Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 10s (2025)

Investigation into Mechanical Characteristics and Fracture Behavior of Self-Compacting Concrete with Chopped Fibers

[1]Manjul Naresh Lanjewar, [2]Akshit Lamba

[1]Department of Civil Engineering, Kalinga University Raipur (CG), India

lanjewarmanjul247@gmail.com

[2]Assistant Professor, Department of Civil Engineering, Kalinga University Raipur (CG), India

Akshit.lamba@kalingauniversity.ac.in

Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

Abstract: This study investigates the mechanical characteristics and fracture behavior of self-compacting concrete (SCC) reinforced with chopped fibers**.** The incorporation of fibers aims to enhance strength, ductility, and crack resistance while maintaining the self-compacting properties of the concrete. Different fiber types and percentages were evaluated to analyze their impact on compressive strength, flexural strength, and fracture toughness**.** Experimental results indicate that chopped fibers improve crack bridging and energy absorption**,** making SCC more durable and resilient for structural applications.

Keywords: Self-compacting concrete, chopped fibers, mechanical properties, fracture behavior, strength, ductility, crack resistance, flexural strength, toughness.

1. Introduction

1.1 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. The SCC in fresh form reports numerous difficulties related to the skill of workers, density of reinforcement, type and configuration of a structural section, pump-ability, segregation resistance and, mostly compaction. The Self Consolidating Concrete, which is rich in fines content, is shown to be more lasting. First, it started in Japan; numbers of research were listed on the global development of SCC and its micro-social system and strength aspects. Though, the Bureau of Indian Standards (BIS) has not taken out a standard mix method while number of construction systems and researchers carried out a widespread research to find proper mix design trials and self-compact ability testing approaches.

1.2 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 like steel. Concrete, which is a „quasi-fragile material‟, having negligible tensile strength.

Several studies have shown that fiber reinforced composites are more efficient than other types of composites. The main purpose of the fiber is to control cracking and to increase the fracture toughness of the brittle matrix through bridging action during both micro and macro cracking of the matrix. Debonding, sliding and pulling-out of the fibers are the local mechanisms that control the bridging action. In the beginning of macro cracking, bridging action of fibers prevents and controls the opening and growth of cracks. This mechanism increases the demand of energy for the crack to propagate.

1.3 Fracture Energy Behavior

The ductility can be measured by fracture behavior of FRSCC and to determine fracture energy. The general idea of this type of test is to measure the amount of energy which is absorbed when the specimen is broken into two halves. This energy is divided by the fracture area (projected on a plane perpendicular to the tensile stress direction). The resulting value is assumed to be the specific fracture energy GF. From the plot we will conclude that more the area occupied by load-displacement curve more is the fracture energy.

1.4 Objective and Methodology

The objective of present research 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. 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.

2. Literature Review

- **M Ouchi, et al. (1997)** the authors have specified the influence of Super Plasticizers on the flow-ability and viscosity of Self Consolidating Concrete. From the experimental investigation author suggested an overview the effect of super plasticizer on the fresh properties of concrete. Author found his studies were very convenient for estimating the amount of the Super Plasticizer to satisfy fresh properties of concrete.

- **Gao Peiwei., et al. (2000)** the authors has studied special type of concrete, in which same ingredients are used like conventional concrete. Keeping in mind to produce high performance concrete, mineral and chemical admixtures with Viscosity Modifying Agents (VMA), are necessary. The objective is to decrease the amount of cement in HPC. Preserving valuable natural resources is the primary key, then decrease the cost and energy and the final goal is long-term strength &durability.

- **Neol P Mailvaganamet al. (2001)** author investigated the properties of Mineral and Chemical admixtures act together with the compounds of binding material and affect the hydration process. According to the performance of the admixtures with concrete like the type and dosage of admixtures, their composition, specific surface area of the cement, type and proportions of different aggregates, water/ cement ratio the dosages is determined.

- **Raghu Prasad P.S. et al. (2004)** the authors has studied that the use of admixtures both initial and final setting times of cement are getting late. This is due to the delayed pozzolanic reaction affected by the addition of particular admixtures. This type of delayed setting property is occasionally helpful during the concreting in summer season. There will also significant strength gain for mixed cements and concretes after 28 days. Due to this reason concrete corrosion will be less.

- **Lachemi M, et al.(2004)**the author stated that to get stable rheology of the SCC use of Viscosity Modifying Agents has been showed to be very operative. To know the appropriateness of four types of poly-carboxylic based VMA for the growth of the SCC mixes was studied. The author found that the new type VMA are the suitable and better for preparing the SCC mix as compared to the commercially accessible VMA. Author also suggested the amount of 0.04% of dosage fulfills the fresh and hardened properties of SCC, which is 6% less than the commercially accessible VMA.

- **Khayat K. H,et al. (1999)**author deliberate the behavior of Viscosity Enhancing Admixtures used in cementitious materials. He has determined that, a fluid without washout-resistant should be formed by properly modifying the mixtures of VEA and High Range Water Reducing agents, that will improve properties of underwater cast grouts, mortars, and concretes, and decreases the turbidity, and rises the pH values of surrounding waters.

- **Yin-Wen Chan,et al. (1999)** by enhancing the micromechanical parameters which control composite properties in the hardened state, the author developed self-compacting Engineered Cementitious Composite (ECC), and the treating parameters, which control the rheological properties in the fresh state. For the growth of self-compacting ECC, micromechanics was accepted to suitably select the matrix, fiber, and interface properties so as to show strain hardening and various cracking behavior in the composites.

3. Methodology

3.1 Materials

3.1.1 Cement

Portland slag cement of Konark brand available in the local market was used in the present studies. The physical properties of PSC obtained from the experimental investigation were confirmed to IS: 455-1989.

3.1.2 Coarse Aggregate

The coarse aggregate used were 20 mm and 10 mm down size and collected from Quarry near Raipur.

3.1.3 Fine Aggregate

Natural river sand has been collected from Mahanadi River, Raipur.

3.1.4 Silica Fume

Elkem Micro Silica 920D is used as Silica fume. Silica fume is among one of the most recent pozzolanic materials currently used in concrete whose addition to concrete mixtures results in lower porosity, permeability and bleeding because its fineness and pozzolanic reaction.

3.1.5 Admixture

The Sika Visco Crete Premier from Sika is super plasticizer and viscosity modifying admixture, used in the present study.

3.1.6 Water

Potable water conforming to IS: 3025-1986 part 22 &23 and IS 456-2000 was employed in the investigations.

3.1.7 Glass Fiber

Alkali resistant glass fiber having a modulus of elasticity of 72 GPA and 12mm length was used.

3.1.8 Basalt Fiber

Basalt fiber of 12mm length was used in the investigations.

3.1.9 Carbon Fiber

Carbon fiber of length 12mm was used in the investigations.

Table 3.1 Mechanical Properties of Fibers

Fiber variety	Length (mm)	Density (g/cm^3)	Elastic modulus(GPa)	Tensile strength(MPa)	Elong. at break(%)	Water absorption
BASALT	12	2.65	93-110	4100-4800	3.1-3.2	<0.5
GLASS	12	2.53	43-50	1950-2050	7-9	<0.1
CARBON	12	1.80	243	4600	1.7	

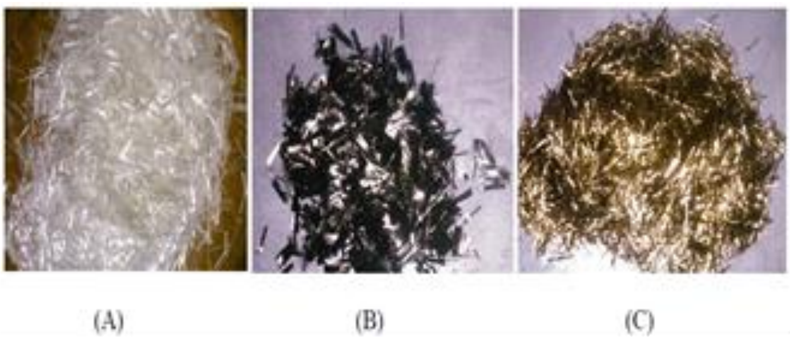

Fig.3.2 (A) Glass Fiber (B) Carbon Fiber (C) Basalt Fiber

3.2 MIX DESIGN OF PLAIN SCC AND TESTING OF ITS FRESH AND HARDENED PROPERTIES

Calculation for M30 grade of SCC was done following EFNARC code 2005 in the mix design 10% of silica fume use as replacement for cement to achieve the target strength. Viscocrete admixture was used to reduce the water content and improve workability as per the requirement for SCC. To determine the fresh properties of the mix prepared conforming to SCC, different fresh tests like slump flow, L-Box, V-Funnel were performed.

The experimental work was conducted at Structural Engineering lab of Civil Engineering Department of NIT, Rourkela. The work involved mixing, casting and testing of standard specimens.

Table 3.2 Adopted Mix Proportions of SCC

Cement (kg/m^3)	Silica fume(kg/m^3)	Water(kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	SP (kg/m^3)
450.33	45.03	189.13	963.36	642.24	5.553
1	0.10	0.42	2.14	1.42	0.012

3.2.1 Mixing Of Ingredients

The mixing of materials was properly mixing in a power operated concrete mixer. Adding coarse aggregate, fine aggregates, cement and mixing it with silica fume were properly mixing in the concrete mixer in dry state for a few seconds. Then the water added and mixing it for three minutes. During this time the air entraining agent and the water reducer are also added. Dormant period was 5mins. To obtain the basalt fiber reinforced SCC, glass fiber reinforced SCC, carbon fiber reinforced SCC the requiredfiber percentage was added to the already prepareddesign mix, satisfying the fresh SCC requirements.

3.2.2 Methods to determine the fresh properties of SCC

To determine the fresh properties of SCC, different methods were developed. Slump flow and V-Funnel tests have been proposed for testing the deformability and viscosity respectively. L-Box test have been propose for determine the segregation resistance.

Fig.3.3 Concrete Mixture Machine & Preparation of SCC Mix

4. Results and Discussion

4.1 Water/cement Ratio of Self-Compacting Concrete

To maintain the basic characteristics of self-compacting concrete a water cement ratio of 0.42 was adopted and a % dosage of super-plasticizer Viscocrete of Sika brand were fixed for all mixes.

4.2 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 behaviour 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.

4.3 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 in Table 4.1

Table- 4.1 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

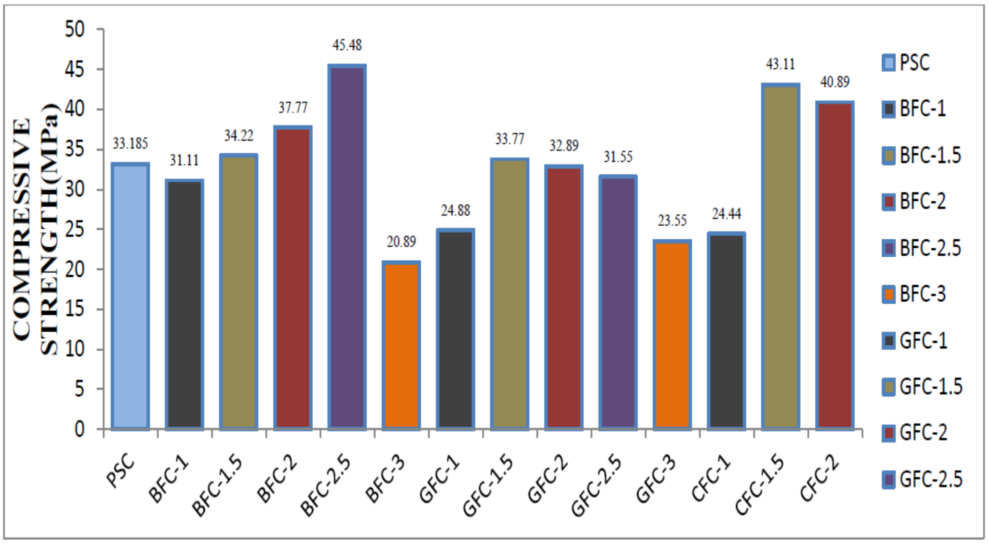

Fig. 4.2 Variation of 7-Days Compressive Strength for Different SCC Mixes

4.4 Compressive Strength

4.4.1 7-Days Compressive Strength

Compared to the plain SCC the compressive strength reinforced with basalt fiber of volume fraction 0.15%, 0.2% and 0.25% increase by 3.12%, 13.82% and 37.05% respectively. Compared with the plain SCC the compressive strength reinforced with glass fiber of volume fraction 0.15% increase by 1.76%. In this study the 7 days compressive strength of glass fiber shows no obvious improvement. Compared with the plain SCC the compressive strength reinforced with carbon fiber of 0.15% and 0.2% increase by 29.9% and 23.22% respectively. Fig. 4.3.1 shows that for CFC and BFC has higher compressive strength at 7 days at volume fraction of 0.15% to 0.25%.

4.4.2. 28-Days Compressive Strength

From Fig.4.3.5.Compared with plain SCC, 0.15% of BFC, GFC and CFC increase 21.72%, 10.52% and 47.6% respectively. For 0.2% of BFC, GFC and CFC increase 24.7%, 15.21% and 35% respectively. For 0.25% of BFC and GFC increases 50.16% and 11% respectively. In this study, Fig.4.2.4 shows that the optimum dosages for BFC are 0.25%, for GFC is 0.2% & for CFC is 0.15%.

4.4.3 Split Tensile Strength

The percentage enhancement of split tensile strength for basalt fiber over plain SCC is 20.44%, 34.56%, 10.24% & 3.41% when adding 0.15%, 0.2%, 0.25% & 0.3% respectively. The percentage enhancement of split tensile strength for glass fiber over plain SCC is 17.31%, 20.73% when adding 0.15% & 0.2% respectively. The percentage enhancement of split tensile strength for carbon fiber over plain SCC is 27.56% & 10.24% respectively. The increase is due to the fiber as explained before.

5. Conclusion

From the present study the following conclusions can be drawn

- Addition of fibers to self-compacting concrete causes loss of basic characteristics of SCC measured in terms of slump flow, etc.
- Reduction in slump flow was observed maximum with carbon fiber, then basalt and glass fiber respectively. This is because carbon fibers absorbed more water than others and glass absorbed less.
- Carbon fiber addition more than 2% made mix harsh which did not satisfy the aspects like slump value, T50 test etc. required for self-compacting concrete.
- Addition of fibers to self-compacting concrete improve mechanical properties like compressive strength ,split tensile strength, flexural strength etc. 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%.

References

[1] **Ouchi M. And Okamura H.** "Mix-Design for Self-Compacting Concrete", Concrete Library of JSCE, No.25, June **1995**(ND), pp107-120.

[2] **Ouchi M. And Okamura H.** “Effect of Super plasticizer On Fresh Concrete”, Journal of Transportation Board, **1997**, pp37-40.

[3] **Khayat. K.H.** "Workability, Testing and Performance of Self-consolidating Concrete" Technical Paper Title No. 96-M43, ACI Journal/May-June **1999**, pp346-353.

[4] **Victor C. Li, H.J.Kong, and Yin-Wen Chan** "Development of Self-Compacting Engineered Cementitious Composites" The University of Michigan, Ann Arbor-MI 48109-2125, USA**,(1999).**

[5] **Gaopeiwei, Deng Min and FengNaiqui**"The Influence of SP and Superfine Mineral Powder on the Flexibility, Strength and Durability of HPC". Cement and Concrete Research. **2000**, vol.31, pp703-706.

[6] **Neol P Mailvaganam**. "How Chemical Admixtures Produce their Effects in Concrete", Indian Concrete Journal, May **2001**, pp331- 334.

[7] **Nan Su, Kung-Chung Hsu, His-Wen Chai** "A Simple Mix Design method for Self-Compacting Concrete" Journal of Cement and Concrete Research 31**(2001)**pp 1799-1807.

[8] **Sonebi. M and Bartos. P.J.M** "Filling ability and Plastic Settlement of Self Compacting Concrete" Materials and Structures, Vol.35 September-October **2002** pp462-469.

[9] **RavindraGettu, Hannah Collie, CamiloBernad, Tomas Garcia and Clotie D Robin** "Use of High Strength Self Compacting Concrete in Prefabricated Architectural Elements", International Conference on Recent Trends in Concrete, Technology and Structures INCONTEST 2003 Coimbatore, September 10-12, **2003**, PP355-363.