# INNOVATION IN STEEL FIBRE REINFORCED CONCRETE-A REVIEW

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## ABSTRACT

*In recent years, considerable works has been performed on steel fibres to increase the load carrying capacity of concrete members. Fibres substantially reduce the brittleness of concrete and improve its engineering properties, such as tensile, flexural, impact resistance, fatigue, load bearing capacity after cracking and toughness. This Paper gives a review of research performed on Steel Fibre reinforced concrete.*

***Keywords****: SFRC, tensile strength, flexure strength, impact, cracking*

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## 1. INTRODUCTION

Concrete is one of the most widely used construction materials. It is used in a variety of applications such as highways, high-rise buildings, dams, bridges, sidewalks, and residential construction. Concrete was used as long ago as the Greek and Roman civilizations . Concrete is used as a good construction material due to its property of high compressive strength. However, since the early 1800's, it has been known that concrete is very weak in tension. This comes from the brittle nature of the material. Weak tensile strength combined with brittle behavior results in sudden tensile failure without warning. This is obviously not desirable for any construction material. Thus, concrete requires some form of tensile reinforcement to make up for its brittleness and improve its tensile strength and strain capacity for it to be used in structural applications. Steel has been used as the material for tensile reinforcement in concrete. For steel reinforcement to be effective, it has to be placed strategically inside concrete where tensile stresses are expected. Unlike conventional reinforcing bars, which are specifically designed and placed in the tensile zone of the concrete member, fibers are thin, short and distributed randomly throughout the concrete member. The random distribution results in a loss of efficiency as compared to conventional reinforced bars, but the closely spaced fibers improve toughness and tensile properties of concrete and help to control cracking. In many situations it is prudent to combine fiber reinforcement with conventional steel reinforcement to improve performance (Derucher, 1998. Although reinforcing brittle materials with fibers is an old concept, modern day use of fibers in concrete is only started in the early 1960s. Realizing the improved properties of the fiber reinforced products, research and development work on fiber reinforced concrete (FRC) are initiated about three decades ago. This paper provides a review of works performed on fiber reinforced concrete.

## 2 EXPERIMENTAL RESEARCH

Romualdi and Batson (1963) after conducting impact test on fibre reinforced concrete specimens, they concluded that first crack strength improved by addition of closely spaced continuous steel fibres in it. The steel fibres prevent the adverting of micro cracks by applying pinching forces at the crack tips and thus delaying the propagation of the cracks. Further, they established that the increase in strength of concrete is inversely proportional to the square root of the wire spacing.

Jack Synder and David hankard (1972) investigated mortars and concrete by reinforcing small short steel fibres in flexure. They concluded that there is significant increase in the first crack strength and ultimate strength. Due to addition of coarse aggregate to a reinforced mortar there is decrease in the first crack and ultimate strength of the material.

Rajagopalan and others (1974) developed equations to predict the first crack and ultimate moment of resistance of the SFRC beams with steel fibres. Also they concluded that there is much improvement in ductility and large rotation capacity which can be used effectively in redistribution of movements in beams and frames.

Swamy, R.N. (1974) studied the mechanical properties and applications of fibre reinforced concrete using polypropylene, glass, asbestos and steel fibres. The factors influencing the effectiveness of fibre reinforcement and the efficiency of stress transfer were discussed. The author concluded that Asbestos, glass and steel fibres can be used at higher temperature than the low modulus fibres like nylon and polypropylene which lose their load carrying capacity around 1000C. The great improvements in impact resistance and ductility at failure provided by glass, steel and plastic fibres are not reflected by asbestos, whose characteristic property is its high tensile strength.

Charles H.Henage (1976) developed an analytical method based on ultimate strength approach, which has taken into account of bond stress, fibres stress and volume fraction of fibres. After his investigations, he concluded that the incorporation of steel fibres significantly increases the ultimate flexural strength, reduces crack widths and first crack occurred at higher loads.

Shah and Naaman (1976) had conducted tensile flexural and compressive tests on mortar specimens reinforced with different lengths and volumes of steel and glass fibres. The flexural tensile strength of the reinforced samples was 2 to 3 times that of plain mortar while corresponding strains or deflections were as much as ten times that of mortar. The stresses and strains at first cracking were not notably diverse from those of plain mortar. The values of the modulus of elasticity and the extent of nonlinearity were observed to depend on the method of deformation measurement. Extensive micro cracking was observed on the surfaces of failed flexural specimens indicating a significant contribution of the matrix even after the first cracking. For steel fibre reinforced specimens, the peak loads and deformations appear to be linearly related to the fibre parameter Vf*L/D. After breakdown, steel fibres pulled out while a large amount of the glass fibres broke.

Hughes and Fattuhi (1976) carried out experimental investigations on the workability of fresh fibrous concrete. They concluded that the workability depends upon the properties and proportions of the ingredients and also the workability decreases with increase in sand content, volume fraction of fibres, aspect ratio, and length of the fibres and with lesser water/cement ratio.

Krishna Raju et al. (1977) after conducting experimental investigation on the compressive strength and bearing strength of steel fibre reinforced concrete with fibre content varying from to 0% to 3%, they concluded that, both compressing and bearing strength increases with increase in fibre content. Also the experimental results were predicted by theoretical method.

Kormeling, Reinhardt and Shah (1980) after carrying out investigations on the influence of using steel fibres on the static and dynamic strength of RCC beams using hooked straight and raddled fibres, they concluded that incorporation of above type of fibres increased the ultimate moment and reduces the crack width and average crack spacing.

Ramakrishnan et al. (1980) carried out experimental investigations on properties of concrete like, flexural fatigue, static flexural strength, deflection, modulus of rupture, load deflection curves, impact strength to first crack, ultimate tensile, compressive strength, plastic workability including vee-bee, slump and inverted cone time by reinforcing two types of steel fibres (straight and fibre with deformed ends) in the concrete. From the investigations, they concluded that no balling of fibres occurred in the cone of hooked fibres, the compressive strength is slight higher than the normal concrete, excellent anchorage by hooked fibres resulting in ultimate flexural strength. Also the hooked end fibres have greater ability to absorb impact than straight fibre reinforced concrete.

Kukreja, C.B. et al. (1980) carried out experimental investigations on the direct tensile strength, indirect tensile strength and flexural tensile strength of the fibrous concrete and compared with the various aspect ratios of the fibres as 100, 80 and 60 respectively. They observed that maximum increase in direct tensile strength obtained by fibres of aspect ratio 80 with 1% as volume fraction. Finally they concluded that indirect tensile cracking stress is an inverse function of fibre spacing and fibre reinforcement is more effective in improving the post cracking behaviors, than the first cracking.

Narayanan and Palanjian (1982) carried out experimental investigation on the properties of fresh concrete like workability in terms of vee-bee time by incorporative crimped steel fibres of circular cross-section. They concluded that vee-bee time increases when the aspect ratio (l/b) of fibres is increased. Balling would occur with smaller fibre content of larger aspect ratio. Also they concluded that optimum fibres content increases linearly with increase in fine aggregate content.

Narayanan and Kareem-palanjian (1984) have studied the effect of addition of crimped and un-crimped steel fibres on the compressive strength, splitting tensile strength and modulus of rupture of concrete. They concluded that fibres with higher aspect ratio exhibited greater pull – out strength and more effective than fibres with smaller aspect ratios. Crimped fibres possess higher bond strength than un-crimped steel fibres, finally they concluded that the strength of concrete after adding steel fibres, is related to the aspect ratio of fibres, fibre volume fraction and bond characteristics the fibres. But these factors are accounted by a single parameter called as fibre factor „F‟ Increase in the Compressive strength, splitting tensile strength, and modulus rupture of concrete are shown by an equation in terms of fibre factor „F‟ and strength of normal concrete.

S.P. Shah, et al. (1986) have found the impact resistance of steel fibre reinforced concrete using modified charpy impact testing machine. The size of the specimens was 76mm x 25mm x 230mm and compressive strength was found using 76mm x 152mm cylinders. They used brass-coated steel fibres at different volume fractions of 0.5%,1% and 1.5% were used. They observed that the impact resistance improved with fibre additions.

Nagarkar, et al. (1987) after conducting experimental investigation on concrete reinforced with steel and nylon fibres, they concluded that the increase in compressive strength, splitting tensile strength and flexural strength of concrete is more prominent in case of addition on steel fibres than nylon fibres. They observed that compressive strength is increased in the range of 5 to 7%, split tensile strength in the range of 15 to 45% and flexural strength in the range of 20% to 60% respectively.

Nakagawa et al. (1989) carried out experimental investigation on the compressive strength of concrete by incorporating short discrete carbon fibres, Aramid fibres and high strength vinyl on fibres. They concluded that compressive strength decreased as the volume fraction of fibres is increased.

Ramakrishna et al. (1989a) conducted experiments to compare the first cracking strength and static flexural strength of plain concrete and steel fibre reinforced concrete. They used hooked end fibres upto 1% by volume. They concluded that hooked - end fibres gave maximum increase in the above mentioned properties when compared to straight steel fibres.

Rachel Detwiler and Kumar Mehta (1989) concluded that silica fume concrete showed the greatest improvement in strength due to combination of cement hydration and the pozzolanic reaction between 7 and 28 days.

Ghosh et al.(1989) after conducting experiments on cylinder split tensile strength and modulus of rupture of concrete by using low fibre content (0.4% to 0.7%) with straight steel fibres, they concluded that split cylinder testing method is recommended for determining the tensile strength of fibre - reinforced concrete as in the case of normal concrete.

Kukreja and Chawla (1989) After conducting experimental investigations on concrete by using straight bent and crimped steel fibres with aspect ratio 80, they published a paper on "flexural characteristics of steel fibre reinforced concrete". They concluded that, based on steel fibre content, its type and orientation, behaviour can range from brittle to very ductile, all for the same range of flexural strength.

Parviz Soroushian & Ziad Bayasi (1991) carried out experimental investigations on the relative effectiveness of straight, crimped rectangular, hooked - single and hooked - collated with aspect ratio of about 60 to 75. They observed slightly higher slumps with crimped fibres and hooked fibres are found to be more effective in enhancing the flexural and compressive behavior of concrete than the straight and crimped fibres.

Ezeldin and howe (1991) investigated the flexural strength properties of rapid - set cement incorporated with four types of low carbon steel fibres (two were hooked, one was crimped at ends and one was crimped though out at ends). They concluded that the flexural strength is controlled by the fibre surface deformation, aspect ratio and volume fraction. They further concluded that steel fibres are very effective in improving the flexural toughness of rapid-set materials.

S.K. Saluja et al. (1992) carried out experimental investigations on the compressive strength of concrete by incorporating straight steel fibres of aspect ratios 75, 90 and 105. They concluded that steel fibres are effective in increasing the compressive strength to a maximum of 13.5% at 1.50% fibre content. Also an equation was developed to predict the experimental results.

Sameer, E.A., and Balarguru P.N. (1992) experimentally investigated the stress-strain behavior of steel fibre reinforced concrete with and without silica fume. They proposed a simple equation to predict the complete stress-strain curve. They observed a marginal increase in the compressive strength, the strain corresponding to peak stress and the secant modulus of elasticity. Also they concluded that increase of silica - fume content renders the fibre reinforced concrete more brittle than non-silica fume concrete.

Balaguru and Shah (1992) said that fibre geometry (aspect ratio) plays of vital role in the performance of straight fibres. They said that ductility increases with the increase in aspect ratio, with the condition, that fibres should be mixed uniformly with the concrete. The matrix composition contributes in at least two ways to strength and energy absorption. The first is its bonding characteristics with the fibre and the second is the brittleness of the matrix itself, which plays an important role in the behavior of steel fibre reinforced concrete.

Balaguru and Shah (1992) In their state of art report say that, the other factors to be considered in the design are, modulus of elasticity, strain at peak load and post peak behavior. They said that the addition of fibres increases the strain at peak load and results in a less steep and more gradual descending branches. Finally, fibre reinforced concrete has been found to absorb much more energy before failure when compared to normal concrete.

Faisal F Wafa and S.A. Ashour, (1992) carried out experimental investigations on properties like, cube compressive strength, splitting tensile strength and modulus of rupture of concrete by incorporating hooked - end steel fibres with 0% to 1.5% as volume fraction. They concluded that addition of 1.50% by volume of hooked end fibres resulted in 4.6% increase in compressive strength, 59.80% increase in split tensile strength and 67% increase in modulus of rupture of plain cement concrete. Also they developed equations for predicting the experimental results.

Bayasi and Zeng (1993) proposed that flexural behavior of polypropylene fibres be characterized by the post-peak flexural resistance. They found that long fibres were more favorable for enhancing the post-peak resistance. The effect of silica fume on the compressive properties of synthetic fibre-reinforced concrete by using fibrillated polypropylene and polyethylene erphalate polyester fibres was studied by bayasi celik. He concluded that both types of fibres improved the compressive behavior by enhancing the toughness and also, both the fibres increased the strain at peak compressive stress.

Alhozaimy, A.M., et al. (1995) After experimental investigations they concluded that increased effectiveness of fibres in the presence of pozzolans could be caused by the improved fibre to matrix bonding associated with the action of pozzolans in the concrete.

Balasubramanian et al. (1996) studied the impact resistance of steel fibre reinforced concrete using drop weight test method. They varied the fibre volume fractions as 0.5% to 2% for each of the three types of steel fibres (Straight, Crimped and Trough shaped fibres). These fibres were of aspect ratio 80. They concluded that impact resistance increased with increase in fibre volume fraction. Also they concluded that among the three types of fibres, crimped fibres showed higher impact resistance than straight and trough shape fibres.

Agrawal, A.K. Singh and Singhal D. (1996) studied the effect of fibre reinforcing index on the compressive strength and bond behavior of steel fibre reinforced concrete by using straight circular Galvanized Iron fibres with aspect ratios of 60, 80 and 100. The maximum fibre content was taken as 1.50% by volume of concrete. The results show an increase in compressive and bond strength of steel fibre reinforced concrete when compared to normal concrete. They also developed relationships to relate compressive and bond strength with fibre reinforcing index (FRI).

Singh, A.P. & Dr. Singhal, D., (1998) After studying the permeability of steel fibre reinforced concrete by using plain steel fibres at various percentages (0% & 4%) they observed that permeability is decreasing significantly with the addition of fibres and it continued to decrease with the increase in fibre content. Also linear relation ship was observed between permeability and compressive and tensile strength for plain cement concrete.

R.M. Vasan et al (1999) investigated the effect of hook shaped steel fibres of circular in cross-section on the compressive strength, flexural strength, impact strength and modulus of elasticity of high strength concrete. From the results, they observed that the above properties of concrete were improved due to the addition of 0.5% volume of steel fibres.

Nataraja, Dhang, Gupta (2001) studied the effect of addition of crimped round steel fibres on the splitting tensile strength of concrete. They proposed equations based on linear regression analysis to correlate splitting tensile strength with the fibre reinforcing index. Linear relation ship between splitting tensile strength and the flexural strength, split tensile strength and compressive strength were also proposed.

Maria de Lurdes et al. (2001) Authors carried out experimental investigations on the compressive strength of steel fibre reinforced high strength concrete (SFHSC) subjected to high temperatures. The concrete samples were preheated to various temperatures, and the subsistence of a cooling stage was measured as a variable. They concluded that during the heating phase the compressive strength of the SFHSC was shown to be more affected by high temperatures than normal - strength concrete without fibres. In general, a gain in compressive strength in the specimens was observed after cooling, except at 3000C, there was always a gain in compressive strength after the specimens cooled for all maximum preheating temperature levels. This recovery varied according to the maximum heating temperature level, but reached as much as 20% for maximum heating temperatures of 500 – 6000C. At 2000C, the residual strength was higher than the concrete strength before heating.

Bindiganavalie. V and Banthia. N (2002) The authors on the topic “Some studies on the Impact Response of Fibre Reinforced Concrete” made an attempt to examine two major issues related to impact loading on plain and fibre reinforced concrete. Firstly, within the context of drop weight impact tests, a number of machine parameters were examined including capacity size (150J – 15,000J) and drop heights (1.2m – 2.5m). It was found that the machine parameters strongly control the experiential material response to impact.

Secondly, a comprehensive test program launched where steel and polymer fibres with widely different constitutive properties were compared as reinforcement in concrete under impact loading.

O.Kayali et al. (2003) carried out experimental investigation on the effect of polypropylene and steel fibres on high strength light weight aggregate concrete. Sintered fly ash aggregates were used in the light weight concrete. By adding polypropylene fibres at 0.56% by volume of the concrete caused a 90% increase in the indirect tensile strength and a 20% increase in the modulus of rupture, where as addition of steel fibres at 1.70% of volume of concrete increased the indirect tensile strength by about 118% and 80% increase in modulus of rupture. Finally there is a significant gain in ductility when steel fibres are used.

Kaushik S.K., et al. (2003) carried out experimental investigation on the mechanical properties of reinforced concrete by adding 1.0% volume fraction of 25mm and 50 mm long crimped type flat steel fibres. It was observed that short fibres acts as crack arrestors and enhances the strength, where as long fibres contributed to overall ductility. They concluded that best performance was observed with mixed aspect ratio of fibres.

Peter H.Bischoff (2003) studied the post cracking behavior of reinforced tension members made with both plain and steel fibre - reinforced concrete. He concluded that specimens with steel fibres exhibited increased tension stiffening and smaller crack spacing, which both contributed to a reduction in crack widths. Also it is observed that cyclic loading did not have a significant effect on either tension stiffening (or) crack width control for the specimens tested.

Song, Hwang and Shou (2004) carried out experimental investigations to study the impact resistance of steel fibre reinforced concrete using drop weight test method. They used hooked end fibres with 0.55mm in diameter and 35mm long. They concluded that steel fibrous concrete improved to various degrees to first crack and failure strengths and residual impact with standing capacity over the non-fibrous concrete.

Kolhapure B.K. (2006) investigated experimentally the mechanical properties of concrete using recron 3S fibres along with super plasticizer. He concluded that compressive strength, tensile strength and flexural strength is increased by 30%, 23% and 24% when compared to plain concrete.

F.B.A. Beshara, I.G. Shaaban and T.S. Mustafa (2009) presented the development of simple semi-empirical formulae for the analysis of nominal flexural strength of high strength steel fiber reinforced concrete (HSFRC) beams in their paper Nominal Flexural Strength of High Strength Fiber Reinforced Concrete Beams. This paper presents a more realistic and semi-empirical approach for predicting the nominal flexural strength on the basis of suitable idealized stress blocks and sectional analysis procedure. The theoretical predictions of the ultimate moment capacity are compared with the measured response for many tested beams in other research programs mentioned in the literature.

## CONCLUSION

During the last decades incredible development have been made in concrete technology. One of the major progresses is Fibre Reinforced Concrete (FRC) which can be defined as a composite material consisting of conventional concrete reinforced by the random dispersal of short, discontinious, and discrete fine fibres of specific geometry. Unlike conventional reinforcing steel bars, which are specifically designed and placed in the tensile zone of the concrete member, fibers are thin, short and distributed randomly throughout the concrete member. Among all kinds of fibers which can be used as concrete reinforcement, Steel Fibers are the most popular one. The performance of the Steel Fiber Reinforced Concrete (SFRC) has shown a significant improvement in flexural strength and overall toughness compared against Conventional Reinforced Concrete.

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