Factors Affecting and Improving Mechanical Properties of Fiber Reinforced Concrete and its Interaction Between Fibre and Matrix

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ABSTRACT **- Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers. Within these different fibers that character of fiber reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation and densities. Some properties may or may not affect by the interaction of fibre and matrix. Also the interfacial bond between fibre and matrix has discussed. So in this paper its affects, detailed study of fibers for various conditions have been covered.**

Keywords**—FRC, Interfacial bond**

1. Introduction

Fiber Reinforced Concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers. Fiber reinforced concrete are of different types and properties with many advantages. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibers.

Fiber is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat. The fiber is often described by a convenient parameter called “aspect ratio”. The aspect ratio of the fiber is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 150

Fiber-reinforcement is mainly used in shotcrete, but can also be used in normal concrete. Fiber-reinforced normal concrete are mostly used for on-ground floors and pavements, but can be considered for a wide range of construction parts (beams, pliers, foundations etc) either alone or with hand-tied rebar’s

Concrete reinforced with fibers (which are usually steel, glass or “plastic” fibers) is less expensive than hand-tied rebar, while still increasing the tensile strength many times. Shape, dimension and length of fiber is important. A thin and short fibre, for example short hair-shaped glass fiber, will only be effective the first hours after pouring the concrete (reduces cracking while the concrete is stiffening) but will not increase the concrete tensile strength

The amount of fibers added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibers), termed "volume fraction" (V_f). V_f typically ranges from 0.1 to 3%. The aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the fiber's modulus of elasticity is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increasing the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers that are too long tend to "ball" in the mix and create workability problems.

Blends of both steel and polymeric fibers are often used in construction projects in order to combine the benefits of both products; structural improvements provided by steel fibers and the resistance to explosive spalling and plastic shrinkage improvements provided by polymeric fibers.

In certain specific circumstances, steel fiber or macro synthetic fibers can entirely replace traditional steel reinforcement bar ("rebar") in reinforced concrete. This is most common in industrial flooring but also in some other precasting applications. Typically, these are corroborated with laboratory testing to confirm that performance requirements are met. Care should be taken to ensure that local design code requirements are also met, which may impose minimum quantities of steel reinforcement within the concrete. There are increasing numbers of tunnelling projects using precast lining segments reinforced only with steel fibers

2. Description

2.1. Classification

Fibers on the basis of origin is broadly classified into two groups i.e

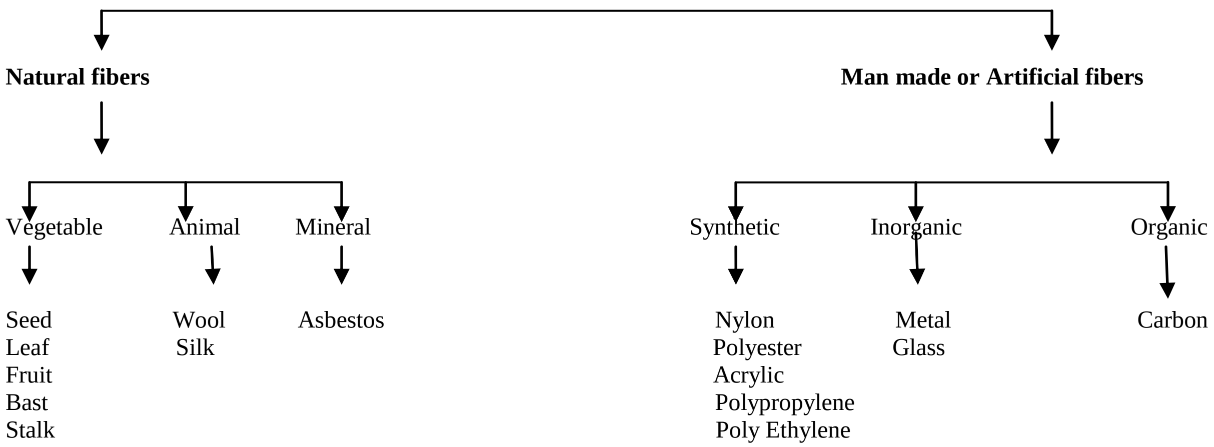


Figure 1. Flow chart of classification of fibres

2.2. Factors Affecting Properties of Fiber Reinforced Concrete

Fiber reinforced concrete is the composite material containing fibers in the cement matrix in an orderly manner or randomly distributed manner. Its properties would obviously, depends upon the efficient transfer of stress between matrix and the fibers. The factors are briefly discussed below:

1. Relative Fiber Matrix Stiffness

The modulus of elasticity of matrix must be much lower than that of fiber for efficient stress transfer. Low modulus of fiber such as nylons and polypropylene are, therefore, unlikely to give strength improvement, but the help in the absorption of large energy and therefore, impart greater degree of toughness and resistance to impart. High modulus fibers such as steel, glass and carbon impart strength and stiffness to the composite.
Interfacial bond between the matrix and the fiber also determine the effectiveness of stress transfer, from the matrix to the fiber. A good bond is essential for improving tensile strength of the composite.

2. Volume of Fibers

The strength of the composite largely depends on the quantity of fibers used in it. Fig 1 and 2 show the effect of volume on the toughness and strength. It can see from Fig 1 that the increase in the volume of fibers, increase approximately linearly, the tensile strength and toughness of the composite. Use of higher percentage of fiber is likely to cause segregation and harshness of concrete and mortar.

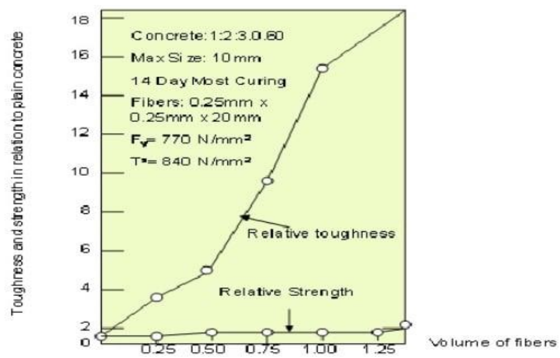


Fig.2: Effect of volume of fibers in flexure

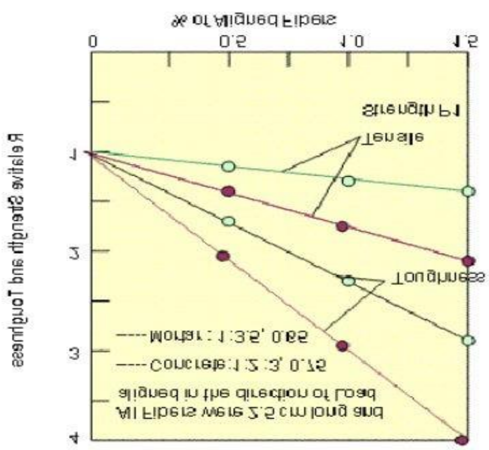


Fig.3: Effect of volume of fibers in tension

3. Aspect Ratio of the Fiber

Another important factor which influences the properties and behavior of the composite is the aspect ratio of the fiber. It has been reported that up to aspect ratio of 75, increase on the aspect ratio increases the ultimate concrete linearly. Beyond 75, relative strength and toughness is reduced. Table-1 shows the effect of aspect ratio on strength and toughness.

Table-1: Aspect ratio of the fiber

Type of concrete	Aspect ratio	Relative strength	Relative toughness
Plain concrete	0	1	1
With	25	1.5	2.0
Randomly	50	1.6	8.0
Dispersed fibers	75	1.7	10.5
	100	1.5	8.5

4. Orientation of Fibers

One of the differences between conventional reinforcement and fiber reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while fibers are randomly oriented. To see the effect of randomness, mortar specimens reinforced with 0.5% volume of fibers were tested. In one set specimens, fibers were aligned in the direction of the load, in another in the direction perpendicular to that of the load, and in the third randomly distributed.
It was observed that the fibers aligned parallel to the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibers.

5. Workability and Compaction of Concrete

Incorporation of steel fiber decreases the workability considerably. This situation adversely affects the consolidation of fresh mix. Even prolonged external vibration fails to compact the concrete. The fiber volume at which this situation is reached depends on the length and diameter of the fiber.

Another consequence of poor workability is non-uniform distribution of the fibers. Generally, the workability and compaction standard of the mix is improved through increased water/ cement ratio or by the use of some kind of water reducing admixtures.

6. Size of Coarse Aggregate

Maximum size of the coarse aggregate should be restricted to 10mm, to avoid appreciable reduction in strength of the composite. Fibers also in effect, act as aggregate. Although they have a simple geometry, their influence on the properties of fresh concrete is complex. The inter-particle friction between fibers and between fibers and aggregates controls the orientation and distribution of the fibers and consequently the properties of the composite. Friction reducing admixtures and admixtures that improve the cohesiveness of the mix can significantly improve the mix.

7. Mixing

Mixing of fiber reinforced concrete needs careful conditions to avoid balling of fibers, segregation and in general the difficulty of mixing the materials uniformly. Increase in the aspect ratio, volume percentage and size and quantity of coarse aggregate intensify the difficulties and balling tendency. Steel fiber content in excess of 2% by volume and aspect ratio of more than 100 are difficult to mix.

It is important that the fibers are dispersed uniformly throughout the mix; this can be done by the addition of the fibers before the water is added. When mixing in a laboratory mixer, introducing the fibers through a wire mesh basket will help even distribution of fibers. For field use, other suitable methods must be adopted

2.3. The role of fibers improving the mechanical properties under different conditions

2.3.1. 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

2.3.2.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 106 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.

2.3.3 Flexural 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.

2.3.4.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 "fmax" to corresponding static flexural strength "fsf" (S =fmax/fsf). 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.

2.4. FIBRE Matrix Bond

Fiber matrix interfacial bond can be studied using either direct or indirect tests. In indirect test , the composite is tested in tension or bending and the fibre contribution is evaluated.

In direct test a pull out test is used for a single fibre to determine the interfacial properties, average bond strength and the load slip behavior.

Embedded single-fiber tension This test determines the shear strength of the interface. A single fiber oriented along the specimen axis is molded into a thin, flat, dog-boned specimen of matrix material. The specimen is typically cast in an open-faced silicone rubber mold. Usually, multiple-cavity molds (10 to 20 cavities or more) are used to accommodate a large number of replicate specimens. The matrix must be ductile enough to absorb, without fracturing, the energy released when the fiber breaks locally under the applied tensile load (local matrix cracking is acceptable). The loading is continued and additional fiber breaks occur until the specimen fractures. The procedure can be observed under polarized light in a microscope. The fiber breaks and debonding along the interface are readily visible. If a transparent matrix is not used, the specimen is simply loaded to failure, the matrix is digested away and the lengths of fiber fragments are measured.

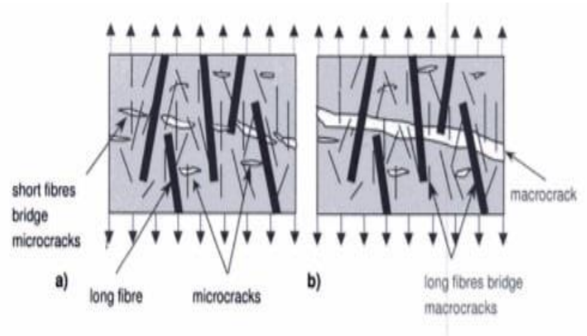
The principle is that the fiber will continue to fragment into shorter and shorter lengths until they are too short to develop tensile stresses via shear transfer from the matrix sufficient to further fracture the fiber. This "critical length" is then used to calculate the interfacial shear strength, knowing the tensile strength of the fiber.

Single-fiber pull-out : In this interfacial shear strength test, a single fiber is fully embedded (typically with both ends protruding from the surfaces, as shown) in a thin sheet or film of matrix material. The force required to pull the fiber out of the film is determined, and the corresponding interfacial shear strength is calculated. For small-diameter fibers that exhibit high interfacial bond strengths — typical of those used in high-performance composites — the matrix film might have to be extremely thin (e.g., 0.05 mm/0.002 inch thick) so the fiber will pull out before it breaks. Because it is difficult to prepare such thin specimens, this method has given way somewhat to the following method.

Microdebond test : Developed in the mid-1980s, this method also tests interfacial shear strength. It is sometimes termed the bead pull-off test to clearly distinguish it from the microdebond test. A bead (drop) of matrix material is cured in place on an individual fiber. Then the bead is restrained by opposing knife edges and stripped off when a tensile force is applied to the fiber. The interfacial shear strength is the force divided by the embedded area of the fiber. The bead must be small enough to permit the fiber to pull out rather than break. Typically, bead diameters in the 100 to 200 μm range are suitable.

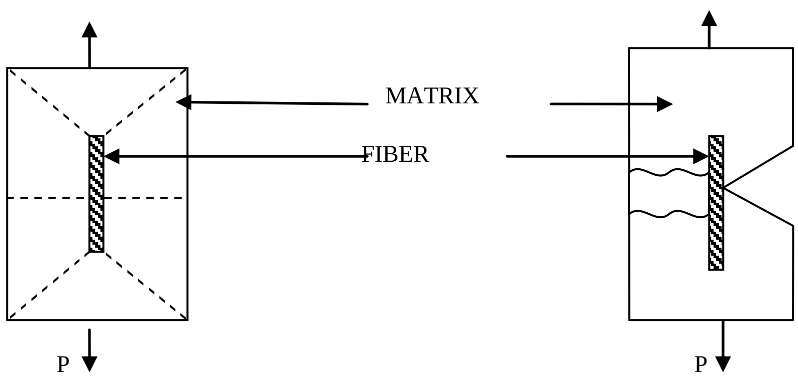
In summary, the embedded single-fiber tension and the microbond (bead pull-off) test which are interfacial shear methods, are most commonly used. The micro bond test is the easiest to perform.

2.5. Interaction Between Fiber Matrix Composite Under Cracked And Uncracked Condition.



2.5.1. Under Cracked Condition

- When Composited fiber matrix is subjected to Tension, the matrix cracks at a certain stage
- The fiber in the matrix carries the load across the crack and transmits the load from one side of matrix to the other.
- The main benefits of fiber in harden concrete relate to post-cracking state,where the fiber bridging the cracks contribute to the increase in strength failure strain and toughness of the composite
- Following are the critical issues in the fiber matrix interaction in cracked stage
  - (i) Load slip variation
  - (ii) Geometry and orientation effect
  - (iii) Identity the pull out resistance of a single fiber
  - (iv) Interaction of randomly distributed fiber



Uncracked matrix in tension Cracked matrix in tension

2.5.2. Under Uncracked Condition

- The interaction between the fiber and matrix is the fundamental properties that affects the performance of cement – based fiber composite material
- Fiber interaction with homogeneous uncracked matrix occurs in almost all composites during the initial stages of loading
- It has very limited importance in practical applications, but even when cracks develop in the composite, the uncracked portions of the structure affects the overall behaviour of the structural system
- The stresses in both the matrix and the fiber are assumed to be none, in the unloaded stage
- When the load is applied to the matrix , part of the load is transferred to the fiber along its surface, due to difference in stiffness between fiber and matrix, shear stress develop along the surface of the fiber
- The deformation at and around the fiber will be smaller, when the fiber is stiffer than the matrix. This is generally occurs in steel and mineral fibers and vice versa(in polymers)
- As long as the matrix and the fiber are within elastic range, elastic stress transfer exists in an uncracked composite.

3. Concluding Remarks

It can be concluded that the fibers are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact–, abrasion–, and shatter–resistance in concrete. Generally fibers do not increase the flexural strength of concrete, and so cannot replace moment–resisting or structural steel reinforcement Indeed, some fibers actually reduce the strength of concrete and this can be improved by adding steel fibers or any other fibers to the concrete. Thus fibers can Improve structural strength, Reduce steel reinforcement requirements, Reduce crack widths and control the crack widths tightly, thus improving durability ,Improve impact– and abrasion–resistance ,improve freeze-thaw resistance Nevertheless, more study should be conducted to understand the behavior of fiber reinforced concrete when subjected to high temperature by varying parameters such as the steel fiber ratio, the type of concrete and the range of temperatures, volume of void inside the sample and its effect on spalling.

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