CHAPTER 2
LITERATURE SURVEY

Strength properties are the most valuable characteristics of concrete. They have a direct relationship to micro structure of hydrated cement past and concrete. These are directly related to other properties of concrete like elasticity, stress, strain and other construction related activities like forms removal etc. The reinforcement in concrete further enhances these strength properties. Because of the flexibility in methods of fabrication, fiber reinforced concrete can be an economic and useful construction material (2). The concrete is mostly utilized in the elastic range and there is a need to know the relationship between stress, strain and the elasticity which is the property of concrete. This will provide information on how to control the deformation of the concrete members. To conduct these tests I.S. 516 and ASTM C 469 procedures are followed (53,18,52 58).

2.1 Elastic Properties of Concrete

Francesco Bencardino et. al., (38) have conducted experimental investigations on the specimens reinforced with steel fibers in compression to study the stress strain behaviour. The test was conducted by using various fiber volume fractions of 1 %, 1.6 % and 3 % on cylindrical specimens as per standard procedure. The authors have concluded that the strains in the specimens at failure exhibited higher values of more than 0.0035. The increase in fiber content improves the post peak behaviour and a more extended softening
curve was observed. The ultimate strain in SFRC specimens at failure has reached 3 to 5 times when compared to the ultimate strain in normal specimens.

**K.K. Sideris et al., (72)** have investigated the relationship between compressive strength, modulus of elasticity of concrete and compressive strength poisson ratio by using cement hydration equation. This equation predicts the final rate of hydration at the age of 15 years of cement used when the hydration ends. The authors have concluded that there always exists a linear relationship between compressive strength-elastic modulus and compressive strength-poisson ratio.

**Byung Wan Jo et al., (25)** have conducted experimental investigations on the stress strain behaviour and elastic modulus of SFRC. Compression test was conducted on concrete having design strength of 30 MPa, 50 MPa and 70 MPa with steel fiber volume fractions of 0 %, 0.5 %, 0.75 %, 1.0 % and 1.5 %. Cylindrical specimens of size 150 mm x 300 mm were used. The authors compared the test results with existing elastic modulus formulas and concluded that SFRC showed ductile behaviour at post maximum load and there was a rapid increase in elastic modulus with the increase in fiber content.

**Sami A Klink (110)** has conducted compression test to measure strains by embedding strain gauge units in the normal weight and light weight concrete cylinders. The elastic modulus of concrete cylinders was considered at their centre. The results showed that the
elastic modulus was 55% higher when compared to the standard test results. Also by empirical formula calculations about 50% higher actual elastic modulus was obtained. The author has concluded that the actual elastic modulus is a function of its density and compressive strength.

Sami A Klink (111) investigated the poisson ratio property of normal weight and light weight concrete at the centre of cylindrical specimen using the embedded strain gauges in concrete. The author has concluded that the poisson ratio was about 55% higher when compared to the results obtained by standard test method and that poisson ratio varies with unit weight and compressive strength of concrete.

Sander Popovics (112) reviewed the work conducted by various researchers on the stress strain relationships for concrete. The author has concluded that the testing conditions such as the rate of loading, number of load repetitions, the magnitude of the repeated stresses influence the stress strain diagram of concrete. The curve deviates gradually from straight line due to progressive propagation of internal cracking in the specimen and the aggregate content of concrete influences the curvature of the stress strain curve. Empirical equations can be used to calculate strain and secant modulus of elasticity at ultimate compressive stress.

2.2 Impact Strength of Concrete

Yaghoob Farnam et. al., (127) have investigated the experimental and numerical effect of high performance fiber reinforced cement
composite behaviour at low velocity impact. The authors tested the casted panels by drop projectiles upto an impact at which failure occurs and used LS-DYNA software for modeling. Investigation and behavior by simulating were carried out based on ACI 544 2R. The authors have concluded HPFRC has higher impact resistance than normal concrete and the results obtained from FE analysis based on number of strikes required for failure initiation of the specimen, midpoint deflection, shape of failure pattern are in good agreement with the corresponding experimental results.

**V. Bindiganivile, N. Banthia (122)** investigated the fiber matrix bond behavior under impact loading in concrete. Fiber matrix bond strength plays an important role in Impact strength of FRC. High strength fiber matrix results in stiffer bond. The fibers used were three polymeric fiber and one steel fiber. The study revealed that with high bond stiffening with impact loading, steel fibers showed the best peak loads for small inclination compared to aligned load. The study showed that the crack opening displacement associated with peak loading is inversely proportional to loading rate thereby proving the stiffness of fiber matrix bonding. The quasi static and impact rates of loading in case of high strength matrix reduces the strength of the fiber-matrix bond. The study concluded that the fiber, that pull out totally during impact loading is the best suited for high strength matrix.

**Atef Badr and Ashraf F.Ashour (23)** dealt with the problems of ACI drop weight test procedure and suggested modification in their
work titled “Modified ACI Drop weight impact test for concrete”, ACI material Journal, V 102 No 4, July-Aug 2005 pg 249-255. Their study revealed that the current ACI test procedure for impact test has certain % error in prediction of result. The authors have proved this by using 40 specimen from polypropylene fiber reinforce concrete. And tested these with their modified method, the coefficient of variation was 39.4% and 35.2% but when the same was done by using the current ACI method the coefficient of variation was 58.6% and 50.2%. The above was done for first crack and ultimate impact resistance. The study also found that number of same composition specimen required was 41 to keep the error at 10% whereas 20 specimens would suffice for the modified test procedure.

**S.Mindess and L.Zhary (107)** studied impact resistance of FRC in their study titled “Impact resistance of fiber reinforced concrete”. High strength FRC was used to study the effect of impact loading at the compressive strengths ranging from 60MPa to 120 MPa. The authors concluded that FRC specimen showed deformation greater than the control specimen, when subjected to compressive impact loading and higher deformation were exhibited by FRC by increasing the drop height.

**Barzin Mobasher et. al., (24)** have conducted investigations to measure the toughness and impact behaviour of GFRC composites using third point flexural and instrumented impact test. The specimens were subjected to loads in uniaxial tension, third point flexure and instrumented impact. The results of the tests showed
better performance of the GFRC specimens when compared to normal specimens. The impact test provided higher first crack load and the modulus of rupture for impact was about 2 times the value of static flexural test.

**N Banthia et.al.,(88)** have conducted studies on measuring the impact resistance of fiber reinforced concrete by using drop weight impact machine at two ambient temperatures of 22°C and -50°C. Two hammer approach velocities of 2.42 and 3.43 m/s on the specimens with 2 % fiber volume fractions of hybrid steel and carbon fibers were investigated. The authors have concluded macrofibers of steel are more effective in improving the toughness than microfibers. In hybrid form the micro and the macro fibers are the toughest. The impact energy was observed to be less at sub normal temperature.

**Han Zhao (47)** in his paper study on testing techniques for concrete like materials under compressive impact loading has used split Hopkinson pressure test bar to explain the problems in testing of concrete. The study showed that the wave dispersion, correction and exact time shifting are indispensable and a good estimate of stress strain curve was obtained by the use of conventional formula to assess impact.

**Wimal Suaris et. al., (123)** have investigated the effect of impact on concrete and FRC specimens by drop weight and instrumented impact test methods. During the impact loads, deflections and strains were monitored. The authors have concluded that the modulus of rupture at high strain rates was up to 2 times that observed at low
strain rates. The energy observed by polypropylene reinforced concrete beams are 1100 times to those of unreinforced beams.

ACI 544.1R (2,3) has demonstrated that for a structure to be reliable and that it shall be able to withstand high impact forces without losing its strength, which can withstand dynamic loads like missile strike, air blast, wind gust, earthquakes etc. This is because a lot of this impact energy is absorbed, resulting in post cracking of concrete by debonding stretching and pulling out of fibers. The different tests employed to measure impact resistance are

1. Weighted pendulum charpy test
2. Drop weight hammer test or drop weight test
3. Constant strain rate test
4. Projectile impact test
5. Split Hopkinson bar test
6. Explosive test
7. Instrumental pendulum impact test.

The simplest of these tests is the drop weight test recommended by ACI (544-2R). This records the first crack and failure strength and has been used in this research work. The amount of energy required to fracture a specimen in terms of blows is the measurement of impact resistance.

2.3 Permeability of Concrete

Ueli Angst et. al., (121) have reviewed the concept of critical chloride content and the influencing factors that induce chloride corrosion of reinforced concrete. The study concluded that an electric
field to accelerate chloride ingress can have a more dominant influence on the results and requires methods to measure free chlorides.

**Julie Rapoport et. al., (71)** have studied the influence of steel fibers on concrete permeability. The authors presented statistical relation between permeability and crack width to correlate the results. Steel fiber reinforcement fractions of 0.5 % and 1.0 % were used in the specimens of size 50 mm thick. The specimens were cracked to a specified crack mouth opening displacement (CMOD) of 100, 200, 300, 400 and 500 µm in the Brazilian splitting tension test. The specimens so obtained were tested for water permeability. The authors concluded that with the crack widths below 100 µm, the steel fibers do not have affect on the permeability of concrete. At only larger crack widths, the steel fibers help in reducing the permeability of crack concrete. The higher volume fiber content specimens reduce the permeability more than the specimens with lower percent of fiber.

**Chung Chia Yang (28)** presented a new method for determining the migration coefficient in concrete from a steady state migration test by measuring the charge passed. The electrochemical technique was applied to accelerate chloride ion migration in concrete. The charge passed from the RCPT and the non steady state charge passed from accelerated chloride migration test (ACMT) was studied. The study concluded that the RCPT has given higher charge passed compared to ACMT test, but good correlation was observed from ACMT test results.
Kyle A. Riding et. al., (76) have developed a simplified method of measuring concrete resistivity as an index of permeability. The cylindrical specimens of size 100 mm x 200 mm were tested as per ASTM C 1202. In this test only one current reading was taken after 5 minutes of start of the test to calculate concrete resistivity to avoid temperature effect. Correlation of the results worked well for the simplified test.

During the last few decades the chemical composition of cements and in general ordinary Portland cement have undergone a significant change in compounds of cement with the tendency to increase the $\text{C}_3\text{S}$ and $\text{C}_2\text{S}$ (tricalcium silicate and dicalcium silicate) to achieve a high strength. These compounds which provide high strength development and rapid hydration produce a concrete which may have a more permeable structure leading to ingress of chemicals like the sulphates which are available as $\text{Na}_2\text{SO}_4$, $\text{MgSO}_4$, $\text{K}_2\text{SO}_4$ AND $\text{CaSO}_4$ in soil, ground water, sea water and in the internal hydration component of cement. The ingress of these sulphates in the cementitious composite leads to deterioration of concrete in the form of spalling, delamination, macro cracking and cohesion loss due to the formation of ettringite (calcium aluminate trisulphate hydrate) formation, gypsum corrosion, recrystallisation of salts etc. The chlorides like $\text{CaCl}_2$, $\text{NaCl}_2$ (deicing salts) and $\text{MgCl}_2$ etc., also produce and deteriorate the concrete (91). The dissolved chlorides in water increase the rate of leaching of portlandite ($\text{C}_3\text{A}$ and $\text{C}_4\text{Af}$ reacts with chlorides) and increase the porosity of concrete resulting in loss of stiffness, strength and hence
corrosion. Also due to acidic reaction with the CSH gel the concrete deteriorates and disintegrates. Bulb diffusion test, salt ponding on concrete slabs, Rapid chloride permeability tests (19) are conducted to know the chloride permeability property of concrete.

2.4 Basic Work Conducted on Fiber Reinforced Concrete (FRC)

The use of steel fibers in concrete dates from 1910 to improve the properties of concrete. The main interest in fibrous reinforcement of concrete originates from the work carried out in the early sixties by various researchers. Romualdi et. al. (102,103,104) studied the mechanism and mechanics of crack arrest properties of steel fibers, tensile strength of uniformly distributed short fiber and the behaviour of reinforced concrete beams. The study concluded that the steel fibers have major influence in enhancing the strength and crack control properties. Hannant (46) studied the effect of post cracking ductility on the cement mortar and concrete specimens reinforced with short steel fibers. The flexural strength test resulted in enhanced ductility compared to specimens without fibers. Naaman and Shah (89) studied the bond properties of randomly oriented and aligned steel fibers using steel fiber and concluded the fibers have good bonding characteristics and hence improvement in the properties of concrete. Gopalratnam et. al. (43) studied the properties of SFRC subjected to impact loading. The results indicated higher energy absorption of the specimen compared to specimens without fiber. Majumdar (81) carried out investigations to study the influence of glass fiber reinforcement in cement mortar and concluded that the
glass fiber enhances properties of cement mortar. Shah et. al. (114) investigated the toughness durability characteristics of glass fiber reinforced concrete and concluded that glass fibers exhibited higher energy absorption leading to a more durable concrete.

The outputs of all these investigations have created the use of fiber reinforced concrete from experimental applications to field applications (2, 10 and 21). This has created a need to review existing test methods and to develop new methods that are necessary for determining the properties of fiber reinforced concrete.

Combinations of two dissimilar fibers are increasingly being used. These combinations are known as hybrid fibers. The resulting hybrid fiber reinforced concrete performance exceeds the sum of the individual fiber performance due to positive interaction between the fibers. The production and properties of these new materials has been the subject to considerable research and development effort in the last decade. N. Banthia et. al. (86) studied the resistance offered by the hybrid fibers in concrete using steel fiber and polypropylene fiber in the cement matrix. After conducting crack test the authors concluded that polypropylene fiber enhances the efficiency of steel fiber.

2.5 VARIOUS STUDIES ON ADMIXTURES AND FIBER REINFORCMENT IN CONCRETE

2.5.1 Effect on Strength Properties

Namshik Ahn (90) studied the sulphate attack on mineral admixture mixed portland cement using ASTM C 1012 procedure. He used Type I cement, Type II cement and Type V cement. Mortar mixes
were made by combining with one class F flyash, one class C flyash and one GGBS presented in varying percentages of volumetric replacement.

ASTM C 1012 was found to be conservative to ASTM C 150 limits. In fact one sample proved that the ASTM C 150 whose test resulted in the sample being moderately sulphate resistant turned out be inadequately sulfate resistance when ASTM C 1012 test criteria was used. The ASTM 1012 carried out for portland cement showed direct proportionality to tricalcium aluminate content and expansion limit. A safe level of C3A for moderate surface environment was 7-8% and for severe sulphate environment it was 4-5%. It found the commendable role of class F flyash in sulfate resistance using ASTM C 1012 expansion standard and a degrading expansion in case of class C flyash thus, making class C fly ash an utter failure in any sulphate environment. GGBS as expected gave good sulphate resistance in any level sulphate environment.

DDL Chung (30) studied the role of silica fume in improving the cement based material properties. The study showed that the silica fume enhanced the chemical attack resistance, corrosion resistance in steel bars and had a high bonding strength with steel rebars. It improved the compressive and flexural modulus, tensile ductility, and compressive strength but reduces the compressive ductility. It is also found to reduce the alkali-silica reactivity, drying shrinkage permeability, creep rate, coefficient of thermal expansion and dielectric constant. The addition of silica fume is found to increase the
air void content, decreasing the density, increased dispersion of microfibers but reduces workability. The silane treated silica fume, when added to concrete increases the specific heat and decreases the air void.

**Sidney Diamond et. al., (116)** studied the densified silica fume particle relating to size and dispersion. Densified silica fumes are available in coarse form with particle size in several mm. But the ultrasound treatment could be done in order to break them down into smaller chains of spheres. But all kind of densified silica fume does not react to the ultrasound treatment and remain as agglomerates. The agglomerates do not perform the filler function as would be desired. These agglomerates could act like ASR reactive aggregate and possibly cause damage in unfavorable conditions.

**S Chandrasekhar et. al., (105)** investigated the possibility of using microsilica from rice husk as a substitute for condensed silica fume. Since CSF is being imported at high cost in India, it becomes important to search for a cheap substitute which can replace the CSF in concrete. For this rice husk from various rice mills in India were collected and those with highest ash contest were chosen. This was then washed dried and heated to different temperatures in furnace that could be programmed. This was done for obtaining amorphous nature, high silica content, large surface area and very white colour. Then two samples of microsilica were obtained. One from Elkem India Pvt. Ltd., named microsilica 920-D and another from Asian laboratories, New Delhi named Microsilica 6-N. Gravimetric method
was used to determine their silica content. The properties of these two microsilica were compared with rice husk. The surface area of RHA was higher than the microsilica meaning RHA is a more porous material. It was also found to have higher time reactivity than the two micro silica samples indicating higher silica content, very fine size particle and higher amorphous nature of RHA. In fact RHA was found to have far superior properties when compared to micro silica and the main attraction is that RHA is sourced from a waste material.

**FM Kilinc Kale, GG Dogan (37)** studied the properties of concrete mixed with water soluble polymers in concrete produced with super plasticizer. The concrete sample with and without polymer with w/c ratio of 0.52, 0.56 and 0.60 was prepared. The polymer used was naphthalene formaldehyde sulphonate, melamine formaldehyde sulphonate and a special type of melamine sulphonated (hyper plasticizer) polymer were used in the ratio of 0.3, 0.5 and 1 % of cement weight. The age for testing was 7, 28 and 56 days. Slumps were observed with w/c ration of 0.56, 0.60 and melamine sulphonated polymer of 1 % weight was used. The workability recorded was highest for hyper plasticizer mixed concrete followed by melamine formaldehyde and naphthalene formaldehyde in that order.

**RM de Gutierrez et. al., (98)** studied the properties of FRC using pozzolans like Silica fume, fly ash, metakaolin in FRC. The fiber used were of six type, three natural i.e. fique, sisal, coir and three synthetic fiber i.e. steel glass and polypropylene all of 10 mm length, replacing 2.5 % by weight of cement. One set was without pozzolonas and
another set was added with silica fume, fly ash and metakaolin. The specimens were immersed in 50 % Nacl solution. The cubic specimens were tested at 3, 7, 28, 60 and 90 days for compressive strength. The cylindrical specimens were used for absorption, permeability tests at 31 days of curing and for testing chloride attacks. The investigation revealed that only fiber specimen showed less compressive strength than pozzolans mixed material. The steel fiber recorded the highest compressive strength.

**Ha-Won Song, et. al., (48, 49)** conducted a study on durability of concrete with silica fume as admixture. The study concluded that the permeability of concrete reduces by addition of silica fumes, which densifies the microstructure of concrete. The permeability showed sudden reduction as the silica fume percentage is increased beyond 8 % upto 12 %, but beyond this there is only marginal reduction. The factors on which this reduction of permeability is based are replacement ratio, water to binder ratio and degree of hydration.

**Swami B.L.P. et. al., (117)** in their experimental investigation conducted on high strength concrete mixes of grades M60, M70, M80 have concluded that 15 percentage micro silica can be considered as optimum and obtained increased strengths when compared to normal specimens tested at different ages of 7 days, 28 days, 56 days and 90 days. In the study against acid resistance of the specimens to H$_2$SO$_4$, HCl and Na$_2$SO$_4$, the authors have concluded that microsilica contributes towards better chemical resistance against sulphates.
Escalante Garcia, J.H. Sharp (34) studied the hydration products micro structure and chemical composition in cement mixed with admixtures in their work. In their study the authors used 60 % GGBS, 30 % fuel ash, 22 % volcanic ash in portland cement. The chemical composition of hydration product was found to be modified i.e. calcium content decreased in mixed concrete and aluminum content increased when compared to non-mixed concrete also silicon content was found to have increased.

Ibrahim Turkmen (61) studied the effect of different curing condition on the properties of concrete mixed with silica fume. Here portland cement was replaced by different percentages of silica fume and blast funance slag. The curing period was 28, 75, 150 and 400 days. The author has concluded that the admixtures improved capillary coefficient, porosity, compressive strength and ultrasonic pulse activity.

A. Elahi et. al., (11) studied the properties of HPC concrete when supplementary cementitious material was added to the concrete. The study showed that, replacement of portland cement with fly ash and GGBS had a detrimental effect on compressive strength at all ages upto 91 days. The 7.5 % silica fume replacement resulted in increased compressive strength in all ages.

Medhat H Shehata et. al., (85) in their research on sulphate attacks on blended concrete, showed that supplementary cementitious materials added to concrete enhanced its sulphate resistance, but the high calcium fly ash when added to concrete did not show much
reduction in resistance to sulphate attack but this was enhanced when gypsum and silica fumes were added to the fly ash mixtures.

**Maher A Bader (84)** in his study of concrete behavior in high chloride and sulphate environs used varying curing time, w/c ratio varying cement content and also used epoxy / polymer additives. The author has concluded that chloride attack decreased with increase in curing period and decrease in the w/c ratio. Latex and epoxy mixed concrete showed marked increase in chloride resistance. Sulphate attack was directly proportional to the w/c ratio. But the polymer added concrete polymerised more effectively in air rather than when kept underground thereby having a better compressive strength when over the ground than when under the ground (buried specimen).

**F.Girardi et. al., (36)** studied the resistance of concrete mixes when cyclically exposed to sulphuric acid and sodium sulphate attack. Here three different types of cement comprising portland limestone, blast furnace slag with and without silica fumes and pozzolanic cement with and without silica fumes was used. These were exposed to sodium sulphate (50 g/l) and sulphuric acid with pH 2 for 6 hours once in a month for 5 years period. Measuring mass loss and expansion were the criteria for studying the corrosion. The study concluded that concrete containing silica fume had least expansion, but mass loss was at a faster rate than those cement without silica fume. Blast furnace concrete and pozzolanic concrete with silica fume showed negligible expansion but a heavy mass loss. And those
samples which did not contain silica fume suffered maximum mass loss and major expansion resulting in highest damage.

**J.Monlenj et. al., (66)** studied sulphuric acid resistance offered by concrete blended with various types of additives. The concrete was mixed with various polymer based additives, silica fume and blast finance slag. The authors have concluded that silica fume mixed specimen slowed the least resistance to 5% H$_2$SO$_4$ followed by styrene-butadiene polymer mixture, vinyl copolymer, styrene acrylic ester polymer, blast furnace cement mix. The cement with low tricalcium aluminate content provided highest sulphuric acid resistance.

**P. Murthi, V. Siva Kumar (92)** used ternary blended concrete to study the acid resistance effect on ternary blended concrete. The authors prepared binary blend comprising 20 % by weight cement replaced by ASTM class F fly ash. Ternary blend used 8 % replacement of cement by silica fume. The concrete grades used were M20, M30 and M40. Time of testing was slated for 28 days and 90 days curing time. The solution used was 5 % H$_2$SO$_4$ and 5 % HCl solution and immersion time was 32 weeks. The study showed that the ternary blend containing 20 % flyash and 8 % silica fume gave the maximum resistance to acid when tested at 32 weeks period. The study concluded that M20, M30, M40 grade PCC suffered severe damage and binary blended concrete shared very slight acid attack at 90 days cured when compared to 28 days cured binary blended which suffered moderate attack. The ternary blended concrete trend showed a lesser attack with increase in curing period.
S.U. Al Dulaijan et. al. (108) studied the sulphate attack on blended concrete. The authors prepared four sample of cements namely Type I, Type V, Type I with silica fume and Type 1 with Flyash. The sodium sulphate concentrate used was 1 %, 1.5 %, 2 %, 2.5 % and 4 %. Type I cement without any addictive showed maximum deterioration and reduction in strength. No deterioration was seen in Type I cement mixed with fly ash. But the strength reduction was almost same in Type V cement, silica fume cement and fly ash cement. Increased concentration of Na$_2$SO$_4$ resulted in increased reduction of strength except for Type I cement mortar where it remained the same.

E.Hewayole et. al., (33) studied the sulphuric acid attack on admixture in their study. The authors used metakaolin, silica fume, organic corrosion Inhibitor (OCI), Caltite and Xypex. The H$_2$SO$_4$ concentration used was 7 % and 3 %. The silica fume cement increased the compressive strength and reduced porosity but its resistance to sulphate attack was very poor. Metakaolin too increased the compressive strength and reduce the porosity of cement but gave a better resistance to sulphate attack when added at 15 %. OCI mixed cement did not show a significant increase in compressive strength and in reducing porosity. Caltite addition showed less compressive strength and not much change in porosity. Xypex on other hand showed higher compressive strength, reduced porosity and low sulphate resistance.
M.R. Nokken, RO Hooton (79) found a relation between pore parameter and permeability in their study. The Katz Thompson relationship was used to relate the pore parameter and permeability. This was validated by measuring the permeability. Thus Katz-Thompson relationship gave an accurate measurement of permeability thus doing away with measurement of permeability which is a tedious process.

Pengei Huang et. al., (94) studied HCl attack on properties of concrete. HCl corrosion becomes fetal when concrete structure is subjected to tensile or bending load. The authors used M25, M45, M55 types of concrete in varying concentration of HCl. The curing period was 360 days and the immersion period was one hour. The study showed that HCl corrosion results in loss of flexural strength, compression strength and elastic modulus of concrete. Also the high strength concrete suffered the highest corrosion due to HCl.

N.Banthia (87) studied the significance of FRC and noted that the technology evolution has definitely brought about a change in the building material. But this is insufficient as it lacks durability and also repair and construction leaves a lot to be desired. The author stated that FRC is the answer to all this as it reduces shrinkage and is a very good crack arrestor thus giving excellent toughness and impact resistance and a very good repair material. The use of FRC in structural concrete is most desirous proposal. So a lot of research and development has to be done in this promising material as there are so
many areas such as sensitive military installation, earthquake resistant structures that require immediate focus.

**Trevor NS and Stephen J Foster (119)** studied the crack resulting from failure by using X-Ray imaging in fiber reinforced concrete. The study showed that mode of failure is determined by angle of fiber that crosses the crack. Different fiber types and aggregate, fiber length that is embedded and fiber inclination indicate the mode of failure crack. High inclination angle indicate that fiber will bend at 5 mm from the exit point during pullout.

**In Hwang Yang et. al., (63)** studied the behavior of ultra high performance concrete beam subjected to bending. The authors have used ultra high performance cement beams having rebar ratio less than 0.02 and steel fibers are added at 2 % volumetric ratio. The results obtained after static loading of UHPC beam was analyzed. The study showed that redistribution of stresses and multiple cracking took place in UHPC where cracking and failure patterns exhibited numerous closely placed cracks which were perpendicular to flexural tensile forces in the beam. Placing of UHPC beams also affects the flexural strength. UHPC placed at the end of the beam gave better flexural strength compared to those placed in the middle.

**Mahmoud Nili, V. Afroughsebet (83)** has studied the properties especially impact resistance of concrete when silica fume and polypropylene fiber was added to it in their work to study the effect of silica fume and poly propylene fiber on the impact resistance and mechanical properties of concrete. Polypropylene fibers were 12mm in
length and fiber volume fraction taken was 0 %, 0.2 %, 0.30 % and 0.5 %. The silica fume is used as 8 % replacement of cement. Thus fibrous and non fibrous specimens with silica fume and without silica fume were prepared for the test. Silica fume when added to fiber helps in dispersion of fibers thus improving the impact resistance and other properties. The conclusions made in the paper were that, the 0.5 % fiber specimens with silica fume increased the compressive strength by 30 % at 90 days. This was due to combination of pozzolonic reaction and crack resistance of silica fume and fiber respectively. Non fibrous silica fume specimen also showed 23 % increase in compressive strength. The number of blows for first crack and failure was maximum in case of 0.5 % fiber in 0.46 w/c ratio and it was nearly 360 % of the reference specimen. Thus fiber specimen showed very good resistance to impact.

**Xiao Hui Wang et. al., (124)** studied the combined effect of steel fiber, silica fume and w/b ratio and its effect on ITZ, strength and fracture behavior of mortar The specimen were prepared using 0 % and 10 % replacement of silica fumes with and without steel fibers and w/c ratio varied between 0.3 and 0.5. This was done to link the smallest and largest mechanical property of w/b ratio. The study showed that irrespective of w/b ratio, silica fume specimen showed increase in compressive strength. But steel fiber specimen showed no significant change in compressive strength. Yield stress and plastic viscosity decrease with increase in w/b rate. The low w/b ratio samples showed an increase in plastic viscosity and yield stress in
silica fume specimens. Ductility increased with the steel fiber addition. Also the toughness of mortar increased with increase in volume fraction of steel fiber at lower w/b ratio.

Fuat Kokasal et. al., (39) studied the combination of silica fume and steel fiber when they are mixed to the concrete. The authors used 65 and 80 aspect ratio for all steel fiber and the addition of silica fume was 0 % to 15 % in the step of 5 %. The volume fraction of the steel fiber was 0.5 % and 1 %. The w/c rate was kept constant at 0.38 for all specimens. The study showed that higher aspect ratio combined with high volume fraction of fiber resulted in higher toughness of high strength concrete. Again the toughness depends on the content of silica fume in that specimen. Silica fume and steel fiber combined specimens gave a better compressive strength than the once containing only silica fume or only steel fiber. Elastic modulus showed an increase with silica fume but reduced with steel fiber content. Brittleness of concrete resulted when only silica fume was introduced in it and ductility was exhibited by concrete in which steel fiber were introduced. In fact the combination of silica fume in the fiber gave a better performance in terms of flexural tensile strength, splitting tensile strength when compared to individual usage of silica fume and steel fiber.

R.M. Damgir, Y.M.Ghugal (99) studied the effect on compressive strength of FRC using silica fume on150x150x150 mm cube with 0 – 5 % fiber increasing in step of 0.5 % fiber volume fraction and used silica fume replacement of 5 %. The study showed that with the
increase in fiber volume there was an increase in the slump loss and reduction in crack width. Crack width reduced from 1.30 to 0.75mm at 28 Days, thus proving the toughness of fiber. The specimen having 2 % fiber and 5 % silica fume recorded maximum compressive strength of 45.22 MPa and 70.15 MPa at 7 days and 28 days respectively.

### 2.5.2 Effect of Using Steel Fibers on Various Properties of Concrete

R.N. Swamy et. al., (100) have conducted studies on flexural strength of steel fiber reinforced concrete using a composite mechanics approach. Equations were derived to predict the first crack and ultimate flexural strength of concrete reinforced with short discontinuous randomly oriented and uniformly dispersed steel fibers in concrete. The authors have concluded that using a composite mechanics approach, equations can be used to predict first crack and ultimate flexural strength of SFRC. The inherent properties of post cracking behaviour and crack control of the material are such that there is little danger of brittle failure.

R.N. Swamy et. al., (101) presented a crack arrest theory to predict the flexural tensile strength of concrete reinforced with short discontinuous randomly oriented and uniformly dispersed steel fibers in cement based matrix. The study showed that fracture of SFRC specimens occurs due to progressive debonding mechanism. Complete pull out of fibers does not occur at the same time as the composite
reaches maximum load. Fibers still pull out at decreasing load beyond the maximum load.

**S. Eswari et. al., (106)** have conducted a study on the ductility performance of dramix steel fiber reinforced concrete to study the effect of micro reinforcement on the strength and ductility. The authors observed that the 2 % addition of hooked end fibers by volume has increased the modulus of rupture and ductility when compared to plain concrete. The study showed that the SFRC beams provide the ductility indices up to 1.59 compared to plain concrete specimens.

**Semsi Yazici et. al., (113)** have studied the effect of aspect ratio (l/d) and volume fraction (v/f) of steel fiber on the mechanical properties of SFRC. The ultra sonic pulse velocity test was also conducted. The authors have considered hooked end bundled steel fibers with three different aspect ratios of 45, 65, 80 and fiber volumes of 0.5 %, 1.0 % and 1.5 %. The study showed that workability gets decreased with fiber addition to concrete. The unit weight of concrete is increased. The mechanical properties have improved, but ultrasonic pulse velocity was decreasing with increase in fiber percentage.

**D. V. Soulioti et. al., (31)** have studied the mechanical behavior of steel fiber reinforced concrete with different fibers geometry and volume fractions. The flexural toughness, flexural strength, were evaluated based on ACTM C 1609 M. Two different fiber geometry of waved and hooked ended were considered with 3 different fiber volume percentages of 0.5, 1.0, 1.5.
The authors have concluded that fibers in fresh state of concrete reduced the workability compared to plain concrete. The air content is increased with high fiber volume fraction of 1.0 % and 1.5 %. The waved fibers exhibited higher compressive strength than the hooked incorporation fibers in concrete. The fibers increased the first crack, ultimate strength and toughness. The hooked end fibers exhibited higher toughness than specimens with wave fibers. But the wave fibers reinforced specimens showed higher first crack strength and ultimate strength.

K. Holschemacher et. al., (74) have conducted experimental investigation to study the effect of steel fibers in flexure, tension and fracture properties of high strength concrete with conventional steel bar reinforcement. Three type of different fibers were considered consisting of two hooked end with different ultimate tensile strength and are with corrugations to obtain a bases for selection of suitable fiber type and content for their most efficient combinations and to allow more economical expenditure of steel. The authors concluded that the beams failed in compression and shear with 20 kg/m3 of fiber control and with 40 kg/m3, the specimens failed in compression for fiber content of 60 kg/m3, the HSC beams with longitudinal reinforcement of 1% failed in compression only.

Ali R. Khaloo et. al., (16) have conducted tests on small steel fiber reinforced concrete slabs to assess their behavior in flexure and also studied the influence of length and volumetric percentage of steel fibers on energy absorption, flexural strength and load on load
deflection curve. The authors showed that energy absorption of slabs is 12 times superior to normal concrete without fibers at 0.5 % fiber volume and when compared to 0.5 % fibers, the 1% fiber volume specimens showed 2 times higher absorption values and in 1.5 % total fiber volume, the energy absorption was about 1.5 times to that of slab specimens with 1.0 % fiber volume. The resistance load after cracking with low fiber volume percentage is low compared to higher percentage. The authors have recommended the usage of fibers in the range of 0.75 to 1.75 for superior results.

A. E. Naaman et. al., (9) have studied the effects of strain rate of loading and the impact properties of SFRC in bending. The authors carried out the investigation by considering three fiber volume fractions of 1 %, 2 % and 3 % with aspect ratios of 47, 62 and 100. The strain rate of loading considered ranges from 0.5 x 10^{-5} to 1.2 strains per second. The study showed that depending on the fiber reinforcing parameters the energy absorbed by the composite at static loads are one to two orders of magnitude higher than that of unreinforced matrix and 3 fold increase in modulus of rupture and energy absorption when the strain rate is increased from 0.5x10^{-5} to 1.2 strain per second. The authors have concluded that the equivalent bond strength of the fibers, their volume fraction and aspect ratio influences the behavior of concrete matrix. The rate of loading is more sensitive to the higher volume and higher aspect ratio of fiber and the increase in composite flexural strength and energy absorbed with
loading rate is related to the strain rate sensitivity of both the matrix and pull out resistance of the fibers.

**Tayfun Uygunoglu (120)** has investigated the microstructure and flexural behavior of SFRC on specimens of size 100 x 9 x 350 mm. The volume percentages of steel fiber taken were 0.2, 0.4, 0.6 and 0.8 having hooked ends. The cast specimens were tested at 7 days, 28 days, 56 days, 180 days for flexural strength and microstructure examination by using SEM and optical microscopy. The author observed good bond between steel fiber and concrete matrix interfacial zone. Flexural strengths are increased with age and with increase fibers percentage the first crack load was higher and the development was significantly decreased by increased fibers volume fractions in all ages. The author concluded that aspect ratio has significant effect on first crack development in bending.

**Liberato Feirara et. al., (77)** have conducted experimental investigations on cast self compacting SFRC precast prestressed roof elements that are to be used in an industrial building to investigate fiber distribution effect. The authors studied the correlation behavior between fiber distribution and the mechanical properties of the composite slabs to optimize the fresh and hardened properties. The distribution of fibers was checked by X-ray inspections. The authors concluded that the fibers distribution in precast panels results in better performance when compared to plain specimens.

**R. Gattu et. al., (95)** have conducted experimentation work to evaluate the homogeneity and orientation of fibers within the casted
specimens. In their study the authors added 40 kg/m3 of steel fibers to conventional concrete to make cylindrical and prism specimens. Three different techniques for compaction were used to study the orientation, segregation and dispersion behavior of fiber in the matrix. The methods adopted were table vibration, hand tamping and internal vibration. The approach consists of sectioning the specimen longitudinally and transversely to expose the fibers. The fibers that appear on the cut surface are counted and the numbers of fibers per unit surface area of the cut are determined. The densities in different areas of the cut are compared to know the homogeneity of the fiber distribution. The orthogonal cuts provide degree of isotropy of fiber orientation. The authors observed that table vibration for prismatic specimens provided horizontal alignment of fibers. The authors concluded that upto 80 kg/m3 of steel fibers that are to be added to concrete, the visual observation are good for identifying the fibers orientation and distribution. The middle portion of the cylinders has shown homogeneous and isotropic distribution and orientation with appropriate compaction.

Dr. N.Ganesan et. al., (32) conducted experimental investigation to study the combined effect of addition of micro silica and steel fiber on the durability of steel fiber reinforced high performance M60 grade concrete composites by conducting permeability test. The authors considered different percentages of microsilica as 2.5, 5, 7.5 and 10 with three different aspect ratios of steel fibers and three different fractions volume of steel fibers. The authors have observed the
resistance to permeability of plain concrete with addition of microsilica was increased by 63% and with addition of steel fiber, it was about 73%. The study concluded that up to 7.5% permeability was reduced and beyond 10% the concrete has become harsh dry and less workable with aspect ratio of 100, volume fraction of fiber and microsilica at 1%, the reduction in permeability was high up to 90%. Beyond this percentage the permeability has decreased.

**J.Premalatha et. al., (67)** have conducted experimental investigation to study the behavior of the effect of steel fibers and longitudinal reinforcement of high strength fibrous concrete beams. The authors have provided reinforcement in tension and compression zone with short steel deformed fibers having aspect ratio of 60 and 80 were evaluated for the flexural rigidity of cracked rectangular reinforced concrete beams by conducting two point load test. The study concluded that steel fibers reduce deflection, increased the beam stiffness and flexural rigidity and suggested a modified procedure for estimating the effective moment of inertia.

**R.Kumutha et. al., (96)** have studied the effect of steel fibers on the compressive and flexural behavior of conventional concrete. The authors considered aspect ratio of 15, 25, 30 and fiber volume fraction percentages of 0.25, 0.50 and 0.75. Accelerated curing was adopted. The authors have concluded that a fiber volume fraction of 0.5% with aspect ratio 25 was found to yield better strength.

**Calogero et. al., (27)** have conducted experimental investigation on rectangular simply supported reinforced concrete beam
incorporated with hooked steel fiber with and without stirrups subjected to 2 point load test. The authors concluded that displacement controlled tests on beams with fibers under combined action of flexure and shear showed a more ductile behavior with reduced crack widths. Comparable performances in terms of ultimate strength by using shear reinforcement in adequate dosages instead of stirrups were obtained. The brittle shear mechanism can be modified into ductile flexural mechanism allowing a large dissipation of energy by using fibers.

2.5.3 Effect of Using Glass Fiber and Admixtures on Various Properties of Concrete

M. J. Roth et. al., (80) have conducted experimental work on ultra high strength glass fiber reinforced concrete. The authors studied the mechanical behavior and material behavior with third point bending direct tension method for flexural response and comparisons were made with the experimental data. The authors concluded that load displacement response of ultra high strength GFRC panels was essentially a bilinear initial elastic stiffness value equal to two times that of a normal concrete. Large range of displacement at ultimate failure was regarded due to stochastic distribution orientation and concentration of the glass fibers.

Alejandro Enfedaque et. al., (15) have analysed the fracture surfaces of glass fiber reinforced cement (GRC) by performing a tensile test on young and aged GRC specimens that were casted by adding AR glass fiber cement mortar, artificial pozzolana, metakaolin and
acrylic resins. Micro graphs of the fracture surfaces were taken to analyze the effects of admixtures on the micro structure of the Glass Reinforced Cement. The authors concluded that the metakaolin added to GRC mortar changes the microstructure. The effect of silica fume and acrylic resin has no significant effect during tensile tests. Fragile damage was observed after 80 days of immersion of specimen in water at 50°C and concluded that in the first 40 days of immersion of specimens in water showed fragile behavior. Jagged fracture surfaces were obtained when large numbers of glass fibers were pulled out. Irregular fracture surfaces were obtained at early age testing due to glass fiber rupture.

**J. Podbradska et. al., (68)** have studied the properties of glass fiber reinforced cement composites together with measurements of their thermal and hygric parameters at high temperatures of 600 °C and 800 °C. Porosimetry and SEM were done and this was compared to specimens not exposed to any thermal load. Three main effects were found to influence the properties of the specimens. The authors have observed decomposition of the cement matrix Ca(OH)\(_2\) at 480-500 °C and of CaCO\(_3\) between 740°C and 810 °C, but the fibers were keeping the cement matrix together. The experimental work was conducted by using these different types of fibers. Glass fibers from nippon electric glass with length of 35 mm and diameter 14 mm were used, CEM-FIL 70/30 with the length of 6 mm and 20 mm diameter and the w/c ratio used were 0.36, 1.46 and 1.40. The specimens were subjected for 2 hours to the high temperature. The authors concluded
that materials composition also effects the decomposition and the way the composite matrix is made and the curing procedure is followed the intensity of pressure application effects crack spacing and stiffness of the composite.

**G.Barluenga et. al., (40)** have carried out experimental work to study the effect of modified concrete with AR glass fibers at early age on the cracking control of concrete and SCC. The authors conducted mechanical characterization of the concretes in compression and flexure test, free shrinkage test with and without air flow over the samples and a cracking behavior of double restrained slabs. The authors concluded that using low glass fiber content cannot be considered as reinforcement and the mechanical properties observed are similar to normal concrete without fibers. They also do not affect much the flowability properties of fresh state of concretes. The short fibers provided a reduction of the cracked area and crack length. Around 600 g/m3 of glass fiber have shown the maximum cracking control and more than this amount of fibers have little effect on the fiber efficiency and that there is no linear relationship between fiber quantity and cracking control. The drying shrinkage depends greatly on air flow velocity at early age and that low amount of AR glass fibers can control cracking due to drying shrinkage at early ages acting as a local reinforcement when concrete cracks. The authors also observed that when a crack appear and elongate perpendicular to a fiber its cracking control capacity is high and can limit the crack growth.
D.D.L.Chung (29) has reviewed the work done on dispersion of short fibers in cement based materials by considering the methods for enhancing fiber dispersion, the factors that affect fiber dispersion and the relation between the properties of concrete and fiber dispersion. The author has focused on the method of electrical conductivity measurement by D.C. Method to assess the degree of fibers dispersion and focused on steel and carbon fibers which are more electrical conductive. The author has concluded that the degree of dispersion is more improved by the use of admixtures such as silica fume, methylcellulose solution, silane, acrylic particle dispersion and by treating the fiber surface with ozone.

Faiz A et. al., (35) investigated the effect of alkali resistant glass fiber reinforcement in light weight concrete for crack resistance, flexural strength, ductility restrained shrinkage cracking and temperature resistance. The authors have worked on the investigation by taking glass fiber at mass fraction upto 3%. The authors concluded that the alkali resistant glass fibers are highly effective in controlling the restrained shrinkage cracking of light weight concrete and observed that the fibers promote multiple cracking and hence the crack widths are reduced. At 1% mass fraction or by 0.25 volume fraction, the fibers are quite effective in enhancing the properties of the concrete.

Yeol Choia et. al., (128) have carried out experimental tests on compression, split tension and flexural properties of Glass fiber reinforced concrete and polypropylene fiber reinforced concrete and
tried to get a relationship between compression strength and split tensile strength of GFRC and PRFC based on experimental and analytical results. The authors concluded that the split tensile strength of SFRC is 0.67 times the flexural strength and 0.09 times the compressive strength and proposed empirical equation from linear regression analysis as a function of fiber reinforcing index.

**Joao G. Ferreira et. al., (69)** have evaluated the experimental and numerical modelling of GRC mechanical behavior in cyclic and monotonic conditions to assess the structural behavior of GRC telecommunication towers. The authors carried out a non-linear structural analysis program of the model allowing for the numerical simulation of the mechanical behavior of GRC structures at collapse load in monotonic behavior simulation even for significant post elastic deformation and wind dynamic loading.

**Yuwaraj M. Ghugal et. al., (129)** in their paper investigated the performance of alkali resistant glass fiber reinforced concrete. The effect of the glass fibers on workability, density and properties like compression, flexure, split tension and bond strength were studied on the different specimen sizes and observed optimum fiber content as to be strength dependent. The authors concluded that the workability of GFRC gets reduced with the increase in the quantity of fiber and the density is marginally increased. When compared to reference concrete the strength properties are higher and load carrying capacity is increased showing increase in flexural stiffness and ductility of concrete. Empirical expressions were established to predict flexural
strength, split tensile strength, elastic modulus, poisson ratio in terms of fiber volume fraction, compressive strength and aspect ratio.

Marko Butler et. al., (82) have conducted the experimental work on durability of textile reinforced concrete made with AR glass fiber and studied the effect of matrix composition on durability by varying hydration kinetics and alkalinity of the binder mix. The reinforced textile concrete specimens were subjected to accelerated ageing at different duration periods and the specimens were tested under tension. The loss of strength and strain capacity was observed through pullout tests and microscopic investigations. The authors have concluded that performance losses with increasing duration of ageing depends basically on the alkaline behavior of the matrix which has influence on the formation of solid phases in the fiber matrix interface and on the filament surface. The thickness and brittleness of these crusts formed, increases with increasing alkalinity of the matrix and increased portlandite formation in the matrices and the precipitation of Ca(OH)$_2$ between the filaments.

2.5.4 Effect of Using Hybrid Fiber and Admixtures on Various Properties of Concrete

C.Scheffler et. al. (26) in their paper on Inter phase modification of ARGF and Carbon fibers for textile reinforced concrete and effect on durability have concluded that an improved durability of ARGF is achieved by nano coatings based on self cross linking styrene butadiene polymer showing increased tensile strengths.
K.Chandramouli et. al., (73) have conducted long term durability studies on glass fiber reinforced concrete specimens with higher grades concrete by using RCPT. The authors incorporated glass fiber at different percentage ranges from 0.03 to 0.1 and durations were taken upto 180 days. The authors have concluded that the permeability of chlorides in GFRC is low compared to normal concrete without fibers.

John S. Lawler et. al., (70) studied the effect of big length and small length mixed fiber in their work micro and macro hybrid fiber reinforced concrete. In this study hybrid specimen containing macro steel fiber and micro poly vinyl alcohol PVA and single fiber specimen of only macro steel fiber was used. Steel fiber + PVA Hybrid gave the best results in ultimate strength. Flexural displacement < 0.5 mm showed better performance of the above specimen but beyond that it resulted in crack formation. The micro fiber arrests the crack formation during stress but these micro fibers coalesce together and results in macro crack. Macro fiber reinforcement results in multiple crack and displayed lower permeability.

Hsie et. al., (50) studied the mechanical properties of polypropylene hybrid fiber. The authors used two types of polypropylene fiber one coarse filament and other staple fiber. The content of coarse filament is varied at 3 kg/m$^3$, 6 kg/m$^3$ and 9 kg/m$^3$, while the staple fiber content is kept constant at 0.6 kg/m$^3$. Another specimen was prepared with only one type of the above fibers. The study found that the complementary properties of the two fibers
comprising the hybrid specimen resulted in better performance in terms of compressive strength, splitting tensile strength and flexural strength compared to single fiber reinforced concrete specimen. The staple fibers are smaller and highly dispersible thus they arrest cracks in early stages thereby delaying the crack. The hybrid fiber lowers dry shrinkage strain. The study noted that polypropylene hybrid fiber increased compressive strength by 14.60 - 17.31 %, splitting tensile strength by 8.88 - 13.35 % and MOR by 8.99 - 24.60 %.

**G. Pons et. al., (41)** researched on properties of hybrid fiber mixed self compacting concrete. The specimens taken were high modulus metallic fiber with slipping synthetic fiber combinations and individual fiber specimen. These fibers were all reinforced in the concrete matrix. The function of these fibers was studied and it was found that high modulus fibers were helpful during the starting of crack formation. Since they are tightly bound to the matrix, they cannot resist the cracking anymore thereafter the crack develops. The low modulus slipping fibers play a major role. They provide a constant and slightly increasing crack resistance as they are gradually pulled out of their places, thus preventing a fatal break down. This study demonstrated that dual fibers reinforced concrete offers very efficient crack resistance.

**A. Ravichandran et. al., (13)** studied the properties of high strength concrete with hybrid fiber. Here steel-polyolefin hybrid fiber, only steel fiber and plain concrete based specimen are taken. The volume fraction of hybrid specimen was 80 % - 20 %, 60 % - 40 % and
volume fraction of steel fiber was 0.5 %, 1 %, 1.5 % and 2 %. The authors have concluded that flexural toughness of the hybridised specimen was much greater than the steel reinforced specimen. Compressive strength did not improve in either of the above specimen. The non fiber specimen showed the lowest flexural strength and splitting tensile strength. The study showed that 80 % steel – 20 % poly olyfin combination at each volume fraction gave the highest flexural toughness, splitting tensile strength. This was highest for the highest volume fraction at 2 % of fiber used. Cracking characteristics showed a uniform distribution of crack in fiber reinforced specimen. These uniformly distributed crack had very reduced width and length compared to non fiber concrete specimen.

Zongcai Deng, Jianhui Li (130) studied the mechanical behavior of synthetic and steel fiber in hybrid combination. The specimen used had a common fiber volume fraction of 1.5 %. The fibers used were steel fiber and synthetic macro fiber. The specimens prepared were single type of steel specimen and steel + synthetic specimen. The result showed that flexural toughness of hybrid fiber specimen was much better than that of single type fiber specimen. The combination of 0.5 % steel fiber and 1 % single fiber specimen gave a flexural toughness of 80. The single fiber specimen gave highest impact failure life and impact ductile index. The combination specimen i.e. steel and synthetic fiber specimen gave higher first crack impact number.

Y. Mohammadi et. al., (126) studied the impact resistance of steel fibrous concrete containing fiber of dual aspect ratio. The
specimens used were 1 %, 1.5 % and 2 % fiber volume fraction of corrugated steel fiber of size 0.6 x 2.0 x 2.5 mm and 0.6 x 2.0 x 50 mm in different proportion. The impact resistance was found by conducting drop weight test. The result showed that the dual fiber reinforced concrete gave a good impact resistance when compared to plain concrete. In fact the highest volume fraction of 2 % along with the condition that long fiber exceeds the short fiber in the specimen gave the best impact resistance.

Singh S.P. et. al., (115) studied the performance of Flexural fatigue strength of steel fibrous concrete containing dual steel fiber in their work. The fatigue strength was studied for SFRC using steel fibers of dual aspect ratio. The specimens used were 500 mm x 100 mm x 100 mm SFRC with varying volume fraction of 1 %, 1.5 % and 2 %. The dual steel fibers used were 0.6 mm x 2.0 mm x 25 mm and 0.6 mm x 2.0 mm x 50 mm in equal ratio i.e. 50:50 by weight. The 2 million cycle fatigue strength was highest at 72.10 % of static flexural strength for 1.0 % volume fraction of fiber followed by 65.4 % for 1.5 % and 65.40 % for 2.0 %. There was an increase of 58.30% in flexural strength when compared to plain concrete.

L. Vandewalle (78) delved on various ways of measuring, monitoring and modelling concrete properties of hybrid fiber reinforced concrete. The author used volume of fraction of 0.75 % of fiber in concrete. The concrete strength used was 55 and 65 Mpa. The fibers used were straight steel fiber of short length and hooked steel fibers of long length. Three point bending test using notched prism
was conducted. The author observed that ductility and flexural strength of fiber mixed concrete was much better than that of plain concrete mix. The test found that short fibers dominated the cross sectional region of the specimen. This result in low scatter observed in short fiber specimen. The longer length and hook shape of steel fiber helped it to perform well in the wide crack widths.

N. Banthia, N. Nandakumar (86) studied the resistance offered when there is a crack growth in HFRC. The authors used steel fiber as macro fiber and polypropylene as secondary micro fiber in the cement matrix. Fundamental crack tests were performed. The fibers act as stress transfer bridges thereby resisting nucleation of crack. But once the crack nucleates the fibers offer increased fracture toughness and crack tip plasticity thereby controlling the progress of the crack. The authors concluded that a nominal dosage of polypropylene which is a secondary fiber in this experiment enhances the efficiency of the primary deformed steel fiber. It plays a role in matrix cracking and also steel fiber pullout.

A. Siva Kumar, Manu Santhanam (14) studied the properties of metallic and non metallic fibers in high strength concrete. The fiber combination used was steel-polypropylene, steel-polyester, steel-glass. Four point bending test was performed on the specimens. The test concluded that an enhanced pre peak and post peak performance was seen in the load-deflection graph of fibrous specimen. Steel polypropylene (0.12%) specimen gave the best performance in all the strengths calculated in comparison to steel specimen. The other
fibrous specimen fell short in flexural strength as the non metallic fiber proportion increased. Glass fiber specimen gave the worst toughness result.

**P. Srinivasa Rao et. al.,** (93) studied the effect of glass fiber in self compacting concrete in their study on durability studies. Here 2 kinds of specimen were used, one containing glass fiber with self compacting concrete and the other comprise only self compacting concrete. The specimens were immersed in Sulphuric acid solution for 28 days, Hydrochloric acid solution for 56 days and Sodium sulphate solution for 90 days. The durability comprising properties like permeability weight loss and compressive strength were studied. The study concluded that glass fiber reinforced self compacting concrete showed improved durability due to presence of glass fiber. The loss of compressive strength improved with age due to the action of fiber bridging cracks and minimizing permeability. Higher resistance to acid attacks and sulphate attack was reported in their paper for the glass fiber reinforced concrete.

**A. Peled et. al.,** (12) studied the matrix modification in their study on effect of matrix modification on durability of glass fiber reinforced cement composite. Glass fiber durability can be enhanced by using blast furnace slag and dimension stabilizing admixture. The acrylic polymer was added to one set of specimen and in the 2nd specimen set it was not added. 28 days curing time was given. The specimens were submerged in hot water at 50°C for 84 days and then tested for flexure and tension. Comparison was made with dry specimens. The
authors concluded that acrylic polymer with blast furnace slag, NSR and glass fiber specimen gave the highest tensile and flexural strength and improved the durability. This was due to absence of hydroxide ions. Accelerated aging in hot water bath revealed non-densification of glass fiber composite with NSR meaning the fiber matrix interface did not affect the NSR using glass fiber specimen.

H. Guypersa et. al., (45) studied the durability of glass fiber composites. The study covers the damages in cementitious composites with respect to constant and variable environmental loading. Here IPC (Inorganic Phosphate Cement) was used which provides non alkaline environment that prevents chemical attack. Two types of specimen were prepared, one comprises portland cement and glass fiber. The other type comprises glass fiber and IPC matrix. They were subjected to cyclic and constant environmental loading and the classical accelerated ageing in studied. In the constant environmental testing where in the specimen were kept in water at 50°C. The specimens with portland cement and glass fiber combination lost 50 % of their initial strength after the accelerated ageing for 90 days was conducted, whereas the IPC specimens with glass fibers lost just 5% of their initial strengths. The study also revealed that pre cracking stiffness is not affected in any of the specimen but the post cracking stiffness in case of portland cement specimen showed that the specimens totally failed even before multiple cracks could develop. In case of IPC specimen no change was observed in post cracking stiffness after the 90 days of accelerated ageing. In case of the cyclic
environmental testing where the specimens were wetting-drying and freezing-thawing, there was negligible damage during freezing thawing in the IPC specimen which later stabilized. During the drying – wetting process IPC specimens reported damage. This was due to mismatch of deformed fiber and matrix.

2.5.5 Load Deflection Characteristics of Fiber Reinforced Concrete Beams

Sanjay Kumar et.al., (109) have studied the flexural behaviour of short steel fiber reinforced concrete beams. The investigations were conducted on M40 grade of concrete with proportions of 1: 0.75: 2.55 with W/C ratio of 0.38. Fiber volume fractions of 0 %, 0.5 %, 1.0 % and 1.5 % with aspect ratios of 25 and 35 were used. The beams of size 125 mm x 150 mm x 1100 mm were tested under two point load for flexural strength. The test results have shown better performance of the beams with fibers in terms of strength and ductility with optimum fiber volume of 1.0 %. The moment carrying capacities of the beams were calculated by the suggested equations. The authors concluded there is a marginal increase in compressive strength with lower aspect ratio of 25 and at higher aspect ratio of 35 there is further increase in the strength. The moment carrying capacity was increased from 11 % to 15 % in specimens with 0.5 % fiber with aspect ratio of 25 and 35. The specimens with 1.0 % fiber and aspect ratios of 25, 35 showed an increase of 16 % and 17 %. The moment carrying capacity was reduced in beams with 1.5 % fiber. The load
deflection curve was found to follow linear relationship upto certain extent and thereafter the curve becomes non linear.

**A. Bentur et. al., (8)** have investigated the properties of concrete reinforced with both steel bars and steel fibers. The beams of size 100 mm x 100 mm x 1000 mm were tested in flexure in third point loading with a span of 900 mm. The authors have concluded in their studies

1. Steel fiber reinforced concrete beams without conventional steel bars have less improvement than those reinforced beams with steel bars.

2. The reinforcement effect in partial reinforcement in the lower half of the beam with 1.0 % fibers gave results similar to the results obtained by reinforcing the entire beam with 1.5 % fibers. With increase in fiber content ultimate strength was also increasing. At 1.5 % fiber there was a maximum of 55 % increase in ultimate strength. The secant modulus of elasticity was found to be 2 to 3 times greater when compared to beams with only steel bar reinforcement.

3. The pattern of cracking of the beams and the number of cracks has increased with the addition of fibers to concrete beam reinforced with steel bars.

**Xu Shi Lang et. al., (125)** have conducted studies to analyze the flexural behaviour of the beams reinforced with textile combined steel during the entire loading to failure period. The authors presented an analytical equation on load carrying deformation capacity of the section and moment curvature relationship. The study investigated
the flexural component reinforced with the epoxy impregnated textile combined with steel bar based on non linear theory. The concrete cover at the tension zone of the R.C element was partially replaced with textile reinforced concrete. The authors concluded that textiles play their role of fiber bridging leading to not only limiting the development of concrete cracks but also effectively dispersing the harmful wide cracks into much smaller cracks. There were no micro cracks at the interface between the concrete. Moment curvature relationship and load deflection equations were suggested by the authors.

Kiang Hwee Tan et. al., (75) have studied the cracking behaviour of reinforced steel fiber concrete beams under short and long term loadings. Hooked end steel fibers 30 mm long, 0.5 mm diameter with an aspect ratio of 60 in the mix proportion of 1: 1.5: 2.5 with water cement ratio of 0.5 were used. The authors concluded that the beams under monotonically increasing loads with the use of fibers showed smaller crack widths. For sustained loading the increase in crack width was smaller when compared to conventionally reinforced concrete beams.

Giuseppe Campione (44) proposed an analytical model to determine the flexural response of supported beams under four point bending tests. The author considered normal strength beam reinforced with longitudinal bars, hooked steel fibers and transverse stirrups. The load deflection behaviour, maximum and ultimate deflections in the case of shear or flexural failure were studied. In the
case of shear failure, the maximum shear strength of beam was evaluated. In the case of flexural failure the hypothesis of perfect bond of steel bars, concrete and limiting the shear to depth ratio to 2 and 4 was considered. A non linear finite element analysis program was utilized to verify the model. The author concluded that the model is able to determine the maximum displacement corresponding to shear failure and ultimate deflection corresponding to shear failure.

R. Sri Ravindra Rajah et. al., (97) have discussed the studies conducted on the influence of steel fiber distribution on the ultimate strength of concrete beams. On the basis of partial reinforced layers volume fractions of 0 %, 1.0 % and 1.5 % were used. The authors concluded that ultimate flexural strength of beam increases with increase in the thickness of the fiber concrete layer and a 2 layer beam with fibers distributed only in bottom layer has greater ultimate strength than that of a corresponding fully fiber reinforced beam.

T.Y. Lim et. al., (118) have investigated into the moment curvature and load deflection characteristics of SFC beam. The authors have presented expressions for elastic modulus and stress strain behaviour. The authors concluded that the analytical expression predicted the behaviour in flexure of the SFC beams from both strength and deformation points tested under third point and centre point loading.

2.5.6 Applications and Uses of Glass Fiber Composites

J.G. Ferreira et. al., (64) have conducted experimental program for assessing the mechanical characteristics of GRC for its structural
use. In their study the authors have concluded that the premix GRC is better adopted for the production of structural elements when compared to spray technique that is adopted for tension loads. The results of the experimental investigations were used in a numerical model to obtain design bending moment and axial load collapse curves of GRC telecommunication towers cross sections. The results given by numerical model closely match the cross sections resistance evaluated in the experimental collapse tests of prototype towers design.

**G.T. Gilbert (42)** in his paper has explained the fundamental principles behind GFRC which is a thin composite based on AR glass fibers with excellent strength to weight ratio and has given examples of applications from highly visible architectural panels on low and high rise buildings to decorative elements. The examples of uses of GFRC are

1. Cladding in modular buildings. The buildings were constructed with AR glass fiber reinforced cementitious sandwich panels integrated into a light weight steel structural frame during erection. The sandwich panels consist of two 8 mm thick AR fiber reinforced concrete skins attached on to both sides of a 155 mm thick core of light weight concrete. These buildings were tested for load capacity, sound insulation, thermal conductivity and fire resistance and were found to be in good serviceable conditions. These are being used in Scotland.
2. GFRC Architectural Facade Panels were used in buildings exterior or as window units, spandrel, soffit, roof elements, cornices and column covers. The panel skin consists of 12.5 mm thick FFRC attached to a structural frame which in turn was attached to the building. These are applied in various projects like City project in Cairo, San Francisco Towers complex in California.

3. Decorative elements, Road and Rail sound walls, Ducts and channels, Cable and pipe ducts, conduits tunnel and sewer lines were applied in Heathrow express railway station construction in London.

4. Pipes, Poles and bridge parapets were used in construction of Skytrain project in Thailand.

J. Jones (65) in his paper describes four specific applications that illustrate the benefits that GFRC offers to the construction industry. The applications include architectural panels, energy efficient housing, sewer lining and permanent formwork.

2.6 CRITICAL OBSERVATION FROM THE LITERATURE REVIEW AND AIM OF THE PRESENT RESEARCH.

Exhaustive literature survey has been conducted on the basic properties of cement concrete and the influence of fibers on concrete behaviour. The benefits of SFRC where in only steel fibers are employed are well known. Most of the researchers have concentrated their effects on the use of steel fiber reinforcement in concrete to enhance its strength properties. There are certain drawbacks in SFRC like inherent brittleness, multiple cracking under crushing loads and not so well defined flexural behaviour particularly when used with
random orientation. Another draw back with SFRC is the balling effect particularly when the fiber percentage is more than 1.0 with aspect ratios of more than 40. There are other types of fibers like polypropylene, glass, polyester etc., which were not tried much in concrete because they do not contribute much towards strength increase, but their influence on cracking ductility etc., may be considerable.

A few researchers have delved on the topic of dual fibers and hybrid fibers making use of synthetic fibers with steel fibers.

In the literary review it was observed that

1) Not much work has been carried out to study the effect of mixed fibers of alkali resistant glass and steel on concrete properties like elastic properties, impact strength, permeability and acid resistance for structural applications.

2) It was observed that not much work has been carried out to find the optimum use of microsilica in the mixed fiber reinforced concrete to produce good strength and durable concrete.

3) It was observed that no work has been carried out to find the optimum mix fiber proportions.

4) It was observed that no work has been carried out to obtain maximum percentage of total fiber to be used in mixed fiber reinforced concrete along with silica fume.

5) It was observed that no work has been carried out to find the effect of mixed fiber reinforced concrete on flexural behaviour of beams for structural applications.
Hence mixed fiber composite consisting of steel and glass fibers may satisfy the requirements of strength, cracking, ductility, acid resistance impermeability etc. Hence the experimental program is planned to study concrete composites using dual fibers to develop Mixed Fiber Reinforced Concrete (MFRC) possessing strength and other properties like crack resistance and durability. Researchers have already established that microsilica is a very useful pozzolona which not only contributes to strength increase but also towards durability. Hence microsilica is also considered in this investigation.