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Properties of Fiber Reinforced High Performance Concrete-A Case Study

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***Abstract* - Concrete is the worldwide used building material. It has many feasible engineering properties, can be molded into any shape and more importantly is produced with cost-effective materials. Large numbers of mineral admixtures, which are waste products of other industries, are being beneficially used in making quality concrete. Fiber Reinforced Concrete is a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibers. This increase the durability along with strength of concrete will lead to the use of high-performance concrete which will be more favorable for environmental attacks on the structure. High-performance concrete involves variation of different parameters like water cement ratio, use of mineral admixture, chemical admixture, temperature, curing regime, etc. The mechanical and environmental performance of concrete was observed to be depending on various types of material used in the concrete. The properties of concrete depend on packing of grains and type of curing regime.**

I. INTRODUCTION

Concrete is a durable and versatile construction material. It is not only strong, economical and takes the shape of the form in which it is placed, but it is also aesthetically satisfying. However, experience has shown that concrete is vulnerable to deterioration, unless precautionary measures are taken during the design and production. For this we need to understand the influence of components on the behavior of concrete and to produce a concrete mix within closely controlled tolerances.

The conventional Portland cement concrete is found deficient in respect of:

- Durability in severe environs (shorter service life and frequent maintenance)
- Time of construction (slower gain of strength)
- Energy absorption capacity (for earthquake resistant structures)
- Repair and retrofitting jobs.

Hence it has been increasingly realized that besides strength, there are other equally important criteria such as durability, workability and toughness. And hence we talk about ‘High performance concrete’ where performance requirements can be different than high strength and can vary from application to application.

High performance concrete is a concrete mixture, which hold high durability and high strength when compared to conventional concrete. This concrete contains one or more of cementious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer. The term ‘high performance’ is somewhat pretentious because the essential feature of this concrete is that it’s ingredients and proportions are specifically chosen so as to have particularly appropriate properties for the expected use of the structure such as high strength and low permeability. Hence High-performance concrete is not a special type of concrete. It comprises of the same materials as that of the conventional cement concrete. The use of some mineral and chemical admixtures like Silica fume and Super plasticizer enhance the strength, durability and workability qualities to a very high extent. High Performance concrete works out to be economical, even though its initial cost is higher than that of conventional concrete because the use of High-Performance concrete in construction enhances the service life of the structure and the structure suffers less damage which would reduce overall costs.

High Performance Concrete can be designed to give optimized performance characteristics for a given set of load, usage and exposure conditions consistent with the requirements of cost, service life and durability. The high-performance concrete does not require special ingredients or special equipments except careful design and production. High performance concrete has several advantages like improved durability characteristics and much lesser micro cracking than normal strength concrete. Any concrete which satisfies certain criteria proposed to overcome limitations of conventional concretes may be called High Performance Concrete. It may include concrete, which provides either substantially improved resistance to environmental influences or substantially increased structural capacity while maintaining adequate durability. It may also include concrete, which significantly reduces construction time to permit rapid opening or reopening of roads to traffic, without compromising long-term serviceability. Therefore, it is not possible to provide a unique definition of High-Performance Concrete without considering the performance requirements of the intended use of the concrete.

American Concrete Institute defines High Performance Concrete as “A concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing and curing practices". The requirements may involve enhancements of characteristics such as placement and compaction without segregation, long-term mechanical properties, and early age strength or service life in severe environments. Concretes possessing many of these characteristics often achieve High Strength, but High Strength concrete may not necessarily be of High Performance. A classification of High-Performance Concrete related to strength is shown below.

Compressive strength (Mpa)	50	75	100	125	150
High Performance Class	I	II	III	IV	V

The demand for high strength, crack, resistant and lighter concrete resulted in development of fiber reinforced concrete. Fibers that are used are steel, nylon, asbestos, glass, carbon, sisal, jute, coir, polypropylene, kenaf. The practice of adding certain fibers to construction material dates back to the ancient times. When horse hair, straws were used to strengthen the bricks. In 1911 Porter found that fiber could be used in concrete. Early 1900 saw the use of asbestos fiber. In 1950 fiber reinforced concrete was becoming a field of interest as asbestos being a health risk was discovered. In 1963 Romualdi and Batson published their classic paper on FRC. Since then there was no looking back, glass, steel, polypropylene fiber were used in concrete. Fiber reinforced concrete is a composite material made of cement-based matrix mixed with metallic or non-metallic fibers, sometimes, admixtures, additives and polymers are added. The desired result of adding fibres to any concrete mix is to enhance its mechanical- and shrinkage properties. The improvements gained by using fibres depend on the properties of the fibre which include the fibre material as well as fibre length and geometry to name a few. Various materials are used to produce fibres for use in concrete. Currently the main distinctly different categories are steel fibres, synthetic fibres, glass fibers and organic- or natural fibres. Additives such as fly ash or condensed silica fume can be added to improve the quality of the concrete composite. During the last ten years, many experimental studies related to fiber reinforced concrete structures have been conducted.

II. DIFFERENT TYPES OF FIBER

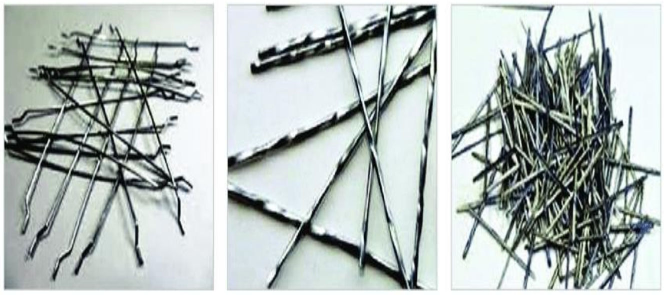
Following are the different type of fibers generally used in the construction industries.

1. Steel Fiber
2. Polypropylene Fiber
3. Glass Fiber
4. Asbestos Fibers
5. Carbon Fibers
6. Organic Fibers

1. Steel Fiber

A number of steel fiber types are available as reinforcement. Round steel fiber the commonly used type is produced by cutting round wire in to short length. The typical diameter lies in the range of 0.25 to 0.75mm. Steel fibers having a rectangular c/s are produced by silting the sheets about 0.25mm thick. Fiber made from mild steel drawn wire. Conforming to IS:280-1976 with the diameter of wire varying from 0.3 to 0.5mm have been practically used in India. Round steel fibers are produced by cutting or chopping the wire, flat sheet fibers having a typical c/s ranging from 0.15 to 0.41mm in thickness and 0.25 to 0.90mm in width are produced by silting flat sheets. Deformed fiber, which are loosely bounded with water-soluble glue in the form of a bundle are also available. Since individual fibers tend to cluster together, their uniform distribution in the matrix is often difficult. This may be avoided by adding fibers bundles, which separate during the mixing process.

Steel fibers



Hooked-end Twisted Straight

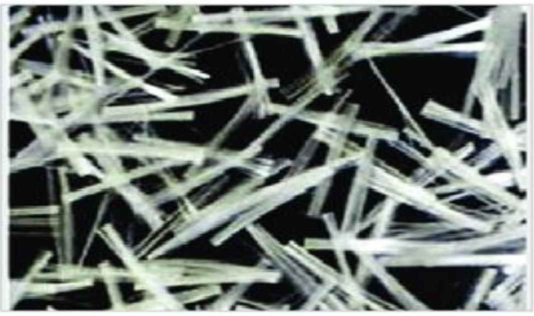
2. Polypropylene Fiber

Polypropylene is one of the cheapest & abundantly available polymers polypropylene fibers are resistant to most chemical & it would be cementitious matrix which would deteriorate first under aggressive chemical attack. Its melting point is high (about 165 degrees centigrade). So that a working temp. As (100 degree centigrade) may be sustained for short periods without detriment to fiber properties. Polypropylene fibers being hydrophobic can be easily mixed as they do not need lengthy contact during mixing and only need to be evenly distressed in the mix. Polypropylene short fibers in small volume fractions between 0.5 to 15 commercially used in concrete.

Polypropylene

3. Glass Fiber

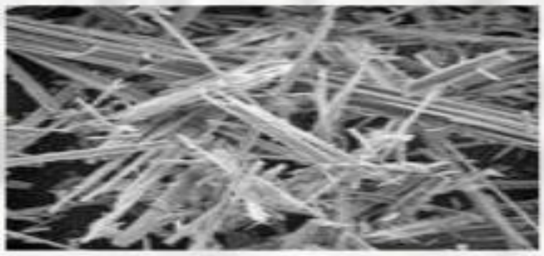
Glass fiber is made up from 200-400 individual filaments which are lightly bonded to make up a stand. These stands can be chopped into various lengths, or combined to make cloth mat or tape. Using the conventional mixing techniques for normal concrete it is not possible to mix more than about 2% (by volume) of fibers of a length of 25mm.The major appliance of glass fiber has been in reinforcing the cement or mortar matrices used in the production of thin-sheet products. The commonly used verities of glass fibers are e-glass used. In the reinforced of plastics & AR glass E-glass has inadequate resistance to alkalis present in Portland cement where AR-glass has improved alkali resistant characteristics. Sometimes polymers are also added in the mixes to improve some physical properties such as moisture movement.



Glass

4. Asbestos Fibers

The naturally available inexpensive mineral fiber, asbestos, has been successfully combined with Portland cement paste to form a widely used product called asbestos cement. Asbestos fibers here thermal mechanical & chemical resistance making them suitable for sheet product pipes, tiles and corrugated roofing elements. Asbestos cement board is approximately two or four times that of unreinforced matrix. However, due to relatively short length (10mm) the fiber have low impact strength.



Asbestos fiber

5. Carbon Fibers

Carbon fibers from the most recent & probability the most spectacular addition to the range of fiber available for commercial use. Carbon fiber comes under the very high modulus of elasticity and flexural strength. These are expansive. Their strength & stiffness characteristics have been found to be superior even to those of steel. But they are more vulnerable to damage than even glass fiber, and hence are generally treated with resign coating.

Carbon

6. Organic Fibers

Organic fiber such as polypropylene or natural fiber may be chemically more inert than either steel or glass fibers. They are also cheaper, especially if natural. A large volume of vegetable fiber may be used to obtain a multiple cracking composite. The problem of mixing and uniform dispersion may be solved by adding a superplasticizer.

Bamboo

III. PROPERTIES OF CONCRETE

3.1 Workability

The strength of all fiber reinforcement is particularly dependent upon attainment of a homogeneous spreading of the fibers in the concrete, successful casting and spraying and their interface with the cement. The addition of more percentage of fibers especially having small diameter, usually have a deteriorating effect on the workability of concrete and results in the requirement for changes in mix design. This is due to fibers with very small diameter have a much greater combined surface area. This extra demand on the addition of more water and cement or admixtures (hence increase in costs), will eventually result in dramatic effect on the workability of the concrete. Peng Zhang and Qing-fu Li (2013) concluded that workability of concrete consisting of silica fumes and fly ash, decreases with addition of polypropylene fibers [5]. They further observed that the fluidity of fresh concrete decreases and the cohesiveness of fresh concrete composite increases with increase in fiber volume fraction. C.D. Atis and O. Karahan(2009) observed that the workability of mix reduces with surge in steel fiber content [6]. D. Foti (2013) observed that concrete mix is hardly workable when dosage of circular PET fibers exceed 1% by weight of concrete [7]. Even after employing superplasticizer, higher amount of fibers is not advisable because concrete is no longer workable. Y. Mohammadi et al (2008) investigated various properties of SFRC consisting fibers of different aspect ratio and compared it with plain concrete [16]. Conclusion argues that workability decreases uniformly with increase in fiber content. Antonio Domingues de Figueiredoa and Marcos Roberto Ceccato (2015) observed that the fibers hindering the movement of the aggregate, chiefly results in loss of mobility and its intensity can be reduced by shortening the aspect ratio of the fibers [9]. But this also results in reduction of post crack strength of hardened fiber reinforced concrete. Conclusion argues to reduce the maximum size of aggregate or increase content of mortar in concrete.Faisal Fouad wafa (1990) studied that increase of fiber content from 0 to 2% results in decrease of slump value from 230mm(for 0%) to 20mm(for 2%) [10]. It was observed that the hooked fibers performed better when compared to straight fiber because balling was prevented during mixing. N.A. Libre et al (2011) concluded that PP fibers have lesser effect on workability of fresh mix, when compared to steel fibers [19]. It was observed that the danger segregation in lightweight concrete reduces due to blocking effect by polypropylene and steel fibers.Chen and Liu (2005) observed that different fibers such as steel and polypropylene have a holding effect which reduces the sedimentation of aggregates, surface bleeding and enhanced uniformity in light weight concrete (LWC) [49]. It was also observed that highest decrease in slump was up to 54.2% due to inclusion of steel fibers in LWC.

3.2 Compressive strength

The ultimate resistance provided by the concrete block just before yielding to the exerted compressive load can be termed as the compressive strength of the concrete. While the plain concrete failed catastrophically during the compression tests, Brandt (2008) advocated that plastic fiber reinforced concrete fails with occurrence of plentiful minor cracks on the surface [9]. S. Spadea et al (2015) investigated that incorporation of very short recycled nylon fibers decreases the compressive strength of inspected mortar (up to -37%) [11]. S.B. Kim et al (2009)observed decrease in compressive strength of about 1 to 9% and of about 1 to 10% for recycled Polyethylene terephthalate(PET) and polypropylene fiber reinforced specimen when compared to the plain specimen, respectively [12]. C.D. Atis and O. Karahan(2009) investigated compressive strength at 7, 28, 90 and 365 days period [6]. They observed rise up to 10% and fall up to 6% in compressive strength of concrete specimen reinforced with steel fibers. Conclusion argues that variation is due to complications in providing a homogeneous spreading of fibers inthe specimen. D. Foti (2013)concluded that concrete containing circular PET fibers do not exhibit any significant increase in compressive strength [7].D.A. silva et al (2005) observed that addition of polyethylene terephthalate (PET) fibers had no significant effect on the compressive strength of mortar [14]. A. Alavi Nia et al (2012)studied that the compressive strength of FRC increases with increase in volume of fiber [15]. Increase of about 14.2% in compressive strength was observed when results were compared to plain concrete. Y. Mohammadi et al (2008) observed 26% maximum increase in compressive strength against 2% fiber volume fraction of steel fibers [16]. This percentage of fiber was reported to be optimum volume fraction. H.T Wang and L.C Wang (2013)conducted experimental investigation on light weight concrete reinforced with volume fraction (0.0%, 0.5%, 1.0%, 1.5% and 2.0%) of fibers [14]. It was concluded that compressive strength improved to some extent with the inclusion of steel fibers. Faisal Fouad Wafa (1990)reported that essentially no impact on compressive strength of concrete was observed due to percentage of fiber volume fraction [10]. Patil Shweta and RupaliKavilkar (2014)observed thatcompressive strength decreased up to 31.10% with incorporation of steel fibers [18]. This maximum drop was observed for 1.5% fiber volume fraction. N.A. Libre et al. (2011)examined effect of the steel fiber on compressive strength of concrete. It was observed that compressive strength of concrete reduced to 50% with addition of steel fibers [19]. C. SelinRavikumar and T.S. Thandavamoorthy(2013) observed that compressive strength of concrete reinforced with glass fiber increases continuously with increase in fiber content [39].A.M Shende et al (2012) conducted experimental investigation on concrete with varying steel fiber content (0%, 1%, 2% and 3%). It was reported that with increase of fiber content, compressive strength also increases [20].PS song et al (2005) conducted comparative experimental investigation of nylon fiber reinforced concrete and polypropylene fiber reinforced concrete.It was observed that nylon fiber improved the compressive strength of concrete by 6.3% when compared to PP reinforced concrete [21]. The increase was due to better distribution and superior tensile strength of nylon fibers. Alhozaimy et al (1996) investigated the effect of various PP fiber content (0%, 0.05%, 0.1%, 0.2% and 0.3%) on the compressive strength of plain concrete along with concrete having various binders (silica fumes, fly ash and slag) [23]. No substantial effect was observed on plain concrete, while concrete with silica fumes demonstrated increase in strength up to 23%. B.Soundara (2015) observed that the compressive strength is slightly increased (about 7%) upon heating irrespective of the addition of different steel fiber percentage and curing period.

3.3 Flexural strength

Flexural strength is the resistance offered by the concrete block just before failing under the application of bending (flexure) stresses induced by appropriate loading. S.B. Kim et al (2009) reported an increase of 25%, 31% and 32% in flexural strength of recycled PET reinforced specimen at 0.5%, 0.75% and 1.0% of fiber volume fraction respectively [12]. C.D. Atis and O. Karahan(2009)reported that no substantial effect was observed on flexural strength at low volume fractions of steel fibers(up to 0.5%) [6]. However, at 1.0% volume fraction, improvement was observed and flexural strength increased up to 15% and further surged up to 30-66% at volume fraction of 1.5%. D. Foti (2013)concluded that concrete containing circular PET fibers do not exhibit any significant increase in flexural strength [7].D.A. silva et al (2005)studied that no substantial effect on tensile strength of mortar was observed when PET fibers were included [14]. Reason states that the strength to the first crack is in close relationship with the resistance offered by the plain mortar. H.T Wang and L.C Wang (2013)observed that theflexural strength was largely improved by the inclusion of steel fibers [17]. This effect was attributed to the ability of steel fibers to arrest the cracks. Y. Mohammadi et al (2008) observed thatthe ultimate increase of 100% in static flexural strength was observed at fiber volume fraction of 2.0% with 100% long steel fibers in concrete [16].Faisal fouadwafa (1990) studied that optimum increase in flexural strength of 67% was observed at addition of 1.5% hooked fibers [10]. Incorporation of 2% straight fibers, increased flexural strength up to 40% compared to plain concrete. At 2% volume fraction of hooked fibers, drop in flexural strength was reported due to difficulties in consolidation and achievement of uniform distribution. Patil Shweta and RupaliKavilkar (2014)studied SFRC by keeping volume fraction of fiber constant at 1.5% and increasing the aspect ratio up to 70 increase up to 58.65% was observed in flexural strength [18]. Further by keeping aspect ratio constant at 70 and increased volume fraction of fibers up to 2.5%, increase up to 119.69% was observed in flexural strength. N.A. Libre et al. (2011)studied that up to 200% increase in flexural strength was observed by addition of steel fibers [19]. Furthermore, some improvement in flexural strength was also observed by addition of 0.4% polypropylene fibers. C. SelinRavikumar and T.S. Thandavamoorthy (2013) studied with 0.5% volume fraction addition of glass fiber, 42% enhancement in flexural strength was observed and 75% increase in flexural strength was reported at 1% volume fraction addition [39]. A.M Shende et al (2012) observed that flexure strength is more at 3% volume fraction addition of fibers compared to 0%, 1% and 2% fibers [20]. Moreover, the flexure strength augmented up to 49% when steel fibers were included. Alhozaimy et al (1996) investigated the effect of various PP fiber content (0%, 0.05%, 0.1%, 0.2% and 0.3%) on the flexural strength of plain concrete along with concrete having various binders (silica fumes, fly ash and slag) [23]. At 99% confidence level, it was observed that strength surged up to 387% with inclusion of 0.3% fiber content. While at 95% confidence level no considerable effect was observed.

3.4 Tensile strength

Resistance offered by the material against the longitudinal stresses, measured in terms of value of longitudinal stress required to rupture the material is commonly known as tensile strength of the material. S. Spadea et al (2015) reported that up to 35% improvement in tensile strength and enhancement of fracture properties of cement mortar was observed by addition of R-Nylon fibers [11].C.D. Atis and O. Karahan (2009) observed that splitting tensile strength increased up to 3%, 5%, 32% and 71% for concrete with and without fly ash having fiber volume fraction of 0.25%, 0.5%, 1% and 1.5% respectively [6].A. Alavi Nia et al (2012)observed that with increase in volume fraction of steel fiber, the tensile strength of concrete (up to +62.1%) also increases [15]. H.T Wang and L.C Wang (2013)studied that thesplitting tensile strength greatly improved by the addition of steel fibers, and variation from 3.99 MPa to 7.68 MPa was observed in tensile strength [17]. This increase was credited to the arresting of cracking by steel fibers. Y. Mohammadi et al (2008) studied that tensile strength increased up to 27%, 51% and 59% for volume fraction addition of 1.0%, 1.5% and 2% of steel fibers to the concrete mix respectively [16]. Mix ratio at 2% volume fraction containing 35% short fibers and 65% long fibers was credited to ultimate increase of 59% in tensile strength. Faisal fouadwafa(1990)It was studied that maximum enhancement of 57% in tensile strength of concrete was observed at 1.5% volume fraction addition of steel fibers to the mix [10].N.A. Libre et al. (2011)reported thatinclusion of both steel and polypropylene fibers enhanced the tensile strength of light weight aggregate concrete up to 116% [19]. C. SelinRavikumar and T.S. Thandavamoorthy (2013)studied that with 0.5% volume fraction addition of glass fiber, 20% enhancement in tensile strength was observed and 37% risein tensile strength was reported at 1% volume fraction addition [39].A.M Shende et al (2012)observed that tensile strength is more at 3% volume fraction addition of fibers compared to 0%, 1% and 2% [20]. Moreover, the tensile strength augmented up to 49% when steel fibers were included.PS song et al (2005)observed that spitting tensile strength of nylon FRC enhanced by 6.7% over those of the polypropylene FRC [21]. The increase is due to slightly better dispersion of nylon fibers in the mixing water. B.Soundara (2015) observed that the tensile strength is slightly increased (at an average of 5%) upon heating irrespective of the addition of different steel fiber percentage and curing period.

3.5 Modulus of Elasticity

Slope of stress-strain curve of the concrete, within the relative limit of the material effectively defines the modulus of elasticity of the concrete. Its value is constant for low level stresses but reduces when concrete cracks and higher level of stresses are developed. C.D. Atis and O. Karahan (2009) studied that concrete containing steel fiber volume fraction of 0.25% and 0.5% had marginally higher value of elastic modulus compared to concrete without fibers [6]. Generally, modulus of elasticity reduces with increase in fiber content. D.A. silva et al (2005) studied that PET fibers virtually had no significant effect on elasticity modulus of mortar in flexural test [14]. S.B. Kim et al (2009) observed that recycled Polyethylene terephthalate(PET) and polypropylene(PP) concrete had lower value of elastic modulus compared to the plain concrete [12]. It was also reported that modulus of elasticity decreased with rise in fiber content.

3.6 Shrinkage Test

When subjected to a drying environment, concrete has a tendency to shrink. Its extent depends up on variety of factors such as material properties, humidity and temperature, size of concrete specimen. If shrinkage is restrained, tensile stresses and cracks may occur. Cracking of walls, pavements and slabs mostly occurs due to shrinkage cracking. Peng Zhang and Qing-fu Li (2013) observed that increase in polypropylene fiber content of the concrete, decreases the dry shrinkage strain [5]. Increase in fiber volume fraction up to 0.12% resulted in 24% decrease in ultimate dry shrinkage strain of 90 days. Malhotra et al (1994) studied that high volume fly ash concrete reinforced with polypropylene (PP) fibers, demonstrated decrease in property of drying shrinkage [21]. Mangat and Azari (1984)stated that fiber by making composite stiffer, stronger and restraining shrinkage by shear, decreases the dry shrinkage [26].C.D. Atis and O. Karahan (2009)studied that increase in steel fiber volume fraction results in reduction of drying shrinkage [6].S.B. Kim (2010)observed increase in free drying shrinkage strain when recycled Polyethylene terephthalate fibers were added in the concrete [12]. While for restrained shrinkage, fibers postponed the formation of cracks and improved tensile resistance.PS song et al (2005)observed that the nylon fiber in mortar has moderately better shrinkage crack reducing potential than that of the polypropylene fibers [21].Kim et al (2008) experimentally investigated result of recycled polyethylene terephthalate (PET) fiber orientation on the plastic shrinkage of the concrete [12]. Conclusion states that plastic shrinkage was affected by fiber geometry only when volume fraction of fiber was reasonably low (up to 0.25%).

3.7 Ductility

Concrete is a brittle material and usually have no substantial post-cracking ductility. Addition of fiber is generally considered to increase the ductility of the material. S. Spadea et al (2015) concluded that the incorporation of recycled fibers to the mix resulted in improvement of ductility properties of concrete and mortar [11]. D. Foti (2013) studied that high volume fraction of fibers enhances ductile behavior of concrete [7]. But high dosage is not recommended because adherence of fibers with concrete is lost and workability is also reduced. Faisal fouadwafa (1990) observed that addition of steel fibers enhances the ductility of concrete and also the capacity to carry post-cracking load [10]. Patil Shweta and RupaliKavilkar (2014) studied that ductile behavior of concrete improves by increasing the fiber volume fraction [18]. Maximum ductile behavior was observed at 2.5% fiber volume fraction with aspect ratio of 70.N.A. Libre et al. (2011)studied that addition of steel fiber in lightweight aggregate concrete (usually brittle), improves its ductile behavior [19].

3.8 Fatigue Behavior

Fatigue may be defined as a process of progressive, permanent internal structural changes in a material subjected to repeated loading. Fatigue failure strength is defined as the ultimate flexural fatigue stress at which the beam can withstand two million cycles of non-reversed fatigue loading. T.Brandshaug (1978) and R.F zollo (1975) advocated that the flexure fatigue strength of the concrete increases with increase in steel fiber volume fraction in concrete [45-46]. Cachim et al (2002) studied fatigue life of concrete reinforced with steel fibers of 30 mm and 60 mm in length [47]. Fatigue life was observed to increase for 30 mm fiber concrete, while it reduced for 60 mm fiber concrete. J. Zhang, H. Stang (1998) observed that incorporation of steel fiber substantially improved the bending fatigue performance of concrete [48].

3.9 Toughness

Toughness is the amount of energy per unit volume that a material can absorb before rupturing.S. Spadea et al (2015) concluded that the incorporation of recycled fibers to the mix resulted in enhancement of toughness properties of concrete and mortar [11]. D.A. silva et al (2005) observed that presence of PET fibers increases the toughness of mortar [14]. However, decrease in toughness with the age of fiber reinforced specimen was also reported. This is credited to deterioration of PET fibers inside mortar. Faisal fouadwafa (1990) observed that addition of hooked and straight fibers results in increase of toughness index of specimen [10]. Toughness index of specimen having hooked fibers was up to 65% more than the specimen containing straight fibers.

3.10 Impact Resistance

ACI committee 544 recommended that to assess the impact strength [41], repeated blows should be subjected. First crack strength is defined as the number of blows required to produce first visible crack on the top of the specimen. Failure strength is the number of blows required for ultimate failure of the specimen. K. Marar et al (2001) observed that impact resistance increases with increase in steel fiber volume fraction for all aspect ratios [43].

Impact resistance of HSC increased up to 74 times when 2% volume fiber of aspect ratio-83 was added.M. Nili (2010)Observed that addition of steel fibers improved the impact resistance of the concrete [42]. It was also reported that inclusion of silica fume along with steel fibers, further increased impact resistance. Alhozaimy et al (1996) observed improvement in impact resistance of concrete due to incorporation of polypropylene fibers. Impact resistance increased up to 171% by addition of 0.2% fiber content. A. Alavi Nia et al (2012) experimentally and numerically studied that inclusion of either hooked-end steel fiber or PP fibers improved the impact resistance of concrete [15]. Steel fiber reinforced concrete was reported to have better impact resistance compared to PP fiber reinforced concrete.N. Banthia et al (1998) investigated response of steel and carbon fibers on impact resistance of mortar and concrete [44]. Significant improvement in impact resistance was observed by inclusion of fibers under both normal and low temperature.

3.11 Durability

3.11.1 Effect of Alkaline Environment

The deterioration of natural fibers engaged in Portland cement is the result of the high alkaline environment which dissolves the fiber and thus making the structure weak. Gram H. (1983) investigated the fiber reinforced concrete incorporating coir and sisal fibers [25]. When specimen was exposed to alkaline solution, degradation of fibers was observed and variations in tensile strength were measured. Ca+2 ions were reported to have negative effect on fibers.Toledo Filho et al. (2000) studied the durability of coconut and sisal fibers when conditioned with alkaline solutions [29]. Coconut and sisal fibers immersed in a sodium hydroxide (NaOH) solutionmaintained respectively 60.9% and 72.7% of their original strength after a period of 420 days. For the fiber immersed in the Ca(OH)2 solution, author noted that original strength was entirely lost due to the crystallization of fiber pores after 300 days. Krishna and Sundararajan (2005) studied the durability of natural fibers and effect of corroded fiber on the strength of mortar [31]. They also reported that natural fibers deteriorated when exposed to an alkaline environment.

3.11.2 Freeze-Thaw Resistance

Seeping of water inside the cracks of the specimen (such as concrete) and its freezing may result in breaking of that specimen. Hence the resistance offered by the specimen against the cyclic freezing and melting is termed as freeze-thaw resistance.Peng Zhang and Qing-fu Li (2013) experimentally observed the effect of varying volume fraction of fiber in FRC [5]. It was observed that freeze-thaw resistance increases up to .08% fiber volume fraction and decreases when it is increased from 0.8% to0.12%. Conclusion argues that when volume of fiber increases the space between fibers decreases. Therefore, increasing the number of weak interface and overlapping of interface area of adjacent fibers. Thus interface area of micro structure tends to be very loose, which reduces the freeze-thaw durability of concrete. C.D. Atisand O. Karahan (2009)reported that concrete specimen with steel fibers has slightly better freeze-thaw resistancewhen compared plain concrete [22]. D. Niu et al (2013) investigated thatthe steel fiber volume fraction hashuge effect on the frost-resisting capacity of steel fiber reinforced concrete [32]. When a steel fiber content of 1.5 vol% is introduced, the frost damage is considerably reduced. However, concrete's frost-resisting property significantly decreased with 2% steel fiber content.

3.11.3 Permeability

Applied load and various other forms of stresses such as thermal, mechanical and chemical may result in growth of cracks and thus in turn increase the permeability of concrete specimen. This increase in permeability leads to deterioration of the specimen.Peng Zhang and Qing-fu Li (2013)experimentally studied that concrete specimen containing silica fume and fly ash was observed to have a reduction in permeability when polypropylene(PP) fibers were included [5]. It was also observed that as fiber volume fraction increases permeability of mix decreases. A.P. Singh and DhirendraSinghal (2011) reported that the permeability reduced considerably with rise in fiber content and escalating curing age [34]. The change in aspect ratio does not have a considerable effect on the water permeability of steel fiber reinforced concrete.

3.*11.4 Carbonation Depth*

The carbonation resistance of concrete can be determined by carbonation depth of specimen under the action of CO_2 pressure, process is to diffuse CO_2 from the surface to inside of the specimen and the as the diffusion depth of CO_2 increases, the carbonation depth also increases.Peng Zhang and Qing-fu Li (2013) observed that Carbonation resistance is increasing uniformly with the increase of volume fraction of polypropylene fibers [5]. Roziere et al (2009) advocated it and stated that fibers block the capillary channels in the mortar and makes capillary pores smaller [35]. Moreover, fibers reduce diffusion channels of CO_2 by reducing micro cracks in concrete.

2.11.5 Fire Resistance

Fire resistance is the ability of concrete to effectively perform its function of load bearing and fireseparating during fire exposure. Explosive spalling and other unique behavior is shown by HSC under elevated temperatures. This behavior has been credited to dense concrete structure of High strength concrete.. Chen and Liu (2004) experimentally investigated specimen at 20°C, 200°C, 400°C, 600°C and 800°C and concluded that explosive spalling is present for ordinary high strength concrete [36]. Strength left in the concrete (residual strength) is merely 10% of original strength at 800oC. It was observed that delay in time when spalling occurs can be increased by addition of steel and carbon fibers in high strength concrete. When temperature ranged 400°C-600°C,no substantial decrease in strength was observed but when temperature exceeds 600°C and reaches 800°C, its residual strength was still 30% of original strength. Dale P. Bentz(2000)suggested the reason that PP fibers enhances the performance level because when specimen is exposed to fire, water vapors is generated by the thermal breakdown of hydrated cement paste and burning of fibers provides a conduit for the release of the water vapor [34]. AminuddinJamerana et al (2015) studied the effect of elevated temperature on steel and PP fiber reinforced concrete [38]. The addition of steel and polypropylene fibers into the concrete mixture minimized the effects by reducing crack growth in the concrete. They also reported that steel fibers are better than PP fibers. C. SelinRavikumar and T.S. Thandavamoorthy (2013) heated glass fiber reinforced concrete with different volume fraction (0%, 0.5% and 1%) for 2 hrs [39]. Decrease in compressive strength to its original strength is 32%, 25%, 10% for 0%, 0.5% and 1% fiber volume fraction respectively.

IV. CONCLUSIONS

Based on the literature, the following conclusions were drawn: -

1. Steel fibers are providing post-cracking bending behavior thanks to their pull-out hook mechanism. Also, it enhances the load carrying capacity and cracking response but it decreases the ductility. The best bending results was achieved in the case of combined use of both carbon and steel fibers.
2. The addition of polypropylene fibres influence the mechanical properties of high-performance concrete which comprise silica fume as the mineral admixture. It has a little effect on the workability but enhances the properties such as compressive strength, flexural strength and split tensile strength.
3. 1.0% glass fibre volume can be taken as the optimum dosage, which can be used for giving maximum possible compressive strength at any age for glass fibre reinforced high performance concrete.
4. Splitting tensile strength of concretes were increased with increasing of hooked-end fibre content.5D hooked-ended steel fibres were increased up the splitting tensile strength as 38.3%. Post cracking behaviours were affected by the amount and type of hookedend of fibres.
5. The compressive strength of concrete is slightly increased (about 7%) upon heating irrespective of the addition of different steel fiber percentage and curing period. The tensile strength is slightly increased (at an average of 5%) upon heating irrespective of the addition of different steel fiber percentage and curing period.
6. Fiber reinforced concrete pavements prove to be more efficient than conventional RC pavements, in several aspects Compressive strength for fibre reinforced concrete is seen to be improved. It can be clearly seen that strength at 28 days for CSFRC 1% is better than other cases

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