Steel Fibre Reinforced Concrete (SFRC): Areas of Application

Navneet T. Narayan
Technical Manager - Bekaert

Concrete has high compressive strength, but is remarkably weak in tension (about one-tenth its compressive strength), and as such is usually reinforced with materials that are strong in tension (often steel). Reinforcement solutions to plain concrete in the form of steel bars have existed and been studied for a long time now. However, a whole new spectrum of possibilities are open with the advent of steel fibres, which have been found improve the properties of plain concrete and cater to a host of various specific applications of structural concrete.

The use of steel fibres in grade slabs such as industrial floors, warehouses, ports and highway pavements is prevalent world over. They are known to have been widely used in Hydro sector, particularly tunnel linings and slope stabilization. In India, thanks to the improvements in steel fibre technology and more user experiences in terms of economy and durability, the use of Steel Fibre Reinforced Concrete (SFRC) is gaining traction. Advancements in admixture technologies over the last few decades coupled with developments in fibre manufacturing technology (e.g. collated/glued fibres) have enabled easier mixing, batching and improved workability of SFRC. There is an increased understanding in the industry that each fibre type behaves differently and this fact must be considered while specifying steel fibres and designing SFRC elements in various projects. However, it is also true that absence of appropriate material specifications for SFRC and lack of Indian standards for testing and design has led to a rather slow acceptance of the concept.

Behaviour of SFRC

SFRC is a concrete that has a homogenous distribution of randomly oriented discontinuous and discrete steel fibres. Steel fibres are introduced in the concrete matrix during the mixing of its constituent ingredients. Upon hardening, these fibres improve the properties of concrete such as ductility, fracture toughness, energy dissipation, impact resistance, fatigue resistance and limiting of crack propagation. Under tension, as cracks start propagating inside concrete, steel fibres present in the matrix bridge the cracks and transfer the tension across them during this process (Figure 1). Thus, SFRC actually causes no considerable increase in the flexural strength (modulus of rupture) of the concrete yet contributes in improving the load carrying capacity of a structural system on account of increased toughness and rotation capacity.

The behaviour of plain concrete and SFRC is made clear with the help of a four point beam bending test as illustrated in Figure 2. It is observed that for plain concrete, a sudden and brittle mode of failure occurs after the peak load is reached which then is used to calculate the flexural strength of the concrete. When sufficient ductility is ensured in the beam with the addition of steel fibres in concrete, a strain softening phenomenon is observed after the load at first crack or peak load in the beam. Thus, with this kind of toughening behaviour in the beam, post-crack flexural strength of SFRC is guaranteed.

Adding steel fibres purely on a volume fraction basis has its disadvantages in that it fails to differentiate between various kinds of steel fibres and considers the volume of steel added as the only criterion. This is obviously not...
true because for a given volume of fibres, smaller diameter fibres are more in number than the larger ones. This consequently results in a larger network of fibres within the concrete matrix which would definitely alter the performance of the concrete due to higher confinement. Similarly, aspect ratio (length/diameter) of the fibre has a greater bearing in the performance of SFRC in that higher aspect ratios yield better performance due to longer anchorage lengths and fibre network. Apart from the differences in sizes and aspect ratios, steel fibres may come to differ in shape (straight/hooked end/ undulated), form (fibres glued together with water soluble glue/ loose), tensile strength (high/medium/low) and materials (mild steel/galvanized/stainless). Thus, all fibres are not alike (Figure 3) and must be selected based on the requirements of the user and applications they will be put to use. Consequently, SFRC should never be simplified as a ‘concrete with steel fibres’. SFRC has to be seen as an engineered material which when added to an appropriate concrete composition according to a suitable fibre type and corresponding dosage meets the given requirements.

Applications of SFRC

Generally, in structural applications, SFRC should only be used in a supplementary role to inhibit cracking, to improve resistance to impact, to resist dynamic loading and material disintegration. In structural members where considerable flexural and axial tensile stresses occur, such as in beams, columns, suspended/roof slabs etc., steel fibres alone are insufficient and should never be wholly used to replace traditional steel reinforcements. Some of the more appropriate examples (Figure 4) of general structural and non-structural uses of SFRC are listed as follows:-

- Hydraulic structures -- Dams, stilling basins, and sluiceways as new or replacement slabs or overlays to resist cavitation damage
- Airport and highway paving and overlays - Particularly where a thinner-than-normal slab is desired
- Industrial floors -- For impact resistance and resistance to thermal shock
- Refractory concrete -- Using high-alumina cement in both castable and shotcrete applications
- Foundation slabs for residential buildings
- Bridge decks -- As an overlay or topping where the primary structural support is provided by an underlying reinforced concrete deck
- In shotcrete linings -- For underground support in tunnels and mines, usually with rock bolts
- In shotcrete coverings -- To stabilize aboveground rock or soil slopes, e.g., highway and railway cuts, and embankments
- Thin shell structures -- shotcreted “foam domes”
- Explosion-resistant structures -- Usually in combination with reinforcing bars
- A possible future use in seismic-resistant structures

Applications in India: Grade Slabs

One of the major application areas of SFRC seen in India happens to be “slab-on grade” (industrial flooring,
concrete pavements, ground slabs etc.) where it establishing itself as a meaningful alternative to plain or reinforced concrete. Slab-on-grade can be defined as a slab that can be fully supported by a sufficiently compacted sub-base (see Figure 5). The general loading cases in such a structure include stationary loads due to racks, pallets, containers etc. and moving loads like trucks, stackers and fork-lifts.

As a design basis, bending moments are calculated according to the appropriate ground support and loading conditions. Depending on whether the slab is plain concrete or SFRC, appropriate design approaches have to be used. Conventional plain concrete slabs work only up to a point where the stresses in the slab lie within the elastic range of the material. As soon as the stresses in the slab exceed the elastic threshold range, the plain concrete cracks in a brittle manner, losing its capability to carry any further substantial loads. Such a scenario in slabs leads to large cracks which require costly repairs. SFRC slabs on the other hand work on the principle of load redistribution which allows the use of a plastic design approach where the stresses in the slab are not just limited to an elastic threshold value, but are allowed to go beyond by the sheer capability of this transformed material. The plastic design approach allows for the full properties of SFRC to be put to use.

Real scale lab tests performed to characterize the behaviour of plain concrete vis-à-vis SFRC reveal a lot of differences. Results show distinct and large cracks appearing in plain concrete slabs that run through the section, dividing the slab into various pieces as soon as the moment capacity is reached while SFRC on the contrary allows for yielding of the slab by progressively smearing the excess moments, leading to finer cracks as illustrated (Figure 6).

Applications in India: Shotcrete Tunnel Linings

Construction of tunnel linings forms an integral part of any tunnel drilling activity. After the drill and blast operation inside a tunnel, the surrounding rock mass requires some kind of a temporary support which is typically provided by thin shotcrete linings. The role of such a shotcrete lining is not to try and support the original ground pressures but to stabilise the deformations required to mobilise the inherent ground strength. Consider an illustration (Figure 7) which details the Ground-Lining interaction inside a tunnel. As excavation proceeds, ground moves into the tunnel and radial pressure required for equilibrium reduces as the ground strength is mobilized. Following completion of lining at B, load from the ground causes inward movement of lining until a point C of equilibrium at which radial pressure required for equilibrium is provided by the lining.

Rock supports in tunnels involve a constant risk of unexpected loads and deformations. In such a case, the best safety is achieved by having a shotcrete layer support that allows for the highest possible fracture energy i.e. toughness or ductility.
Performance characterization for SFRC

One needs to understand that although all the different types of fibres mentioned previously work in improving the properties of concrete in some way; they do so with varying degrees of performance. For example, and not all of them fulfill the requirements on field and lack technical details that a designer needs to assess the fibre performance in the structure. The idea is to have an "engineered fibre" not just any alternative to make the solution work in a manner it is envisioned to in the structure. Some of the important parameters are listed below:

- **Shape** (straight, hooked, undulated, crimped, Twisted, coned)

- **Length** (12.7 to 63.5 mm)
- **Diameter** (0.4 to 1.05mm)
- **Tensile Strength** (1000 - 2500 N/mm²)

Effect of Fibre Parameters

There are several ways in which one can quickly ascertain the performance of various fibre types. According to Shape, hooked end fibres have been time tested and have proved to be the most economical form of anchorage improving the fibre performance compared to straight fibres and of various other shapes. Also, collated or glued fibres have been specially developed by some manufacturers to enable a homogenous fibre distribution in concrete and prevent balling of fibres while mixing with concrete.

Another one of the most important performance parameters for fibres happens to be Aspect Ratio. Aspect ratio in a layman's term is the ratio of Fibre Length to Diameter. As length of the fibre increases, the region covered by fibre in the concrete also increases. Similarly, with the reduction of fibre diameter, number of fibres per unit weight increases, thereby increasing network of wires per unit volume of concrete. Refer following typical data (Table 1), which compares three different types of fibres of a particular manufacturer based on aspect ratio. These properties will vary from one steel fibre manufacturer to manufacturer.

This simply means that a higher aspect ratio has a larger network of fibres compared to lower aspect ratio fibres for the same level of performance. This in essence would also translate to lower dosages for higher aspect ratio fibres. The usual amount of steel Fibres ranges from 10 kg/m³ for higher aspect ratios (80), to 80 kg/m³ for lower aspect ratio (50). Thus, simply comparing a fibre dosage with another fibre dosage would not lead to the right conclusions as it would depend on number of variables.
Conversely, performance for same quantity of different fibres would be different, as illustrated in Figure 8.

Tensile strength of fibres also plays a major role in pinning the performance of SFRC. The strength should be large enough to undergo substantial yielding and not snap at the crack interface. More important then becomes the tolerance levels of fibre components as it is essential to guarantee the minimum tensile strength for each and every fibre strand to achieve the required performance.

Table 2 gives a comparison on the performance of SFRC proportioning procedures that apply to conventional concrete may not be entirely applicable to SFRC. In addition, to improve the workability of higher fibre volume dosages, super-plasticizers are often used.

Most commonly, when using a transit mixer or revolving drum mixer, the fibres should be added last to the wet concrete. The concrete alone, typically, should have a slump of 15-25 mm greater than the desired slump of the SFRC or 50-60 mm in case of SFRS.

Uniform dispersion of fibres is critical for the structure to perform as designed. However, loose fibres tend to form lumps during mixing and have to be manually broken or eliminated from the mix. This often leads to a network of fibres lower than what is needed to guarantee the design performance. The use of collated/Glued fibres held together by a water-soluble component which dissolves during mixing largely eliminates this problem of clumping/Balling. This is a single most essential factor which differentiates the performance of loose fibres from the collated ones. The finishing operations with SFRC are essentially the same as for ordinary concrete, though

---

**Table 2 Sample Dosage of Steel fibres for SFRC slab on grade**

<table>
<thead>
<tr>
<th>S No.</th>
<th>Aspect Ratio (L/D)</th>
<th>Type</th>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>Length (m/kg)</th>
<th>Dosage (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>Loose</td>
<td>50</td>
<td>1.05</td>
<td>147</td>
<td>31.5</td>
</tr>
<tr>
<td>2</td>
<td>67</td>
<td>Glued</td>
<td>60</td>
<td>0.9</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>Glued</td>
<td>60</td>
<td>0.75</td>
<td>276</td>
<td>15</td>
</tr>
</tbody>
</table>

Slab on grade using various fibre geometries, loadings 3 T to 7 T UDL on a 5 % CBR sub-base. The dosage of fibres varies depending on the aspect ratio, tensile strength, anchorage etc. Please note that these are case specific results and presented for ease of understanding of the concept only.

**Practical aspects of SFRC**

One of the basic concerns in SFRC is to introduce sufficient volume of fibres to be uniformly dispersed (Figure 9 ) to achieve the desired improvements in mechanical behaviour, while retaining sufficient workability in the fresh mix to permit proper mixing, placing and finishing. Several procedures for proportioning SFRC mixes are available, which emphasize the workability of the resulting mix. Smaller dosages of Steel fibres in concrete usually do not entitle too many changes in the design mix as the workability of concrete is not severely affected by fibre addition. However, there are some considerations that are particular to SFRC. In general, SFRC mixes contain higher ratios of fine to coarse aggregates than in ordinary concretes, and so the mix proportioning procedures that apply to conventional concrete may not be entirely applicable to SFRC. In addition, to improve the workability of higher fibre volume dosages, super-plasticizers are often used.

Most commonly, when using a transit mixer or revolving drum mixer, the fibres should be added last to the wet concrete. The concrete alone, typically, should have a slump of 15-25 mm greater than the desired slump of the SFRC or 50-60 mm in case of SFRS.

Uniform dispersion of fibres is critical for the structure to perform as designed. However, loose fibres tend to form lumps during mixing and have to be manually broken or eliminated from the mix. This often leads to a network of fibres lower than what is needed to guarantee the design performance. The use of collated/Glued fibres held together by a water-soluble component which dissolves during mixing largely eliminates this problem of clumping/Balling. This is a single most essential factor which differentiates the performance of loose fibres from the collated ones. The finishing operations with SFRC are essentially the same as for ordinary concrete, though
perhaps more care must be taken regarding workmanship.

Concluding remarks on SFRC

Steel fibres have been in prevalence elsewhere in the world for over 4 decades in various applications. Consequently a lot of international guidelines exist which detail the testing and design aspects of SFRC structures. It is indeed the need of the hour to see some such developments into standardization in India as well for wider acceptability of steel fibres. Reduced construction time, simplified reinforcement drawings, no stockyard, enhanced job safety and increased durability and ductility are only some main benefits of SFRC, which are mentioned in that context. At the same time it needs some special knowledge to understand, design and execute this special building material.

References

- Ramakrishnan, V.; Coyle, W. V.; Kopac, Peter A.; and Pasko, Thomas J., Jr., "Performance Characteristics of Steel Fibre Reinforced Superplasticized Concrete," Developments in the Use of Superplasticizers, SP-68, American Concrete Institute, Detroit, 1981, pp. 515-534.
- Johnston, C. D., "Steel Fibre Reinforced Mortar and Concrete-A review of Mechanical Properties," Fibre Reinforced Concrete, SP-44, American Concrete Institute, Detroit, 1974, pp. 127-142.
- Deutscher Beton- und Bautechnik-Verein e.V.: DBV-Merkblatt "Stahlfaserbeton". Fassung Oktober 2001
- Ganesh P. Chaudhari, Design Of Durable SFRC Industrial floor ACI Seminar 2008, Rantagiri, India
- Österreichische Vereinigung für Beton- und Bautechnik "Richtlinie Faserbeton" Fassung Juli 2008
- DIN EN 14889-1: Fasern für Beton Teil 1: Stahlfasern - Begriffe, Festlegungen und Konformität
- RILEM TC 162-TDF: "Test and design methods for steel fibre reinforced concrete Background and experiences", Chairlady L. Vandewalle, March 2003
- Bekaert, brochure: Recommendations for handling, dosing and mixing

J K Cement's Super Slag now in Southern Markets

J.K. Cement Ltd. has announced the extension of its popular brand 'JK Super' to the Slag cement category, re-introducing the brand with multimedia campaigns. The overall potential per month for Slag in the markets is an estimated 5 lakhs MT and JK Cements plans on acquiring a 10% share over a one year period aiming to sell about 5-6 lakhs MT from launch date.

The company has charted out a roadmap of expansion and differentiated branding initiatives to achieve its growth targets such as, roping in Sehwag as a brand ambassador and opening a maiden overseas plant in UAE. On 15th December 2011, the new brand 'J K Super Slag Cement' was launched at Belgaum and is made available to the customers through an authorized stockist network in Karnataka, Goa, Kerala & Maharashtra from 18th December onwards.

Mr. Antony Joseph Head Marketing (Grey South) remarked, that the Company apart from being strategically located, would use its traditional strengths of high quality products, widespread distribution and relationship with business partners to reach out to customers in the south.

Mr. Shabbor Khan Unit Head, JK Cement Works, Muddapur was noted saying that the super slag cement category is extremely diverse and eco-friendly. He also emphasized that the high resistance to chemical attack from chlorides and sulphates, prevalent in coastal areas makes this product far more durable as compared to OPC.

Mr. Raghavpat Singhania, Special Executive J.K. Cement Ltd. remarked, "The southern market for grey cement is of strategic importance for the Company as this is our first step towards becoming a national player in the Grey Cement Industry."

The Masterbuilder - December 2011 • www.masterbuilder.co.in