Chapter 3

LITERATURE REVIEW

Shah and Rangan [1970, 1971] established that fiber-reinforced concrete can be designed to obtain a specific ductility or energy absorption.

For straight steel fibers, the primary factors that controlled the properties of the composite were fiber volume fraction and length/diameter, or aspect, ratio of the fibers. The amount of fiber used ranged from 900 to 1200 N/m³ of concrete. The aspect ratios were in the range of 60 to 100. The major problems encountered in the early stages were difficulty in mixing and workability. At higher volume fractions, fibers were found to ball up during the mixing process. This process, called balling, was found to occur frequently for longer fibers. The size of the coarse aggregate was normally restricted to facilitate the use of shorter fibers and to avoid balling of fibers. Additionally, the mortar fraction of concrete was increased to combat the balling problem. There was always a reduction in workability with the addition of fibers. This tends to affect the quality of concrete in place, especially for higher fiber volume fractions.

The advent of deformed fibers and high-range water-reducing admixtures provided a big boost to the fiber-reinforced concrete use in the field.

Shah and Vijay Rangan [1971] investigated mechanical properties of concrete and mortar reinforced with randomly distributed smooth steel fibres. Different volumes, lengths, orientations and types of fibres were used. Fibres were compared with conventional reinforcement in flexure tension and compression. It was observed that the significant reinforcing effect of fibres is derived after the cracks are initiated in the matrix. The post cracking resistance of fibres is considerably influenced by their lengths orientation and stress strain relationship. The spacing of reinforcement appears to have little influence on crack propagation below a certain length. The reinforcing action of fibres was analytically predicted by using the composite materials approach based on the properties of individual components.

Shah and Rangan [1971] reported that the presence of steel fibres does not significantly influence the rupture strength of the matrix in bending but differs from those reported by Romualdi and Mandel [1964]. However steel fibres considerably increase the resistance of the mortar to crack propagation. The ultimate strength in axial compression of the composite is less than the ultimate strength of the mortar. However the
presence of the fibre increases the ductility of the composite. They further suggested that a strong material could be obtained if the wires of smaller diameter and longer length were used, provided that the problem of bundling is overcome. It can be avoided by trial mixing as suggested by Romualdi and Mandel [1964].

Snyder and Landkard [1972] investigated the effect of steel fibre parameters and concrete mix parameters on the flexural strength properties of steel fibrous concrete and mortar. They have reported that significant increase in the first crack flexural strength (up to three fold) and ultimate flexural strength (up to four fold) of mortar and concrete can be achieved through the use of short length (6.4 to 63.5 mm) having small diameter (0.15 to 0.79 mm) steel fibres. There exists a linear relationship between first crack flexural strength and ultimate flexural strength as a function of fibre content for (0.25 x 25.4 mm) fibres in mortars containing 4 percent fibres by volume.

Hughes and Fatruhi [1974] examined the effects of the addition of various fibres including fibrillated polypropylene as well as round straight duoform, crimped and hooked steel on the compressive stress strain properties of concrete matrix. They concluded that the addition of polypropylene fibres decreased the density, dynamic modulus of elasticity and the compressive strength of concrete, but enhanced its ductility. The maximum increase observed in the compressive strength of the concrete of nearly 7 percent was achieved by the addition of 0.25 x 25 mm duo-form steel fibres. They have further mentioned that the strength and the initial slope of the stress strain curves for all the fibre mixes increased slightly with age and are generally similar in nature.

Rajagopalan et al., [1974] carried out experimental work on the behaviour of fibre reinforced concrete in direct tension and flexure. Based on their study they concluded that closely spaced and well-bonded steel fibres increase the strength of concrete beams both at first crack and at failure. The inclusion of fibres to the concrete imparts enormous ductility and large rotation capacity. Significant increase in flexural strength is obtained by the inclusion of fibres in the tension zone. They have presented empirical formula to predict the strength of fibre reinforced concrete beams.

Ramey et al., [1974] have reported that the fatigue strength of fibre concrete reinforced with 13mm long, 0.148mm diameter un-deformed brass coated steel wires (2 percent by volume of mix) is of the order of 9
percent of the static strength. This is considerably greater than 55 percent usually associated with concrete fatigue tests.

Swamy and Mangat [1974] have presented equations using a composite mechanics approach to predict the first crack and ultimate flexural strength of concrete reinforced with short discontinuous steel fibres randomly oriented and uniformly distributed throughout the concrete mass. From these equations, design equations are derived, which are sufficiently, lower bound to be usable in practice. The equations are shown to be valid for a wide range of mix proportions aggregate size and fibre geometry that is likely to be met in construction practice.

Samarrai and Elvery [1974] investigated the possibility of incorporating steel fibres in steel reinforced concrete to retard the development of cracks so that steel of higher strengths can be used in the concrete. They tested 75 x 75 x 500 mm, concrete prisms in uniaxial tension applied to the protruding ends of the concentrically placed reinforcing bars. The inclusion of steel fibres in the concrete significantly increased the stress in the reinforcement corresponding to the development of the maximum allowable crack width in concrete.

Gunsekaran [1975] conducted tests to investigate the flexural strength and load deflection behaviour of light weight concrete beams (150 mm x 900 mm) made with sintered fly ash aggregates and regulated set cement and included steel fibre reinforcement. Three different aspect ratios of about 47, 50 and 63 were used for the fibres. It was found that beams containing fibres with an aspect ratio of 50 had the best flexural strength 3.45 N/mm², but the beams containing fibres with an aspect ratio of 62.5 had better ductility, although lower flexural strength, 2.53 N/mm². In both cases the quantity of fibres used was the same. Beams made with concrete having the same total quantity of fibres as before, but comprising 50 percent fibres with an aspect ratio of 62.5 and 50 percent with an aspect ratio of 50, possessed considerable ductility with out any reduction is flexural strength. They have concluded that for equal quantities of fibre reinforcement, a blend of fibres consisting of both long and short fibres results in greater structural benefits in concrete then identical fibres with a high aspect ratio, and low aspect ratio fibres act as crack arresters in the finite volume enclosed by the high aspect ratio fibres, the latter are primarily responsible for the enhanced ductility of fibre reinforced concrete.
Swamy and Strvrides [1975] have reported that the properties of fibre-reinforced composites are largely determined by the method of fabrication. With steel fibre concrete, geometry of the fibre, the method of casting and compaction and compactability of the fibre concrete mix, all significantly influence the disposition of the fibres in the hardened composite. Tests on fibre concrete mixes with adequate flowability characteristics showed that apart from these factors the size, shape, and surface texture of the aggregates all very much affect not only the fibres orientation but also the fibre distribution during the manufacturing process. The degree of compaction as measured by the solidity of the compacted concrete is influenced both by the method of compaction and when vibrated, by the duration of vibration. Internal vibration increased compressive strength marginally compared to external vibration, but the latter increased the flexural strength substantially compared to internal vibration. The effect of vibration was more pronounced vibrated with dry mixes. Increasing the size and the roughness of the surface texture of the aggregates reduced the flexural strength by as much as 25%. Vertical casting reduced not only flexural strength but also the capability of the fibres resisting the stress in the post cracking stages. Loading in the "as cast" direction produced a small, but noticeable increase in flexural strength but negligible effect in compression. Round and smooth aggregates encouraged fibre settlement in the bottom half of the "as cast" section but this was counteracted by larger aggregate sizes crushed aggregates and higher fibre volumes. The results showed that good mix design and external vibrations are necessary to optimize the performance of the fibre.

Naaman and Shah [1976] have reported that the efficiency of fibre orientation for steel fibre reinforced concrete cannot be predicted from static continuum considerations. This is because the fibre contribution in such brittle matrices is significant only after matrix cracking and because the pull out mechanism of inclined fibres is substantially different from that of aligned fibres. They have shown that pullout resistance calculated from the pullout test of a single fibre does not always correspond well with the fibre contribution in the composite, where a group of fibres are simultaneously pulling out from cracked surfaces. For a large number of fibres the fibre contribution depends significantly on the capacity of the matrix to withstand the forces enclosed by the fibres bridging the cracked surfaces. They observed that spalling and disruptions of the mortar matrix lead to a substantial reduction in the pull out resistance. To increase the efficiency of the steel fibres in
concrete matrices it seems necessary to increase both the bond properties of the fibre and properties of the matrix.

Krishana Raju et al., [1977] have reported the results of a laboratory investigation on the compressive strength and bearing strength of steel fibre reinforced concrete using three different grades of concrete with the fibre content varying from 0 to 3 percent. The ratio of the bearing area to the punching area was varied in steps within the range of 5 to 20. Test results indicated that the compressive strength and bearing strength of concrete increases with the percentage of fibre content. They have developed empirical formula on basis of test results for the prediction of the compressive strength and bearing strength of fibre reinforced concrete.

Walkus et al., [1979] studied the cracking behaviour, strength properties and deformations properties of tensile specimens of concrete reinforced with short steel fibres. They noticed that the addition of short steel fibres to the concrete increase its strength but only up to some critical amount of micro reinforcement (i.e.1.2% to 1.8% by volume). A volume of steel fibres of about 1.2 percent seems to be the best. The influence of micro reinforcement arrangement on the cracking behaviour was analyzed on the basis of x-ray photography. It was observed that the location of cracks depends on the orientation and number of fibres in the cross-section.

Hillerborg [1980] gave in its simplest form, use of linear elastic fracture mechanics to solve the problem of crack initiation, growth, arrest, and the stability in the presence of fibers through appropriate changes in the stress intensity factor. In earlier models, perfect bond was assumed to exist between the fiber and the matrix. In the development that followed, the inelastic interface response during the crack growth was incorporated using a nonlinear stress-displacement relationship for the fiber-bridging zone.

This approach has come to be known as the cohesive crack model. Several researchers for developing prediction procedures used this basic approach. The researchers used different assumptions for crack initiation, singularity at the crack tip, and crack growth and stability.

Kukreja et al., [1980] have reported that tests were conducted to compare the direct tensile strength, indirect tensile strength and flexural tensile strength of the fibrous concrete with that of plain concrete. They used fibres obtained by cutting the wires on a hand-operated machine in three lengths 46mm, 36.8 mm and 27.6mm having aspect ratio of 100, 80 and 60 respectively. They observed that the percentage increase in the direct tensile strength is directly proportional to fibre concentration for a constant aspect ratio. Maximum
increase of 46.33 percent was obtained with fibres of aspect ratio 80 with 1 percent volume concentration and the maximum increase in indirect tensile strength is 40 percent for fibres having aspect ratio 80 and volume percentage of 1.5 percent. Flexural strength increases by 46.15 percent for fibres having aspect ratio 80 and volume percentage 1.5.

They have concluded that indirect tensile cracking stress is an inverse function of fibre spacing and fibre reinforcement is more effective in improving the post cracking strength than the first cracking strength of the composite. They have further added that the energy absorption capacity of the fibrous composite in flexure increases by 14.98 times due to addition of fibres of aspect ratio 80 and volume concentration 1.5 percent over plain concrete composite.

Ramakrishna et al., [1980] have presented a comparative evaluation of two types of steel fibres used as reinforcing materials in concrete. The fibres used were 25.4 mm long straight fibres and 51 mm long fibres with deformed ends, which were glued together into bundles with water-soluble adhesive. They conducted tests for (1) flexural fatigue (2) static flexural strength including strain, deflection, modulus of rupture, load deflection curves, determination of first crack load, and determination of post cracking strength of two sizes of beams (3) impact strength to first crack and ultimate failure (4) compressive strength and (5) plastic workability including vee-bee slump and the inverted cone time immediately after mixing and after one hour. The complete series of tests were run for two concentrations of the collated and hooked fibres and with pozzolan and straight cement mixes. The workability and handling of the plastic hooked fibre mix with 480 N/m³ was good, while the higher fibre content restricted the workability of this mix.

Based on the experimental investigation they concluded that no balling of fibres occurred in the case of hooked fibres even though they were dumped into the mixes all at once along with the aggregate. The compressive strength of the fibrous concrete is slightly higher than the compressive strength of plain concrete mix. The static flexural test shows that an excellent end anchorage is established between the hooked fibre and the matrix resulting in a high ultimate flexural strength, high load carrying capacity, and high ductility of the composite material. The hooked fibre reinforced concrete shows a greater ability to absorb impact loading than straight fibre reinforced concrete. For the two hooked fibre concentrations used no significant difference was
recorded in the ultimate flexural strength, post cracking load carrying capacity and ductility. However impact resistance and toughness increased with the increased fibre content.

Swamy and Al Taan [1981] have presented an extensive experimental data on the deformation characteristics and ultimate strength in flexure of concrete beams made with 20mm maximum size of aggregates and reinforced with bar reinforcement. Fibres were provided either over the whole depth of the beams or in the effective tension zone only surrounding the steel bars. It was shown that ultimate strength is increased only marginally, the fibres arrest cracks and increase the post cracking stiffness at all stages of loading up to failure which results in narrow crack widths and less deformation. The tests showed that at failure the compressive strains reached values of 0.005 to 0.006 and reinforcing bars attain stresses well in excess of their yield strengths. They further proposed an ultimate strength theory, which shows good agreement with the experimental data.

Swamy and Sa’ad (1981) had done an investigation on Deformation and ultimate strength of flexural in the reinforced concrete beams under four point loading with the usage of steel fibres, where consists of 15 beams (dimensions of 130 x 203 x 2500mm) with same steel reinforcement (2Y-10 top bar and 2Y-12 bottom bar) and variables of fibres volume fraction (0%, 0.5% and 1.0%). As they concluded that fibres were effective in resisting deformation at all stage of loading from first crack to the failure and increasing the flexural stiffness at the failure stage of the beams.

Furthermore, this investigation shows that role of steel fibres prevents any advancing cracks and increase the ductility and post-cracking stiffness of the beam right till to failure.

Similar crack behaviour investigation, which based on combination of 5 full scale reinforced concrete beams (350 x 200 x 3600mm) with steel fibres (volume fraction of 0.38% and 0.56%) were done by Vandewalle (2000). In this investigation, the experimental results and theoretical prediction on the crack widths was compared. Vandewalle (2000) also concluded that the addition of steel fibres decreases the cracking spacing and crack width. However, he reported that prediction of crack widths stated Eurocode 2 on the combination of fibres with conventional steel reinforcement overestimates measured values. Thus, he established a simple empirical expression on the final cracking spacing of steel fibre reinforced member.

Keer and Hughes (1982) have conducted an experimental investigation on polypropylene reinforced cement sheeting for use as roofing and cladding elements. In this experimental investigation fundamental
research conducted at the University of Survey were related to parameters, which are important for an effective-material for corrugated sheeting. The tensile stress-strain curve and flexural load-deflection curve, the achievement of closely spaced, virtually invisible cracks and the impact strength of the composite were discussed in relation to fibre volume content, fibre modulus of elasticity and fibre characteristics affecting bond between matrix and fibre. The load-deflection relationship of a typical polypropylene-reinforced cement corrugated sheet was compared to that of an asbestos-cement sheet of similar profile and was discussed with reference to performance standards for fibre-reinforced cement sheeting.

Based on the experimental investigation they have drawn the following conclusions.

Cement composites reinforced by continuous opened networks of fibrillated polypropylene film is an economic alternative to the use of asbestos-cement as roofing or cladding element. Corrugated sheets of similar profile and section to standard asbestos-cement sheets can sustain the loads required by UK and international standard specifications and remain serviceable. The impact performance of the sheeting is a considerable improvement over that of asbestos-cement.

Mashima and Okada [1982] have conducted an experimental investigation on application to structural use of glass fiber reinforced concrete. This experimental investigation describes two series of test results about glass fiber reinforced concrete, which consists of ordinary cement concrete and reinforcing glass fiber to study the properties both of fresh and hardened state and to improve the placing method. In the first case, the slump tests and the Vee-Bee tests of fresh concrete and the compressive, splitting tensile and flexural tests of hardened concrete are carried out to obtain the referring data for the design of mixing proportion. Also, fracture toughness is evaluated by the results of the flexural tests with a stiff loading machine. The second experiments are trial of placing poor consistency concrete such as fiber reinforced concrete.

Based on the experimental investigation they have drawn the following conclusions.

The flexural strength is increased by compaction on both plain concrete and fiber reinforced concrete and this is the effect of compaction in placing concrete. The following process mainly causes these phenomena

(1) Consolidation of fresh concrete (2) drainage of free water (3) increase in the strength

The increasing rate of the flexural strength of plain concrete is not so large as compared with fiber reinforced concrete in spite of increase in drainage water. The water cement ratio becomes below 0.4 at
compacting stress over 0.3MPa from the calculation by amount of drainage water but the increase of the flexural strength is not so much. This difference is due to drain cement particles accompanied with dehydration.

It is very difficult to place glass fiber reinforced concrete with usual method over the fiber content 1% because of zero slumps. If placed, a lot of air void remains in hardened concrete and the strength is decreased.

However, it becomes capable to use more amount of glass fiber content 1% and it is not observed the decrease of strength in 'compacted concrete' of this experimental studies. Besides, the flexural strength is increasing both the compaction force and fiber content up to 2%. The flexural strength of fiber reinforced concrete with 3% glass fiber falls down, as the compaction effect cannot overcome to bulky effect supposed amount of drainage water.

There is an upper limit for the compacting stress, which is nearly 0.3MPa, and drainage water approaches to constant value regardless the fiber content. These effects are not influenced so much by compaction method, the release method or the continuous method.

ACI Committee 544[1984] have published a guide for specifying, mixing, placing and finishing steel fibre reinforced concrete. This guide describes the current technology in specifying, mixing, placing and finishing of steel fibre reinforced concrete (SFRC). The emphasis in this guide is on the differences between conventional concrete and SFRC and on how to deal with them. Guidance is provided in mixing techniques

Zollo [1984] reported that polypropylene fibers; and other polymeric fibers made of nylon, polyester, polyethylene; and cellulose can also be used for many applications. For the improvement in properties of hardened concrete such as resistance to cracking caused by drying shrinkage, a volume fraction substantially higher than 0.1 percent is necessary.
Achyutha and Sabapathi [1987] have conducted an experimental investigation on cracking characteristics of R.C. beams with steel fibres. The primary variable considered in this study was effects of steel fibres (smooth round G1 wires) in reinforced concrete beams. Factorial experimental design principle was adopted in arriving at the number of beam specimens to be tested. The influence of concrete strength, aspect ratio and volume of steel fibres and quantity of tensile reinforcement on the cracking characteristics was studied. The beneficial effect of steel fibres in reinforced concrete beams in increasing the working loads at a particular crack width was highlighted.

Based on the experimental investigation they have drawn the following conclusions

1. Load at first visible crack increases by 50 to 128% due to inclusion of steel fibers over the whole section of a reinforced concrete beam. But the increase is of the order of 30% only, in beams with fibres around the tension steel only, compared to beams without fibres and beams extra reinforcement equivalent of fibre around tension steel in lieu of fibres.

2. The presence of fibres on reduces the crack height by about 25%

3. The effect of fibres on maximum or mean crack spacing has been found to be insignificant irrespective of the fibre aspect ratio and volume percentage.

4. There is a reduction of 50 to 90% in the maximum crack width at working load depending on the fibre aspect ratio.

5. The general trend is that an increase in the fibre content and aspect ratio increased the percentage increase in service load at a special crack width.

Abdul hafeez khan and Samal Mohamed laid [1987] have conducted the investigation on experimental study of SFRC under compression, indirect tension and pure bending. The primary variables considered in the study were length, diameter and volume. Some test data was viewed in the light of the composite material theory and the spacing theory. The spacing varied through the volume fraction of fibres has an effect over the tensile strength of SFRC; while the spacing varied through fibre diameter have little effect.

Based on the experimental investigation they drawn the following conclusions
1. The compressive, tensile and flexural strengths of SFRC are functions of volume fraction of fibres. However there is a limit up to which volume fraction can be increased. The use of dispersers helps elevate this limit, but then this also up to a limit.

2. The aspect ratio has an effect on the compressive, tensile and flexural strengths. There is a limit of aspect ratio up to which strengths progressively increase.

3. The strengths were seen to be nearly linear function of Ip/d ratio, this being the combined effect of aspect ratio and fibre volume fraction.

4. The tensile strength of SFRC increases with decrease of fibre spacing when the variation in spacing is obtained by varying fibre volume fraction, keeping the diameter of fibre constant. But when the spacing were varied through fibre diameter while keeping the fibre volume fraction constant, little effect on the tensile strength was discerned.

5. The fact that the fibre spacing varied through fibre volume fraction (keeping the diameter constant) alone affects the tensile strength of SFRC points out an existing common ground between the two theories namely the spacing theory and the composite material theory which were hither to thought as opposed to each other.

Arockiasamy et al., [1987] have conducted an experimental investigation on behavior of fiber reinforced concrete panels subjected to impact loads. In this experimental and analytical investigation the impact forces and the structural responses of modeled concrete shell panels of a gravity platform to iceberg collision were considered. The percentage increase in strength due to the addition of fibres was determined based on tests of plain reinforced and FRC panels. Impact resistance tests were carried out on ten fiber reinforced and plain reinforced concrete shell panels. A three-dimensional non-linear finite element program was developed. Using eight-noded brick elements, for the static analysis of the concrete cylindrical shell panels; the nonlinearity was prescribed using the experimental stress-strain curves obtained from compression tests on fiber/plain reinforced concrete cylinders. The experimental results were also verified using other empirical formulae suggested by earlier investigators. In addition to the results of finite element analysis, while the failure modes of plain reinforced concrete panels are due to punching shear, those of the fiber reinforced panels could be attributed to the combined effects of punching shear, bending and elastic wave propagation.
Based on the experimental investigation they have drawn the following conclusions

1. The model-prototypes modeling and predication seems to work out fairly well for plain reinforced concrete panels.

2. The impact resistance modeling has to take into account the following parameters, while preparing a geometric model, viz., the mass, velocity and shape of impacting surface, the scaling of panel parameters (concrete strength, thickness, panel dimensions, reinforcement and fiber volume) and the impact interface stiffness. While the failure mode seems to remain the same for plain reinforced concrete panels. It seems to vary considerably for FRC panels.

Balaguru [1987] has conducted an experimental investigation on behavior of slurry infiltrated fiber concrete (SIFCON). In this experimental investigation the behavior of SIFCON in compression, tension, flexure and shear were studied. The main thrust of the investigation was placed on the flexural member. More than 70 flexural specimens were tested under monotonic and high amplitude cyclic loading. The behavior under shear was studied using double L type specimens. Both strength and ductility aspect were studied. The tensile properties were evaluated using standard (tapered) tension specimens cut from SIFCON slabs. Cylinders were used for the tests in compression.

Based on the experimental investigation he has drawn the following conclusions

1. The flexural strengths of SIFCON could be an order of magnitude higher than that of normal fiber reinforced concrete.

2. The tensile and shear strengths of SIFCON are about 14 and 30 MPa respectively. The shear strength is about 5 times the shear strength of plain concrete. The increase in tensile strength as about 200% as compared to plain concrete. The increase in compressive strength is about 50%.

3. The SIFCON exhibits extremely high ductility in all the four modes of loading namely; flexure, tension, compression and shear.

4. Limited amount of fine sand can be added to the cement slurry without adversely affecting strength properties.

Banthia and Mindess [1987] have conducted an experimental investigation on steel fibre reinforced concrete under impact. In their investigation a drop-weight impact machine was used to carry out impact tests on
plain and steel fibre reinforced concrete beams, 150 mm wide, 150 mm deep, and 1500 mm long. The beams were supported on a 960mm span, and were struck in the middle by a hammer weighing 3385N. Strain gauges were mounted in the striking end of the hammer, and in one of the support anvils. Three accelerometers were mounted along the length of the beam to record the beam response and to account for the specimen inertia. For the comparison, static testing was carried out using a conventional universal testing machine.

The mix (0.5:1.0:2.0:3.5) had developed a compressive strength of 42 MPa at the time of testing. The fibres used were steel fibres, 50mm long, 0.60mm in diameter, and with both ends hooked. Their volume fraction was 1.5%.

Based on the experimental investigation they have drawn the following conclusions:

1. Both plain concrete and SFRC are stronger and more ductile under impact than under static loading. In the impact range, an increase in the hammer drop height resulted in an increase in the strength and the fracture energy of both plain concrete and SFRC.

2. The use of fibres was found to be advantageous in both static and impact conditions. The six-fold improvement observed in the fracture energy due to the fibre inclusion in the case of static loading, however, was reduced to only a two-fold improvement in the case of impact.

3. While only one peak was observed in the load verses deflection plots for plain concrete, two peaks were observed for SFRC under both static and impact conditions. The first peak load obtained in the SFRC was found to be the same as the absolute peak load obtained for plain concrete; it represented the matrix failure. The fibres, therefore, do no significantly modify the behavior of the matrix itself.

Batson and Alguire [1987] have conducted an experimental investigation on steel fibres as shear reinforcement in reinforced concrete T-beams. In this experimental investigation the effectiveness of hooked end steel fibres and or vertical stirrups as shear reinforcement was evaluated by testing eleven reinforced concrete T-beams simply supported and loaded at mid span. Only the volume percentage of the steel fibers and the spacing of the stirrups were varied.

Based on the experimental investigation they have drawn the following conclusions:

1. For the size and loading of the T-beams investigated, a combination steel fibers and widely spaced stirrups were more effective as shear reinforcement than either steel fibers or stirrups separately. It
appears that the minimum volume percentage of fibres is about 0.5 to achieve flexure failures. These results are consistent with published results for flexure failures.

2. Equations proposed to predict the shear and moment capacity were satisfactory for T-beams that failed in shear, but were satisfactory for flexure failures.

3. The data for the T-beams that failed in shear did not satisfy the lower bound limit state theorem of plasticity for concrete beams with vertical stirrups. Research is needed to develop appropriate values for the parameters, the effective strength factor and the degree of shear reinforcement.

Burakiewicz et al., [1987] have conducted an experimental investigation on creep recovery of steel fibre reinforced concrete in relation to material structure. In this experimental investigation flexure tests were performed on beams 50 x 50 x 1000mm (four points tests). During the tests mid span deflection and the strain in the tensile and compressive zone of the beams were recorded. In preparation of the specimens the structural components were qualitatively and quantitatively varied, the type of coarse aggregates was basalt or lime stone, and the steel fibre content was 0.0%, 0.7%, 1.3% by volume (fibres 0.4 x 40.0mm). Also two load levels were investigated 0.3Pmax and 0.7 Pmax. The creep recovery was observed until the deformation and strain variation was stabilized.

Based on the experimental investigation they have drawn the following conclusions:

1. The load level has a significant influence to the deformation process and is strongly correlated to the fibre volume content.

2. With the increase of the fibre content the creep recovery decreases.

3. For the higher fibre content the permanent deformation εp is higher, present the relation of each component in the complete deformation εp is higher.

4. The stabilization of creep recovery process is more rapid for the lower fibre contents.

5. There is no significant influence to the creep recovery process by the type of the aggregate used.

Dwarakanath and Nagaraj [1987] have conducted the experimental investigation on flexural behavior of reinforced fibre concrete beams. The primary variables considered in this study was beams reinforced with high strength deformed bars, both under reinforced and over-reinforced with fibres disposed in two types of
locations are considered in their investigation. The two types of locating the fibres are i.) Over the entire depth and, ii.) Over half the depth of the beams on the tension side.

Based on the experimental investigation they have drawn the following conclusions

1. The partial inclusion of the fibres over half the depth, in the case of under reinforced beams, is equally beneficial as the full depth inclusion, in controlling cracking and deflection and in increasing the stiffness of the beams right from the beginning of loading up to the ultimate.

2. In the case of over-reinforced beams, fibres in small quantities are not found to be effective in bringing about any appreciable modification in the deformation behavior of the beams.

3. In the case of conventionally under-reinforced and over-reinforced beams, the increase in ultimate flexural loads decreases as the percentage of conventional steel provided is increased. The increase in fibre content alone will not bring about correspondingly commensurate improvements and hence, use of lesser volume fractions of fibres with improved geometry appears to be more effective. Half depth mode of inclusion of fibres for under-reinforced beams and full depth mode of inclusion for over-reinforced beams are recommended for desired improvements in the deformational characteristics.

Gopalaratnam et al., [1987] have conducted an experimental on investigation on pull-characteristics of steel fibres from mortar matrices. Primary parameters taken up for the study include fiber length, fiber diameter and matrix quantity. The article describes a servo-controlled pull-out test developed for an ongoing study on the behavior of nonlinear interfaces in ductile fiber-brittle matrix composites.

Based on the experimental investigation they have drawn the following conclusions

1. A slip-controlled closed loop pull-out test yields a stable load-slip characteristic and hence may be more reliable for fracture studies of the interface.

2. Fiber embedment length plays an important role in the stress transfer mechanism in the pull-out test. Average bond strength is inversely related to the embedment length. Critical fiber length for the matrix mix and fibers used in the study is approximately 2 inches. Slips corresponding to the peak pull-out load energy absorbed are directly related to the fiber embedment length. Larger extent of pre-peak inelastic behavior was observed for the pull-out of longer fibres.
3. Although fiber diameter does not play as significant role as the fiber embedment length, the average bond strength of an interface increases with an increase in fiber diameter.

4. From the cyclic tests, degradation of specimen stiffness was observed prior to the peak pull-out test load. Little additional stiffness degradation was observed beyond slips corresponding to the peak pull-out load.

5. The peak pull-out load for identical fibers being pulled fibers being pulled out from matrices of higher compressive strength is not necessarily higher. Higher frictional bond strength which might be unrelated to matrix compressive strength is perhaps the reason for the higher pull-out loads observed for the weaker mix.

Jakob et al., [1987] have conducted an experimental investigation on dynamic loading resistance of fibre reinforced concrete containing thin and short fibres. In this experimental investigation concrete mixes were considered with 0.1 and 0.5% volume percentage fibres for shotcrete, and 1.3, 2.6 and 5.1 volume percentages for normal concrete. In addition, one mix without fibres was made for each kind of concrete. Portland cement with 30% of slag was used for shotcrete. The aggregate used was crushed gravel with a maximum particle size of 4mm. an accelerator was added as a chemical admixture. Normal concrete were prepared with the same content.

The aggregate maximum particle size was 8mm the concrete were super plasticized. Both groups of concrete were designed at a w/c ratio of 0.50. All the samples were cured in a climate chamber at a temperature of 20°C and at 95% relative humidity.

Shotcrete specimens were tested for compressive, flexural, static modulus of elasticity, watertightness and dynamic loading (fatigue) resistance and normal concrete specimens were tested for compressive, flexural, static modulus of elasticity, corrosion of fibres and resistance to blows(toughness) at flexure.

Based on the experimental investigation and results they have drawn the following conclusions

1. First investigations of concrete containing thin and short steel fibres show that considerable increases in resistance to blows and fatigue resistance can be expected. Flexural strength and crack resistance increase with the use of these fibres too.
2. A more detailed evaluation of the stated improvements will be given after further investigations. It will be necessary to study the fatigue mechanism, which represents a complex problem in composite materials because it depends on several parameters, which must all be determined or known.

Komolos and Brull [1987] have conducted an investigation on early age shrinkage of fibre reinforced cements and mortars. The primary variables considered in the study were the effect of fibre reinforcement/ glass, basalt, and steel fibres were applied on the early shrinkage of cement composites. The investigations carried out on fibre reinforced cement pastes and mortars in their early period of setting and hardening. The four phases in which the early volume changes of cement pastes can be divided are described.

Phase-I: Shortly after placing the investigated sample in to the mould
Phase-II: As soon as the surface water layer evaporates
Phase-III: For several hours after reaching the maximum of primary shrinkage
Phase-IV: The secondary shrinkage

Based on the experimental investigation they have drawn the following conclusions

The investigations carried out have shown that the influence of randomly spaced fibres on the early age shrinkage of cement composites is very significant. The influence is higher in cement pastes than in cement mortars. Glass fibres in the amount of 2% by weight cause a reduction of the maximum primary shrinkage value of more than five times, and in the case of mortars up to 4.5 times. Basalt fibres in the same content as above cause a reduction in the maximum shrinkage value in the case of cement pastes up to three times, and in the case of mortars up to 2.4 times. The incorporation of steel fibres results in the reduction of the above described shrinkage value of cement pastes up to 2.7 times and of mortars up to 2.6 times.

Kukreja et al., [1987] have conducted an experimental investigation on ultimate strength of fibre reinforced concrete slabs. In this investigation, four two way slabs were cast, one without fibres and three with fibres containing fibres, in 0.5, 1.0 and 1.5 volume percentage, and having an optimum aspect ratio of 80 and tested in simply supported on all four edges and corners were not held down. At the centre of an I-section frame a 20mm rod was welded and the slab was placed on this frame for testing. To simulate a uniformly distributed load, the load was applied at 16 points with the help of a 20 tones capacity hydraulic jack operated by a test
cylinder plant. The slabs were tested in a 300 tons test frame. The effective span of the slab was 900 x 1190mm with bearing of 37.5mm on each edge. The load was applied in 15 increments at intervals of about 10 minutes. The tensile side of the slabs was white washed for better crack observations. Deflections were measured with dial gauges located at the center of the slab and at quarter points on both the centre lines of the slab. The crack widths were measured with a crack measuring instrument and the cracks were marked after each load increment. The control cubes were also tested in the corresponding day and their average values are listed.

Based on the experimental investigation and results they have drawn the following conclusions

1. The first cracking strength of reinforced fibre concrete slabs increases with the increase in the fibre content. The maximum increase of 35% is obtained. The ultimate strength also increases and the maximum increase of 80.92% is obtained.

2. The deflection at serviceability limit state in reinforced fibre concrete slabs are about 21% lesser with fibres having aspect ratio 80, and volumetric percentage of 1.5. The deflections at failure loads in reinforced fibre concrete slabs are nearly 2 times of deflection in slabs without fibres.

3. The crack widths at limit state of cracking in reinforced fibre concrete slabs get reduced. The maximum reduction of 36% is obtained. The crack widths at failure also get reduced. Hence lesser cover to conventional reinforcement can be recommended for reinforced fibre concrete slabs.

4. Much thinner sections can be used in exposed conditions than would otherwise be possible, thus greatly reducing the self weight of the slab. Improved post-cracking behavior and greater ductility will enable higher load carrying capacity for reinforced fibre concrete slabs.

Liqin Guan and Guofan Zhao [1987] have conducted an experimental investigation on a study on the post-cracking behavior of SFRC working together with steel bar in uniaxial tension. In this experimental investigation in order to simulate concrete covers around steel bars in realistic engineering structures, the prisms with dimension of 60 x 60 x 180 (mm) were prepared for tension, each with an indented steel bar, diameter 14mm, placed through its central axis. The primary variables considered in this experimental investigation were two types of steel fibres with three different fibre volume fractions, varying from 1 to 2%. The water-cement ratio and the fibre-sand content were kept constant for all the specimens, which were cast and cured under the same direction, for the differing mix proportions.
Tests were carried out on standard material testing machine. The average longitudinal concrete strains on each of the four sides of the specimens were measured by four electrical resistance strain gauges, 8 x 80 mm gauge length, glued on the concrete surfaces. The average longitudinal strains of the central steel bar at each load intervals were measured by eight electrical resistance strain gauges, gauge length 3 x 5 mm, placed in the channels on the two opposite sides of the bar. The channels were tightly and carefully sealed before casting. Tensile load was applied to the bar and transferred to the SFRC by bond stress.

Based on the experimental investigation they have drawn the following conclusions

1. The post-cracking stress-strain relationship of SFRC in SFBRC subjected to uniaxial tension pears to be linear which facilitates computations in the structural analysis.

2. The liner-descending pattern of the curve indicates that the cracking of the matrix in BRC does not result in the abrupt load increment in steel bars as what happens in conventionally reinforced concrete. This gradual load transfer gives rise to a more ductile failure, i.e. greater energy dissipation capacity which is expected in seismic design

3. The method used in this paper for analyzing the properties of steel fibre and bar reinforced concrete by regarding it as a whole and applying the theories of the composite proved to be worth.

4. The theoretical stress-strain equations for the ascending portion of SFRC in uniaxial tension discussed here is recommended here for use in structural analysis.

Murty and Venkatacharyulu [1987] have conducted an experimental investigation on fibre reinforced concrete beams subjected to shear force. In this experimental investigation a total of eleven rectangular beams were tested to failure. Variables that were studied included shear/depth ratio, aspect ratio of fibres and volume percentage of fibres.

Based on the experimental investigation they have drawn the following conclusions

1. Steel fibres appear suitable as shear reinforcement for beams.

2. The replacement of vertical stirrups by round steel fibres provided effective reinforcement against shear failure.

3. Shear strength predication by the IS code for beams without any shear reinforcement and stirrup reinforcement is conservative.
4. Shear strength predication for beams with fibre as shear reinforcement is predicated by the equation proposed by Muhidin though it is adequate; it appears to over estimate, the influence of concrete strength.

Nagaraja and Swami [1987] have conducted an experimental investigation on the fibre reinforced concrete with non-metallic fibres. In their investigation the strength properties of concrete reinforced with short pieces of random fibres of nylon, bamboo and coir have been studied. Tests were performed on specimens to determine the compressive strength, split tensile strength, flexural strength, energy absorption and modulus of elasticity and the results are compared with those of plain concrete. The aspect ratio of the fibres and the concrete mix were maintained constant throughout the test series. The volume percent of fibres adopted was 0.5 and 1 for nylon, 2 and 3 for bamboo and 1.5 and 2 for coir. Nominal concrete mix of 1: 2: 4 by weight with a w/c ratio of 0.65 with medium workability was used for casting the specimens for each percentage of fibre 5 specimens was used. All the specimens were cast and cured as per standard procedure and tested at the age of 28 days.

Based on the experimental investigation they have drawn the following conclusions

1. From the value of the average cube compressive strength, it is observed that the inclusion of nylon fibre has no effect on the crushing strength. All the plain concrete specimens exhibited severe spalling at failure where as the nylon FRC specimens exhibited very mild spalling.

2. In the case of specimens with bamboo fibres the average cube compressive strength is decreased. This, probably due to the lower specific gravity of the bamboo fibre. However, spalling has been arrested appreciably. The behavior of the specimens with coir fibres is more or less similar to those with bamboo fibres.

3. The load-deflection curves show that the transfer of stress from the concrete matrix to the fibres takes place when the matrix starts cracking and this indicated by the change in the slope of the curve from linearity. With further loading the fibres start either pulling out or debonding with the matrix until it reaches its ultimate failure load. With higher percentage of nylon fibres there is considerably increase in the flexural strength of concrete.
4. Modulus of elasticity as computed from the observed deflection is found to be considerably decreasing in the case of FRC compared to plain concrete. This enables the FRC more ductile.

5. It is seen that the ultimate shear strength is fairly increasing due to the addition of nylon fibres and this increase is less with bamboo fibres. But with coir fibres the ultimate shear strength is decreasing. This may be attributed to the stretching property of coir fibre in wet condition.

6. It is observed from the tested specimens that the addition of fibres is effective in arresting the growth as well as propagation of cracks. This can be due to the dissipation of part of the energy available for developing crack surface is considerably reduced. It has also been found that FRC beams have failed with a single crack traversing almost straight up to the neutral axis at the cracking load in addition to the numerous micro cracks that have formed in the tensile zone of the beam. The plain concrete beams have failed suddenly into two pieces without any warning.

7. Based on the appreciable resistance to the growth and propagation of cracks in FRC, it can also be concluded that the resistance of FRC to impact and fatigue loadings is fairly greater than plain concrete.

8. The addition of nylon fibres by 0.5% and 1% indicated an increase in the average tensile strength by 25.94% and 26.03% respectively. In the case of specimens with bamboo fibres by 2% and 3% by volume this increase is 15.65% and 20.72% respectively. With coir fibres, there is no improvement in the tensile strength of concrete. However, specimens with all the above fibres avoided the brittle nature of failure, which is common with plain concrete specimens.

9. The addition of nylon fibres by 0.5% and 1% has increased the flexural strength by 7.3% and 24.4% respectively. There is no improvement in the flexural strength with bamboo fibres. With coir fibres there is some reduction in the flexural strength but the tensile crack propagation in the specimens was considerably reduced.

Nagarkar et al., [1987] have conducted a research on study of fibre reinforced concrete. The primary variables considered in the research work are Nylon and steel having different aspect ratio. The object of the study was to determine compressive strength, flexural strength, split tensile, bond with steel, abrasion resistance and modulus of elasticity for the parameters viz randomly oriented, percentage of reinforcement and the effect of aspect ratio on the properties of concrete.
Based on the research work they have drawn the following conclusions

1. In general, the compressive strength is increased by 5 to 57% with the addition of fibres. However, this increase is more predominant in case of steel fibres than nylon fibres.

2. The split tensile/flexural strengths are increased with the addition of fibres. The split tensile strength is increased by 15 to 45% and flexural strength from 20 to 60%.

3. Bond with steel is improved with the addition of fibres. Aspect ratio has very little effect on the bond strength of fibre reinforced concrete.

4. It is generally observed that the properties of fibres reinforced concrete vary to a great extent mostly because of random orientation of fibres.

Neelamegam and Venkateshwari [1987] have conducted an experimental investigation on properties of glass fibre reinforced cement composites with and without polymer impregnation. Glass fibre is a versatile reinforcement for thin micro-concrete members as it imparts better workability than steel fibres and it does not pose any corrosion problem. Experiments have been conducted at Structural Engineering Research Centre, Madras, on glass fibre reinforced cement composites with and without polymer impregnation does not give scope for ingress of external elements for any chemical reaction inside the composite material and non-alkali resistant glass fibres were used in these experiments.

Based on the experimental investigation they have drawn the following conclusions

1. Addition of glass fibres to cement composites reduces the workability. This reduction is more pronounced with fibres longer than 6mm.

2. Split tensile strength, modulus of rupture, and ductility which is measured by the toughness index of GFRMC was found to increase with fibre content. However, PIGFRMC showed marginal increase of these properties with the fibre content.

3. The ratio of tensile strength of GFRMC is related to the bond strength and the volume fraction of the fibres, and the tensile strength of cement matrix as given by equation. The value of $\alpha$ which is the ratio of the bond strength of the mortar was found to vary between 2.5 and 5 for volume fraction of 6mm long fibres up to 2%. 
4. The density and the compressive strength of GFRMC with and without polymer impregnation were found to possess more wear resistance than GFRMC.

5. The abrasion resistance of GFRMC was found to possess more wear resistance than GFRMC.

6. The PIGFRMC was found to possess better chemical resistance than GFRMC. The GFRMC showed 80% of losses when it was immersed in 15% dilute H₂SO₄ for 40 days. This loss was reduced to 20% in the case of PIGFRMC. In the case of 15% dilute HCl and HNO₃, the chemical attack on GFRMC was not so severe. The maximum loss in weights of GFRMC and PIGFRMC were found to be 25% and 15% respectively, when they were immersed in 15% dilute HCl for 40 days. These were reduced to 15% and 8% in the case of dilute HNO₃. There was no deterioration of GFRMC and PIFGRMC when they were immersed in 15% dil NaOH.

Otter and Naaman [1987] have conducted an experimental investigation on strain rate effects on the compressive properties of fiber reinforced concrete. The primary variables considered in this experimental investigation were fiber material (steel, or polypropylene) and the shape of fiber (straight or hooked) and compression test results of plain and FRC cylinders were subjected to three different strain rates (at loading rate of 100 μ/s, 1000 μ/s and 3000 μ/s micro strain/second).

Based on the test results they have drawn the following conclusions

1. Considerable scatter in the data can be expected when studying the properties of FRC at different strain rates. The scatter in the data makes it extremely difficult to isolate the separate effects due to fiber type, volume fraction, or aspect ratio. The scatter obtained in the toughness data was larger than that obtained in strength data.

2. Increasing the strain rate of loading affects the compressive properties of FRC in a similar manner but possibly to a lesser extent than it does plain concrete. A similar conclusion was reached in when comparing plain and confined concrete. In this study, increases of about 10% in strength and 15% in toughness were observed when the strain rate of loading was increased from 1000 μ/s to 3000 μ/s.

3. The strain rate of loading does not seem to affect the shape of the stress-strain curve of FRC in compression.
4. On the average, specimens reinforced with glass or polypropylene fibers were more sensitive to the rate of loading the specimens reinforced with steel fibers; however, the differences between fiber types are hard to delimit due to large variations.

Proctor [1987] has conducted an experimental investigation on the development and performance of alkali resistant glass fibres for cement reinforcement. The main objective of this experimental investigation was to study the effect of zirconia glasses content on fibre strength retention is discussed and the performance of zirconia glasses is compared with that of other suggested alkali resistant compositions.

Based on the experimental investigation he has drawn the following conclusions

1. Additions of relatively large proportions of zirconia to silicate glasses have led to the development of a range of commercially available alkali resistant glass fibres with sufficient strength retention to provide useful reinforcement in cement product.

2. Fibre strength loss and composites property loss still occurs on ageing. Some progress has been made in significantly reducing the rate at which this occurs by using surface treated fibres—further progress via composition development has been shown to be possible—whether it is commercialized or not depends on the perceived balance of cost/performance advantage factors in the market place.

3. Extensive weathering programmes and accelerated test work in the laboratory show that currently available GRC materials do provide stable and useable long term strength, albeit with a brittle failure characteristic. Design must take account of this, which has always been done by responsible GRC users.

Rao et al., [1987] have conducted an experimental investigation on steel fibre reinforced concrete column with and without conventional bar reinforcement under uniaxial bending. In this experimental investigation the influence of fibre reinforcement on the ultimate strength in combined axial compression and uniaxial bending of concrete columns with and without reinforcement were studied. The test specimens comprised of short columns 1200mm in length and 100 x 150mm in cross section. The principal variables used were eccentricity of applied compression; the eccentricity relative to the central axis of the columns was varied from 0 to 150mm.

Based on the experimental investigation they have drawn the following conclusion.
1. Addition of steel fibres into plain concrete columns improved the ductility, cracking strength and ultimate strength substantially. The greater the eccentricity of applied load, the higher was the relative increase in strength.

2. Fibre inclusion in columns with bar reinforcement improved cracking and ultimate strength in a limited measure, though improvement in deformation characteristics was substantial.

3. The theory predicted accurately and conservatively the strength of fibre reinforced concrete columns under axial load and bending, with or without bar reinforcement. The theory under predicted the strength of columns without bar reinforcement by 33% and the strength of columns with bar reinforcement by 20%.

Rao et al., [1987] have conducted an experimental investigation on structural applications of fibre reinforcement in reinforced concrete members. The investigation was designed to obtain experimental data on the deformation characteristics and strength of RC beams with steel fibres in pure bending. A total of 14 beams 75mm x 150mm x 1850mm casted and tested to destruction to evaluate the effect of such variables as grade of bar reinforcement, length, diameter, aspect ratio, volume fraction and location of steel fibre in the concrete. The mix (0.6:1.0:1.4:2.8) had developed a compressive strength of 42 MPa at the time of testing. The two aspect ratios of fibre, 100 and 83.33 were used. Two volume fractions of fibre, 0.5 and 1.0 were employed. Flexural bar reinforcement was either plain mild steel or high yield strength-deformed steel of diameter 0.3, 0.4 and 10mm were employed.

Based on the experimental investigation they have drawn the following conclusions

1. The test results of this investigation clearly established that steel fibres permit substantial increase in bending moment to be developed, before a particular width of crack occurs.

2. The improvement of crack control due to the addition of fibres was more pronounced with deformed bars than with plain bars.

3. One of the very significant roles played by steel fibres is arresting advancing cracks and reducing the crack widths. Addition of even a small quantity of fibre of 0.5% caused significant reduction in crack widths.
4. The increased depth of neutral axis and the increased flexural stiffness of the fibre reinforced concrete beams at all stages of loading reflected the ability of fibres in arresting the crack growth and crack widening.

5. At all stages, of loading, from first crack to ultimate, fibres were effective in resisting deformations.

6. The concrete compressive strains at the attainment of ultimate load ranged between 330 to $700 \times 10^{-5}$ m/m.

7. Even at ultimate fibres were effective in reducing deformations and increasing flexural stiffness.

8. The influence of steel fibres in increasing the ultimate strength of an ordinary reinforced concrete beam is limited, in comparison with the substantial beneficial effects imparted to such beams, relative to reduction in crack width, and deformations and increase in stiffness up to ultimate stage.

Ramkrishnan and Charles Josifek [1987] have conducted an experimental investigation on performance characteristics and flexural fatigue strength of concrete steel fibre composites. The primary variables considered in the study were flexural strength of concrete reinforced with deformed (corrugated) and melt extract steel fibres. The test program included i) Flexural fatigue and endurance limit ii) Static flexural strength including load-deflection curve, determination of first crack load and toughness index iii) Compressive strength iv) Static modulus v) Pulse velocity vi) Unit weight, workability and finish ability of fresh concrete.

Based on the experimental investigation they have drawn the following conclusions

1. Satisfactory workability can be maintained in fresh concrete reinforced with corrugated and melt-extract steel fibres even with the addition of about 1% by volume.

2. There was no balling of fibres even with higher concentration of fibres.

3. When compared to plain concrete, the fibre reinforced concrete had less bleeding, was more stable and had better finishability.

4. The addition of fibres did not produce any significant changes in the compressive strength, static modulus and pulse velocity values. A significant increase in the static flexural strength (modulus rupture) was noticed in fibre concretes.
5. Due to the addition of steel fibres the mode of failure was changed from a brittle failure to a fully ductile failure with a great increase in the post-crack energy absorption capacity. There was a significant increase in the toughness index.

6. Flexural fatigue strength and the endurance limits were increased substantially with the addition of corrugated and melt extract steel fibres.

Ramanathan et al., [1987] have conducted an experimental investigation on yeast fibre reinforced concrete. In this experimental investigation an attempt was made to study the effect of yeast-blended water used for making concrete and the results are compared with test samples made from pure water. The following experiments were conducted to ascertain the behavior of the new fibre concrete.


Based on the experimental investigation they have drawn the following conclusions

1. Addition of yeast to the mixing water is found to increase both the compressive strength and the tensile strength significantly.

2. The workability of concrete is also found to have increased by the addition of yeast.

3. There is a considerable increase in the cracking load and the ultimate load of R C beams, made from yeast-blended water.

4. Yeast cells can also be nourished by adding small quantities of potato slice or sugar to mixing water.

Sabir et al., [1987] have conducted an experimental investigation on the fracture toughness of fibre reinforced concrete. Their investigation demonstrates the usefulness of applying fracture mechanics in evaluating the enhanced toughness properties of fibre reinforced OPC/microsilica concrete. Both numerical modeling, by finite elements, and laboratory testing on standard concrete cubes modified by the introduction of two notches on opposite faces are carried out. The test specimen results in unstable fracture and linear elastic fracture mechanics (LEFM) was used to evaluate the fracture toughness on the basis of the stress intensity factor. The post-cracking performance was assessed by a toughness index determined from the load-deflection relationship.

Based on the experimental investigation they have drawn the following conclusions
1. The addition of the fibres leads to reductions in the fracture toughness of the concrete which are similar to those obtained in the compressive strengths.

2. The post-cracking toughness index for the fibre concrete employed in the present study varies between 0.3 and 0.4. The toughness index is zero for plain concrete and has a theoretical maximum value of unity for fibre concrete.

Kukreja and Sanjeev Chawla [1989] have conducted experimental investigation on flexural characteristics of steel fibre-reinforced concrete. In this experimental investigation the various aspects of flexural behaviour of fibre-reinforced concrete and, particularly, the influence of fibre shape on flexural strength were studied. For this purpose, three shapes of fibres, namely, straight, bent and crimped were used with varying volume percentages, i.e., 0.5, 1.0 and 1.5 aspect ratio of the fibre was kept at 80.

They have drawn the following conclusions based on the experimental study

1. Flexural strength alone does not adequately describe the behaviour of fibrous concrete. Depending upon steel-fibre content, its type and orientation, behaviour can range from brittle to very ductile, all for the same range of flexural strength.

2. End anchorage is an efficient way to consistently enhance post-cracking resistance.

3. Flexural stiffness of fibrous concrete is higher than that of ordinary concrete, thus emphasizing the ability of the fibres to arrest cracks due to the bridging action of the fibres.

4. The strain and curvature distribution curves do not show any significant variation with different shapes of fibres, at a particular percentage of fibre and load range, before the elastic limit.

5. The plain concrete failed in a brittle manner due to crushing of the concrete. A beam with fibrous concrete is able to carry higher loads due to ductile behaviour followed by extensive cracking deflection and plastic rotations. Thus, fibrous concrete will enable a higher percentage of tensile reinforcement to be used to resist bending than is currently allowed.

6. The presence of fibres in the compression zone prevents disintegration of compression concrete, unlike in ordinary concrete. There was no breaking up of the compression concrete and no falling of debris, and the integrity of the beam was preserved even after failure.
Concrete reinforced with crimped fibres shows a lower flexural strength than that with straight fibre, although they possess better control of cracking and associated properties. The reason being the balling effect of fibres during mixing.

Sabpathi and Achyutha [1989] have presented a flexural theory for the analysis of steel fibre reinforced concrete beams in post cracking range based on the load slip curves obtained from the pull out tests of fibres. Modulus of rupture or ultimate moment values of SFRC beams based on the proposed theory are found to be in good agreement with the present experimental and some of the earlier investigations.

Samen Ezeldin and Balaguru [1989] have investigated on bond behavior of normal and high strength fiber reinforced concrete. In their investigation experimental results on the bond behavior of normal and high strength concrete made with and without fibres are reported. A total of 18 mix proportions were investigated. The variables were 1. Silica fume content 2. fibre length 3. fibre content, and 4. Bar size.

The silica fume content was varied from 0 to 20% by-weight of cement. Steel fibres with hooked ends were used in the quantities of 0, 30, 45, and 60 Kg/m³; the fiber lengths and reinforcement bar sizes were 30, 50 and 60mm and 9, 16, 19 and 25mm respectively. The bond tests were conducted using a modified pull out test in which the concrete surrounding the bar was in uniform tension. From the investigation they have drawn the following conclusions regarding the bond behavior of fiber reinforced concrete with and without silica fume are

1. The pullout failure type is usually obtained for 9mm bar specimens with and without steel fibers.
2. While an explosive splitting of concrete type of failure occurs for bar diameters greater than 16mm without steel fibers, this failure becomes more ductile with the inclusion of steel fibers.
3. The addition of steel fibers contributes a little to the bond strength of specimens with small bar specimens (9mm), because the failure is due to the collapse of compression struts not greatly strengthened by steel fibers. But the presence of steel fibers, giving an effect comparable to confining concrete, has a more effective contribution to the bond strength of larger bar specimens (16mm and up)
4. The presence of silica fume enhances the bond strength. However, the bond strength increases is still proportional to $\sqrt{f_c}$.
5. The slip value corresponding to the maximum pullout load increases with the addition of steel fibers.
6. The presence of steel fibers provides a major contribution to the ductility (area under the load-slip curve) of concrete. The effect of fibres on bond strength is similar to the behavior in compression.

7. The presence of silica fume renders the concrete more brittle. For silica fume fibrous concrete, higher fiber content is needed to maintain ductility.

Jenn-Chuan and Chin-Huai Young [1990] have conducted an experimental investigation on study of factors influencing drying shrinkage of steel fiber reinforced concrete. Shrinkage data are reported here with parameters including specimen size, fiber type, fiber content, and age of concrete when drying begins. The shrinkage tests were conducted in the drying room, which was automatically controlled to maintain a constant temperature and a constant humidity. Specimens were of three different sizes viz cylinders (150mm x 300mm), prisms (75mm x 75mm x 300mm and 50mm x 50mm x 300mm). Each test included four specimens; two were for drying tests while two other specimens remained in a moist room as control specimens.

The concrete mix was designed according to ACI committee 544 recommendations and grading of the materials satisfies ASTM C 33 and all specimens were unsealed and cured according to ASTM C 512-87, i.e. in a fog room at 23 degree centigrade until the day of testing.

Shrinkage specimens placed in the drying room were sealed with foil to prevent moisture loss from their tops and bottoms. This was to insure that the moisture diffusion in the specimens would be limited to one dimension to facilitate analysis using constitutive law and the investigation of drying creep.

Tests of concrete shrinkage were carried out according to ASTM C 341-84; a mechanical gauge was used to measure the strains of specimens at proper time intervals. The effective drying shrinkage was taken as the difference between the amount of shrinkage measured in the drying room and that of the control specimen.

The compressive strength and shrinkage test results are given as the average of two shrinkage specimens dried together. For each shrinkage specimen, the shrinkage strains were obtained by averaging the measured strains on two opposite surfaces. The compressive strength of concrete, which reflects the basic material property of the mix, was obtained by averaging the strength of two cylinders.

From the investigation they have drawn the following conclusions from the results of shrinkage of plain and steel fiber reinforced concrete are
1. The exposure age of specimens in shrinkage tests has a significant effect on the magnitude of shrinkage of SFRC. The older the specimen at time of drying, the less is the shrinkage.

2. Steel fibers restrain deformations more effectively at later ages due to the development of higher interfacial bond strength between fibers and matrix.

3. The shapes of shrinkage-time curves are similar for steel fiber reinforced concrete and plain concrete; therefore, the drying of SFRC is closely associated with nonlinear diffusion theory as that of plain concrete.

4. Based on the volume fraction of steel fibers, concrete specimens containing a higher fraction yield less shrinkage at drying conditions. The optimal volume fraction of steel fibers to reduce shrinkage is no more than 2%. The poor workability of specimens containing 4% fiber volume fraction may impair its strength and decreases the effectiveness of the fiber to reduce shrinkage.

5. The shrinkage of SFRC is smaller for specimens containing fibres with higher aspect ratios.

Kosa et al., [1991] have reported the comparison of the durability of four types of fibre reinforced cement composites. Four composites were conventional steel, polypropylene, glass fibre reinforced mortar and slurry infiltrated fibre concrete (SIFCON). They concluded that polypropylene fibre reinforced mortar has the best overall durability, while glass fibre reinforced mortar shows the poorest overall performance. Steel fibre reinforced mortar showed noticeable reduction in flexural strength and a dramatic increase in toughness. For SIFCON the reductions in both strength and toughness were moderate. They also presented a prediction model for the long-term deterioration of steel fibre reinforced mortar. The analysis indicated that corrosion can be very critical for thin panel structures of the order of 12.5 mm in depth but diminishes substantially for structures with depth about 100 mm or more.

Mir Shouketh Ali et al., [1991] have conducted an experimental investigation on fibre reinforced flyash concrete. In this experimental investigation structural behaviour of steel fibre reinforced flyash concrete under compression and flexure were studied by conducting test on standard control specimens.

From the study conducted on fibre-reinforced flyash concrete, they have drawn the following conclusions

1. Fibre reinforced concrete is very much effective in resisting the flexural tensile stresses as compared to compressive stresses.
2. Specimens containing 0.5% and 1.0% fibres with 20% and 30% replacement of cement by flyash are more effective in resisting the flexural tensile stresses as well as compressive stresses. Hence an optimum percentage of fibre-flyash reinforced concrete can be 0.5% - 1.0% of fibres and 20% - 30% of flyash.

3. Workability of concrete will also get enhanced due to the addition of flyash, which is required specially in higher percentages of fibres.

Surendra P. Shah [1991] has conducted an experimental investigation on increasing the tensile strength of cement-based matrixes by using fibers. In their experiment they showed that possible of incorporating relatively large volumes (ranging up to 15 percent) of steel, glass, and synthetic fibers in concrete and fibers may substantially increase the tensile strength of matrixes.

He has drawn the following conclusions from the result obtained.

The results indicate that the presence of continuous aligned fibers substantially enhances the tensile load-carrying capacity of the matrix. This may be attributed to the fact that, fibers suppress the localization of microcracks into macrocracks and consequently the apparent tensile strength of the matrix increases. Similar characteristics might exist for the composites containing distributed, short fibers. However, because not enough experimental results are available for this type of composite studies need to be conducted.

Balaguru et al., [1992] have conducted an experimental investigation on flexural toughness of steel fiber reinforced concrete. The primary variables considered were three fiber type (hooked ends, deformed ends and corrugated), four fiber length (1.18, 1.97, 2.36 and 1.0), and four volume fraction (30, 60 and 90 and 120 Kg/m³) and matrix composition were evaluated.

Based on the test results they have drawn the following conclusions

1. For all three fiber types used in this study, there was no problem in mixing up to 120Kg/m³ of fibers. The fiber distribution was found to be uniform.

2. Toughness values calculated based on the ASTM C 1018 procedures, and accurate measurement of deflections (excluding extraneous deformations), are quite different from values reported in the literature.
3. Toughness indexes $I_5$ and $I_{10}$ computed using the ASTM procedures do not provide a good indication of the variations that are present in load-deflection responses. With accurate deflection measurement, it is possible to compute toughness index at large deflections, such as $I_{100}$. These indexes at higher deflections rather than $I_5$ or $I_{10}$ should be used for the evaluation of FRC.

4. Hooked-end fibers are very effective in improving toughness. Fiber content in the range of 30 to 60 Kg/m$^3$ is sufficient for obtaining ductile behavior. For the other two fiber types, a higher volume fraction is needed to obtain the same amount of toughness.

5. For fibers with hooked ends, the lengths of the fibers do not affect toughness significantly.

6. Increase in matrix strength generally leads to a faster drop in post-peak load. Higher fiber volume fractions can be successfully used to obtain the desired toughness for high strength concrete.

7. Addition of silica fume improves strength and slightly reduces ductility. Here again, fiber content can be increased to obtain ductile post-peak behavior. A fiber content of 120 Kg/m$^3$ resulted in a very ductile failure even at a silica fume content of 20% by weight of cement.

Dwarakanath and Nagraj [1992] studied experimentally the deformational behaviour of conventionally reinforced steel fibre concrete beams in pure bending. They conducted the experiments with two groups of the beams. One group of beams has steel fibres dispersed in the entire volume of the beam and the second has fibres dispersed over half the depth of the beam on the tension side. Based on their study they have concluded that the half depth fibre inclusion requiring only half the quantity of fibres of full depth inclusion is found to be equally effective in improving the deformational behaviour of the beam.

Krishnamoorthy et al., [1993] have conducted an experimental investigation on flexural behavior and toughness of steel fibre reinforced concrete. The primary variables considered in the study were SFRC flexural specimens in which four types of steel fibers (crimped, trough-shaped, and straight-1 and 2) were used and incorporated in the common mix proportion of 1:1.65:3 with w/c ratio 0.45. Twenty-eight SFRC beams and two companion plain concrete beams were casted. Tested, using universal testing machine in accordance with ASTM C-1018.

They have drawn the following conclusions from the investigations carried out on SFRC beams.
1. The first crack load is found to increase with increase in the fibre volume fraction of steel fibres. The increase is as high as 66% for a 2% volume fraction of crimped and trough-shaped fibres.

2. The apparent (Ultimate) flexural strength is also found to increase with the increase in fibre volume fraction. In this case, however, trough-shaped and straight-2 fibers are found to give better results than the other two types.

3. The toughness indices $I_5$, $I_{10}$, and $I_{30}$ are not influenced significantly by either the volume fraction or the type of steel fibres.

4. The values of $T_{10}$ computes in accordance with reference I, are also found to increase with the increase in the volume fraction of the steel fibres, irrespective of the type of fibres used. The same cannot be said about values of $T_{max}$ and $T_{50}$.

5. The toughness indices, expressed in terms of energy as per JCI method, are found to increase with the increase in the volume fraction for all types of steel fibres investigated.

6. Generally beams with trough-shaped and straight-2 steel fibres showed better flexural and toughness characteristics as compared to other types of fibres.

7. The improvement in the toughness indices of SFRC beams is found to be about 30-40 times when computed as per the ASTM-testing method, about 150-500 times when computed as per the JCI-testing method, over the corresponding indices exhibited by plain concrete.

Nanni et al., (1992) conducted an investigation on the use of newly developed aramid fibres for the reinforcement of Portland cement based concrete. The aramid fibres were produced in chopping a bundle made of epoxy-impregnated braided into aramid filaments. In this investigation, the behaviour of reinforced concrete of aramid fibres was compared to steel fibres and polypropylene fibres. Beams of 100 x 100 x 350mm were tested under four point flexural loading. It was found that aramid fibres acts similar to steel fibres and is superior to polypropylene fibres. They concluded aramid fibres were lack in corrosion problems while having a higher performance than polypropylene fibres. However, the use of aramid fibres was not very economical.

Saluja et al., [1992] have conducted an experimental investigation on flexural and shear strength of fibre reinforced concrete beams. They have conducted an experimental investigation to study the effect of mild steel fibres on flexural and shear strength of plain concrete beams.
Based on the experimental investigations they have drawn the following conclusions:

1. Mild steel fibres are effective in increasing flexural and shear strength of concrete beams. Additions of 1.5 percent fibres content increase the flexural and shear strengths by 47.0 and 71.0 percent respectively.

2. Flexural strength of fibre reinforced concrete beams having mild steel fibres can be calculated by using Eq. \( \sigma_{fl} = 0.976\sigma_{cm}V_m = 19.176V_e(L_d/d) \)

3. Ultimate shear strength of fibre reinforced concrete beams having mild steel fibres can be reasonably estimated by using Eq. \( V_u = [0.504\sqrt{f_c} = (176p_d)/(M/V) = \sigma_{cm}]bd \)

Prakash Desayi et al., [1993] have conducted an experimental investigation on fibre reinforced edge column connections in flat slabs. This experimental investigation aims at studying the effects of fibre inclusion on the behaviour of such connections are reported.

Based on their investigation they have drawn the following conclusions:

1. The load carrying capacity is marginally increased by the addition of fibres.

2. The sudden punching failure is converted into a more gradual punching failure by adding fibres. With higher percentage of fibres, the failure can be converted into a flexural failure.

3. The post cracking behaviour is significantly improved by the addition of fibres.

Prakash Desayi and Seshadri [1993] have conducted an experimental investigation on behaviour of fibre reinforced column-slab connections. The primary variables considered in this experimental investigation were the reinforcement ratio, volume fraction of fibres in the concrete mix and the moment to shear ratio. Eleven specimens representing the corner slab-column connections were tested to failure.

Based on their experimental investigation they have drawn the following conclusions:

1. Increase in \( V_f \) and \( \rho \) increases the first crack load, ultimate load and ductility of the slab-column connection.

2. Increase in \( V_f \) decreases the deflection at all load due to increase in stiffness of the connection stages.

3. Increase in \( V_f \) increases the strain in slab reinforcement at location near the inner column corner where shear forces are concentrated.
4. The fibres play an important role in changing the mode failure from a brittle shear to a ductile flexure-shear flexure failure.

5. Increase in \( V_r \) or \( p \) increases the energy absorbed by the specimen. Ductility factor and energy absorbed by the specimen.

Samir A. Ashour and Faisal F. Wafa [1993] have conducted an experimental investigation on flexural behavior of high-strength fiber reinforced concrete beams. In this experimental investigation the effect of inclusion of steel fibers on the flexural behavior of high-strength concrete beams were investigated. Eight high-strength concrete beams with different fiber contents and shear span-depth ratios were tested to study the inclusion of steel fibers on the flexural behavior of high-strength concrete beams is investigated. Eight high-strength concrete beams with different fiber contents and shear span-depth ratios were tested to study the influence of fiber addition ultimate load, crack propagation, flexural rigidity, and ductility. The contribution of steel fibers to the enhancement of the flexural rigidity and ductility of high-strength concrete beams was investigated. One type of steel fiber was used in singly reinforced concrete beams with an average concrete compressive strength of 88 MPa (12,800 psi) subjected to a two-point flexural loading.

Based on the experimental test results, they have drawn the following conclusions:

1. The presence of steel fibers reduces the crack propagation in the tested beams and enhances the flexural rigidity, resulting in better deflection control.

2. The post-cracking stiffness of the load-deflection curves increases due to the presence of steel fibers.

3. The ACI effective moment of inertia underestimated the actual moment of inertia of the tested beams, resulting in the overestimation of the experimental deflection in the working range.

4. A proposed formula is presented for the estimation of the effective moment of inertia of simply supported HSFRC beams, which is a function of both the fiber content and the a/d ratio. The predicted deflections using the proposed formula agree well with the experimental deflections of the tested beams.

5. Higher ductility is obtained by using steel fibers for the a/d ratio used.

6. The addition of steel fibers increases the length of the plastic hinges developed in the tested beams. This length was found to be proportional to the fiber content.
Shaaban and Gesund [1993] have conducted an experimental investigation on splitting tensile strength of steel fiber reinforced concrete cylinders consolidated by rodding or vibrating. In this experimental investigation the relative strengths of rodded and externally vibrated steel fiber reinforced concrete cylinders were compared for both standard compression and split-cylinder tension tests. Fiber concentrations ranged from 0 to 8 percent by weight of concrete were considered.

Based on the experimental investigation they have drawn the following conclusions:

A pilot program of external vibration of cylinders resulted in considerable increase in the split-cylinder tensile strength of steel fiber reinforced concrete compared to rodded specimens. Vibration did not have a similar effect on the tensile strength of un-reinforced concrete or the compressive strength of either reinforced or un-reinforced concrete.

The number of tested specimens was relatively small. A much larger testing program should be undertaken to obtain more statistically valid relations among the various parameters.

Siddique and Sahay [1993] concluded in their research paper that san fibre improves the split tensile strength and flexural strength, but does not significantly affect the compressive strength of concrete. San fibres help to improve the ductility of concrete, and there seems to be good matching between experimental and theoretical load-deflection curves.

Tan et al., (1993) conducted some investigation on the Shear behaviour of steel fibre reinforced concrete. Six simply supported I-beams were tested under two-point loading with hooked steel fibres of 30mm long and 0.5mm diameter, as the fibre volume fraction increased every 0.25% from 0% to 1.0%. This investigation confirms that the shear strength increased as much as 70 percent by adding small quantities of steel fibres (1.0%) into ordinary reinforced concrete. Further more, the steel strains on steel fibre reinforced concrete less than reinforced concrete at diagonal cracking of the web.

Ziad Bayasi and Jack Zeng [1993] have conducted an experimental investigation on properties of polypropylene fiber reinforced concrete. This experimental research investigation reported on the material properties of fresh and hardened states of fibrillated polypropylene fiber reinforced concrete. Seven mixtures were prepared. Fiber lengths were, ⅛ and ¼ in., and volume fractions were 0.1, 0.3 and 0.5%. Fiber effects on concrete properties were assessed. Properties studied were slump, inverted slump cone time, air content, compressive and
flexural behaviors, impact resistance and rapid chloride permeability, and volume percent of permeable voids. An innovative method of characterizing the flexural behavior of fibrillated polypropylene fiber concrete was proposed. The new method was dependent on the post-peak flexural resistance of concrete and can facilitate comparison of the effectiveness of various fiber types and volumes as concrete reinforcement.

From their experimental investigation they have drawn the following conclusions

1. Fibrillated polypropylene fibers have no detectable effect on the workability and air content of fresh concrete at volumes below 0.3 percent. An adverse effect on workability and an increase in air content of concrete resulted from the application of fibrillated polypropylene fibers at 0.5 percent volume.

2. Fibrillated polypropylene fibers tend to increase the permeability of concrete. With ½-in-long fibres, the increase was relatively mild. With ¾-in-long fibres, the increase was significant.

3. Polypropylene fibers had relatively small favorable effect on compressive strength of concrete toughness when ¾-in-long fibres were used.

4. It was proposed that the flexural behavior of polypropylene fibers concrete be characterized by the post-peak flexural resistance (load or stress). It was found that, for volumes equal to or less than 0.3 percent, ¾-in-long fibres were more favorable for enhancing the post-peak resistance. For 0.5 percent volume, ½-in-long fibres were more effective.

Trottler et al. (1994) investigated the Toughness of fibre reinforced concrete by using different geometry of steel fibres, which include hooked end, crimped circular, crimped crescent and twin cone end steel fibres. One fibre volume fraction (40kg/m³) was used throughout the research. The test included compressive strength test and flexural strength test, with measurement of deformation of specimen as the load applied. They found out that fibres brought significant improvement in the toughness and energy absorption capacity of concrete. Based on four fibre geometries, fibres with deformations only at end appear more effective than those with deformations over the entire length.

Balamukund (1995) has conducted an experimental investigation to study the bond strength of fibre reinforced concrete. In this experimental investigation the contribution of fibres towards the bond strength characteristics of FRC is investigated. A total of 18 tensile bond prisms were cast to study the variation in bond resistance due to variation in percentage volume of steel fibres and the aspect ratio of the fibres. The 18 prisms
consisted of two identical sets of prisms, one using fibre reinforced concrete and the other making use of plain concrete with centrally placed medium tensile steel bar as reinforcement. A definite increase in the interfacial force at the surface of the reinforcing bar is observed due to use of fibre reinforced concrete replacing ordinary concrete. The contribution of fibres in increasing the interfacial forces is evaluated in terms of percentage increase over plain concrete.

He has drawn the following conclusions based on the experimental investigation

1. Inclusion of steel fibres in concrete increases the bond strength between reinforcing brand concrete.
2. As the percentage volume of fibres increases the bond strength between reinforcing bar and FRC increases. This increase is up to 166% for a fibre volume % of 2.5 over plain concrete.
3. The bond strength increases with the increase in aspect ratio of fibres for a given volume percentage of fibres.

Balanubramanian et al., [1995] have presented an overview report on slurry infiltrated fibrous concrete (SIFCON). SIFCON considered as a special type of fibre reinforced concrete (FRC). SIFCON it differs from FRC in the method of production and fibre content. While in conventional FRC, the volume fraction of fibres varies from 1 to 3 per cent, in the case of SIFCON; it varies from 6 to 15 per cent. Because of the high fibre content the process of making SIFCON is also different. In FRC, the fibres are added to dry or wet mix of the concrete manually or using fibre dispensing machine. In the SIFCON only cement mortar is used and is prepared by infiltrating cement slurry into a bed of preplaced fibres. Because of its high tensile strength, ductility and superior impact resistance the SIFCON composite has excellent potential for structural applications like blast-resistant structures. From a detailed review of literature the method of production, properties and applications of SIFCON are presented in this overview. Results of developmental work carried out at SERC on SIFCON were discussed and they have drawn the following conclusion.

SIFCON is a relatively new material having high performance and high strength. It should be noted that the properties of SIFCON depend on fibre and matrix parameters. They also depend on slurry penetration, fibre-matrix bond characteristics, vibration, and placement techniques. In view of its outstanding strength and ductility characteristics, SIFCON may be suitable material, where the conventional concrete and FRC do not perform
For the different types of steel fibres available in the country, detailed investigations will be required to establish the structural response of SIFCON to formulate design guidelines.

Bharatkumar et al., [1995] have reported about toughness characteristics of steel fibre reinforced concrete. In review, results of flexural toughness tests carried out by the various researchers viz ASTM method, Robert Ward method and JCI method and Results of tests carried out at the Structural Engineering Research Centre (SERC), Madras were considered.

Based on the review of the test results reported by various researchers, the following observations are made with regards to flexural toughness of SFRC are

1. First-crack deflection can vary by as much as an order of magnitude depending upon the method used to measure deflection.

2. Toughness values calculated based on the ASTM C-1018 procedure with accurate measurement of deflections excluding extraneous deflections are quite different from the values reported in the literature which uses the common method of measuring deflection which includes an extraneous deformations such as the elastic and inelastic deformation of the fixture/supports and local deformations of the specimen at its supports.

3. With accurate deflection measurement, it is possible to compute toughness indices at large deflection, such as $I_{50}$ and $I_{100}$, for all fibre types having fibre content greater than or equal to 30Kg/Cu.m

4. Increase in fibre constant results in consistent increase in ductility and energy absorption capacity, which in turn gives higher toughness indices

5. The ASTM C-1018 toughness indices ($I_s$, $I_{10}$ and $I_{30}$) are generally observed to be relatively insensitive to fibre type and fibre volume fraction, whereas $I_{50}$, and $I_{100}$ are found to be sensitive to fibre types and fibre volume.

6. Toughness as a measure of absolute energy, like $T_{jci}$, is capable of distinguishing among composites with different types and fibre volume fractions.

7. The toughness indices are almost independent of concrete strength in so far as the compressive strength remains below 50MPa.

8. In general, it has been observed that high-strength concrete exhibits a more brittle post-peak failure pattern and it is advisable to use higher fibre volume fraction to obtain desirable toughness.
9. The first-crack strengths are sensitive to rate of testing and the age of the concrete, whereas toughness indices and residual strength factors are minimally dependent on these testing variables.

Balasubramaian et al., [1996] have conducted an experimental investigation on impact resistance of steel fibre reinforced concrete. This experiment presents the details of investigations on impact resistance of steel fibre reinforced concrete (SFRC) using drop weight impact method.

Based on the experimental investigations conducted on impact resistance of plain and fibre reinforced concretes (SFRC) they have drawn the following conclusions.

1. The fibre reinforced concrete showed ability to control cracking under impact loading and is found to absorb substantially higher number of blows when compared with the plain concrete. In the present investigation, addition of steel fibres of 0.5 percent volume fraction in concrete matrix resulted in at least 3.5 times increase in the number of blows to failure at 28 days when compared with plain concrete specimens. With higher percentage of volume fraction of steel fibres in concrete matrix, there was further increase in impact resistance.

2. Addition of fibres, even in a small quantity, considerably improves the impact resistance of concrete

3. As age of concrete increased from 28 to 90 days; number of blows to first crack got doubled for trough-shaped fibres for all volume fractions. In the case of crimped-shaped fibres having a volume fraction above 0.5 percent, number of blows to first crack got trebled as age of concrete increased from 28 to 90 days. However, the corresponding increase in the number of blows to days was only 1.1 times for trough-shaped fibres and 2.5 times for crimped fibres.

4. Among the three types of fibres, the impact resistance of specimens with crimped fibres is found to be consistently higher at all ages (7, 28 and 90 days) and for the four volume fractions than that of specimens with other two types of fibres.

5. With an adequate fibre volume, the failure mode of concrete under repeated impact loading is transformed from sudden brittle failure for plain concrete specimens to gradually increasing multiple cracking, concrete crushing and disintegration for SFRC specimens.

6. Schrader's drop-weight impact testing method used in the present investigations gives a reliable estimate of the impact resistance of concrete composites such as SFRC. Hence this test device, which
is economical, simple, and portable, could be used to evaluate qualitatively and quantitatively the impact resistance of plain and fibre reinforced concrete.

Parameshwaran [1996] have reported about research and applications of FRC in India. Research and developmental work in fibre reinforced concrete (FRC) composites which started in India during early 1970s has now reached a stage when fibre concrete technology no longer remains confined to laboratory experiments alone but has found significant application in the production of precast concrete components and in in-situ strengthening and repairs of concrete structures. The current applications include flooring and roofing components, pipes, manhole covers and frames, precast thin wall elements, tunnel lining, construction of blast-resistant structures and currency vaults. Large-scale application of this material is however, yet to catch-up in India.

Steel fibre reinforced concrete has many potential areas of applications such as mass concrete structures, pavements, bridge decks, airport runways, tunnel linings, defence installations and precast products. The technology is quite well known in India in spite of the fact that metal fibres are not being manufactured in India at present on a commercial scale. Commercial production of melt-extracted steel fibres is expected to be started in India in the near future and this may boost up the use of SFRC composites for a variety of applications. Natural fibres have also proved effective and useful in making low-cost roofing sheets and tiles and their use in housing schemes is also likely to increase.

Taylor et al., [1996] have conducted an measurements on toughness characterisation of fibre-reinforced concrete. The primary variables considered in this experimental investigation were strength and toughness measurements on a range of normal and high strength concrete mixes, with and without fibre reinforcement. Cube strength, modulus of rupture, cylinder splitting and torsional-tension test results are reported together with toughness measurements for polypropylene and steel fibre-reinforced concrete. The toughness measurements were carried out via two fracture-type test specimens rather than the traditional four-point loading arrangement on unnotched beams. In the toughness tests, crack mouth opening displacement (CMOD) was measured and used in a closed loop-testing mode to achieve complete load/displacement curves. Three different concentrations of polypropylene and steel fibres have been investigated for each nominal grade of concrete (40, 60, 80 and 120 N/mm²) by making 40 mixes in total.
Based on the test results they have drawn the following conclusions

1. Plain HSCs with high workability and good stability can be easily produced in the laboratory using good quality aggregates, silica fume and super plasticizer. The rheology of these concrete is such that sufficient volumes of polypropylene and steel fibre to significantly increase their toughness, while their strengths in compression and tension remain relatively constant can reinforce them.

2. This study shown that fracture-type tests using notched test geometries with CMOD deformations measured directly off the test specimens provide a good basis of quantifying material behavior and are an improvement on the traditional test procedures wherein deformations are recorded via the testing machine. Further research studies are required to determine what minimum portion of the load/CMOD curves is required to provide sufficient data to evaluate.

3. The work reported here shows the potential use of the notched cube test geometry to study size effects in fibre-reinforced concrete. The implications of possible size effects in the toughness measurements reported here have not been considered. However, the notched cube geometry would be more suitable for such studies due to the very compact nature of the test geometry.

Khatri and Sirivivatnanon [1997] have conducted an experimental investigation on methods for the determination of water permeability of concrete. In their experimental investigation two test methods have been successfully used to determine the water permeability of different concrete. The methods are based on the determination of coefficient of permeability using either a constant flow or a depth of penetration technique. The flow method has generally been found to suit concrete with higher permeability. While the penetration method is used for concrete, with very low permeability. Presently no clear guidelines exist for the selection of the appropriate method for a particular type of concrete. This study was carried out to examine the correlation between the two methods. A broad guideline has also been established for the selection of the appropriate method for a particular concrete with respect to its binder composition, 28 days compressive strength, and age. The concrete examined were prepared from five types of binders and with a grade range of 35-50 MPa.

It has been found that good correlation exists between the coefficients of permeability determined by both techniques on the same concrete. A general limit has also been found for the flow method, beyond which the penetration method has to be used. This limit has been found to depend on the 28-day compressive strength and
the age of the concreter and is independent of the type of binder used. The limit corresponds to a coefficient permeability of about $1.3 \times 10^{-13}$ m/second.

Kumar et al., [1997] have conducted an experimental investigation on statistical prediction of compressive strength of steel fibre reinforced concrete. In this experimental investigation, cubes of size 150 mm x 150 mm x 150 mm were cast with PCC and SFRC with three fibre contents of 0.5%, 1.0% and 1.5% (by volume) and three aspect ratios of 40, 60, and 80. Concrete mix M20 was designed and used as per IS recommendations. They have drawn the following conclusions based on the investigation.

1. The compressive strength of SFRC increases steeply with increasing fibre content up to 1.0% (by volume) beyond which the rate of increase in strength reduces.

2. The compressive strength of SFRC increases with increase in aspect-ratio up to 60% beyond this the rate of increase reduces.

3. The compressive strength of SFRC increases with increasing FRI up to 90 for straight fibres and up to 60 for crimped fibres, beyond which the strength decreases.

4. The compressive strength of SFRC can be estimated by a third degree polynomial relation as suggested in eqn.

5. The compressive strength of SFRC with crimped fibres is found to be less than straight fibres. This may be due to balling of crimped fibres during mixing and needs further investigation.

Prakash K B and Krishnaswamy [1997] have conducted an experimental investigation on Fibrous ferrocement. In this experimental investigation, the compressive strength, flexural strength and impact resistance of fibrous ferrocement were compared with ferrocement. The effect of superplasticizers on this strength was also compared. Attempts show that the addition of fibres into ferrocement along with superplasticizers can improve the properties of ferrocement and can overcome the limitations of ferrocement and fibre reinforced concrete.

Based on the experimental investigation they have drawn the following conclusions.

1. The compressive strength of fibrous ferrocement increases as the reinforcement layers and percentage of fibres increase.
2. The flexural strength of fibrous ferrocement increases as the reinforcement layers and percentage of fibres increase.

3. The impact strength of fibrous ferrocement increases as the reinforcement layers and percentage of fibres increase.

4. Use of superplasticizer increases the compressive strength, flexural strength and impact strength of fibrous ferrocement along with the increase in workability.

5. By increasing the percentage of superplasticizers the degree of workability can be increased. Thus the use of superplasticizers can eliminate the constructional limitation of fibrous ferrocement.

6. Since strength is enhanced in fibrous ferrocement and its constructional limitations can be overcome by the use of superplasticizers, fibrous ferrocement becomes an ideal material for pre-cast industries.

Siddique [1997] presented results of an experimental investigation carried out to study the effects of twines made of natural san fibres, used as reinforcement in concrete beams. On the basis of the results, he has concluded that twines made of natural san fibres enhances the load carrying capacity and ductility, and can be effectively used as reinforcement in concrete beams.

Bharatkumar et al., [1998] have conducted an experimental investigation on behaviour of steel fibre reinforced concrete subjected to cyclic loading to study the behaviour of SFRC under static and cyclic compression loading.

They have drawn the following conclusions, based on the investigations carried out on SFRC specimens and the companion plain concrete specimens to study their behaviour under monotonic and cyclic loadings.

1. The addition of steel fibres of small volume fraction (i.e. up to 0.75 per cent) does not change the peak load under monotonic compression and the stress-strain path up to peak load remains the same for both plain concrete and SFRC. However, the addition of even small volume traction of fibres leads to an appreciable change in the post-peak path (i.e. the descending portion) of the stress-strain curve and the post-peak stress-strain path of SFRC is flatter compared to that of plain concrete.

2. Higher volume traction of fibres (i.e. more than 1.0 per cent) influences both strength and stress-strain characteristics of concrete.
3. The peak compressive strain for SFRC under monotonic loading is in the range of 0.003 to 0.006 as against 0.0015 to 0.002 for plain concrete.

4. Cyclic loading at or nearer to the peak load strain was not possible in the case of plain concrete under compression as they failed suddenly, whereas, SFRC possesses high resilience even when loaded cyclically at a strain of 0.007 in the post peak region.

5. The SFRC specimens did not suffer damage during the cyclic loading and were able to sustain strains as high as 0.02 even after being subjected to cyclic loading under compression.

Ganesh and Indira [1998] have conducted an experimental investigation on confined polymer modified steel fibre concrete for seismic resistant structures. This experimental investigation describes the strength and behaviour of confined polymer modified steel fibre concrete under cyclic axial compressive loading. A total number of sixty cylindrical specimens were cast and tested to failure under repeated loading. The polymer considered in this investigation was natural rubber latex. The volumetric ratio of confinement, the volume fraction of steel fibres and the percentage of natural rubber latex in the form of dry rubber content were the main variables considered in this study.

Based on the experimental investigation they have drawn the following conclusions

1. By choosing proper proportions of fibres, polymer and volumetric ratio of confinement, the strain at peak could be improved significantly. Hence the confined polymer modified steel fibre concrete appears to be a useful material in the case of structures subjected to seismic loads / repeatedly applied loads.

2. The addition of fibres and latex to the confined concrete improve the energy absorption capacity and toughness index of the material significantly up to a certain value of confinement-latex-fibre-index.

3. In-view of the above, there is a good scope for using polymer modified steel fibre concrete in seismic resistant structures.

Gopalakrishnan et al., [1998] have conducted an experimental investigation on durability characteristics of steel fibre reinforced concrete to find the influence of corrosion of steel fibres on the strength and toughness characteristics of SFRC by subjecting the specimens to accelerated corrosion by continuous wetting in salt solution and subsequent drying. Steel fibres produced in India were used in the investigation.
From their experimental investigations they have drawn the following conclusions

1. Even though brown stains were noticed on the surface of the SFRC specimens, both flexural strength and toughness characteristics of SFRC are not affected.

2. The fibres inside the concrete matrix did not corrode at the end of 250 cycles of accelerated corrosion, thereby indicating that SFRC can withstand corrosion causing environments and would be durable.

3. Addition of steel fibres in concrete matrix having rebar resulted in decreased crack width when compared with companion RC specimens. Weight loss in HSD bars due to corrosion in the case of SFRC specimens was less when compared with RC specimens. It is also noted that addition of steel fibres in RC result in delayed cracking of concrete. Therefore, steel fibres in RC enhance the integrity of concrete and offer increased resistance to corrosion.

Nataraja et al., [1998] have conducted an experimental investigation on impact strength of fibre reinforced concrete. In this investigation an attempt was made to study the behaviour of fibre reinforced concrete under impact as determined from drop weight test. Drop weight test apparatus was fabricated as per ACI Committee 544 report and the impact strength of fibre reinforced concrete was determined from the Number of blows corresponding to first crack and ultimate stage is reported. 150 mm x 64 mm cylindrical discs cut from 150 mm x 300 mm cylinder are used for testing. M20 concrete designed as per IS 10262-1982 is considered and 0.5% and 1.0% volume fraction was used in this preliminary investigation. Two types of fibres namely crimped flat and crimped round were used for the study. Two aspect ratios of 55 and 82 were considered for round fibres.

From the above study they have made the following conclusions

1. There is a considerable variation in the impact strength due to high scatter of results.

2. Aspect ratio and type of fibre seems to have no influence on the impact strength due to high variability in the test results.

3. Impact strength increases considerably for FRC compared to plain concrete. The increase is many folds depending on the volume traction of fibre. Nearly a threefold and ten fold increase can be expected for volume traction of 0.5 % and 1 % of fibres respectively.

4. Impact strength increases with volume fraction.

5. Due to high variability in the test results, one need to consider more samples for impact strength and the
results are to be interpreted statistically. Extremely high and low values are to be discarded to minimise the variations.

The drop weight test can establish the relative merits of the different mixes tested. The local weaknesses of the specimen have a great influence on the relative, strength of the specimen. The tests results show wide scattering possibly because redistribution of stresses is possible during the very short period of deformation.

The addition of fibres to concrete greatly increases the energy absorption and cracking resistance. Despite this, there is no standard method for determining the impact resistance of such composites.

From the above studies it is clear that the addition of steel fibres significantly improves the impact strength of concrete. Increase in impact strength is many with fibre reinforced concrete over plain concrete. Thus fibre reinforced concrete most ideal material for structures subjected to impact such as explosion resistant seismic resistant structures.

Nataraja et al., [1998] have conducted an experimental investigation on study on steel fiber reinforced concrete composite using ultrasonic pulse velocity technique. In this experimental investigation an attempt was made to study the variation in ultrasonic pulse velocity for plain and steel fiber reinforced concrete at different ages. The variable considered was to study the effects of volume fraction of fiber on pulse velocity for two grades of concrete namely M20 and M30.

They have drawn the following conclusions based on the experimental investigation.

1. The increase in pulse velocity between one day and 28 days is about 14.67 percent, between 7 days and 28 days is about 1.84 percent and between one day to 7 days is about 12.93 percent for M20 concrete for both plain and fiber reinforced concrete. The corresponding increases for M30 concrete are 11.20, 1.37 and 9.70 percent respectively.

2. In general the pulse velocity varies from about 4100 m/s to about 4800 m/s from one day to 28 days for M20 concrete. The corresponding values for M30 concrete are 4250 m/s and 4859 m/s respectively.

3. In general the pulse velocity at 28 days for steel reinforced concrete will vary from about 4750 m/s to 4850 m/s depending on the volume fraction of the fiber.

4. The pulse velocity for M30 concrete for the give reinforcing parameters and age is marginally higher
compared to that of M20 concrete.

5. As the volume fraction increases the pulse velocity also increases marginally by about 50 m/s to 100 m/s at 28 days compared to the un-reinforced matrix. However for few sample the pulse velocity has decreased marginally for higher volume fraction on account of air entrapment in the form of voids, which is very clear from the observation of the cut surfaces of the samples.

6. Pulse velocity measurements taken at different positions of the specimen is more or less the same indicating the uniformity of the concrete and the fiber distribution. This is also evident form the observations of the cut surfaces of the prisms.

7. The general trend in the variation of the pulse velocity is more or less follows the trend of compressive strength variation indicating a direct relation between the two parameter.

8. The quality of concrete is found to be excellent since pulse velocity is greater than about 4575 m/s at 28 days in all cases.

9. Based on the above studies it is observed that the pulse velocity at 7 days and 28 days can be easily predicted knowing the pulse velocity at one day (i.e. pulse velocity measured immediately after the removal of shuttering) using an amplification factor of 1.11 and 1.13 over the one day pulse velocity for both plain and fiber reinforced concrete up to a compressive of about 50 MPa with in 2 percent error.

Natraja et al., [1998] have conducted an experimental investigation on steel fibre reinforced concrete under compression. In this experimental investigation the behaviour of SFRC under compression for cylinder compressive strength ranging from 30N/mm² to 50 N/mm² were studied. Round crimped fibres with three volume fractions of 0.5%, 0.75% and 1% (39, 59 and 78 kg/m³) and two aspect ratios of 55 and 82 were considered.

Based on the experimental investigation they have drawn the following conclusions

1. Addition of crimped steel fibres to concrete increases the compressive strength of the concrete marginally

2. Linear regression equations are proposed to quantify the effect of fibre addition on the compressive strength of concrete in terms of fibre reinforcing index up to a compressive strength of 50N/mm².
3. The proposed equations may be used for concrete containing crimped fibres up to 1% volume fraction.

4. Addition of fibres to concrete significantly increases its toughness and makes it more ductile as observed from the modes of failure of the test specimens.

**Pal and Rao [1998]** have conducted an experimental investigation on evaluation of mechanical properties of steel fibre reinforced concrete. In this investigation large number of cubes and beams were cast to evaluate various mechanical properties of steel fibre reinforced concrete. The variables considered in this were mix proportion 1: 3 for mortar and 1: 2: 3 for concrete and w/c ratio 0.5 and 0.6. Aspect ratios 10, 25, 50, 75 and 100, three-volume fractions 0.5%, 0.75% and 1.00% and four shear span ratios (a/d) 2.0, 2.5, 3.5 and 5 were considered.

Based on the experimental investigation they have drawn the following conclusions:

1. Addition of fibres influences to a great extent the rheological properties of fresh fibre mix. It has been observed that there is difficulty in obtaining SFRC mix if the fibre content is more than 1.5% by volume. It is suggested that the fibre content should be limited to 1% by volume of the concrete.

2. Apart from the fibre geometry and fibre volume, the size, shape and volume fraction of coarse aggregate also have a pronounced influence on the fibre-aggregate interaction and the rheology of the fresh fibre mix. The larger the size of aggregate and the greater the roughness of the surface texture, the more severe the problems of aggregate fibre interference. It is generally advantageous to increase the fibre size as the aggregate size is increased. Use of pozzolanic admixture and superplasticizer will increase the workability of the mix.

3. The presence of fibres can greatly enhance the strain capability of the un-reinforced matrix and holds the matrix together even after complete failure. It also widens the gap between first crack and ultimate strength, thus imparting more post cracking strength due to absorption of fibres. All these abilities both in tension and compression are a unique property of the fibre composite.

4. Steel fibres are very effective as shear reinforcement. Their incorporation greatly improves the shear and moment capacities. The maximum increase was obtained using fibres of aspect ratio 75. The mode of failure changed from shear in reference RCC beam to moment or moment-shear failure in SFRC beams.
3. The proposed equations may be used for concrete containing crimped fibres up to 1% volume fraction.

4. Addition of fibres to concrete significantly increases its toughness and makes it more ductile as observed from the modes of failure of the test specimens

Pal and Rao [1998] have conducted an experimental investigation on evaluation of mechanical properties of steel fibre reinforced concrete. In this investigation large number of cubes and beams were cast to evaluate various mechanical properties of steel fibre reinforced concrete. The variables considered in this were, mix proportion 1: 3 for mortar and 1: 2: 3 for concrete and w/c ratio 0.5 and 0.6. Aspect ratios 10, 25, 50, 75 and 100, three-volume fractions 0.5%, 0.75% and 1.00% and four shear span ratios (a/d) 2.0, 2.5, 3.5 and 5 were considered.

Based on the experimental investigation they have drawn the following conclusions

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The mode of failure changed from shear in reference RCC beam to moment or moment-shear failure in SFRC beams.
5. The ultimate deflections in SFRC beams were found to be about 4 times that of reference beams indicating a large increase in both toughness and ductility of the composite making it more suitable for application in case of shock and blast loading.

Parviz Soroushian and Slavosh Ravanbakhsh [1998] have conducted an experimental investigation on control of plastic shrinkage cracking with specialty cellulose fibres. The investigation reported herein concerns the effects of specialty cellulose fibers on the restrained plastic shrinkage cracking of conventional and high-performance concrete. Cellulose fibers were used here at 0.06% volume fraction, which is equivalent to a fiber content of 0.9 kg/m³. Plastic shrinkage crack occur when the early-age shrinkage movements (prior to final set) are restrained. This commonly occurs on the surfaces of concrete which produces internal restraint against shrinkage movements of the surface layers.

Replicated tests were conducted in order to derive statistically reliable conclusions in light of the inherently high variability of the plastic shrinkage cracking results.

From the investigation they have drawn the following conclusions:

1. Cellulose fibers have statistically significant effects, at 95% level of confidence, on reducing the plastic shrinkage cracking of conventional and high-performance concrete.

2. The total plastic shrinkage crack area in conventional and high-performance concrete was reduced, on the average, by 78% and 40%, respectively. In spite of this difference in average crack reduction, cellulose fibres were found to have statistically comparable effects in conventional and high-performance concrete. Cellulose fibers also reduced the maximum plastic shrinkage crack width of conventional and high-performance concrete by 47% and 34%, respectively.

3. The restrained plastic shrinkage cracking test results show relatively high variability; the coefficients of variation of total crack area measurements for different concrete mixtures ranged from 28% to 90%; this high variability is reportedly inherent to plastic shrinkage cracking of concrete.

Rehan Ahmad Khan et al., [1998] have conducted an experimental investigation on the effect of fibre diameter on the flexural behaviour of fibre reinforced cement flyash concrete. In this experimental investigation the effect of fibre diameter on the strength and deformation potentiality of the flexural members of fibre reinforced cement flyash concrete were studied. Tests were conducted on the cement flyash fibre reinforced
concrete members having fibres of 0.457mm (26SWG), 0.3759 mm (28SWG) and 0.315mm (30SWG) diameter. Fibres of each diameter were used in three different percentages i.e. 0.5%, 0.75% & 1% by volume of concrete in different sets of specimen. Three beams with each percentage of fibres of all the three diameters were cast and tested after 28 days of curing. Aspect ratio of fibres was kept as 100 throughout and 20% of cement by weight was replaced by flyash in each case.

On the basis of the results of the experiments conducted on the fibre reinforced cement flyash concrete beams, they have drawn the following conclusions:

1. The workability of fibrous concrete mix is improves with the reduction in fibre diameter.
2. The ultimate load of fibre reinforced cement flyash concrete increases with the reduction in fibre diameter. This trend of the enhancement of ultimate load on the reduction of fibre diameter is consistent for all the percentages of fibre used in this work.
3. The first crack load has also been found enhancing with the reduction of fibre diameter for all the fibre contents
4. The deformations have been found increasing with the reduction of fibre diameter
5. The ductility increases when the fibre diameter is reduced.

Singh and Singhal [1998] have conducted an investigation on effect shapes on compressive and bond strengths of steel fibre reinforced concrete. They conducted investigation with the aim to find the effects of fibre shapes and their content on compressive and bond strength of SFRC. Three shapes of fibres were used i.e. plain, crimped, and wavy. The aspect-ratio of fibres was 67. Cubes of 100mm side and Cylinders of size 150 x 300mm of M-20 grade (0.54:1.1:1.73:2.83) mix proportion of concrete were cast with three different fibre contents i.e. 1.55, 3.10 and 4.65 % (by weight). For the reference purpose, cubes and cylinders of conventional concrete were also cast. Tor steel bar of 10 mm nominal diameter was embedded to a depth of 150mm at the centre of cylinder. The specimens were tested in surface dry saturated condition on universal testing machine.

From the investigation they have drawn the following conclusions regarding the compressive and bond strength to study the effects of fibre shape are

1. Plain fibers are more effective at higher content whereas more deformed fibres such as wavy fibres are more effective at lower fibre content
2. Fibres are more effective in compression than under bond.

3. It is not easy to relate compressive strength with fibre parameters for different shapes of fibres by a single relationship.

4. The load-deformation under pull-out can be divided into various zones and the total deformation reduces with deformed fibres.

5. Economy can be achieved with the use of more deformed fibres such as wavy fibres as the content required would be less to achieve any target strength.

Zhang Jun and Henrik Stang [1998] have conducted an experimental investigation on fatigue performance in flexure of fibre reinforced concrete. In this experimental investigation the behavior of fibre reinforced concrete under cyclic flexural loading were studied. One type of polypropylene and two types of steel fibers in two different volume concentrations were studied.

Load-deflection response is obtained for constant amplitude fatigue loading as well as for static loading. The damage level is recorded under static and fatigue loading using acoustic emission techniques.

Data is presented in terms of complete load-deflection diagrams (for static loading) and in terms of S-N diagrams (for fatigue loading). Damage evolution is described in terms of acoustic emission activity as a function of deflection (static loading) or cycles (fatigue loading).

Based on the experimental investigations they have drawn the following conclusions:

1. Fatigue performance (fatigue strength relative to the static strength relative to the static strength) can be improved using steel fiber reinforcement; however, there seems to be an optimum fiber volume concentration around 1 vol. percent (less than 2 vol. percent). Use of polypropylene fiber in addition to steel fiber seems to have little effect on fatigue performance.

2. Using AE count as damage measure, much more damage is accumulated in static as well as fatigue testing of steel fiber concrete compared to plain concrete. Using steel fiber concrete the accumulated damage at failure is increased by two orders of magnitude when $S_{\text{max}}$ is decreased from 1 to 0.9 while it is virtually unchanged when $S_{\text{max}}$ is decreased from 0.8 in plain concrete. Using AE counts at failure it is possible to distinguish fiber concrete with high fatigue performance from fiber concretes with low fatigue performance.
3. The deflection at failure under constant amplitude flexural fatigue loading can be predicted using the static load deflection curve as an envelope curve for the fatigue testing; Thus, at failure the maximum deflection for fatigue loaded specimens is the same as the deflection for static loaded specimens on the descending part of the load-deflection curve subjected to a load corresponding to the maximum load in the fatigue testing. However, even though the deflection is similar in these two states the accumulated damage is very different.

Barros and Figueiras [1999] have conducted an experimental investigation on flexural behaviour of SFRC. In this experimental investigation the performance of structural elements made of steel fiber reinforced concrete (SFRC) were studied. Fiber content of the concrete ranged from 0 to 60 kg/m³. Using the results of the uni-axial compression tests performed under displacement control condition, a stress-strain relationship for fiber concrete in compression was derived. Three-point bending tests on notched beams were carried out to simulate the post cracking behavior and to evaluate the fracture energy. Based on the constitutive relationships derived from the experiments, a layered model for the analysis of steel fiber reinforced concrete cross sections was developed. The model performance and the benefits of fiber reinforcement on thin slabs reinforced with steel bars were assessed by carrying out tests on slab strips.

Based on the experimental investigations they have drawn the following conclusions

1. Based on the results obtained from the uni-axial compression tests on SFRC cylinder specimens, a compression stress-strain law was proposed for the composites analyzed. From the results of the three-point bending notched beam tests, the post-peak tensile behavior of SFRC structures was assessed by using the fracture energy concept.

2. To evaluate the flexural resistance and the ductility of cross sections or SFRC members under bending, a numerical model was developed. This model applies the constitutive laws and the material fracture parameters determined from the experiments carried out. The model performance was assessed by simulating either the response of SFRC beams tested by other researchers, as well as the behavior of SFRC slab strips tested in this work. The concrete slab strips reinforced with wire mesh and with different percentages of steel fibers were tested in bending. The increase in fiber percentage has significantly improved the load-carrying capacity and decreased the crack. Opening and crack spacing,
it was observed that mixes with 60 kg/m³ of fibers exhibited an ultimate load twice the ultimate load of the slab. Strips with the reinforcing bars (wire mesh) but without fibers.

3. The simple but yet accurate model developed gives the complete moment-curvature relationship of an SFRC cross section. Either the moment-curvature or the stress-strain relationships derived in the present work are fitted to be used in finite element models for the nonlinear analysis of SFRC bi-dimensional structures.

Choudhari [1999] have conducted an experimental investigation on an experimental approach to the behaviour of beam using steel fibers. In this experimental investigation structural as well as flexural behaviours of R.C.C. beam were discussed with short discontinuous steel fibres randomly oriented uniformly dispersed in concrete mix. The theoretical mechanism of fiber reinforced concrete outlines the behaviour of this concrete under the loading the fracture arrest mechanisms were also investigated relating with the quantity of fibres added in concrete.

They concluded that the theoretical as well as the experimental data reveals that the inclusion of steel fibers in conventional reinforced concrete beam brings desirable modification in the deformational characteristics of such beams subjected to pure bending strains in steel, deflection & crack pattern are reduced at any given load level by including steel fiber.

Job Thomas and Syam Prakash [1999] have conducted an experimental investigation on Strength and behavior of plastic fibre reinforced concrete. Investigation was carried out to study the feasibility of use of plastic fibres and the effect of fibre length and content on the structural properties such as cube compressive strength, cylinder compressive strength, split tensile strength, modulus of rupture and modulus of elasticity of this composite. Tests were conducted on beams with optimum fibre parameters, and the results compared with those of identical RCC beam.

They have drawn the following conclusions from the study

The salient conclusions are

1. An increase of 29% of the cube compressive strength of PFRC over plain concrete
2. An increase of 19% of the cylinder compressive strength of PFRC over plain concrete
3. The ratio of cube strength to cylinder strength is obtained as 1.37 for PFRC and 1.26 for plain concrete.
4. An increase of 99% of split tensile strength of PFRC over plain concrete

5. An increase of 62% of modulus of rupture of PFRC over plain concrete

6. The modulus of elasticity obtained of PFRC is 35.56 KN/mm² and for plain concrete is 25.48 KN/mm².

7. The experimental results of the basic structural properties found to be the maximum for the same mix. Thus the mix P₂, with fibre length of 60mm and fibre content of 0.15% by weight, is that optimum mix for the type of fibre used in this investigation.

Juji Zhang et al., (1999) have studied on Fatigue life prediction of fiber reinforced concrete under flexural load. In this experimental investigation a semi-analytical method to predict fatigue behavior in flexure of fiber reinforced concrete (FRC) based on the equilibrium of force in the critical cracked section is under taken. The model relies on the cyclic bridging law the so-called stress-crack width relationship under cyclic tensile load as the fundamental constitutive relationship in tension. The numerical results in terms of fatigue crack length and crack mouth opening displacement as a function of load cycles are obtained for given maximum and minimum flexure load levels. Good correlation between experiments and the model predictions is found. Furthermore, the minimum load effect on the fatigue life of beams under bending load, which has been studied experimentally in the past, is simulated and a mechanism-based explanation is provided in theory. This basic analysis leads to the conclusion that the fatigue performance in flexure of FRC materials is strongly influenced by the cyclic stress-crack width relationship within the fracture zone. The optimum fatigue behavior of FRC structures in bending can be achieved by optimising the bond properties of aggregate-matrix and fiber-matrix interfaces.

Khan et al., [1999] have conducted an experimental investigation on tensile strength of jute fiber reinforced concrete. In this investigation the tensile strength of ordinary concrete 1: 1.5: 3 with various water-cement ratios (by mass) and low and economic percentage of jute fibers of 0.7 (by volume) were studied. Such characteristics were compared with those obtained from concrete without jute fiber and studied under identical conditions of mixing, compacting, vibrating and testing.

They have drawn the following conclusions based on the experimental investigation

1. Nominal-mix proportions of 1: 1.5: 3 using water-cement ratios of 0.45, 0.55 and 0.65 and locally available aggregates yield satisfactory ordinary concrete with or without jute fibres.
2. Workability of concrete considerably reduces with the addition of jute fibers because of their absorptive properties. Workability increases with increase of water-cement ratio and vice-versa.

3. The organic fiber, jute, being confined in concrete, does not contribute towards tensile strength because of the decaying properties of the fiber. However, except few stray cases, tensile strength decreases with the increase of water-cement ratio and vice-versa.

4. Use of jute fibers for enhancing strength of plain concrete being not encouraging, such concrete may be useful in very unimportant work.

Krishna Rao et al [1999] have conducted an experimental investigation on workability of SFRC using a cone penetration test. In this investigation a new cone penetration test developed by Prof C.V.S. Kameswara Rao and A.K. Sachan was used to study the influence of aspect ratio and total aggregate to the cement ratio on the workability of SFRC. The results of cone penetration test were compared and correlated with those of conventional workability tests viz. V-B time test slump cone test, Compaction-factor test, and ACI-inverted cone test.

Three types of mix proportions for various fibre contents of straight round steel fibres, with different aspect ratios and water cement ratios were investigated. The results were compared with those of earlier studies. Based on the experimental investigation they have drawn the following conclusions

1. The new cone penetration test devised to assess the workability of fibre reinforced concrete is found to be easy to conduct, reliable, and suitable for concretes with low w/c ratio and higher fibre content.

2. There is a consistent correlation between the new cone penetration test and other conventional tests of workability.

3. The test results indicate the reduction in workability with the increase in aspect ratio, which is mainly due to the balling phenomenon of fibres while mixing.

4. The workability of the mixes is found to decrease with increase in total aggregate to cement ratio for the reason that the total percentage of fines is less.

5. The reduction in workability is found to be independent for all mix proportions, when aggregate to cement ratio and aspect ratios were increased and vice versa.
Nataraja et al., [1999] have conducted an experimental investigation on stress-strain curves for steel-fiber reinforced concrete under compression. In this experimental investigation, an attempt was made to generate the complete stress-strain curve experimentally for steel-fiber reinforced concrete for compressive strength ranging from 30 to 50 MPa. Round crimped fibers with three volume fractions 0.1%, 0.5%. 0.75%, and 1.0% (19.59, and 78 kg/m³) and two aspect ratios of 55 and 82 were considered. The effect of fiber addition to concrete on some of the major parameters namely peak stress, strain at peak stress, the toughness of concrete and the nature of the stress-strain curve were studied. A simple analytical model was proposed to generate both the ascending and descending portions of the stress-strain curve. There exists a good correlation between the experimental results and those calculated based on the analytical model. Equations were also proposed to quantify the effect of fiber on compressive strength, strain at peak stress and the toughness of concrete in terms of fiber reinforcing parameter.

The following equations were found to best describe the relationship for the crimped fibres, for compressive strength up to 50 MPa

\[
\beta = 0.001E_i - 0.5811, \ (r = 0.96)
\]

\[
E_i = 1930 \ R_i^{(0.7406)}, \ (r = 0.97)
\]

\[
\beta = 0.5811 - 1.93 \ R_i^{(-0.7406)}
\]

The above equations can be used for reinforcing index up to 3 for a crimped fiber

Based on the experimental investigation, they have drawn the following conclusions regarding the compression behavior of steel-fiber reinforced concrete

1. Addition of crimped steel-fibers to concrete increases the toughness considerably. The increase in toughness is directly proportional to the reinforcing index. Increase in toughness is marginally higher for lower grade of concrete compared to higher grade of concrete. A marginal increase in compressive strength, strain at peak stress is also observed. This increase is directly proportional to the reinforcing index.

2. An analytical expression is proposed to generate the complete stress-strain curve for a steel-fiber reinforced concrete containing crimped fibers based on the parameter \( \beta \) and the strain corresponding to the peak compressive strength.
3. The proposed equation to determine the value of $\beta$ is valid for crimped steel-fiber with reinforcing index value ranging from 0.9 to 2.7.

4. The proposed expression provides a good correlation between the predicted and the experimental results. The toughness ratio calculated, from the stress-strain curves based on the predicted equations, matches with those calculated from the experimental stress- strain curves, within an acceptable limit of error.

5. The proposed equations can be used to estimate the parameters of steel-fiber reinforced concrete as a function of reinforcing index, knowing the respective parameters of the un-reinforced concrete.

Nataraja et al., [1999] have conducted an experimental investigation on a study on steel fibre reinforced concrete using ultrasonic pulse velocity technique. In this experimental investigation the variation in ultrasonic pulse velocity for plain and steel-fibre reinforced concrete at different ages were studied. For the two mixes namely M20 and M30 covering a strength range up to 50 N/mm$^2$ were considered. Three volume fractions of round crimped fibres, namely, 0.5%, 0.75% and 1.0% (39kg/m$^3$, 58kg/m$^3$ and 78kg/m$^3$) and for two aspect ratios of 55 and 82(average) were investigated.

Based on the experimental investigation they have drawn the following conclusions

1. The pulse velocity at 7 days and 28 days can be easily predicted knowing the pulse velocity at one day (i.e. pulse velocity measured immediately after the removal of shuttering) using amplification factor of 1.11 and 1.13 over the one day pulse velocity for both plain and fibre reinforced concrete up to compressive strength of about 50 MPa within 2% error.

2. In general the pulse velocity varies from about 4100m/s to about 4800m/s from one day to 28 days for M20 concrete. The corresponding values for M 30 concrete are 4250m/s and 4850m/s, respectively.

3. In general, the pulse velocity at 28 days for steel fibre reinforced concrete will vary from about 4750m/s depending on the volume fraction of the fibre.

4. As the volume fraction increases the pulse velocity also increases marginally by about 50 m/s to 100 m/s at 28 days compared to the un-reinforced matrix.
5. Pulse velocity measurements taken at different positions of the specimen were more or less the same indicating the uniformity of the concrete and the fibre distribution. This is also evident from the observations of the cut surfaces of the prisms.

6. The quality of concrete was found to be excellent since pulse velocity was greater than about 4575 m/s at 28 days in all cases.

7. Addition of crimped steel fibres to concrete increased the compressive strength of concrete marginally and made it more ductile as observed from the modes of failure of the test specimens.

Nataraja and Muralidhara Rao [1999] have conducted an experimental investigation on ultrasonic pulse velocity and rebound hammer studies on steel fibre reinforced concrete. In this experimental investigation an attempt was made to correlate the effect of fibre reinforcement on the strength of concrete by non-destructive method using ultrasonic pulse velocity and rebound hammer techniques. Variations of pulse velocity and rebound numbers were studied for fibre contents varying from 0.25% to 1.0 % and for two aspect ratios of 80 and 110.

Based on the experimental investigation they have drawn the following conclusions

1. The data obtained from the pulse velocity measurements for different percentages of fibre content and corresponding 7 and 28-day compressive strengths are presented in table. The data clearly shows increase in pulse velocity with increase in fibre content. Also the compressive strength was found to increase by about 15-20% for a fibre content of 1.0%.

2. Further it is very much clear from the data obtained that there is a apparently no significant effect of fibre content on rebound number. In other words rebound number is insensitive to the presence of fibres in the concrete. This is true because the rebound number depends on the quality of the surface concrete only.

3. It was noted during the experimental process, that brittleness of concrete specimens decreased to a considerable extent with the addition of fibres. Even after the repeated successive loading the specimens did not crumble but still were held by the fibres. It was also observed that failure of the specimens was due to de-bonding effect rather than yielding of fibres.
4. The test results clearly indicate that there is a linear variation between pulse velocity and percentage fibre. Pulse velocity increases with increase in fibre content. By the method of least square the following expression is derived with a correlation coefficient of 0.93.

\[ V_e = 4.42 + X \frac{(5.90 - V_c)}{100} \]

Where, \( V_e \) and \( V_c \) are velocities in fibre reinforced and plain reinforced concrete respectively, \( X \) is the fibre content in percentage.

Thus it can be concluded that the addition of steel fibre to concrete increases compressive strength, pulse velocity and ductility of the concrete while in turns improves its durability.

Peled et al., [1999] have conducted an experimental investigation on flexural performance of cementitious composites reinforced with woven fabrics. In this experimental investigation the influence of a woven fabric structure on the flexural behavior of cementitious composites was studied. The fabrics used were all plain weave with different fills densities of 5, 7, or 10 fills per cm and the warps density was kept constant (22 warps per cm). The yarns were all monofilament from polyethylene. The crimped geometry of the individual yarn in the fabric might influence the bonding between that matrix and the fabrics and the overall performance of the composite. Two different types or composites were prepared (1) Samples with fabrics; and (2) sample with crimped yarns that were untied from the fabrics. Three different tests, flexural, tensile, and pullout, were carried out to characterize the mechanical performance of the composite and the bond between the fabrics and the matrix. Special attention was given to the characterization of multiple cracking, which may contribute to the understanding of the bonding between the fabrics and the matrix was found that the fabric structure, which yields a high bond, did not provide a composite with better properties than in the case of crimped untied yarns. Weakening of the matrix due to less efficient compaction was detected as a significant parameter. When fabrics were used the compaction is less efficient and the performance was poorer. The lower stress magnitude for first crack appearance supports that observation.

They have drawn the following conclusions based on the experimental investigation

1. Increasing the crimped structure of individual yarns enhances the bonding with the matrix. The bond of the fabric to the matrix increases with the density of the fabric; it is also larger than the bonding of
crimped yams, untied from the fabric. Consistent bond data were obtained from pullout tests and indirect calculation based on multiple crack spacing.

2. Generally, the enhanced bonding of the crimped yarn or fabric is reflected in enhanced performance of the composite, compared with a composite with a similar reinforcement ratio of straight yarns. However, the trends of increased bond are not always identical with the trends of increased flexural performance: the fabric structure that resulted in a high bond did not provide with properties better than those obtained in a reinforced by crimped untied yams. It is suggested that, the decrease in performance is the result of weakening of the matrix due to less efficient compaction. The compaction is less efficient in composites reinforced with fabrics, as manifested also by the lowering of the first crack stress.

3. Based on the above considerations of the matrix quality, it is expected that better performance may be obtained when the production process of the composite is improved.

Rafeeq Ahmed [1999] has conducted an experimental investigation on fatigue behaviour of steel fibre reinforced concrete-In direct compression. In this experimental investigation primary variables considered were, straight, (volume fraction one percent) and hooked (volume fractions of one percent and two percent) steel fibres. Both S-N (strength-number of cycles) and strain behaviours were investigated. The maximum stress levels ranged from 95 to 55 percent of the static compressive strength while the minimum was kept one million. Strains were measured at different stages of fatigue cycling.

Based on the results of this investigation, he has drawn the following conclusions

1. The incorporation of steel fibres reduces the variability in the fatigue strength or fatigue life of concrete. The higher the fibre content, lower is the scatter or spread.

2. Fibre incorporated concrete shows greater fatigue strength than plain concrete, at any, given value of number of cycles. The higher the fibre content, higher is the fatigue strength. The fatigue strength, at one million cycles, based on straight-line fits for plain concrete, one percent SFRC, one percent HFRC, and two percent HFRC are 52, 54, 56 and 60 percent of the static ultimate strength of respective batches.
3. The spread between the characteristic (five percent defective) curves and the mean curves reduces as the stress level decreases. This suggests that the mean 5-N curves themselves can be used for design purposes instead of characteristic curves when the stress levels are low. This suggestion is made when it is costly or time consuming to test a large number of specimens for purposes of obtaining the characteristic curves.

4. Strain behaviour of both plain and fibre reinforced concretes follow a common trend exhibiting three distinct stages, namely, stage I, stage II and stage III.

5. While the strain builds up rapidly at higher stress levels, it builds up more slowly at lower stress levels, but the failure strains at lower stress levels were greater than those at the higher stress levels.

6. Fibres increased the strain sufferance capability of plain concrete, and in this respect hooked fibre reinforced concrete is seen to be better than straight fibre reinforced concrete. The capability, in terms of failure strain increase, is almost about 50 percent more for hooked fibre reinforced concrete.

7. Increasing the fibre content from 1 percent to 2 percent by volume of concrete does not necessarily confer greater strain sufferance capability at failure, but the increase in the fibre content reduces the variability of the brittle material response.

Senthil Kumar [1999] has conducted an experimental investigation on concrete reinforced with flat fibres. Experimental investigations were undertaken by the author to determine the behavior of test specimens in compression, tension and flexure. The specimens include cubes, cylinders and beams of M20 concrete reinforced with flat steel fibres of aspect ratios varying from 20 to 50. Using volume fractions of fibres, ranging from 0.25% to 0.5%, were considered.

He has drawn the following conclusion based on the experimental investigation results:

The addition of steel fibres makes concrete ductile and tough in SFRC elements under tension, the numerous steel fibres bridge the micro-cracks and transfer stresses, thus increasing the load carrying capacity. From the test results, for an aspect ratio of 50 and volume fraction of 1.25 to 1.5%, the tensile strength and toughness of concrete are maximum. These values of aspect ratio and volume fraction of fibre are considered optimum in the case of beams; proper distribution and orientation of fibres in critical locations are suggested for improving the flexural strength, the use of SFRC structural element.
for pavements, canal linings and foundations is suggested as a cost-effective and structurally efficient civil engineering design solution.

Siddique [1999] has conducted an experimental investigation on study of concrete beams reinforced with jute fibres and twines. In this experimental investigation, the effect of jute twines on the flexural behavior of concrete beams reinforced with or without fibres was studied. Jute fibre and twines were used as reinforcement in concrete beams, concrete mixes were prepared with jute fibre 0.75% by volume of concrete and fibre length 25mm. Concrete beams were cast with four different percentages of jute twines (0.56%, 0.94%, 1.12% and 1.88%) with and without fibres. After setting, the specimens were immersed for curing for 28 days. After 28 days the specimens were removed from the water surface, dried before testing. Beams were placed in Universal testing machine under two-point load. On an average three specimens were tested for each series and the average values are reported here. Flexural strength and central deflection was measured at an interval of 2000N and the curves were plotted.

He has drawn the following conclusions from the study

1. Jute can be effectively used as a reinforcing material in concrete.
2. Jute also improves the ductility of plain concrete.
3. Jute enhances the flexural strength of concrete. The flexural strength of concrete beams reinforced with jute twines is increased by 100% at ultimate load while for fibrous concrete beams reinforced with jute twines is 121%.
4. The first crack strength and ultimate load strength were both found to be increased with addition of fibres and twines.
5. Jute also improves the load carrying capacity of concrete. For concrete beams reinforced with jute twines the load carrying capacity increases (12.2% to 30%) at ultimate load while for fibrous concrete beams reinforced with jute twines is (19.3% to 37.3%).

Siddique and Karanbir singh [1999] has conducted an experimental investigation on effect of san fibre on the impact strength of high fly ash concrete. In this experimental investigation the effects of replacement of cement (by mass) by three percentages of high fly ash, and the effect of addition of san fibres on the impact
strength of high fly ash concrete was investigated. Cement was replaced by mass with 40, 45 and 50% of fly ash content. Four percentages of san fibres (0.25, 0.50, 0.75 and 1.00%) of 25 mm in length were used in the investigation. The impact strength tests have been performed on sheets measuring 500 x 500 x 30 mm by using drop-weight method at the end of 28 and 90 days of curing.

They have drawn the following conclusions from the investigation

1. There is tremendous increase in impact strength at ultimate failure both at 28 and 90 days of high fly ash concrete with the addition of san fibres. Strength is found to increase with the increase in percentage of fibres. With the addition of fibers, there is 1 to 3 times increase in the impact strength at 28 days, the maximum occurs with 40% fly ash and 1.00% fibres, whereas the increase is 1 to 4.5 times at 90 days, the maximum is with 40% fly ash content and 1.00% fibre content.

2. Variation of san fibre concentration has no effect on the initiation of first crack.

3. With the increase in fibre concentration, the failure mode of high fly ash fibre reinforced concrete transformed from sudden brittle to gradual increase in multiple cracking and localized crushing.

Singhal [1999] has conducted an experimental investigation on effects of chloride environment on steel fibre reinforced concrete. This experimental programme was carried out to investigate the behaviour of steel fibre reinforced concrete (SFRC), when it is exposed to aggressive chloride environments by curing it in sodium chloride solutions after 24h of casting.

Based on the experimental investigation he has drawn the following conclusions

1. Ordinary cement concrete, when exposed to chloride environment in 24 h of casting, has a lower compressive strength than referral concrete cured in potable water at all the ages.

2. Addition of fibres is effective in retaining the strength of concrete to a significant extent in aggressive chloride environment.

3. SFRC exposed to aggressive chloride environment suffers lesser leaching out of soluble compounds and also lesser ingress of chlorides. Steel fibres decrease chloride diffusivity in the concrete.

4. SFRC maintained a better alkalinity than PCC at relatively lower chloride salt concentrations and thus fibres are more effective in SFRC against corrosion from the point of maintenance of alkalinity.
Thirugnanam and Govindan [1999] have conducted an experimental investigation on influence of high performance fibre reinforced concrete in hinged zones of flexural members. This experimental investigation explores the structural use of HPFRC and presents the effect of this material in selected fuse locations of the flexural members subjected to central point cyclic loading. The test results were compared with that of conventional reinforced concrete beams subjected to similar type of loading and important conclusions they have drawn are:

1. The first crack load has been increased by 33% by adding SIFCON in the hinged zones of RC beams.
2. The ultimate load carrying capacity of RC beam was not affected by adding SIFCON in the hinged zone.
3. The cumulative ductility of RC beam was increased by 150% by simply adding SIFCON in the hinged locations of the beam.
4. The cumulative energy absorption capacity of the SIFCON (H) beam was 1.4 times that of RC beam.
5. The first crack load of SIFCON beam was 2 times that of SIFCON (H) beam the ultimate load carrying capacity of SIFCON beam was 1.4 times that of SIFCON (H) beam.
6. The cumulative ductility of SIFCON beam was nearly equal to that of SIFCON (H) beam.
7. The cumulative energy absorption capacity of SIFCON beam was 1.5 times that of SIFCON (H) beam.
8. The test results show the advantages of using steel fibrous concrete in the hinging zones of flexural members subjected to cyclic loads. The result of this test conclusively shows that better performance can be derived with respect to stiffness, cracking resistance, ductility and energy absorption characteristics.
9. From the above study it is concluded that the presence of HPFRC in the selected fuse locations, satisfies the requirement of high strength and ductility, which are essentially needed for earthquake resistant structures.

Vasan et al., [1999] have conducted an experimental investigation on structural behaviour of high strength SFRC pavements. In this investigation a comparative study on high strength concrete (HSC) and high strength with steel fibre reinforced concrete (HS-SFRC) were conducted. The strength characteristics like compressive strength, flexural strength, impact strength, and modulus of elasticity were estimated for two mixes.
The plate load tests on 250 mm thick HSC pavement laid over 150 mm water bound macadam (WBM) and, 150 mm thick HS-SFRC pavement laid over the same type of base were conducted.

They have drawn the following conclusions from the study

1. The design of HS-SFRC mix may be carried out using the ACI method of mix design as the conventional methods are for mixes up to the strength of 40 N/mm².

2. During the construction of the slab, the workability was adequate, the slump being 20 mm for HSC and 14 mm for HS-SFRC (0.5 percent fibre volume). The HS-SFRC slab could be conveniently laid and no balling of fibres was observed. This establishes feasibility of its use in airfield pavements.

3. The compressive strength of HS-SFRC was found to be 44.3 N/mm² as compared to 32.37 N/mm² for HSC. Hence the incorporation of fibres up to 0.5 percent leads to an increase in compressive strength by 37 percent. Similarly, the flexural strength registered an increase of 21 percent.

4. By analyzing the number of blows at failure, the impact resistance of HS-SFRC was found to be 484.18 kN-mm, 8.0 times more than that of HSC.

5. The HS-SFRC exhibited a modulus of elasticity of $3.39 \times 10^4$ N/mm² as compared to $2.69 \times 10^4$ N/mm² for HSC, an increase of 26 percent. These results indicate that the HS-SFRC pavements have the advantage of extended life because of better fatigue and impact resistance capacity, increased spacing of joints and higher resistance to spalling and cracking.

6. The observed deflections in HS-SFRC pavements slab are quite small as compared to the limiting deflection of 21.5 mm. The maximum deflections observed in HS-SFRC slab were 1.23 mm for central, 2.80 mm for edge and 7.03 mm for corner region, as compared to 1.76 mm, 4.34 mm and 7.90 mm for HSC slab in corresponding regions respectively.

7. The ultimate load carrying capacity of HS-SFRC slab determined by analytical method was 290 KN at centre, 245 KN at edge and 150 KN at corner.

8. The cost of the HS-SFRC pavement slab, designed and checked by experimental investigation was found to be 98.2 percent of the cost of HSC slab. The extra cost of fibres is well compensated by the possible reduction in the section.
Abdeldjelil Belarbi and Huanzi Wang [2000] have conducted an experimental investigation on bond-slip response of FRP reinforcing bars in fiber reinforced concrete under direct pullout. In this experimental investigation the results of a subtask dealing with the bond behavior hybrid reinforcing system under monotonic direct pullout tests were studied. Bond behavior was studied with 27 pullout specimens. Short fibers, bar surface and embedment length’s effect on bond characteristics were investigated.

Based on the experimental investigation they have drawn the following conclusions

1. The addition of polypropylene fibers did not increase the ultimate bond strength, while providing much more ductile bond behavior.

2. Totally different bond mechanisms were observed for CFRP and GFRP due to their different surface treatments. Bond strength decreased with increasing of embedment length for GFRP rebars, while opposite results were observed for CFRP.

3. Bond value corresponding to 0.050 mm of free-end slip was recommended as designing bond strength. The proposed equation agrees with the current equation proposed by ACI 440.

Bhupinder Singh [2000] have conducted an experimental investigation on structural characteristics of flyash-steel fibre reinforced concrete. In this experimental investigation the effects of flyash on steel fibre reinforced concrete were studied when added in different percentages.

Based on the experimental investigation they have drawn the following conclusions

1. The 5 percent flyash by weight of cement can be added in fibrous mix to improve characteristics like bleeding, permeability, resistance to weathering action and in fact durability itself, without affecting its strength.

2. Up to 20 percent cement-flyash replacement in fibrous mix reduction in modules of rupture values observed were 7.00, 7.60 and 8.80 percent for fibre content of 0.50, 1.00 and 1.50 percent respectively, corresponding ultimate shear strength reduction were 8.7, 7.6 and 8.10 percent reduction in compressive and split tensile strength observed were 7.90 and 8.20 percent respectively. These reductions are within permissible limit. The reductions were not found within permissible limits for 20 to 40 percent cement-flyash replacement. Hence in fibrous concrete replacement of cement with flyash up to 20 percent by weight can be made without much harmful effects on its strength.
Gupta et al., (2000) conducted Impact test on fibre reinforced wet mix. It is known that shotcrete is often subjected to impact and dynamic load. Ten different commercially available shotcrete fibres were investigated in wet-mix shotcrete. The ten fibres included: four deformed steel fibres, two straight polypropylene fibres, one crimped polypropylene fibre, two straight carbon micro fibres and one deformed polyvinyl alcohol (PVA) fibre. The mixes were shot onto wooden forms (600 x 500 x 100mm) with fibre volume fraction of 10 to 60 kg/m³, and eight beams (100 x 100 x 350mm) were sawn after demoulded and cured for 28 days. Four beams were tested under impact loading with 60kg hammer dropped from a height of 0.45m, producing potential energy of 266J and velocity of 2.97m/s. The remaining four beams were tested under static loading with a circular 100mm diameter-loading cylinder and all four edges were supported on a rigid support frame. The results showed that, fibre reinforcement in wet-mix shotcrete improves the fracture energy absorption and toughness under impact loading. However, the improvement does not happen under static conditions. Furthermore, Gupta et al concluded that wet-mix shotcrete is highly sensitive to the rate at which load is applied.

Iliff and Ramadevi Dhanshekar [2000] have conducted an experimental investigation on water permeability of concrete by means of the constant flow method. Their report lists a number of methods that can be used to determine the water permeability of concrete. The concrete sample had a w/c ratio of 0.4 and contained 92 ml of water-reducing admixture. This was to ensure the slump and workability of the mix was within an acceptable range. The mix ratio for the concrete was similar to the nominal concrete previously tested with a w/c ratio and the test results of the permeability compared with the co-efficient found by testing completed by Mark Lucy, 2003.

From the investigation they have drawn the following conclusions

1. From the results, it is evident that the concrete sample has a very low coefficient of permeability. The daily readings taken were fluctuated quite dramatically over the course of the 24-day test duration. A 3mm constant drop in the manometer was used to calculate the coefficient of water permeability for the tested concrete sample, as it was the most common reading.

2. Once the testing had finished, the sample was broken in half to check if the concrete was saturated. It was discovered however that the water had only penetrated an average of approximately 10mm. It is
therefore assumed that given extra time to continue the testing, the sample would have been saturated and constant flow would have occurred.

3. Darcy's equation was used to evaluate the coefficient of permeability with the constant drop in the manometer and it was determined to be $0.09 \times 10^{-10}$ cm/sec. Furthermore, Mark Lucy, another Central Queens land University graduate, tested a nominal concrete with the same mix ratio and a water/cement ratio of 0.5. He obtained a coefficient of water permeability using the constant flow method of $0.179 \times 10^{-10}$ cm/sec. Both of these values fit between the ranges of $0.01 \times 10^{-10}$ to $0.5 \times 10^{-10}$ cm/second that was found as acceptable coefficients for permeability. It was established therefore that the lower value for the coefficient came from the concrete containing the admixture.

Jamal Shannag and Will Hansent [2000] have conducted an experimental investigation on tensile properties of fibre-reinforced very high strength DSP mortar. In this experimental investigation the tensile behaviour of fibre-reinforced densified small particle (FR-DSP) cement containing high volume fractions of steel fibres (more than 2%) and main reinforcement (1-3%) in direct tension were considered. Approximately 30 tensile plate specimens were made. Parameters investigated include a very high strength cement-based matrix with a compressive strength of more than 150 MPa, fibre volume fraction within the matrix, and main reinforcement ratio.

They have drawn the following conclusions based on the experimental investigation.

1. Increasing the fibre volume fraction up to 6% within the DSP composites doubled the matrix tensile strength.

2. A significant improvement in total tensile strain capacity and ultimate strength of FR-DSP was obtained as a result of adding high fibre volume fractions (>2%) of discrete, discontinuous steel fibres and a minimum of 1 % as a main reinforcement.

3. The behaviour of a very strong and brittle material such as DSP can be transformed into a ductile one by incorporating 6% of fibres and 1 % of main reinforcement near the specimen edges.

Jun Zhang et al., [2000] have conducted on Experimental study on crack bridging in FRC under uniaxial fatigue tension. In this investigation the study on crack bridging in steel-fiber-reinforced concrete (SFRC) materials under deformation-controlled uniaxial fatigue tension were considered. Two types of
commercially available steel fibers, straight steel fiber and hooked end steel fiber was used separately in this experimental investigation. A total of six series of fatigue tensile tests with constant amplitude between maximum and minimum crack openings were conducted. The experimental results show that the bridging stress decreases with the number of load cycles, and this phenomenon is termed bridging degradation. The general behavior of the bridging degradation with the number of cycles in SFRCs is represented by a fast dropping stage (reduction in bridging stress within the first 10-15 cycles) with a decelerated degradation rate, followed by a stable stage with an almost constant degradation rate for straight SFRC, or by several periods with a decelerated rate in each period for hooked SFRC. Although fiber deformation, such as in hooked end fiber, can improve the monotonic crack bridging significantly, faster bridging degradation is found in hooked SFRC than in straight SFRC with the same maximum crack width (0.1 mm) and minimum load condition.

The crack bridging behavior of SFRC materials reinforced with two types of commercially available steel fibers, smooth and hooked-end respectively, were investigated in the present study under uniaxial fatigue tensile load with constant amplitude between minimum and maximum crack widths. Based on the experimental investigation they were drawn the following conclusions

1. The crack bridging in SFRC materials degrades with the number of cycles under deformation controlled fatigue tensile load. The behavior of crack bridging degradation in SFRC is a fast dropping stage (within the first 10-15 cycles) with a decelerated degradation rate followed by a stable stage with an almost constant degradation rate for SSFRC or by several periods with a decelerated rate in each period for HSFRC. Faster bridging degradation is found in HSFRC than in SSFRC with the same maximum crack width and minimum load condition, particularly in the cases of maximum crack widths - 0.1 mm. For SSFRC, the maximum bridging stress degradation occurs close to the full-debonding point of all fibers. Before this point, the stress degradation increases with maximum crack opening, and after that it decreases. For HSFRC no peak degradation is found in the present investigated range of maximum crack width from 0.05 to 0.5 mm because the hook has not been totally degraded before the maximum crack width <0.5 mm. The larger the maximum crack width, the larger the bridging degradation.
2. The largest reduction on crack bridging stress in SSFRC and HSFRC can be >50 and >80% of the values at the first cycle after 10 cycles within the experimental range (i.e., the maximum crack openings between 0.05 and 0.5 mm).

3. Although the fiber deformation, such as hooked end fiber, can improve the monotonic crack bridging of SFRC materials significantly, this mechanical action offered by hooks will also increase the elastic slippage of fibers during fatigue loading, which in turn speeds up the bridging stress degradation. This influence becomes more pronounced with the increase of maximum crack width.

Krishna moorthy, et al [2000] conducted an experimental investigation on durability characteristics of SFRC. This investigation carried out to find the influence of corrosion of steel fibres on the strength and toughness characteristics of steel fibre reinforced concrete (SFRC). The specimens were subjected to accelerated corrosion by continuous wetting in salt solution and subsequent drying. It is found that there was no corrosion of steel fibres embedded in concrete even after exposure to 250 cycles of corrosion. Galvanostatic studies were also conducted on rebars embedded in fibre reinforced concrete to study the effectiveness of steel fibres in controlling the cracking and the rate of corrosion of rebars.

Based on the results of tests on the SFRC specimens, which were exposed to accelerated corrosion, they have drawn the following conclusions

1. Steel fibres at or near the surface of the specimens corroded causing brown stains on the surface.

2. Even though brown stains were noticed on the surface of the SFRC specimens, both flexural strength and toughness characteristics of SFRC were not affected.

3. The fibres inside the concrete matrix did not corrode at the end of 250 cycles of accelerated corrosion, thereby indicating that SFRC would withstand corrosion-causing environments and exhibit better durability characteristics.

4. Addition of steel fibres in concrete matrix having rebar resulted in decreased crack width when compared with companion reinforced concrete specimens. Weight loss in HSD bars due to corrosion in the case of SFRC specimens was less when compared with reinforced concrete specimens. It is also noted that addition of steel fibres in reinforced concrete results in delayed cracking of concrete.
Therefore, steel fibres in Reinforced Concrete enhance the integrity of concrete and offer increased resistance to corrosion.

Rehsi et al. [2000] have carried out the study on accelerated testing of 28-day Strength of Concrete. The conclusions reached were as follows. The accelerated test procedure recommended by the British Accelerated Testing Committee can be adopted to predict 28-day strength and control the quality of concrete. As a check the strength of concrete cured in water for 28 days may also be determined from time to time. The experience gained and data on accelerated test strength and 28 days water cured strength obtained by various construction departments, in due course of time would not only give confidence but could also form the basis of developing a national standard on the subject.

Victor (2000) has studied on large volume, high-performance applications of fibers in Civil engineering. In this article author presents an overview of fiber applications in cementitious composites. The fiber reinforced cementitious materials in particular was described. Current FRC applications were summarized, and the where, how, and why fibers were used in these applications, was documented. The R & D and industrial trends of applying fibers in enhancing structural performance were depicted. An actual case study involving a tunnel lining constructed in Japan in given to illustrate how a newly proposed structural design guideline takes into account the load carrying contribution of fibers. Composite properties related to structural performance were described for a number of FRCs targeted for use in load carrying structural members. Structural applications of FRCs were currently under rapid development. In coming years, it is envisioned that the ultra-high performance FRC with ductility matching that of metals, will be commercially exploited in various applications. Highlights of such a material are presented in this article.

He has drawn the following conclusions based on the review:

1. A wide range of current concrete elements and products take advantage of a variety of properties offered by FRCs. Although some aspects of mocha meal-performance improvements are achieved, most of these current applications involve concrete elements that are not designed as load-carrying structural members. Nevertheless, new applications of FRCs are continuously uncovered worldwide.

2. Laboratory research has demonstrated that fibers can lead to enhancements in structural performance. Structural members loaded in bending, shear, torsion, and compression show improvements in struc-
ural capacity and ductility. However, the laboratory investigations are usually limited to steel fibers and field demonstrations are lacking.

3. The degree to which fibers are effective in structural enhancements depends not only on the FRC properties themselves, but also on the amount of conventional steel reinforcement present. Fibers are particularly effective in applications in which conventional steel reinforcement is difficult or undesirable. Fibers can be used structurally to replace steel, such as stirrups, or to reduce steel congestion in structural elements designed to withstand seismic loads. However, in some structural elements, the synergistic interaction between fibers and conventional reinforcement and strategic location of FRC in the member can lead to significant enhancements in structural performance.

4. The design of concrete structures using FRC having just begun remains largely to be explored. The design process must take into account the proper load-carrying capability of fibers. This will also allow characterization of fiber, interface, and concrete properties optimal for structural performance.

5. Structural members, whether cast-in-place or precast are emerging as the next target for fiber application. Structural performance demand, demonstrated effectiveness of fiber reinforcement, and continuously improved FRC properties, combined to guide industry leaders to adopt FRC as a structural material. Global competition among construction companies, among precast products producers (which may take the form of competition between concrete-versus-steel or plastics products), and demand for more durable and safe infrastructures, will continue to exert pressure for new concrete with properties not available without fiber reinforcements. Advanced FRCs will be needed for both new and repaired infrastructures.

6. Current high-performance FRCs targeted at structural applications tends to involve a high-volume fraction of steel fibers. The potential of other fiber types such as synthetic fibers and carbon fibers are under explored.

7. Pseudo-strain-hardening cementitious composite with high tensile ductility could eventually become economically competitive for use in structural members. With the drastically different (but improved) mechanical properties, structural design procedures will also need to be modified to take proper advantage of this material.
8. The building and construction industry has very high sensitivity to material cost. Introduction of fibers into concrete must therefore bring about significant improvements in structural performance. Systematic material optimization—using the minimum amount of expensive material for maximum structural enhancement, rather than empirical trial-and-error approach, should provide the most direct path to satisfying the required benefit/cost ratio in this industry.

9. The successful introduction of carbon and PVA fibers into concrete elements in Japan appears to have benefited from a strategic alliance between fiber producers and constructed facilities providers. This creates a healthy feedback loop on end-user needs and fiber characteristics engineering. Strategic alliance should be particularly helpful in new market penetrations.

10. With improved understanding of the link between fiber characteristics and composite/structural performance based on micro-mechanics, the opportunity for tailoring of fibers for use in the high-volume construction market exists, particularly for load-carrying structural systems.

Ganesan et al., [2001] have conducted an experimental investigation on effect of polymer and steel fibres on the strength and ductility of confined concrete columns. In this experimental investigation the combined effect of polymer and steel fibres on the strength and ductility of confined reinforced concrete specimens subjected to uniaxial monotonic and cyclic compression were studied. The polymer considered in this investigation was natural rubber latex. A total number of 128 cylindrical specimens, 16 column specimens and 10 beam-column joints were cast and tested until failure. The main variables considered in this study include the volumetric ratio of confinement, volume fraction of steel fibres and the percentage of dry rubber content.

Based on the experimental investigation, they have drawn the following conclusions:

1. An increase in volumetric ratio of the transverse reinforcement has resulted in the increase of ultimate strength. However the percentage increase in strength is more in the case of confined latex modified steel fibre concrete (15 to 40%).

2. Incorporation of steel fibres and latex modification of confined concrete improve the strain at peak load significantly (1.5 to 4 times).

3. By choosing a proper combination of volumetric ratio of confinement, volume fraction of fibres and percentage of dry rubber content the overall engineering properties of conventional concrete like
strength, strain at peak load, ductility etc. could be improved. This study reveals that the combination with $P_s = 5.43\%$, $V_r = 1.0\%$ and $L_p = 0.5\%$ has been found to be optimum for the range of variables considered in this study.

4. The addition of latex to confined concrete columns has no significant effect on strength and strain at peak load. However the inclusion of both latex and steel fibres improve the above said properties markedly.

5. Additions of steel fibres and latex, to the core of the conventional reinforced concrete beam-column joint region improve the strength and ductility of the joint.

6. By using latex modified steel fibre reinforced concrete, the spacing of hoops provided in the core of the beam column joint can be increased while maintaining ductile behaviour of the frame. This reduces congestion of reinforcement in the joint and hence eases construction difficulties.

7. Apart from the improvement in strength and ductility noticed, the other aspects like integrity and dimensional stability could be achieved by the addition of steel fibres and latex to the confined reinforced concrete.

Jun Zhang and Victor [2001] have carried out a study on influence of fibre on drying shrinkage of fibre reinforced cementsations composite. The conclusions reached were as follows

1. With the same fibre content and fibre geometry, the higher the moduli ratio between fibre and matrix, the smaller the composite. Shrinkage.

2. The elastic modulus fibres are more effective than those with low elastic modulous regarding composite shrinkage reduction.

3. The fibre aspect ratio is an important material parameter that strongly influences the composite shrinkage behaviour. For the same fibre content, composite shrinkage decreases non-linearly and gradually shifts to a constant with an increase in the fibre aspect ratio.

4. A critical fibre aspect ratio exists regarding a composite shrinkage reduction, and a further increase in the fibre aspect ratio beyond this critical value does not contribute to reducing the composite shrinkage.

Lai Segio [2001] has conducted an experimental investigation on estimation of frost resistance of fiber reinforced concrete. This experimental investigation was conducted to determine the freezing-and-thawing
resistances of fibre reinforced concrete with polypropylene fibres containing micronised silica. The tests were conducted in accordance with ASTM C-666 procedure a modification and UNI Standard 7087-72. Particular attention was focused on the prediction of freeze-thaw resistance on the basis of tests of short duration.

Based on the experimental investigation he has drawn the following conclusions:

1. Results of the freeze-thaw testing accordance with UNI Standard and ASTHC-666 procedure a modified on rectangular specimens shows in general that after 30 cycles with the UNI standard test, not only is there no decline in elastic-dynamic modulus but also there is even a slight improvement.

2. After 300 cycles the reduction inelastic modulus fluctuates between 22 and 44 % (plain concrete) and between 14 and 28 % (conglomerates modified with microsilica and poly propylene fibers). A drop of about 5 % (HC 30B), 6 % (HC 30A), 8 % (HC50B) and 10 % (HC50A) after 30 cycles. The plain concrete pronounced reduction. Controls obviously exhibit a more. The concretes containing microsilica and polypropylene fibers exhibited a comparable decline in compressive strength and elastic-dynamic modulus with the UNI Standard test and that proposed here (14-28%, against 5-10%, with a ratio of 3/1).

Luo et al., (2001) studied and conducted test on the Mechanical properties and resistance against impact on steel fibre reinforced high-performance concrete. Five different geometry of fibres included steel-sheet-cut fibres and steel ingot-milled fibres with four fibre volume fractions (4%, 6%, 8% and 10%) were applied into the mix. Beams (100 x 100 x 400mm) and cubes (100 x 100 x 100mm) were casted. The projectiles used in the test were armor penetration projectiles with diameter of 37mm and weight of 0.9kg. The projectile was launched at a high velocity between 365m/s and 378m/s. The investigation shows that increase in fibre percentage improves the mechanical properties, where compressive strength and flexural strength peak reached 140MPa and 80MPa, respectively increased 61% and 774% compared to specimens containing no fibres. In impact test, the specimens containing no fibres were smashed up and steel fibre reinforced high-performance concrete were kept intact with some radial cracks developed in front faces and minor cracks in side faces. Fatigue is an important consideration with regard to the durability of thin concrete repairs. Repeated loading and restrained shrinkage can cause damages and debonding of repair layer.
Nattraja and Dhang [2001] have conducted an experimental investigation on splitting tensile strength of SFRC. The primary objective of the experimental investigation was to study the behaviour of steel fibre reinforced concrete (SFRC) cube in a splitting test. Equations were proposed, based on the linear regression analysis, to correlate splitting tensile strength with the fibre-reinforcing index. Linear relations between the splitting tensile strength and the flexural tensile strength, and splitting tensile strength and compressive strength were also proposed. The experimental data provides an encouragement for a wider acceptance of this testing method, as it is a reliable and an economical test for determining the tensile properties of SFRC.

Based on the above experimental investigation they have drawn the following conclusions

1. Addition of steel fibre in concrete increases the splitting tensile strength significantly. This increase is proportional to the reinforcing index, which is defined as the product of weight fraction and the aspect ratio of the fibres. An increase of about 32 percent in splitting tensile strength was observed for a reinforcing index of 2.67.
2. Based on the linear regression analysis, equations were fit to represent the effect of fibre addition on splitting tensile strength as a function of reinforcing index.
3. Splitting tensile strength was 0.67 times the flexural tensile strength for crimped fibres for compressive strength up to 50 MPa.
4. Splitting tensile strength was 0.09 times the compressive strength for crimped fibres for compressive strength up to 50 MPa.
5. Based on the splitting tensile strength of plain concrete, an estimate of the splitting tensile and flexural tensile strength of SFRC can be made from the knowledge of fibre properties (reinforcing index).
6. Splitting tension test was found to be simple and economical which adequately describes the performance of SFRC and can be considered as a viable alternative to the flexural test where simple beam reparation or flexural testing equipment is in question.

Singh and Dhirendra Siaghal [2001] have conducted an investigation on effect of cement and fibre contents on permeability of SFRC. Investigation was carried out to study the effects of fibre and cement contents on permeability of SFRC using plain fibres. Simultaneously, compressive and tensile strengths were also determined in order to establish a relationship between permeability and strength parameters. Three design mixes
were used in this study. Plain steel fibres having an aspect ratio of 85 and a length of 46 mm were used. 43-grade ordinary portland cement including all other materials testing were satisfy the codal requirements. Cube samples of concrete were cast and tested after 7, 14, 28, and 60 days of curing. Permeability tests were conducted using permeability test apparatus as per the procedure prescribed in IS: 3085-1965. Equations correlating the permeability with age of curing and the fibre content have also been developed using regression analysis.

From their investigation they have drawn the following conclusions

1. Addition of steel fibres in to concrete resulted in significant decrease in permeability due to arrest of plastic shrinkage cracks.
2. The decrease in permeability with addition of fibres continued with increasing weight fractions of fibres but the effect was more pronounced at 1.0% weight fraction.
3. The permeability of SFRC as well as PCC decreased with increasing cement content.
4. The fibres were found to be more effective in reducing the permeability than in increasing the compressive as well as tensile strengths.

Thirugnanam et al., [2001] have conducted an experimental investigation on ductile behavior of SIFCON structural members. This work highlights the structural uses of SIFCON and presents the effect of using this material in the hinging zones of the multi-storey frames subjected to cyclic loading.

From the experimental investigation they have drawn the following conclusions

1. The use of SIFCON, in the hinging zones of RC structures, increases the first crack load by 40%.
2. The cumulative ductility has been increased by 100% by incorporating SIFCON in the hinged location
3. Energy absorption capacity is found to increase by 50% by adopting SIFCON in the selected fuse locations of the RC structures.
4. The presence of steel fibres helps in reducing the crack widths and causes lesser damage to the structure than that of RC specimens

Ziad Bayasi and Henning Kaiser [2001] have conducted an experimental investigation on steel fibres as crack arrestors in concrete. This experiment investigates the cracking behaviour of steel fibre reinforced concrete (SFRC). Concrete mixtures containing steel fibres in volume fractions \( V_f \) of 0, 0.5, 1.0, and 2.0 percent were investigated. Three beam specimens in each volume fraction were subjected to four-point loading,
utilising linear variable differential transducers (LVDTs) to measure crack width and deflection. Test results indicated that the incorporation of steel fibres significantly enhanced the cracking behaviour of concrete. Steel fibres increased cracking closure stress for constant crack width. Furthermore, for a constant closure stress, increasing steel fibre volume allowed for significant increase in crack width, thereby effectively enhancing material toughness. It was also found that flexural stress increased with an increased fibre content, which improved material damage tolerance.

Based on the experimental investigation they have drawn the following conclusions

This experimental investigation has investigated crack widths and flexural behaviour of SFRC. Different samples were tested, each with different fibre content, ranging from 0 to 2 percent by volume. Crack widths and mid span deflections were automatically measured and stored during the test. Such observations have shown that an increased amount of steel fibres improves the crack arresting capacity of concrete and increases the closure stress at constant crack width, thereby, significantly enhancing the energy absorption capacity. Furthermore, at constant crack width, higher stresses can be reached by increasing the amount of steel fibres. Finally, it was found that the stress-deflection capacity was improved - with an increase of fibre content.

Athel E Allos [2002] have conducted an experimental investigation on shear transfer in fibre reinforced concrete. In this experimental investigation the influence of conventional reinforcement on the shear capacity or reinforced concrete structures and shear transfer capacity of steel fibre reinforced concrete (SFRC) was investigated with the use of both straight and hooked end steel fibres. The research programme consisted of testing 113 push-off specimens under the combined action of direct compression and shear. The effect of different fibres and different volume fractions of fibres on the failure envelope were reported. They have drawn the following conclusions based on the experimental investigation.

1. The shear transfer capacity of concrete can be increased to about 60% of the concrete compressive strength by the addition of steel fibres. This value is about twice the shear capacity of specimens with very low fibre content.

2. An empirical equation is presented to predict the shear transfer strength of fibre reinforced concrete when subjected to zero normal stress. This equation was found to be best related to the fibre parameter.
3. The shear transfer capacity was observed to increase to a maximum value when subjecting the specimens to a normal compressive stress of about 40% of the compressive strength.

4. The effect of normal compressive stress on the shear transfer of fibre reinforced concrete can be well represented by applying the internal friction theory.

Bindiganaville and Banthia [2002] have conducted experimental investigation on some studies on the impact response of fibre reinforced concrete. The two major variables considered in this experimental investigation related to impact loading on plain and fibre reinforced concrete were studied. 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).

They have drawn the following conclusions from the experimental investigation:

1. For cement-based materials, the measured impact response is highly dependent on the characteristics of the drop-weight impact machine used for testing. The pulse duration was found to depend upon the drop weight, with greater drop-heights leading to shorter pulses. Results appear to be far less sensitive to the mass of the hammer than to the drop-height. This observation forms a useful basis for standardizing impact testing of plain and fibre reinforced concrete. Results from two different machines with varying hammer masses can be compared if the drop-heights were identical.

2. Crimped polypropylene fibre is less effective than steel fibre at 'quasi-static rates of loading. However, a higher stress rates, it performed better than the steel fibre. This switch in the behaviour of FRC is attributed to the greater strain rate sensitivity of polypropylene vis a vis steel.

Gargett and Dhanasekar (2002) have conducted an experimental investigation on Steel fibre reinforced concrete (SFRC) exposed to sea water. In this experimental investigation Specimens of SFRC were fabricated and exposed to either plain water, or seawater. The dye penetration method was to be used to determine the depth of infiltration of the seawater. This was to involve the use of a planimeter to determine the average depth of infiltration of the red dye.

Based on the experimental investigation they have drawn the following conclusions:
1. As discussed above, the specimens involved in this project demonstrated no infiltration of water, as displayed by the presence of red dye on the internal surface. As shown in the digital photographs, the red dye only penetrated into the concrete to the depth of external voids, causing the external surface to be redder over time. This demonstrates that the porosity of this concrete is limited to the depth of the greatest pore depth.

2. Steel fibre is often used in concrete for its high strength, and it may have also resulted in a low permeability for the concrete and its good condition, as the steel fibre held a good bond with the concrete mix even when split under force.

3. It can also be seen from the various internal surface photographs (one included previously) that there is very little voids in this concrete. This relates to low porosity and therefore permeability of the concrete, as there is no network of voids for the water to travel easily through the concrete. Due to this, no true comparison can be made between the differences in impact of exposure in terms of plain or seawater.

4. This shows that the concrete mix used is durable over the specific exposure times and conditions, including full immersion, partial immersion, and air and oven dry which model wet and dry cycles in the splash zone.

5. It is also accepted that if this concrete were used in a structure, one would not expect any level of infiltration over the relatively short exposure time experienced in this project.

Julie Rapoport et al. [2002] have conducted an experimental investigation on permeability of cracked steel fiber-reinforced concrete. This research work explores the relationship between and crack width in cracked, steel fiber-reinforced concrete. In addition, it inspects the influence of steel fiber reinforcement on concrete permeability. The feedback-controlled splitting tension test is used to induce cracks of up to 500 microns in concrete specimens without reinforcement, and with steel fiber reinforcement volumes of both 0.5% and 1%.

From the investigation they have drawn the following conclusions

1. Cracks were induced to a specified crack mouth opening displacement (CMOD). The cracks then relaxed somewhat once they were unloaded. The unreinforced concrete (no steel fibers) shows the most crack relaxation where the cracks relax by about 62% on average. The cracks in the concrete with steel fibers seem to relax less, with an average relaxation of about 55%. This indicates that the fiber-
reinforced concrete under goes more inelastic (unrecoverable) deformation than the unreinforced concrete.

2. Two specimens in each test series were cracked to each specified CMOD. The cracks relaxed and the samples were tested. (The final CMOD after relaxation for each crack level was quite close for each treatment. The difference in CMOD of relaxed cracks was generally no more than 5 microns for the 100 micron cracks and 20 microns for the cracks larger than 100 microns). The data each test series are the first is that, at higher levels of cracking, steel-reinforcing fibers clearly reduce permeability. Further, the 1% steel fiber test series reduces permeability more than the 0.5% test series. More steel reduces permeability.

Piti Sukontasukkul (2002) have conducted an experimental investigation on fracture of hybrid steel-polypropylene fibre reinforced concrete under direct tension. In this experimental investigation two different fibres, steel and polypropylene, were used to form single-and hybrid-FRC systems at five different volume fractions (1% to 5%).

Based on the experimental investigation he has drawn the following conclusions

1. The tensile behaviour of FRC was found to be different depending on the type and content of fibre, and the selected system (i.e., single fibre, hybrid)

2. Steel fibres seemed to contribute mostly to the first peak strength of FRC; this was because of their high strength and stiffness. They were also able to react to the load more quickly than the polypropylene fibres, as seen by the higher strengths and larger fracture energies at small deflection. However, in the case of steel fibres, once the load pass the peak, most fibres were either pulled out or fractured. As a result of this, a quick drop in load and fracture energy was found right after the peak.

3. Polypropylene fibres, because of their low stiffness, seemed to react to the load more slowly than the steel fibres. It took more deformation to get the polypropylene fibres to start carrying some load. As a result, SP-FRC was not efficient in terms of carrying loads at small deflections. However, at larger deformations, once the fibres started to be mobilized, the load recovery began. Hence, the typical responses of most SP-FRCs were found to be double-peak responses. The second peak happened late at
large deformations and was solely due to the fibres themselves. The polypropylene fibres appeared to contribute more to the toughness (energy absorption) at large deformation after the first peak.

4. In the hybrid systems, there was a more balanced FRC system in terms of both strength and toughness. The hybrid system appears to gain advantages from both types of fibres. It exhibited a higher peak than SP-FRC at the beginning (or small deformation). It was also more ductile indicated by larger fracture energy at 10 mm) than SS-FRC.

5. It could be seen that the efficiency of high content FRC (for both types of fibre) was quite high. This could be the result from the orientation of fibres. With large numbers of fibres and the pre-lay-up casting technique used for high volume FRC, the fibres were likely to orient in the load direction which led to the highly effectiveness of the fibre.

Sekar and Mahendira Pallavan [2002] have conducted an experimental investigation on impact studies on polymer composite. In this experiment the impact behaviour of Kevlar/Epoxy laminated composite square plate (size 250 mm x 250 mm) was investigated. The thickness of the composite plate and the orientation of the kevlar fiber in the plate were altered and the variation of the properties was determined. The Experimental testing consisted of impacting square specimens using vertical drop-weight apparatus. The thickness of the specimen adopted in the study were 2.1mm, 5mm and 7.9 mm and the orientation of the fiber was kept at 0/90 deg and 0/90/45/-45/90/0 degree. The tensile strength of the plates was also found out. The load-deflection curves were arrived at by conducting test on composite plates (simply supported condition, subjected to central concentrated load). From the plot of the load deflection curve, the static stiffness was determined. The acceleration was measured by conducting impact test on the composite specimens.

Based on the experimental investigation they have drawn the following conclusions.

1. Tensile strength increases with increase in thickness of the plate. But within the same thickness class the tensile strength for 0/90/45/-45/90/0 orientation decreases. The percentage decrease of tensile strength is nearly 18.71 % for 2.1 mm thickness, 11.24% for 5 mm thickness and 9.92% decrease for 7.9 mm thickness for changing the orientation from 0/90 to 0/90/45/-45/90/0.

2. The static stiffness of the composite specimen increases as the thickness of the plate increases. Also, for the same thickness class the 0/90/45/-45/90/0 gives a higher value of force. The percentage increase of
static stiffness is nearly 18.65% for 2.1 mm thickness, 24.163% increase for 5 mm thickness and 25.70% increase for 7.9 mm plate thickness for changing the orientation from 0/90 to 0/90/45/-45/90/0.

3. The impact resistance of the specimen is indicated by the acceleration of the specimen due to the impact, which increases as the thickness of the plate increases. Also, for the same thickness class the 0/90/45/-45/90/0 gives a higher value of resistance. The percentage increase of acceleration due to the applied impact load is nearly 38.45% for 3 layers thickness, 16.30% increase for 7 layers thickness and 15.71% increase for 11 layers thickness for changing the orientation from 0/90 to 0/90/45/-45/90/0.

4. Overall results indicate that the specimens having their fibers oriented at 0/90/45/-45/90/0 angles are the best suited for impact resistance.

Srinivasa Rao [2002] have conducted an experimental investigation on fibre reinforced concrete and flyash Composite. In this experimental investigation an attempt was made to study the properties of fibre reinforced concrete with partial replacement of cement by flyash with a view to reduce the cost of concrete and at the same time to study the possibility of having a concrete with superior performance characteristics over plain concrete. The strength variations in fibre reinforced concrete are studied when cement is replaced by flyash up to 60% and volume percentage of fibres up to 1.5%.

Based on the experimental study, he has drawn the following conclusions

1. In general, the workability of FRC is less compared to plain concrete for the same water cement ratio. But with the addition of flyash in the composites the workability of FRC is marginally increased.

2. The compressive strength of plain concrete is decreased with the increase in flyash content in the mix. In the FRC composite, the compressive strength is marginally increased with fibre content. Hence in the case of fibre reinforced flyash concrete the compressive strength can be maintained at the same level.

3. The split tensile strength is decreased with increased flyash concretes. But in FRC, the split tensile strength increases with increased fibre percentages. Hence, practically useful concrete mixes can be prepared even with flyash and by adding a suitable percentage (1.5%) of steel fibre.

4. It is recommended that the flexural strength of concrete mix can be substantially increased even with 25% flyash content by addition of 1.5% steel fibres.
5. The ultimate load carrying capacity of a plain concrete beam is increased by 50% even with 25% flyash content and 1.5% steel fibres.

6. Finally, it may be recommended that by limiting the flyash content in the ranges of 25 to 30% and using steel fibres at a percentage of 1.00 to 1.50% optimum properties can be achieved for concrete beams. At the same time this is also cost effective.

Antolae E. Naaman [2003] have mentioned about engineered steel fibers with optimal properties for reinforcement of cement composites. This paper describes the rational and technical background behind the development and design of a new generation of steel fibers for use in cement, ceramic and polymeric matrices. These fibers are engineered to achieve optimal properties in terms of shape, size, and mechanical properties, as well as compatibility with a given matrix. They are identified as Torex fibers. Typical tests results are provided and illustrate without any doubt the superior performance (2 to 3 times) of Torex fibers in comparison to other steel fibers on the market. The new fibers will advance the broader use of high performance fiber reinforced cement composites in structural applications such as in blast and seismic resistant structures, as well as in stand-alone applications such as in thin cement sheet products.

Based on the comparison he has drawn the following conclusions

1. Increasing the lateral surface area of a fiber or the same cross-section, increases frictional and adhesive bond forces along the fiber and leads to an increase in pull-out resistance and thus in fiber efficiency.

2. In existing art, twisting is the best way to improve the mechanical component of bond of fibers. It preserves the elastic response of the fiber (i.e. elastic modulus) and, with proper design, leads to a pullout load versus slip response with unique slip hardening characteristics (Naaman, 1999).

The other noted Advantages of optimized Torex fibers are

1. Section efficiency advantage: Using simply geometric configurations and a smooth lateral surface, the newly engineered fibers can be up to 300% more efficient than round fibers. 200% efficiency seems attainable immediately with primarily triangular fibers. That is, for the same required composite post-cracking strength and toughness, the volume fraction of triangular fibers will be half that required with round fibers.

2. Twisting Advantage: The bond strength of smooth steel fibers embedded in concrete is generally small and mostly frictional in nature. Most fibers used as reinforcement in cementitious composites, generally are
mechanically deformed to improve their bond and thus lead to improving other mechanical properties of the composite such as strength and toughness. Mechanical deformations include: hooked ends, buttoned ends, indenting the surface, and crimping. Because of the polygonal nature of their optimized fiber section, Torex fibers can be twisted, thus improving their mechanical bond significantly. In extensive experimental tests, the improvement of bond due to twisting is found to be far superior to any other form of mechanical deformation process used to date.

3. Mixing Advantage. Because significantly less-amount of fibers (by volume or weight) is needed to achieve a given composite performance, difficulties encountered in practice in pre-mixing a large amount of fibers are minimized.

4. Compatibility with Prior Art. Plain or twisted polygonal fibers with improved geometry, can also be cramped or have hooks at their ends, similarly to other fibers on the market, should there be need for additional mechanical bond. So far, from observed tests, this does not seem necessary.

5. Extension of concept. The concepts and ideas developed for discontinuous fibers are generic in nature and accommodate metallic and non-metallic materials. They also apply to continuous reinforcing bars as well, and are particularly suitable for fiber reinforced polymeric (FRP) reinforcements used in reinforced and pre-stressed concrete, because they offer better bond properties, i.e. larger fiber intrinsic efficiency ratio (FIER), which translates in better development lengths or transfer lengths.

6. Superior performance. From extensive tests, it seems now possible to develop fiber reinforced cement composites with about half the fiber content and a performance about equal to that obtained with currently available fibers. On the other hand, for the same fiber content, performance with the new Torex fibers is expected to be far superior.

The new fibers will advance the broader use of high performance fiber reinforced cement composites which are characterized by a strain hardening behavior in tension [Reinhardt and Naaman, 1992, 1999, and Naaman and Reinhardt, 1996, 2003]; these composites offer a combination of high tensile strength, ductility and toughness. They are suitable in structural applications such as in blast and seismic resistant structures, as well as in stand-alone applications such as in thin sheet products for housing, claddings for buildings, shells, pipes, and the like. With Torex fibers, the engineering dream that started more than a century ago, to mix fibers with
concrete, like sand or gravel, to achieve a self-sufficient structural material, without reinforcing bars, is closer than ever.

Ashok K Jain and Vasan [2003] have conducted and experimental investigation on effect of elongated aggregate on the flexural strength of steel fiber reinforced concrete. They describe the problems encountered during a recent road pavement project.

Based on the results, they have drawn the following significant conclusions

1. The high strength and high performance SFRC can be achieved by using clean and strong non-elongated gravel aggregate. The flexural strength of PCC using elongated and non-elongated aggregate was 4.3 MPa and 5.4 MPa, respectively. Similarly, the flexural strength of SFRC with 1.25% fibers using elongated and non-elongated aggregate was 6.5 MPa and 7.6 MPa, respectively.

2. The flexural strength of SFRC is very sensitive to the quality of fine and coarse aggregate and balling of fibers. The maximum increase in flexural strength of the SFRC over that of PCC was 70%. Sometimes there was no increase at all in the flexural strength of the SFRC over that of the PCC depending upon the method of mixing of steel fibers, aspect ratio of fibers, volume of fibers and water-cement ratio.

3. The BIS, IRC, BS and ACI specifications clearly state that elongated particles must not be used in concrete work. The project authority must carry out detailed mix design using the locally available aggregate and then only tender specifications should be spelled out in detail.

4. A series of mix trials is essential under the prevailing site conditions before the commencement of the actual production of HPC. It is also necessary to develop a pretender qualification program so that only competent contractors/concrete producers remain serious bidders. This will require a change in the definition of L-1, the lowest bidder.

Desai et al., (2003) have conducted an experimental investigation on mechanical properties of concrete reinforced with AR-Glass fibers. In this experimental investigation two types of concrete mixtures representing a lean mixture and an HPC (High Performance Concrete) mixture were used. Two types of AR Glass fibers High dispersion (HD) and High Performance (HP) with different sizing formulations to help with distribution, bonding and durability were considered. High dispersion (HD) AR Glass fibers of several different lengths were used to evaluate the effect of fibers, which disperse thoroughly throughout the mixture. These were
compared with High Performance (HP) type AR Glass fibers, which maintain the bundle characteristics throughout the mixing and casting and are designed to help with long term strength and ductility. Both mixtures were compared with control specimens without fibers.

Based on the experimental investigation they have drawn the following conclusions

Effect of short AR glass fibers on the strength and ductility of concrete was studied and indicate a potential for reinforcing the concrete material both from an early age property modification and also from the strengthening and toughening perspective. Closed loop testing was conducted to characterize the response of specimens in compression, and flexure. It was observed that concrete with 12 mm HP fibers exhibits higher compressive strength than other fiber lengths. During the early ages, due to the fact that the concrete strength is sufficiently low, fibers contribute to toughening, whereas during the later stages of age, the contribution is mainly in increasing the strength. The ability of AR Glass fibers to provide both strengthening and toughening mechanism for concrete was investigated using an R Curve approach.

Dhirendra Singh et al., [2003] have conducted an experiment on effect of fibre shape on bond strength of SFRC. Experiment was conducted with the aim to find the effects of shapes of steel fibres on the bond strength of SFRC. Three shapes of fibres were used i.e. plain, crimped, and wavy. The aspect-ratio of fibres was 67. Cylinders of size 150 x 300mm of M-20 grade (0.54:1.1:1.73:2.83) mix proportion of concrete were cast with three different fibre contents i.e. 1.55, 3.10 and 4.65 % (by weight). For the reference purpose, cylinders of conventional concrete were also cast. Tor steel bar of 10 mm nominal diameter was embedded to a depth of 150mm at the centre of cylinder. The specimens were tested in surface dry saturated condition on universal testing machine.

From the investigation they have drawn the following conclusions regarding the bond strength and workability to study the effects of fibre shape are

1. Workability reduced with fibre addition and deformations of fibres and minimum slump was observed with wavy fibres at 4.65% fibre content
2. Bond strength increases with the fibre addition
3. The increase in bond strength was observed with wavy fibres as 32.05% at 1.55% fibre content.
4. It is difficult to relate bond strength with fibre parameters when different shapes of fibres are used.
5. Economy can be achieved with the use of deformed fibres

Ganesan [2003] have conducted an experimental investigation on effect of confined polymer modified steel fibre concrete on ductility. From this experiment the effect of confinement, influence of steel fibres and polymers on the strength, strain at peak load and ductility were investigated.

Based on the experimental investigation carried out, he has drawn the following conclusions.

1. An increase in the volumetric ratio of transverse reinforcement increases the ultimate strength of reinforced concrete and SFRC specimens. However, the percentage increase was found to be higher in confined SFRC specimens than in reinforced concrete specimens.

2. Strain at peak load was significantly higher in confined SFRC specimens.

3. For lower levels of confinement in SFRC, there exist equivalent higher levels of confinement in reinforced concrete.

4. Addition of steel fibres and latex to the confined concrete improve the strength, energy absorption capacity and ductility significantly up to a certain value of confinement latex fibre index.

5. Apart from the improvement in strength and ductility noticed in confined polymer modified steel fibre concrete, other aspects such as tensile behaviour, structural integrity and dimensional stability can be achieved by the addition of steel fibres and polymers to confined concrete.

Prakash, K. B. et al., [2003] have conducted an experimental investigation on performance evaluation of mixed (coiled & straight) fibre reinforced concrete containing microsilica-600. In this experimental investigation the effect of microsilica-600 on the mixed (coiled & straight) fibre reinforced concrete were studied. The strength characteristics like compressive strength, tensile strength, flexural strength and impact strength of mixed fibre reinforced concrete with different percentage addition of microsilica-600 were presented. Workability characteristics of FRC were also presented. The effect of addition of super plasticizer was also found on the mixed fibre reinforced concrete.

They have drawn the following conclusions from the observations made in the experimentation.

1. Maximum possible compressive strength, split tensile strength, flexural strength and impact strength is obtained with 10% addition of microsilica-600, for the selected mix proportions.
2. Workability achieved is also maximum for 10% addition of microsilica-600.

3. The addition of super plasticizer has increased the strength of mixed fibre reinforced concrete.

Raghunath et al., [2003] have conducted an experimental investigation on shear capacity of fibre reinforced concrete cored beams. In this experimental investigation ten FRC cored beams of rectangular cross-section with a circular core were tested. The Principal variables were the fibre volume fraction and the shear span-to-depth ratio. The specimens were subjected to two-point loading system and tested to failure. The specimens were properly instrumented to obtain information on the strength and deformation characteristics. The observed results were compared with those obtained analytically.

Based on the experimental investigation they have drawn the following conclusions

1. The shear strength predicted through the proposed equation agreed well with the experimental values.

2. The shear at cracking and ultimate stages is found to increase with an increase in fibre volume fraction.

3. The shear at cracking and ultimate stages is found to increase with a decrease of (X/D) ratio.

4. The incorporation of steel fibres provided an effective reinforcement against shear failure.

Sarvanan and Sekar [2003] have conducted an experimental investigation on flexure impact resistance of steel fiber reinforced concrete using 50-FMC-draft recommendation for impact testing apparatus. The primary variables considered in this experimental investigation were two types of mild steel fibers that are straight and crimped having diameter 40mm length and 0.4mm diameter. Test specimens were cast using two fiber volume fractions, namely 0.5% and 1.0% for each of the two types of fibers (viz., straight and Crimped). Companion specimens in plain concrete were also cast. Tests were carried on M20 and M35 mix with various fiber volume fractions to determine the impact resistance for 7 days, 14 days and 28 days.

Based on the experimental investigation they have drawn the following conclusion

1. Among the two types of fibers, the impact resistance of specimen with straight fibers is found to be considerably higher at all ages (7,14 and 28 days) and for the two volume factions than that of specimens with other type of fibers.

2. With in adequate fiber volume, the failure mode of concrete under repeated impact loadings transformed from sudden brittle failure for plain concrete specimens to gradually increasing multiple cracking, concrete crushing and disintegration for SFRC specimens.
50 FMC draft recommendation impact tidying method used in the present investigation gives a reliable estimate of the impact resistance of concrete composite such as SFRC. Hence, this test device, which is economical, simple and portable, could be used to evaluate the qualitatively and quantitatively the impact resistance of plain and fiber reinforced concrete.

Teesing.D Jemlimah and Jayagopal [2003] have conducted an experimental investigation on permeability studies on steel fiber reinforced concrete and influence of fly ash. The investigation was carried on, to study the permeability of steel fibre reinforced concrete with partial replacement of cement by flyash. Corrugated steel fibres were used and the fibre constant varied as 0%, 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, and 1.5% by weight. Flyash from Mettur thermal plant of Tamil Nadu was used as partial replacement to cement, which was in terms of 0%, 10%, 20%, 30% and 40%. Permeability tests were conducted using permeability test apparatus as per the procedure prescribed in IS: 3085-1965.

From the investigation they have drawn the following conclusions

1. Addition of steel fibres and fly ash results in significant decrease in permeability
2. The permeability of concrete decrease with the increase in fly ash and fibre content.
3. The porosity of concrete also decreases with the increase in fly ash and fibre content.
4. Flyash up to 30% by weight may be used as a replacement to cement for the improving the strength of concrete at the age of 90 days. Maximum compressive, flexural and split tensile strength were observed in the specimens made with 30% flyash.
5. Concrete with partial replacement of cement by 40% flyash had shown improved impermeability characteristics.
6. Therefore it is concluded that considering the strength and durability criteria, steel fibres may be added up to 1.5% by weight of concrete and flyash up to 30% by weight of cement as partial cement concrete.
7. Steel fibres up to 1.5% by weight of concrete and flyash up to 30% by weight of cement as partial replacement may be used for improving the strength of concrete at the age of 90 days. Maximum compressive, flexural and split tensile strength were observed in the specimens made with 1.5% steel fibres and 30% flyash.
8. Concrete with 1.5% steel fibres by weight fraction and characteristics and with partial replacement of cement with 30% flyash had shown improved impermeability characteristics.

9. Steel fibres up to 1.25% by weight may be added to the concrete without flyash for improving the strength at the age of 90 days. Maximum compressive, flexural and split tensile strength were observed in the specimens made with 1.25% steel fibres.

10. Concrete with 1.0% and 1.25% steel fibres by weight of concrete had shown improved impermeability characteristics.

Thirugnanam et al., [2003] have conducted experimental investigation on use of HPFRC in earthquake resistant structures. In this experimental investigation the advantages of using SIFCON (Slurry Infiltrated Fibrous Concrete) in the hinging zones of multi story frames is studied. They have drawn the following conclusions based on the experimental investigation of quarter size, two bays, five story RC frames with and without SIFCON joints.

1. The first crack load has been increased by 40% by adding SIFCON in the beam column joints of multistory frames.

2. The initial stiffness of the frame RSF was 25% higher than that of frame RCF.

3. By introducing SIFCON in the beam-column joints of multistory frames, 80% increase in ductility has been achieved.

4. The cumulative energy absorption capacity has been increased by more than 40% by simply adding SIFCON in the hinged zones of multistoried buildings.

5. The presence of steel fibres helps in reducing the crack widths and causing lesser damages to the structure than that of conventional reinforced concrete frame.

Chandra Sekhar Rao [2004] have conducted an experimental investigation on mechanical characteristics of steel fiber reinforced concrete. In their investigation an attempt was made to quantify the improvement in the compressive strength and tensile strength of the basic matrix with the addition of steel fibres.

Steel Fibres aspect ratio was varied between 50 and 70. The mechanical characteristics at green stage i.e. compacting factor and at hardened stage i.e. compressive strength and tensile strength were determined. For the lower aspects ratios (l/d = 50) the increase in the compressive strength is at uniform state, as the percentage fiber
increases. For the higher aspect ratios \( \text{I/d}=70 \), the compressive strength is increased considerably (more than 20\%) upto 1 \% fiber content and beyond 1 \% fiber content compressive strength decreased. For the lower aspects \( \text{I/d}=50 \) there is considerable increase in the tensile strength as the percentage fiber increases, for the higher aspect ratios \( \text{I/d}=70 \) the increase in the tensile strength is considerably high upto 1 \% fiber content and beyond that increase in the percentage fiber decreased increase in the tensile strength. Workability is reducing with increase in the percentage fiber for aspect ratios of 50 and 70.

From the experimental investigation they have drawn the following conclusions

1. Addition of fibers to the concrete mix improves the compressive strength and tensile strength of the basic matrix to a moderate level.

2. Fiber inclusion decreases the workability of the matrix. However to avoid this suitable admixtures may be adopted.

3. Workability of steel fiber reinforced concrete will be adversely affected with the increase in the aspect ratio of the fiber.

4. Increase in the aspect ratio of the fibers will increase the compressive strength and tensile strength of the matrix noticeably.

Ganesan et al., [2004] have conducted an experimental investigation on flexural behaviour of reinforced concrete beams with confined SFRC in the compression zone. The primary variables considered in the study were: (i) two values of volumetric ratio of confinement, viz.4.22\% and 8.44\% and (ii) three values of volume fraction of fibres, 0.5\%, 1.0\% and 1.5\%. Totally 12 reinforced concrete beams of size 100mm x 200mm x 2000mm were cast and tested with an effective span of 1800 mm.

Based on the experimental investigation, they have drawn the following conclusions

1. In general the strength and ductility of conventional RCC beams can be increased by confining the concrete in the compression zone with either square or circular hoops.

2. Addition of steel fibres to the concrete in the confined compression zone significantly increases the strength and energy absorption capacity. The addition of steel fibres does not seem to increase the strength of specimen significantly. However ductility was found to increase considerably with the increase of volume fraction of fibres.
3. The inclusion of steel fibres in the compression zone has significant influence on the ductility only at higher values of confinement, whereas this influence is very little at low confinement.

4. The Confinement Fibre Index (CFI) proposed in this study can be used to represent the effect of combination of several material properties like volume fraction of fibres, volumetric ratio of confinement, yield strength of confining steel and the strength of concrete.

5. The experimental investigation indicate that the brittle behaviour of over reinforced flexural members can be converted to ductile by confining the compression zone along with the addition of steel fibres.

Premalatha et al., [2004] have conducted an experimental investigation on experimental investigations on impact strength of high strength steel fibre reinforced silica fume concrete. In this experimental investigation the behavior impact specimens were cast for M60 grade of concrete with steel fibers of aspect ratio 50 with different percentages of steel fibres and with partial replacement of cement by silica fume in different percentages. Control specimens were also cast along with the specimens made for impact. Specimens were tested for 7 days; 14 days and 28 days strength and their behaviors were studied. Specimens were cast and tested to study their behavior under impact as per the method recommended by ACI 544 committee.

From the experimental investigation they have drawn the following conclusions

1. Impact strength of steel fiber reinforced concrete without silica fume was found to increase in volume fraction of steel fibers and maximum increase was observed in 1.5% fibre content. The 7 days and 14 days strength were found to increase marginally than the specimens without steel fibers. Maximum increase in strength was observed in concrete with 1.5% volume fraction of fibers, which was found to be 7.2 times the concrete without fibres.

2. The impact strength of concrete with 5% silica fume was found to increase up to 1.5% volume fraction of steel fibers and the strength was found to decrease for 2% volume fraction of fibers. The maximum increase was found to be 5.8% times the strength of concrete without steel fibers at the age of 28 days. The maximum increase observed in the 7 and 14 days strength was found to be 2 times strength of concrete without steel fibres.

3. The impact strength of concrete with 10% silica fume was found to increase up to 1.5% volume fraction of steel fibres and the strength was found to decrease for 2% volume fraction of fibers. The maximum
increase was found to be 9.3 times the strength of concrete without steel fibers at the age of 28 days. The maximum increase observed in the 7 and 14 days strength was found to be 2 times the strength of concrete without steel fibers.

4. The impact strength of silica fume concrete without steel fibers has shown no improvement in impact strength and the material behaved in a brittle manner. The impact strength of this concrete can be improved only by the addition of steel fibres.

5. The behavior of concrete with and without silica fume and steel fibres were unpredictable and the number of blows required for ultimate failure was very random. Hence theory can be developed on the test results of number of blows required for first crack.

6. Compressive strength of concrete with and without silica fume is found to decrease with increase in volume fraction of fibres for 7 and 14 days curing. For 28 days, the strength was found to increase for 1 % volume fraction of fibers. The maximum increase observed was 37% for concrete with 1 % volume fraction of fibres and with the addition of 10% silica volume.

Seshagiri Rao and Ali Sirajuddin [2004] have conducted an experimental investigation on studies on strength and behavior of high volume flyash concrete with steel fibre reinforcement. The experimental investigation conducted to improve the performance of concrete by using flyash up to 50% as a replacement of cement and steel fibers up to 1 %. The development of compressive strength at different ages apart from the splitting tensile strength and secant modulus of elasticity have been observed and compared with those of the corresponding reference mix. The stress- strain behavior as well as the load-deflection behavior has been thoroughly studied in all the cases. The results have shown that strengths of flyash concrete slightly reduce with the replacement of flyash but are compensated with the use of fibres. The addition of fibers with flyash shows excellent static and dynamic characteristics and has drastically changed the post cracking behavior.

From the experimental investigation they have drawn the following conclusions

1. The early age strengths in flyash concretes is considerably low for 30-50 % Flyash. This can be offset by the incorporation of fibers, which make the strengths comparable.

2. The later age strengths of flyash concrete is comparable with conventional concrete and replacement up to 30-40% can be safely made when structure is expected to take the design load at 60 days.
3. Flyash concrete shows slightly lower flexural strengths at 28 days. This can be overcome by use of fibers. The splitting tensile strength of flyash concrete is slightly greater than the conventional concrete and increases drastically in fiber composites.

4. The modulus of elasticity of flyash concrete is comparable to the control mix and slightly reduces in fiber composites.

5. Hence a balance can be struck between the percentage replacement of flyash for better durability and the incorporation of fibers for excellent static and dynamic properties. The authors suggest that a replacement of 30% flyash with 1% fibers is optimum, considering the strength as well as the cost of the composite.

Vijaya lakshmi et al., [2004] have conducted an experimental investigation on behavior of steel fiber reinforced concrete under compression and tension. In view of the above they made an attempt to study the behavior of SFRC under the axial compression and tension. The variables considered were the M20, M30, M40 and M50 grade of concrete as per design mix proportion and the volume fraction of the fiber like 0, 0.3, 0.6, 0.9 and 1.2. It was observed in compression tests that the plain concrete cubes failed suddenly in a brittle manufacture where as the SFRC cubes produced significant cracks with increase in the post cracking strength. In case of cylinders it was observed that the top and bottom surfaces of plain concrete cylinders were crushed where as in SFRC no such crushing was observed which an indication of ductility of SFRC.

From the experimental investigation they have drawn the following conclusions

1. Inclusion of steel fibres improves the compressive strength and tensile strength of the basic matrix up to certain volume fraction of fiber. In this investigation this limiting volume fiber content was found to be 0.9%.

2. Addition of steel fibres increases the toughness of the concrete as indicated by the area under stress strain curve under compression even beyond 0.9% addition of fiber volume.

3. Fiber inclusion improved the strain at ultimate stress in all grades of concrete.

Balguru and Ramkrishnan [2005] have conducted an experimental investigation on properties of fiber reinforced concrete: workability, behaviour under long-term loading, and air void characteristics. In this experimental investigation two mixture proportions with cement contents of 363 and 474 kg/m³ were considered. The lower cement content that was used with a w/c ratio of 0.4 and higher cement content that was used with a
w/c ratio of 0.3. High range water reducers and air-entraining admixtures were used for all the mixtures. Collated 50mm long steel fibers with hooked ends were used for fiber concrete. The experiments were conducted using the appropriate ASTM standards. The air-void characteristics were studied using the linear traverse method.

Based on the experimental investigation they have drawn the following conclusions.

1. The initial and final setting times of plain and fiber reinforced concrete are about the same.

2. The addition of fibres reduces the slump and the air content. The rates of loss of slump and air content are slightly higher for fiber reinforced concrete.

3. Shrinkage strains are slightly less for fiber reinforced concrete. Measurable shrinkage stops at an earlier age of fiber concrete.

4. Fiber reinforced concrete under goes more creep deformations. Creep recovery characteristics are similar for both the concrete.

5. Air-void characteristics are similar for both the concrete except the specific surface of bubbles, which is lower for fiber concrete. In terms of chord-intercept distributions, plain concrete has more bubbles with chord-intercept lengths less than 0.05mm, as compared to fiber concrete. But, for this difference, the frequency distributions of chord-intercepts are similar for plain and fiber reinforced concretes.

Radhakrishnan et al., [2005] have conducted an experimental investigation on seismic response of fibre reinforced concrete plates under impact load. This experimental investigation describes the dynamic behaviour of steel fibre reinforced cement concrete (SFRC) plates. The variables considered were percentage volume fraction of steel fibres, aspect ratio, the angle of impact and the thickness of the plate. The observations of acceleration, frequency response and the shape of the impulse curve were studied.

Based on the experimental investigation conducted on the steel fibre reinforced concrete plates under impact loading, they have drawn the following conclusions.

1. Instantaneous peak acceleration increases with increased angle of impact. But the acceleration response does not increase in the same order in which the angle of impact is increased and the response saturates towards higher impact angle. The damping ratio of the frequency response is 7%.

2. The frequency of response as obtained from the FFT shows that the plate with two side support always exhibit lower frequency value (2-4%) compared to that with all four sides supported.
3. The shape of the impulse curve is triangular and generally does not alter with fibre content 0.5%, 0.75%, and 1.0%, and length of fibre 35 mm, 52.5 mm and 70 mm. The time duration of the impulse curve is between 0.4 to 0.8 million seconds.

4. The response frequencies are generally more for plates of higher thickness (viz. 30 mm and 25 mm) compared with 20 mm plates. The plates with two edge supports show an increased frequency when the thickness is 30 mm (the average frequency for 30 mm plate is around 135 Hz). Similarly, the frequency of 20 mm plate is around 100 Hz. The same trend is seen in the case of reinforced concrete plate without fibres where the frequencies of two edge supported RC plates are 112 Hz and 84 Hz for 30 mm and 20 mm plates, respectively.

5. The natural frequency of impacted plates as exhibited from the higher angle of impact shows marginally lower frequency 2-4% compared to the soft impact. The difference, though marginal, is clearly seen in the response and is found to show the same behaviour for both the two edge and four edge-supported plates.

6. The change in frequency of response of slabs was marginal (i.e., variation in the range of 5-10%) when fibre volume fraction increased from 0.5 to 1%. The effect of increase in the length of fibre is to bridge more number of micro cracks and to cause a marginal increase in the stiffness of the slab.

Sudarsana Rao and Ramana [2005], have conducted an experimental investigation on behavior of slurry infiltrated concrete (SIFCON) simply supported two-way slabs in flexure. They gave the information on behavior of two-way slabs in flexure. Flexure and cyclic load tests have been conducted and compared with fibre reinforced concrete (FRC) and plain concrete slabs. Both strength and deflection characteristics have been studied.

The major objective of the investigation is to produce SIFCON slabs with locally available fibres for Indian applications. SIFCON slabs with different volume fractions of fibres have been produced and tested under uniformly distributed load. Cyclic loading tests also have been performed. The superiority of SIFCON slabs over fibre reinforced concrete slabs and plain concrete slabs has been demonstrated. The experimental program comprises casting and testing of nine SIFCON slabs, three fibre reinforced concrete slabs (2% fibre) and three plain concrete slabs (M20) simply supported on all four edges. The mix proportions of the various slabs are
1:1 (cement and sand) and 1: 1.54: 3.17 (cement, sand and coarse aggregate). All the slabs are square and are of size 600 x 600 x 50mm. The simply supported edge condition has been simulated by supporting the slabs on 10mm diameter steel rods.

Analyzing the results obtained from this investigation they have drawn the following conclusions were drawn.

1. The load carrying capacity of the SIFCON slabs is much higher than the fibre reinforced concrete and plain concrete slab specimens.
2. The stiffness of SIFCON slabs is an order of higher magnitude than that of fibre reinforced concrete and plain concrete slab specimens.
3. The SIFCON slab specimens exhibited greater ductility. Even at the ultimate stage, SIFCON slab specimens were intact while the plain concrete slab specimens broke into pieces.
4. The SIFCON slab specimens behaved well in cyclic loading test.
5. The crack width is much less in SIFCON slab specimens than the FRC specimens.

Wafa Labib and Nick Eden (2005) wrote report on an investigation into the use of fibres in concrete industrial ground-floor slabs. This paper reports upon the literature review of using various types of fibres as a replacement to steel-fabric reinforcement in industrial ground floors.

Based on the review they drawn the following conclusions

1. The use of structural synthetic fibres as a replacement for steel reinforcement in flooring has various advantages: light weight, tight cracks, ease of use, safe handling, rapid dispersion and no corrosion. However, measuring the post-crack capacity of the fibre-reinforced concrete section could compare the relative performance of different fibre products. As a result, comparing post-crack performance of synthetic fibres with steel fibres and mesh will reveal the differences in the way the materials work. In light of the above, a beam test on reinforced concrete sections incorporating: steel fibres, structural synthetic fibres and steel fabric will be carried out according to ASTM C-1018 for two purposes: first to compare the post-crack capacity performance of the three sections and, second, to use the flexural strength parameter resulted from beam tests as an input data into the stress analysis of fibre reinforced concrete floors using nonlinear finite element analysis programme. After using the finite element analysis to study the fracture behaviour of ground floor-slabs and in order to validate the numerical
analysis, three full-scale tests on slabs incorporating steel fibres, structural synthetic fibres and steel fabric will be performed and the experimental results will be compared with the ones obtained from the numerical analysis.

Ganesan et al. [2006] have conducted an experimental investigation on ultimate strength of steel fibre reinforced self-compacting concrete flexural elements. In this experimental investigation the effect of steel fibres on the strength and behaviour of self-compacting concrete (SCC) flexural elements were studied. Twenty beams were cast for this study out of which two were plain SCC beams without fibres. The variables in this study were aspect ratio (0, 15, 25 and 35) and percentage of volume fraction of fibres (0, 0.25, 0.5 and 0.75). First crack load and the post cracking behaviour were found to have improved significantly due to the addition of fibres.

A marginal improvement in the ultimate strength was observed. The addition of fibres enhanced the ductility significantly. The optimum volume fraction of fibres for better performance in terms of strength and ductility was found to be 0.5 percent. Experimental values of the ultimate moment were compared with various analytical models. The comparisons indicate that Swami and Taan model compares better with the test results than that of the other models.

Based on the above experimental investigation they have drawn the following conclusions

1. Addition of steel fibres improved, in general, the first crack load and the ultimate load of self-compacting concrete specimens under flexure. The improvement was significant in the case of first crack load.
2. The strength and ductility of fibre reinforced SCC specimens were found to increase substantially in the case of specimens with volume fraction of 0.5 percent for aspect ratios of 15 and 35.
3. The ductility factor increased up to a volume fraction of steel fibres of 0.5 percent for all the aspect ratios.
4. All the models available in the literature were found to underestimate the ultimate strength of SFRSCC flexural specimens. Hence, appropriate modifications are required in these models to reduce the range of predictability of the ultimate moment of SFRSCC members.

Ganesan and Sekar [2006] have conducted an experimental investigation on effect of micro-silica and steel fibres on the strength of high performance concrete composites. This experimental investigation was carried
out to study the combined effect of addition of micro-silica and steel fibres on the mechanical properties of steel fibre reinforced-high performance concrete (SFR-HPC) composites. The various mechanical properties considered include: cube compressive strength, cylinder compressive strength, split tensile strength, modulus of rupture and modulus of elasticity of concrete. A high performance concrete (HPC) of M60 grade with a constant micro-silica dosage of 7.5% by weight of cement was considered. The main variables considered in this study are: (i) 3 different aspect ratios of steel fibres viz. 50, 75 and 100, and (ii) 3 different volume fractions of steel fibres viz. 0.5%, 0.75% and 1.0%. A total of 243 numbers of concrete specimens were cast using both micro-silica and steel fibres and tested as per IS: 516 and IS: 5816 specifications.

Based on the experimental investigation they have drawn the following conclusions:

1. In general, addition of micro-silica and steel fibres to HPC enhances its mechanical properties at 7 and 28 days age. However, the rate of strength gain is higher during first 7 days.

2. For a constant fibre length, the strength of concrete increases as the fibre content increases up to 1.0% of fibres. Further increase in the values of volume fraction causes balling-effect.

3. By adding both micro-silica and steel fibres to HPC, the improvement achieved in cube compressive strength, cylinder compressive strength, split tensile strength, modulus of rupture and modulus of elasticity were higher by 33.7%, 39.5%, 48.4%, 37.9% and 30.9% respectively, compared to the corresponding values for HPC.

4. The strength-to-weight ratio achieved by adding both micro-silica and steel fibres to HPC is 27.11% higher compared to the corresponding value for HPC.

Raul L. Zerbino et al., [2006] have conducted an experimental investigation on pseudo-ductile behaviour of steel fibre reinforced high-strength concretes. This experimental investigation analyses the behaviour of steel fibre reinforced high-strength concrete, with emphasis on toughness parameters determined through the ASTM C 1018 procedure. The effects of matrix strength level, fibre type and dosage have been studied. The geometry of the specimens and loading configuration has also been varied. In addition, the failure mechanism under compressive loading has been analysed using the critical stress concept. Fibre reinforced concretes with compressive strengths up to 77 MPa have been analysed. The load-deflection behaviour under flexure loading, for different specimen sizes and test configurations, were studied, followed the general
guidelines of ASTM C 1018. The absolute area under the load-deflection curve has also been used to define equivalent post-peak strengths. In addition, the pre-peak non-linearity under compressive loading has been evaluated.

Based on the experimental investigation they have drawn the following conclusions:

1. During compression failure, fibres restrain crack propagation leading to an increase in the post-peak non-linearity of the high strength concrete.

2. For the same fibre type and dosage, improvements in loading capacity and post-peak softening behaviour are observed for higher matrix strength.

3. For high strength matrices, a notable improvement in the behaviour is observed, especially at large deflections, when high carbon steel fibres are employed.

4. From the comparison of the behaviour of specimens of different depths and loading configurations, it appears that the toughness indices are generally comparable. However, they tend to increase with a decrease in the beam height and are lower for centre-point loading than for third-point loading.