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# A Study on Mechanical Properties and Fracture Behavior of Chopped Fiber Reinforced Self-Compacting Concrete

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**ABSTRACT**

**The growth of Self Compacting Concrete is revolutionary landmark in the history of construction industry resulting in predominant usage of SCC worldwide nowadays. It has many advantages over normal concrete in terms of enhancement in productivity, reduction in labor and overall cost, excellent finished product with excellent mechanical response and durability. Incorporation of fibers further enhances its properties specially related to post crack behavior of SCC. Hence the aim of the present work is to make a comparative study of mechanical properties of self-consolidating concrete, reinforced with different types of fibers. The variables involve in the study are type and different percentage of fibers. The basic properties of fresh SCC and mechanical properties, toughness, fracture energy and sorptivity were studied. Microstructure study of various mixes is done through scanning electron microscope to study the hydrated structure and bond development between fiber and mix.**

**The fibers used in the study are 12 mm long chopped glass fiber, carbon fiber and basalt fiber. The volume fraction of fiber taken are 0.0%,0.1%,0.15%,0.2%,0.25% ,0.3%. The project comprised of two stages. First stage consisted of development of SCC mix design of M30 grade and in the second stage, different fibers like Glass, basalt and carbon Fibers are added to the SCC mixes and their fresh and hardened properties were determined and compared.**

**The study showed remarkable improvements in all properties of self-compacting concrete by adding fibers of different types and volume fractions. Carbon FRSCC exhibited best performance followed by basalt FRSCC and glass FRSCC in hardened state whereas poorest in fresh state owing to its high water absorption. Glass FRSCC exhibited best performance in fresh state. The present study concludes that in terms of overall performances, optimum dosage and cost Basalt Fiber is the best option in improving overall quality of self-compacting concrete.**

**Keywords: Self-Compacting Concrete, fiber, fracture energy, carbon, and basalt.**

## INTRODUCTION

### 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. The work of Self Compacting Concrete is like to that of conventional concrete, comprising, binder, fine aggregate and coarse aggregates, water, fines and admixtures. To adjust the rheological properties of SCC from conventional concrete which is a remarkable difference, SCC should have more fines content, super plasticizers with viscosity modifying agents to some extent.

However, various investigations are carried out to explore various characteristics and structural applications of SCC. SCC has established to be effective material, so there is a need to guide on the normalization of self-consolidating characteristics and its behavior to apply on different structural construction, and its usage in all perilous and inaccessible project zones for superior quality control.

### 1.1 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. The linear elastic behavior of the matrix is not affected significantly for low volumetric fiber fractions.

At initial stage and the hardened state, Inclusion of fibers improves the properties of this special concrete. Considering it, researchers have focused on studied the strength and durability aspects of fiber reinforced SCC which are:

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1. Glass fibers

2. Carbon fibers

3. Basalt fibers

4. Polypropylene fibers etc.

Fibers used in this investigation are of glass, basalt & carbon, a brief report of these fibers is given below.

### 1.2 Alkali Resistance Glass Fibers

Glass fibers are formed in a process in which molten glass is drawn in the form of filaments. Generally 204 filaments are drawn simultaneously and cooled, once solidify they are together on a drum into a strand containing of the 204 filaments. The filaments are treated with a sizing which shields the filaments against weather and abrasion effects, prior to winding.

Different types of glass fibers like C-glass, E-glass, S-glass AR-glass etc. are manufactured having different properties and specific applications. Fibers used for structural reinforcement generally fall into E-glass, AR-glass and S-glass owing to alkali resistant. By far the E-glass is most used and least expensive. Glass fibers come in two forms (1) Continuous fibers (2) Discontinuous or chopped fibers Principal advantages are low cost, high strength, easy and safe handling, and rapid and uniform dispersion facilitating homogeneous mixes which in term produce durable concrete. Limitations are poor abrasion resistance causing reduced usable strength, Poor adhesion to specific polymer matrix materials, and Poor adhesion in humid environments.

## II. WHY AN EVALUATION IS NEEDED

An Evaluation and implementation can be a major business investment. Due to this fact, Dattakumar and Jagadeesh (2003) had listed and compared several literature reviews on an evaluation . From their study, they highlighted the essence, focus and objective of all these literatures on the an evaluation . They found that the focus of an evaluation literature has shifted and addresses issues on improving the an evaluation process such as in-depth study of an evaluation to identify the missing links. Watson (1993) had highlighted the elements that the companies must have in order to overcome the global competition and linearization of national economies.

The elements are: quality beyond the competition; technology prior to the competition; and costs lower than the competition. In other words, many companies must provide a superior, faster and cheaper services or products than their competitors. To achieve this goal, an important evaluation process can be done to achieve perfect tool for making improvement of current products and services and also innovation of new products and services. Further to this, Kempner (1993) held the view that the goal of an evaluation is to provide key personnel in charge of processes with an external standard for measuring the quality and cost of internal activities and thus helps to identify where opportunities for improvement might be found.

### Basalt Fibers

Basalt Fibers are made by melting the quarried basalt rock at about 1400 $^{0}$C and extrude through small nozzles to create continuous filaments of basalt fibers. Basalt fibers have alike chemical composition as glass fiber but have better-quality strength characteristics. It is extremely resistant to alkaline, acidic and salt attack making it a decent candidate for concrete, bridge and shoreline structures. Compared to carbon and aramid fiber it has wider applications like in higher oxidation resistance, higher temperature range (-269$^0$C to +650$^0$C), higher shear and compressive strength etc. Basalt fibers are ascertained to be very efficient in conventional and SCC concrete mixes for improving their properties.

**Carbon Fibers**

Carbon fibers have low density, high thermal conductivity, good chemical stability and exceptional abrasion resistance, and can be used to decrease or reduce cracking and shrinkage. These fibers increase some structural properties like tensile and flexural strengths, flexural toughness and impact resistance. Carbon fibers also help to improve freeze-thaw durability and dry shrinkage. The adding of carbon fibers decreases the electrical resistance.

### 1.2 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.

## III 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. 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 (i.e., 0%, 0.1%, 0.15%,0.2%, 0.25%, 0.3%) will be studied in fresh and hardened state. With the help of scanning electron microscope (SEM) the microstructure of fibered concrete was also studied.

- 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.

## V. RESULTS

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 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.

### 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 |
| 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 |

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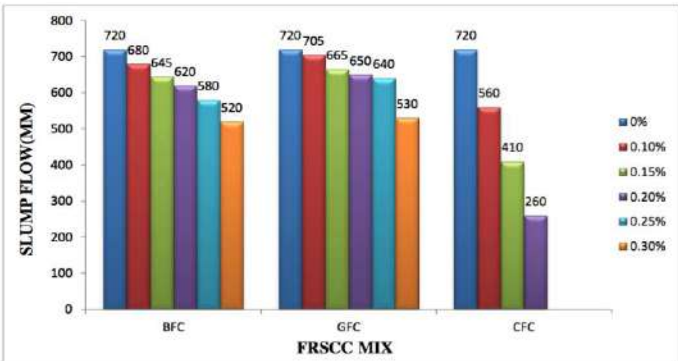
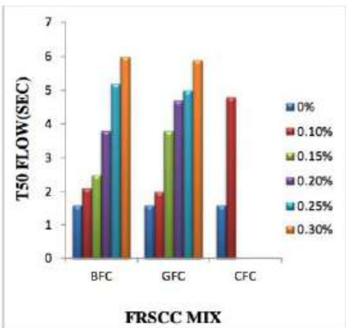
**Table.2: Results of the Fresh Properties of Mixes**

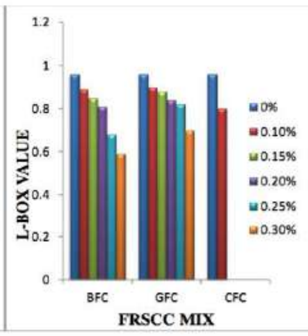
| sample | Slump flow 500-750mm | $T_{50}$ flow 2-5sec | L-Box($H_2/H_1$) 0.8-1.0 | V-Funnel 6-12sec | T5 Flow +3sec | Remarks |
|---|---|---|---|---|---|---|
| PSC | 720 | 1.6 | 0.96 | 5 | 9 | Low viscosity (Result Satisfied) |
| BFC-1 | 680 | 2.1 | 0.89 | 8 | 12 | Result Satisfied |
| BFC-1.5 | 645 | 2.5 | 0.85 | 8 | 13 | Result Satisfied |
| BFC-2 | 620 | 3.8 | 0.81 | 9 | 14 | Result Satisfied |
| BFC-2.5 | 580 | 5.2 | 0.68 | 10 | 16 | High viscosity Blockage (RNS) |
| BFC-3 | 520 | 6 | 0.59 | 11 | 18 | Too high viscosity Blockage (RNS) |
| GFC-1 | 705 | 2.0 | 0.90 | 7 | 10 | Result Satisfied |
| GFC-1.5 | 665 | 3.8 | 0.88 | 7.7 | 11 | Result Satisfied |
| GFC-2 | 650 | 4.7 | 0.84 | 8.5 | 12 | Result Satisfied |
| GFC-2.5 | 640 | 5.0 | 0.82 | 9 | 12 | Result Satisfied |
| GFC-3 | 530 | 5.9 | 0.70 | 11 | 15 | Too high viscosity Blockage (RNS) |
| CFC-1 | 560 | 4.8 | 0.80 | 10 | 14 | Result Satisfied |
| CFC-1.5 | 410 | _ | _ | 18 | _ | Too high viscosity Blockage (RNS) |
| CFC-2 | 260 | _ | _ | 23 | _ | Too high viscosity Blockage (RNS) |




(A)




(B)




(C)

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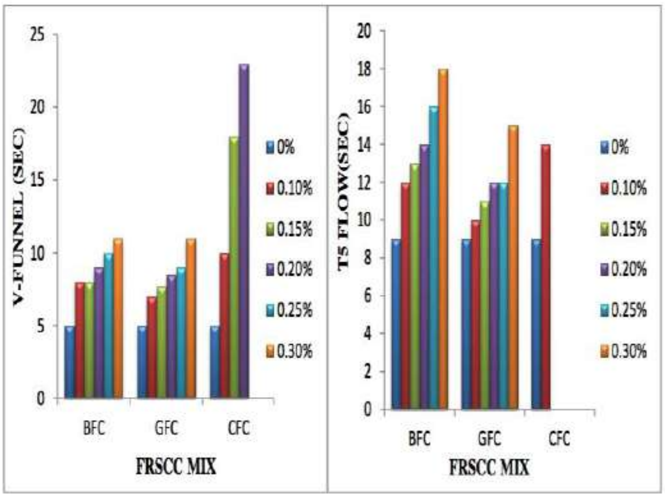


(D) (E)

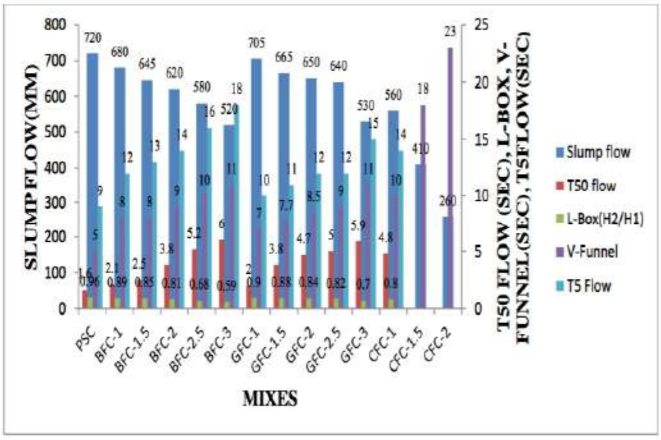


**Figure (A)(B)(C)(D)(E): Shows Mixes**

## VI. CONCLUSION

From the present study the following conclusions can be drawn an 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%., 0.25% addition of basalt fiber to SCC was observed to increase the 7-days compressive strength by 37.05%, 28-days compressive strength by 50.16%, split tensile strength

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by 34.56%, flexural strength by 61.736%. Glass FRSCC exhibited improvement in all mechanical properties especially in early ages, with higher volume fraction. It showed better performances in fresh state. Apart from being cheapest its performance in fresh state but displayed minimum strength, highest sorptivities. The microscopic study (SEM) exhibited better bond development than other two types in early days. 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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