of fibers to self-compacting concrete improves mechanical properties like compressive strength, split tensile strength, flexural strength of the mix. There was an optimum percentage of each type of fiber provided maximum improvement in mechanical properties of SCC. Mix having 0.15% carbon fiber, 0.2% of glass fiber and 0.25% of basalt fiber were observed to increase the mechanical properties to maximum. 0.15% addition of carbon fiber to SCC was observed to increase the 7-days compressive strength by 29.9%, 28-days compressive strength by 47.6%, split tensile strength by 27.56%, flexural strength by 67.16%. FRSCC mixes exhibited increase in ductility measured through load deflection diagrams. The basalt fiber reinforced SCC exhibited maximum increment than carbon and glass FRSCC. SEM analysis of microstructure of FRSCC exhibited good physical bond between all types of fiber and the hydrated matrix. A dense structure of matrix was observed in each mixes owing to addition of silica fume. No apparent variation was observed between mix of 7days and 28 days. The performance of carbon fiber reinforced SCC mixes was better than basalt FRSCC and glass FRSCC mixes. Glass FRSCC exhibited improvement in all mechanical properties especially in early ages with higher volume fraction. It showed better performances in fresh state. Basalt FRSCC exhibited better properties in fresh state and hardened state compared to the Glass FRSCC. In terms of the cost it is cheaper than carbon hence basalt fiber performance is overall best compared with glass and carbon fiber.

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