A STUDY ON MECHANICAL PROPERTIES AND FRACTURE BEHAVIOR OF CHOPPED FIBER REINFORCED SELF-COMPACTING CONCRETE

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A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
In
Structural Engineering

By

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CERTIFICATE

This is to certify that the thesis entitled, **“A STUDY ON MECHANICAL PROPERTIES AND FRACTURE BEHAVIOR OF CHOPPED FIBER REINFORCED SELF-COMPACTING CONCRETE”** *submitted by* ***BISWAJIT JENA*** *bearing Roll No.* ***213CE2063*** *in partial fulfillment of the requirements for the award of* ***Master of Technology*** *Degree in* ***Civil Engineering*** *with specialization in* ***“Structural Engineering”****during 2014-15 session at National Institute of Technology, Rourkela is an authentic work carried out by him under our supervision and guidance.*

To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Prof. ASHA PATEL

Date:
Place:Rourkela

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.

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BISWAJIT JENA

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ABBREVIATIONS

ACI	American Concrete Institute
BRE	Building Research Establishment
BIS	Bureau Of Indian Standard
BFC	Basalt Fiber Reinforced Self Compacting Concrete
CA	Coarse Aggregate
CFC	Carbon Fiber Reinforced Self Compacting Concrete
CTM	Compression Testing Machine
ECC	Engineered Cementitious Composite
EFNARC	The European federation of national association representing for concrete
FRC	Fiber Reinforced Concrete
FRSCC	Fiber Reinforced Self Compacting Concrete
FA	Fine Aggregate
GFC	Glass Fiber Reinforced Self Compacting Concrete
PF	Packing Factor
PSC	Plain Self Compacting Concrete
RCC	Reinforced Cement Concrete
RMC	Ready Mixed Concrete
RS	Result Satisfactory
RNS	Result Not Satisfactory
SCC	Self Compacting Concrete
SP	Super Plasticizer
VMA	Viscosity Modifying Agent

NOTATIONS

bwc	by weight of cement
c/c	center to center
E	modulus of elasticity
F	stress
f_{ck}	characteristic compressive strength
gm/m^2	grams per squre meter
kN	kilo newton
kg/m^2	kilogram per cubic meter
L	length
MPa	mega pascal
m	meter
m^3	cubic meter
mm	millimeter
w/c	water to cement ratio

CHAPTER 1

INTRODUCTION

1.0 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.

As compared to conventional concrete the benefits of SCC comprising more strength like non SCC, may be higher due to better compaction, similar tensile strength like non SCC, modulus of elasticity may be slightly lower because of higher paste, slightly higher creep due to paste, shrinkage as normal concrete, better bond strength, fire resistance similar as non SCC, durability better for better surface concrete.

Addition of more fines content and high water reducing admixtures make SCC more sensitive with reduced toughness and it designed and designated by concrete society that is why the use of SCC in a considerable way in making of pre-cast products, bridges, wall panels etc. also in some countries.

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:

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.

1.1.1 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.

1.1.2 Basalt Fibers

Basalt Fibers are made by melting the quarried basalt rock at about 1400^0C 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 (-269^0C 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.

1.1.3 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.

In detail, this thesis is divided into five chapters. Though the current chapter deals with introduction & methodology of fiber reinforced self-compacting concrete (FRSCC), the 2nd chapter describes the literature review studied for this investigations on FRSCC. The 3rd chapter touches the experimental work already done on different kinds of FRSCC is taken up in these investigations. In the 4th chapter, the results of the experiments presented & discussion on results are discussed. In the last chapter, all the findings of the foregoing chapters are summed up.

1.3 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. 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.

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.

1.4 Methodology

- 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.

CHAPTER-2

LITERATURE REVIEW

2.0 BRIEF RIVIEW

Fiber reinforced SCC are currently being studied and applied around the world for the increasing of tensile and flexural strength of structural concrete members. The literature review has been split up into three parts, namely super plasticizers, preparation of SCC, Fiber-Reinforced SCC as given under.

2.1 SUPER PLASTICIZERS

2.1.1 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.

2.1.2 GaoPeiwei., et al. (2000) the authors has studiedspecial 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.

2.1.3 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.

2.1.4 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.

2.1.5 Lachemi M, et al.(2004)the author statedthat to getstable 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.

2.1.6 M.Collepardi, et al.(2006)the author studied the role of VMA with the non-availability of the chosen volume range 170-200 liters /m^3 of binding material (max size = 90µm) to create consistent SCC and determined that the combination of VMA and without mineral filler. In such a case, a minor increase convoyed by cement content must be in the dosage of VMA (for instance from 3 to 8 Kg/m^3 to attain an unsegregable SCC without mineral filler. In short, the dosages of mineral and chemical admixtures are necessary in keeping the fresh and hardened properties, and improving the durability characteristics of SCC.

2.2 DEVELOPMENT OF SELF COMPACTING CONCRETE

2.2.1 Okamura et al. (1995) author established a special type of concrete that flows and gets compacted at every place of the formwork by its own weight. This research work was started combined by prof. Kokubu of Kobe University, Japan andProf. Hajime Okamura. Previously it was used as anti washout concrete. They initiate that for attainment of the self-compact ability, usage of Super Plasticizer was necessary.The water/cement ratio should be in between 0.4 to 0.6. The self-compactability of the concrete is mainly affected by the material characteristics and mix proportions. Author restricted the coarse aggregate content to 60% of the solid volume and the fine aggregate content to 40% to attain self-compact ability.

2.2.2 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.

2.2.3 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. Self-compact ability of ECC was then understood by the organized rheological properties of fresh matrix,comprising deformability and flow ratewith the certain ingredient materials. Self-compactability was a result of accepting an optimum mixture of super plasticizer and viscosity modifying agent. According to fresh test results, ECC developed in this study is verified to be self-compacting. Flexural tests show that the mechanical performance of self-compacting ECC is unaffected to the exceptionally applied consolidation during placing. This result approves the efficiency of the self-compact ability in keeping the quality of structural elements.

2.2.4 Kung-Chung Hsu, et al. (2001) Authors projected a new mix design technique for SCC and their main emphasis was with binder paste to fill voids of loosely filled aggregate. They familiarized a factor called Packing Factor (PF) for aggregate. It is the ratio of mass of aggregates in firmly packed state to the one in loosely packed state. The method completely influenced bythe Packing Factor (PF). The amount of binders used in the proposed method can be less than that required by other mix design methods due to the increased sand content. Packing factor influence the aggregate content and that affects the fresh properties of concrete.

2.2.5 M. Sonebi,et al. (2002) Thisresearch shows results of fresh properties of self-compacting concrete, like, filling ability measured by slump flow apparatus and flow time measured by orimet apparatus and plastic fresh properties measured by column apparatus. The fresh properties were affected by water/binder ratio, nature of sand, slump were estimated. The fresh tests and hardened test results like compressive strength and splitting tensile strength were compared to a control mix. The properties of fresh SCC improved by increasing in water/binder ratio and nature of sand but the volume of coarse aggregate and dosage of chemical admixture kept constant.

2.2.6 Hajime Okamura et al. (2003) The authors differentiate that when self-compacting concrete becomes so widely used that it should be seen as the "Standard Concrete" rather than a "Special Concrete", it will be successful in constructing durable and reliable concrete structures that need very little repairs work.

2.2.7 R.SriRavindrarajah, et al. (2003)the author obtained an experimental investigation between the properties of flowing concrete and self-compacting concrete mix having different percentage of high-water reducing super-plasticizer. The properties investigated were workability, bleeding capacity, segregation potential, compressive and tensile strengths, and drying shrinkage. Drying shrinkage was influenced by the mix compositions and super-plasticizer dosage.

2.2.8 ShettyR.G,et al. (2004) The authors in their topic suggested Self consolidating concrete is appropriate for concreting in dense reinforcement structures and explained the methodology adopted how to design and simple testing of SCC mixes and the methods implemented for testing the concreting walls and structures housing a condenser cooling water pump at Tarapur Atomic power project 3 & 4 (TAPP).

2.2.9 Frances Yang,et al. (2004) this paper investigates the technique to develop SCC as well as its components and mix proportioning methods. It highlights several benefits of using SCC and mentions to several tools used to measure its properties. Again, it reports the protective measures that should be taken for preparing and developing the mix and some model applications of SCC was proposed by the author, for example, Toronto International Airport. A high strength SCC was used for constructing compactly reinforced elements poured in beneath freezing weather for the 68 Story Trump Tower in New York cityof USA.

2.2.10 Geert De Schutter,et al. (2005)the results belong to creep and shrinkage of SCC are described in this investigation. The ACI model gives accurate prediction when experimental results was made Comparison with some traditional. The models proposed by "Delarrard" and "Model Code" lead to in underestimation of the deformations. The use of SCC needs no extra provisions while considering the shrinkage and creep of the structure.

2.2.11 "The European Guidelines for Self-Compacting Concrete" (2005) The proposed specifications and associated test methods for ready-mixed and site-mixed concrete is offered aiming to facilitate standardization at European code.The method is to encourage increased adoption and use of SCC.The EFNARC defines SCC and many of the technological terms utilized to define its properties and function.They also present data on standards connecting to testing and to related constituent materials used in the manufacture of SCC.

2.2.12 T. SeshadriSekhar, et al. (2005) the authors established SCC mixes of grades M30, M40, M50 & M60. Again as compared to the lower grade of SCC mixes, cast 100 mm dia. cylinders so as to test the permeability characteristics by loading in the cells duly applying constant air pressure of 15 kg/mm^2 along with water pressure of 2Kg/ mm^2 for a definite period of time and found coefficient of permeability to determine that the higher the grade of SCC mixes.

2.2.13 AnirwanSenguptha, et al. (2006) the author founded the optimum mixture for preparation of SCC as per EFNARC 2005 code. All design mixes fulfilled the EFNARC standards and exhibited good segregation resistance, passing ability, and filling ability.For designing SCC, high amounts of powder contents were necessary. The SCC mixes with greater powder contents resulting in greater compressive strengths. A good correlation was perceived between V- funnel time and T-50 slump flow test.

2.2.14 G. Giri Prasad, et al. (2009) author developed M60 grade SCC and compared with conventionally prepared concrete mix for hardened properties. Analytical equations for stress-strain curve proposed by different authors were verified the obtained experimental data. It was seen that the values of stock at peak stress under axial compression for both the concretes are near to 0.002 as given in IS:456-2000.

2.3 FIBER REINFORCED SELF-COMPACTING CONCRETE

2.3.2 M. VIJAYANAND, et al (2010) The present study proposes to study the flexural behavior of SCC beams with steel fibers. An experimental program has been contrived to cast and test three plain SCC beams and six SCC beams with steel fibers. The experimental variables were the fiber content (0vf%, 0.5VF% and 1.0VF %) and the tensile steel ratio (0.99%, 1.77% and 2.51%).

2.3.3 V.M.C.F. Cunha, et al. (2011) the author establishes numerical model for the ductile behavior of SFRSCC. They have presumed SFRSCC as two phase material. By 3-D smeared crack model, the nonlinear material behavior of self-compacting concrete is applied.The mathematical model presented good relationship with experimental values.

2.3.4 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.

2.3.5 M.G. Alberti. Et al (2014) in 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.

2.3.6 Chihuahua Jiang, et al (2014) in this field, the effects of the volume fraction and length of basalt fiber (BF) on the mechanical properties of FRC were Analyzed.The outcomes indicate that adding BF significantly improves the tensile strength, flexural strength and toughness index, whereas the compressive strength shows no obvious gain. Furthermore, the length of BF presents an influence on the mechanical properties.

CHAPTER-3

EXPERIMENTAL INVESTIGATION ON SELF-COMPACTING CONCRETE

3.0 GENERAL

In this study, the mechanical behavior of fiber reinforced self-compacting concrete of M30 grade prepared with basalt fiber, glass fiber and carbon fiber were studied. For each mix six numbers of cubes (150×150×150) mm, three numbers of cylinders (150×300) mm and six numbers prisms (100×100×500) mm were cast and investigations were conducted to study the mechanical behavior, fracture energy behavior, microstructure of plain SCC, basalt fiber reinforced SCC (BFC), glass fiber reinforced SCC (GFC), carbon fiber reinforced SCC (CFC). The observational plan was held up in various steps to accomplish the following aims:

1. To prepare plain SCC of M30 grade and obtain its fresh and hardened properties.
2. To prepare basalt, glass & carbon fiber reinforced SCC of M30 grades and study their fresh and hardened properties.
3. To analyze the load-deflection behavior of SCC, BFRSCC, GFRSCC & CFRSCC.
4. To examine the fracture energy behavior & the micro structure of plain SCC, BFC, and GFC & CFC.

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 nearRourkela.

3.1.3 Fine Aggregate

Natural river sand has been collected from Koel River, Rourkela, Orissa and conforming to the Zone-III as per IS-383-1970.

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 SikaViscoCrete 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 3.1.1 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	

(A) (B) (C)

Fig.3.1.1 (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. Results are given in table- 4.2.1.

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 3.2.1 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.3.2.1 Concrete Mixture Machine & Preparation of SCC Mix

3.2.2.1 Slump Flow Test And T_{50} Test

The slump flow test is used to determine the free flow of self-compacting concrete without obstacles.

Fig. 3.2.3.1 Slump Flow Apparatus & Testing

- Six liter of concrete was prepared for the test.
- Then inside surface of the slump cone was moisten. The test platform was placed on the leveled surface then the slump cone coincident with the 200 mm circle on the platform and hold in position by standing on the foot pieces, ensuring that no leakage of concrete was occur under the cone.
- The cone was filled up with concrete without tamping. Then base was cleaned if any surplus concrete around the base of the cone.
- The cone was vertically lifted and allows the concrete to flow out freely. Immediately the stop watch was started, and reading was recorded for T_{50} test when concrete reached 500mm marked circle.
- Finally, the final diameter of the concrete spread was measured in two perpendicular directions. The average of the two diameters was measured. (This is slump flow in mm)

Analysis of the results: Higher slump flow value indicates the greater ability to fill the formwork under its own weight. A minimum value of 650mm is necessary for SCC. The T_{50} time is a subordinate indication of flow. A lower time means greater flow ability. The research suggested a time range of 2-5seconds for general housing applications.

3.2.2.2 V-Funnel Test

This test is performed to determine the filling ability (flow-ability) of self-compacting concrete.

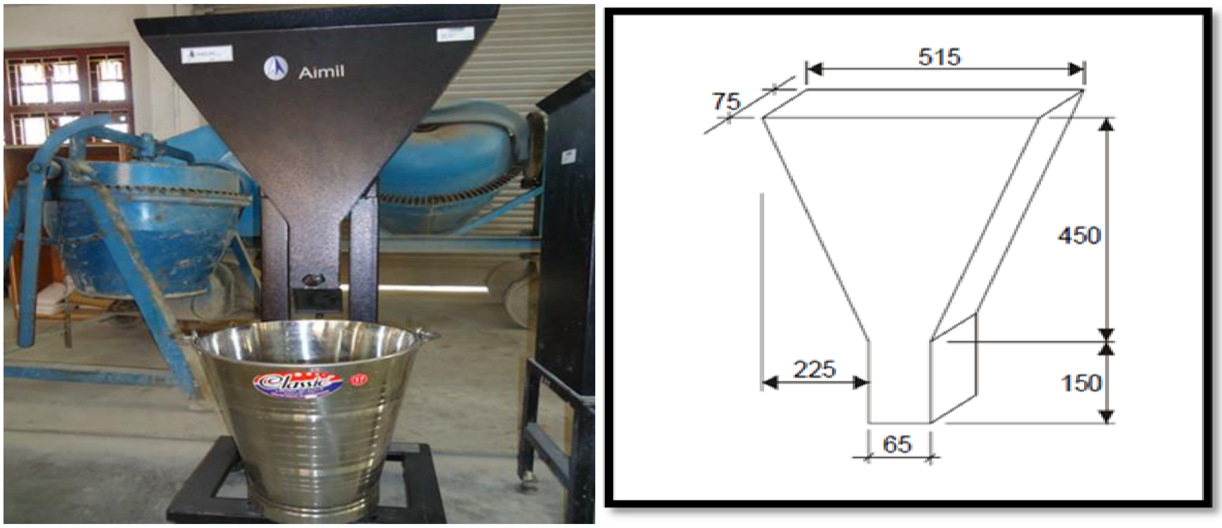


Fig.3.2.3.2 V-Funnel Apparatus & Schematic Diagram

- Twelve liter of concrete was prepared for the test. Then moisten the inside surfaces of the funnel were moistening.
- The V-funnel apparatus was placed on leveled surface.
- The entire prepared SCC sample was filled the funnel without any tamping or vibrating.
- Then after 10 sec of filling the trap door was opened and allow the concrete to flow out under gravity.
- Immediately the reading was recorded by means of stop watch till the discharge to fully complete (the flow time) and light was seen from top through the funnel.
- Again without cleaning or moisten the inside surfaces of the V-funnel apparatus

- The entire prepared SCC sample was filled the funnel without any tamping or vibrating. A bucket was placed underneath.
- After 5 minutes of filling the trap door was opened and allows the concrete to flow out under gravity.
- Immediately the reading was recorded by means of stop watch till the discharge to fully complete and light was seen from top through the funnel. (The flow time in secis T_5test).

Analysis of results: The above test gives indirect measure of viscosity. Time was measured to discharge the concrete through the bottom opening. The criteria for SCC is time should be 10±3secs.

3.2.2.3 L-Box Test

The test is for measuring the flow of the SCC and the blocking resistance.

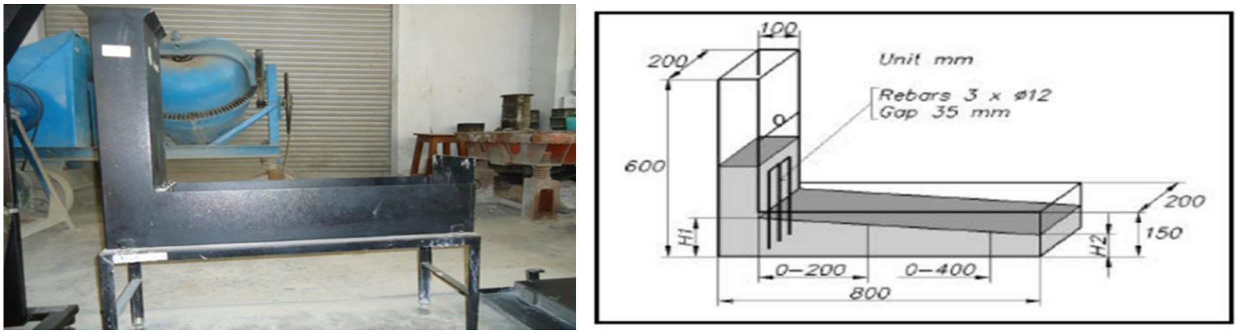


Fig. 3.2.3.3 L-Box Apparatus & Schematic Diagram

- Fourteen liter of concrete wasprepared for the test.
- The apparatus was placed on the leveled surface. The inside surfaces of the L-Box apparatus was moistened.
- The vertical part of the box was filled with concrete, which is left to rest for 10secs.
- Then the gate was opened.
- The distance “H_1” and “H_2” are measured, when the SCC stops flowing.

Analysis of results: the height of the vertical fill (H_1) and the height of the concrete in horizontal phase (H_2) were measured. The criteria to satisfy SCC is ${H_2}/{H_1}$ should be at least 0.8.

3.2.3 Casting of Specimens

Eighty four numbers cubes(150×150×150)mm, forty two numbers cylinders(150×300)mm, eighty four numbers prisms(100×100×500)mm were casted and investigations were conducted to study the mechanical behavior, fracture behavior, microstructure of plain SCC, basalt fiber reinforced SCC (BFC), glass fiber reinforced SCC(GFC), carbon fiber reinforced SCC(CFC).

Fig. 3.2.4 Casting Of Specimens

3.2.4 Curing Of SCC Specimens

After casting was done the cubes were kept in room temp. For 24 hours then the moulds were removed and taken to the curing tank containing fresh potable water to cure the specimen for 7 days and 28days.

Fig. 3.2.5 Curing Tank

3.2.5 Testing Of Hardened SCC

A proper time schedule for testing of hardened SCC specimens was maintained in order to ensure proper testing on the due date. The specimens were tested using standard testing procedures as per IS: 516-1959.

3.2.5.1 Compression Test

For each mix six numbers of cubes of (150×150×150) mm were cast to determine the compressive strength, after the required curing period of the specimen. So in total eighty four numbers cubes were casted to measure the compressive strength after 7-days and 28-days. The size of the cube is as per the IS code 10086-1982.

Fig: 3.2.6.1 Compression Test Set-Up

3.2.5.2 Split Tension Test

For each mix six numbers of cylinders of (150×300) mm were cast to determine the split tensile strength, after the required curing period of the specimen. So in total forty two numbers cylinders were casted to measure the split tensile strength after 28-days.

Fig: 3.2.6.2 Split tensile Test Set-Up

The split tensile strength = $2P / \pi LD$

Where P = Compressive load applied on the cylinder

L = Length of the specimen D = diameter of the cylinder.

3.2.5.3 Flexural Strength

The flexural strength test was carried out on a prism specimen of dimension 100mm×100mm×500mm as per IS specification. So in total forty two numbers prisms were cast to measure the flexural strength after 28-days. The flexural strength of specimen shall be calculated as:

$$PL / BD^2$$

Where P = load applied on the prism (KN), L = length of the specimen from supports (mm)

B = measured width of the specimen (mm), D = measured depth of the specimen (mm)

Fig.3.2.6.3 Flexure Test Set-Up

3.3 PREPARATION FIBER REINFORCED SELF-COMPACTING CONCRETE

3.3.1 Addition Of Fibers To SCC Mixes

Alkali resistance glass fibers were added in different percentages to the preparedSCC mixes.In the present study and glass fiber reinforced self-compacting concrete (GFC) was prepared. Similarly, the percentages of basalt fibers were added and basalt fiber reinforced self-compacting concrete (BFC) prepared and then the percentages of carbon fiber were added, carbon fiber reinforced self-compacting concrete (CFC) was prepared. After adding fibers to SCC mixes, again the same methods were followed for the determination of properties in the fresh state and hardened state for all these fiber reinforced SCC.

Fig. 3.3.1 Addition of Fiber to the SCC Mix

3.4 Ultrasonic Pulse Velocity Test

The test instrument consists of a means of producing and introducing a wave pulse into the concrete and a means of sensing the arrival of the pulse and accurately measuring the time taken by the pulse to travel through the concrete.

The equipment is portable, simple to operate, and may include a rechargeable battery and charging unit. The measured travel time is prominently displayed. The instrument comes with set of two transducers, one each for transmitting and receiving the ultrasonic pulse. Transducers with frequencies 25 kHz to 100 kHz are usually used for testing concrete.

Fig. 3.2.6.4 UPV Test Set-up

3.5 STUDIES ON FRACTURE BEHAVIOR OF SCC AND FRSCC MIXES

In the present study fracture behavior was studied for the plain SCC and FRSCC mixes. The inclusion of fiber in concrete improves ductility because the fibers act like crack arrester. The ductility can be measured by fracture behavior of FRSCC and to determine fracture energy, prisms specimen of dimension 100mm×100mm×500mm were cast with a notch of 5mm width (n_0) and 30mm depth as per the specification for the specimen. The schematic diagram of specimen and loading arrangement of test setup shown in the Fig.3.5.1 & Fig. 3.5.2.During testing, Crack Mouth Opening Displacement (CMOD) were noted using through two dial gauges as shown in fig.

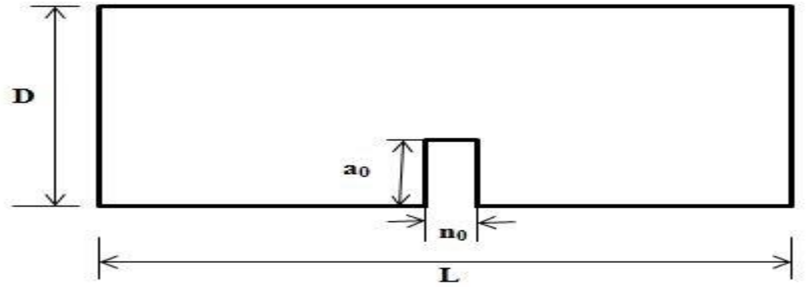


Fig.3.5.1 Schematic Diagram of Notched Prism Specimen

($a_o = 0.3D$, $n_o \leq 5$mm, $L \geq 3.5D$, $D \geq 4d_a$)

source: Japan Concrete Institute Standard (JCI-S-001-2003)

Fig. 3.5.2 Loading Arrangement for Fracture Test

3.6 STUDIES ON LOAD-DEFLECTION BEHAVIOR OF SCC AND FIBER REINFORCED SCC MIXES

The inclusion of fiber improve the toughness index of concrete mix to study this property a prism100mm×100mm×500mm was tested under 3-point loading in a electronic UTM. The load-deflection curve obtained from machine for different mix were analyzed and compared.

Fig. 3.5 Loading Arrangement for Load-Displacement Test

3.7 STUDIES ON SEM ANALYSIS OF FIBER REINFORCED SCC MIXES

To study the Microstructure of the mixes incorporated with different types of fibers SEM analysis were conducted in SEM lab of MM dept. of NIT ROURKELA. The study was done to determine the bond development and different period between different fibers and cement matrix. The sample was cured for 7 and 28 days.

Fig.3.6 Scanning Electron Microscope

3.8 STUDIES ON SORPTIVITY TEST OF FIBER REINFORCED SCC MIXES

Cube specimens were cast to determine capillary absorption coefficients after 28 days curing. This test was conducted to check the capillary absorption of different FRSCC mortar matrices which indirectly measure the durability of the different mortar matrices.

Procedure:

- The specimen was dried in oven at about 105^0C until constant mass was obtained.
- Specimen was cool down to room temperature for 6hr.
- The sides of the specimen were coated with paraffin to achieve unidirectional flow.
- The specimen was exposed to water on one face by placing it on slightly raised seat (about 5mm) on a pan filled with water.

- The water on the pan was maintained about 5mm above the base of the specimen during the experiment as shown in the figure below.
- The weight of the specimen was measured at 15 min and 30 min. intervals.
- The capillary absorption coefficient (k) was calculated by using formula:

$$k = \frac{W}{A\sqrt{t}}$$

Where W is amount of water absorbed

A = cross sectional area in contact with water (m^2)

t = time (hr)

Fig. 3.7 Set-Up of Sorptivity

CHAPTER-4

RESULTS OF THE EXPERIMENTAL INVESTIGATIONS ON FRSCC

This chapter deals in detail with the results of experimental investigations and discussion carried out in different stages.

4.1PREPARATION 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 3.2.1.

4.1.1 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.

4.1.2 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 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.

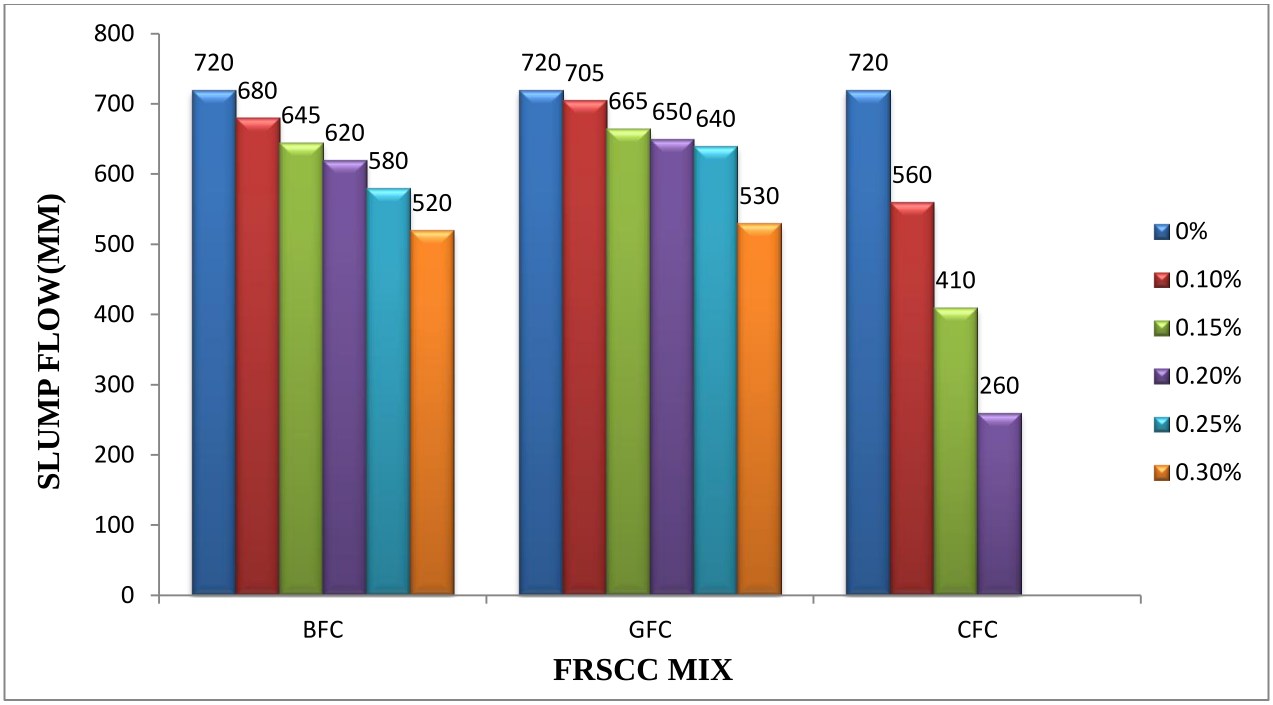
Table 4.1.1 Description of Mixes

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

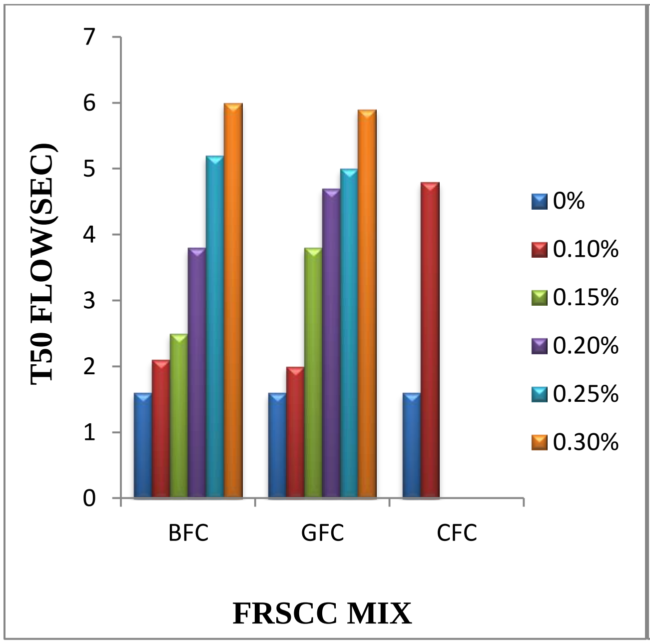
4.2 Results and Discussion

Table 4.2.1 Results of the Fresh Properties of Mixes

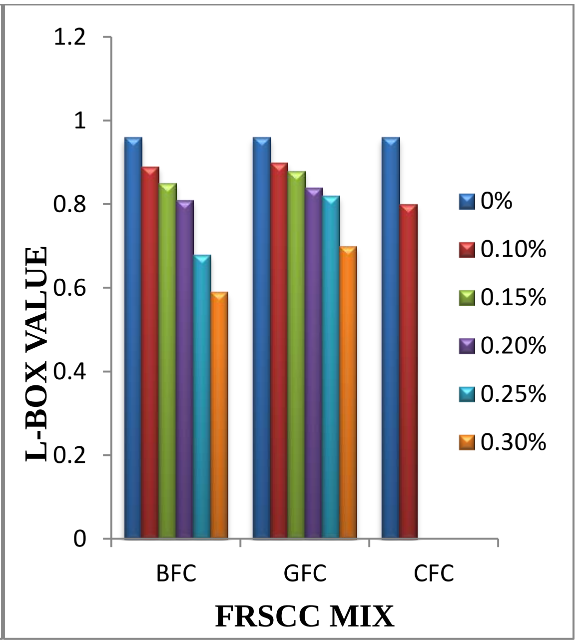
sample	Slump flow 500-750mm	T_{50} flow 2-5sec	L-Box(H_2/H_1) 0.8-1.0	V-Funnel 6-12sec	T5 Flow +3sec	Remarks
PSC	720	1.6	0.96	5	9	Low viscosity (Result Satisfied)
BFC-1	680	2.1	0.89	8	12	Result Satisfied
BFC-1.5	645	2.5	0.85	8	13	Result Satisfied
BFC-2	620	3.8	0.81	9	14	Result Satisfied
BFC-2.5	580	5.2	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)


SLUMP FLOW(MM)
800
700
600
500
400
300
200
100
0
720
680
645
620
580
520
720
705
665
650
640
530
720
560
410
260
BFC
GFC
CFC
FRSCC MIX
0%
0.10%
0.15%
0.20%
0.25%
0.30%

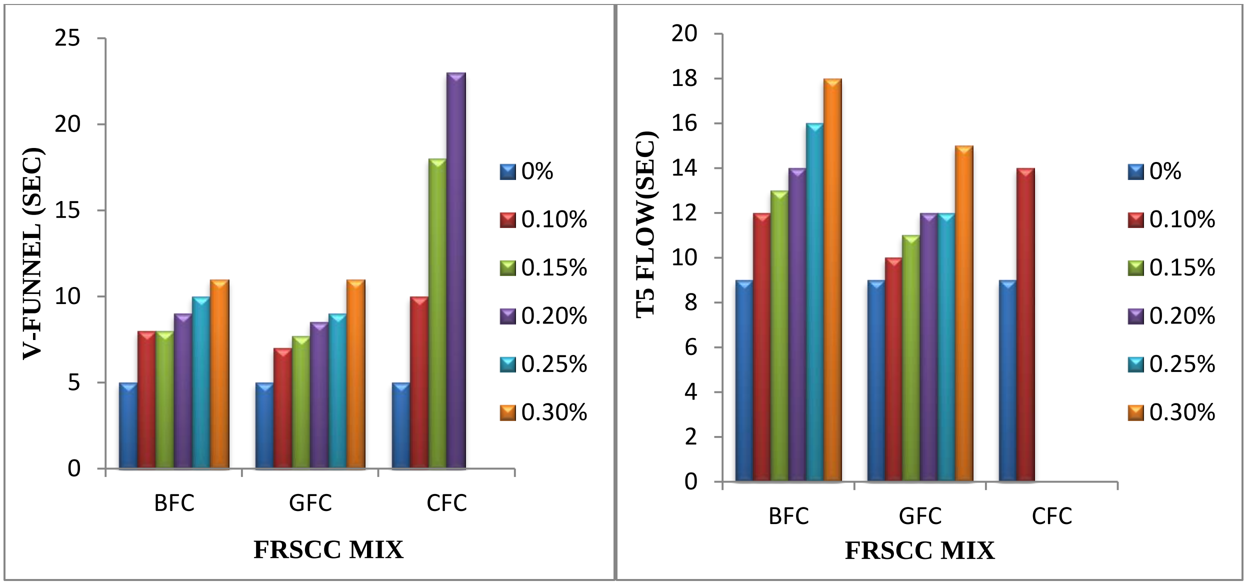
(A)


T50 FLOW(SEC)
7
6
5
4
3
2
1
0
BFC
GFC
CFC
FRSCC MIX
0%
0.10%
0.15%
0.20%
0.25%
0.30%

(B)


L-BOX VALUE
1.2
1
0.8
0.6
0.4
0.2
0
BFC
GFC
CFC
FRSCC MIX
0%
0.10%
0.15%
0.20%
0.25%
0.30%

(C)



(D) **(E)**

Fig. 4.2.1 (A),(B),(C),(D),(E) Variation of Fresh properties with FRSCC Mix

4.2.1 Properties in Fresh state:

The Table 4.2.1 and the Fig.4.2.1 indicate reduction of flow value owing to inclusion of fibers. The reason for this phenomenon is that a network structure may form due to the distributed fiber in the concrete, which restrains mixture from segregation and flow.

4.2.1.1 Slump Flow

The slump flow decreases with increase in fiber percentage. The decrease in flow value is observed maximum 63.88% for carbon fiber, 26.38% for glass fiber and 27.77 % for basalt fiberw.r.t control mix. This is because carbon fibers absorbed more water from the mix and beyond 0.2% fiber addition the mix did not satisfied the norms of self-compacting concrete. Glass fibers absorb lowest water.

4.2.1.2 T50 Flow

The T50 flow, which was measured in terms of time (seconds) increases as the slump flow value decreases. The decrease in slump value is due to the increase in the percentage of fiber which was explained in previous section. The maximum time taken to flow was observed at 0.1% for carbon fiber, 0.3% for glass fiber and 0.3% for basalt fiber.

4.2.1.3 L-Box

The L-Box value increases as the slump flow value increases. The increase in slump value is due to the increase in the percentage of fiber as well as the L-Box value also increases. The maximum value obtained in the case of control mix but as per SCC specification 0.2% basalt fiber. 0.25% glass fiber & 0.1% carbon fiber fulfill the requirements.

4.2.1.4 V-Funnel & T5 flow

The V-Funnel test & T50 flow, which was measured in terms of time (seconds) & both the value measured are dependent with each other. V-Funnel value and T5 flow increases as the slump flow value decreases. The decrease in slump value is due to the increase in the percentage of fiber. It was observed that at 0.1% of carbon fiber, 0.2% of basalt fiber and 0.25% og glass fiber the SCC specification were satisfied.

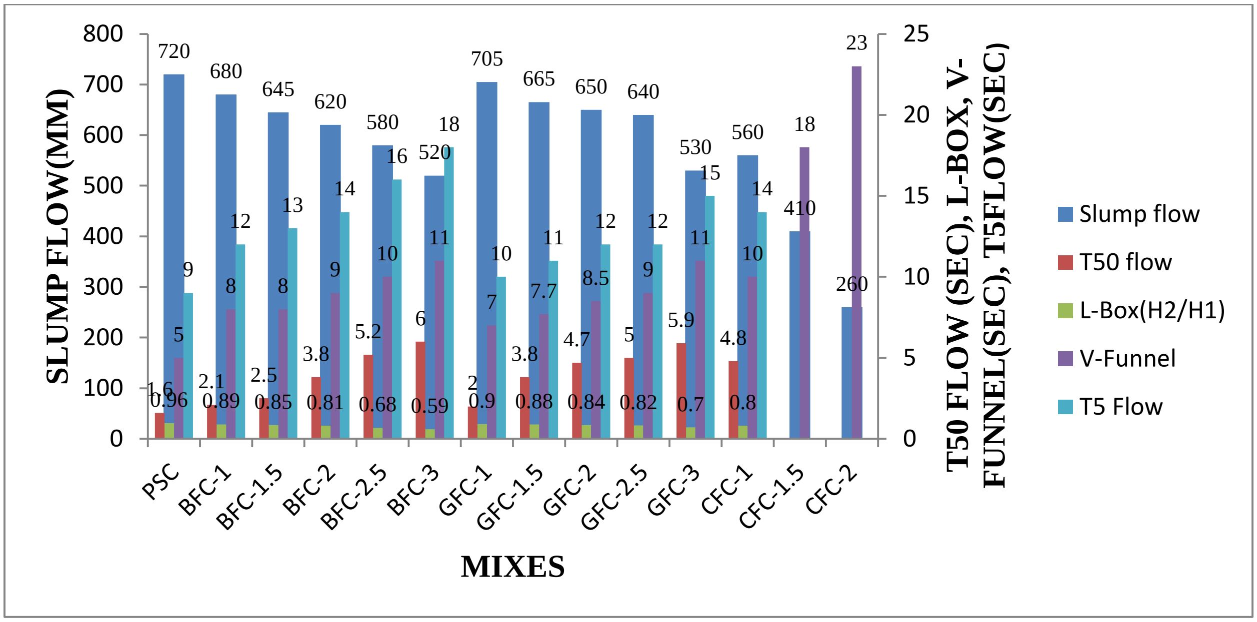


Fig. 4.2.2 Variation of Fresh Properties of FRSCC Mixes with Different Percentage of Fiber Mix

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 4.3.1

Table- 4.3.1 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

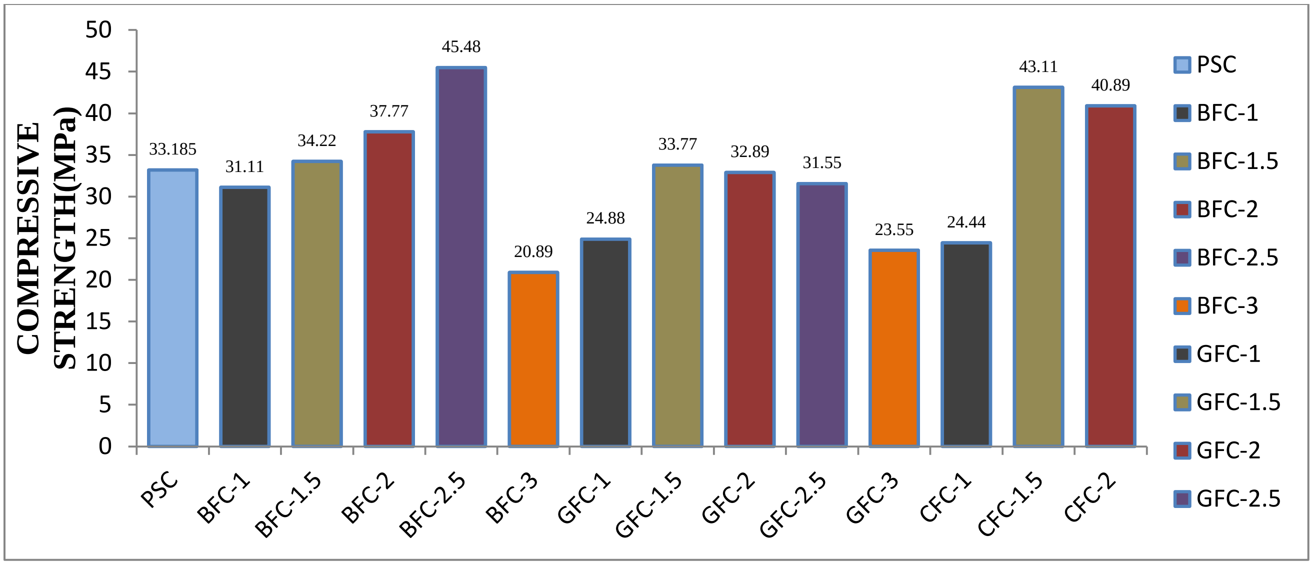


Fig. 4.3.1 Variation of 7-Days Compressive Strength for Different SCC Mixes

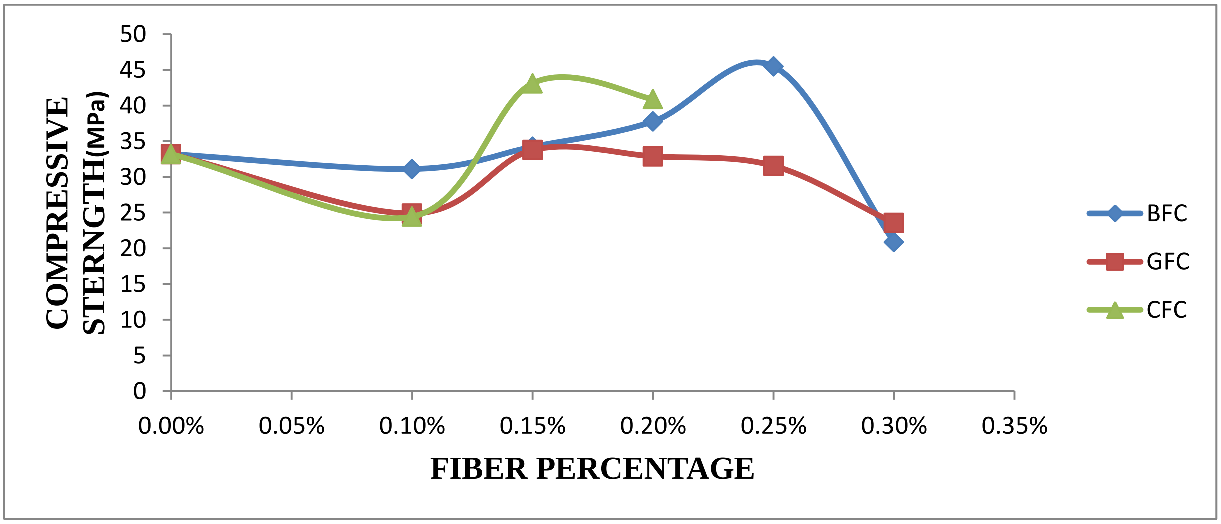


Fig. 4.3.2 Comparison of Different Percentages of Fiber Mixes with 7 days Compressive Strength

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, 45.48MPa was observed with 0.25% basalt fiber 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.

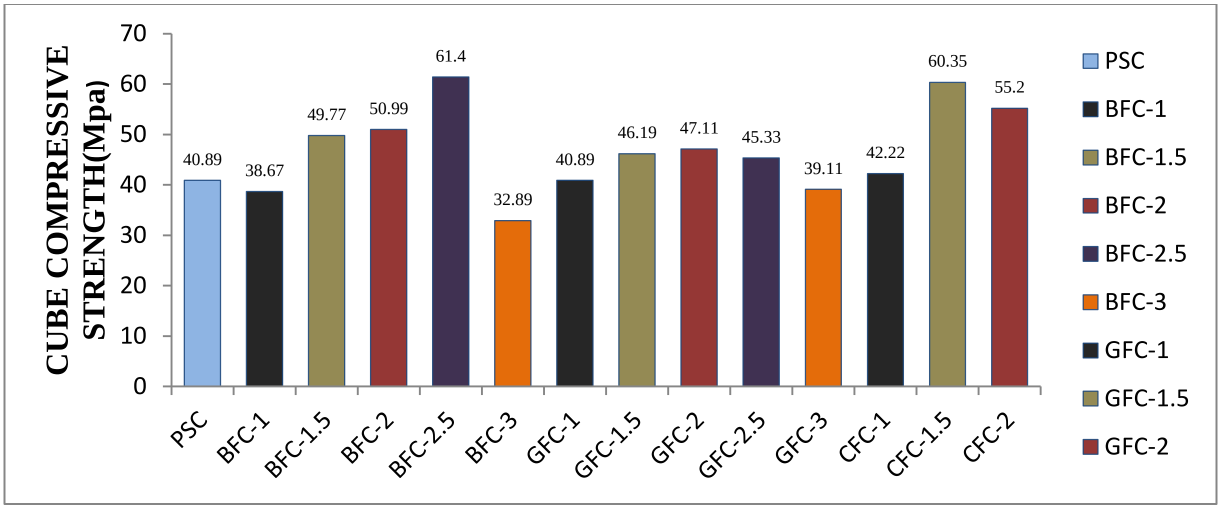


Fig. 4.3.3 Variation of 28days Compressive Strength for Different SCC Mixes

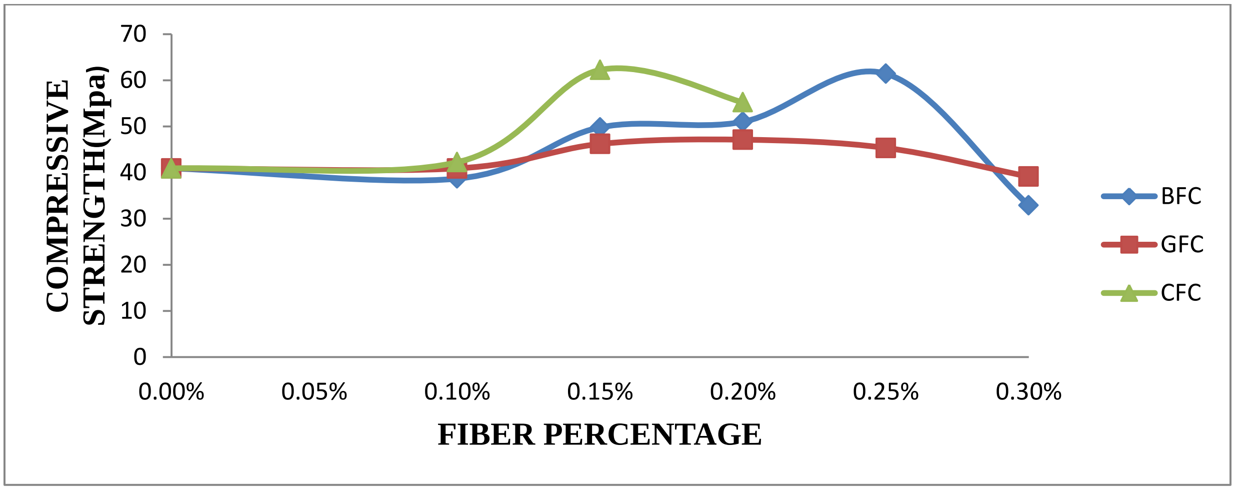


Fig. 4.3.4 Comparison of Different Percentages of Fiber Mixes with 28 days Compressive Strength

The fig.4.3.4 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. The highest 28-days compressive strength was observed for mix with 0.25%basalt fiber and lowest for mix with 0.3%basalt fiber.

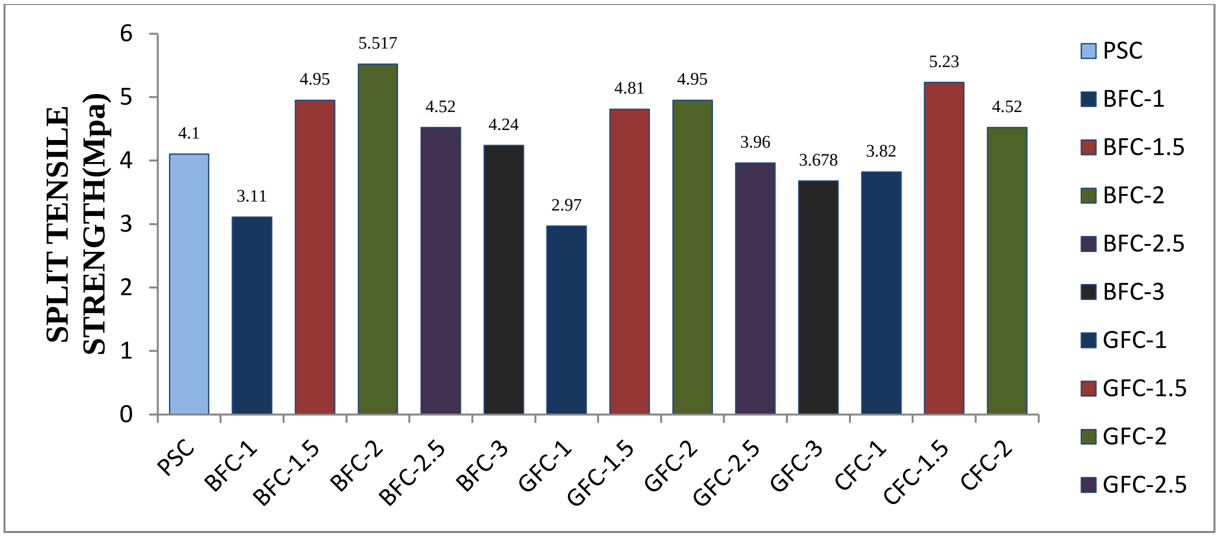


Fig. 4.3.5 Variation of Split Tensile Strength for Different SCC Mixes At 28days

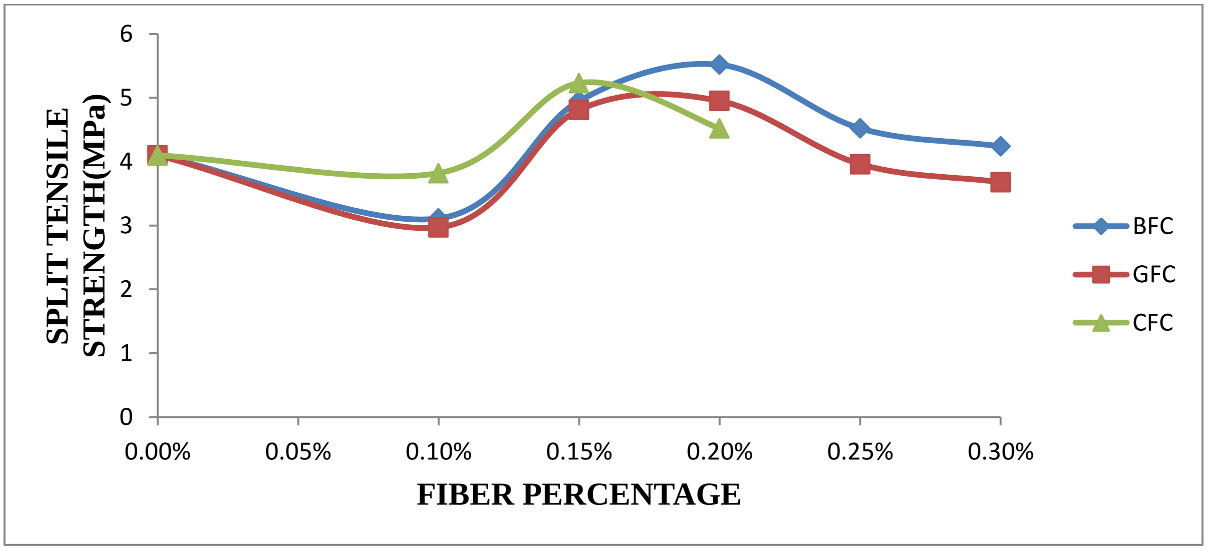


Fig. 4.3.6 Comparison of Different Percentages of Fiber Mixes with 28 days Split Tensile Strength

The Fig. 4.3.6 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 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.

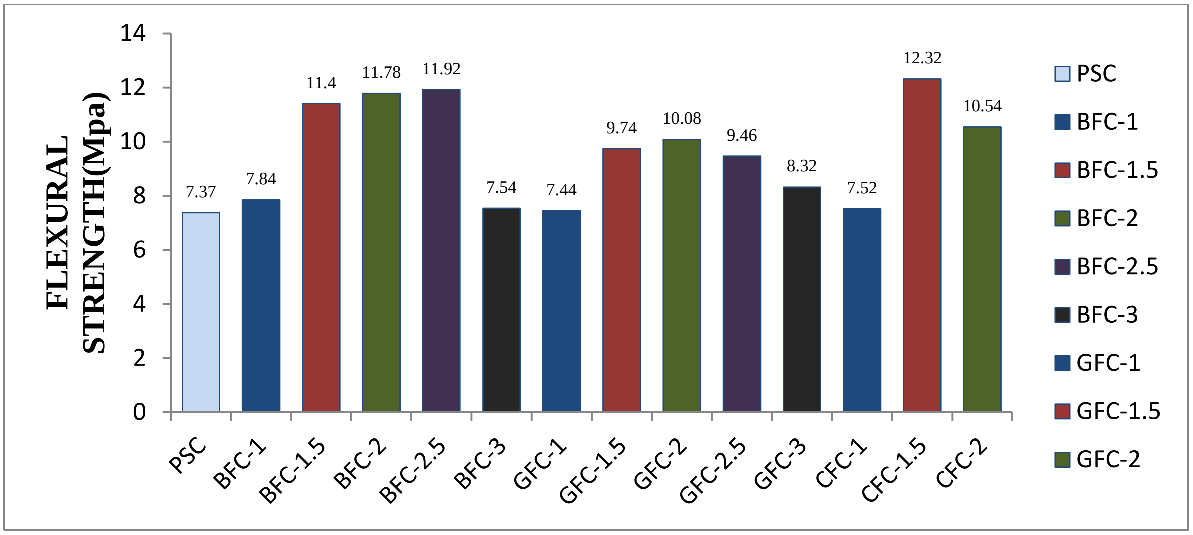


Fig. 4.3.7 Variation of Flexural Strength for Different SCC Mixes At 28days

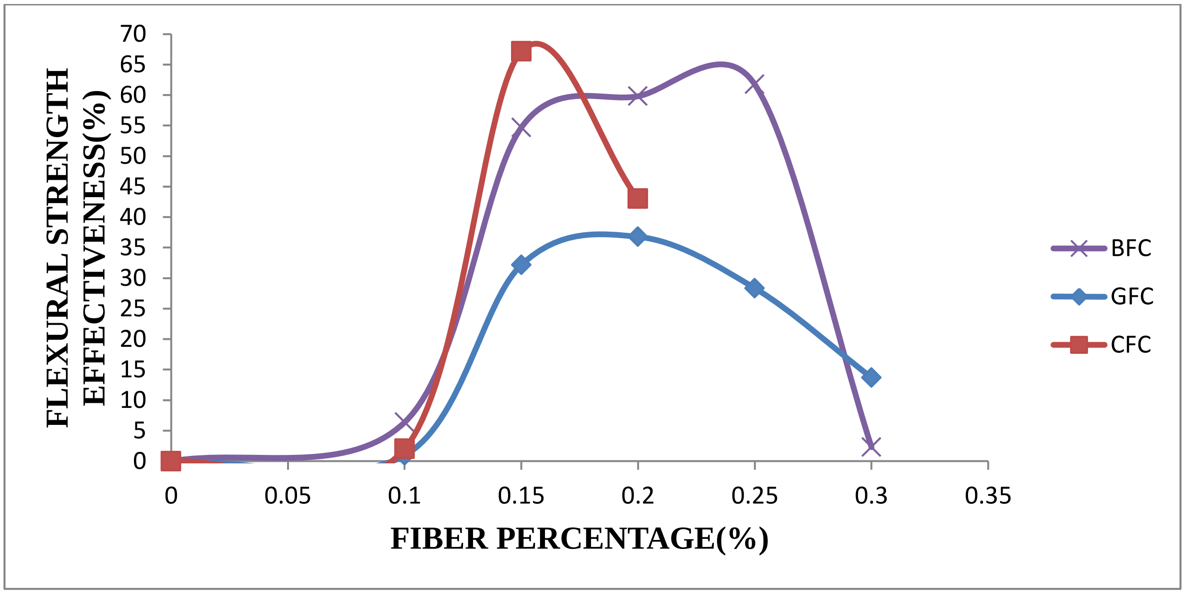


Fig. 4.3.8Flexural Strength-Effectiveness of FRSCC at 28-Days

The Fig. 4.3.8 shows the optimum fiber content in mixes with different fibers. The maximum strength of 12.32MPa was observed with 0.15% carbon fiber content, 11.92MPa was observed with 0.25% basalt fiber content and 10.08MPa was observed with 0.2% glass fiber content. The highest 28-days flexural strength was observed for mix with 0.15%carbon fiber and lowest for mix with 0.1%glass fiber.

4.3.1. Compressive Strength

4.3.1.1 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%.

4.3.1.2. 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%.

4.3.2 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.

4.3.3 Flexural Strength

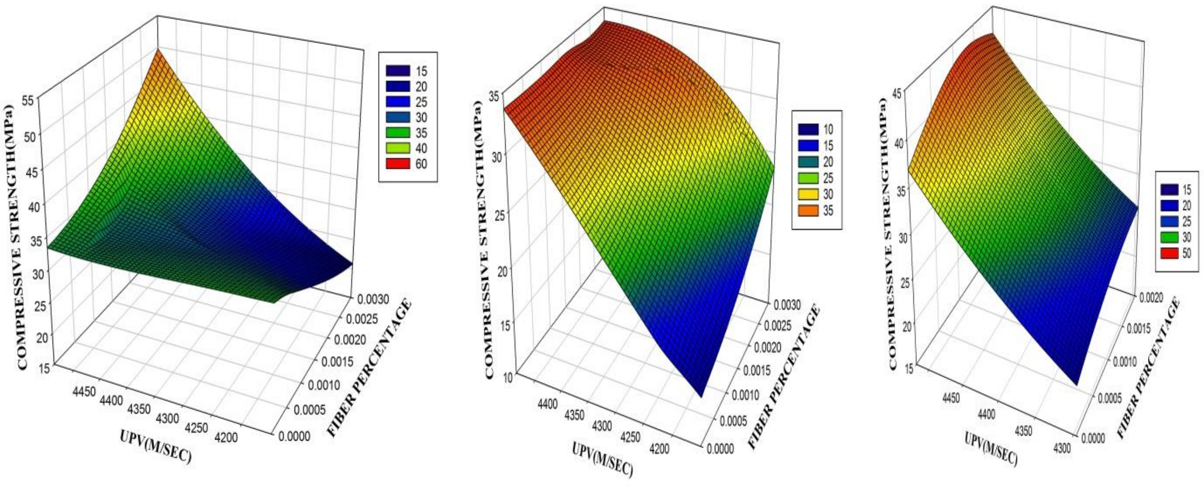
Table 4.3.1 & Fig. 4.3.7 shows flexural strengths of FRSCC mixes after 28 days and fig.4.2.8 shows the optimum fiber fraction imparting maximum flexural strength with different fibers. As expected, all FRSCC specimens show an increase in flexural strength with increase in fiber content. Compared with the plain SCC the enhanced percentage of the flexural strength of carbon FRSCC were observed in the range of 2.03% to 67.16% while 0.15% gave maximum strength. Increase in flexural strength were observed in ranges from 0.95% to 36.77% for GFC with the fiber percentage of 0.1% to 03% ,the and enhanced percentage flexural strength ranges from 2.37% to 61.736% were observed for basalt fiber with percentage fiber ranges from 0.1% to 0.3%. Maximum flexural strength 12.32MPa was observed for carbon FRCCC for 1.5% of fiber percentage.

4.4 ULTRASONIC PULSE VELOCITY

The UPV meter acts on principle of wave propagation hence higher the density and soundness, higher the velocity of wave in it.

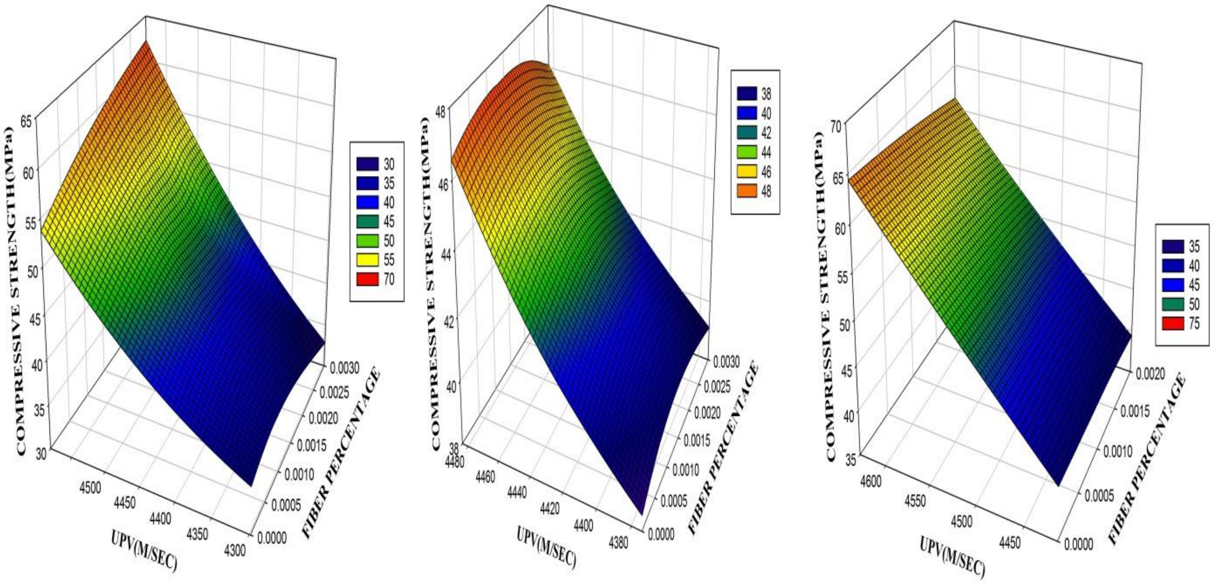
Table 4.4.1 Ultrasonic Pulse Velocity Results

SPECIMEN	7-DAYS AVG. UPV OF CUBE (M/SEC)	28-DAYS AVG. UPV OF CUBE (M/SEC)
PSC	4477.6	4416.34
BFC-1	4275.43	4337
BFC-1.5	4492	4493.67
BFC-2	4498.67	4505.33
BFC-2.5	4537.67	4582.33
BFC-3	4151.34	4298.33
GFC-1	4299.34	4399
GFC-1.5	4486.67	4473
GFC-2	4454	4483.67
GFC-2.5	4296.67	4469.33
GFC-3	4153	4374
CFC-1	4296.67	4434.34
CFC-1.5	4518.6	4629.66
CFC-2	4508.34	4574.67



(A) **(B)** **(C)**

Fig.4.4.1 Comparison between 7days Avg. UPV vs. Fiber percentage vs. Compressive Strength of (A) Basalt (B) Glass (C) Carbon



(A) **(B)** **(C)**

Fig. 4.4.2 Comparison between 28 days Avg. UPV vs. Fiber percentage vs. Compressive Strength of (A) Basalt (B) Glass (C) Carbon

The addition of silica fume, having micro grains acts like filler and improve density, whereas super-plasticizer facilitate the uniform distribution of all particles including fiber and impart cohesiveness to the mixes. These factors improve density and homogeneity of mixes in short overall soundness of concrete improves. The results indicates that 1% fiber addition were ineffective in improving the UPV value in fact they were observed to be less than SCC without fiber. In each case there were an optimum percentage of fibers exhibiting maximum UPV values.

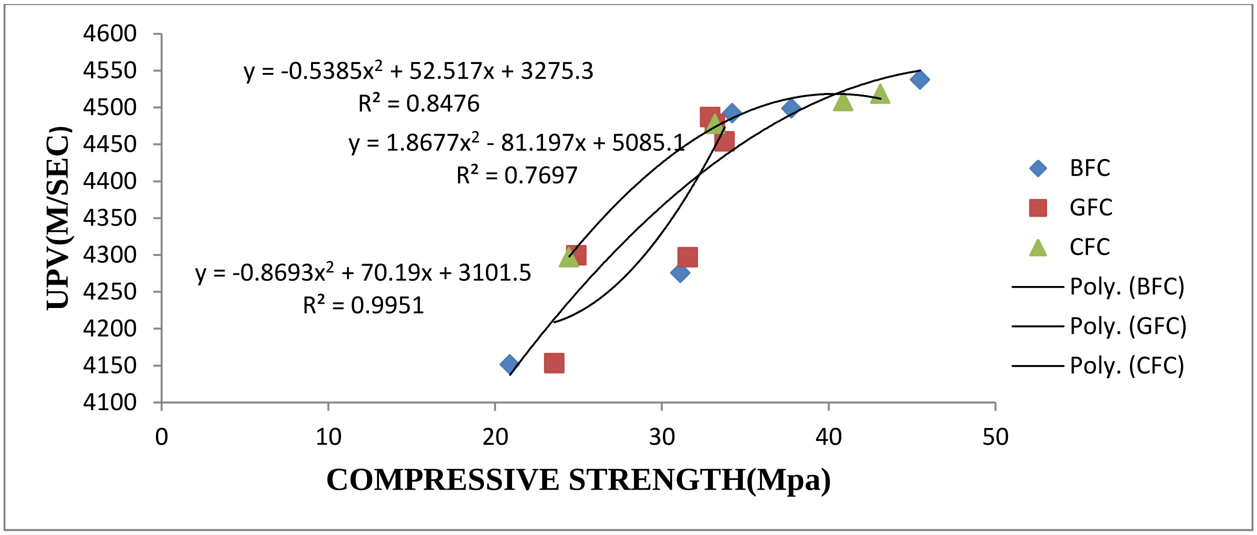


Fig.4.4.3 Correlation Curves between Avg. UPV values & 7-days Compressive Strength

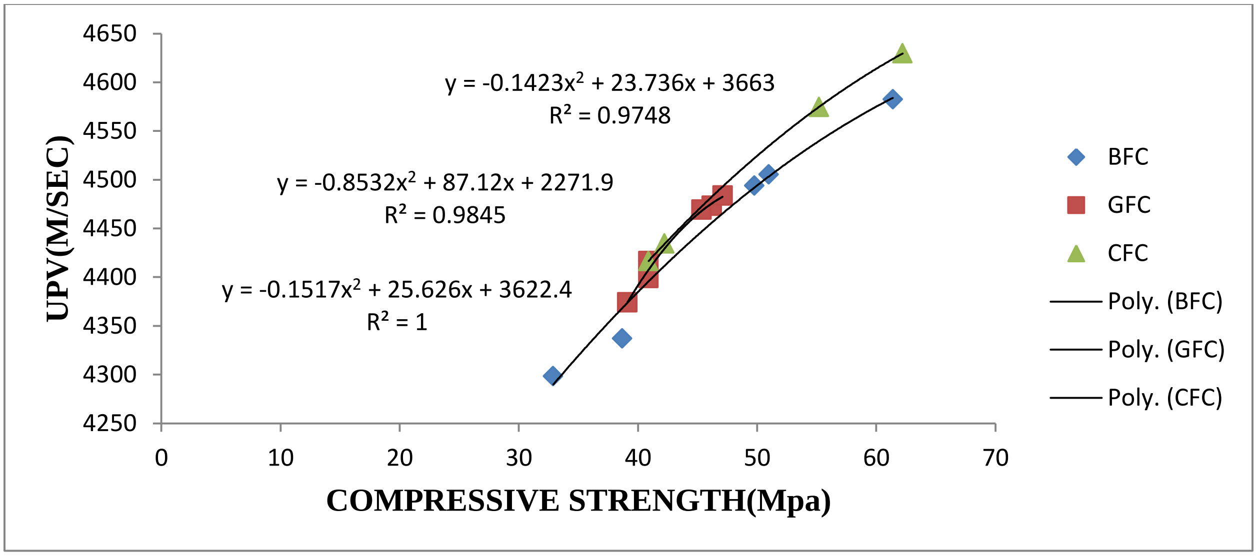


Fig.4.4.4 Co-Relation between Avg. UPV & 28-days Compressive Strength

A regression analysis of UPV values and compressive strength after 7-days and 28 days were conducted and found to be in good correlation. Highest correlation coefficient was obtained for carbon FRSCC, then for basalt FRSCC and lowest for the glass FRSCC. The result proved that the combination of silica fume with different fibers can enhance the UPV properties of SCC.

From the table 4.4.1 it is shown that the addition of 0.25% of basalt fibers to a self-compacted plain concrete increased the UPV by 1.35% in 7-days & 3.75% in 28days. For glass fiber addition of 0.2% fiber, increased the UPV by 0.2% in 7days & 1.52% in 28 days. For carbon fiber addition of 0.15% fiber, increased the UPV by 0.91% in 7days & 4.83% in 28 days. Whereas if addition of fiber is more than the optimum dosages different for different fibers, UPV decreased. Therefore, 0.25% volume fraction of basalt fibers was the optimum dosages to be used in BFC, 0.2% for GFC and 0.15% for CFC.

4.5 LOADS-DISPLACEMENT BEHAVIOR AND TOUGHNESS INDEX

The load deflection (vertical) diagrams obtained from electronic UTM clearly proved that addition of fibers to SCC increase ductility whereas control beam PSC exhibited brittle behavior. The maximum increment was observed from carbon fiber than the basalt and the lowest from the glass fiber. In each series the mix which gave maximum compressive strength rendered maximum ductility. The area below the load deflection curve represents toughness. Almost same pattern of behavior were observed from all mixes.

Fig.4.5.1 Crack Pattern of PSC

Fig. 4.5.2Crack Pattern of BFC

Fig. 4.5.3Crack Pattern of GFC

Fig. 4.5.4Crack Pattern of CFC

Table 4.5.1 Load - Displacement Result

Specimen	Ultimate load(KN)
PSC	12.800
BFC-1	15.540
BFC-1.5	20.690
BFC-2	22.420
BFC-2.5	22.540
BFC-3	15.810
GFC-1	15.650
GFC-1.5	19.580
GFC-2	19.620
GFC-2.5	17.900
GFC-3	17.590
CFC-1	15.950
CFC-1.5	23.330
CFC-2	19.980

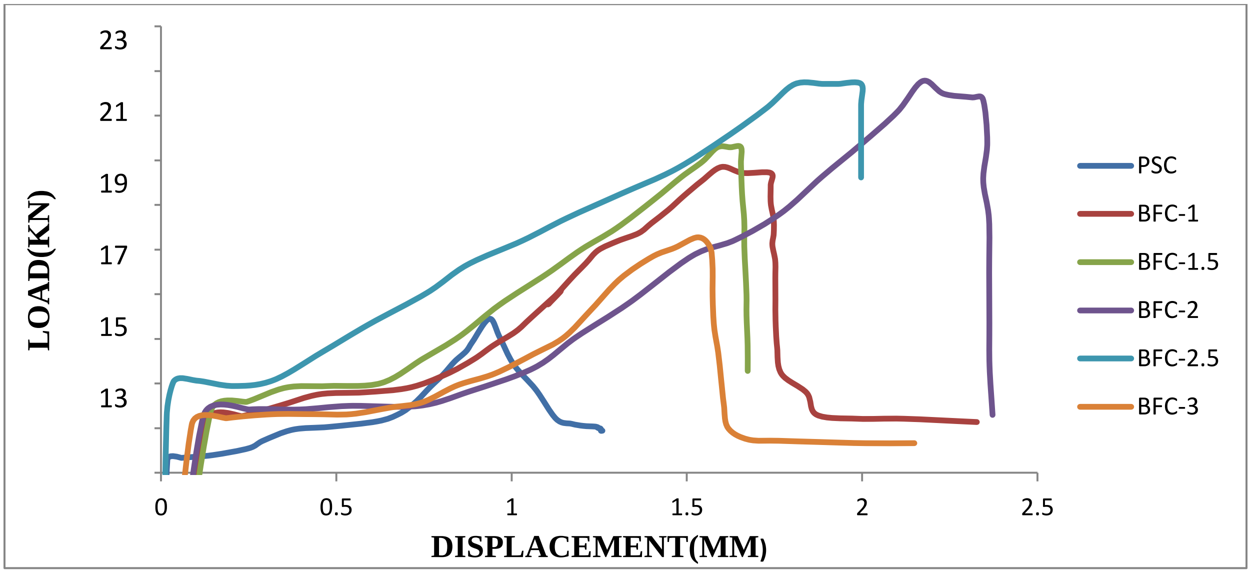


Fig. 4.5.5 Load-Displacement Curve For BFC

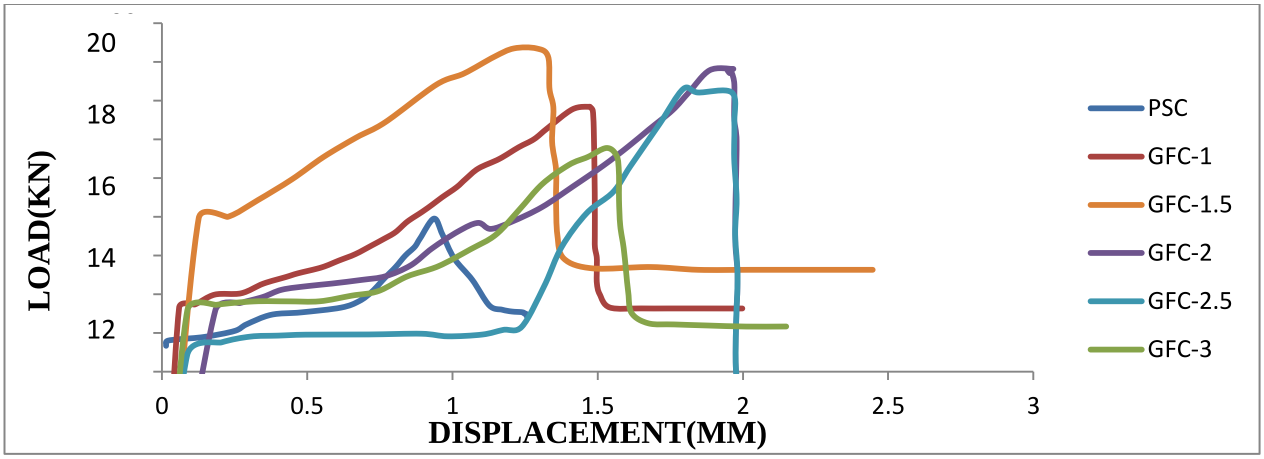


Fig. 4.5.6 Load-Displacement Curve For GFC

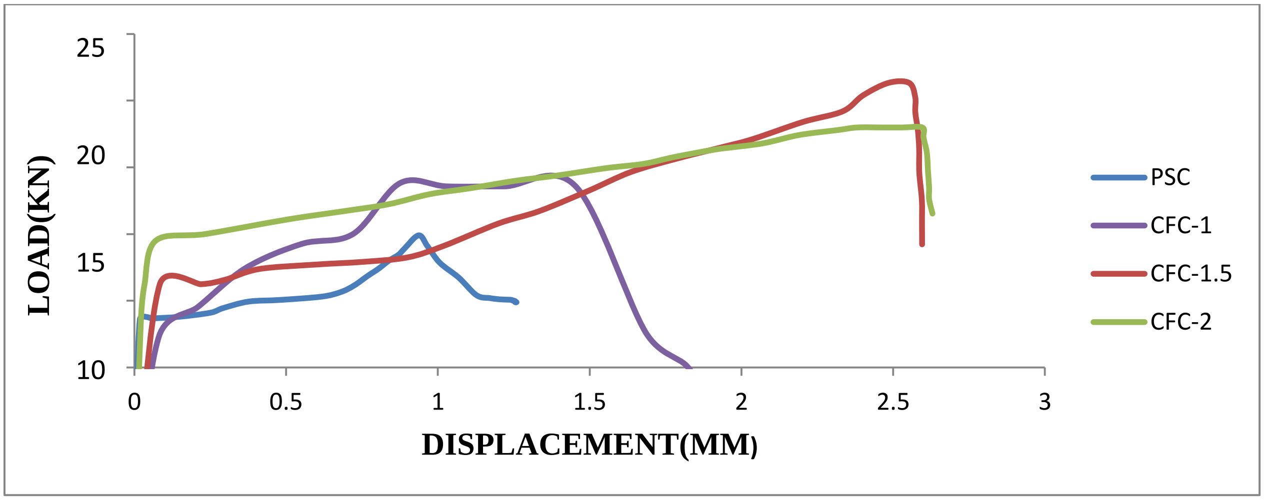


Fig. 4.5.7 Load-Displacement Curve For CFC

Fig 4.5.5 to 4.5.7 shows the load-displacement curves of the plain SCC with different FRSCC samples. It is found that for the plain SCC, the load decreases rapidly with the increase of deflection after peak load (curve of PSC). Whereas for the FRSCC, the decrease trends show flatter (curve of FRSCC). The bridging action offered by the fibers can effectively improve the toughness and ductility, and thus eliminating the sudden brittle fracture after peak load presented in plain SCC. Table 4.5.1 presents the result of ultimate load of plain SCC and FRSCC. It can be seen from table 4.5.1 that the ultimate load taken by FRSCC increase compared to plain SCC. Basalt& carbon fiber shows most obvious improvement.

4.6 LOAD-CMOD BEHAVIOUR

The load vs. crack mouth opening deflection diagrams obtained clearly proved that addition of fibers to SCC increase ductility whereas control beam PSC exhibited brittle behavior. The maximum increment was observed from carbon fiber than the basalt and the lowest from the glass fiber. In each series the mix which gave maximum compressive strength rendered maximum ductility. The area below the load deflection curve represents toughness. Almost same pattern of behavior were observed from all mixes.

The observations made during the tests (LOAD-CMOD) were used to draw the LOAD-CMOD curves. The ultimate load and the fracture parameters were determined.

Table 4.6.1 LOAD-CMOD RESULT FOR GFC

LOAD(KN)	CMOD(MM)					
	PSC	GFC-1	GFC-1.5	GFC-2	GFC-2.5	GFC-3
0	0	0	0	0	0	0
0.75	0	0	0.001	0	0	0
1	0	0	0.002	0	0	0
2	0.01	0.004	0.006	0	0	0
3	0.08	0.006	0.008	0	0.02	0
4	0.26	0.009	0.024	0	0.05	0.04
4.25	0.28	0.01	0.033	0	0.06	0.05
5		0.16	0.05	0	0.08	0.09
5.5		0.2	0.11	0	0.09	0.13
6		0.41	0.18	0	0.13	0.16
6.5			0.25	0.01	0.17	0.18
6.75			0.3	0.03	0.18	0.19
7				0.03	0.21	0.22
8				0.06	0.32	0.35
9				0.13	0.46	0.51
9.5				0.18	0.5	
10				0.22		
10.25				0.27		

Fig 4.6.1 Crack Pattern of PSC

Fig. 4.6.2 Crack Pattern of GFC-1

Fig. 4.6.3 Crack Pattern of GFC-1.5

Fig.4.6.4 Crack Pattern of GFC-2.5

Fig 4.6.5Crack Pattern of GFC-3

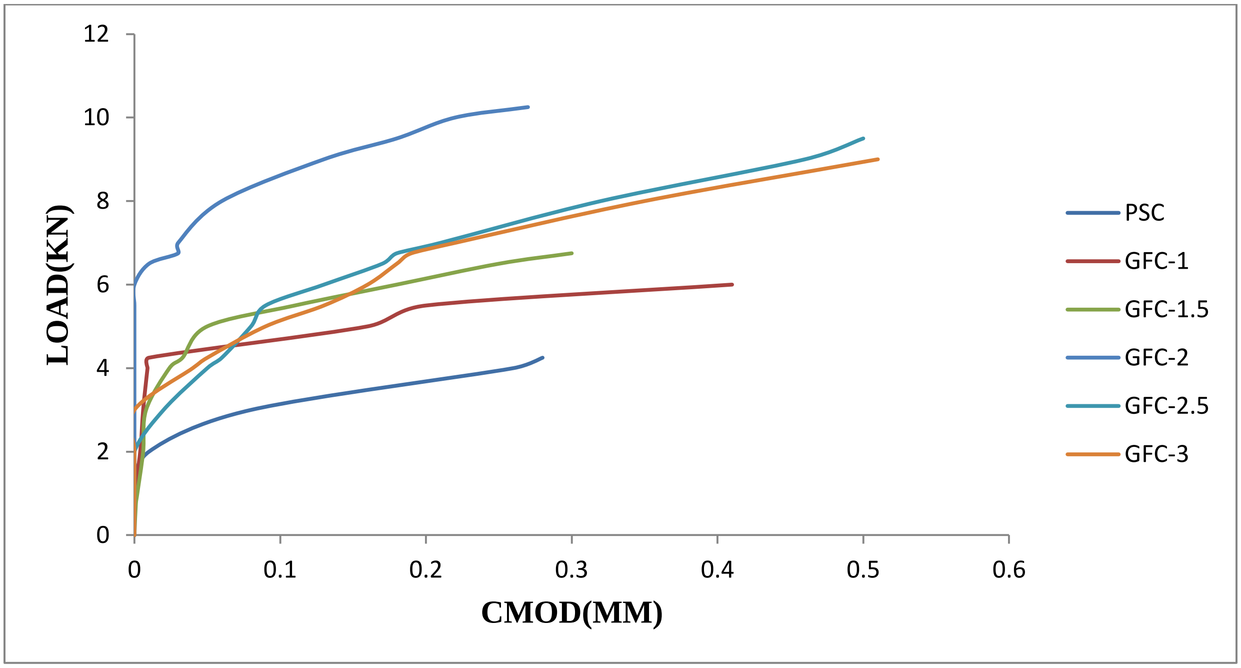


Fig. 4.6.6 LOAD-CMOD Curve For GFC

4.6.1 Fracture Behavior of Glass Fiber Reinforced SCC (GFC)

From table 4.6.1& fig 4.6.6 it is observed that the fracture behavior of GFC is more than PSC in all fiber contents. As compared to PSC the increase in ultimate load for GFC was around 41.17%, 58.8%, 141.17%, 123.52%, 111.76% when adding 0.1%, 015%, 0,2%, 0.25%, 0.3% fibers respectively. As the fiber content increased, the fracture behaviors were also found to be increased for GFC. Fig.4.6.2 to fig. 4.6.5 shows the crack pattern of GFC.

Table 4.6.2 LOAD-CMOD RESULT FOR BFC

LOAD(KN)	CMOD(MM)					
	PSC	**BFC-1**	**BFC-1.5**	**BFC-2**	**BFC-2.5**	**BFC-3**
0	0	0	0	0	0	0
2	0.01	0	0.004	0	0	0
3.25	0.1	0.01	0.009	0	0	0
4	0.26	0.05	0.019	0.01	0	0.02
4.25	0.28	0.06	0.023	0.015	0	0.05
6		0.1	0.053	0.06	0.08	0.13
6.25		0.3	0.059	0.09	0.1	0.16
6.5		0.36	0.065	0.15	0.12	0.19
6.75			0.08	0.18	0.14	0.36
7			0.1	0.21	0.17	
7.75			0.33	0.28	0.23	
8					0.26	
9.75					0.36	
10.5					0.43	
10.75					0.45	

Fig. 4.6.7Crack Pattern of BFC-1

Fig. 4.6.8Crack Pattern of BFC-1.5

Fig. 4.6.9Crack Pattern of BFC-2

Fig. 4.6.10Crack Pattern of BFC-2.5

Fig. 4.6.11Crack Pattern of BFC-3

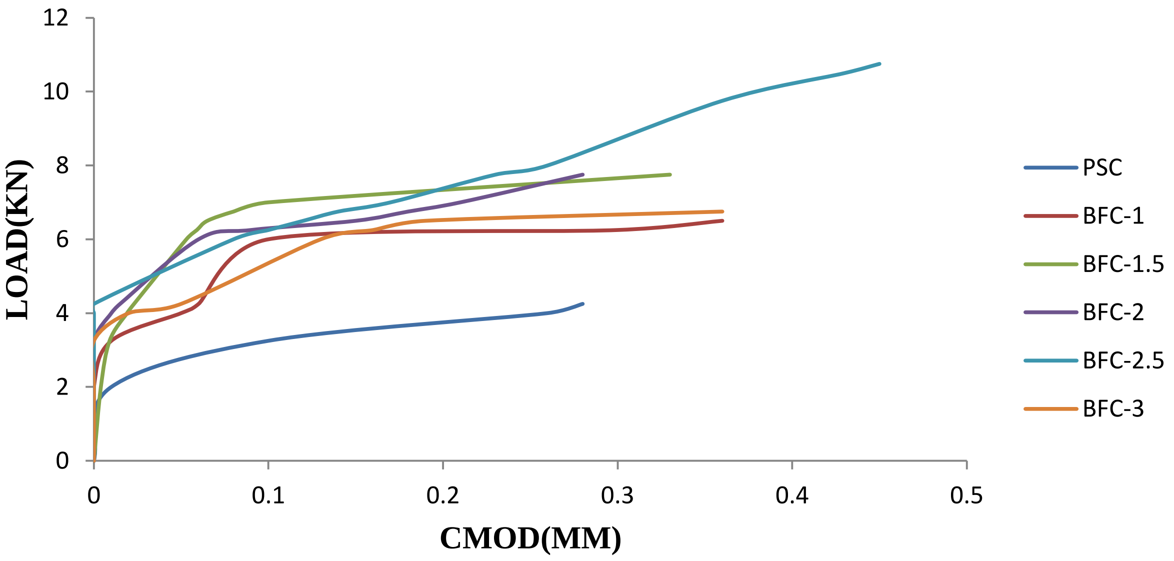


Fig. 4.6.12LOAD-CMOD Curve For BFC

4.6.2 Fracture Behavior of Basalt Fiber Reinforced SCC (BFC)

From table 4.6.2 & fig 4.6.12 it is observed that the fracture behavior of BFC is more than PSC in all fiber contents. As compared to PSC the increase in ultimate load for BFC was around 52.94%, 82.35%, 82.35%, 152.9% & 58.8% when adding 0.1%, 015%, 0.2%, 0.25%, 0.3% fibers respectively. As the fiber content increased, the fracture behavior was also found to be increased for BFC. Fig.4.6.7 to fig. 4.6.11 shows the crack pattern of BFC.

Table 4.6.3 LOAD-CMOD RESULT FOR CFC

LOAD(KN)	CMOD(MM)			
	PSC	CFC-1	CFC-1.5	CFC-2
0	0	0	0	0
2	0.01	0	0	0
3	0.08	0	0	0
4	0.26	0.01	0	0
4.25	0.28	0.02	0	0
4.75		0.05	0	0.02
5		0.07	0	0.02
6		0.13	0	0.07
6.5		0.18	0.01	0.08
7		0.2	0.03	0.13
8		0.25	0.06	0.21
9			0.12	0.3
9.5			0.15	0.35
10			0.21	
11			0.3	
11.75			0.34	

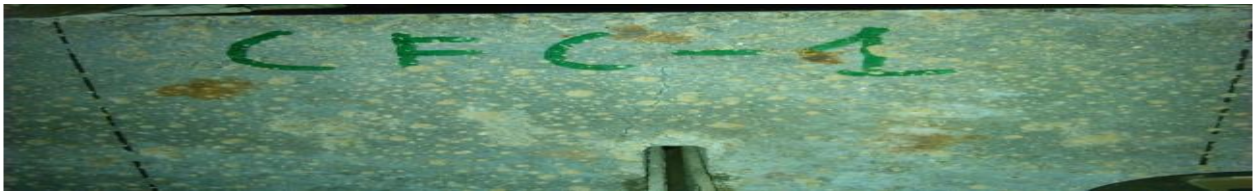


Fig. 4.6.13Crack Pattern of CFC-1

Fig.4.6.14Crack Pattern of CFC-1.5

Fig. 4.6.15Crack Pattern of CFC-2

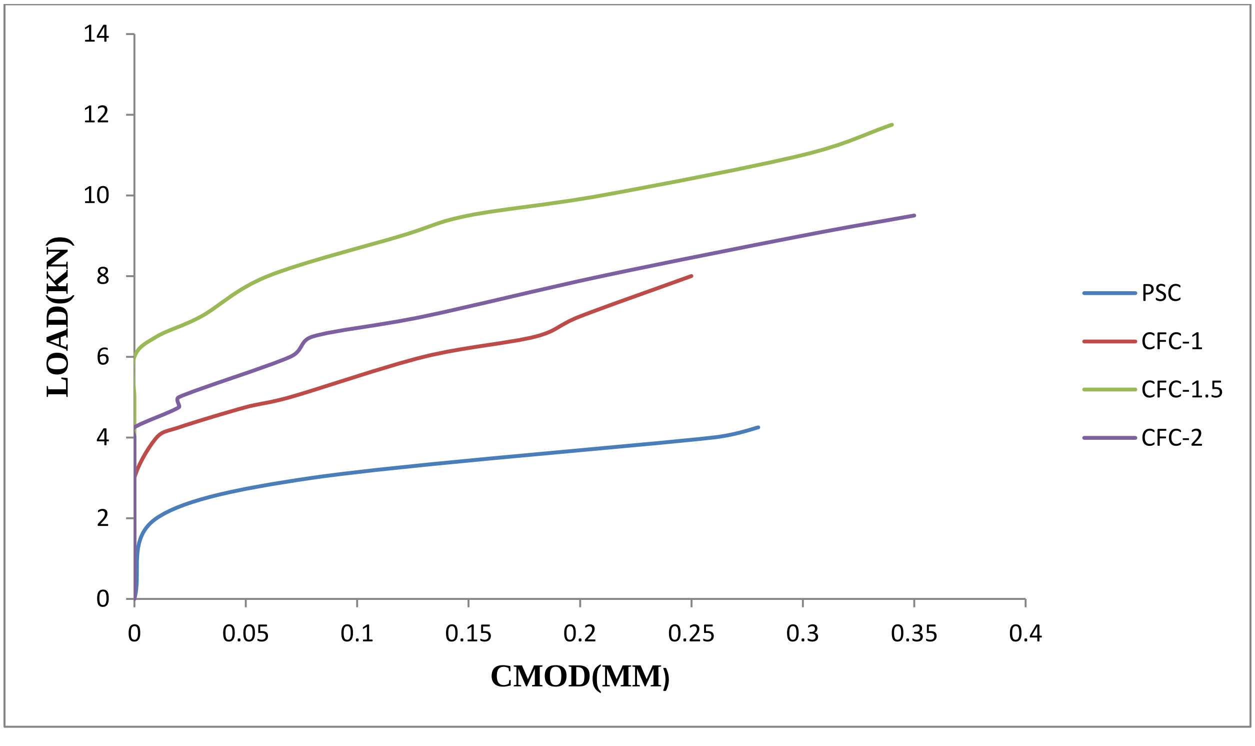


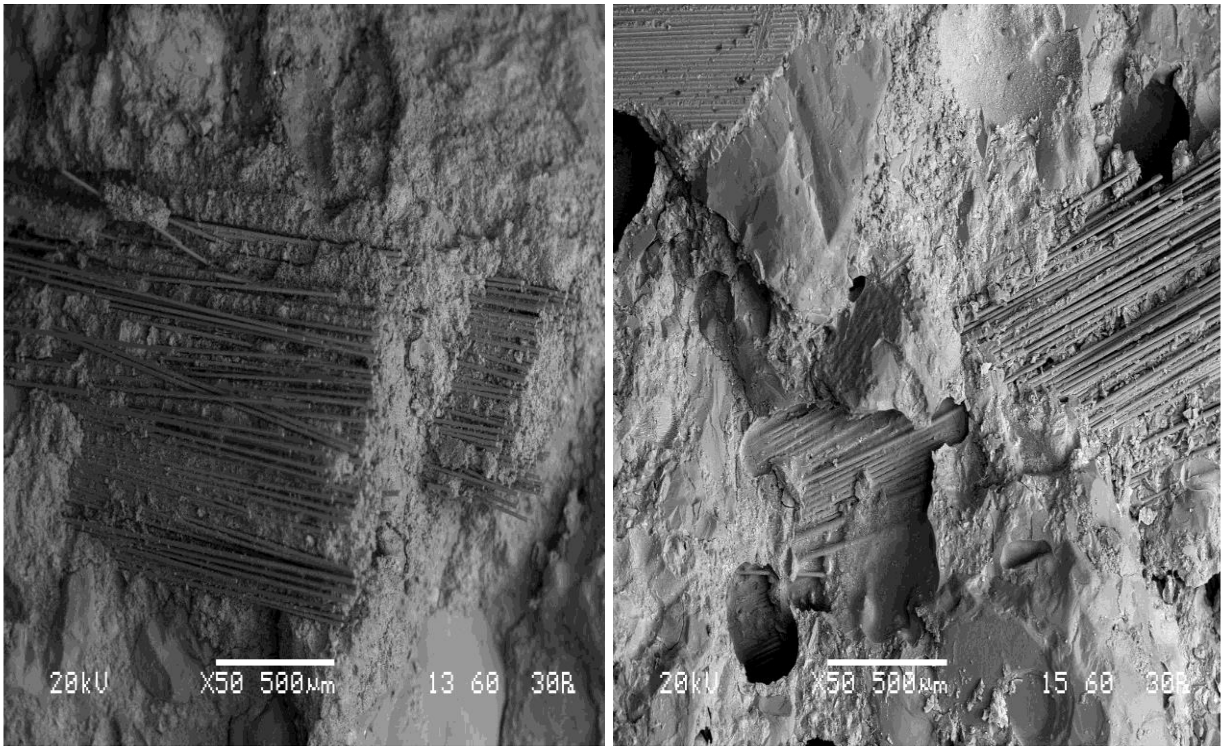
Fig. 4.6.16LOAD-CMOD Curve For CFC

4.6.3 Fracture Behavior of Carbon Fiber Reinforced SCC (CFC)

From table 4.6.3 & fig 4.6.16 it is observed that the fracture behavior of CFC is more than PSC in all fiber contents. As compared to PSC the increase in ultimate load for BFC was around 88.23%, 176.47% & 123.53% when adding 0.1%, 015% & 0.2% fibers respectively. As the fiber content increased, the fracture behavior was also found to be increased for CFC. Fig.4.6.13 to fig. 4.6.15 shows the crack pattern of CFC.

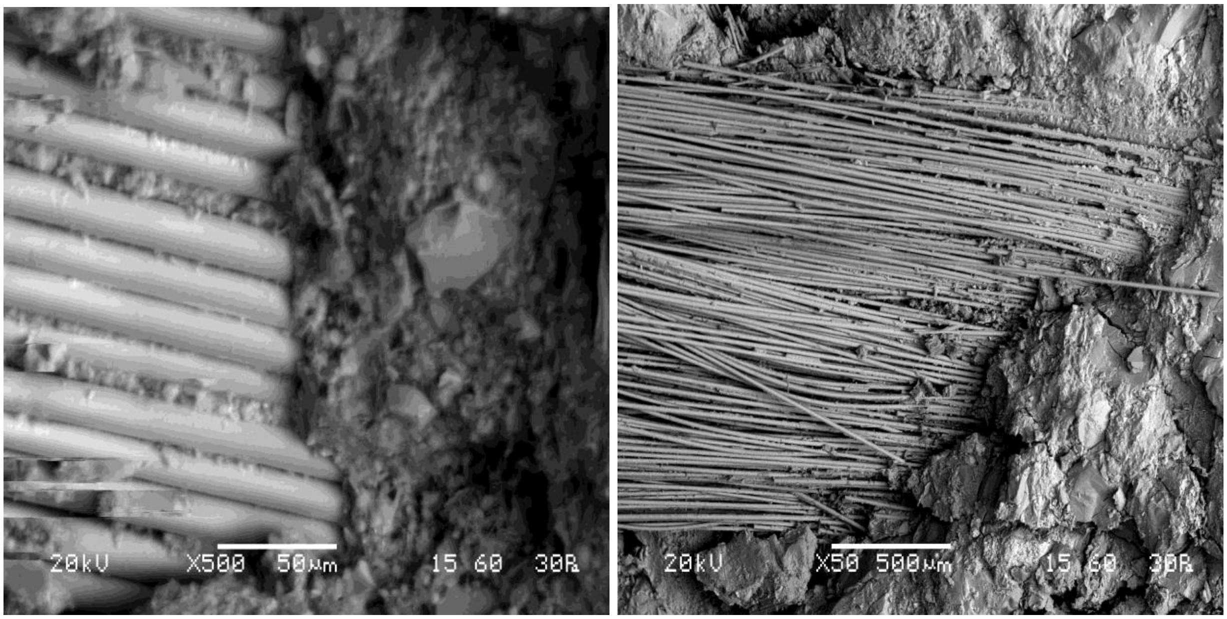
4.7 MICROSTRUCTURE BEHAVIOR

SEM test is the actual way to study the microstructure of the hydrated cement based products. To assessment the bond characteristics of BFC, GFC & CFC mix at 7 and 28days, the microstructure of FRSCC was studied by means of SEM.



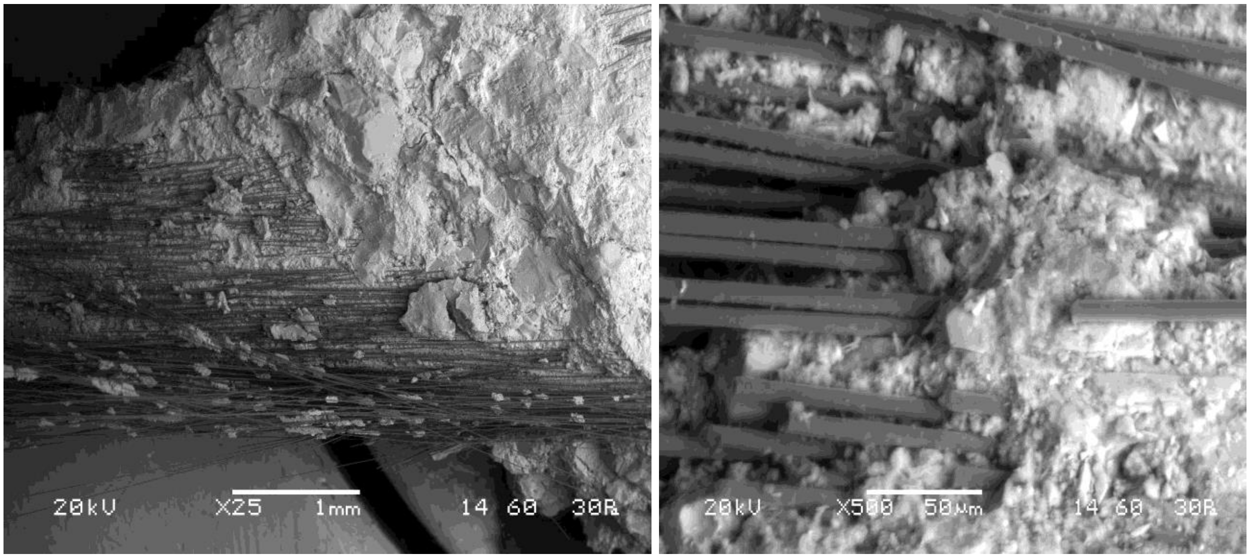
(A) **(B)**

Fig.4.7.1 SEM photographs for (A) 7-Days & (B) 28 days concrete & basalt fiber matrix



(A) (B)

Fig.4.7.2 SEM photographs for (A) 7-Days & (B) 28 days concrete & glass fiber matrix



(A) (B)

Fig.4.7.3 SEM photographs for (A) 7-Days & (B) 28 days concrete & carbon fiber matrix

Fig.4.7.1 to 4.7.3 shows the photographs of microstructure of fiber surfaces and hydrated concrete matrix. It is observed from fig that basalt and carbon fiber SCC surfaces covered with densely hydrated concrete matrix than GFC.

4.8 SORPTIVITY

Sorptivity is a measure of the capillary force exerted by the pore structure causing fluids to be drawn into the body of the material. It is calculated as the rate of capillary rise in a concrete prism placed in 2 to 5 mm deep water. For one-dimensional flow, the relation between absorption and sorptivity is given by, k = $\frac{W}{A\sqrt{t}}$ where, $\frac{W}{A}$ is the cumulative water absorption per unit area of inflow surface, k is the sorptivity and t is the elapsed time. The test was conducted in the laboratory.

At selected intervals of 30min, 1hr, 2hr, 6hr, 24hr and 48hr; the sample was removed and was weighed after blotting off excess water. The gain in mass per unit area over the density of water (gain in mass/unit area/density of water) versus the square root of time was plotted. The slope of the best fitting line was reported as the sorptivity.

Table 4.8.1 Capillary Water Absorption Test Results

Sample	**Initial Wt.(gm.)**	**Weight(gm.)**					
		30min	**1hr**	**2hr**	**6hr**	**24hr**	**48hr**
GFC	7499	7509	7510	7512	7514	7519	7521
BFC	7471	7483	7486	7488	7490	7496	7500
CFC	7604	7618	7620	7623	7626	7632	7640

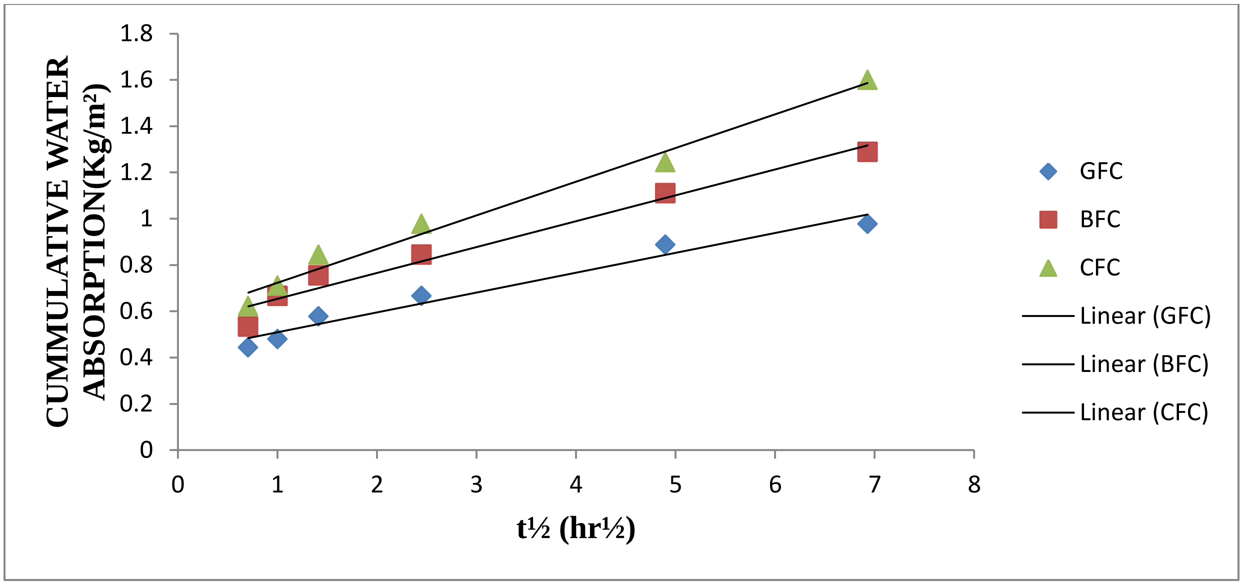


Fig. 4.8.1 Capillary Water Absorption at Different Time Interval

The capillary water absorption in terms time (square root of time in hours) is plotted in Fig. 4.8.1. The water absorption for CFC samples is the higher than BFC & GFC samples, which is due to the additional water absorbed by the fibers. The higher sorptivity value was obtained for specimens containing CFC fibers.

CHAPTER-5

CONCLUSION

From the present study the following conclusions can be drawn

1. Addition of fibers to self-compacting concrete causes loss of basic characteristics of SCC measured in terms of slump flow, etc.

2. 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.

3. 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.

4. Addition of fibers to self-compacting concrete improve mechanical properties like compressive strength ,split tensile strength, flexural strength etc. of the mix.

5. There was an optimum percentage of each type of fiber, provided maximum improvement in mechanical properties of SCC.

6. 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.

7. 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%.

8. 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 by 34.56%, flexural strength by 61.736%.

9. 2% addition of glass fiber to SCC was observed to increase the 7-days compressive strength by 1.76%, 28-days compressive strength by 15.21%, split tensile strength by 20.73%, flexural strength by 36.77%.

10. The FRSCC mixes exhibited increase in ductility measured through load deflection diagrams. The basalt fiber reinforced SCC exhibited maximum increment than carbon and glass FRSCC.

11. The load vs. crack mouth opening displacement diagrams for FRSCC exhibited increase in fracture energy properties of the mixes. This is owing to crack arresting mechanism of the fibers in the matrix. In this regard the carbon fiber exhibited best performance, then the basalt and then glass fiber.

12. Correlation graph between compressive strength and avg. UPV values for 28 days indicated good correlation for carbon FRSCC (R^2= 1), basalt FRSCC (R^2 =0.9845) and glass FRSCC (R^2 =0.9748). These values represent sound concrete having uniform distribution of fibers and concrete ingredients, dense structure in all FRSCC mixes.

13. The 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.

14. Capillary absorption of water by FRSCC mixes were determined by sorptivity test. The higher sorptivity coefficient was observed for carbon FRSCC mixes because carbon fibers absorbed more water. Least values were observed by basalt FRSCC.

15. The performance of carbon fiber reinforced SCC mixes was better than basalt FRSCC and glass FRSCC mixes. Then carbon fiber FRSCC exhibited best mechanical properties with comparatively lower volume fraction but its effect on SCC fresh properties was just reverse. Its inclusion reduced flow-ability, deformability because it absorbs more water. Other drawback is that it is costliest than other two types of fibers.

16. 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.

17. 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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7. IS : 1199-1959 Methods for sampling and analysis of concrete
8. IS : 5816-1970 Methods of test for splitting tensile strength of concrete cylinders