A
MAJOR PROJECT
ON

EFFECT OF STEEL FIBRES ON FLEXURAL STRENGTH OF CONCRETE

SUBMITTED IN THE PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF DEGREE OF

MASTER OF ENGINEERING
(STRUCTURAL ENGINEERING)

SUBMITTED BY:

GIRIRAJ PRASAD GUPTA

COLLEGE ROLL NO. 06/STR/09
UNIVERSITY ROLL NO. 9076

Under the esteemed Guidance of,
Dr. A.K. Gupta
Professor

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(FORMERLY DELHI COLLEGE OF ENGINEERING)
NEW DELHI

2009-2011

CERTIFICATE

It is certified that the work presented in this thesis entitled **"EFFECT OF STEEL FIBRES ON FLEXURAL STRENGTH OF CONCRETE"** by me, University Roll No. 9076 in partial fulfillment of the requirement for the award of the degree of Master of Engineering in Structural Engineering, Delhi Technological University (Formerly Delhi College of Engineering), Delhi, is an authentic record. The work has been carried out by me under the guidance and supervision of Prof. A. K. Gupta in the academic year 2010-2011.

This is to hereby certify that this work has not been submitted by me, for the award of any other degree in any other institute.

Giriraj Prasad Gupta
College Roll No. 06/STR/09
University Roll NO. 9076

Date:

This is to certify that the above statement made by GIRIRAJ PRASAD GUPTA bearing roll no. is correct to the best of my knowledge.

Dr. A. K. Gupta
Professor
Project Guide
Department of Civil & Environmental Engineering
Delhi Technological University (Formerly Delhi College of Engineering)
Delhi-110042

ACKNOWLEDGEMENT

It is a matter of great pleasure for me to present my thesis report on **“EFFECT OF STEEL FIBRES ON FLEXURAL STRENGTH OF CONCRETE”**. First and foremost, I am profoundly grateful to my project guide **Dr. A. K. Gupta** Professor of Civil and Environment Engineering Department and for their expert guidance and continuous encouragement during all stages of thesis. Their help in the form of valuable information and research thoughts at proper time has brought life in this thesis. I feel lucky to get an opportunity to work with him. I am thankful to the kindness and generosity shown by him towards me, as it helped me morally to complete the project.

I am grateful to my parents for their moral support all the time; they have been always around to cheer me up, in the odd times of this work. I am also thankful to my classmates for their unconditional support and motivation during this work.

Giriraj prasad Gupta
M. E. (Structural Engineering)
College Roll No. 06/STR/09
University Roll No. 9076
Department of Civil & Environment Engineering
Delhi Technological University (Formerly Delhi College of Engineering)
Delhi-110042

ABSTRACT

An experimental investigation has been carried out of study the behavior of steel fiber reinforced concrete under flexural loading. Concrete is very strong in compression but weak in tension. The tensile strength of concrete is less due to widening of micro-cracks existing in concrete subjected to tensile stress. Due to presence of fiber, the micro-cracks are attested.

The study deals with steel fiber reinforced concrete mechanical static behavior and with its classification with respect to fibers content and mix-design variations. A number of experimental tests were conducted to investigate uniaxial compressive strength and flexural strength. Different mixtures were prepared varying both mix-design and fiber content. Fibers content in volume was of 0%, 0.5%, 1%, 1.5% and 2%. Mechanical characterization was performed by means of uniaxial compression tests and flexural tests with the aim of deriving the ultimate compressive strength and flexural strength of fiber concrete.

A total of 60 numbers of concrete specimens (30 cube of size 150mm x 150mm x 150mm and 30 prism of size 150mm x 150mm x 700mm) were cast with and without fiber.

The experimental tests showed the different behavior of SFRC with respect to the different Fiber content and mix design.

The mass, Rebound number, compressive strength of cubes, and flexural strength of prisms, made up of fiber reinforced concrete increased with increase in % of fiber content. Thus the FRC mixes has been proved to be stronger than the ordinary concrete.

CONTENTS

LIST OF FIGURES AND TABLES

FIGURES

TABLES

AIMS AND OBJECTIVES

Aim :- To investigate the effect of steel fibers on flexural strength of concrete.

Objectives :-

- To determine basic properties of cement, aggregate and fiber.
- To prepare various concrete mixes with and without fiber.
- To examine various properties of these mixes like compressive strength and flexural strength.
- To investigate the non destructive parameters such as mass, Rebound number.
- To investigate the compressive strength and flexural strength of pure concrete and fiber reinforced concrete.
- To investigate the effect of steel fibers on compressive strength and flexural strength of concrete.

CHAPTER 1
INTRODUCTION

Concrete is known to be easily cracked under low level tensile stress, for its inherent weakness in resisting tensile forces. Incorporation of fibers into concrete is not only an effective way to enhance concrete tensile stress, but also fracture toughness, impact strength, durability, etc. Inspired from the ancient application of techniques of natural fibers (straw, chip, horse tail, goat hair and plume, etc.), artificial fibers are commonly used nowadays in order to improve the mechanical properties of concrete. Especially vitreous, synthetic, carbon and steel fibers used in concrete caused good results to improve numerous concrete properties. In general, tensile, flexural, impact, fatigue and wear strength, deformation capability, loads bearing capacity after cracking and toughness properties of concrete are significantly improved by use of fibers in concrete mix. Steel fiber is one of the most popular and widely used fibers in both research and practice. During the past four decades, numerous works pertaining to experimental and analytical methods for evaluating strength characteristics of SFRC have been reported, with the consideration of concrete grades, concrete types, curing time, steel fiber geometry, aspect ratio and volume fraction, etc. Moreover, it now has been well accepted that incorporation of steel fiber can greatly benefit the mechanical behaviors of concrete, especially tensile strength and fracture toughness.

The most important effect of vitreous, synthetic, carbon and steel fibers used in conventional concrete is prevention of crack propagation in concrete. Thus, extension and propagation of micro cracks that occur due to internal stress in concrete are prevented by stress transfer capability of fibers. According to their shape and quantity, fibers bear some stress that occurs in cement matrix themselves and transfer the other portion of stress at stable cement matrix portions. This behavior of fibers under stress dominates the SFRC compared to the conventional concrete.

The concept of using fibers has been increasingly used in structural engineering applications. The mechanical properties of fiber reinforced concrete depend on the type and the content of the added fibers. Research and design of steel fiber reinforced concrete (SFRC) began to increase about 40 years ago. Various types of steel fibers have been developed. They differ in size, shape and surface structure (see Fig. 1). These fibers have different mechanical properties such as tensile strength, grade of mechanical anchorage and capability of stress distribution and absorption. Hence they have different influence on concrete properties.

Fig 1: Different types of steel fibers

In SFRCs, the most important factors affecting the concrete properties are aspect ratio (*l/d)* and volume fraction (V_f) of fibers. *l/d* ratio is important at mixing and replacement stages of concrete production . Generally, *l/d* ratios of steel fibers used in concrete mix are varied between 50 and 100. Probability of heterogeneous distribution and flocculation of fibers in concrete mix is increased by increasing *l/d* ratios. Also, V_f significantly affects the workability of concrete. The most suitable V_f values for concrete mixes are between 0.5% and 2.5% by volume of concrete. Homogeneous distribution of fibers at mixing and placing is required regardless of the type of fibers.

Mix-design is a fundamental aspect in steel fiber reinforced concrete (SFRC) behaviour, meaning that the correct proportion between different constitutive materials has to be properly designed. Physical and mechanical properties of the composite depend on the dosage and properties of the components (i.e. cementitious matrix and fibers). Because the presence of steel fibers reduces the mixtures workability, an improvement of it can be obtained by increasing fine aggregate content or adding fluidifying additives. Moreover, the minimum cement dosage depends on the maximum coarse aggregate size; consequently, water-to-cement ratio, which defines the mechanical strength of hardened concrete, depends on the cement proportioning. Finally, the addition of steel fibers to concrete, expressed as volume fractions, increases both strength and ductility properties, but reduces the workability.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Although several studies have been carried out on SFRC, experimental data, related to selection of fibers configuration and content for SFRC is limited. Hence an extensive experimental program has been carried out recently in order to study the effect of fibers content on the mechanical properties of SFRC.

2.2 Recent Studies

Jianming Gao, Wei Suqa & Keiji Morino(1997), concludes that the compressive strength of high strength, lightweight concrete was only slightly improved with the addition of steel fiber. However, splitting tensile and flexural strength were largely improved, and the flexural and splitting tensile strength varied from 4.95 to 8.8 MPa and from 6.2 to 11.8 MPa, respectively. The tensile/compressive strength ratio was obviously enhanced. These were attributed to the effect of the steel fiber arresting cracking. Also for steel fiber-reinforced, high-strength, lightweight concrete, the modulus of elasticity varied from 23.1 to 27.9 GPa depending on V_f and L_f/d_f which was lower than that of steel fiber-reinforced normal concrete. The Poisson's ratio varied from 0.215 to 0.166 for different L_f/d_f. They also stated that the effect of steel fiber on flexural behavior was extremely prominent, the deflection corresponding to the ultimate load increased with the increase in V_f and L_f/d_f, the shape of the descending branch of load-deflection curves tended towards gently, and flexural fracture toughness was largely improved because the fiber pull-out and debond increased the value of the fracture energy.

According to ***Qian Chunxiang, Indubhushan Patnaikuni (1999)***, the Steel fiber can increase flexural rigidity of reinforced high strength concrete beams before yield stage. The load-central displacement ratio is improved by about 21.6, 30.0 and 5.8%, respectively, by the addition of 1% steel fibers with aspect ratio of 46, 38 and 45 respectively. Also Steel fibers can increase the displacement of beams at failure. The central displacement at 80% ultimate load in the descending curve is increased by about 12.2, 35.1 and 12.2%, respectively, by the addition of fibers with aspect ratio of 46, 38 and 45 respectively. And after 80% ultimate load in descending, the load-displacement curve of concrete beams without steel fibers falls much faster with the increase in displacement, which means that the concrete beams with steel fibers possess better ductility. He also observed that the smaller fibers are much better at improving the flexural rigidity and Steel fibers reduce the number of cracks and the size at comparable load levels.

M.C. Nataraja, N. Dhang, A.P. Gupta(1999) found experimentally that the addition of crimped steel-fibers to concrete increases the toughness considerably. The increase in toughness is directly proportional to the reinforcing index. Increase in toughness is marginally higher for lower grade of concrete compared to higher grade of concrete. A marginal increase in compressive strength, strain at peak stress is also observed. This increase is directly proportional to the reinforcing index. Also an analytical expression is proposed to generate the complete stress strain curve for a steel fiber reinforced concrete containing crimped fibers based on the parameter b and the strain corresponding to the peak compressive strength. They also proposed 3 equations which can be used to estimate the parameters of steel fiber reinforced concrete as a function of reinforcing index, knowing the respective parameters of the unreinforced concrete.

Fatih Altun, Tefaruk Haktanir, Kamura Ari(2007) reports that the toughnesses of steel-fiber-added concretes of C20 and C30 classes with a SFs dosage of 30 kg/m^3 increase appreciably as negligible losses in ultimate strength and modulus of elasticity are incurred. Because doubling the mass of SFs to a dosage of 60 kg/m^3 causes only small improvements in toughness, clearly the SFs dosage of 30 kg/m^3 is better than that of 60 kg/m^3. Also the result of bending experiments on so many beams in a beam-loading machine shows that both the ultimate loads and the flexural toughnesses of reinforced-concrete beams produced with concrete classes of C20 and C30 with SFs at a dosage of 30 kg/m^3 increase appreciably as compared to those RC beams without steel fibers.

Semsi Yazıcı , Gozde Inan, Volkan Tabak(2007) shows experimentally that fibers with selected l/d ratios and fiber volumes in this study decreased the workability of concrete mixtures. Especially, workability of reinforced concrete mixture is dramatically decreased for fibers with l/d ratio of 80 and V_f of 1.0% and 1.5%. Also unit weight of concrete is increased with using fibers. This increase varies with the aspect ratio and volume of fibers. Usage of steel fiber in concrete increases the compressive strength of concrete by about 4–19% and significantly increases thesplit tensile and flexural strength of concrete. Split tensile strength of SFRC are higher about 11–54% than the control mixture. Besides, flexural strengths of SFRC are higher by about 3–81% than control mixture. In addition, flexural strength of SFRC is higher than the split tensile and compressive strength. Besides, the increase in the flexural strength of SFRCs is significantly improved with increasing l/d ratio and V_f. In addition, Ultrasonic pulse velocity of SRFCs decreased with fiber content.

According to ***Constantin E. Chalioris, Chris G. Karayannis(2009)*** Fibrous concrete beams exhibited improved overall torsional performance with respect to the corresponding non-fibrous control beams. The main contribution of steel fibers on the torsional behaviour is mainly observed after concrete cracking. The addition of steel fibers was essential to the beams without conventional steel reinforcement since fibers were the only reinforcement and proved capable to provide enhanced torsional moment capacities, especially in the beams with high volume of fibers (V_f = 3%). Furthermore, comparisons between the experimental results showed that the use of high fractions of steel fibers (V_f = 3%) in torsional beams with longitudinal bars (without stirrups) provided increased strength and ductility capabilities. This improvement due to the addition of steel fibers seemed to be more effective in the beams with rectangular cross-section than in the corresponding flanged beams.

According to ***K. Holschemacher, T. Mueller, Y. Ribakov(2010)*** Strength and geometry of fibers have a direct influence on the load bearing capacity of HSSFRC beams without bar reinforcement. Using high-strength fibers resulted in a clearly better ductile behaviour and higher load levels in the post-cracking range, compared to normal strength ones. Specimens with high-strength fiber had lower number of broken fibers in the failed cross-sections, compared to those with normal strength ones. However, experiments show that using high strength fibers in bar reinforced HSC beams is not necessary as no increase in the load bearing capacity, compared to beams with normal-strength fibers, was observed. In cases of fiber contents of 0 and 20 kg/m^3 the specimens, containing bar reinforcement of 1%, failed in shear or compression. For specimens with fiber content of 40 kg/m^3 primary compression failure was observed. For fiber content of 60 kg/m^3 the HSC beams with longitudinal reinforcement ratio of 1% failed in compression only.

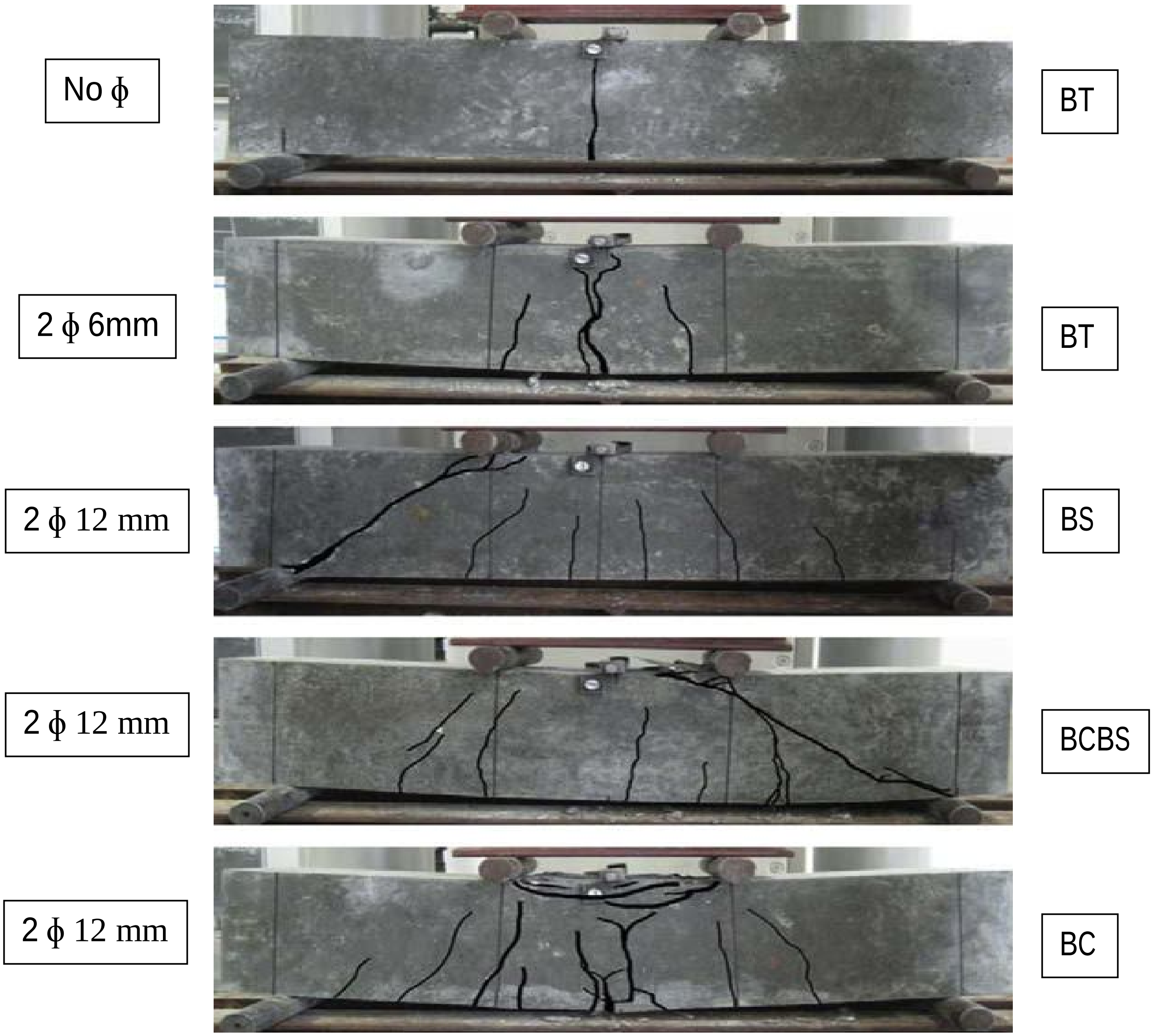

Fig 2: Failure modes of beams with different bar reinforcements

Here, BT – failure in bending, tensile reinforcement bars are failed;

BC – failure in bending, concrete in the compressed zone is collapsed,

BS – failure in shear.

Uniaxial compressive tests by ***R.S. Olivito, F.A. Zuccarello(2010)*** showed how the compressive strength of the material is less affected by the presence of fibers, whereas compressive failure mode of reinforced specimens considerably changes form fragile to ductile. Due to fibers bridging effect, cubic specimen did not crush but they held their integrity up to end of the test. From the experimental results, they also found that the ductility and tenacity of SFRC increases when fiber content in volume increases and, at the same fiber content, when fiber length increases. This phenomenon is due to the higher deformability and energy absorption of SFRC during the cracking phase; SFRC shows a higher bending stiffness and a different cracking pattern than normal concrete. Moreover, post-cracking behaviour is affected by the different fiber length: in fact, specimens realized with short fibers showed a softening behaviour, while specimens realized longer fibers showed a plastic or a hardening behaviour as well as a maximum load increment. Therefore, an increment of fiber content in volume produces: ductility, first crack strength and flexural strength increase, but none indicative variation for compressive strength.

V.M.C.F. Cunha, J.A.O. Barros, J.M. Sena-Cruz(2011) assessed the fibers micro-mechanical behaviour by means of single fiber pullout tests along with influence of the fiber orientation (0°, 30° and 60°) and fiber embedded length (10, 20 and 30 mm) on the fiber pullout behaviour. Two main pullout failures modes were observed during the pullout tests. The complete fiber pullout was observed for aligned hooked fibers, aligned smooth fibers and inclined smooth fibers, whereas for inclined hooked fibers the observed principal failure mode was fiber rupture. In general, the maximum pullout load had an almost linear increase with the L_b for both hooked and smooth fibers. Regarding the effect of the fiber orientation angle, the maximum pullout load increased up to an inclination angle of 30° and then decreased for a 60° inclination angle. For both smooth and hooked aligned fibers a slight increase of the slip at peak load with the fiber L_b was observed. On the other hand, regarding the influence of the fiber orientation angle, a slight increase on the slip at peak load was observed for a 30° angle, whereas for a 60° angle the slip at peak stress increased considerably. This significant increase for a 60°angle can be ascribed to other additional mechanisms that usually occur on the pullout of inclined fibers in opposite to aligned fibers.

2.3 Advantages

- Fiber reinforced concrete is better suited to minimize cavitations / erosion damage in structures such as sluice-ways, navigational locks and bridge piers where high velocity flows are encountered.
- Prevent Plastic Shrinkage Cracks
- Increases Impact Resistance
- Increases Toughness
- Increases Tensile Flexible Strength
- Increases Abrasion Resistance
- Increases Fatigue Resistance
- Increases Freeze Thaw Resistance
- Increases Shear Strength
- Increases Overall Durability
- Provide Anti Crack Strength

2.4 Disadvantages

The main disadvantage associated with the fiber reinforced concrete is fabrication. The process of incorporating fibers into the cement matrix is labor intensive band costlier than the production of the ordinary concrete. The real advantages gained by the use of FRC overrides this disadvantage.

2.5 Applications

I. Slab on Ground

✓ Industrial floor ✓ Commercial floor ✓ Equipment Foundation ✓ Railway Platform ✓ Ammunition Depot ✓ Cold Storage Plant ✓ Multipurpose Basement ✓ Sport Complex	➢ Increase in wear resistance ➢ Increase against cracking resistance ➢ Increases the toughness of floor ➢ Minimum Dusting ➢ Low production cost ➢ Reduction in the maintenance cost

II. Highway Pavement and Airport

✓ Concrete Road ✓ Airport Runways ✓ Taxi Tacks ✓ Hanger ✓ Space ✓ Shuttle Launchers	➢ Increase the impact Resistance ➢ Reduced slab thickness ➢ Earlier utilization ➢ Increases cohesiveness ➢ More dense concrete ➢ Better load bearing capacity

III. Hydraulic Structures

✓ Dams ✓ Spillways ✓ Hydroelectric Plant ✓ Port and Harbor ✓ Water Treatment plant ✓ Sewage Treatment Plant	➢ Excellent resistance to cavitations or erosion damage by high velocity water flow ➢ Most economical for repairing of spillways. The concrete is reinforced throughout the concrete section

IV. Shotcrete (Dry and Wet)

✓ Tunnel Lining ✓ Mine Lining ✓ Rock Slope Stabilization ✓ Aqueduct Rehabilitation ✓ Water Containment Reservoir ✓ Retaining walls ✓ External and Internal Plasters ✓ Dome Structures	➢ Improves Flexural Ductility ➢ Improves Impact Resistance ➢ Eliminates welded wire mesh fabric problem at site (safe and easy to use) ➢ Reduces construction time ➢ Reduces plastic shrinkage and settlement cracks

V. Precast Products

✓ Concrete Pipes ✓ Manhole Covers and Frames ✓ Drain Covers ✓ Bridge Span Segments ✓ Precast Paver Block For Walkways ✓ Kerb Stone ✓ Coffins	➢ Eliminates cumbersome placement of rebar and wire mesh ➢ Reduces thickness of concrete for precast application (saving in material cost) ➢ Different shapes and sizes are possible ➢ Increases Toughness and crack resistance ➢ Works as a micro reinforcement

VI. Overlays

✓ Overlays For Bridge Decks ✓ City Flyovers Overlay ✓ Factory Floor ✓ Parking Decks ✓ Petrol Pumps ✓ Workshops ✓ Walkways ✓ Automobile Showrooms ✓ Road and Floor Repairs	➢ Only 75 to 100 mm thick concrete layer is good enough over damage surface ➢ It is possible to lay an overlay over the deteriorated Asphalt Pavements ➢ Lower Production Cost ➢ Increased in wear resistance up to 100% to 150% ➢ Monolithic surface is obtained

2.6 Types of Fiber

The fibers can be broadly classified as

- Metallic Fibers
- Polymeric Fibers
- Mineral Fibers
- Naturally occurring Fibers

They can be classified into two basic categories, namely, those having a higher elastic modulus than concrete matrix (called hard intrusion) and those with lower elastic modulus (called soft intrusion). Steel, Carbon and Glass have higher elastic modulus than cement mortar matrix and polypropylene and natural vegetable fibers are the low modulus fibers. High modulus fibers improve both flexural and impact resistances, simultaneously whereas low modulus fibers improve the impact resistance of concrete.

Different type of fibers such as steel, Carbon, Polypropylene, Nylon, Polyester, Rayon, Glass etc. are available. The fibers suitable for reinforcing the concrete have been produced from steel, glass and organic polymers. Fibers are available in different sizes and shapes.

2.6.1 Metallic Fibers

- **Steel**

Steel fibers have been used in concrete since the early 1900s. The early fibers were round and smooth and the wire was cut or chopped to the required lengths. The use of straight, smooth fiber has largely disappeared and modern fiber have either rough surface, hooked ends or are crimped or undulated through their length. Modern commercially available steel are manufactured from drawn steel wire, from slit sheet steel or by melt- extraction process which produces fiber that have a crescent shaped cross section. Typically steel fiber have equivalent diameters (based on cross sectional area) of from 0, 1.5mm to 2mm and lengths from 7 to 75mm. Aspect ratios generally range from 20 to 100. (*Aspect ratio* is defined as the ratio between fiber length and its equivalent diameter, which is the diameter of a circle with an area equal to the cross section area of the fiber).

Carbon steels are most commonly used to produce fiber but fibers made from corrosion-resistant alloys are available. Stainless steel fibers have been used for high-temperature application. Some fibers are collated into bundles using water-soluble glue to facilitate handling and mixing. Steel fibers have high tensile strength (0.5 to 2GPa) and modulus of elasticity (200GPa), a ductile/plastic stress-strain characteristic and low creep. Steel fibers have been used in conventional concrete mixes, shotcrete and slurry-infiltrated fiber concrete. Typically, content of steel fiber ranges from 0.25% to 2.0% by volume. Fiber contents in excess of 2% by volume generally result in poor workability and fiber distribution, but can be used successfully where the paste content of the mix is increased and the size of coarse aggregate is not larger than about 10mm.

Steel fiber reinforced concrete containing up to 1.5% fiber by volume has been pumped successfully by using pipelines of 125 to 150 mm diameter. Steel fiber contents up to 2% by volume have been used in shotcrete applications using both the wet and dry processes. Steel fiber contents of up to 2.5% by volume have been obtained in slurry-infiltrated fiber concrete. Concretes containing steel fiber have been shown to have substantially improved resistance to impact and greater ductility of failure in compression, flexure and torsion.

Compression and modulus of rigidity in torsion are no different before cracking when compared with ordinary concrete tested under similar conditions. It has been reported that steel fiber reinforced concrete, because of the improved ductility, could find applications where impact resistance is important. Fatigue resistance of the concrete is reported to be increased by up to 70%. It is thought that the inclusion of steel fiber as supplementary reinforcement in concrete could assist in the reduction of spalling due to thermal shock and thermal gradients. The lack of corrosion resistance of normal steel fibers could be a disadvantage in exposed concrete situations where spalling and surface staining are likely to occur.

2.6.2 Synthetic Fibers

Synthetic fibers are manmade fiber resulting from research and development in the petrochemical and textile industries. There are two different physical fiber forms: monofilament fiber and fiber produced from fibrillated tape. Currently there are two different synthetic fiber volumes used in application, namely low-volume percentage (0.1% to 0.3% by volume) and high-volume percentage (0.4% to 0.8% by volume).

Most synthetic fiber applications are at the 0.1% by volume level. At this level, the strength of the concrete is considered unaffected and crack control characteristics are sought. Fiber types that have been tried in cement concrete matrices include: aramid, acrylic, carbon, nylon, polyester, polyethylene and polypropylene.

- **Acrylic**

  Acrylic fibers have been used to replace asbestos fiber in many fiber reinforced concrete products. In this process fibers are initially dispersed in a dilute water and cement mixture. A composite thickness is built up in layers using a pressure forming process and vacuum dewatering. Acrylic fibers have also been added to conventional concrete at low volumes to reduce the effects of plastic-shrinkage cracking.

- **Aramid**

  Aramid fibers are two and half times as strong as glass fibers and five times as strong as steel fibers, per unit mass. Due to the relatively high cost of these fibers, aramid fiber reinforced concrete has been primarily used as an asbestos cement replacement in certain high strength applications.

- **Carbon**

  Carbon fiber is substantially more expensive than other fiber types. For this reason its commercial use has been limited. Carbon fibers are manufactured by carbonizing suitable organic materials in fibrous forms at high temperature and then aligning the resultant graphite crystallites by hot stretching. The fibers are manufactured as either Type I (high modulus) or Type II (high strength) and are dependent upon material source and extent of hot stretching for their physical properties. Carbon fibers are available in a variety of forms and have a febrile structure similar to that of asbestos.

  Carbon fiber made from petroleum and coal pitch is less expensive than the conventional carbon fiber made from fibrous materials. The Type I and II carbon fibers produced by carbonizing suitable organic materials other than petroleum based types are 20 to 40 times stronger and have a modulus of elasticity up to 100 times greater than the pitch based carbon fiber. Carbon fiber is available as continuous strands or as individual chopped fibers. Continuous strands are normally pre-placed and aligned to provide the optimum fiber orientation during fabrication. Chopped fibers are generally incorporated during the mixing process and are therefore oriented randomly throughout the mix. A satisfactory mix of chopped carbon fiber, cement, and water is difficult to achieve because of the large surface area of the fiber. Research has shown that uniform dispersion of discontinuous low-modulus carbon fiber has been achieved using an omni mixer and admixture. Carbon fiber has high tensile strength and modulus of elasticity and a brittle stress-strain characteristic. Additional research is needed to determine the feasibility of carbon fiber concrete on an economic basis. The fire resistant properties of carbon fiber composites need to be evaluated, but ignoring economics, structural applications appear promising.

- **Nylon**

  Nylon is a generic name that identifies a family of polymers. Nylon fiber's properties are impacted by the base polymer type, addition of different levels of additive, manufacturing conditions and fiber dimensions. Nylon is heat stable, hydrophilic, relatively inert and resistant to a wide variety of materials. Nylon is particularly effective in imparting impact resistance and flexural toughness and sustaining and increasing the load carrying capacity of concrete following first crack.

- **Polyester**

  Polyester fibers are available in monofilament form and belong to the thermoplastic polyester group. They are temperature sensitive and above service temperatures their properties may be altered. Polyester fibers are somewhat hydrophobic. Polyester fibers have been used at low contents (0.1% by volume) to control plastic shrinkage cracking in concrete.

- **Polyethylene**

  Polyethylene has been produced for concrete in monofilament form with wart-like surface deformations. Polyethylene in pulp form may be an alternate to asbestos fibers. Concrete reinforced with polyethylene fibers at contents between 2 and 4% by volume exhibits a linear flexural load deflection behavior up to first crack, followed by an apparent transfer of load to the fibers permitting an increase in load until the fibers break.

- **Polypropylene**

  Polypropylene fiber was first used to reinforce concrete in 1960s. Polypropylene is a synthetic hydrocarbon polymer, the fiber of which is made using extrusion processes by hot-drawing the material through a die. Polypropylene fibers are produced as continuous mono-filaments, with circular cross section that can be chopped to required lengths, or fibrillated films or tapes of rectangular cross section. Polypropylene fibers are hydrophobic and therefore have the disadvantage of poor bond characteristics with cement matrix, a low melting point, high combustibility and a relatively low modulus of elasticity. Long Polypropylene fibers can prove difficult to mix due to their flexibility and tendency to wrap around the leading edges of mixer blades. Polypropylene fibers are tough but have low tensile strength and modulus of elasticity; they have a plastic stress-strain characteristic.

Monofilament Polypropylene fibers have inherent weak bond with the cement matrix because of their relatively small specific surface area. Fibrillated Polypropylene fibers are slit and expanded into an open network thus offering a larger specific surface area with improved bond characteristics. Polypropylene fibers have been reported to reduce unrestrained plastic and drying shrinkage of concrete at fiber contents of 0.1 to 0.3% by volume.

2.6.3 Natural Fibers

Natural reinforcing materials can be obtained at low cost and low levels of energy using local man power and technology. Utilization of natural fibers as a form of concrete reinforcement is of particular interest to less developed regions where conventional construction materials are not readily available or are too expensive. Sisal fiber reinforced concrete has been used for making roof tiles, corrugated sheets, pipes, silos and tanks. Elephant grass reinforced mortar has been used for low cost housing projects. Wood cellulose fiber reinforced cement has commercial applications in the manufacture of flat and corrugated sheet and non-pressure pipes. Natural fibers can be either unprocessed or processed.

- **Unprocessed Natural fibers**

  Products made with Unprocessed Natural fibers such as coconut coir, sisal, sugarcane bagasse, bamboo, jute, wood and vegetable fibers have been tested in a number of countries. Problems have been reported with the long term durability of some of the products.

  The properties of concrete made using Unprocessed Natural fibers depend on a number of factors including the type and length of fiber as well as the volume fraction. To show some improvement in mechanical properties, the minimum fiber content is of the order of 3% by volume.

- **Processed Natural fibers**

  Wood cellulose is the most frequently used natural fiber. It is most commonly obtained using the Kraft process. This process involves cooking wood chips in a solution of sodium hydroxide, sodium carbonate and sodium sulphide. Different grades of wood-cellulose fiber containing more or less of the three main constituents, cellulose, hemi cellulose and ligna can be obtained by bleaching.

  Wood-cellulose fiber has relatively good mechanical properties compared with many manmade fibers such as polypropylene, polyethylene, polyester and acrylic. Delignified cellulose fiber can be produced with tensile strengths up to approximately 2.0GPa from selected grades of wood, and using suitable pulping processes. Fiber tensile Strengths of 500MPa can be routinely obtained using a chemical pulping process and the more common, less expensive, grades of wood.

  Using conventional mixing techniques, the amount of fiber that can be incorporated into the cement matrix at low water contents is limited by the capacity of the fibers to be mixed uniformly into the matrix. Fabrication techniques that involve mixing fiber with the matrix at initially high water contents and then using dewatering procedures are therefore effective and common. Wood-cellulose fiber that has not been delignified can adversely affect the curing of the cement matrix. This is because leaching of sugar and other organic impurities into the cement matrix can retard or completely inhibit cement set. Results obtained from autoclaved wood-cellulose cement composites indicate that such products can be sensitive to moisture content. Published information on the performance of wood-cellulose fiber composites is conflicting. However, Bantur and Mindess state "Although the strength and other properties of the cellulose-pulp fiber are inferior to those of many other fibers, such as asbestos, they are highly cost effective". This combined with their compatibility with processes for producing asbestos cement, makes the cellulose-pulp fibers an attractive alternative to asbestos. As a result of intensive research and development, cellulose-pulp fibers are now used in some places as partial or full replacement for asbestos in cement composites.

CHAPTER 3

MATERIALS AND MIX DESIGN

3.1 Materials

The materials used for the manufacturing of ordinary concrete and fiber reinforced concrete and properties of various materials used in the investigation are as follows.

3.1.1 Cement

The shree ultra 43 grade cement (OPC) of one batch was procured in the laboratory. The physical properties of the cement were determined in laboratory and are given in table 1.

Table 1

Sr. No.	Properties	Value
1	Specific Gravity	3.2
2	Normal Consistency	30 %
3	Initial Setting Time (min)	58
4	Final Setting Time (min)	280

3.1.2 Coarse Aggregate

For this study the natural coarse aggregate of 10 mm and 20 mm were used. Specific gravity was determined by using pycnometer apparatus.

(A) Specific Gravity using pycnometer is given by expression

Specific gravity = $(W_2-W_1) / ((W_2-W_1)-(W_3-W_4))$

$= (899-575) / ((899-575)-(1873-1671))$

$= 2.655$

Where,

W_1 = Weight of empty pycnometer = 575 gm

W_2 = Weight of pycnometer + weight of oven dried aggregate = 899 gm

W_3 = Weight of pycnometer + aggregate + water = 1873 gm

W_4 = Weight of pycnometer + water = 1671 gm

3.1.3 Fine Aggregate

For this study Badarpur sand was used as a fine aggregate. Test for specific gravity and sieve analysis (Table 2) were performed. All test result on aggregate are as follows.

(A) Specific Gravity using pycnometer is given by expression

Specific gravity = $(W_2-W_1) / ((W_2-W_1)-(W_3-W_4))$

= (873-555) / ((873-555)-(1847-1651))

= 2.606

Where,

W_1 = Weight of empty pycnometer = 555 gm

W_2 = Weight of pycnometer + weight of oven dried sand = 873 gm

W_3 = Weight of pycnometer + sand + water = 1847 gm

W_4 = Weight of pycnometer + water = 1651 gm

(B) Sieve analysis

Sand Sample = 1000 gm of Badarpur sand

Table 2

Sieve size	Mass retained (gm)	Mass retained (%)	Cumulative retained (%)	Cumulative passing (%)
4.75 mm	4	0.4	0.4	99.6
2.36 mm	211	21.1	21.5	78.5
1.18 mm	289	28.9	50.4	49.6
600 micron	193.3	19.33	69.73	30.27
300 micron	145.8	14.58	84.31	15.69
150 micron	80.1	8.01	92.32	7.68
75 micron	39.5	3.95	96.27	3.73
Pan	37.3	3.73	100	0.00

The grading of fine aggregate used was found to be Zone I as per IS:383-1970.

3.1.4 Fiber

Steel fibers were NOVOCON XR1050 supplied from NINA CONCRETE SYSTEMS PVT. LTD., Mumbai, Maharashtra. The properties of steel fiber are given in Table 3 below:

Table 3

Fiber Length	50 mm
Equivalent Diameter	0.85 to 1.25 mm
Tensile Strength	1000 N/mm^2
Deformation	Continuously Deformed
Appearance	Bright and Clean Wire

The aspect ratio l_f/d_f (ratio between fiber length and its equivalent diameter) was equal to 40-58 and their length equal to 50 mm.

3.1.5 Water

Water for mixing and curing was normal tap water and it was free from organic and suspended impurities.

3.1.6 Admixture

Conplast SP430 based on Sulphonated Naphthalene Polymers complies with IS: 9103:1999 procured from the FOSROC CHEMICAL LTD. was used as a high range water reducing Admixture. The amount of super plasticizer used was 1.0 % of the weight of cement. Properties are given in table 4 below.

Table 4

Particulars	Properties
PH	7.54
Specific gravity	1.205
Chloride content	Nil to IS:456
Alkali content	Less than 1.5 g Na_2O equivalent per liter of admixture
Optimum dosage	.5 to 2.0 liters per 100kg of cementitious material

3.2 Mix Design

According to IS:456-2000 and IS:1393-1980 the design of concrete mix should be based on the following factors:

- Grade of designation
- Type of cement
- Maximum nominal size of aggregates
- Grading of combined aggregates
- Water-cement ratio
- Workability
- Durability
- Quality control

As with any other type of concrete, the mix proportions for FRC depend upon the requirements for a particular job, in terms of strength, workability, and so on. Several Procedures for proportioning concrete mixes are available, which emphasize the workability of the resulting mix. However, there are some considerations that are particular to FRC.

In general, FRC mixes contain higher cement contents and higher ratio of fine to coarse aggregate than ordinary concretes, and so the mix design procedures that apply to conventional concrete may not be entirely applicable to FRC. Commonly, to reduce the quantity of cement, up to 30% of the cement is replaced with fly ash. In addition, to improve the workability of higher fiber volume mixes, water reducing admixtures and in particular, super plasticizers are often used, in conjugation with air entraining agent.

A particular fiber type, orientation and percentage of fibers, the workability of the mix decreased as the size and quantity of aggregate particles greater than 5 mm increased; the presence of aggregate particles less than 5 mm in size had little effect on the compacting characteristics of the mix.

The mixtures adopted for the present work were prepared to provide a cubic compressive strength for concrete higher than 30 N/mm^2, taking into account all factors affecting the mechanical behavior of fiber reinforced concrete, such as dosage and mechanical properties of components, fibers type, water-to-cement ratio, aggregates quality and dosage, and taking into account the current codes.

Ten different mixtures were prepared **(Table 5)**, varying the following parameters: fiber content in volume, aggregate fractions and cement content.

The dosage of Ordinary Portland Cement type grade 43 has been designed with respect to maximum aggregate size.

Table 5

Material \ Sample	A0	A1	A2	A3	A4	B0	B1	B2	B3	B4
Cement (kg/m^3)	380	380	380	380	380	350	350	350	350	350
Coarse Aggregate (kg/m^3)	1280	1280	1280	1280	1280	1350	1350	1350	1350	1350
Fine Aggregate (kg/m^3)	620	620	620	620	620	725	725	725	725	725
Steel Fiber [kg/m^3, V_f %]	0	39.25, 0.5	78.5, 1.0	117.75,1.5	157,2.0	0	39.25, 0.5	78.5, 1.0	117.75,1.5	157,2.0
Water (l/m^3)	160	160	160	160	160	140	140	140	140	140
Super plasticizer (l/m^3)	3.8	3.8	3.8	3.8	3.8	3.5	3.5	3.5	3.5	3.5
W/C Ratio	0.42	0.42	0.42	0.42	0.42	0.40	0.40	0.40	0.40	0.40

Fibers content in volume has been set equal to 0%, 0.5%, 1%, 1.5% and 2% corresponding to 0, 39.25, 78.5, 117.75 and 157 kg/m3 respectively. Water-to-cement ratio has been set equal to 0.40 and 0.38 such as to provide good mechanical strength and adequate workability of the mixtures.

Thirty cubic specimens having dimensions 150mm x 150mm x 150mm, three specimens for each mixture, are designated for compressive tests. And thirty prisms of size 150mm x 150mm x 700mm, three specimen for each mixture, are designated for flexural tests.

Mixtures and specimens preparation followed the current codes, both during the mixing and moulds filling phases and during the compaction phase occurred by means of a vibrating table. The slump of fresh reinforced concrete was also measured by means of Slump Cone Test to define its consistency class and designation. Twenty-four hours after the mixtures preparation, the specimens were taken out of the moulds and cured in tanks with temperature at 20^0C and relative humidity of 90%. Specimens were taken out of the curing tank 48 h before tests started.

Fig 3: Appearance of one of the batches of SFRC while fresh

CHAPTER 4

EXPERIMENTAL EQUIPMENT AND TEST PROCEDURES

4.1 Sieve Analysis:

This is the name given to the operation of dividing a sample of aggregate into various fraction each consisting of particles of same size. The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which we call gradation.

Grading curve:

The results of a sieve analysis can be grasped much more easily if represented graphically and, for this reason, grading charts are very extensively used. By using a chart, it is possible to see at a glance whether of a given sample conforms to that specified, or is too coarse or deficient in a particular size.

In the grading chart commonly used, the ordinates represent the cumulative percentage passing and the abscissa show the sieve opening plotted to a logarithmic scale. Since the openings of sieves in a standard series are in the ratio of ½, a logarithmic plot shows these opening at a constant spacing.

Grading Zone of Fine Aggregates

Table 6

IS SIEVE DESIGNATION	PERCENTAGE PASSING FOR			
	GRADING ZONE I	GRADING ZONE II	GRADING ZONE III	GRADING ZONE IV
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

4.2 Specific Gravity Test:

To determine the specific gravity (G) pycnometer test was done.

Empty pycnometer	=	A gm
Sand + pycnometer	=	B gm
Sand + water + pycnometer	=	C gm
Water + pycnometer	=	D gm

$$G = \frac{(B - A)}{\left((B - A) - (C - D)\right)}$$

4.3 Compression Test:

One of the important properties of concrete is its strength in compression. The strength in compression has a definite relationship with all the other properties of concrete, i.e., these properties are improved with the improvement in compressive strength, hence the importance of the test. Compression tests of cube specimens are made after 24 hrs of removal from the curing tank. Specimens are placed centrally on the location marks of the compression testing machine and load is applied continuously, uniformly and without shock. The rate of loading is continuously adjusted. The load is increased until the specimen fails and the maximum load carried by each specimen was recorded during the test. The detail of test result obtained is given in table no. 7

Cube Strength = Average load / Area of cross-section

4.4 Flexural Strength Test:

The determination of flexural tensile strength is conducted to estimate the load at which the concrete members may crack. The modulus of rupture is determined by testing standard test specimens of size 150mm x 150mm x 700mm over a span of 600mm, under the symmetrical two point loading. The detail of test result obtained is given in table no. 8.

4.5 Rebound Hammer Test:

The rebound hammer test was carried on the cube samples and prisms and rebound number was correlated with the compressive strength of concrete. The detail of rebound number is given in table no. 9.

CHAPTER 5

RESULT AND DISCUSSION

1. **Sieve Analysis:** The fine aggregate is confirming to Grading Zone III.

2. **Specific Gravity Test:**

The specific gravity of Coarse Aggregate is 2.655

The specific gravity of Fine Aggregate is 2.606

3. **Consistency of Cement:** Consistency of cement is 30%.

4. **Initial Setting Time of Cement:** Initial setting time of cement is 58 min.

5. **Final Setting Time of Cement:** Final setting time of cement is 280 min.

6. **Compressive test:**

Compression test results are shown in Table 7, these results allowed the mechanical characterization of the material and the evaluation of its compressive strength.

Table 7

Specimen	Weight (kg/m^3)	Load (kN)	Compressive strength (N/mm^2)	Compressive strength mean value (N/mm^2)
A0-1	2430	853	37.91	37.98
A0-2		849	37.73	
A0-3		862	38.31	
A1-1	2460	870	38.66	38.14
A1-2		848	37.69	
A1-3		857	38.09	
A2-1	2475	865	38.44	38.88
A2-2		877	38.98	
A2-3		883	39.24	

A3-1	2500	891	39.60	39.88
A3-2		898	39.91	
A3-3		903	40.13	
A4-1	2520	895	39.78	40.10
A4-2		910	40.44	
A4-3		902	40.09	
B0-1	2526	1079	47.95	47.80
B0-2		1062	47.20	
B0-3		1086	48.26	
B1-1	2560	1095	48.66	48.66
B1-2		1100	48.89	
B1-3		1090	48.44	
B2-1	2573	1110	49.33	49.48
B2-2		1105	49.11	
B2-3		1125	50.00	
B3-1	2592	1115	49.55	50.11
B3-2		1135	50.44	
B3-3		1133	50.35	
B4-1	2580	1137	50.53	50.68
B4-2		1141	50.71	
B4-3		1143	50.80	

Experimental results showed that compressive strength of SFRC is less affected by the presence of fibers. However, failure mode considerably changes from fragile to ductile. Due to bridging effect of the fibers, the cubic specimens did not crush but held their integrity up to the end of the test.

7. Flexural Strength Test:

The strength in bending is given by the extreme fiber stress on the tension side at the point of flexure.

If fracture occurs within middle third of the span, then

$$f = \frac{Wl}{bd^2}$$

Where,

f = Modulus of rupture or extreme fiber stress in tension

W = Load applied by testing machine

b = Width of beam at the point of failure

d = Depth of beam at the point of failure

l = Distance from failure point to the nearest support measured along the center line of the tension face.

The modulus of ruptures of different specimens is given in table no. 8.

Table 8

Specimen	Load W (kN)	l (mm)	Modulus of rupture "f" (N/mm^2)	Mean "f" (N/mm^2)
A0-1	42	280	3.48	3.54
A0-2	46	285	3.88	
A0-3	39	283	3.27	
A1-1	45	290	3.86	4.06
A1-2	48	279	3.97	
A1-3	52	283	4.36	
A2-1	58	287	4.93	5.28
A2-2	62	294	5.40	
A2-3	63	296	5.52	

A3-1	67	275	5.46	5.60
A3-2	68	282	5.68	
A3-3	67	285	5.65	
A4-1	70	290	6.01	5.90
A4-2	72	268	5.71	
A4-3	70.5	286	5.97	
B0-1	52	280	4.31	4.42
B0-2	52	285	4.39	
B0-3	56	276	4.58	
B1-1	60	283	5.03	4.84
B1-2	54	290	4.64	
B1-3	57	287	4.85	
B2-1	62	275	5.05	5.41
B2-2	65	292	5.62	
B2-3	66	285	5.57	
B3-1	63	282	5.26	5.65
B3-2	67	294	5.83	
B3-3	72	275	5.86	
B4-1	70	280	5.80	5.95
B4-2	72	282	6.01	
B4-3	74	276	6.05	

8. Rebound Hammer Test:

With increase in fiber content the compressive strength increases, rebound hammer helps in to determine the surface hardness of the concrete specimen without destroying the sample.

The result of rebound hammer test on the cubes is given in table no. 9.

Table 9

Specimen	Compressive strength (N/mm^2)		Specimen	Compressive strength (N/mm^2)	
	Individual	Mean		Individual	Mean
A0-1	35.5	36.73	B0-1	46.3	45.90
A0-2	36.7		B0-2	43.2	
A0-3	38.0		B0-3	48.2	
A1-1	36.5	37.00	B1-1	45.6	47.93
A1-2	37.0		B1-2	49.8	
A1-3	37.5		B1-3	48.4	
A2-1	36.4	38.16	B2-1	46.3	48.46
A2-2	38.9		B2-2	49.1	
A2-3	39.2		B2-3	50.0	
A3-1	37.6	39.20	B3-1	49.5	49.13
A3-2	39.9		B3-2	50.4	
A3-3	40.1		B3-3	47.5	
A4-1	38.7	39.70	B4-1	48.5	50.00
A4-2	40.4		B4-2	50.7	
A4-3	40.0		B4-3	50.8	

Discussion

As mention previously, mechanical properties of SFRC could be affected by factors, like specimen geometry, curing time, water/binder ratio (w/b), types of cement and supplementary cementitious material, steel fiber geometry, aspect ratio, volume fraction, etc.

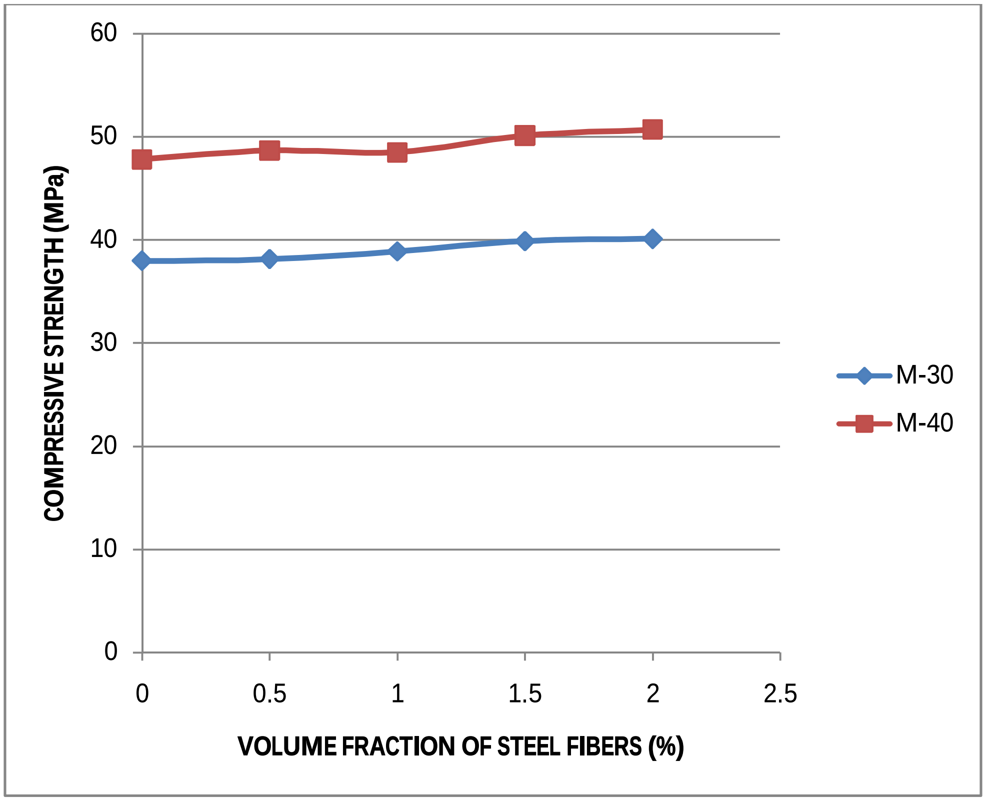

Fig 4: Graph between Compressive Strength and Volume fraction

Because of micro-cracks and other interstices in concrete, the transfer of shear stresses is irregular. The steel fibers, when homogeneously dispersed, act like small bridges and help for a better distribution of tensile and shear stresses. Therefore, the cracks in SFRC are smaller in size and they are spread more evenly. For example, the cubical samples of SFRC of our study did not break into pieces at the ultimate load, and the terminal stresses seemed to be distributed all over.

Fig 5: One of the concrete cubes with steel fiber after testing

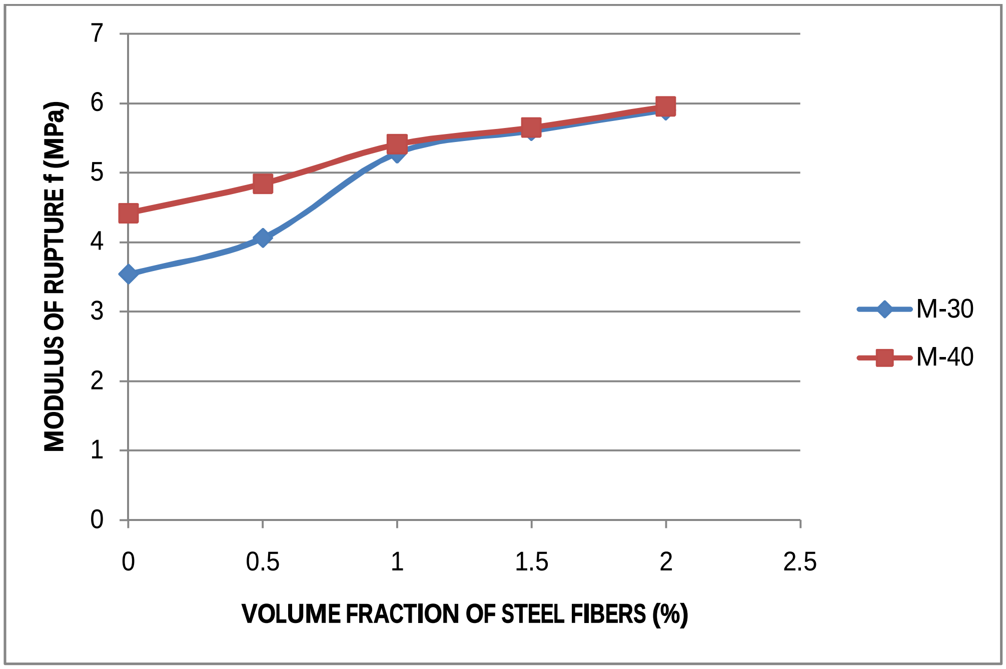

Fig 6: Graph Between Modulus of Rupture and Volume fraction of steel

When the fiber volume fraction increased from 0 to 2%, flexural strength increased from 3.54 to 5.9 MPa. The rate of increase of flexural strength is 14.6 to 66.6%, depending on the fiber volume fraction and aspect ratio. The fracture process of steel fiber-reinforced concrete consists of progressive debonding of fiber, during which slow crack propagation occurs. Final failure occurs due to unstable crack propagation when the fibers pull out and the interfacial shear stress reaches the ultimate bond strength. The reason for the increase in flexural strength is that, after matrix cracking, fibers will carry the load that the concrete sustained until cracking by interfacial bond between fibers and matrix.

Fig 7: One of the concrete samples with no steel fiber

Fig 8: One of the concrete samples with 0.5% volume of steel fiber

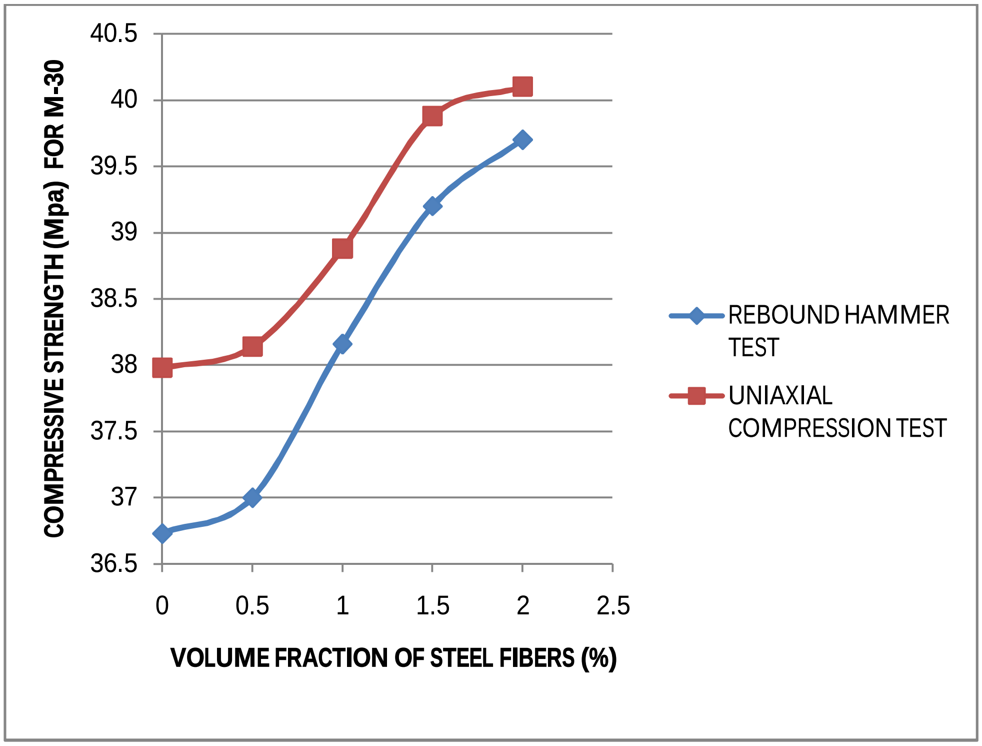

Fig 9: Graph between Rebound Hammer and Uniaxial compression test for M-30 grade of concrete

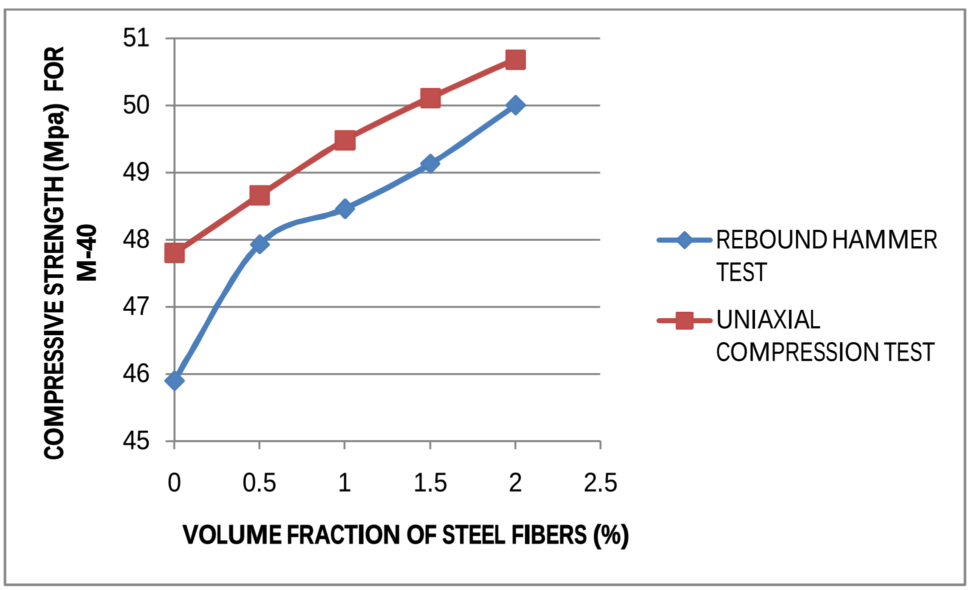

Fig 10: Graph between Rebound Hammer and Uniaxial compression test for M-40 grade of concrete

CHAPTER 6

CONCLUSION

The present experimental analysis was carried out in order to investigate steel fiber reinforced concrete mechanical behavior with respect to mix-design variations and different fiber content in volume values.

It is well known that one of the important properties of steel fiber reinforced concrete is its resistance to cracking. As a result, SFRC has increased extensibility and tensile strength under flexural loading. The fibers hold the matrix together even after extensive cracking. It yields pronounced post – cracking ductility, compared to ordinary concrete. Transformation from a brittle to ductile type of material increases the energy absorption characteristics of steel fiber reinforced concrete and its ability to withstand repeatedly applied, shock or impact loading. Conventional concrete structures in some structural applications are nowadays being substituted by steel fiber reinforced concrete. Hence, proper selection of fiber content, type and distribution is a keyword for ensuring quality of such structures.

From the above graphs between volume fraction of steel fibers, compressive strength of concrete and Flexural strength of concrete, it is clearly visible that the compressive strength and flexural strength of concrete increases with increase in dosage of steel fibers. However the increase in compressive strength is less as compared to increase in flexural strength.

Use of steel fibers in this study decreased the workability of concrete mixtures.

Unit weight of concrete is increased with using fibers.

Fibers play an important role in reaching a definite load bearing capacity after the matrix fracture, depending on allocation, orientation and embedded length. All these features are influenced by concrete composition (aggregate size and shape, concrete content, w/c-ratio, admixtures), fiber type, rheological properties, casting method, consolidation and others. As it was shown in this study, there is a clear dependence of the post-cracking load on the fiber content. From the experimental results, an important aspect could be noticed, which is the ductility and tenacity increase of SFRC when fiber content in volume increases. This phenomenon is due to the higher deformability and energy absorption of SFRC during the cracking phase; SFRC shows a higher bending stiffness and a different cracking pattern than normal concrete.

REFRENCES

- SHETTY, M.S, ‘Concrete technology’, S. Chand Publication.
- NEVILLE, A.M, ‘Properties of concrete;, IV edition, Pearson Education Pvt. Ltd. 2005
- M.C. Nataraja1, N. Dhang, A.P. Gupta / Cement & Concrete Composites 21 (1999) 383-390
- Fatih Altun, Tefaruk Haktanir, Kamura Ari / Construction and Building Materials 21 (2007) 654–661
- K. Holschemacher et al. / Materials and Design 31 (2010) 2604–2615
- Semsi Yazıcı, Gozde Inan, Volkan Tabak / Construction and Building Materials 21 (2007) 1250–1253
- B.W. Xu, H.S. Shi / Construction and Building Materials 23 (2009) 3468–3474
- V.M.C.F. Cunha, J.A.O. Barros, J.M. Sena-Cruz / Cement and Concrete Research 41 (2011) 64–76
- C.E. Chalioris, C.G. Karayannis / Cement & Concrete Composites 31 (2009) 331–341
- P.S. Song, S. Hwang / Construction and Building Materials 18 (2004) 669–673
- Jianming Gao, Wei Suqa & Keiji Morino / Cement and Concrete Composites 19 (1997) 307- 313
- Fushu Jeng, Ming-Lang Lin, Shih-Che Yuan / Tunnelling and Underground Space Technology 17 (2002) 69-82
- Qian Chunxiang, Indubhushan Patnaikuni, / Cement and Concrete Composites 21 (1999) 73-81
- R.S. Olivito, F.A. Zuccarello / Composites: Part B 41 (2010) 246–255
- IS:456-2000; ‘Plain and reinforced concrete – Code of practice’, BIS, New Delhi.
- IS:383-1970; ‘Specifications for coarse and fine aggregate from natural sources for concrete’, BIS, New Delhi.
- IS:516-1959; ‘METHODS OF TESTS FOR STRENGTH OF CONCRETE’, BIS, New Delhi.