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Review Article

STEEL POLYPROPYLENE FIBRE REINFORCED PAVEMENT QUALITY CONCRETE: A REVIEW

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ABSTRACT
In highway pavements, due to varying traffic condition, the formation of micro cracks in the pavement quality concrete layer under the wheel load take place. Due to faomation of such type of cracks, flexural strength decreases, thus PQC layer deteriorated rapidly. The Steel polypropylene fibre reinforced concrete (SPFRC) plays a vital role to eliminate the deficiencies related with the plain concrete. SPFRC is useful in concrete pavement to control cracking (plastic shrinkage, reflection etc.), to enhance flexural strength, to impart high toughness (ability to absorb energy after cracking), to provide post crack ductility, to improve impact resistance and flexural fatigue endurance. This paper presents a review on usage of steel polypropylene fibre reinforced concrete in PQC. It lays emphasis on stee and polypropylene fibre which can effective for enhancement of mechanical prorties of PQC mixes. Further this paper deals with the various reasons for providing the steel and polypropylene fibres in concrete, fibre distribution charectirstics, effect of geometry of fibres and the effects of varying temperatures on behaviour of SPFRC.

Keywords: *Pavement Quality Concrete, Steel Fibres, Polypropylene Fibres, Flexural Strength*

INTRODUCTION
Steel Polypropylene Fibre Reinforced Concrete
The steel-polypropylene FRC is composite of conventional concrete and uniformly dispersed steel & polypropylene fibre. In this steel fibre provides the structural improvement where as polypropylene fibre enhances the resistance to plastic shrinkage cracking.
Concrete pavement is, in general, consists of three layers – Sub grade, Base layer (DLC, drainage layer & filter layer) and Concrete slab.

CONCRETE SLAB (PQC)
DRY LEAN CONCRETE (DLC) **DRAINAGE LAYER** **FILTER / SEPERATION LAYER**
SUBGRADE

Figure 1: Typical cross section of concrete pavement (Source : IRC:58-2011)

The concrete slab is of M40 grade of concrete and is called as pavement quality concrete (PQC). PQC layer made with plain Concrete is; relatively strong in compression but weak in tension, limited ductility, little resistance to cracking, high brittleness, poor toughness, and so on that restrict its application. Fibre reinforced concrete (FRC) provides solutions for these shortcomings. Inclusion of fibres as reinforcement to concrete results as crack arrestor and improves its static and dynamic properties by preventing the propagation of cracks as well as increases tensile strength of concrete. Combination of both steel and polymeric fibres increases the overall performances of concrete. The structural improvement is obtained by steel fibre whereas resistance to plastic shrinkage cracking is obtained by polymeric micro fibres.

It is obvious that the behaviour of Fibre Reinforced Concrete depends on the fibre content, aspect ratios, orientations, geometrical shapes (Chang and Chai, 1995; Indian Road Congress, 2013; Kang *et al.*, 2010; Kumar and Khadwal, 2014; Qureshi *et al.*, 2013). Also the dispersion of fibre in concrete allow a noticeable improvement of concrete mechanical properties, mostly in term of dynamic and fatigue resistance, shear and post cracking strength. Non-uniform fibre distribution decreases the strengthening effect of fibre (Kang *et al.*, 2010).

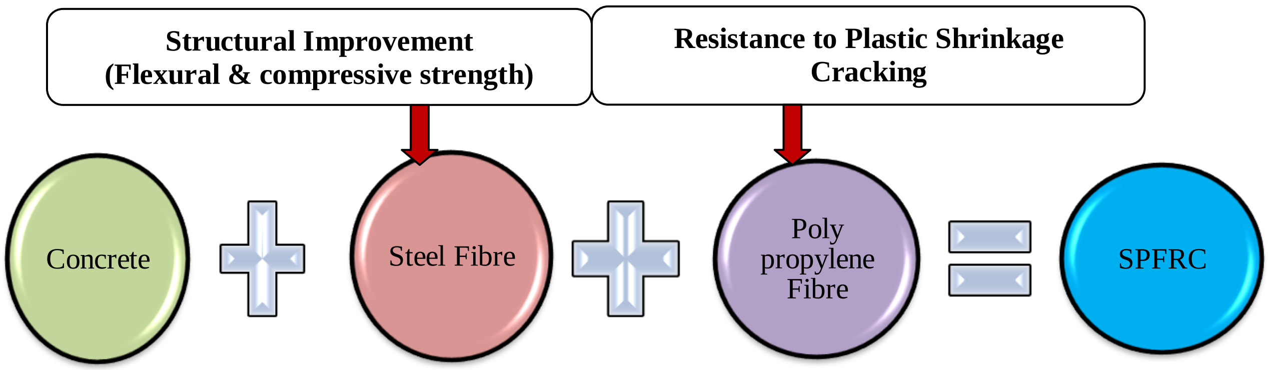

Figure 2: Concept of SPFRC Mix

Fibrous Materials

Steel Fibres

Steel fibres have been used in concrete since the early 1900s. These fibres are available in different geometrical shapes like; straight, crimped, hooked end etc. Modern commercially available steel fibres are manufactured from drawn steel wire, from slit sheet steel or by the melt-extraction process which produces fibres that have a crescent-shaped cross section. Steel fibre should have an ultimate tensile strength of at least 800 MPa (Indian Road Congress, 2013).

Polypropylene Fibres

Polypropylene fibres are hydrophobic, so they don't absorb water and have no effect on concrete mixing water requirements. They are in two forms –

(i) Fibrillated bundles
(ii)Monofilaments

During mixing, cement paste penetrates into the network of fibres filaments resulting in better mechanical anchoring to the concrete.

Monofilament fibres are fine, cylindrical strands that separate during mixing. The monofilament fibres are smooth and have a small surface area; hence they don't anchor into the cement matrix as well as fibrillated fibres.

The previous Research work shown that lower volumes of fibrillated fibres than of monofilament fibres are needed to improve the post-cracking load carrying capacity and ductility of concrete. Since the Polypropylene fibres is their non-polar nature , which inhibits adhesion to concrete. To obtain good mechanical properties for concrete there should be proper bond between the concrete matrix and the fibre (Buratti *et al.*, 2011).

Surface treatments are able to modify the fibre/concrete interface by roughening the fibre surface, altering surface polarity. The modification of the surface chemistry and morphology of polymers increase the interfacial strength compared to untreated PP fibres (Buendía *et al.*, 2013). Polypropylene fibres have been reported to reduce unrestrained plastic and drying shrinkage of concrete at fibre contents of 0.1 to 0.2% by volume of concrete (Indian Road Congress, 2013).

Table 1: Properties of Fibres

SN	Type of Fibre		Length (mm)	Dia (mm)	Specific Gravity	Tensile Strength (MPa)	Elastic Modulus (GPa)
1	Steel		7 -75	0.2 – 2	7.85	500-2000	200
2	Polypropylene Fibre	Polymeric Micro Fibre	12-40	≤ 0.2	0.91	140– 700	3.5-8.5
		Polymeric Macro Fibres	30-60	> 0.2			

(Source: The Concrete Institute (2013), IRC (2013), Zheng et al., 1995)

Figure 3: Polymeric Fibrillated

Figure 4: Polymeric Mono Filament

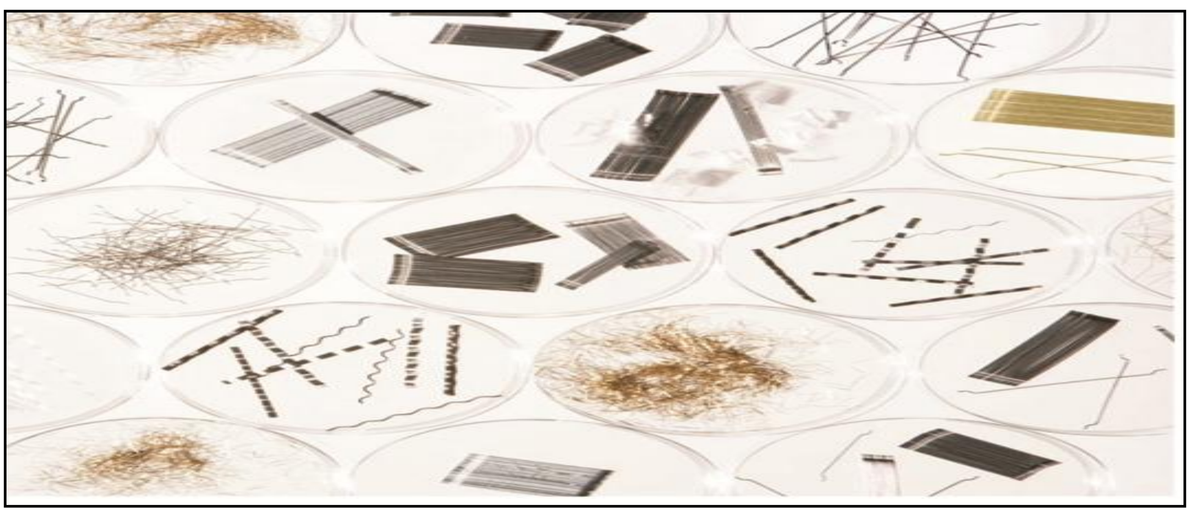

Figure 5: Different types of steel fibres (Source: IRC (2013), Kumar *et al.*, (2014))

Reasons for Providing Steel and Polypropylene Fibres in Concrete

Romualdi and Batson first studied the behaviour of fibres-reinforced concrete. They suggested that with the use of steel fibres; increases in flexural strength and ductility of concrete dut to the ability of the fibres to restrain cracks.

All concrete contains flaws which could increase in size under loads which were less than 50% of the ultimate load. The fatigue failure mechanism for concrete or mortar develops in three stages (Chang and Chai, 1995).

- **The first stage**, flaw initiation, is an inherent quality of concrete such as the presence of air voids and weak or debonded regions between aggregate and paste.
- **The second stage**, the slow growth of flaws to a critical size, is a complex mechanism in a heterogeneous material such as concrete. The growth of the inherent flaws under static loading of concrete is called micro cracking. From the previous studies it was stated that there would be some flaws of a shape, size and orientation in the stress field that may grow slowly in a stable manner to a critical size and then increase rapidly.
- **In this third stage**, when a sufficient number of unstable cracks join to form a continuous crack, failure of the member follows quickly.

The first and third stages of the failure mechanism cannot be prevented, but there is the possibility of retarding the growth of the flaws in the second stage by using closely spaced and randomly dispersed steel & polypropylene fibres as reinforcement in the concrete or mortar. The steel & polypropylene fibres can improve the performance of concrete –

(i) During and before the attainment of substantial strength.
(ii) During the service life of member.

Behaviour of Steel & Polypropylene Fibres in Concrete: Bridging Effect of Fibres

The experimental work is oriented towards concrete reinforced with steel and polypropylene fibres, so it is most important to understand how these fibres behave in the concrete mix.
The behaviour of SPFRC under loading can be understood from the Figure.

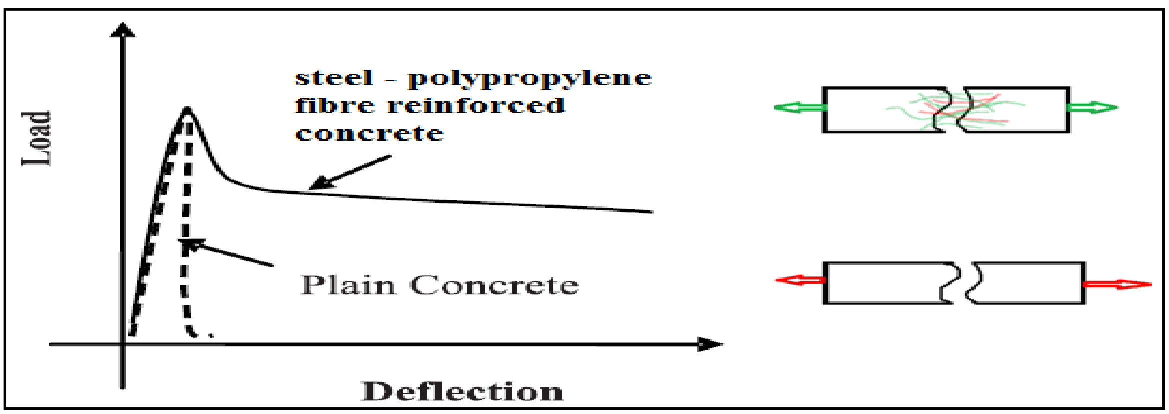

Figure 6: Bridging effect of fibres (Source: Brown *et al.*, (2002), Narayan *et al.*, 2013)

The plain concrete structure cracks into two pieces when the structure is subjected to the peak tensile load and cannot withstand further load or deformation. The fibre reinforced Concrete structure cracks at the same peak tensile load, but does not separate and can maintain a load to very large deformations. The area under the curve shows the energy absorbed by the SPFRCs after cracking when subjected to tensile load. This can be termed as flexural toughness or the post cracking behaviour of the SPFRCs.

In hardened FRC fibres of much elastic modulus are effective in crack prevention. For both of plastic shrinkage and structural strength a proper combination of micro polymeric fibres (i.e. polyester, polypropylene, polyethylene, nylon etc.) and macro fibres (which may be polymeric or steel fibre) may gives the economical span. Hence, it can be concluded that to control cracks in all stages of concrete, hybrid fibres can be more effective.

Effect of Fibre Volume Contents on the Behaviour of SPFRC

Workability: Workability is the property of SPFRC which determines the ease and homogeneity with which it can be mixed, placed, compacted and finished. Major factors affecting the workability are –

water content, cement content, aggregate content, fibre type & their content, air content, temperature, mixing conditions, chemical admixtures etc. After the additions of significant reduction in fresh properties of concrete (Indian Road Congress, 2013; Yap *et al.*, 2013). The reduction in workability due to strong fibre matrix bond in the concrete mix. Due to this bond viscosity of concrete increases and the distribution of the cement matrix is restricted; thus significant reduction in the workability was observed. The addition of superplasitciser, plasticizer or mineral admixtures can improves the workability by dispersing the fibres in mix uniformly and reducing the viscosity of cement paste (Kaikea *et al.*, 2014). Temperature plays an importante role for the workability behaviour. As temperature varies, the loss of workability and hence change in the admixture dosing. At the time of pouring of concrete its temperature should not be exceed 30 ^{0}C as per IRC:15. Temperature of concrete in the batch mix plant will normally be aroud 25^{0}C (Indian Road Congress, 2013).

Compressive strength: Of the various strength of concrete the determination of compressive strength has received a large amount of attention as concrete is primarily meant to withstand compressive stresses. The addition of fibres enhances the compressive strength of concrete (Parveen, 2013; Qureshi *et al.*, 2013; Yap *et al.*, 2013). The compressive strength is significantly influenced by steel fibres and increases by increasing quantity of steel fibre (Chang and Chai, 1995; Kumar and Khadwal, 2014). From the previous studies, it was concluded that, steel fibre provides the ductility to concrete, as they have high strength & high modulus of elasticity thus have more ability to arrrst the macro cracks.

Tensile strength: It is well known; concrete is strong in compression but weak in tension. Even a very small eccentricity of load will induce bending and axial force condition and the concrete fails at apparent tensile stress other than the tensile strength (Gambhir, 2010). Under an increasing compression loading, cracks will initiate and advance. When the advancing crack approaches a fibre, the debonding at the fibre–matrix interface begins due to the tensile stresses perpendicular to the expected path of the advancing crack. As the advancing crack reaches the interface, the crack tip stress concentration is reduced, and, thus, the propagation of cracks is blunted and blocked. This process is the bridging effect or crack arresting ability of fibres in concrete (Yap *et al.*, 2013). The uniformly dispersed fibres creat the bridging effect of fibre, hence tensile strength increases.

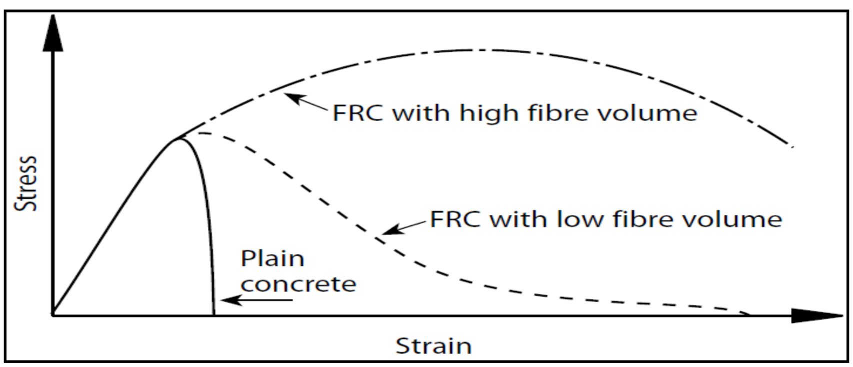

Figure 7: Typical stress-strain curve for fibre-reinforced concrete
Source: (The concrete institute, 2013)

Flexural strength: The flexural tensile strength is important parameter to estimate the load at which the concrete member may crack. As it is difficult to determine the tensile strength of concrete by conductiong a direct tension test, it is computed by flexural testing. When the concrete has more flexural strenghth, it will be more fstigue resistant. In highway pavements, due to varying traffic condition, the formation of micro cracks in the pavement quality concrete layer under the wheel load take place. Due to faomation of such type of cracks, flexural strength decreases, thus PQC layer deteriorated rapidly. The steel fibre has more modulus of rupture than polypropylenen fibres, hence they provide the structursl improvement i.e arrest the macro cracks and under go the ductile failure, while polypropylene fibres provide the resistant to plastic shrinkage cracking and undergo the brittle failure. Thus the mixture of steel – synthetic fibres (polypropylene, nylon fibres etc) shows the better performance during flexural sttength test (Buratti *et al.*, 2011; Girish *et al.*, 2012; Kumar and Khadwal, 2014; Qureshi *et al.*, 2013). The manufacturing techniques & therir testing direction considerably affect the flexural behaviour of SPFRC. When testing direction is perpendicular to casting direction, specimens exhibit reductions in both flexural strength and toughness compared to the case when testing and casting directions are parallel (Yap *et al.*, 2013).

Toughness: It is the ability to absorb energy after crcking. This is also defiend by area under the stress strain curve of SPFRC. Toughness is increase with the addition of fibres. Thus the FRC is able to sustain loads at deflection much greater than those at which cracking first appears in the matrix.Stress-Strain relationship shows that strain increases as the percentage of polypropylene fibre increases, thus enhancing the toughness of concrete (Parveen, 2013).

Effectiveness of Spfrc at Low and High Temperature

Concrete is though not a refractory materials, is incombustible and has good fire resistant properties. The effect of temperature onthe strength of concretre is not much upto a temperature of about 250 °C but above 300 °C, considerable loss od strength take place (shetty). It is concluded that incorporating steel fibre remains beneficial to concrete which has been exposed to high temperatures up to 1200 °C. At high temperature loss in static modulus of elasticity of concrete. Up to 1000 °C, no effect on poison ratio (Lau and Anson, 2006).

The results show that the toughness of SFRC under flexural loading increases with a decrease in temperature. This increase appears to be related to the increase in the strength of the matrix at low temperatures (because of the freezing of water in the capillary pores), which increases the energy required for fiber pull-out. The toughness increase was observed both for normal and high performance concretes, and for both types of fibers at both dosages (Pigeon and Cantin, 1998).

Conclusion

With the high performance of tensile strength, large aspect ratio uniform separation in the concrete, reinforced Steel fibres concrete can bear more loads and absorb more deformation. The profile of steel fibre either hooked end or crimped ensure optimum anchorage between steel fibres and concrete, which enable the Steel fibres to transfer and distribute stress effectively. The polypropylene fibres act as tiny bridges and control the crack initiation and extension in the concrete. Steel fibres concrete has high performance of wear ability and fatigue resistance.

It is especially suitable for the project position subject to serious impact damage and high fatigue architectural structure. Such enhanced compressive strength and flexural strength will permit reduction of slab thickness in wearing surface of cement concrete pavements, due to higher flexural strength leads to less material usage. This will further lead to savings in material and labour cost by eliminating conventional reinforcement. Typically the thickness reduction can be achived approximately 20% – 25%. Also the Polypropylene fibres is non-polar nature, which inhibits adhesion to concrete., which can be further improved by surfave treatment of polypropylene fibres.

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