AN APPRAISAL OF USING STEEL FIBRE REINFORCED CONCRETE FOR PAVEMENTS

Dr. Sanjiv Kumar Aggarwal
Department of Civil Engineering
GZS Campus College of Engineering & Technology
Bathinda, Punjab, India

Abstract - In recent times, considerable interest has been generated in the use of Steel Fibre Reinforcement Concrete (SFRC) in several civil engineering applications. The most significant influence of the incorporation of steel fibres in concrete is to delay and control the tensile cracking of the composite material. Concrete is a brittle material that will not carry loads under pure bending when cracked. By incorporating steel fibres, the mechanical properties of concrete are changed, resulting in significant load carrying capacity of concrete even after it has cracked. Also, the major incentive for adding steel fibres is to improve the flexural behavior of a concrete slab. These improved properties result in SFRC being a useful material for concrete pavements, but still SFRC is not a complete solution to the several other problems faced by the concrete pavements.

Keywords – Steel Fibres, Reinforcement, Pavement, Concrete, SFRC.

I. INTRODUCTION
Concrete is the most widely used structural material in the world with an annual production of over seven billion tons. High strength concrete with compressive strength more than 25 MPa is being increasingly used in reinforced and pre-stressed concrete construction of buildings, bridges, and other structures. However, one of the major drawbacks of the high strength concrete is that it is brittle. For a variety of reasons, much of this concrete is cracked. The reason for concrete to suffer cracking may be attributed to structural, environmental or economic factors, but most of the cracks are formed due to the inherent weakness of the material to resist tensile forces. However, an ideal solution to overcome this serious disadvantage of concrete is to add fibres in concrete to achieve ductility and hence to avoid sudden failures. The incorporation of steel and other fibres in concrete has been found to improve its resistance to cracking, impact and fatigue and modifying its brittle behaviour to obtain appreciable ductility. However, steel fibres are the only fibres that can be used for long-term load bearing application, such as in concrete pavements.

Addition of steel fibres to conventional plain or reinforced and prestressed concrete members at the time of mixing/production imparts improvements to
several properties of concrete, particularly those related to strength, performance and durability. The weak matrix in concrete, when reinforced with steel fibres, uniformly distributed across its entire mass, gets strengthened enormously, thereby rendering the matrix to behave as a composite material with properties significantly different from conventional concrete. 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.

II. FIBRE REINFORCED CONCRETE

Fiber reinforced concrete (FRC) is defined as a composite material consisting of concrete reinforced with discrete randomly but uniformly dispersed short length fibers. The fibers can be made of steel, polymer or natural materials. Woven fabrics, long wires, bars, and continuous wire mesh are not considered discrete fibers. Fiber reinforced concrete is considered as a material of improved properties and not as reinforced cement concrete whereas reinforcement is provided for local strengthening of concrete in tension region. Fibre reinforced concrete differs fundamentally from other forms of reinforced concrete in that the amount and location of the reinforcement are not governed by the loading conditions, and the location and magnitude of the resultant tensile stresses. Instead of local strengthening of concrete in those sections of the structural members, which are subjected to tensile stresses beyond the capacity of concrete, the reinforcement in this case aims at uniformly improving the structural quality of the material as a whole. Since in Fiber reinforced concrete, fibers are distributed uniformly in concrete, it has better properties to resist internal stresses due to shrinkage. As fibers improve specific material properties of the concrete, impact resistance, flexural strength, toughness, fatigue resistance, ductility also improves. Fibers generally used in cement concrete pavements are steel fibers and organic polymer fibers such as polypropylene and polyester. The uniformly distributed, randomly oriented, short length fibers; provide a crack arresting mechanism at the micro level. In addition to improvements in the tensile strength, FRC also has improved toughness and fatigue strength, as compared to plain cement concrete conventionally used in rigid pavements.

III. STEEL FIBRE REINFORCED CONCRETE

Steel fibers have been used in concrete since the early 1900s. The early fibers were round and smooth and the wire was cut or chopped to the required lengths. The use of straight, smooth fibers has largely disappeared and modern fibers have either rough surfaces, hooked ends or are crimped or undulated through their length. Modern commercially available steel fibers are manufactured from drawn steel wire, from slit sheet steel or by the melt-extraction process which produces fibers that have a crescent-shaped cross section. Steel fibers have been used for a long time in construction of roads and also in floorings, particularly where heavy wear and tear is expected. Steel Fibre Reinforced Concrete (SFRC) is a composite material, which essentially consists of conventional concrete reinforced by random dispersal of short, fine steel fibres of specific geometry. The role of these fibres in the cement-based matrix is rather complex. Essentially, these fibres act as the crack arrestors, restricting the development of cracks and thus transforming an inherently brittle material with its low
tensile strength and impact resistance, into a strong composite with superior crack resistance, improved ductility and distinctive post cracking behaviour prior to failure. 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
- Very high flexural, shear and tensile strength
- Resistance to splitting/spalling, erosion and abrasion
- High thermal/temperature resistance
- Resistance to seismic hazards.

IV. USING SFRC FOR PAVEMENTS

A. General

Considering the importance of concrete in pavement construction, and in view of its well-known weakness in tension and against impact, SFRC is a suitable material to be used for pavement and overlay construction. SFRC has extra strength in flexure, fatigue, and impact etc. as compared to plain cement concrete. All these properties are primary requirements for concrete pavements for highways, bridge deck, runway or taxiway to maintain high quality and smooth riding surface without irregular depressions. The ability of SFRC to provide a thin overlay is of great value in cases where overhead clearances are critical. Thus, SFRC could usefully be deployed in the following areas:

- New pavements slab for roadways, bridge decks or runways.
- Overlays for rehabilitation of roadways, bridge decks, and runways.
- Overlays for strengthening of existing pavements to increase the load carrying capacity.
- Thin repairs of damaged patches in bridge decks or pavement slabs.

B. Design Aspects

1) Subgrade and subbase – The subgrade for SFRC slabs shall comply with the requirements as per IRC:15-1981. However, SFRC pavement should never be laid directly over the subgrade. Since relatively higher stresses are induced in the subbase under SFRC pavement, an adequate subbase thickness as per IRC:60 and IRC:74 should be provided over the compacted subgrade to reduce the deflections before laying the SFRC pavement. An impermeable membrane of polyethylene sheet may be provided between the subbase and the SFRC pavement.

2) SFRC pavement thickness – Since stress induced in a rigid pavement slab under load is approximately inversely proportional to the square of thickness, an empirical approach has been suggested on this basis to obtain the equivalent thickness of SFRC pavement from that required for PCC (plain cement concrete), as specified in IRC:58.

\[ h_{SFRC} = h_{PCC} \left(\frac{f_{PCC}}{f_{SFRC}}\right)^{1/2} \]

where,

- \( h_{SFRC} \) = required slab thickness for SFRC, cm
- \( h_{PCC} \) = required slab thickness for PCC, cm
- \( f_{PCC} \) = design flexural strength of PCC, kg/cm²
- \( f_{SFRC} \) = design flexural strength of SFRC, kg/cm²

3) Pavement joints – For pavement thickness of 15 cm and above, use of load transfer devices at joints may be considered in order to avoid high edge stresses. Suitable joints to control contraction cracking are required and SFRC pavement should be constructed to the same length and width as plain cement concrete slabs of similar thickness. Joint spacings, load transfer devices and tie bars may be provided as per standard practice for PCC pavements.
The same spacing of joints as used for PCC should avoid or minimize the problem of uncontrolled cracking.

4) Specifying SFRC - SFRC is usually specified by strength and fibre content. For paving works, normally flexural strength is specified. A typical range of design flexural strength used is 60-70 kg/cm². All the ingredients such as cement, aggregate, water, and admixtures used for SFRC shall conform to the standard specifications used for conventional concrete. Steel fibres normally used are cut from mild steel wire conforming to IS:280. The wire dia adopted is in the range of 0.5 mm to 1.0 mm. Steel fibres should be clean, free from rust, oil and deleterious materials. The length of a single fibre is generally 3 to 5 cm. Ordinary Portland Cement to be used for SFRC should preferably be not less than 43 grade (IS:8112). Aggregate shall conform to IS:383. The maximum size of the aggregate is to be limited to 12 mm.

C. Characteristics of Fibres

The efficiency of the fibre reinforcement is influenced by many factors, such as the geometry, length, and cross section of the fibre, the fibre volume, and the max. size of the aggregate in the mix etc. The volume of the fibre used may vary between 0.5 – 3% of concrete volume, fibre diameter being between 0.25 – 0.76 mm, and the length to diameter ratio (called aspect ratio) between 30 to 150. The maximum size of aggregate should be 40 mm. The fibres can be straight or have different shapes, some being prepared from drawn wires, while others are punched out of sheet metal.

The volume percentage and the aspect ratio have significant effect on the properties of the SFRC. For a given volume of fibres, the workability of the mix decreases as the aspect ratio of the fibre increases. Fibre aspect ratio of 80 to 100 has been found to be optimum for meeting the requirements of mixing, placing and compaction, as well as strength development. It must be kept in view that higher aspect ratios and higher volumes of fibre in a mix tend to cause ‘balling’ of the fibres, making homogeneous mixing difficult. Increase in the maximum size of aggregate in the mix interferes with the uniform distribution and random orientation of the fibres. It is important that the fibres be dispersed uniformly throughout the mix. This can be done during the mixing phase, preferably before the mix water is added.

D. Mix Design

SFRC mix differs from the conventional concrete mixes in having higher cement paste contents, and lower size and percentage of coarse aggregates. Presence of fibres in concrete reduces workability, for which appropriate adjustments have to be made. Thus, to maintain the level of workability and to ensure adequate bond of fibres to concrete mix, it is essential that the SFRC mix should have more cement paste. The maximum size aggregate should preferably be limited to 12mm. Further increase in maximum size of aggregate interfere with uniform distribution and random orientation of fibres. For SFRC, strength decreases with increase in the maximum size and proportion of coarse aggregate.

E. Steel Fiber Reinforcement in Cement Treated Base

Cement treated base is often an economically suitable material for highway construction, but many highway authorities have discouraged its use because of the known problem of reflective cracking, from thermally induced transverse cracks. However, fiber reinforcement in a cement bound road base has the
potential to improve performance in the following areas:

- Resistance to damage due to concentrated and impact loading.
- Improved resistance to reflective cracking of the asphalt.
- Cost effective as it reduces slab thickness and may eliminate use of conventional reinforcement.

F. Limitations of Fibre Reinforced Concrete for Pavements

Concrete slab pavements have been extensively used for highway construction in many parts of the world. Studies have indicated that concrete pavements are structurally more durable than bituminous pavements. However, it is also true that majority of the slabs do not last as long as they should be. Surface deterioration of the concrete slab, edge cracking and joint spalling have been identified as the important factors responsible for the shorter than expected service life of these pavements. The actions of water and traffic loadings are the two key elements that are primarily responsible for this problem. The excess rainfall and the repetitive traffic loading make concrete pavements particularly vulnerable to the surface deterioration process. The numerous cycles of alternate wetting and drying also contribute in accelerating the pace of deterioration. Most concrete pavements fail not due to inadequate concrete strength, but rather to joint related problems and inadequate strength of the subgrade or the sub base. Water is the key culprit and failure types include: joint deterioration, pumping, edge deflection, and dowel corrosion etc. Thus, fibre reinforced concrete pavement does not help greatly in preventing the above problems.

V. CONCLUSIONS

The performance of a pavement or overlay depends on the engineering properties of the materials used in construction. The application of SFRC as composite matrix is potentially advantageous from the viewpoint of its capacity to bear much higher stresses. Under the same loading conditions, the pavement thickness can be considerably reduced; hence saving in material by way of reduction in section thickness. However, the reduced thickness of pavements results in transfer of excessive stresses to the subgrade. Since relatively higher stresses are induced in the base under SFRC pavement, an adequate base thickness should be provided over the compacted subgrade to reduce the deflections before laying the SFRC pavement. For constant thickness, the material promises an appreciably higher life expectancy. Reduced crack widths and extent of cracking offer better serviceability of SFRC pavements.

VI. REFERENCES


Dr. Sanjiv Kumar Aggarwal, has to his credit an excellent and meritorious academic career from the prestigious technological institutions of the country. He earned his Doctorate in Civil Engineering (Transportation) from the Indian Institute of Technology, Roorkee. He is presently serving as Professor of Civil Engineering at Giani Zail Singh Campus College of Engineering & Technology, Bathinda. He is also serving as Director, Punjab Institute of Technology, GTB Garh, Moga, which is a constituent college of Maharaja Ranjit Singh Punjab Technical University, Bathinda. He has participated in more than 50 Conferences, Seminars, and Workshops in India, France and United Kingdom to present his professional work. He has published more than 60 technical/research papers in various Journals and Conference Proceedings. He has delivered more than 30 expert lectures in various FDPs, STCs and Workshops conducted by several universities and professional organizations. He has guided more than 25 postgraduate students for their M.Tech. Dissertations and one research scholar for his PhD Thesis. Seven other PhD scholars are currently pursuing their research work under his supervision. He is an active member of the various International and National professional organizations such as REAAA, IRC, IEI, ISTE, IIBE, and IUT etc. He has been honoured with several awards such as Vikas Rattan Award, Bharat Jyoti Award, and Shiksha Rattan Award for his contribution to the society through his profession. He has been actively engaged in providing technical consultancy to several government and private organization in the field of highways, railways and airport engineering. He is also coordinating the State Technical Agency set up by Government of India for implementation of prestigious Prime Minister’s Rural Road Programme in the state of Punjab.