FIBERS IN STRUCTURAL CONCRETE - A CRITICAL REVIEW

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Abstract—In this paper the recent progress and achievement in the application of fibers in concrete has been intensively investigated. Most of the conclusions on fibers are arrived at by conducting experiments on plain and reinforced concrete. The significance of this paper is in the collation of the research works reported to date in the area of fibers/hybrid fibers on plain, reinforced and prestressed concrete. Research efforts on the behavior of fiber reinforced high strength concrete in the area of prestressed concrete structures are limited. If the addition of fibers proves to improve the ductility and post crack strength of prestressed concrete, it would be a boon to the construction industry.

I. INTRODUCTION

According to ACI 544.1, “fibers may also enhance the properties of concrete including the tensile strength, compressive strength, elastic modulus, crack resistance, crack control, durability, fatigue life, resistance to impact and abrasion, shrinkage, expansion, thermal characteristics, and fire resistance.” The addition of randomly oriented discontinuous fibers in cementitious materials reduces the level of micro-cracking and enhances the toughness, ductility and post-cracking tensile resistance of concrete members. Literature reveals that Polypropylene can improve mix cohesion, early age crack resistance, resistance to plastic shrinkage during curing and early age crack resistance. Steel fibers can improve structural strength, reduce steel reinforcement requirements, improve ductility, and reduce crack widths thus improving durability. Basalt fiber can improve the flexural strength and toughness of concrete to a great extent compared to other non metallic fibers. Blends of both steel and polymeric fibers are often used in construction projects in order to combine the benefits of both steel fibers and polymeric fibers.

II. FIBERS

Using high strength concrete leads to brittleness of concrete; this can be avoided by adding fibers. Non metallic fibers like Polypropylene result in good fresh concrete properties and reduced early age cracking. Whereas metallic fibers like steel improve the post crack strength. Also fibers with Young’s modulus less than that of cement enhance the strain performance and more than that of cement enhance the strength performance. Hybridization of fibers is done for synergetic effect of material properties based on the performance to be enhanced. For example when short and long fibers are hybridized, during the initial phase of tensile loading, short fibers efficiently bridge the micro cracks and at a later stage when cracks grow bigger, long fibers come into action. Similarly the advantages of both metallic and non metallic fibers can be combined.

III. FIBERS IN PLAIN CONCRETE

Fibers in general increase the flexural strength, split tensile strength and toughness. Compressive strength does not significantly increase with addition of fibers. The fibrous matrix take some load at the interface, because of which the split tensile strength increases. Glass fiber separately or when combined with other fibers increases split tensile strength because of its high stiffness. Polyester fiber, because of its difficulty in getting dispersed into concrete, result in low split tensile strength. (Singh et al. 2010). Fiber concrete gives better flexural strength. Combination of steel and glass fiber gives the best performance. (Sivakumar 2011)
All the fiber concretes yield higher toughness compared to control concrete. Also compared to mono steel fiber concrete, combination of steel with glass and polypropylene gives better toughness indices. But replacement with non metallic fibers should be done without compromising on the toughness. (Sivakumar 2011). When structures are exposed to aggressive environment they undergo alkali silica reaction, which leads to rapid crack propagation. This can be controlled by using fiber reinforced concrete. Also fibers conserve the residual loading capacity after the alkali silica reaction. (Giaccio et al. 2015)

Dove tailed (DT) steel fibers have great gripping effect because of the stretching and diameter change. It carried significantly higher peak impact load than the other fibres. Also it displayed the lowest impact to break point due to superior bond strength and the ability to redistribute the impact forces. It has high impact energy due to its ability to absorb large degrees of strain. (Richardson and Coventry 2015)

Addition of hybrid fibres improves the ductility performance also. When a polyolefin-steel hybrid fibre reinforced system is considered, steel fiber improves the first crack strength and polyolefin improves the toughness and strain capacity in post crack zone. The addition of 2.0% by volume of hybrid fibres improved the ductility performance, modulus of rupture and load carrying capacity appreciably. (S.Eswari, P.N.Raghunath 2008)

When concrete with and without steel fibers are exposed to high temperature, loss of compressive strength was more in control samples. Also the variation in tangent and secant modulus of elasticity was in parallel with compressive strength. (Düğenci et al. 2015)

In high performance fiber reinforced concrete corrugated steel fibers are used for energy dissipation and also decrease the width of cracks more than the value of free shrinkage. Therefore it is useful for earthquake resistant design. Also a comparison made by adding different mineral admixtures like silica fume and blast furnace slag revealed that to maintain the compressive strength constant, a relative dosage of 10% of silica fume by weight of cement shall be replaced by a 20% dosage of blast furnace slag. (Kaïkea et al. 2014). Hybridization of steel and palm fiber in high strength flowing concrete proved that mono steel fiber was efficient in increasing the compressive strength and density of concrete. Whereas flexural strength and toughness increased during hybridization. (Dawood and Ramli 2014)

IV. FIBERS IN REINFORCED CEMENT CONCRETE

In earthquake prone regions conventional concrete has limitations which can be overcome by using reinforced cement concrete with fibers. Fibers improve the load carrying capacity, ductility and energy absorption characteristics of RCC. Also it is proved that hybrid fibers perform in a better way than using single fiber. (Sharmila and Thirugnanam 2013). Steel fiber reinforced concrete beams have better stiffness characters than normal RC beams. Also they improve the ultimate load carrying capacity. Theoretical results coincide with the experimental results. (Shukla 2011). Type and volume of fibers influence the shear strength of beams to a great extent. Shear reinforcement can be completely eliminated in shear span if fibers are provided. Due to the bridging action of fiber, post peak strength could also be improved. Here too the combination of polypropylene and carbon performed better than individual fibers for 1% volume fraction. (Sahoo et al. 2015). Addition of steel fibers improve the load carrying capacity, whereas polypropylene fibers enhance the ductility characteristics of RC beams. When both steel and polypropylene fibers were added in an equal volume fraction of 1%, better post yield strain-hardening response was noted. (Sahoo et al. 2014). Fibers distributed in all the directions of concrete can also improve the shear resistance under the influence of shear and bending. This is due to the reduction in spacing and width of cracks. Fiber reinforced SCC showed superior shear performance than conventional FRC because of better workability and elimination of mechanical vibration. Hybrid effect of macro steel and plastic fibers when combined enhanced the shear toughness to a great extent. The addition of standard size and shape steel fibers to concrete improves crack behavior, makes the concrete ductile, increases its tensile strength, and improves its durability appreciably. Steel fibers improve the post cracking stage...
behavior depending on the matrix properties, fiber type, geometry and content. When FRC beams with steel and polypropylene fibers were tested for shear, it was observed that the progress of cracking was relatively slow. (Ding et al. 2010).

V. FIBERS IN PRESTRESSED CONCRETE (PSC)

Advantage of prestressed beams over reinforced beams is better durability due to absence of cracks in the tension zone. When high strength concrete is used, in prestressed concrete performance was enhanced except for some decrease in ductility. When prestressed concrete beams with bonded and unbonded tendons were casted using normal and high strength concrete, it was observed that PSC beams with bonded tendons showed improved ductility, initial stiffness and ultimate deflection. Also PSC beams with non-prestressed reinforcement showed better ductility than beams without them. (Hussien et al. 2012). Advantage of post tensioning can still be improved by adding fibers. Fibers can reduce the amount of shear reinforcement and even elimination of it in cases. When steel fibers are used, bonded post tensioning technique need to be adopted. When similar beams were casted and tested in bending to investigate their behavior when simply reinforced, simply post-tensioned, unbonded post-tensioning and post-tensioned and steel fibre reinforced, the fiber reinforced post tensioned beams performed well in flexure due to reduction of crack opening at equal deflection and a very significant reduction of the peak loss after failure in compression, that contributes to increase their ductility. (Dozio and Engineering n.d.)

When half scale T-shaped post-tensioned simple beams with steel and polypropylene fibers were casted and tested in four points, there was appreciable enhancement in the crack distribution, crack width and spacing, concrete tensile strength and flexural stiffness in all beams with steel fibrous concrete. But beams with polypropylene fibers showed slight decrease in the flexural strength and a slight increase in flexural stiffness. Both the beams showed enhanced ductility and energy absorption. Parameters tested were prestressing ratio, type of fiber and content. Steel fibers proved to be more structurally efficient. (Elsharkawy et al. 2013).

Reinforcement ratio played a significant role in the behavior of prestressed concrete beams made with ultra high performance cement and steel fibers, viz load bearing capacity, deflection and crack pattern. Steel fibers with a volume fraction of 1% had appreciable enhancement in post cracking stiffness and ductility. It was concluded that beams with high reinforcement ratio should be provided with shear reinforcement too. (Guo et al. 2015)

Fiber addition to PSC beams improved the ultimate shear strength up to 95%. PSC beams showed significant strength gain after the first crack whereas conventional PSC beams failed immediately after first crack. (Narayanan and Darwish 1987). High strength Steel fiber reinforced Prestressed concrete beams were casted with different fiber location and volume fractions. When they were subjected to shear, beams with fibers over full length and without stirrups failed in brittle shear mode. The same beams when provided with stirrups, the failure mode changed from brittle shear to ductile flexure. When the location of the fibers was considered, it was concluded that use of fibers only in the shear span could be economical for enhancing shear strength. (Padmarajaiah and Ramawamy 2001). Minimizing the need for traditional shear reinforcement would result in a reduction in time and labour costs associated with their placement and fabrication. (Tadepalli et al. 2011). From 2008, ACI allows SFRC to replace conventional shear reinforcement even if the design shear force is greater than half of the concrete shear strength. Experiments conducted showed that steel fiber reinforced PSC beams had better shear strength an ductility due to arch action as primary shear resisting mechanism. (Yoon and Nishiyama 2012)

To study the effect of mineral admixtures in prestressed concrete, beams were casted with different proportions of metakaolin and fly ash. Beams with metakaolin performed better than beams with fly ash in flexure. (Patil and Sangle 2013). Steel fiber reinforcement has the potential to reduce or in some cases eliminate the need for traditional shear reinforcement (stirrups) in some structures. Addition of trough shaped steel fibers to prestressed beams increased cracking strength and peak strength. When structures are subjected to high strains full depth fiber reinforcement is required,
otherwise inclusion fiber over partial depth would be economical. The load deformational characteristics from the experiment were in close agreement with the finite element solution. (Padmarajaiah and Ramaswamy 2002)

VI. CONCLUSION

This paper has presented the state of the art in the use of different fibers. Use of single fiber or hybrid fibers were critically reviewed. Various structural applications of FRC were summarized and reviewed. Critical parameters of concrete affected because of the presence of fibers were reviewed, including the toughness, ductility, post crack strength, ultimate load carrying capacity, shear and flexural behavior. The following conclusions are made from this study:

1. Hybrid fibers perform better than mono fibers in terms of toughness, ductility and post crack strength.
2. Only in plain concrete many of the new generation fibers like carbon, glass and basalt had been used and tested
3. In Fiber reinforced RCC and PSC beams the percentage of shear reinforcement can be reduced because of the fiber bridging action.
4. In most of the Fiber reinforced RCC and PSC beams in literature, steel and polypropylene fibers are used.
5. Most of the PSC beams are pre tensioned. More intense experiments need to be conducted in post tensioned structures which are widely used currently.

VII. RESEARCH NEEDS

In the present scenario post tensioned beams are widely used in the construction industry. Adding fibers in post tensioned beams improve flexural, shear, energy absorption and ductility. Most of the research work is done using steel and polypropylene fibers. Synergetic effect of fibers is yet to be tested on post tensioned beams using new generation fibers.

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REFERENCES


