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# Steel Fiber Reinforced Concrete: An Analysis

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*Abstract:*

*Steel Fiber Reinforced Concrete is a composite material made of hydraulic cements, water, fine and coarse aggregate, and a dispersion of discontinuous, small fibers. It may also contain pozzolans and admixtures commonly used with conventional concrete.Because of the vast improvements achieved by the addition of fibers to concrete, there are several applications where Fibers Reinforced Concrete (FRC) can be intelligently and beneficially used. This paper basically deals with discussion of SFRC and the very sources of inception of Fiber Rienforced Concrete. Furthermore, paper is devided into different parts which involves breif discussion about each and every aspect related to FRC'c focusing on SFRC mainly. In the last part of the paper various conclusions that has been put forwarded by various research scholars and from the author itself has been portraied.*

*KEYWORDS: Steel Fiber Reinforced Concrete, Fibers Reinforced Concrete (FRC), Glass, Steel, Synthetic Fiber, natural Fiber, mixing, Reinforcement mechanism.*

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# *Steel Fiber Reinforced Concrete: An Analysis*

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## PART I

### 1.1 INTRODUCTION

SFRC namely **Steel Fiber Reinforced Concrete** is a composite material made of hydraulic cements, water, fine and coarse aggregate, and a dispersion of discontinuous, small fibers. It may also contain pozzolans and admixtures commonly used with conventional concrete. All admixtures meeting ASTM specifications for use in concrete are suitable for use in SFRC. Because of the vast improvements achieved by the addition of fibers to concrete, there are several applications where Fibers Reinforced Concrete (FRC) can be intelligently and beneficially used. These fibers have already been used in many large projects involving the construction of industrial floors, pavements, highway-overlays, etc. in India. The principal fibers in common commercial use for Civil Engineering applications include steel (SFRC/SFRS), glass, carbon and aramid. These fibers are also used in the production of continuous fibers and are used as a replacement to reinforcing steel. High percentages of steel fibers are used extensively in pavements and in tunnelling.

Since, concrete is characterized by brittle failure, the nearly complete loss of loading capacity, once failure is initiated. This characteristic, which limits the application of the material, can be overcome by the inclusion of a small amount of short randomly distributed fibers (steel, glass, synthetic and natural) and can be practiced among others that remedy weaknesses of concrete, such as low growth esistance, high shrinkage cracking, low durability, etc. Steel fiber reinforced concrete （SFRC） has the ability of excellent tensile strength, flexural strength, shock resistance, fatigue resistance, ductility and crack arrest.

### 1.2 Generes of Fibers available;

below are the most commonly used fibre types isdiscussed, giving information on the manufacture of the fibre, its properties, fibre content in applications and the effects of the fibre type on concretes and mortars.

#### 1.2.1 Glass

In the form first used, glass fibres were found to be alkali reactive and products in which they were used deteriorated rapidly. Alkali-resistant glass containing 16% zirconia was successfully formulated in the 1960's and by 1971 was in commercial production in the UK. Other sources of alkali-resistant glass were developed during the 1970's and 1980's in other parts of the world, with higher zirconia contents. Alkali-resistant glass fibre is used in the manufacture of glass-reinforced cement (GRC) products, which have a wide range of applications.

#### 1.2.2 Steel

Steel fibres have been used in concrete since the early 1900s. The early fibres were round and smooth and the wire wascut or chopped to the required lengths. The use of straight, smooth fibres has largely disappeared and modern fibres have either rough surfaces, hooked ends or are crimped or undulated through their length. Modern commercially available steel fibres are manufactured from drawn steel wire, from slit sheet steel or by the melt-extraction process which produces fibres that have a crescent-shaped cross section. Typically steel fibres have equivalent diameters (based on cross sectional area) of from 0,15 mm to 2 mm and lengths from 7 to 75 mm. Aspect ratios generally range from 20 to 100. (Aspect ratio is defined as the ratio between fibre length and its equivalent diameter, which is the diameter of a circle with an area equal to the cross-sectional area of the fibre).

### 1.2.3 Synthetic fibres

Synthetic fibres are man-made fibres resulting from research and development in the petrochemical and textile industries. There are two different physical fibre forms: monofilament fibres, and fibres produced from fibrillated tape. Currently there are two different synthetic fibre 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 fibre 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.

### 1.2.4 Fabric and composite fibre reinforcement

South African manufacturers have been extremely innovative in developing versions of fibre for use with concrete. To overcome the bond and elastic modulus problem of polypropylene fibres, one development has been that of a composite of a core fibre (which can be polypropylene or a stiffer material such as acrylic, Kevlar, glass or carbon fibres) around which is spun a fluffy coating of polypropylene or ellulose. The coating can be bonded to the core at intervals to enhance the composite behaviour. These composite strands can be woven into a textile, or cut into appropriate lengths for a range of applications, especially thin elements such as permanent forms and decorative

cladding units.

### 1.2.5 Natural fibres

Natural reinforcing materials can be obtained at low cost and low levels of energy using local manpower and technology. Utilization of natural fibres 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-fibre 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-fibrereinforced cement has commercial applications in the manufacture

of flat and corrugated sheet and non-pressure pipes.

### 1.3 New Developments

A development of the last few decades has been significant research activity and increasing application of high-performance fibre-reinforced cement-based composites (HPFRCC). This has led to design recommendations being proposed for these materials recently in Japan. Particular classes are ultra high performance (UHPFRC) and strain-hardening (SHCC) fibre-reinforced cement-based composites. These composites are designed for particular applications varying from the requirement of high strength to that of high ductility. For instance UHPFRC have been designed for and applied in thin bridge decks or bridge deck overlays, with compressive strengths in the range 120 to 180 MPa and flexural strengths in the range 20 to 40 MPa. On the other hand, the requirement of energy dissipation in earthquake-resistant buildings has led to the use of highly ductile SHCC in coupling beams of cores of high rise reinforced concrete buildings in Japan. Other uses of SHCC include direct exploitation of its tensile deformability in bridge deck movement joint replacement, and protection of reinforced concrete structures by its multiple, fine cracking nature, which significantly retards the ingress of moisture, gas and chlorides. An example of this application is a thin SHCC overlay of an existing dam face.

## PART II

### 2.1 Background of Fiber Reinforced Concrete

Portland cement concrete is considered to be a relatively brittle material. When subjected to tensile stresses, non-reinforced concrete will crack and fail. Since mid 1800's steel reinforcing has been used to overcome this problem. As a composite system, the reinforcing steel is assumed to carry all tensile loads. The problem with employing steel in concrete is that over time steel corrodes due to the ingress of chloride ions. In the northeast, where sodium chloride de-icing salts are commonly used and a large amount of coastal area exists, chlorides are readily available for penetration into concrete to promote corrosion, which favors the formation of rust. Rust has a volume between four to ten times the iron, which dissolves to form it. The volume expansion produces large tensile stresses in the concrete, which initiates cracks and results in concrete spalling from the surface. Although some measures are available to reduce corrosion of steel in concrete such as corrosion inhibitive admixtures and coatings, a better and permanent solution may be replace the steel with a reinforcement that is less environmentally sensitive.

More recently micro fibers, such as those used in traditional composite materials, have been introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. FRC is Portland cement concrete reinforced with more or less randomly distributed fibers. In FRC, thousands of small fibers are dispersed and distributed randomly in the concrete during mixing, and thus improve concrete properties in all directions. Fibers help to improve the post peak ductility performance, pre-crack tensile strength, fatigue strength, impact strength and eliminate temperature and shrinkage cracks.

Several different types of fibers, both manmade and natural, have been incorporated into concrete. Use of natural fibers in concrete precedes the advent of conventional reinforced concrete in historical context. However, the technical aspects of FRC systems remained essentially undeveloped. Since the advent of fiber reinforcing of concrete in the 1940's, a great deal of testing has been conducted on the various fibrous materials to determine the actual characteristics and advantages for each product.

## 2.2 Performance Characteristics of Fiber Reinforced Concrete

### Reinforcement Mechanisms

Concrete carries flaws and micro-cracks both in the material and at the interfaces even before an external load is applied. These defects and micro-cracks emanate from excess water, bleeding, plastic settlement, thermal and shrinkage strains and stress concentrations imposed by external restraints. Under an applied load, distributed micro-cracks propagate coalesce and align themselves to produce macro-cracks. When loads are further increased, conditions of critical crack growth are attained at the tips of the macro-cracks and unstable and catastrophic failure is precipitated.

The micro and macro-fracturing processes described above, can be favorably modified by adding short, randomly distributed fibers of various suitable materials. Fibers not only suppress the formation of cracks, but also abate their propagation and growth.

Soon after placement, evaporation of the mix water and the autogenous process of concrete hydration create shrinkage strains in concrete. If restrained, this contraction can cause stresses far in excess of those needed to cause cracking. In spite of every effort, plastic shrinkage cracking remains a serious concern, particularly in large surface area placements like slabs on grade, thin surface repairs, patching and shotcrete linings. With large surface areas, fibers engage water in the mix and reduce bleeding and segregation. The result is that there is less water available for evaporation and less overall free shrinkage . When combined with post-crack bridging capability of fibers, fibers reduce crack widths and cracks areas when concrete is retrained.

In the hardened state, when fibers are properly bonded, they interact with the matrix at the level of micro-cracks and effectively bridge these cracks thereby providing stress transfer media that delays their coalescence and unstable growth. If the fiber volume fraction is sufficiently high, this may result in an increase in the tensile strength of the matrix. Indeed, for some high volume fraction fiber composite, a notable increase in the tensile/flexural strength over and above the plain matrix has been reported. Once the tensile capacity of the composite is reached, and coalescence and conversion of micro-cracks to macro-cracks has occurred, fibers, depending on their length and bonding characteristics continue to restrain crack opening and crack growth by effectively bridging across macro-cracks. This post-peak macro-crack bridging is the primary reinforcement mechanism in the majority of commercial fiber reinforced concrete composites.

Based on the discussion above, it emerges that fiber-reinforced cementitious composites can be classified into two broad categories: normal performance (or conventional) fiber-reinforced cementitious composites and high-performance fiber-reinforced cementitious composites. In FRCs with low to medium volume fraction of fibers, fibers do not enhance the tensile/flexural strength of the composite and benefits of fiber reinforcement are limited to energy absorption or ‗toughness‘ enhancement in the post-cracking regime only. For high performance fiber reinforced composites, on the other hand, with a high fiber dosage, benefits of fiber reinforcement are noted in an increased tensile strength, strain-hardening response before localization and enhanced ‗toughness‘ beyond crack localization.

### 2.3 Fiber-Matrix Bond

As in any fiber reinforced composite, fiber-matrix bond in FRC is of critical importance. However, unlike fiber reinforced polymers (FRPs) used in aerospace and automobile industries where fibers are employed to enhance strength and elastic modulus, in FRCs, toughness or energy absorption capability is of primary interest. Therefore, inelastic bond failure mechanisms such as interfacial crack growth, crack tortuousity and fiber slip are of greater relevance. Fiber pull-out tests are often performed to assess fiber efficiency in FRC and in such tests fiber bond and slip are monitored simultaneously.

For a fiber embedded in a cementitious matrix and subjected to a pull-out load, shear-lag will occur and interfacial debonding will commence at the point of fiber entry which will slowly propagate towards the free end of the fiber. Thus, some energy absorption will occur at the fiber-matrix interface while the bond is being mobilized and the fiber prepares to slip. Early in the development of fiber reinforced concrete it became apparent that for large, macro-fibers with small surface areas, a straight fiber will pull-out at low values of interfacial stress and will generate stress in fiber far below its tensile strength. Most commercial macro-fibers of steel and other materials (polypropylene, for example) are now deformed to enhance their bond with the surrounding matrix. However, even here there is a limit. If deformed excessively, fibers may develop stresses that exceed their strength and fracture in the process. The energy absorption in such cases is limited, and although some fiber slippage may precede fracture, poor toughening ensues. For maximized fiber efficiency, a pull-out mode of fiber failure where pull-out occurs at a fiber stress close to its tensile strength is preferred. It is important to mention that fiber failure mode is highly dependent on the angle at which fiber is inclined with respect to the direction of the pull-out force.

## PART III:

### 3.1 Enforcement of SFRC's and Its Importance

The randomly-oriented steel fibres assist in controlling the propagation of micro-cracks present in the matrix, first by improving the overall cracking resistance of matrix itself, and later by bridging across even smaller cracks formed after the application of load on the member, thereby preventing their widening into major cracks.

In general, SFRC is very ductile and particularly well suited for structures which are required to exhibit:

- Resistance to impact, blast and shock loads and high fatigue
- Shrinkage control of concrete (fissuration)
- Very high flexural, shear and tensile strength
- Resistance to splitting/spalling, erosion and abrasion
- High thermal/ temperature resistance
- Resistance to seismic hazards.
- The degree of improvement gained in any specific property exhibited by SFRC is
- Dependent on a number of factors that include:

- Concrete mix and its age
- Steel fibre content
- Fibre shape, its aspect ratio (length to diameter ratio) and bond characteristics.

The efficiency of steel fibres as concrete macro-reinforcement is in proportion to increasing fibre content, fibre strength, aspect ratio and bonding efficiency of the fibres in the concrete matrix. The efficiency is further improved by deforming the fibres and by resorting to advanced production techniques. Any improvement in the mechanical bond ensures that the failure of a SFRC specimen is due mainly to fibres reaching their ultimate strength, and not due to their pull-out.

### 3.2 Mix Design for SFRC

Just as different types of fibres have different characteristics, concrete made with steel fibres will also have different properties. When developing an SFRC mix design, the fibre type and the application of the concrete must be considered. There must be sufficient quantity of mortar fraction in the concrete to

adhere to the fibres and allow them to flow without tangling together, a phenomenon called ‘balling of fibres’. Cement content is, therefore, usually higher for SFRC than conventional mixes Aggregate shape and content is critical. Coarse aggregates of sizes ranging from 10 mm to 20 mm are commonly used with SFRC. Larger aggregate sizes usually require less volume of fibres per cubic meter. SFRC with 10 mm maximum size aggregates typically uses 50 to 75 kg of fibres per cubic meter, while the one with 20 mm size uses 40 to 60 kg. It has been demonstrated that the coarse aggregate shape has a significant effect on workability and material properties. Crushed coarse aggregates result in higher strength and tensile strain capacity. Fine aggregates in SFRC mixes typically constitute about 45 to 55 percent of the total aggregate content.

Typical mix proportions for SFRC will be: cement 325 to 560 kg; water-cement ratio 0.4- 0.6; ratio of fine aggregate to total aggregate 0.5-1.0; maximum aggregate size 10mm; air content 6-9%; fibre content 0.5-2.5% by volume of concrete. An appropriate pozzolan may be used as a replacement for a portion of the Portland cement to improve workability further, and reduce heat of hydration and production cost. The use of steel fibres in concrete generally reduces the slump by about 50 mm. To

overcome this and to improve workability, it is highly recommended that a super plasticizer be included in the mix. This is especially true for SFRC used for highperformance applications.Generally, the ACI Committee Report No. ACI 554 'Guide for Specifying, Mixing, Placing and Finishing Steel Fibre Reinforced Concrete' is followed for the design of SFRC mixes appropriate to specific applications.

### 3.3 EFFECT OF STEEL FIBER ON COMPRESSIVE, SPLITTING TENSILE AND MODULOUS OF RUPTURE OF CONCRETE:

Presently, a number of laboratory experiments on mechanical properties of SFRC have been done. Shah Suendra and Rangan, in their investigations conducted uni-axial compression test on fiber reinforced concrete specimens. The results shown the increase in strength of 6% to 17% compressive strength, 18% to 47% split tensile strength, 22% to 63% flexural strength and 8% to 25% modulus of elasticity respectively. Byung Hwan Oh, in their investigations, the mechanical properties of concrete have been studied, these results shown the increase in strength of 6% to 17% compressive strength, 14% to 49% split tensile strength, 25% to 55% flexural strength and 13% to 27% modulus of elasticity respectively. Barrows and Figueiras, in their investigations the mechanical properties of concrete have been studied, these results shown the increase in strength of 7% to 19% compressive strength, 19% to 48% split tensile strength, 25% to 65% flexural strength and 7% to 25% modulus of elasticity respectively. Chen S. investigated the strength of 15 steel fiber reinforced and plain concrete ground slabs. The slabs were 2x2x0.12m, reinforced with hooked end steel fibers and mill cut steel fibers.

Dwaraknath and Nagaraj,predicted flexural strength of steel fiber concrete by these parameters such as direct tensile strength, split cylinder strength and cube strength. James stated that the minimum fiber volume dosage rate for steel, glass and polypropylene fibers in the concrete matrix is calculated approximately 0.31%, 0.40% and 0.75%. Patton and Whittaker,investigated on steel fiber concrete for dependence of modulus of elasticity and correlation changes on damage due to load. Rossi et. All analyzed that the effects of steel fibers on the cracking at both local level (behavior of steel fibers) and global level (behavior of the fiber/cement composite) were dependent to each other. Sener et. Al, calibrated the size effect of the 18 concrete beams under four-point loading. Swami and Saad, had done an investigation on deformation and ultimate strength of flexural in the reinforced concrete beams under 4 point loading with the usage of steel fibers, where consists of 15 beams (dimensions of 130x203x2500mm) with same steel reinforcement (2Y-10 top bar and 2Y-12 bottom bar) and variables of fibers volume fraction (0%, 0.5% and 1.0%). Tan et al,concluded some investigation on the shear behavior of steel fiber reinforced concrete. 6 simply supported beams were tested under two- point loading with hooked steel fibers of 30mm long and 0.5mm diameter, as the fiber volume fraction increased every 0.25% from 0% to 1.0%. Vandewalle had done a similar crack behavior investigation, which based on combination of five full scale reinforced concrete beams (350x200x3600mm) with steel fibers (volume fraction of 0.38% and 0.56%).In this investigation, the experimental results and theoretical prediction on the crack width was compared. Pereira et al. had an experimental research on the steel fiber-reinforced self-compacting concrete and numerical simulation of punching test. Using notched cylindrical specimens, fracture energy of steel fiber reinforced concrete was measured, and a new trilinear cohesive law was proposed by Kazemi et al.. By testing the deformational behavior of conventionally reinforced steel fiber concrete beams in pure bending, Dwarakanath and Nagaraj gave an economical and efficient use of steel fibers. The study results given by Thomas and Ramaswamy indicate that the fiber and matrix interaction contributes significantly to enhancement of mechanical properties caused by the introduction of fibers. Numerical analysis and field test on performance of steel fiber reinforced concrete segment in subway tunnel were described by Zhu. Bending and uniaxial tensile tests on hybrid fiber reinforced concretes combining fibers with different geometry and material have been done by Sorelli et al.

## PART IV: CONCLUSION

The study on the introduction of effect of steel fibers can be still promising as steel fiber reinforced concrete is used for sustainable and long-lasting concrete structures. Steel fibers are widely used as a fiber reinforced concrete all over the world. Lot of research work had been done on steel fiber reinforced concrete and lot of researchers work prominently over it. This review study tried to focus on the most significant effects of addition of steel fibers to the concrete mixes. The steel fibers are mostly used fiber for fiber reinforced concrete out of available fibers in market. According to many researchers, the addition of steel fiber into concrete creates low workable or inadequate workability to the concrete, therefore to solve this problem of superplasticizer without affecting other properties of concrete may introduce.

Following conclusions are drawn based on the published literature on SFRC and new

generation high performance fiber reinforced concrete:

- The growth of the amount of research and applications of steel fiber reinforced concrete (SFRC) and high performance concrete has been phenomenal in the past seven or eight years. High performance concrete has become widely accepted practically on all continents.
- A generalized definition of high performance concrete seems to have been accepted by the engineering community. Such a definition is based on achievement of certain performance requirements or characteristics of concrete for a given application that otherwise can not be obtained from normal concrete as a commodity product. In many applications use of fiber is mandatory
- Much of the application of HP-SFRC remains in the areas of long-span bridges and high-rise buildings. It is used more for bridges than buildings in Europe and Japan, while more

buildings than bridges used HPC in the U. S. However, the situation is changing. Use of HPC in buildings is increasing these days.

- Increasing emphasis is being placed on concrete durability than its strength. In many applications, high strength concrete is used only because of its high durability quality rather than the need for its strength.
- Much research continues to be focused on the mechanical properties of high- and very-high-strength concretes with and without fibers and their structural applications. The results of this research are being incorporated into various national codes of practice. However, more information is needed on the behavior of the concrete at its early age and its relationship to the long-term performance.

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