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Effects Of Steel Fibres in Reinforced Concrete

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Abstract

Steel fibre reinforcement concrete (SFRC), a composite material made of hydraulic cements, water, fine and coarse aggregate and dispersion of discontinues small fibres (steel fibre) is well as one of the superior crack resisting building materials. The primary function of steel fibre is to modify micro and macro cracking by intercepting cracks at their origin and inhibit crack growth. As a result of this ability to arrest cracks, fibre composite possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading ; and the fibres are able to hold the matrix together even after extensive cracking.,

Steel fibre transforms the concrete which is brittle in to ductile, robust, durable and resistant composite materials. This transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied , shock or impact loadings. Above all, significant cost saving are often achieved by the use of steel fibres ; mainly by partial or total replacement of ordinary reinforcement, but also by improving serviceability and durability. Today, the major fibre applications are as a replacement of the welded mesh in industrial floors, and as reinforcement in sprayed concrete.

Key words: Steel fibre, Ductile, Crack, Brittle, Concrete.

1.Introduction

The advantages of using fibres as reinforcement have been known since ancient times; e.g. 3500 years ago, sun-baked bricks were reinforced with straw. In modern times, in the early 1900s, asbestos cement was the first widely used manufactured composite.

In the 1960s, research on fibre-reinforced concrete was already advancing fast, and at the present time, fibres of various kinds are used to reinforce concrete in structural applications. Due to its high stiffness, the steel fibre is probably the most commonly used fibre material. However, synthetic fibres are gaining ground, and new materials are under continuous development.

The fibre-reinforced concrete materials may be classified as strain hardening or strain softening, to a large extent depending on the amount of fibres added. Strain hardening is recognized by an increasing tensile stress after the first cracking, and it is accompanied by multiple cracking; strain-softening materials exhibit a decreasing tensile stress after the first cracking.Strain softening materials are composed of moderate amounts of fibre, typically Vf < 1.0% by volume. They have become quite popular in the construction of industrial floors and are frequently used for tunnel linings (as sprayed concrete).The benefits of a strain-softening, fibre-reinforced material, as opposed to plain concrete, is mainly the greater possibility to control the size of the crack widths; thus it may play a major role from the point of view of durability. That is, smaller crack widths will delay the initiation of corrosion of the conventional reinforcement and consequently increase the possibility of a longer life span of the structure. In the past decade, self-compacting, fibre-reinforced concrete (SCFRC), has attracted increased scientific attention.With the use of SCFRC, the concrete is able to fill the mould driven by its own weight, thus avoiding the settling of fibres and aggregates, which may be caused by vibration.Strain hardening may be obtained by increasing the amount of fibre, although this is not quite as straightforward as it may appear. For the slender fibres that are preferred for improved toughness, the reduced workability at increasing amounts of fibre, limits the maximum amount of fibres that can be incorporated in the FRC mix. Although this can be overcome by different techniques, e.g. by reducing the aggregate size, increasing the paste content (water, cement, mineral additions and fine particles) and introducing super-plasticizers, or by pre-placing the fibres, as in SIFCON (slurry infiltrated fibre concrete) and SIMCON (slurry infiltrated mat concrete), these techniques are quite costly. By optimising the different components of the FRC, strain hardening may be achieved without simply an increase in fibre volume. Methods for obtaining strain-hardening composites with a normal strength matrix and moderate fibre content of about 2 % by volume.

2.Design methods for fibre-reinforced concrete

At the time this work on steel fibre effects began, test methods were available together with proposals for design methods for fibre-reinforced concrete (FRC), but nothing existed that was completely accepted and agreed upon within the concrete community.The interest in fibres as reinforcement can be seen in the numerous workshops and conferences. For the continued work within the project, it was realized that most of the current literature on FRC concerns the effect of fibres on the load-bearing capacity and increased ductility. Although several approaches to analytical descriptions can be found for analysing the flexural behaviour of FRC there is still a gap in the literature: that of small crack widths. The crack width depends among other factors on the crack spacing that the formulation for crack spacing was not applicable to FRC. In the modified proposals for the calculation of crack spacing in FRC and in the Italian design draft for FRC by Ascione, Berardi et al. (2006), the aspect ratio (ratio of fibre length to fibre diameter) was taken into account. By multiplying the formula for crack spacing in plain concrete by the factor (50 df / lf), the contribution of the fibre to reduced crack spacing was assumed to have been accounted for. However, the actual fibre content was not. Hence, a fibre-volume fraction Vf = 0.25% would yield the same crack spacing as Vf = 1.0%

3.The effect of fibre distribution

As expected, the fibre distribution has a major effect on the residual capacity, which is why it is important to be able to control this. The cracking stress was affected by the fibre-free areas in the cross sections since they act as defects in the material. Fibre distribution and orientation have been found to depend on many factors, including: casting and placement technique, specimen size, fibre size, geometry and fibre content, and maximum aggregate size.

Small fibre-volume fractions exhibit a larger scatter in fibre distribution than higher fibre-volume fractions. In addition, owing to workability, there exists a critical upper limit of the amount of fibre that can be added directly to the concrete. The workability problem can be overcome by special techniques, such as (slurry infiltrated fibre concrete) and (slurry infiltrated mat concrete). For the steel fibres are placed in a mould, with fibre volumes of typically 4 to 12%, and the concrete paste is then infiltrated.

4.Properties of SFRC

4.1. Compressive Strength:

SFRC has many developed properties as compare to those of plain concrete. Fibres do little to enhance the static compressive strength of concrete, with increases in strength ranging from essentially nil to perhaps 25%. Even in members which contain conventional reinforcement in addition to the steel fibres, the fibres have little effect on compressive strength. However, the fibres do substantially increase the post-cracking ductility, or energy absorption of the material. Figure 1 shows the stress-strain curves of SFRC as compared with plain concrete.

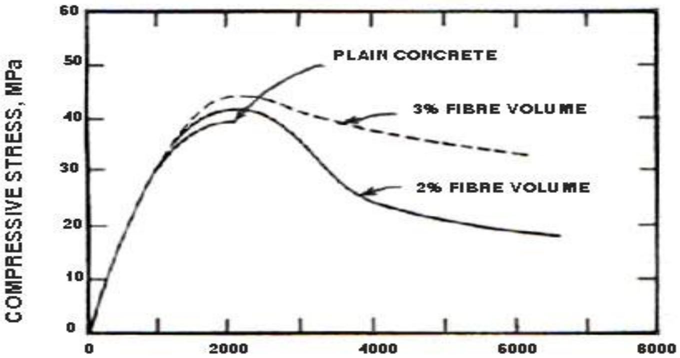

Figure 1: Stress-Strain curves in compression for SFRC. [5]

4.2. Tensile strength

Fibres aligned in the direction of the tensile stress may bring about very large increases in direct tensile strength, as high as 133% for 5% of smooth, straight steel fibres. However, for more or less randomly distributed fibres, the increase in strength is much smaller, ranging from as little as no increase in some instances to perhaps 60%, with many investigations indicating intermediate values, as shown in figure 2. Splitting-tension test of SFRC show similar result. Thus, adding fibres merely to increase the direct tensile strength is probably not worthwhile. However, as in compression, steel fibres do lead to major increases in the post-cracking behaviour or toughness of the composites.

Figure 2 shows the influence of fibre content on tensile strength of concrete.

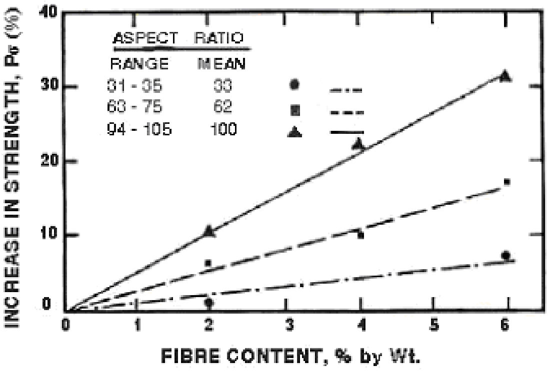

Figure 2: Influence of fibre content on tensile strength. [5]

4.3. Flexural Strength

Steel fibres are generally found to have aggregate much greater effect on the flexural strength of SFRC than on either the compressive or tensile strength, with increases of more than 100% having been reported. The increase in flexural strength is particularly sensitive, not only to the fibre volume, but also to the aspect ratio of the fibres, with higher aspect ratio leading to larger strength increases. Figure 3 describes the fibre effect in terms of the combined parameter W*l/d*, where *l/d* is the aspect ratio and W is the weight percent of fibres. It should be noted that for W*l/d* > 600, the mix characteristics tended to be quite unsatisfactory. Deformed fibres show the same types of increases at lower volumes, because of their improved bond characteristics. Figure 3 shows the increase in flexural strength in concrete with respect to increase of steel fibres.

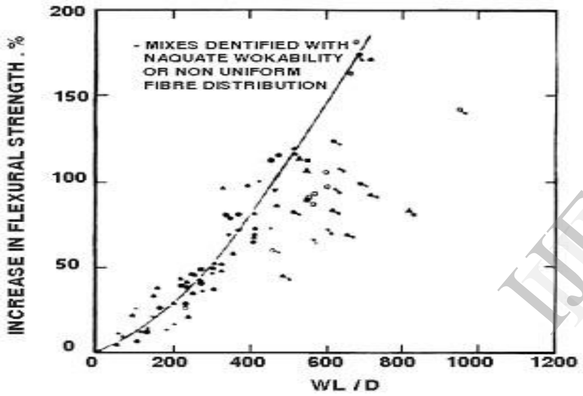

Figure 3: The effect of Wl/d on the flexural strength of mortar and concrete. [5]

5. Scope and limitations

Self-compacting fibre-reinforced concrete was used in all tests, as this type of concrete has the benefits of improving the mechanical properties (e.g. bond and strength), allowing larger amounts of fibre to be added and reducing the amount of work required to compact the concrete. Moreover, this type of concrete also eliminates settling of the fibres due to vibration, although it may cause other types of orientation effects. With respect to bond properties, comparisons with conventional vibrated concrete were made by referring to earlier calibrations of the bond model used in the finite element analyses and comparing with the bond model. SFRC can, in general, be produced using conventional concrete practice, though there are obviously some important differences. The basic problem is to introduce a sufficient volume of uniformly dispersed to achieve the desired improvements in mechanical behaviour, while retaining sufficient workability in the fresh mix to permit proper mixing, placing and finishing. The performance of the hardened concrete is enhanced more by fibres with a higher aspect ratio, since this improves the fibre-matrix bond. On the other hand, a high aspect ratio adversely affects the workability of the fresh mix. In general, the problems of both workability and uniform distribution increase with increasing fibre length and volume.

One of the chief difficulties in obtaining a uniform fibre distribution is the tendency for steel fibres to ball or clump together. Clumping may be caused by a number of factors:

i. The fibres may already be clumped together before they are added to the mix; normal mixing action will not break down these clumps.
ii. Fibres may be added too quickly to allow them to disperse in the mixer.
iii. Too high a volume of fibres may be added.
iv. The mixer itself may be too worn or inefficient to disperse the fibres.
v. Introducing the fibres to the mixer before the other concrete ingredients will cause them to clump together.

6. Experimental procedures

As with any other type of concrete, the mix proportions for SFRC depend upon the requirements for a particular job, in terms of strength, workability, and so on. Several procedures for proportioning SFRC mixes are available, which emphasize the workability of the resulting mix. However, there are some considerations that are particular to SFRC. In general, SFRC mixes contain higher cement contents and higher ratios of fine to coarse aggregate than do ordinary concretes, and so the mix design procedures the apply to conventional concrete may not be entirely applicable to SFRC. Commonly, to reduce the quantity of cement, up to 35% of the cement may be replaced with fly ash. In addition, to improve the workability of higher fibre volume mixes, water reducing admixtures and, in particular, super-plasticizers are often used, in conjunction with air entrainment. The range of proportions for normal weight SFRC is shown in table 1. For steel fibre reinforced shotcrete, different considerations apply, with most mix designs being arrived at empirically. Typical mix designs for steel fibre shotcrete are given in table 2. A particular fibre 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. Figure 4 shows the effects of maximum aggregate size on workability.The second factor which has a major effect on workability is the aspect ratio (l/d) of the fibres. The workability decreases with increasing aspect ratio, as shown in figure 5, in practice it is very difficult to achieve a uniform mix if the aspect ratio is greater than about 100.

Table 1: Range of proportions for normal weight fibre reinforce Concrete. [1]

Property	Mortar	9.5mm Maximum aggregate size	19 mm Maximum aggregate size
Cement (kg/m^3)	415-710	355-590	300-535
w/c ratio	0.3-0.45	0.35-0.45	0.4-0.5
Fine/coarse aggregate(%)	100	45-60	45-55
Entrained air (%)	7-10	4-7	4-6
Fibre content (%) by volume			
smooth steel	1-2	0.9-1.8	0.8-1.6
deformed steel	0.5-1.0	0.4-0.9	0.3-0.8

Table 2: Typical steel fibre reinforced shotcrete mixes.[7]

Property	Fine aggregate mixture (Kg/m^3)	9.5 mm Aggregate mixture (Kg/m^3)
Cement	446-559	445
Blended sand(<6.35mm)	1438- 1679	697-880
9.5mm aggregate		700- 875
Steel fibres	35- 157	39-150
Accelelator	Varies	Varies
w/c ratio	0.40- 0.45	0.40-0.45

- The sand contained about 5% moisture
- 1% steel fibres by volume = 78.6kg/m3
- Since fibre rebound is generally greater than aggregate rebound. There is usually a smaller percentage of fibres in the shotcrete in place.

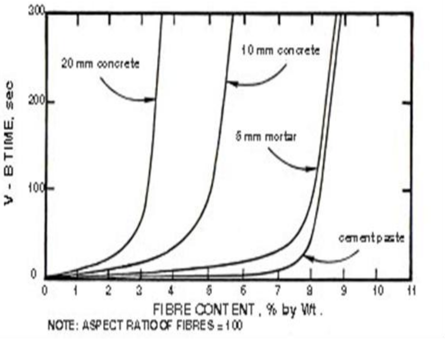

Figure 4: Workability versus fibre content for Matrices with different maximum aggregate sizes. [13]

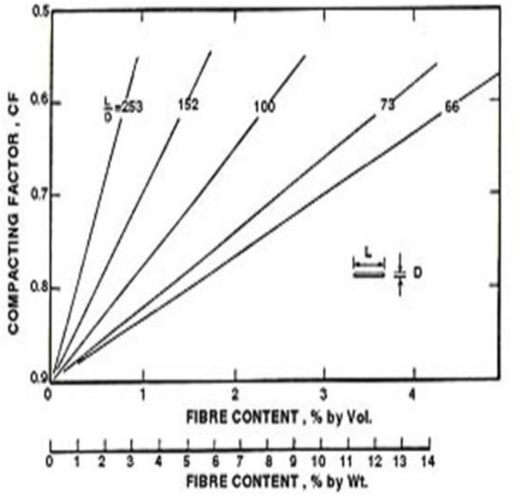

Figure 5: Effect of fibre aspect ratio on the workability of concrete, as measured by the compacting factor. [13]

7. Procedure

After calculation, for each mould of 150mm3 capacity, the required cement is 1400gm, sand is 2100gm,coarse aggregate is 4200gm and water required is 700gm. Thus for all the 4 cubes 5600gm of cement, 8400gm of sand, 16800 gm of coarse aggregate (20mm) and water of 2800gm were taken in a mixing tray. The concrete mix is placed in two cube one after another with proper tamping. And then for the two remaining cubes concrete is placed with proper placing of the beakert's steel fibres by proper interval totalling of 124 numbers each in the remaining 2 cubes.After keeping the cubes in 27'C for 24 hrs, the cubes are kept in curing tank for 28 days. The compresive strength and tensile strength of each cubes are then compared.

Table 3. Weight Mix For Plain Concrete and Reinforced Concrete for 150 mm^3 mould:

Materials	Plain concrete	Fibre reinforced concrete
Cement	1400 gm	1400 gm
Blended sand	2100 gm	2100 gm
20 mm aggregate	4200 gm	4200 gm
Steel fibres	Nill	124 nos.
Water	700 gm	700 gm

8.Typical properties of SFRC compared to ordinary concrete found in the Tests.

For the study test was performed on 4 cubes with a size of (150 x 150 x 150)mm^3.
The results are as follows:

Properties:

Improvement over ordinary concrete

Ductility 5 to 10%

Impact resistance 100 to 500%

Cracking & flexural strength 80 % to 120%

Shear strength 50% to 100%

Bearing strength 50% to 100%

Abrasion resistance Several times

N.B : All the tests were performed in accordance to the Indian Standard code book, **IS 456:2000**.

The cement used was "Max 43 grade OPC", the sand (fine aggregate) is from Zone II (by sieve analysis) and coarse aggregate of 20mm size.

PHOTOGRAPHS TAKEN DURING THE MAKING OF THE CONCRETE (16th April, 2013)

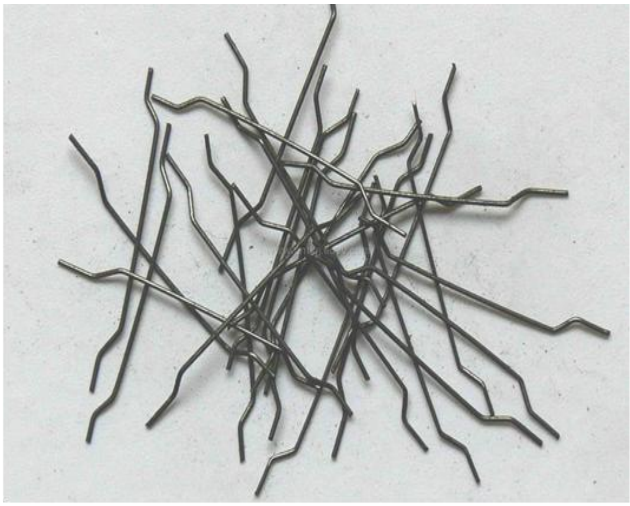

Photo 1. Dramix Steel fibre RC- 80/60

Photo 2: Sieve analysis of 20 mm aggregate

Photo3&4: Aggregates and cement ready to use
Mixing of aggregates

Photo 5: Concrete after being poured
Photo 6: Concrete blocks after 28 days (20th May, 2013)

PHOTOGRAPHS TAKEN DURING THE COMPRESSIVE TEST OF THE CUBES AFTER 28DAYS. (20th May, 2013)

Photo 7: Testing of plain concrete and SFRC cubes in the CTM(compressive testing machine)

CONCLUSION

From the experiments the following conclusion may be drawn:

- the inclusion of fibres, for the herein used fibre type and amounts, had no effect on the initial from transversal reinforcement.
- the tension stiffening effect was markedly improved by fibre reinforcement.
- the crack spacing was reduced and the characteristic crack widths turned out

to be significantly reduced by the fibres

- it was found that the inclusion of fibres reduced the initial sudden crack opening (caused by elastic unloading)

- the herein used fibre type, and fibre amounts, did not affect the bond properties at the interface layer, no effect on the peak bond stress and the ascending part was observed.

- after cracking, the fibres provided a confining effect (for splitting cracks), which could be compared with the one from transversal reinforcement.

- from the self-compacting concrete, there were indications of an increased initial bond stiffness.

- The favourable effects of steel fibers on the cracking behaviour and the toughness of concrete make SFRC an ideal construction material for many fields.

- It is claimed as "THE MODERN COST-EFFICIENT BUILDING MATERIAL".

- It is seismic resistant, fire resistant.

- It is much tougher and more resistant to impact.

- As compared with plain concrete it has much more strength.

From the above studies and tests we can encourage the use of SFRC although it is a new technology , comparatively.

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