A MAJOR PROJECT REPORT

ON

"EFFECT OF STEEL FIBERS ON STRENGTH PROPERTIES OF SELF COMPACTING CONCRETE"

Submitted in partial fulfilment of the requirements

for the award of the degree of

Master Of Engineering

(Structural Engineering)

By

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CERTIFICATE

This is to declare that the major project thesis **"EFFECT OF STEEL FIBERS ON STRENGTH PROPERTIES OF SELF-COMPACTING CONCRETE"** is a bonafide record of work done by me in partial fulfilment requirement for the award of the degree of master of engineering (Structural Engineering) from Delhi Technology University (Delhi College Of Engineering).

This project has been carried out under the supervision of Dr A. K. Gupta.

I have not submitted the matter embodied in this report to any other university for the award of any degree.

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Certificate:

This is to certify that the above statement laid by the candidate is correct to the best of my knowledge.

Dr A.K Gupta

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Praise to Almighty who has decided whatever is best for us.
This project would not be what it is if it hadn't been for the people whose constant comments and valuable guidance had made this project successful.

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Thank you all!!

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ABSTRACT

The present study aims to investigate the fresh, strength and durability properties of Self Compacting Concrete (SCC), with fly ash as partial replacement of cement, incorporating steel fibers . For this purpose fly ash from Panipat Thermal Power station, Panipat was used. A super plasticizer of Fosroc chemicals named STRUCTURO 100M (an aqueous solution of carboxylic ether polymer) was used to increase the workability of concrete. The super plasticizer dosage was kept constant for all the SCC mixes .To take the SCC mix economical, cement was replaced with fly ash (36%and 29%). The proportions of coarse as well as fine aggregates were kept constant for all mixes. Steel fibers (0-1.5%) were incorporated in the mixes to improve the strength properties of SCC while satisfying the fresh properties of SCC.

Slump flow (diameter and T_{500}) tests, V-funnel (T_{10sec} and T_{5min}) tests, L-box tests and U-box tests were carried out to obtain the fresh properties of SCC mixes i.e. filling ability, passing ability and segregation resistance. Strength properties of hardened concrete were investigated in terms of compressive strength and split tensile strength. Durability properties i.e. effect of chemical action on hardened concrete was investigated in terms of compressive strength. Specifications and Guidelines are given in EFNARC for Self Compacting Concrete.All the mixes, satisfied most of the requirements of fresh properties as per EFNARC (Europian Federation Of National Trade Associations Representing Producers And Applicators Of Specialist Building Products) specifications, for SCC mix.

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NOTATIONS	DESCRIPTION
• SCC	Self Compacting Concrete
• NVC	Normal vibrated concrete
• NC	Normal concrete
• FRC	Fiber reinforced concrete
• FRSCC	Fiber reinforced SCC
• UHSSCC	Ultra high strength SCC
• SP	Superplasticizer
• VMA	Viscosity modifying agent
• HPSCC	High performance SCC
• FA	Fly ash
• SiF	Silica fume
• S	Slag
• LP	Limestone powder
• QP	Quartz powder
• w/p	Water-powder ratio
• SF	Steel fibers
• CF	Carbon fibers
• MF	Metal fibers
• PP	Polypropylene
• H_1-H_2	U-box blocking difference
• H_1/H_2	L-Box blocking ratio
• T_{500}	Time taken by mix to reach 500 mm diameter mark

CHAPTER 1

INTRODUCTION

1.1 HISTORY OF SCC

The concept of SCC was first given by Professor Hajime Okamura of Kochi University Of Technology Japan in 1986. During his research Okamura found that the main cause of poor durability performance of Japanese concrete in structure was the inadequate consolidation of concrete in the casting operation. By developing concrete that self consolidates he eliminated the main cause for the poor durability performance of their concrete. The First paper on SCC was presented at the Second East Asian and Pacific Conference On Structural Engineering and Construction (EASEC-2) in 1989 followed by another presentation at an Energy Diversification Research Laboratories (CANMET)/American Concrete Institute (ACI) meeting in 1992. In 1997 a RILEM committee (TC174) on SCC was founded.

1.2 BASIC PRINCIPAL OF SCC

Self-compacting concrete is a fluid mixture suitable for placing in structure with congested reinforcement without vibration. SCC is highly workable concrete that can flow under its own weight through restricted section without segregation and bleeding. Application of concrete without vibration in highway bridge construction is not new such as seal concrete which is placed underwater by using Tremie without vibration, mass concreting and shaft concrete. But these mass, seal and shaft concrete are generally of lower strength, less than 34.5 MPa and difficult to attain consistent quality. Morden application of SCC is focused on high performance, better and more reliable quality, dense and uniform surface texture, improved durability, high strength and faster construction. SCC has been described as “the most revolutionary development in concrete construction for several decades”

1.3 ADVANTAGES OF SCC

SCC produces low noise level in plants and construction site and it eliminates problem associated with vibration. It requires lesser labour and involves faster construction. It improves quality and durability and produces high strength. As there is no particular code for design of SCC so there is a greater freedom in design. It is very useful in thinner concrete section.

Fig 1.1In these type of structure SCC is only choice.

1.4 NEED OF FIBERS IN SCC

SCC have advantages over NC but still in hardened state it behave as same as NC. So SCC in hardened state has some limitations due to which fibers should be added to improve its properties. The durability of concrete when reinforced with conventional rebars is a major concern in aggressive environments. To address this problem, there have been efforts, in recent years, to develop alternatives to conventional rebars. Fiber reinforced concrete have shown better behaviour because of their inherent ability to stop or delay crack propagation. The main properties of FRSCC in tension, compression and shear are influenced by the type of fiber, volume fraction fibers, aspect ratio and orientation of fiber in the matrix.

In SCC, increased risk of drying shrinkage is likely due to rich powder content and lower coarse aggregate content. SCC has a heterogeneous structure and due to complex structure of concrete internal stress developed. These internal stresses result in micro-cracks developed in fresh or hardened state of concrete. Such micro-cracks exist at cement paste –aggregate inter faces with in concrete even prior to any load or environmental effects .When SCC is exposed to external structural loads or environmental effects, concentration of tensile stresses causes the growth of micro –cracks in size and number ; propagation of micro cracks and eventual joining micro cracks yield to large cracks and lead to failure of concrete .

Steel fibers improve properties of SCC like shear resistance, ductility and cracks control. On addition of fibers' behaviour of concrete changes as discussed below;

1.5 Behaviour in Tension

The most significant effect of incorporating steel fibers is to delay and control the tensile cracking of its composite material. The fibers provide a ductile member in a brittle matrix and resulting composite has ductile properties. The fiber and matrix share the tensile load until the matrix cracks and then almost the full force gets transferred to the fiber. This mechanism gives rise to favourable dynamic properties such as energy absorption and fracture toughness. The effect of fibers in a cementious material is principally to cause relief of tensile stress at the crack tip and prevent unstable crack propagation.

1.6 Behaviour in Compression

On adding fiber, the post –cracking compressive stress-strain response of concrete changes substantially. This change is generally characterized by a noticeable increase in strain at peak load and a significant increase in ductility beyond ultimate load, resulting in substantially higher toughness. This increased toughness is advantageous in preventing sudden catastrophic failures especially under earthquake and blast type of loading.

1.7 Behaviour under shear

The shear strength and toughness index of compact cube specimens reveals that the shear strength was not affected by fiber volume. However, the post cracking toughness increases uniformly with increase in fiber content. This again shows a favourable FRC behaviour in earthquake and blast prone areas.

1.8 HOW WE WILL GET SELF COMPACTIBILITY OF FRESH CONCRETE?

1. **By limiting aggregate:-** energy required for flowing is consumed by internal stress (it is increased due to decrease distance between particles that is due to high deformability) resulting in blockage of aggregate particles limiting coarse aggregate content whose energy consumption is intense to a level lower than normal is effective in avoiding this type of blockage

2. **Low water/powder ratio and super-plasticizer usage: -** for providing high viscosity with high deformability can be achieved only by application of a super-plasticizer keeping w/p ratio to a very low value.

1.9 MIX DESIGN:-

Before any SCC is produced at a concrete plant and used at construction site the mix has to be design and tested during this evolution the equipment and local material used at plant have to be tested to find new concrete mixes with right mixing sequences and mixing time valid for that plant and material used and also suitable for element to be cast. Various kinds of fillers can results in different strengths, shrinkage and creep but shrinkage and creep will usually not to be higher than for traditional vibrated concrete.

1.9.1 MIX DESIGN PRINCIPLES:-

The flow ability and viscosity of the paste is adjusted and balanced by careful selection and proportioning of the cement and additions by limiting water powder ratio and then by adding a superplasticizers and VMA (optionally) correctly controlling these components of SCC their compatibility and interaction is the key to achieving good filling ability, passing ability and resistance to segregation. For controlling temp, rise and shrinkage cracking as well as strength, the powder ratio can be increase. The paste is the vehicle for the transport of aggregate therefore the volume of the paste must be greater than void volume in the aggregate. The coarse to fine aggregate ratio in the mix should be low to achieve a good passing ability between congested reinforcement.

SCC should have:-

- Low coarse aggregate content
- Increased paste content
- Low water powder ratio
- Increased superplasticizers dosage
- Sometimes VMA can be used

1.9.2 Constituent materials:-

A) The role of Superplasticizers and powder or cementitious materials:-

When we increase the slump of concrete over 175mm by increasing amount of water the bleeding increases too much but with superplasticizers flowing concrete with slump level up to 250mm can be manufactured with no or negligible bleeding.

The most important basic principle for flowing and cohesive concrete (SCC) is the use of superplasticizers combined with a relatively high content of powder materials in terms of Portland cement mineral additions ground fillers and very fine sand.

B) The role of viscosity modifying agents:-

With these admixtures (0.1 to 0.2% by mass of cementitious materials) SCC can be made with a reduced volume of fine materials

- ✓ Following are the basic types of VMA:

- Traditional pumping aids, admixtures used to improve the cohesiveness of lean concrete mixtures to be pumped and chemically based on modified cellulose or hydrolyzed starches
- Polyethylene glycol and biopolymers which appear to be the most effective VMA's for SCC

C) Cement: any type of standard can be used.

D) Addition: Due to fresh property requirements of SCC, inert and Pozzolanic or hydraulic additions are commonly used to improve and maintain the cohesion and segregation resistance.

Additions are also regulating the cement content in order to reduce the heat of hydration and thermal shrinkage.

The additions are classified according to their reactive capacity with water

Type 1

- ✓ Inert or semi inert
- Mineral filler (limestone, dolomite, etc.)
- Pigments

Type 2

- ✓ Pozzolanic
- Fly ash
- Silica fume
- Hydraulic
- Ground granulated blast furnace slag

E) Mineral fillers: The particle size distribution shape and water absorption of mineral fillers may affect the water demand or sensitivity. $CaCO_3$ based minerals fillers are widely used and can give excellent rheological properties and a good finish.

F) Fly ash: It enhances cohesion and reduces sensitivity to changes in water content. However high levels of fly ash may produce a paste fraction which is so cohesive that it can be resistant to flow.

G) Marble powder: Marble powder enhances segregation resistance to the concrete and when marble powder is used in dry form it absorbs moisture.

H) A high volume of fine Aggregate: In order to ensure sufficient workability while limiting the risk of segregation or bleeding, SCC contains a large amount of fine particles (around 500 kg/m^3) nevertheless in order to avoid excessive heat generation the Portland cement is generally replaced by mineral admixtures like lime stone fillers and fly ash.

Nature and amount of fillers added are cohesive in order to comply with the strength and durability requirements.

I) A low volume of coarse aggregates: It is possible to use natural rounded semi crushed or crushed aggregate to produce SCC as coarse aggregate plays important role on passing ability of SCC in congested area the volume has to be limited on the other hand the use of coarse aggregates allows optimising the packing density of the skeleton of the concrete and reduction of the paste volume needed for the target workability. Generally max. aggregate size is in 10 to 20mm.

J) Admixtures: Superplasticizers or high range water reducing admixtures are essential components of SCC.

VMA may also be used to help reduce segregation and sensitivity of the mix due to variation in other constituents especially to moisture content

- Superplasticizers and high range water reducing admixtures: The admixture should bring about the required water reduction and fluidity but should also maintain its dispersing effect during the time required for transport and application.
- VMA: VMA significantly increases cohesive property of SCC. These admixtures reduce the effect of variations of moisture content.
- Air entraining admixtures: Increases freeze-thaw durability. They are also used to improve the finishing of flat slabs.

K) Pigments: Due to the high fluidity of SCC the dispersion of the pigment is more efficient and more uniform colours are usually achieved both with in between batches. The higher paste content of SCC may result in a higher dosage of pigment to achieve the required colour density.

L) Fibers: Both metallic and polymer fibers have been used in the production of SCC. Due to the use of fibers flow ability and passing ability of SCC can be reduced. Trials are therefore needed to establish the optimum type length and quantity to give all the required properties to both the fresh and hardened concrete.

M) Mixing water: Same water may be used as for simple concrete. Where recycled water recovered from processes in the concrete industry is used the type/content and in particular any variation in content of suspended particles should be taken into account at this may affect batch uniformity of mix.

1.10 PROPERTIES OF FRESH SCC:-

The main characteristics of SCC are properties in fresh state. SCC mix design is focused on the ability of flow under its own weight without vibration, ability of flow through heavily congested reinforcement under its own weight, and ability to obtain homogeneity segregation of aggregate.

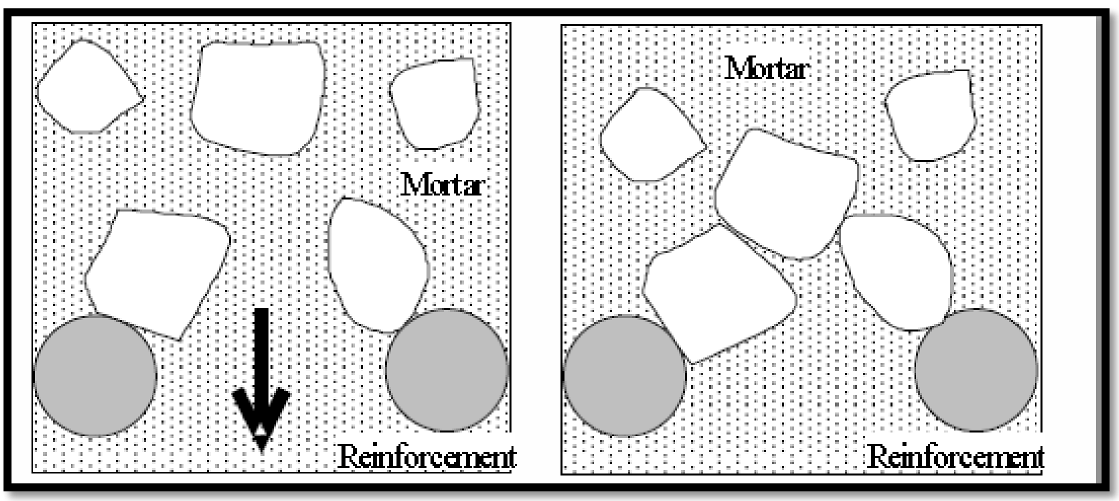


FIG1.2. **Arching phenomenon on during flow in congested area**

1.10.1 Hardened Properties

In general terms the project has been directed at facilitating the introduction of SCC into general concrete construction. In order to do so it is necessary to demonstrate that the hardened properties of this type of concrete make it fit for purpose. The basic materials –aggregates and cements - are the same as those used in traditional vibrated concrete, if indifferent proportions; and the new, specialised materials – admixtures – are insignificant in terms of unit-volume of concrete, though of course essential to the special *fresh* properties of the material. The investigation therefore started from the premise that the *hardened* properties should be the same as those of normal concrete, and this, indeed, is the fundamental requirement of concrete users. In order to try to demonstrate this, three types of SCC (housing, civil engineering and steel fiber-reinforced), and two types of reference concrete (housing and civil engineering) were designed, produced and supplied commercially. The housing and civil engineering mixes were designed with characteristic cube strengths of 35 and 60 MPa respectively. A wide variety of specimens (cubes, cylinders etc.) and full size columns and beams were cast from each of the five types of concrete, so that direct comparisons of all aspects of the hardened concrete could be made between the SCCs and the reference mixes.

1.10.2 Compressive strength

In all SCC mixes compressive strengths of standard cube specimens were comparable to those of traditional vibrated concrete made with similar water/cement ratios - if anything strengths were higher. There is little difficulty in producing self-compacting concrete with characteristic cube strengths up to 60MPa.In-situ strengths were derived from core samples taken along the whole length of the full-size elements. A number of comments can be made:· In-situ strengths of SCC are similar to those of traditional vibrated concrete, indeed somewhat higher when limestone powder is used as a filler, probably because of a densifying mechanism and the observed lower susceptibility to imperfect curing, both attributable to this type of filler.· The in-situ strengths of both types of civil engineering concrete, SCC and traditional vibrated concrete, were closer to standard cube strengths than those of the housing mixes; again, this is typical of higher strength concrete.· In vertical elements, in-situ strengths of both SCC and traditional vibrated concrete are higher at the bottom than at the top; variation of in-situ strengths, for both types of concrete, is much lower in horizontal elements, in this case the beams. These observations are characteristic of traditional vibrated concrete· The in-situ strengths of elements cast and cured outdoors in winter (the beams), whether SCC or conventional, were lower than those cast indoors at the same time (the columns).Overall, we might conclude that the fresh self-compacting properties of the concrete have little effect on the in-situ strengths.

1.11 Objective of present study

The present research work is carried out to study the effect of incorporation of steel fiber in SCC. SCC has several advantages over NVC. The addition of fiber improves behaviour of concrete under different conditions .Thus SCC and fiber can be combined to achieve more durable concrete. The effect of steel fibers was studied on fresh, strength and durability properties of SCC. Steel fibers in varying proportions of 0%, 0.5%, 1% and 1.5% by weight of concrete mix were added to SCC with tests carried out to evaluate the results regarding fresh, strength and durability properties.

1.12 DISADVANTAGES

SCC production is a complicated process. There is no standard procedure for mix design of SCC. SCC mix is design on the basis of available materials required performance specification and production practices.

CHAPTER 2
LITERATURE REVIEW

GENERAL:-

A large amount of research is going on in designing and use of SCC incorporating steel fibers. Some of the literature has been reviewed to get the idea about the development of fiber reinforced self-compacting concrete to its present stage.

2.1 REVIEW OF LITERATURE:-

1.) Grunewald and Walraven (2001) studied the influence of steel fibre and coarse aggregate content on the fresh properties of SCC. SF of length varying between 30mm and 60mm and aspect ratio varying between 45 and 80 were taken with dosages varying from 1% to 5%. Cementitious material was replaced with 40% FA. Superplastcizer as 0.5% of cementitious materials and 0.29% as w/o ratio by mass were taken. Fresh properties with the help of various tests were studied. These tests were slump flow test, V-funnel tests, fibre tunnel test, filling vessel test and box test. A method was proposed to design SCC reinforced with steel fibres. Also, it was found that the flow behaviour of fibre reinforced mixtures differs from that of plain SCC. The combination of test devices and observations that were applied during experiments could be regarded as an appropriate tool to describe the properties of FRSCC. The slump flow test detected the clustering of coarse particles. In addition, to avoid the risk of blocking a larger free bar spacing compared with plain SCC appears to be necessary if steel fibres were applied. Finally, it was found that considerable amount of fibres allowed self-compacting behaviour.

2.) Cornaldesi and Moricono (2004) prepared concrete to manufacture thin elements for non-structural applications, required both the self-compaction and mechanical requirements. Durability of such concrete incorporating steel fibers was studied. SF having length of 11mm and 0.4mm with aspect ratio of 28 were used with fiber contents of 2.2%. LP with 15% replacement was used as filler. Water-to-powder ratio of 0.34 and super plasticizer of 1.6% of cementious material were used. Slump flow and L-box tests were performed to evaluate concrete properties in fresh state. Compressive and flexural tests were carried out in order to evaluate the contribution of steel fibers in counteracting the high concrete strains due to low aggregate cement ratio. Secondly, the resistance to freezing and thawing cycles was investigated on concrete specimens in some cases superficially treated with a hydrophobic agent. Lastly, both carbonation and chloride penetration tests were carried out to assess durability behaviour of this concrete mixture.

3.) Nehdi and Ladanchuk (2004) investigated potential synergistic effects in SCC incorporating fibres. FA and SiF with 20% and 4.5% were used as filler material with w/p ratio taken as 0.38. Different types of steel and synthetic polymer(macro and micro) fibres in varying proportions from 0-1% were used. The workability of each mixture was evaluated using the slump flow and L-box flow tests. Moreover compressive strength, first crack strength in bending, flexural toughness and post-first-crack behaviour were investigated. The result of this research indicated that fibres had rheological and mechanical synergistic effects, and that optimized fibre combinations could better increase toughness and flexural strength while maintaining adequate flow properties for FRSCC. Addition of steel fibre to SCC reduction its workability and ability to flow. Combination of steel and synthetic macro fibres(with the volume of synthetic macro-fibres not exceeding 0.25%) had better L-box flow test result then incorporating either steel or synthetic macro fibre alone. Synthetic macro fibres tended to decrease compressive strength but this effect could be reduced when such fibres used in hybrid blends along with steel fibres. Micro-macro fibre combinations lead to higher first crack loads than that for combinations of macro fibres. The best post-first-crack residual strength results for all FRSCC mixtures were achieved by combining steel synthetic macro fibres.

4.) Sahmaran et al., (2005) studied effect of fibers on workability of self-compacting concrete. LP as filler with 15% replacement was used and w/p ratio was taken as 0.35. SP as 1.6% of cementious material was used. Two types of SF of length 6mm and 30mm having aspect ratios 37.5 and 55 respectively were used. Samples were made having fibers in different proportions while keeping total fiber content of 2.5% as constant. Tests were performed to study the effect of these fibers on fresh and hardened state of concrete. For fresh properties, slump flow tests, T_{500} slump flow tests, J-Ring and V-funnel tests were performed. In hardened state, compressive strength, split tensile and ultrasonic pulse velocity tests at different ages were carried out, it was observed that it was possible to achieve self-compaction with considerable fiber inclusion (2.5%). Although, results obtained from some of the mixes exceeded the upper limits suggested by EFNARC. All mixes had good flow ability and possessed self-compaction characteristics. The mix reinforced with only one type of fiber having lesser length and aspect ratio gave highest compressive strength and mix containing equal amounts of both types of fibers gave highest split tensile strength value.

5.) Ganesan et al., (2006) made an attempt to study the effect of steel fibers on the ultimate strength and behaviour of SCC flexural elements. Twenty beams were cast for this study out of which two were plain SCC beams without fibers. FA and SiF were used as filler with 10% and 5.5% replacement and w/p ratio of 0.38 was kept constant. SP as 1% of cementious material was used. The variables in this study were aspect ratio (0, 15, 25, and 35) and percentage of volume fraction of fibers (0, 0.25, 0.5, and 0.75). In order to study the effect of fibers on behaviour of flexural specimens various tests were performed. First crack load, ultimate load, flexural strength, cube compressive strength, and spilt tensile strength of specimen were checked. They also checked beam for improvement in ductility by deflection at 80%ultimate load and deflection at first yield. First crack load and the post cracking behaviour were found to have improved significantly due to addition of fibers enhanced the ductility significantly. The optimum volume fraction of fibers for better performance in terms of strength and ductility was found to be 0.5.

6.) Sengul et al., (2006) studied the mixture design, workability and mechanical properties of the FRSCC mixtures. Silica powder with fraction 13%, 31%, 34%, and SiF 11% were used as filler. Water-powder ratio used was 0.18. Steel fibers used were 30mm long with aspect ratio of 54.5. SP varying from 0.75 to 1.6% of cementious material was used. The compressive and split tensile strengths and energy absorption capacities of SCC with different cementious materials contents, fiber contents and fiber strengths were compared. The fiber addition increased flow time of the concrete for only concrete mixtures with low cement content. The split tensile strength of the high-strengths fiber reinforced concrete was higher than the concrete reinforced with low-strength fibers. Fibers addition increased the ductility significantly. The fracture energy was affected more than the compressive strength. The fracture energy values, up to 10mm deflection, of the fiber reinforced concrete were 15 to 50 times higher, greater than those of plain concrete.

7.) Ganesan et al., (2006) studied the effect of steel fibers on the durability parameters of SCC such as permeability, water absorption resistance, resistance to marine as well as sulphate attack. The variables considered were aspect ratio (0, 15, 25, 35) and volume fraction(0, 0.25, 0.5, 0.75%) of SF. The w/p ratio of 0.36 and a trinary blend of cement, FA (10%) and SiF(6%) were used. SP and VMA added were 2.5% of cementious material and 0.01% of water respectively. It was observed that the coefficient of permeability and wear of SFRSCC were lower than the moderate strength concrete. Under the marine and sulphate attack, the losses in mass of concrete and compressive strength of cubes were found to be negligible. It was observed that SFRSCC resists these attacks within tolerable limits and optimum dosage of fibers for better performance was found to be 0.5 percent.

8.) Sahmaran and Yaman (2007) studied fresh and mechanical properties of FRSCC. In this, FA content of 50% and LP of about 15% of cementious material wire used. Water-powder ratios used were 0.36 and 0.4. SP of 0.95% and VMA of 1.1% of cementious material were used. Fly ash used did not meet the fineness requirements. Two different sizes of SF while keeping total fiber content of 2.5% as constant were incorporated. The length of steel fibers was 6mm and 30mm having aspect ratios 37.5 and 55 respectively. Slump flow diameter and T_{500} tests and V-funnel tests were used to study fresh properties. Compressive strength, split tensile strength and ultra sonic pulse velocity tests were performed on specimens to study the effect of fibers in hardened concrete. It was observed that, incorporation of high volume FA reduced the water requirement of SCC mixture. FA caused significant losses to the SCC mixture, as used in high volumes. Fibers with hooked ends were more effective in characterizing the tensile strength of concrete whereas compressive strength was partially off-set by use of fibers with straight ends.

9.) Pons et al. (2007) studied the mechanical behaviour of SCC with hybrid fiber reinforcement. Cement was replaced with 38.5% FA and water with the w/p ratio lies between 0.42-0.44 was added. SP with 0.8% of cementious material was used. Two different types of fibers i.e. metal fibers and synthetic fibers, ABD cocktail of fibers were used. Amorphous metal fiber of length 30 mm and polypropylene fiber of 50mm length with rectangular cross-section were added. Fiber contents investigated were 0.87% and 0.4% for the amorphous metal and the PP fiber respectively. Also, hybrid mix of fibers with combination of 50% of the earlier contents was used. In order to investigate the workability characteristic they performed slump flow diameter tests. T_{500} flow time slump tests, avg. J-Ring diameter tests. Flow time T_{500}, J-Ring tests, V-Funnel tests and stability at 5mm sieve tests were performed. For behaviour of specimen in hardened state compressive strength tests, split tensile strength tests and four point bending tests were investigated. As MF provided an sufficient restraint of cracks and PP-fibers provided safety against catastrophic breaking, combining these with self-compacting agilities was of special interest in case of precast building component subjected to low stresses. During bending tests in controlled deflection, a change in the specimen behaviour was observed at a deflection of 0.6mm. Below this value, the action of MF was dominant and beyond it. The slipping synthetic fibers merely controlled the post crack flexural behaviour. The comparison between vibrated and self-compacting concrete of similar mechanical characteristic indicated a possible better fiber-matrix bond in the case of self-compacting types. The result also showed that the properties of hybrid reinforced SCC could be inferred from the properties of the individual single-fiber reinforcements and their respective proportions through simple mix-rules.

10.) Bassuoni and Nehdi (2007) studied the resistance of SCC to sulphuric acid attack with consecutive pH reduction. The main tests variables included the cementious material (single, binary, tertiary and quaternary, binders), the sand to total aggregates mass ratio, and the inclusion of fiber reinforcement (single and hybrid). SiF (0-8%), S(0-45%), FA(0-20%), and LP(15%) in different combinations were used as filler. SF having length of 38mm and aspect ratio of 34 with dosages 0.4 and 0.5% and micro PP fiber (0.1%) were used. Water-to-powder ratio (0.38) was kept constant. The investigation comprised two consecutive 6-week phases of immersion of tests specimens in sulphuric acid solutions with a maximum pH threshold of 2.5 and 1.0, respectively. The study revealed that the rate of attack, as expressed by mass loss versus time, was controlled by different factors at each exposure phase. The advantages of blend binders and hybrid (steel+polypropylene) fibers in improving the resistance of SCC to sulphuric acid attack were highlighted. Microanalysis conducted upon tests termination elucidates the damage mechanisms and it was shown that there was no direct correlation between the rate of attack expressed by mass loss and the compressive strength loss after exposure to sulphuric acid.

11.) Aydin A.C (2007) studied the effects of inclusion on the compact ability of hybrid fiber reinforced concrete. In this research, two different types of fibers i.e. SF and CF with length 6mm and 5mm with diameter 16m and 15m were used. QP as filler with 20% replacement and w/p ratio of 0.484 were used. SP as 33% of cementitious material was used. Properties of SCC in fresh and hardened state containing fibers in different combinations and different proportions keeping total fiber content of 2% were studied. Fresh properties with slump, T_{500}, L-box, V-funnel tests were investigated. For various combinations of fibers compressive strength, split tensile strength and flexural strength were tested. In order to retain high level workability with fiber reinforcement, the amount of paste in the mix should be increased to provide better dispersion of fibers. All mixtures tested were able to attain 2%volume fraction of steel and carbon fibers without loss of flow of workability. The mix reinforced with only steel fibers had the highest compressive strength, split tensile strength and flexural strength values.

12.) Torrijos et al., (2008) studied physio-mechanical properties and meso structure of plain and steel fiber reinforced (SFR) SCC. Limestone powder (LP) with replacement of 23%with cement and w/p ratio of 0.38 was used. SP used was 1.6% of cementious material. Steel fibers were used in dosages of 1.08% and 2.16% by weight having 50mm length and aspect ratio of 50. In fresh state, rheological parameters were obtained with concrete BML viscometer and self-compact ability was measured with slump flow, V-funnel and J-Ring.In hardened state, the density of coarse aggregate and fibers along the height of the specimen was calculated by the analysis of images taken from horizontal cuts. The studies also supported by measures of modulus of elasticity, compressive strength and ultrasonic pulse velocity. The meso structural homogeneity of plain and steel fiber reinforced SCC to be used in slender elements of considerable height, avoiding the use of conventional reinforcement were analyzed. Tests were made in fresh state that includes the measurement of the rheological properties and self- compact ability through engineering tests. Slender columns were filled with plain and SFR SCCs. In hardened state, studies at meso structural level included the quantification through image analysis of the distribution of the course aggregate and fibers along the height of columns and measures of modulus of elasticity, compressive strength ultrasonic pulse velocity. SCC with fiber content of 2.16% could not be considered to be self-compacting. The physico mechanical properties did not vary significantly along the height of the columns, through a decrease was observed in the superior third of the elements, the compressive strength was the most affected parameter. The aggregate distribution was slightly more homogeneous in the case of fiber concretes.

13.) Ding et al., (2008) investigated workability of fiber cocktail reinforced HPSCC.FA with 33%replacement used as supplementary cementitious material. Water with w/p ratio of 0.33and SP varying from 1to1.35% was added. PP micro fibers of length 12mm, 14mm with dosages of 1-2kg/m^3 and macro fibers of length varying from 40-55mm dosages of 7kg/m^3 were used .SF of

lengths 30mm and 6mm and aspect ratios of 50 and 37.5 in dosages of 50kg/m^3 and 10 kg/m^3 respectively were used. Mixtures were tested using flow channel tests, Ring tests, L-box tests, viscosity tests with rheometer were various methods used for evaluating the flowability,
filling ability and segregation risk of fresh concrete .PP micro –fiber dosage of 2kg/m^3 had strong negative influence on the workability and was not suitable for reinforcing HPSCC .The rheometer alone could not evaluate the segregation properties .The workability of macro fibers could be assessed better with J-Ring and L-box than with slump flow tests alone .Compared to slump flow tests, J-Ring and L-box could assess both the flow ability, the segregation resistance and passing ability, levelling ability and the time dependent behaviour of fresh fiber reinforced concrete like flow time and flow speed. The macro PP-fibers were not found suitable for FRHPSCC.

14.) El-Dieb A.S. (2009) carried out research to study the durability, mechanical and micro-structural characteristics of UHSSCC incorporating fibers. SF was used in different fiber volume fraction i.e. 0.08%, 0.12%and 0.52% with length of 25mm and aspect ratio of 50 .Silica flume (SiF) 15-17.5% used as filler and w/p ratio of 0.23 and 0.24 was taken. The effect of including steel fibers with various fiber volume fractions on the flow ability characteristics of concrete was evaluated by the slump flow tests. Cubes and cylinders were used to evaluate the compressive and split tensile strength of the concrete respectively. Rapid chloride permeability tests, concrete electrical resistivity and chloride bulk diffusion tests were used to evaluate the concrete durability against reinforcement corrosion and chloride attack and chloride induced corrosion. Also, Concrete Sorptivity was conducted as an indirect tests to evaluate the concrete water permeability which could be used as an indicator for other aggressive environments. The most important observation during testing was the significant change of the failure mode of the concrete as the steel fibers were included in the mix and also as the steel fiber volume fraction increases .The failure mode changes from sudden explosive failure resulting in complete damage of the specimen into a more ductile failure in which the specimen was still intact after failure . Mechanical properties were improved by the incorporation of steel fibers especially split tensile strength .Steel fibers increased the total charge passing and electrical conductivity of the concrete and increase depends on the volume fraction of steel fibers. Bulk chloride diffusion and water sorptivity was not affected by the inclusion of steel fibers did not had any significant effect on resistance to high sulphate and temperature exposure condition.Microstructural features supported the view of improved ductility due to very strong bond between fibers and the cement paste.

15.) Ding et al., (2009) carried out a series of experiments to assess the influence of different fibers on compressive strength, flexural toughness and failure pattern of beams and slabs made of high performance SCC (HPSCC). FA of about 35% as filler material and w/p ratio of 0.33 was used. Superplasticizer (SP) used was 1% of binder material. PP-fiber (L=40-50mm) of dosage 0.3% and SF (L=30mm) of dosages 0.9 to 2.2% were used in various combinations. Compression, flexural beam and energy absorption in deflection of flexural panel tests were conducted to evaluate the characteristics. Although the addition of fibers aids in converting the brittle properties of concrete into a ductile material, but no significant trend of improving compressive and flexural strength was found . The analysis of the increase rate of the toughness parameter demonstrates was found. The analysis of the increase rate of the toughness parameter demonstrates the possible cost benefit of using fiber cocktail. The beam failure pattern changed from only one main crack into multiple crack pattern in case of steel fiber reinforced beams with fiber content more than 50kg/m^3 . The failure pattern of various fibers in the fiber cocktail reinforced HPSCC were different. The steel fiber was pulled out and the PP-fibers were partly broken down and partly pulled out. This observation supported the use of fiber cocktail in HPSCC because the tensile capacity of PP-fibers could be better exploited and fiber cocktail could better prevent the further pulling out of steel fibers from the concrete matrix after the cracking.

16.) Basuoni and Nehdi (2009) investigated the suitability of a wide range of SCC mixture designs used in various infrastructure applications exposed to combined sulphate attack, cyclic environmental conditions and flexural loading. SiF (0-8%), S(0-45%), FA(0-20%) and LP(15%) were used as in binary, tertiary and quaternary binder of cementious material .SF with 0.4% and micro PP fibers 0.1% dosages were added. Durability of specimens was evaluated in two separate ways. In first, specimens were dipped in 5% sodium sulphate solution. Secondly, specimens were exposed to combined damages of sulphate attack and successive summer and winter seasons with or without flexural loading .In case of combined exposure, cyclic environmental conditions and flexural loading caused cracking in the cementious matrix and led to direct ingress of the solution into considerable depths of the SCC specimens. Entrained air bubbles offered host locations for the nucleation and growth of sulphate reaction products and salt crystallization, thus reducing the rate of damage .While the incorporation of hybrid fiber reinforcement controlled the expansion of SCC specimens, the existence of corroded steel fibers on the surface provoked the first-cracking at relatively low stress levels, which could cause serviceability problems under similar combine exposure. The accumulation of voluminous sulphate reaction products with salt crystallization created expanding zones at exposed surfaces, which when coupled with flexural loading seemed to increase the net tensile stresses, and thus initiated the breakage of specimens.

17.) Aggarwal, P.(2009) carried out the design of SCC mixes and investigated the fresh properties (slump flow, T_{50cm} J-Ring, V-Funnel, L-box, U-box). Strengths such as compressive strength, split tensile strength, and durability properties such as carbonation, deicing salt surface scaling, rapid chloride penetration resistance of the mixes with fly ash(15, 20, 22, 25, 30 and 36%) of total powder content .Fine aggregate was replaced with bottom ash (0 to 30% with increment of 10%) for all the fly ash contents. Model using linear regression, artificial neutral network, and support vector machines were also developed, to predict strength from relative contents of mix components at various ages. Compressive strength between 18 and 35 MPa at 28-days.with variation of bottom ash from 0 to 30% and fly ash from36 to 15% was obtained 28-day split tensile strengths of 2.4 to 1.27 MPa with variation of bottom ash from 0 to 30% and fly ash from 15to 36% were obtained .The botton ash and fly ash content were main factor governing the carbonation resistance, deicing salt surface scaling, rapid chloride penetration resistance of SCC mixes. The carbonation depth at 10% was observed to be less than that for the mixes 0% bottom ash.The 20% replacement (optimum level in this research) has the same effect on carbonation as the 0% replacement mixes .The results obtained were of important practical value as no previous knowledge or results were available.

18.) Aoude et., (2009) studied the behaviour of columns constructed with fibre reinforced SCC. Specimens were cast using SCC that contain various quantities of fibres' and containing varying amount of transverse reinforcement with specimen tested under pure axial compression loading .Steel fibre of length 30mm and aspect ratio of 55 with dosage of 1%, 1.5% and 2% were used. Water-cement ratio used was 0.42 and no filler was used. These test examined the influence of several parameters, including the effect of fibre on confinement, cover spalling, and bar buckling. There was limited fibre content (1.5% in this test program), however above which the SCC mixture could lose much of its workability, leading to reduced fibre efficiency. The addition of steel fibres' in reinforced concrete columns could lead to improvements including an increase in peak load –carrying capacity of the column and a significant improvement in the post-peak response of the column .The results showed that steel fibers, up to approximately 1.5%by volume, could partially substitute for the transverse reinforcement in RC columns and hence could result in improved constructability. It was observed that fibres transform the cover spalling from a sudden mechanism to a gradual mechanism. The addition of fibres', however, did not prevent bar buckling from occurring.

2.2 CONCLUDING REMARK

Most of the researchers have studied effect of steel fibers on strength or durability properties of SCC. Filler (i.e. fly ash, limestone powder, quartz powder, slag, silica fume, silica powder) of about 35% was used in majority of the studied reviewed in literature. Water-powder ratio of about 0.3-0.45 was used with dosage of SP (1.5% - 10%). VMA was also used in few of studies. SF of about 0-2% was major percentage of fiber added in mix but study related more than 0.5% steel fibers either studied fresh properties or use blend of fibers. Although, strength properties (like compressive, split tensile) were also studied but the effect of steel fiber on flexural strength is very less reported. Durability properties, in the reviewed literature, like bulk chloride diffusion, water Sorptivity and sulphate attack with pH reduction were studied but none included effect of sodium chloride and sodium sulphate in combination on compressive strength of concrete except one study on effect of sodium sulphate alone in 5% solution but fiber content was limited to 0.5%.

In further, study can be done by increasing the percentage of fiber content and different type of fibers like synthetic fiber, carbon fiber, or glass fiber may be used for further investigation.also durability properties, SCC mixes containing fibers exposed to freezing and thawing cycle, can be investigated.and SCC mixes containing fibers subjected to elevated temperatures also investigated.

In the present study, FA (36%) was used as filler and SF were incorporated in proportions varying from 0-1.5%. Also, the SCC was developed without using VMA. In strength properties compressive strength and split tensile strength was studied.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 GENERAL:-

This chapter explains the properties of material used for SCC mix composition. The effect of steel fibers was studied on fresh, strength and durability properties of SCC. Steel fibers in varying proportions of 0%, 0.5%, 1% and 1.5% by weight of concrete mix were added to SCC with tests carried out to evaluate the results regarding fresh, strength and durability properties. The testing procedure used for **Fresh properties** are such as:-

1. Slump flow
2. V- Funnel
3. L-box
4. U–BOX

Strength properties:-

1. Compressive strength
2. Split tensile strength

Durability properties:-

Regarding strength variation on sulphate and sodium chloride attack.

3.2 MATERIALS

3.2.1 CEMENTS:-

In the present study ordinary Portland cement (43 grades) conforming to IS: 8112-1989 was used. The cements was tested in accordance to tests methods specified in IS: 4031- 1988 and results obtained are shown in table 3.1

Table 3.1 Tests results of cement sample

S.NO.	CHARACTERISTICS	EXPERIMANTAL VALUE	REQUIREMENTS AS PER IS:8112-1989
1.	Consistency (%)	28	-
2.	Specific gravity	3.15	3.15
3.	Initial setting time(min)	95	>30
4	Final setting time(min)	215	<600
5	Fineness (%)	5	10
6.	Soundness(mm)	2.55	<10
7.	Compressive strength		
a)	3 days(MPa)	26.10	≥23
b)	7 days(MPa)	36.69	≥33
c)	28 days(MPa)	46.56	≥43

3.2.2 FLY ASH

Fly ash obtained from 'Panipat thermal power station, Panipat', Haryana was used. The finer quality of fly ash is obtained from the electro- static precipitators in the plant. The physical and chemical properties of fly ash are shown in Table 3.2 and 3.3 respectively.

Table 3.2 Physical properties of Fly Ash

PHYSICAL PROPERTIES	TESTS RESULTS
Colour	Grey(blackish)
Specific gravity	2.13
Lime reactivity- average compressive strength after 28 days of mixture 'A'	4.90MPa

Table 3.3 Chemical properties of Fly Ash

CHEMICAL PROPERTIES	PERCENTAGE BY WEIGHT
Calcium oxide (CaO)	2.24
Silica (SiO_2)	58.45
Alumina ($Al_2 O_3$)	28.10
Iron oxide(Fe_2O_3)	3.45
Magnesium oxide(MgO)	0.33
Total sulphur(SO_3)	0.08
Loss of ignition	4.18
Insoluble residue	-
Sodium oxide(Na_2O)	0.60
Potassium oxide(K_2O)	1.25

The properties of fly ash conform to IS 3812:1981

3.2.3 SUPERPLASTICIZER :-

Superplasticizer STRUCTURO 100(M) (Fosroc chemicals) was used as admixture. Structro 100(M) combines the properties of water reduction and workability retention. Specifications of Superplasticizer are shown in Table 3.4

Table 3.4 Specifications of Superplasticizer by Fosroc

PARTICULARS	PROPERTIES
Appearance	Light yellow
Basis	Aqueous solution of carboxylic ether polymer
Ph	6.5
Density	1.06 kg/litre
Chloride content	Nil to IS:456
Alkali content	Less than1.5g Na_2O equivalent per litre of admixture
Optimum dosage	0.5 to 3.0 litre per 100kg of cementitious material

3.2.4 AGGREGATES

Aggregates constitute bulk of the total volume of concrete. The characteristics of aggregates affect the properties of SCC.

3.2.4 a) FINE AGGREGATES

Locally available natural river sand was used as the fine aggregates. Its sieve analysis and physical properties are shown in Table 3.5 and 3.6 respectively.

Table 3.5 Sieve analysis of fine Aggregate

Weight of sample taken= 2 kg

IS SIEVE SIZE (mm)	RETAINED WEIGHT(Kg)	% WEIGHT RETAINED	CUMULATIVE % Wt RETAINED	% PASSING
10.0	0.00	0.00	0.00	100
4.75	0.068	3.40	3.40	96.6
2.36	0.080	4.00	7.40	92.6
1.18	0.147	7.35	14.75	85.25
600u	0.162	8.10	22.85	77.15
300u	1.095	54.75	77.60	22.4
150u	0.335	16.75	94.35	5.65
PAN	0.113	-	-	-
TOTAL	2.0		220.35	

FINENESS MODULOUS = 220.35/100 = 2.2035

Sand conforms to grading zone III as per IS: 383-1970.

Table 3.6 Physical properties of fine aggregate

PARTICULARS	PROPERTIES
Specific gravity	2.67
Fineness modulus	2.20
Bulk density (loose). Kg/m^3	1590
Bulk density(compacted), Kg/m^3	1780

3.2.4 b) COARSE AGGREGATES

Crushed stone conforming to IS: 383-1970 was used as coarse aggregates. Its sieve analysis and physical properties are shown in Table 3.7 and 3.8 respectively.

Table 3.7 Sieve analysis of coarse aggregate

IS sieve size(mm)	RETAINED WEIGHT(Kg)	%WEIGHT RETAINED	CUMULATIVE %Wt RETAINED	% PASSING
20	0.00	0.00	0.0	100
16	0.00	0.00	0.0	100
12.5	0.125	2.5	2.5	97.5
10	2.393	47.86	50.36	49.64
4.75	2.455	49.1	99.46	0.54
2.36	0.027	0.54	100	0.0
1.18	-	-	100	0.0
600u	-	-	100	0.0
300u	-	-	100	0.0
150u	-	-	100	0.0
Total	5.0		652.32	

FINESS MODULUS = 652.32/100= 6.5232

COARSE AGGREGATES CONFORM TO IS: 383-1970

Table 3.8 Physical properties of coarse aggregate

PARTICULARS	PROPERTIES
Specific gravity	2.67
Fineness modulus	6.52
Bulk density(loose)(kg/m^3)	1460
Bulk density(compacted)(kg/m^3)	1650
Maximum size, mm	10

3.2.5 FIBERS

The various types of fibers like carbon, glass, synthetic, steel etc. can be used in reinforcing concrete. In this study, steel fibers were incorporated in concrete mass. Steel fibers were added in different proportions of 0%, 0.5%, 1% and 1.5% of total concrete mass. Physical properties of steel fibers used are shown in table 3.9

Table 3.9 Physical properties of steel fibers

PARTICULARS	PROPERTIES
Shape	Cylindrical
Type	Straight
Length, mm	20
Diameter, mm	0.4
Aspect ratio	50

3.2.6 MIX DESIGN METHODS FOR SCC

3.2.6 a) MIX DESIGN:-

There are various methods available for mix design like Japanese method, LCPC etc. there is no standard procedure available for SCC mix design. However, different research agencies like EFNARC, PCI etc. made their own specifications for SCC workability characteristics.

Japanese method

Japanese method was initially used for mix design of SCC. This method is most useful in field application is given in Appendix-I. The mix ratio used for study is 1:1.64:1.09.

Fly ash was added with 36% and 29% replacement by weight of cement and water-to-powder ratio used was 0.53 and 0.52 respectively. Mix composition used in study is given in table 3.11. The various proportions were adjusted to satisfy most of the fresh properties, so that the mix could be designated as SCC and further maintains itself on addition of fibers.

The typical range as per EFARC for SCC mix composition is shown in table 3.10.

Table 3.10 Typical range of SCC mix composition

CONSTITUENT	TYPICAL RANGE BY MASS Kg/m^3
Powder	380-600
Water	150-210
Coarse aggregate	750-1000
Fine aggregate	48-55% of total aggregate weight

Table 3.11 Mix Composition

Mix		Cement (kg/m^3)	Fly ash (kg/m^3)	Fine agg. (kg/m^3)	Coarse agg. (kg/m^3)	SP (l/m^3)	Steel fiber (%)	Steel fiber (kg/m^3)	Water (l/m^3)	w/p Ratio	w/c Ratio
	M_1	350	200	900	600	5.5	0	0	291.5	0.53	0.83
	M_2	350	200	900	600	5.5	0.5	11.62	291.5	0.53	0.83
SCC-I	M_3	350	200	900	600	5.5	1.0	23.24	291.5	0.53	0.83
	M_4	350	200	900	600	5.5	1.5	34.86	291.5	0.53	0.83
	M5	390	160	900	600	6.0	0	0	280.5	0.51	0.75
SCC-II	M6	390	160	900	600	6.0	0.5	11.62	280.5	0.51	0.75
	M7	390	160	900	600	6.0	1.0	23.24	280.5	0.51	0.75
	M8	390	160	900	600	6.0	1.5	34.86	280.5	0.51	0.75

3.2.7 MIXING AND CASTING OF SPECIMENS MIXING:-

The mixing of concrete was done to have a homogeneous mixture of all ingredients in concrete. The hand mixing was done for the ingredients. Batching of concrete was done by weight and the mixing process was as given below-

1. Firstly, coarse aggregate was weighted and put in mixing pan.
2. Fine aggregate was added to the coarse aggregate.
3. Fly ash and cement were added to the aggregates. The mixture was thoroughly dry mixed so that the colour of the mixture was uniform and no concentration of any material was visible.
4. Steel fibers added as per proportion or quality recommended for the study.
5. The required quantity of Superplasticizer was added to required quantity of water. To make solution water was added and mixed thoroughly until uniform coloured mixture was obtained.

6. The addition of fly ash to the mix required more time of mixing. After the mix starts flowing, the fresh properties were found. The mixing process was continued till the completion of all the tests.

Fig 3.1 Mixing of materials.

3.2.8 CASTING OF SPECIMENS:-

The moulds of cubes and cylinders were cleaned thoroughly. A thin layer of oil was applied to inner surface of the moulds to avoid the adhesion of concrete with the inner surface of the moulds.

Fig 3.2 Casting of specimens

Cubes of size 150mm x150mm x 150mm were cast for compressive tests and durability tests. Cylinders of size 300mm x 150mm were fused for split tensile strength tests. Tests were performed for compressive and split tensile at ages of 3, 7, 28, 56 and 90 days and durability tests will carry out at 28days, 56 days and 90days.

3.2.9 CURING:

The specimens were kept in clean water tank just after removal from the mould and kept continuously moist till the time of testing.

3.2.10 FRESH PROPERTIES:-

Self Compacting Concrete in its fresh state is tested for properties like filling ability, passing ability and segregation resistance.

a) FILLING ABILITY:-

The ability of SCC to flow and fill completely all spaces within the formwork, under its own weight. In order to filling ability following tests are conducted.

1. Slump flow
2. T_{500} slump flow
3. V- funnel

b) PASSING ABILITY:-

The ability of SCC to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking. To study passing ability following tests are conducted.

1. L- box
2. U- box

c) SEGREGATION RESISTANCE:-

The ability of SCC to remain homogeneous in composition during transport and placing. To study segregation resistance following tests is conducted:-

- V- Funnel at T_{5min}

Table 3.12 Workability properties of SCC and alternative tests method

PROPERTY	TESTS METHODS Lab	TESTS METHODS Field
Filling ability	Slump flow T_{500} slump flow V-funnel	Slump flow T_{500} slump flow V-funnel
Passing ability	L-box U-box	J- ring
Segregation resistance	V-funnel at T_{5min}	V-funnel at T_{5min}

In the present study, slump flow, T_{500} slump flow, V- funnel, L- box, U- box and V- funnel at T_{5min} tests were conducted to determine the filling ability, passing ability and segregation resistance of SCC reinforced with steel fibers in different proportions.

3.2.11 SLUMP FLOW DIAMETER TESTS

Slump flow diameter tests was used to assess the horizontal free flow of SCC in the absence of obstructions. The slump cone, filled with concrete, was lifted off and concrete flows the horizontal diameter of the flowed diameter was measured. The average diameter of the concrete circle was a measure for the filling ability of the concrete. According to EFNARC, a slump flow of 650-800mm is required for SCC. There is no generally accepted advice on what are reasonable tolerances about a specified value, though 650$\pm$50mm as with related flow table tests, might be appropriate.

Fig. 3.3 Slump flow diameter test

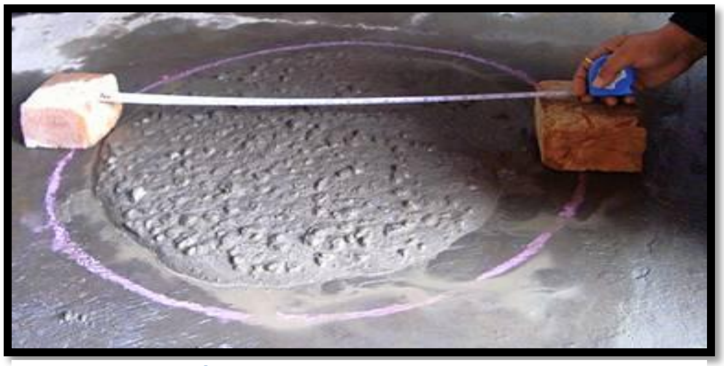
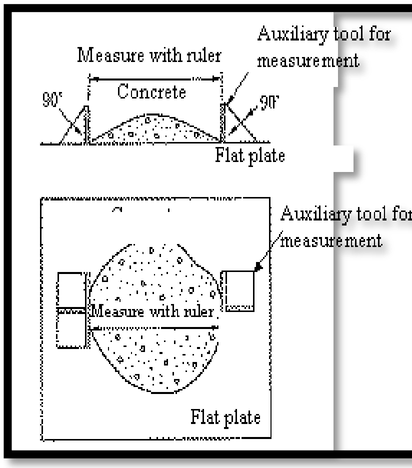


Fig3.4 T_{500} Slump flow diameter test



T_{500} SLUMP FLOW TESTS:-

The time T_{500} is a secondary indication of flow. It measures the time taken in seconds from the instant the cone is lifted to the instant when horizontal flow diameter reaches 500mm. A lower time indicates greater flow ability. According to EFNARC standards, time of 2-5 seconds is required for SCC.

3.2.11(a) V-FUNNEL T_{10sec} TESTS:-

The flow ability of fresh concrete can be tested with the V- funnel tests, where by the flow time is measured. The funnel is filled with about 12 litres of concrete and the time taken for it to flow through the apparatus is measured. For SCC a flow time of 10 seconds is considered appropriate.

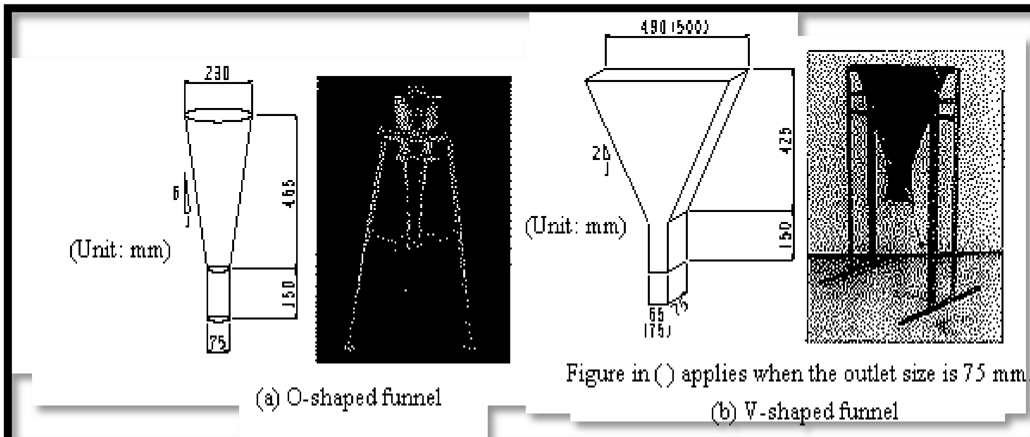


Fig.3.5 Shape dimension and overview of funnel

3.2.11(b) V-FUNNEL T_{5min} TESTS.

Segregation resistance is determining by using the V-funnel tests as T_{5min}. For this, the V-funnel can be refilled with concrete left for 5min to settle. If the concrete shows segregation, the flow time will increase significantly. According to EFNARC, the limit for time increase should not be more than T_{10sec} of V- funnel time + 3 seconds.

3.2.12 L-BOX TESTS:-

The passing ability is determined using the L- box tests. The vertical section of L-box is filled with concrete, and then the gate is lifted to let the concrete flow into the horizontal section.
The height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the times taken to reach 200mm and 400mm marks of horizontal section of L-box. These are the indications of ease of flow of the concrete.
According to EFNARC standards, the blocking ratio (H_2/H_1) should be in the range of 0.8 to 1. . T_{200} & T_{400} times can give some indication of ease of flow, but no suitable values have generally

been agreed. Obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.

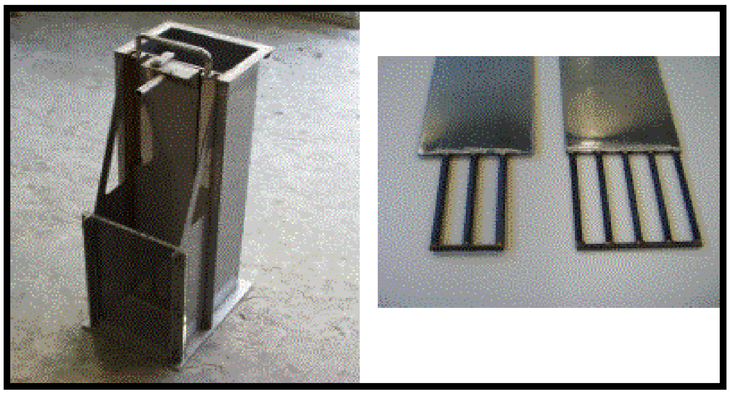


Fig.3.6 Box Type Filling Unit and Flow Obstacle *L-Box tests*

3.2.13 U-BOX TESTS:-

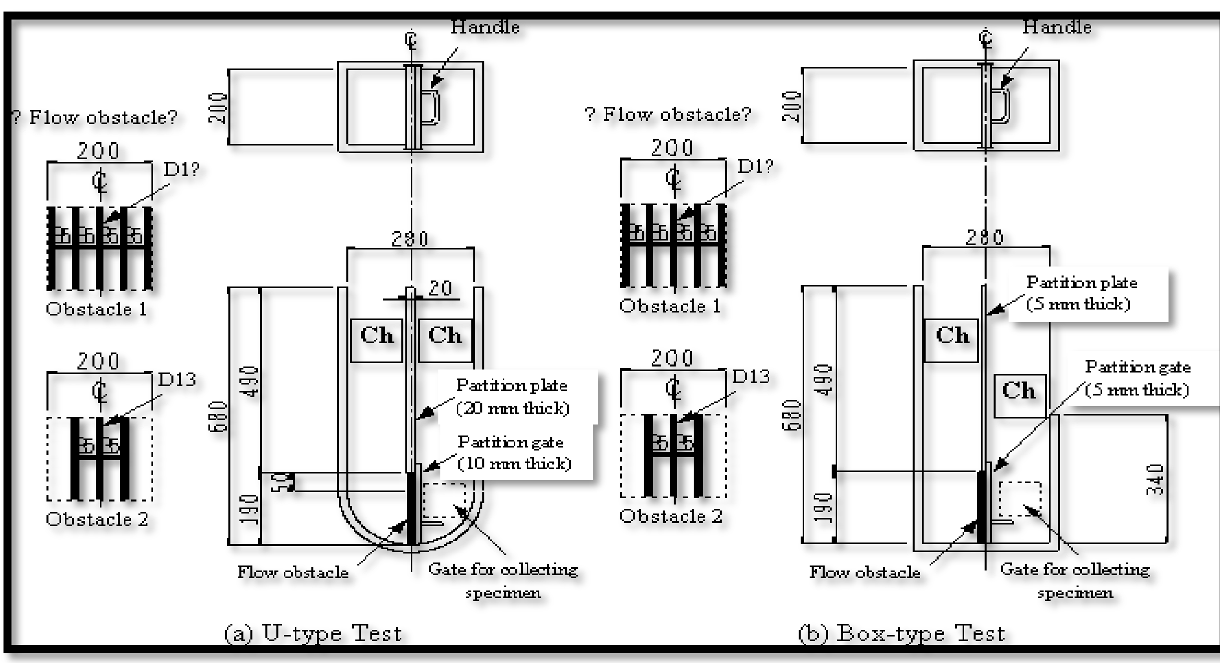


Fig 3.7 U box tests.

U-box tests is used to measure the filling ability of SCC. The left hand section of the U-box apparatus is filled with about 20litres of concretes. Then the gate is lifted and concrete flows upwards into the other section. The height of the concrete in U-box is less than 30cm. it provides a good direct assessment of filling ability.

Table 3.13 EFNARC Specifications

WORKABILITY CHARACTERISTICS	TESTS METHODS	RECOMMENDED VALUES
Filling ability	Slump flow T_{500}	650-800mm 2-5 sec
Passing ability	V-funnel L-box H_2/H_1 U-box (H_2-H_1) j-ring	6-12sec 0.8-1.0 0-30mm <10mm
Segregation resistance	V- funnel at T_{5min}	6-15 sec

3.3 STRENGTH PROPERTIES

3.3.1 COMPRESSIVE STRENGTH TESTS:-

Compressive strength tests is initial step of testing concrete because the concrete is primarily meant to withstand compressive stresses. Compressive strength tests were carried out on 150mm x150mm x 150mm with compression testing machine of 3000KN capacity. The specimens after removal from the curing tank were cleaned and properly dried.

Fig 3.8 Compression testing

The surface of the testing machine was cleaned. The cube was then placed with the cast faces in the contact with the platens of the testing machine. Cubes were tested at 3, 7, 28, 56and 90 days of casting.

3.3.2 SPLIT TENSILE STRENGTH TESTS:-

The split- tensile strength tests is an indirect method to determine tensile strength of concrete. The test consists of applying compressive line loads along the opposite generators of concrete cylinder placed with its axis horizontal between the platens. Cylinders of size 150mm diameter and 300mm height were cast to check the splitting tensile strength of the concrete. Specimens were tested at 3, 7, 28, 56 and 90 days.

Fig. 3.9 Split tensile testing

3.4 DURABILITY STUDIES:-

A durable concrete is one which can withstand the conditions for which it has been designed, without deterioration over a period of years. There are various conditions that affect durability of concrete. These conditions may be physical, chemical like leaching out of cement, actions of sulphates, sea water or slightly acidic water, environmental such as extreme temperatures, abrasion, attack by natural or industrial liquids gases, alkali- aggregate reaction etc. Cubes of 150mm were cast to check the durability of SCC under the action of sodium sulphate and sodium chloride. Sodium sulphate and sodium chloride were added to curing water so as to make two solutions of 1% and 5 % of both sodium sulphate and sodium chloride. Testing will done at 28 days, 56 days and 90 days for both 1% and 5% solution.

Fig3.10: Cubes under chemical action

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 FRESH PROPERTIES:-

The result of fresh properties for SCC mixes contain different percentages of fibers is discussed below.

4.1.1 SLUMP FLOW:-

The consistency and workability of self-compacting concrete was evaluated using slump flow tests. The results as given in table 4.1 show that the self-compacting concrete was complying with the requirements found in the literature. The limit specified by EFNARC for slump diameter was 650-800 mm and specified limit for T_{500} was 2-5 sec. For all mixes with various fibers content, slump flow was observed to be above 650 mm and T_{500} was less than 5sec. So, all mixes with different fiber content hold good for filling ability as required for concrete to be SCC.

4.1.2 V-FUNNEL:-

Time taken by concrete to pass and empty the funnel immediately after filling it, lies within permissible limits. The results of T_{10sec} in Table 4.1 indicate that SCC mix had good passing ability through narrow openings. Results were within permissible limits i.e. 6-12sec for T_{10sec} tests for all proportion of fibers used in research work. T_{5min} result shows in Table 4.1 indicate that the segregation resistance of mixes was within limits up to fibers content of M_3 but mix M_4 gives the V-funnel time as 20sec which was higher than specified in EFNARC(**E**uropean **F**ederation of **N**ational **A**ssociations **R**epresenting producers and applicators of specialist building products for **C**oncrete.).

Table 4.1 Fresh Properties.

	MIX	Slump flow diameter (mm)	T_{500} (sec)	V-funnel at T_{10sec} (sec)	V-funnel at T_{5min} (sec)	L-box (H_2/H_1)	U-box(H_1-H_2) (mm)
	M_1	675	3.4	7	10	0.86	14
SCC-I	M_2	668	3.9	9.5	12.5	0.92	20
	M_3	665	4.2	9.4	13.8	0.98	22
	M_4	660	4.8	11	20	0.73	29
	M_5	685	3.6	6	9	.85	12
	M_6	678	4	8.5	11.3	0.9	17
SCC-II	M_7	674	4.1	9	12.5	0.95	23
	M_8	668	4.5	11	15	0.81	28

4.1.3 L-Box

L-box tests results give the passing ability of SCC, blocking ratio of L-box is given in Table 4.1 the limit for the Blocking ratio is 0.8-1.0. Result of mixes M_1, M_2 and M_3 were satisfactory except M_4.

4.1.4 U-box:-

In this test blocking resistance (H_1-H_2) with respect to w/p ratio and corresponding steel fiber content is given in Table 4.1. The limit for U-box tests as per EFNARC was 0-30mm all mixes are shown results within the specified limits. All the mixes i.e. M_1, M_2, M_3 and M_4 gave satisfactorily results for fresh properties, except M_4 which was not according to EFNARC specification in V-funnel T_{5min} tests and L-box tests.

4.2 STRENGTH PROPERTIES

The results for strength properties for SCC mixes containing different percentage of fibers are discussed below.

4.2.1 COMPRESSIVE STRENGTH

The mix M_1 was used as control mix i.e. fiber content as 0% and compressive strength at 28 days was 22.6MPa.

Table4.2. COMPRESSIVE STRENGTH OF SCC-I MIXES

MIX	Strength in MPa				
	3 DAYS	7 DAYS	28 DAYS	56 DAYS	90 DAYS
M1	10.78	13.25	22.60	25.40	26.40
M2	11.23	14.01	24.20	26.90	28.40
M3	11.34	15.23	25.30	28.10	30.20
M4	12.98	15.76	29.20	31.20	34.30

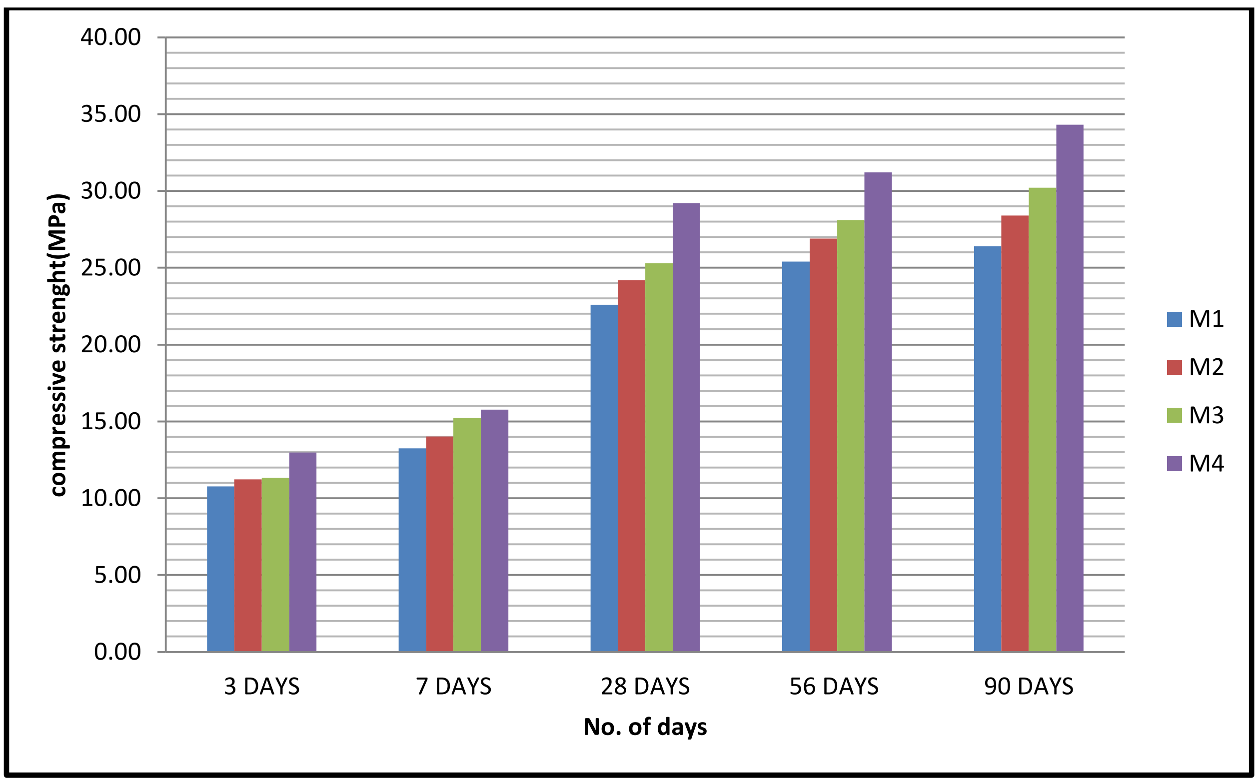


Fig.4.1 Compressive strength tests results of SCC-1.

Compressive strength of M_2, M_3, M_4 was found to increase by 7%, 12%, 29.2% of M_1 at 28 days respectively.

At age of 3 days M_1, M_2, M_3, M_4 achieved 47.7%, 46.4%, 44.8%, and 44.4% of the age at 28 days strength, respectively.

At age of 7 days M_1, M_2, M_3, M_4 achieved 58.6%, 57.9%, 60%, and 53.9% times the 28 days strength, respectively. At age of 56 days M_1, M_2, M_3, M_4 compressive strength increased by 12.38%, 11.15%, 11% and 6.8% times the 28-day strength respectively. At age of 90 days M_1, M_2, M_3, M_4 compressive strength increased by 16.8%, 17.3%, 19.36% and 17.46% respectively.

Table4.3 COMPRESSIVE STRENGTH OF SCC-II MIXES

MIX	Strength in MPa				
	3 DAYS	7 DAYS	28 DAYS	56 DAYS	90 DAYS
M5	15.21	19.67	27.40	31.20	33.30
M6	15.98	20.23	28.91	33.10	34.70
M7	16.56	20.89	30.30	35.10	37.50
M8	18.31	22.23	33.61	35.80	38.23

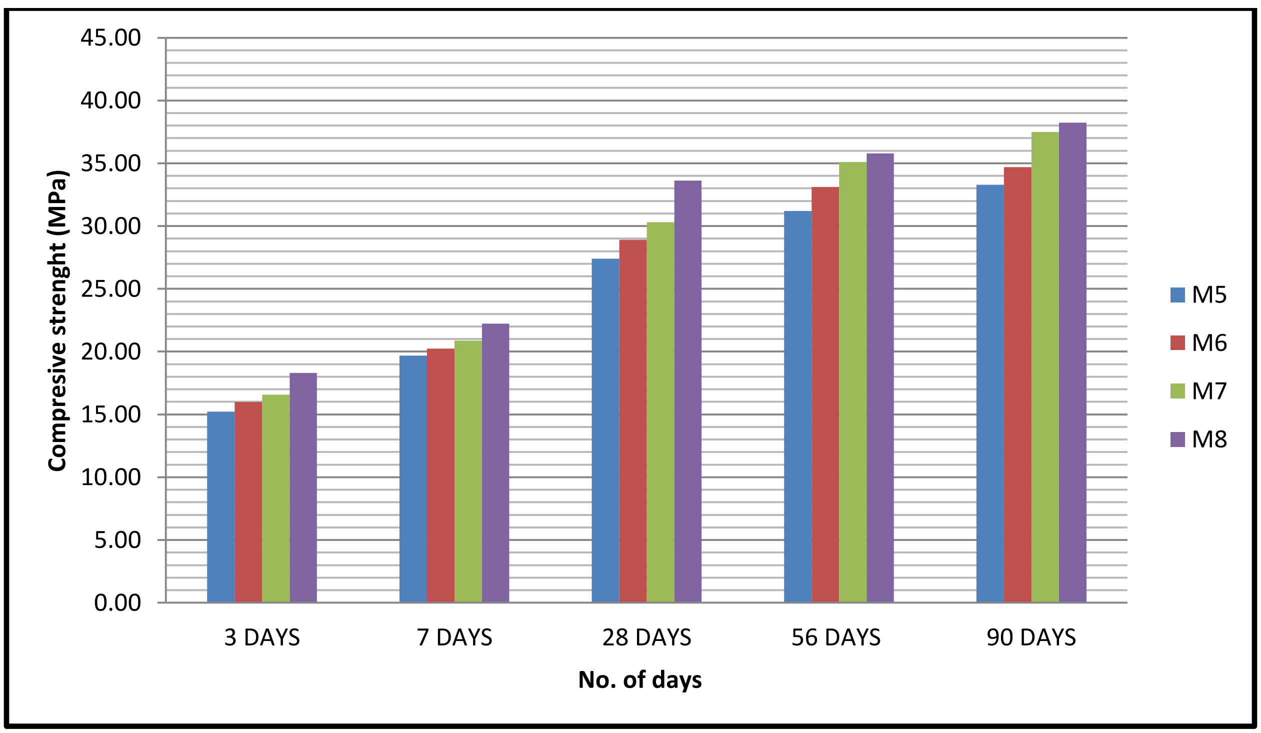


Fig4.2 Compressive strength tests results of SCC-II.

Compressive strength of M_6, M_7, M_8 was found to increase by 5.5%, 10.6%, 22.62% of M_5 at 28 days, respectively.

At age of 3 days M_5, M_6, M_7 and M_8 achieved 55.5%, 55.2%, 54.65% and 54.49% of the at 28 days strength respectively. At age of 7 days M_5, M_6, M_7 and M_8 achieved 71.7%, 69.9%, 68.9% and 66% times the 28 day strength, respectively. At age of 56 days M_5, M_6, M_7 and M_8 compressive strength increased by 13.8%, 14.5%, 15.8% and 6.51% times the 28 day strength, respectively. At age of 90 days M_5, M_6, M_7 and M_8 compressive strength increased by 21.5%, 20%, 23.7%, 13.7% respectively.

In the present study, the increase in strength for mix containing 1% fiber was observed to be approx. 15% at 7-day strength and 12% at 28- day strength, when compared to mix containing 0% fiber content. Also, the increase in strength for mix containing 1.5% fiber was observed to be 29.2% at 28-day strength, when compared to mix containing 0% fiber content.

Nehdi and Ladanchuk (2004) reported that on addition of 1% steel fiber increases in strength of 19.6% at 7 days and 17.5% at 28 days was observed.

Sengul et al. (2006) reported, using high performance SCC (cement content of 350 Kg/m^3), increase of 25.7% at 28-day strength with fiber content of approx. 1.5%.

At fiber content of 1% and 1.5% observed increase observed was strength is almost equal to increase reported in the literature. Almost same increase in strength was reported at 1.5% fiber content in literature, on using high performance SCC.

4.2.2 Split tensile strength

The split tensile strength of M_1 was 1.20 MPa. Split tensile strength of M_2, M_3 and M_4 was found to increase by 7.5%, 9.2% and 11.6% at 28 days respectively, when compared to M_1.

At age of 3 days, M_1, M_2, M_3 and M_4 achieved 65%, 55.8%, 58%, and 65% of the strength at 28 days, respectively. At age of 7 days, M_1, M_2, M_3 and M_4 achieved 73.3%, 79.8%, 82.4% and 82.5% of the strength at 28 days, respectively. At age of 56 days, M_1, M_2, M_3 and M_4 split tensile strength was strength was increased by 5%, 14.7%, 16% and 18%, respectively. At age of 90 days M_1, M_2, M_3 and M_4 split tensile strength was increased by 11.67%, 23.25%, 31.3%, and 34.96% respectively.

Table.4.4 SPLIT TENSILE STRENGTH OF SCC-I MIXES

MIX	Strength in MPa				
	3 DAYS	7 DAYS	28 DAYS	56 DAYS	90 DAYS
M1	0.78	0.88	1.20	1.26	1.34
M2	0.72	1.03	1.29	1.48	1.59
M3	0.76	1.08	1.31	1.52	1.72
M4	0.93	1.18	1.43	1.69	1.93

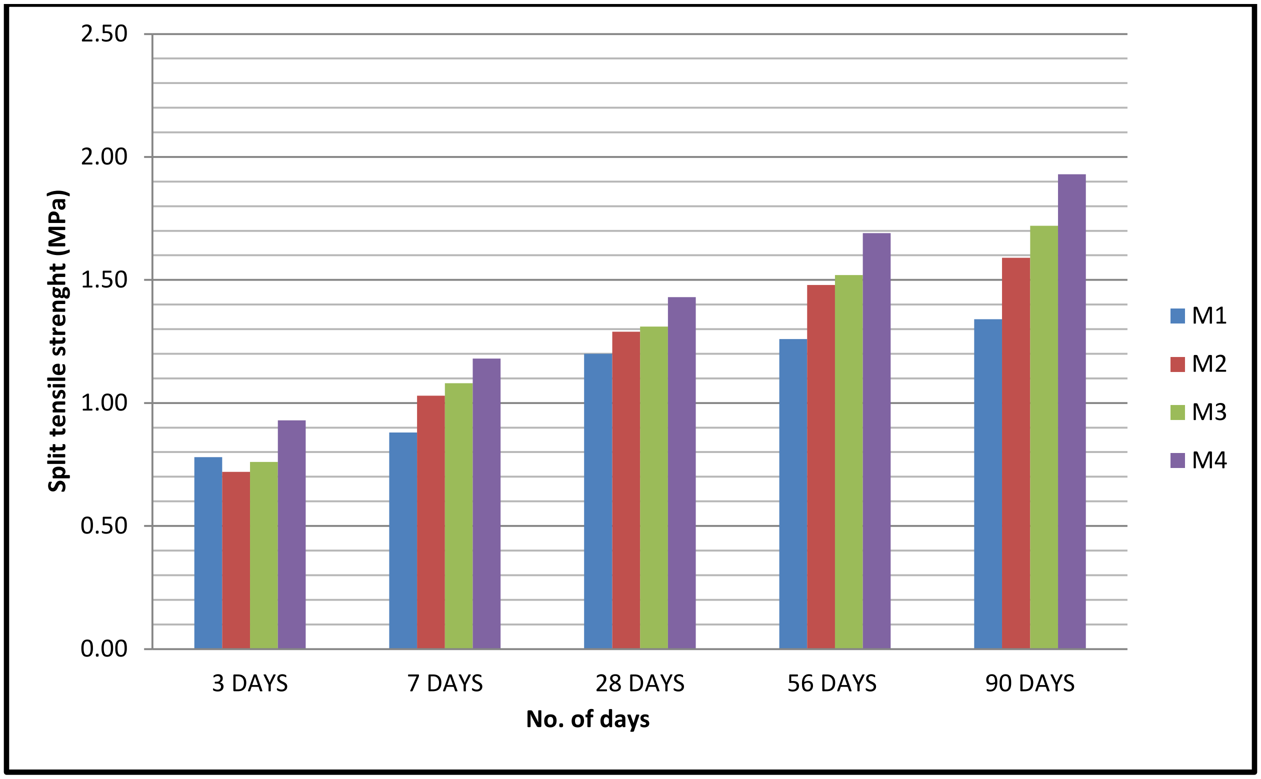


Fig.4.3 SPLIT TENSILE STRENGTH RESULTS OF SCC-I MIXES

Split tensile strength of M_6, M_7, M_8 was found to increase by 21.3%, 23.66%, and 27.48% at 28 days respectively, when compared to M_5. At age of 3 days, M_1, M_2, M_3 and M_4 achieved 68.7%, 57.86%, 58.64% and 63.5% of the strength at 28 days respectively. At age of 7 days, M_1, M_2, M_3 and M_4 achieved 89.3%, 90%, 86.4%, 88.6% of the strength at 28 days, respectively. At age of 56 days, M_1, M_2, M_3 and M_4, split tensile strength was increased by 11.4%, 24%, 20.7%, and

22%, respectively. At age of 90 days M_1, M_2, M_3 and M_4 split tensile strength was measured by 15.2%, 16%, 18.5%, and 20.3% respectively.

Table.4.5 SPLIT TENSILE STRENGTH OF SCC-II MIXES

MIX	Strength in MPa				
	3 DAYS	7 DAYS	28 DAYS	56 DAYS	90 DAYS
M5	0.90	1.17	1.31	1.46	1.51
M6	0.92	1.43	1.59	1.78	1.84
M7	0.95	1.40	1.62	1.85	1.92
M8	1.06	1.48	1.67	1.92	2.01

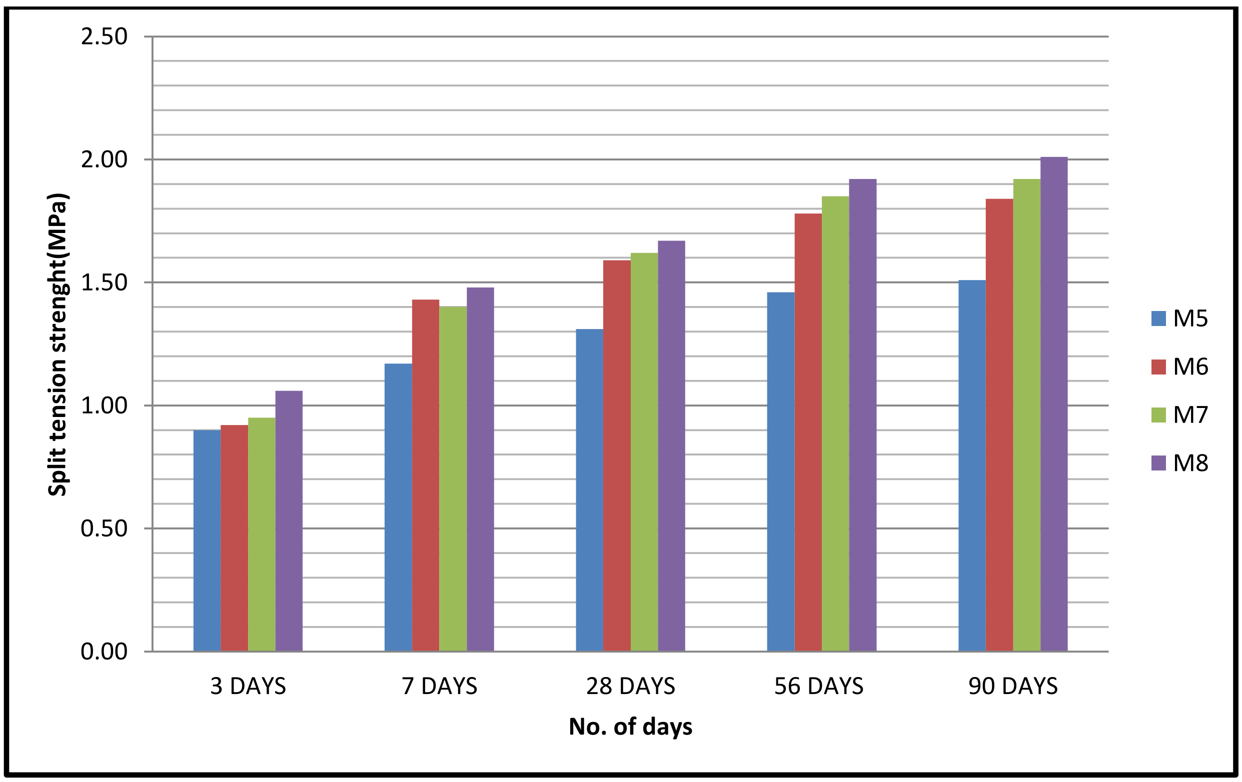


Fig..4.4 SPLIT TENSILE STRENGTH RESULTS OF SCC-II MIXES

In the present study, with fiber content of 1% increase of approx. 19.8% and 23.67% at 7 days and 28 days strength was achieved respectively, when compared to mix containing 0% fiber content. On addition of 1.5% fibers, increase of approx. 26% at 28-day strength was achieved when compared to mix containing 0% fiber content.

Pons et al. (2007) reported increase of approx. 11.5% at 7-day strength and approx. 31.2% at 28 days strength, on addition of fibers content of approx. 1% (approx**.).**

Sengul et al. (2006) reported, using high performance SCC (cement content of 350 Kg/m), increase of 15.3% at 28 days strength with fiber content of 1.5 %(approx.)

It is observed that increase in split tensile strength, in the present study, was less at 1% fiber content and almost double at 1.5% fiber content, as compared to increase in strength reported in literature. Also, strength achieved, in the present study, at 7 days and 56 days and 90 days was more for 0.5% fiber content as compared to 1% fiber content.

4.3 Durability studies

Dualities of concrete mean its resistance to deteriorating influences, which may reside inside the concrete itself, or to the aggressive environments. The ability of concrete to resist weathering action, chemical attack, and abrasion is known as its durability. Factors affecting durability are surface wear, cracking due to crystallization of salts in pores, exposure to temperature extreme such as during frost action / fire. Expansion reaction involving sulphate attack, alkali aggregate reaction and corrosion of embedded steel in concrete.

Table4.6 DURABILITY (1 % SOLUTION RESULTS OF SCC-I MIXES

Mix	**Strength in (MPa)**			**56 days/28 days**	**90days/28 days**
	28 days	**56 days**	**90 days**		
M1	21.13	25.36	26.34	1.20	1.25
M2	23.82	26.80	28.20	1.13	1.18
M3	24.59	27.93	30.04	1.14	1.22
M4	27.23	30.98	34.04	1.14	1.25

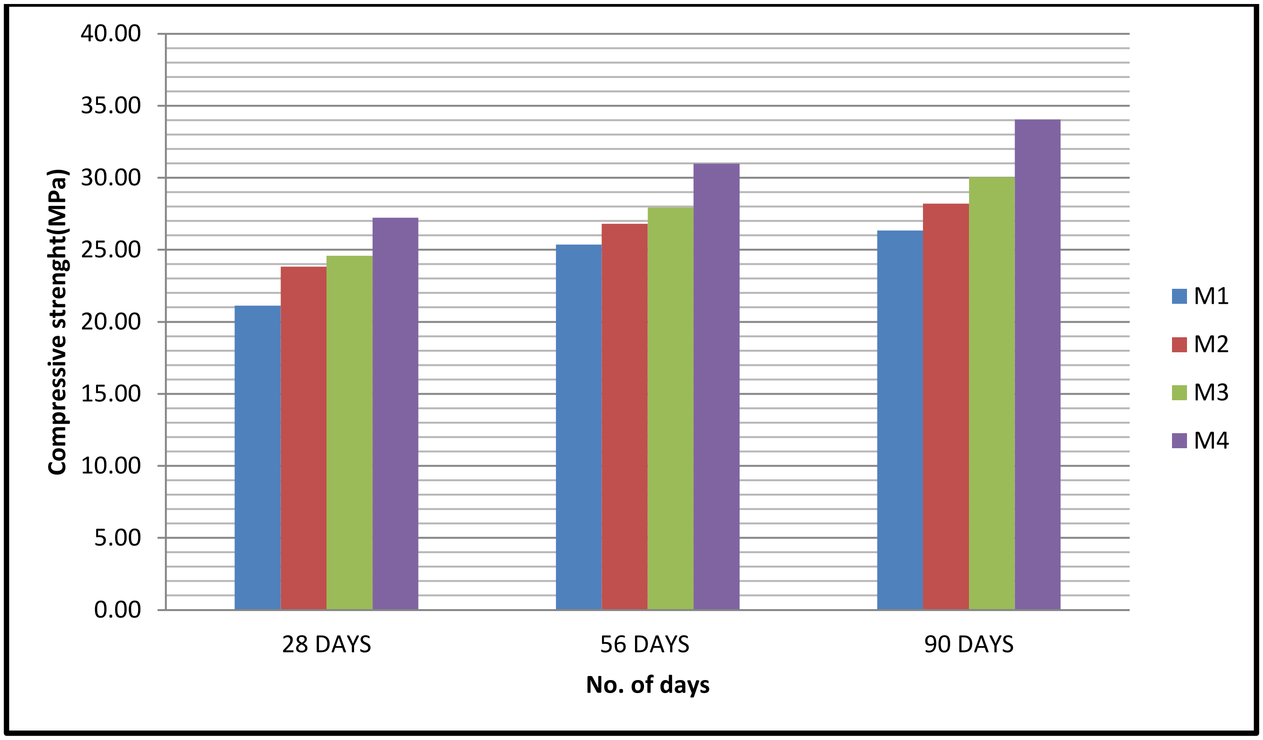


Fig.4.5 DURABILITY (1 % SOLUTION RESULTS OF SCC-I MIXES

The ratio between compressive strength for mixes M_1, M_2, M_3 and M_4 at ages 56 days to 28 days was found to be vary from 1.12-1.20 and at ages 90 days to 28 days vary from 1.18 -1.25., as shown in table 4.6, when cured in 1% sodium chloride and sodium sulphate solution. The decrease in 56 day compressive strength of M_1, M_2, M_3 and M_4, cured in 1% solution, was found to be 0.15%, 0.37%, 0.59% and 0.70%, when compared to specimen cured in water. The decrease in 90 days compressive strength of M_1, M_2, M_3 and M4 cured in 1% solution was found to be 0.21%, 0.44%, 0.62%, 0.75% when compared to specimen cured in water.

Table.4.7 DURABILITY (1% SOLUTION) RESULTS OF SCC-II MIXES

Mix	Strength in (MPa)			56 days/28 days	90days/28 days
	28 days	56 days	90 days		
M5	26.64	31.16	33.25	1.17	1.25
M6	28.52	32.98	34.57	1.16	1.21
M7	28.82	34.96	37.25	1.21	1.29
M8	31.76	35.63	37.90	1.12	1.19

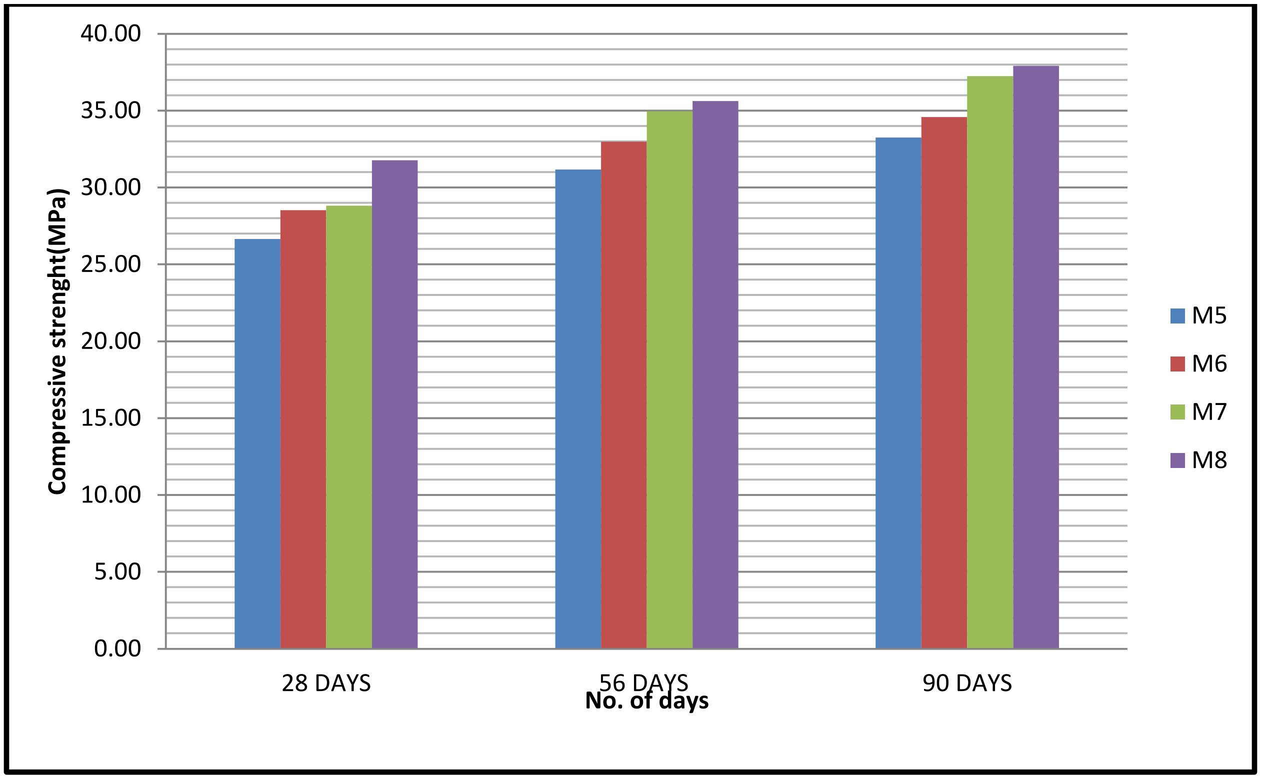


Fig.4.6 DURABILITY (1% SOLUTION) RESULTS OF SCC-II MIXES

The ratio between compressive strength for mixes M_5, M_6, M_7 and M_8 at ages 56 days to 28 days was found to be vary from 1.12-1.21 and at ages 90 days to 28 days vary from 1.19 -1.29 as shown in table 4.7, when cured in 1% sodium chloride and sodium sulphate solution. The decrease in 56 day compressive strength of M_5, M_6, M_7 and M_8, cured in 1% solution, was found to be 0.11%, 0.33%, 0.39% and 0.47%, when compared to specimen cured in water. The decrease in 90 days compressive strength of M_1, M_2, M_3 and M_4 cured in 1% solution was found to be 0.15%, 0.38%, 0.65%, 0.78% when compared to specimen cured in water.

Table4.8 DURABILITY (5% SOLUTION) RESULTS OF SCC-I MIXES

Mix	Strength in (MPa)			56 days/28 days	90days/28 days
	28 days	56 days	90 days		
M1	20.94	25.32	26.34	1.21	1.26
M2	23.88	26.72	28.21	1.12	1.18
M3	24.34	27.86	29.93	1.14	1.23
M4	27.36	30.89	33.98	1.13	1.24

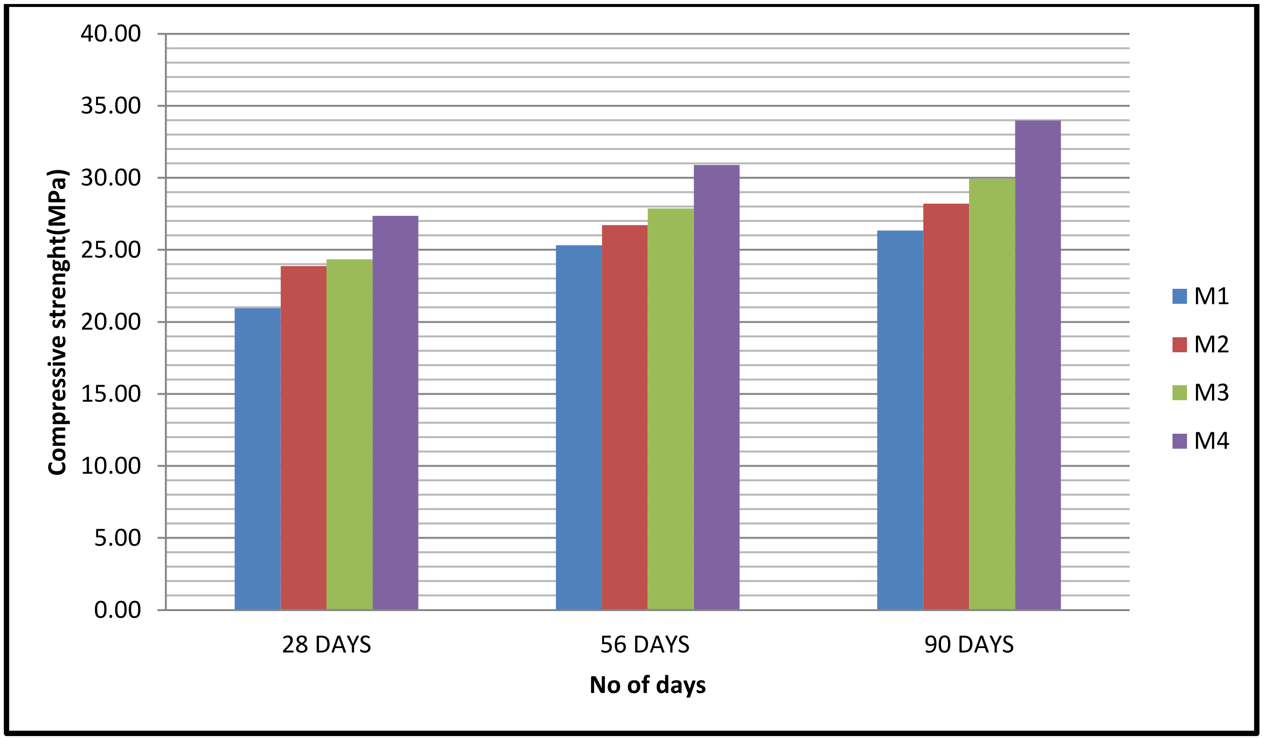


Fig4.7. DURABILITY (5% SOLUTION) RESULTS OF SCC-I MIXES

The ratio between compressive strength for mixes M_1, M_2 M_3 and M_4 at ages 56 days to 28 days was found to be vary from 1.12-1.21 and at ages 90 days to 28 days vary from 1.18 -1.25., as shown in table 4.8, when cured in 5% sodium chloride and sodium sulphate solution. The decrease in 56 day compressive strength of M_1, M_2, M_3 and M_4, cured in 5% solution, was found to be 0.3%, 0.65%, 0.82% and 0.97%, when compared to specimen cured in water. The decrease in 90 days compressive strength of M_1, M_2, M_3 and M_4 cured in 5% solution was found to be 0.2%, 0.68%, 0.89%, 0.90% when compared to specimen cured in water.

Table4.9 DURABILITY (5% SOLUTION) RESULTS OF SCC-II MIXES

Mix	Strength in (MPa)			56 days/28 days	90days/28 days
	28 days	56 days	90 days		
M5	26.50	31.14	33.21	1.18	1.25
M6	28.72	32.91	34.50	1.15	1.20
M7	28.98	34.83	37.20	1.20	1.28
M8	31.20	35.51	37.86	1.14	1.21

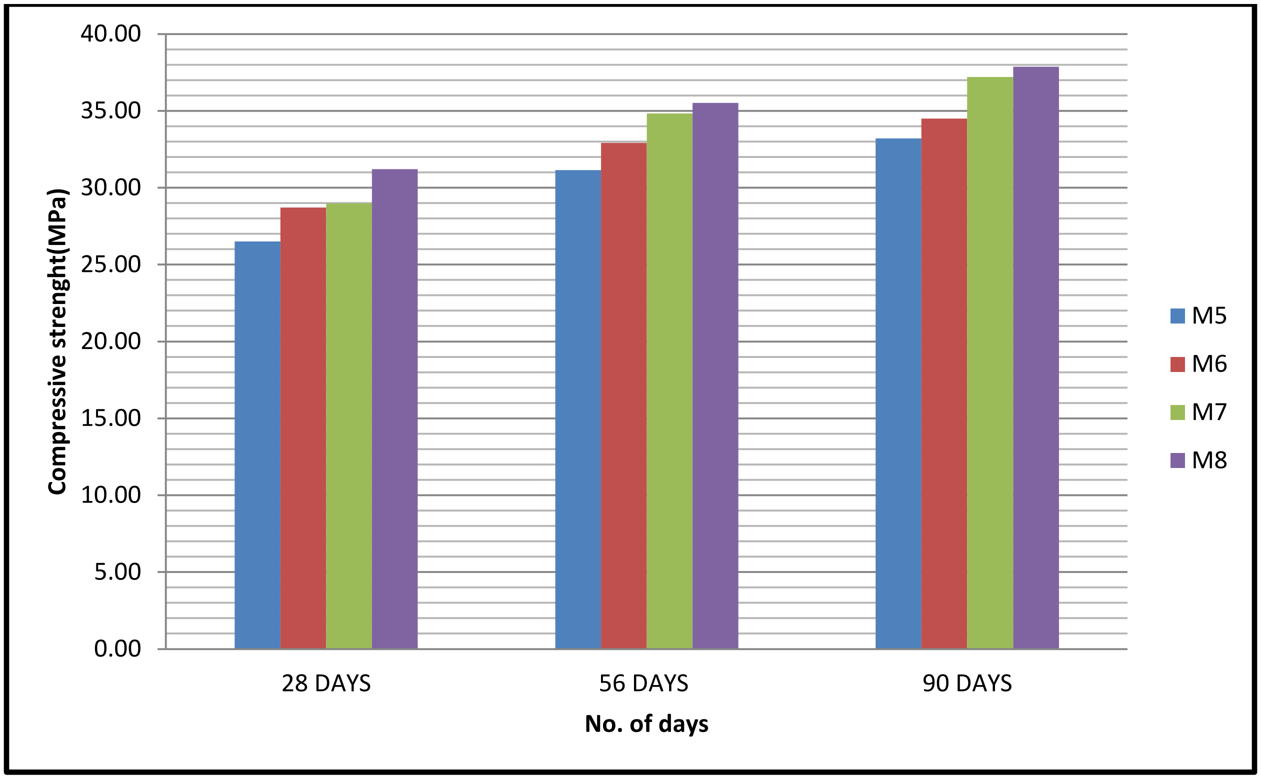


Fig. 4.8 DURABILITY (5% SOLUTION) RESULTS OF SCC-II MIXES

The ratio between compressive strength for mixes M_5, M_6, M_7 and M_8 at ages 56 days to 28 days was found to be vary from 1.13-1.20 and at ages 90 days to 28 days vary from 1.20 -1.28., as shown in table 4.9, when cured in 5% sodium chloride and sodium sulphate solution. The decrease in 56 day compressive strength of M_5, M_6, M_7 and M_8, cured in 5% solution, was found to be 0.19%, 0.55%, 0.77% and 0.81%, when compared to specimen cured in water. The decrease in 90 days compressive strength of M_5, M_6, M_7 and M_8 cured in 5% solution was found to be 0.26%, 0.58%, 0.79%, 0.88% when compared to specimen cured in water.

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE STUDY

5.1 CONCLUSIONS

1. The fresh properties of all SCC mixes satisfied the ranges specified the ranges specified by EFNARC except M_4 as shown in table 4.1.
2. The 28-day compressive strength of SCC-I mixes with fiber content of 0.5 %, 1 % and 1.5 %, were found to be increased by 7 %, 12 % and 23 %, when compared to strength at 0 % fiber content.
3. The 28- day compressive strength of SCC-II mixes with fiber content of 0.5 %, 1 % and 1.5%, were found to be increased by 5.5%, 10 %, 22 %, when compared to strength at 0% fiber content.
4. The 28- day split tensile strength of SCC –I mixes with fiber content of 0.5%, 1% and 1.5%,were found to be increased by 7.5 %, 9 %, 19%,when compared to strength at 0% fiber content.
5. The 28-day split tensile strength of SCC-II mixes with fiber content of 0.5 %, 1 % and 1.5 %, were found to be increased by 21 %, 24 %, 27 % when compared to strength at 0% fiber content.
6. The ratio between compressive strength of mixes M_1, M_2, M_3 and M_4 at ages 56 days to 28 days was found to be vary from 1.12-1.21 & at ages 90/28 days was found to be vary from 1.18-1.25, when cured in 1% and 5% sodium chloride and sodium sulphate solution as shown table 4.5 and 4.7 .
7. The ratio between compressive strength of mixes M_5, M_6, M_7, and M_8 at ages 56 days to28 days was found to be varying from 1.12-1.21 and 90 days to 28 days was found to be vary from 1.19-1.29 & when cured in 1% and 5% sodium chloride and sodium sulphate solution as shown in table 4.6 and 4.8 .

8. The decrease in 56- day compressive strength of M_1, M_2, M_3, M_4, M_5, M_6, M_7, and M_8 cured in 1% solution, was found to be 0.16%, 0.37%, 0.61%, 0.71%, 0.13%, 0.36%, 0.40% & 0.48% when compared to specimen cured in water.

9. The decrease in 56- day compressive strength of M_1, M_2, M_3, M_4, M_5, M_6, M_7, and M_8 cured in 5% solution, was found to be 0.31%, 0.67%, 0.86%, 1%, 0.19%, 0.57%, 0.77% & 0.81% when compared to specimen cured in water.
10. The decrease in 90 days compressive strength of M_1, M_2, M_3, M_4, M_5, M_6, M_7, and M_8 cured in 1% solution was found to be 0.22%, 0.53%, 0.76%, 0.15%, 0.37%, 0.67%, 0.79% when compared to specimen cured in water.
11. The decrease in 90 days compressive strength of M_1, M_2, M_3, M_4, M_5, M_6, M_7, and M_8 cured in 5% solution when found to be 0.22%, 0.67%, 0.9%, 0.94%, 0.27%, 0.58%, 0.80%, 0.89% when compared to specimen cured in water
12. Thus, it could be concluded that SCC with fibers is an alternate to the normal concrete with fibers, with other advantages of SCC being used**.**

5.2 Scope for future study

1. Further study can be done by increasing the percentage of fiber content
2. Different type of fibers like synthetic fiber, carbon fiber, or glass fiber may be used for further investigation.
3. In durability properties, SCC mixes containing fibers exposed to freezing and thawing cycle, can be investigated.
4. Further study can be done on SCC mixes containing fibers subjected to elevated temperatures.

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APPENDIX 1:

JAPANESE METHOD FOR MIX DESIGN OF SCC

Total concrete	=1000L
Assume air content	= 2%
Air	=20L
Net Concrete	=1000-20
	=980L
Coarse aggregate by bulk volume	=37%(Say)
Coarse aggregate(CA)	=980x0.37
	=362.6L
Compacted bulk density of CA	=1.65
Mass of CA	=362.6x1.65
	=598.29 kg
Absolute volume of CA	=598.29/2.67
	=224.08L
Volume of mortar in concrete	=980-224.08
	=755.92L
If Fine Aggregate (FA) content is taken as 44.6% volume of mortar,	
The volume of paste (cement+filler+water)	=55.4% volume of mortar
	=755.92x0.554
	=418.78L
Water- powder ratio (say)	=1.11
Water	=(418.78x1.11)/2.11
	=220.306L
Powder	=418.78-220.306
	=198.474L
Let powder consist of 56% of cement and 44% of fly ash on solid volume basis	
Cement	=198.474x0.56

	=111.145 L
Mass of cement	=111.145x3.15
	=350..107 kg
Fly ash	=198.474 x 0.44
	=87.329 L
Mass of fly ash	=87.329 x 2.13
	=186.011 kg
Total powder	=350.107+186.011
	=536.118kg
Fine aggregate volume	=0.446 x 755.92
	=337.14 L
Mass of fine aggregate	=337.14 x 2.67
	=900.164 kg
Total mass of concrete	=Powder +FA+CA+water
	=536.118+900.164+598.29+ 220.306
	=2254.878 kg

Summary of volume fractions:

V_{ca} = 0.224

V_{paste} = 0.419

V_{fa} = 0.337

Total = 0.980