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Applications and Properties of Fibre Reinforced Concrete

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ABSTRACT
In conventional concrete, micro-cracks develop before structure is loaded because of drying shrinkage and other causes of volume change. When the structure is loaded, the micro cracks open up and propagate because of development of such micro-cracks, results in inelastic deformation in concrete. Fibre reinforced concrete (FRC) is cementing concrete reinforced mixture with more or less randomly distributed small fibres. In the FRC, a numbers of small fibres are dispersed and distributed randomly in the concrete at the time of mixing, and thus improve concrete properties in all directions. The fibers help to transfer load to the internal micro cracks. FRC is cement based composite material that has been developed in recent years. It has been successfully used in construction with its excellent flexural-tensile strength, resistance to spitting, impact resistance and excellent permeability and frost resistance. It is an effective way to increase toughness, shock resistance and resistance to plastic shrinkage cracking of the mortar. These fibers have many benefits. Steel fibers can improve the structural strength to reduce in the heavy steel reinforcement requirement. Freeze thaw resistance of the concrete is improved. Durability of the concrete is improved to reduce in the crack widths. Polypropylene and Nylon fibers are used to improve the impact resistance. Many developments have been made in the fiber reinforced concrete.
Key words: Fiber Reinforced Concrete; Steel Fiber; Glass Fiber; Natural Fiber; Aspect Ratio; Mechanicaland Structural Properties.

I. INTRODUCTION

Concrete made from Portland cement, is relatively strong in compression but weak in tensionand tends to be brittle(Banthia N (2012)).The weakness in tension can be overcome by the use of conventional steel bars reinforcement and to some extent by the mixing of a sufficient volume of certain fibers. The use of fibers also recalibrates the behavior of the fiber-matrix composite after it has cracked through improving its toughness (Nataraja M.C., Dhang N).This thesis is aims to provide information on the properties and applications of the more commonly available fibers and their uses to produce concrete with certain characteristics. A new kind of fibre reinforced concrete is developed which is made from cellulose fibers.

A fibre is a small discrete reinforcing material produced from various materials like steel, plastic, glass, carbon and natural materials in various shapes and size(ACI Committee 440. 1996).

A numerical parameter describing a fibre as its aspect ratio, which is defined as the fibre length, divided by an equivalent fibre diameter [l/d].Typical aspect ratio[l/d] range from 30 to 150 for length dimensions of 0.1 to 7.62 cm typical fibre diameters are 0.25 to 0.76 mm for steel and 0.02 to 0.5 mm for plastic.

The plain concrete fails suddenly when the deflection corresponding to the ultimate flexural strength is exceeded, on the other hand fiber-reinforced concrete continue to sustain considerable loads even at deflections considerably in excess of the fracture deflection of the plain concrete.

1.0FIBER REINFORCED CONCRETE –

1.1 STEEL FIBER REINFORCED CONCRETE-teel fibre reinforce concrete is a composite material which is made up from cement concrete mix and steel fibres as a reinforcing. The steel fibres, which are uniformly distributed in the cementations mix .This mix, have various volume fractions, geometries, orientations and material properties. It has been shown in the research that fibres with low volume fractions (<1%), in fibre reinforced concrete, have an insignificant effect on both the compressive and tensile strength.

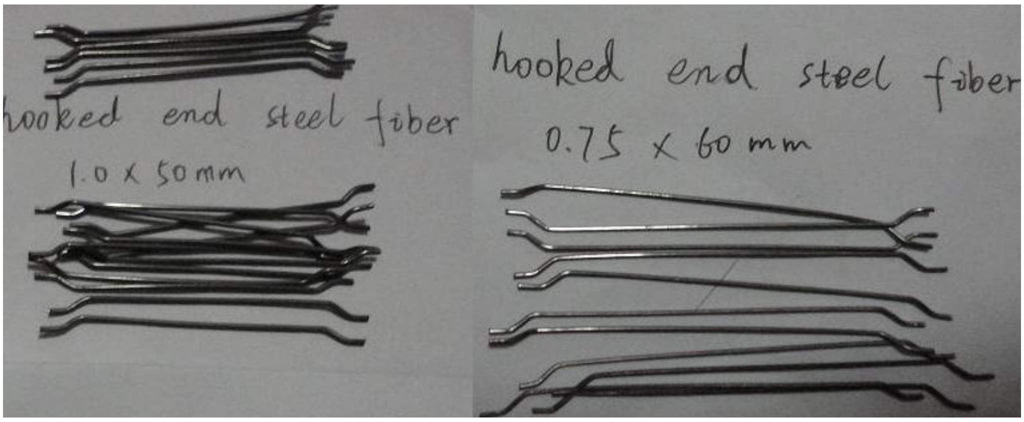

Figure -1 Steel Fiber

The types of steel fibers are defined by ASTM A820:-

- Type I: cold-drawn wire
- Type II; cut sheet
- Type III: melt-extracted
- Type IV: mill cut
- Type V: modified cold-drawn wire

Generally SFRC is very ductile and particularly well suited for structures which are required to exhibit:-

- High fatigue strength resistance to impact, blast and shock loads
- Shrinkage control of concrete
- Tensile strength, very high flexural, shear
- Erosion and abrasion resistance to splitting
- Temperature resistance, high thermal
- Earth quake resistance

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 fiber content, volume fraction
- Fiber geometry, its aspect ratio (length to diameter ratio) and bond characteristics volume fraction

1.2-GLASS FIBER REINFORCED CONCRETE -Glass fibre–reinforced concrete is (GFRC) basically a concrete composition which is composed of material like cement, sand, water, and admixtures, in which short length discrete glass fibers are dispersed. Inclusion of these fibres in these composite resultsin improved tensile strength andimpact strength of the material.GFRC has been used for a period of 30 years in several construction elements but at that time it was not so popular, mainly in non-structural ones, like facingpanels (about 80% of the GRC production), usedin piping for sanitation network systems, decorativenon-recoverable formwork, and other products.

Figure - 2 Glass Fibers

At the beginning age of the GFRC development, one of the most considerable problems was the durability of the glass fiber, which becomes more brittle with time, due to the alkalinity of the cement mortar. After some research, significant improvement have been made, andpresently, the problem is practically solved with the new types of alkali-resistant (AR resistance) glass fibers and with mortar additives that prevent the processes that lead to the embrittlement of GFRC**.**

1.3-POLYMER FIBER REINFORCED CONCRETE:-Civil structures made of steel reinforced concrete normally suffer from corrosion of the steel by the salt, which results in the failure of those structures. Constant maintenance and repairing is needed to enhance the life cycle of those civil structures.

There are many ways to minimize the failure of the concrete structures made of steel reinforce concrete. The custom approach is to adhesively bond polymer fiber composites onto the structure. This also helps to increase the toughnessand tensile strength and improve thecracking and deformation characteristics of the resultant composite. But this method addsanother layer, which is prone to degradation. These fiber polymer composites have been shown to suffer from degradation when exposed to marine environment due to surface blistering. As a result, the adhesive bond strength is reduced, which results in the de-lamination of the composite.

Figure - 3 Polymer Fibers

A uniform distribution of fibers throughout the concrete improves the homogeneity of the concrete matrix. It also facilitates reduced water absorption, greater impact resistance, enhanced flexural strength and tensile strength of concrete. The use of polymer fibers with concrete has been recognized by the Bureau of Indian Standards (BIS) and Indian Road Congress and is included in the following Standard documents:-

IS: 456:2000 – Amendment No.7, 2007
IRC: 44-2008 – Cement Concrete Mix Designs for Pavements with fibers
IRC: SP: 76:2008 – Guidelines for Ultra-Thin White Topping with fibersVision: 2021 by Ministry of Surface Transport, New Delhi

Polymer Fibre Reinforced concrete has been approved by National bodies like:-

* Central Public Works Department (CPWD)
* Airport Authority of India
* Military Engineering Services
* Defence Airfields
* NF/Southern Railway
* ISRO, Bangalore

1.4 - NATURAL FIBER REINFORCED CONCRETE –The first use of fibers in reinforced concrete has been dated to 1870's. Since then, researchers around the world have been interested in improving the tensile properties of concrete by adding, iron and other wastes.

Local interest has been demonstrated through research work performed. In addition to industrial fibers, natural organic and mineral fibers have been also investigated in reinforced concrete. Wood, sisal, jute, bamboo, coconut, asbestos androckwool, are examples that have been used and investigated.

Figure - 4 Natural Fibers

Specification for Concrete Aggregates -

Water and admixtures - The water to be used for the mix should be clean and of good quality. Admixtures such as accelerating agents may be used in order to decrease the influence of the glucose retardant.

Fibres - The length of fibers may vary from 1 to 2 in. (25 to 500 mm). Because natural fibers are naturally available materials, they are not uniform in diameter and length. Typical values of diameter for unprocessed natural fibres vary from 0.004 to 0.03 in. (0.10 to 0.75 mm).

Methods of mixing- The two methods of mixing and placing are:-

1.Wet mix
2. Dry-compacted mix.

In the wet mix, a low volume fraction of fibres is used. The water to be added to the mix has to take into account the high natural water content in the natural fibers

1.5 SYNTHETIC FIBRE-Synthetic fibres are no substitute for primary reinforcement in concrete because they add little or no strength. But structural reinforcement doesn't provide its benefits until concrete hardens. That's why some contractors add synthetic fiber to concrete as secondary. Unlike structural reinforcement, synthetic fibers providebenefits while concrete are still plastic. They also enhance some of the properties of hardened concrete.

1.5.1 Synthetic fibres types- The number of synthetic fibre has grown in recent years, the primary types of synthetic fibres commercially available in the India are polypropylene, polyester, and nylon. Though the fibres within each type come in various lengths, thicknesses, and geometries, synthetic fibres provide similar benefits when used as secondary concrete reinforcement.

Polypropylene- The synthetic fibers available in the United States, polypropylene is the most widely used in ready mixed concrete .Polypropylene fibers are hydrophobic, so they don't absorb water and have no effect on concrete mixing water requirements. They come as monofilaments.

Polyester- Though not as widely used as polypropylene fibers, polyester fibers are offered by several manufacturers. The fiber bundles come only in monofilament form in lengths from 0.75 to 2 inches.

Nylon- Like poly-ester fibres, nylon fibres come only in monofilament form. What primarily distinguishes them from polypropylene and polyester fibers is their hydrophilic nature. Nylon fibre manufacturers also report that their fibres have higher aspect ratios (ratio of length to diameter) than those made of polypropylene. Therefore, they can be added in smaller dosages to produce the same reinforcing effects. Usually no more than 1 pound per cubic yard is needed.

Mixing - Fibres can be added with the coarse and fine aggregate at the batch plant or to the central or truck mixer at the jobsite. If adding the fibers with other mix ingredients, no extra mixing time is needed. If adding the fibers to mixed concrete, agitate the concrete an additional 3 to 7 to disperse the fibers thoroughly.

II. Mechanical Properties of FRC-

2.1 COMPRESSION-

The presence of fibers may alter the failure mode of cylinders, but the fiber effect will be minor on the improvement of compressive strength values (0 to 15 %).

STEEL FIBER-The presence of fibers may alter the failure mode of concrete, but the fibers effect will be minor on the improvement of compressive strength values (0 to 15 percent).
The strain of SFRC corresponding to peak compressive strength increases as the volume fraction of fibers increases. As aspect ratio increases, the compressive strength of SFRC also increases marginally.

As the load increases, the deflection also increases. However the area under the load–deflection curve also increases substantially depending on the type and amount of fibers added.

GLASS FIBER – Glass fibers mixed thoroughly mixed in the composition and filled in the Steel mould of size 150 x 150 x 150 mm is well tighten and oiled thoroughly. They were allowed for curing in a curing tank for 28 days and they were tested in 200-tonnes electro hydraulic closed loop machine. The test procedures were used as per IS: 516-1979[16].

POLYMER FIBER - Compressive strength is essentially matrix dependent.In-plane ("edgewise") compressive strength will be somewhat lower than cross-plane strength due to the layers of glass fibers affecting the continuity of the matrix. Cross-plane compressive strength ("flatwise") is not influenced by the presence of glass fibers and will be about the same as the compressive strength measured on bulk matrix materials in cube or cylinder tests

NATURAL FIBERS- The cubes tests prepared with different fibers, different fibers volumetric ratios and different reductions in coarse aggregate, showed large variations in the test results as compared to the control specimens with no fibers. The variation in the results could be attributed to the relatively small size of the cube which may result in erroneous data compared with 15x30 cm standard cylinders.

SYNTHETIC FIBERS - The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is used primarily to resist compressive stress. The compression test was conducted on cube specimens cured for 7, 14 & 28 days. The test cubes were removed from the moist storage 24 hours before testing. The top and bottom bearing plates of the compression testing machine were wiped and cleaned before the placement of the specimen.

2.2 MODULUS OF ELASTICITY – Modulus of elasticity of FRC increases slightly with an increase in the fibers content. It was found that for each 1 percent increase in fiber content by volume there is an increase of 3 percent in the modulus of elasticity.

STEEL - The main parameters that characterise the compressive behaviour of concrete are the slope of the ascending branch (Young's modulus),the compressive strength, and the strain at peak stress. These parameters were determined from the respective average curve for each composite.

GLASS FIBER - Flexural stress-strain curves are used to determine values of modulus of elasticity for design purposes. Values of flexural modulus of elasticity are normally in the 1.5 to 2.9 X 10^6 Psi range, and will vary in accordance with water-cement ratio, sand content, cure, density, and degree of micro cracking. There is a lack of a continuous network of micro cracks at low stress level versus well develop network of micro cracks at or near flexural strength, thus giving lower E-value than normally associated with precast concrete panels.

NATURAL FIBER - The elastic modulus of composites was determined using tensile tests. Tensile tests were performed according to ASTM D 638 specification. Tensile tests were carried out using an MTS testing machine with load cell capacity of 10kN at a cross-head speed of 5 mm/min. Tensile elastic moduli were determined from the slopes of the stress strain curves.

SYNTHETIC FIBERS - Modulus of elasticity is a measure of a material's stiffness under tension: The constant relating stress (force) and strain (deformation) within the elastic range of a material or an engineering term used to describe a material's ability to stretch without losing its ability to return to its original physical properties. The higher the modulus of elasticity the stiffer the material.

2.3FLEXURAL STRENGTH –

STEEL FIBERS - For flexural strength test beam specimens of dimension 100x100x500 mm were cast. The specimens were demoulded after 24 hours of casting and were transferred to curing tank wherein they were allowed to cure for 28 days. These flexural strength specimens were tested fewer than two point and four point loading as per I.S. 516-1959, over an effective span of 400 mm on Flexural testing machine. Load and corresponding deflections were noted up to failure. In each category three beams were tested and their average value is reported.

GLASS FIBERS - The Steel mould of size 500 x 100 x 100 mm is well tighten and oiled thoroughly. They were allowed for curing in a curing tank for 28 days and they were tested in universal testing machine. The test procedures were used as per IS 516-1979.

NATURAL FIBERS – Flexure load involves the ability of the material to bend. Flexure loads are really a combination of tensile, compression and shear loads. When load is applied the upper surface is put into compression, the lower face is in tension, and the central portion of the partition experiences shear.

SYNTHETIC FIBERS - The current Standards for determining the post-cracking strength or residual strength of fiber reinforced concrete such as ASTM 1018, JSCE-SF 4, assume a linear elastic behaviour to calculate the post cracking strength. This implies that the post cracking strength of fiber reinforced concrete can be easily calculated using the equivalent

2.4 FATIGUE STRENGTH -

Fatigue is exhibited when a material fails under stress applied by direct tension or compression, torsion, bending or a combination of these actions.

STEEL FIBERS – All fatigue tests carried out using a closed loop Electrohydraulic Universal Testing Machine. The third point loading configuration used for determining the flexural fatigue strength test. The fatigue tests were conducted at various stress level

"S", which relates the maximum fatigue stress "f_{max}" to corresponding static flexural strength "f_{sf}" (S $=f_{max}/f_{sf}$). The stress level "S" ranged from 0.65 to 0.90. The fatigue test was carried out by applying constant amplitude sinusoidal non-reversal loads at a constant frequency of 20 cycles per second (20Hz).

GLAS FIBERS - Glass fiber reinforced polymer (GFRP) has a very important role to play as reinforcement in concrete structures which is exposed to harsh environment conditions where traditional steel reinforcement could corrode. It was found that the unique physical properties of GFRP that made it suitable for applications where conventional steel would be unsuitable. Compressive strength, flexural strength and split tensile strength for these AR glass fibers are more as compared to other glass fibers.

NATURAL FIBERS - The use of thenatural fibers in concrete mixes has beneficial effects with respect to increasing the flexuralstrength and providing a ductile post-cracking behaviour of the fiber reinforced concrete mix,especially for the industrial hemp samples. Similar to the compression tests, specimensprepared with 0.75 or 1% hemp fibers and 20% reduction in coarse aggregate providedrelatively good results. As for samples prepared with 0.5% palm with (10-20) % coarseaggregate reduction and with 1% banana fibers, the results were satisfactorily but to a lesser extent.

SYNTHETIC FIBER – Fatigue strength can be increased by inclusion of macro-fiber in concrete. Essentially, it is the ability of concrete to withstand under cyclic load without failure when exposed to a load. Plain, un-reinforced concrete, when subjected to a bending load, will withstand that load with very little movement until the cyclic load exceeds its fatigue strength.

2.5 STRUCTURAL BEHAVIOUR OF FRC SHEAR –

Addition of fibers increases shear capacity of reinforced concrete beams up to 80 percent. Addition of randomly distributed fibers increases shear-friction strength, the first crack strength, and ultimate strength.

STEEL FIBERS- In steel fiberAn important factor to take into account when evaluating the shear performance of fiber reinforced beams is the type of fibers**,** the increase in shear strength attributed to the fibers depends not only on the amount of fibers, usually expressed as the fiber vol.fractions V_f but also the aspect ratio and the anchorage conditions of steel fibers.
GLASS FIBERS- Shear is transmitted from one plane to another in various ways in reinforced concrete members. The behaviour, including the failure modes, depends on themethod of shear transmission. The simplest method of shear transfer is by shearing stresses. This occurs in uncracked members or in the uncracked portions of structural members.

NATURAL FIBERS – This load is tries to slide adjacent layers of fibres over each other. Under shear loads the resin plays the major role, transferring the stresses across the composites. For the composite to perform well under shear loads the resin element must not only exhibit good mechanical properties but must also have high adhesion to the reinforcement fibre. The interlaminar shear strength (ILSS) of a composite is often used to indicate this property in a multi-layer composite.

III. CONCLUSION –

1. STEEL FIBER - (Reference 15)
Superplasticizer – Superplasticizer Conforming IS 9103.

Fiber Type	Dia.	Length	Aspect Ratio	Density	Qty. of Fiber	W/c Ratio	Water	Cement	Fine aggr.	Course aggre.
Straight , Hook end	0.3 – 0.7 mm Max	25-35 mm	45,55 65,80	7900kg Per cu.	10kg Per m^3	0.50	180 kg Per m^3	OPC 53	Passing 4.75mm	20 mm

Improvement in Concrete Properties by Steel Fibers –

Compressive strength - Improved strength
Tensile strength - Improved tensile
Flexural Strength - It's improved up to 3 times more as compared to conventional concrete.
Fatigue Strength -Increase in 1.5 times
Impact strength- Improved and better resistance to wear and tear

Permeability - Improved permeability by inclusion of fibers
Corrosion – It may affect, but in extreme condition

2. GLASS FIBERS -(Reference 15)

Fiber Type	Dia.	Length	Aspect Ratio	Qty. of fiber	W/c Ratio	Water	Cement	Fine aggre.	Course aggre.
CemFil Anti-Crack HD	0.5 – 0.6 mm	25-35 mm	45,55,70	212 x 10^6	0.55	186 kg Per m^3	PPC Conf. IS: 4031	Passing 4.75mm	20 mm

Improvement in Concrete Properties by Glass Fibers –
Compressive strength –Increased about 20 – 30%
Tensile strength–It is improved compared to conventional concrete
Flexural Strength–Increased about 25 – 30%
Split Strength –Increased up to 25 – 30%
Impact strength - Improved and better resistance to wear and tear
Permeability - Improved permeability by inclusion of fibers
Corrosion – Better resistance to atmospheric effect compared to normal concrete

4. POLYMER FIBER **(Reference** 17)

Fiber Type	Dia.	Length	Sp. gravity	Aspect Ratio	W/c Ratio	Water	Cement	Fine aggre.	Course aggre.
Poly propylene (Fibrillated)	0.2-0.3 mm	12- 20 mm	0.91	45,60,70, 100	0.50	180 kg Per m^3	OPC 53	Passing 4.75mm	9 -19 mm

Improvement in Concrete Properties by Polymer Fibers –

Compressive strength –Increased about 16 %
Split strength –It is improved up to 23%
Flexural Strength – Increased about 30%
Abrasion resistance– Increased up to 20 – 50%
Toughness- Increases of 15%
Permeability - Improved,permeability decreases of 33% to45%by inclusion of fiber.

3. NATURAL FIBER **(**Reference 16)

Fiber Type	Dia.	Length	Aspect Ratio	Qty. of Fiber	W/c Ratio	Water	Cement	Fine aggr.	Course aggre.
Coir	0.6 mm.	30mm	50	10kg Per m^3	0.68	272 litres	PPC IS 4031	Passing 4.75mm	20 mm

Improvement in Concrete Properties by Natural Fibers –

Compressive strength –Increased about 10%
Tensile strength –It is improved compared up to 1.78%
Flexural Strength – Increased about 25 – 30%
Split Strength – Increased up to 25 – 30%
Impact strength - Improved and better resistance to wear and tear
Permeability - Improved permeability by inclusion of fibers
Corrosion – Better resistance to atmospheric effect compared to normal concrete

IV. SOME CONSIDERABLE FACTS FOUND -

1. Fiber addition improves ductility of concrete and its post-cracking load-carrying capacity.
2. Fibre reinforced concrete requires large quantities of fibres in order to make a difference regarding resistance.
3. Fiber addition improves ductility of concrete and its post-cracking load-carrying capacity.
4. There has been significant interest and development in the use of continuous fiber reinforcement for improving the behaviour of concrete. Fiber Reinforced Polymers (FRP) or sometime also referred to as Fiber Reinforced Plastic are increasingly being accepted as an alternative for uncoated and epoxy-coated steel reinforcement for pre-stressed and non-Pre-stressed concrete applications.
5. The most important contribution of fiber reinforcement in concrete is not to strength but to the flexural toughness of the material.
6. Plain concrete fails suddenly once the deflection corresponding to the ultimate flexural strength is exceeded, on the other hand, fiber-reinforced concrete continue to sustain considerable loads even at deflections considerably in excess of the fracture deflection of the plain concrete.
7. In FRC crack density is increased, but the crack size is decreased.The addition of any type of fibers to plain concrete reduces the workability.
8. Fiber-reinforced concrete is generally made with a high cement content and low water/cement ratio
9. Steel fibres reinforced concrete against impact forces, thereby improving the toughness characteristics of hardened concrete.
10. The largest application for steel fiber reinforced concrete is floor slab construction, although it's use as a replacement for or complement to structural reinforcement in other applications is growing fast.
11. Slump tests were carried out to determine the workability and consistency of fresh concrete. The efficiency of all fiber reinforcement is dependent upon achievement of a uniform distribution of the fibers in the concrete, their interaction with the cement matrix, and the ability of the concrete to be successfully cast or sprayed (Brown J. & Atkinson T.2012) [19].

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