CHAPTER 2
REVIEW OF LITERATURE

2.1 GENERAL

Many scientists and researchers have studied the various aspects of causes of damages and remedial measures to bring the structures to the design intents. The repair and rehabilitation methods have been carried out in many ways on damaged structures in the construction industry. Many retrofitting techniques used for strengthening of new and existing structures are available in the market. A brief review of various repair, rehabilitation and retrofitting methods adopted in the civil engineering structures are presented in this chapter.

2.2 STUDIES ON REHABILITATION OF RC STRUCTURES

2.2.1 Studies on Rehabilitated Beams with FRP Laminates

Sharif et al (1994) demonstrated the feasibility of strengthening structurally deteriorated concrete beams using externally bonded GFRP plates. Their primary interest was the achievement of the full flexural capacity of the strengthened beams. They formulated theoretical analysis for predicting the flexural strength and the plate separation load and compared them with the experimental results. The flexural capacity of the strengthened beams is found by means of a simple flexural theory based on the ACI ultimate strength method considering strain hardening in steel. They assumed that the strain at the extreme bottom fibre and the flexural strength were computed from compatibility and equilibrium equations, using trial and error procedures. They used three different thickness of GFRP plates such as 3 mm, 2 mm, and 1 mm. They found ultimate flexural strength for the repaired beams with 3 mm, 2 mm, and 1 mm plate thickness and compared the results theoretical results.

Tom Norris et al (1997) studied the behaviour of retrofitted RC beams with CFRP sheet by experimental and analytical investigations. The CFRP sheets bonded the web and soffit of RC beams for flexure and shear strengthening. The strength and stiffness of beam was found for different CFRP sheets fibre orientation with the axis of the beam. The stiffness and strength were increased to a greater extent when the CFRP fibres were placed perpendicular to the crack of beams. The stress
concentration near the ends of CFRP leads to concrete rupture that resulted in a brittle failure. The stiffness and strength increased in a small way when the CFRP fibres were placed obliquely to the crack of beam. Warning signs such as snapping sound or peeling of CFRP were observed by a more ductile mode of failure that is in relation to the off-axis application of CFRP.

**Khalifa et al (1998)** conducted tests for shear capacity on RC flexural member externally bonded with FRP. They used carbon FRP bonding system for increasing capacity of beam in shear by varying parameters and presented the performance of strengthened beams.

**Saadatmanhesh and Malek (1998)** presented new guidelines to use epoxy bonded FRP plates to strengthen reinforced concrete beams. Before upgrading a concrete beam, it undergoes stresses and the effect of that was considered in the design principle. The rupture of plate and concrete crushing at ultimate load level were considered as failure modes of strengthened beams. They have developed a set of equation to predict the load carrying capacity of beams based on developed stress in tension and compression at failure. Failure of beams due to debonding of plates was also considered in developing these guidelines. Local failure of concrete beam at the plate end and debonding the plate due to shear stress concentration at the flexural cracks were also considered in developing these guidelines. They included reliability studies to develop appropriate strength reduction factors particular to the unique nature of their structural system.

**Spadea et al (1998)** studied the CFRP strengthened beams for flexure. They have tested four beams using sophisticated instrumentation. The width and depth of beams were 140 mm and 300 mm respectively. The length of beam was 5 m with an effective span of 4.8 m. They used high sensitivity load cell of 100 N and tested by displacement control system. They used highly sophisticated instrumentation to find the strains, deflection and curvature over the entire loading upto failure of beams. They found that anchorage system at plate ends and at different locations showed better results when compared to strengthened beams without any anchorage system. The maximum benefit was achieved by using suitable external anchorage system provided at critical sections along the span of the CFRP strengthened beams. The
structural degradation of FRP strengthened beams was found due to bond slip between FRP plate and bottom face of the concrete surface of the beam. They found that the suitable external anchorages can improve the ultimate load carrying capacity of beams upto 70% when compared to control beams.

**Mahmoud et al (2000 a)** presented an analytical study to estimate the load carrying capacity of beams strengthened with fibre reinforced polymer plates. They used compatibility and equations of equilibrium for finding load carrying capacity of beams for rectangular and T-beam sections. The maximum and minimum area of FRP plates were established to ensure ductile failure of strengthened beams. They developed nomograms for design procedure for FRP strengthened beams. They have compared the available experimental data in the literature with their developed analytical procedure. They analysed FRP strengthened RC beams using three failure modes namely compressive zone concrete crushing before steel yielding, tension steel yielding with rupture of FRP plates and tension steel yielding with crushing of concrete. In addition, some other failure modes also considered such as shear failure of concrete, anchorage failure and FRP plate debonding from the bottom face of concrete beams.

**Mahmoud et al (2000 b)** investigated the deflection of FRP strengthened RC beams. They proposed a design procedure to find out the deflections of FRP strengthened beams under flexure. This gives a better result when compared with Branson’s equations adopted by the ACI code. They have considered three stages of load deflection curve namely precracking, cracking and postcracking stages for FRP laminated RC beams. They developed new expressions for the calculation of effective moment of inertia for FRP strengthened beams at the cracking and post cracking stages. The deflections calculated using these expressions were found to correlate well with the measured deflections in laboratory beam tests. They have presented a numerical example to calculate the load carrying capacity and deflection of beams using their developed equations.

**Rabinovitch et al (2001)** developed a design procedure for testing of CFRP and GFRP strips strengthened beams for flexure using non-linear analysis. They used closed form higher order approach in non-linear analysis to predict the flexural behaviour of RC beams. The developed models were based on compatibility,
equation of equilibrium and non-linear analysis of various materials. The analytical predictions with experimental values were compared and found very close correlation among them. They found that the use of linear analysis for predicting the behaviour of RC beams underestimated the stresses in the FRP layer and in the adhesive layer. They modelled FRP strip strengthened beams by introducing prestress in the FRP strip. The stresses at the ends induced by the prestressed FRP strips are found very high.

**Sobhy Masoud et al (2001)** carried out an experimental programme to investigate the structural behaviour of RC strengthened beams exposed to a corrosive environment. They strengthened the beams by CFRP sheets and corroded the beams by accelerated corrosion process. They tested the beams for monotonic loading and fatigue loading. They tested the beams for flexure using four point bending system. They found that the CFRP strengthened beams subjected to corrosion enhanced the structural behaviour of beams. They concluded that CFRP strengthened-corroded beams could take 37% to 87% more load than those predicted in unstrengthened - uncorroded beams in monotonic loading and 2.5- 6 times more in fatigue loads than in unstrengthened corroded beams.

**Kim and Sebastian (2002)** tested externally strengthened beams with CFRP plates. They studied the behaviour of the plate - to - concrete bond in FRP plated concrete beams under short term loading. They found that a majority of bond failures occurred through the concrete layer at 6 mm from the plate adhesives. The degree of simulated corrosion of the steel bar increased from 57% to 78% then a loss of rebar area occured over a short length near mid span and 50% reduction of the flexural crack - bond failure load.

**Malek et al (2002)** developed equations for strengthening of flanged beams by FRP laminates subjected to gravity loads. The equations based on resistance factor and the ultimate load factor were calculated. They found a close agreement between experimental results and equations developed. They considered the failure of strengthened beams due to rupture of plates, shear failure of plate ends and crushing of concrete.
Alagusundaramoorthy et al (2003) studied the flexural behaviour of carbon fibre reinforced polymer sheet bonded beams and found the increase in load carrying capacity of strengthened beams. They tested fourteen beams in four point bending and found the enhancement of ultimate load of beams. The load carrying capacity of CFRP plated beams showed an increase of 49% over the control beams and anchored CFRP sheet strengthened beams showed an increase of 58% over the control beams. The beams strengthened with CFRP fabric showed an increase of 40% load carrying capacity over the control beams.

Deniaud et al (2003) conducted tests on shear strength of T-beams strengthened with FRP sheets. They used uniaxial glass fibre, uniaxial carbon fibre and triaxial glass fibre for strengthening the web of Tee beams. The beams exhibited the increase in maximum shear strength between 15.4 and 42.2 percent over beams with no FRP. They found that the glass fibre reinforced beams exhibited more ductile failure than the other FRP reinforced beams.

Hsu et al (2003) studied the flexural behaviour of RC beams strengthened with CFRP sheets using anchorage at the ends of CFRP strips on the tension face of the beams. They conducted tests on strengthened beams designed as under and over reinforced beams. The flexural capacity and ductility of strengthened under reinforced beams were adequate while these parameters did not improve in strengthened over reinforced beams.

Aiello and Ombres (2004) presented the developed non-linear model derived for RC beams strengthened with CFRP sheets using cracking and deformability analysis. They considered bond stress and slip in cracking analysis. Tension stiffening of concrete was also taken into account for the calculations of load carrying capacity of beams. They studied load transfer mechanism between concrete and CFRP sheets. The slip between the concrete and steel bar was also considered. The developed model was validated with the experimental results obtained by Beber et al (2001) and Spadea et al (1998). Their non-linear analysis predicts flexural behaviour of RC beams strengthened with FRP sheets accurately.

Bonfiglioli et al (2004) assessed the stiffness variations based on modal analysis due to damage and retrofitting with CFRP sheets in RC beams. The dynamic tests were
performed with shock excitation, applied by an impact hammer. Accelerometers were used as receiving transducers. The frequency was measured by fast fourier transform. The decreased values of frequency in damaged beams and improvement in retrofitted beams were clearly observed. They developed an analytical model based on fracture mechanics to simulate both static and dynamic behaviour of beams, with and without cracks.

Heffernan and Erki (2004) tested the fatigue behaviour of twenty numbers of RC beams strengthened with CFRP laminates. The cross section of beams was kept constant as 150 mm x 300 mm and cast beams with two different length of 3 m and 5 m. They tested CFRP strengthened beams with 2, 4 and 6 CFRP sheets and compared the results with control beams. In 5 m span, brittle failure of beams was observed and reported. The static and cyclic loading were applied on beams and found similar behaviour at all instances when compared to theoretical calculations for both 3 m and 5 m beams. They found that the tensile stress in steel used in CFRP strengthened beams was less when compared to control beams. The load carrying capacity and stiffness of CFRP strengthened beams was also increased when compared to control beams.

Kutarba et al (2004) evaluated the flexural strength of corrosion damaged and strengthened beams with CFRP sheets. The corrosion was introduced to embedded reinforcement after applying small amount of flexural loading to cause cracking of concrete and salt solution was allowed to penetrate into the beams. A constant current of 5 V was applied to accelerate the corrosion process in the reinforcement for 28 weeks. The damaged cover concrete was removed and new concrete was applied to regain its original shape. Then 1 mm thick CFRP laminates were bonded and corroded for about 22 weeks. They found that the post repaired and strengthened specimen showed 9 to 12% reduction in load carrying capacity of beams. They also found that stiffness of beams gets reduced due to corrosion of reinforcement and the stiffness was improved in CFRP laminated beams. The corrosion rate was decreased in CFRP laminated beams due to lesser amount chloride diffusion.

Sang Hun Kim and Riyad (2004 a) investigated the flexural strength of CFRP sheet strengthened RC beams. Sixteen full-scale beams were tested in four groups with rectangular and T beams. They have strengthened the beam with different
pattern of CFRP reinforcement in longitudinal as well as lateral direction with different end anchorages. They found that the flexural capacity of beams with CFRP diagonal anchorage system was showing increase in flexural strength and ductility at the ultimate load level. The diagonal anchoring system changed the mode of failure in CFRP laminated beams from brittle mode to ductile mode because the diagonal anchors sustained the longitudinal CFRP reinforcement even though it was totally debonded from the concrete surface. For the comparison, analytical ultimate strength was calculated based on equations provided by ACI 440 Report (2000). The ACI 440 design practice considered two additional reduction factors, the long term environmental reduction factor and additional strength reduction factor. The long term environmental effects value of 0.95 was for interior exposure and a value of 0.85 was for exterior exposure. The additional strength reduction factor of 0.85 specified in the ACI 440 Report was used. The CFRP composite laminates are very effective in increase in load carrying capacity of beam in flexure. The use of the CFRP strengthening system resulted in increasing shear demand. The use of the additional anchorage system can further increase the flexural strength and ductility.

**Sang Hun Kim and Riyad (2004 b)** conducted FEM analysis for CFRP sheet strengthened RC beams to increase the load carrying capacity as well as ductility of beams. The FEM model utilizing both perfect bonding and without perfect bonding elements at the concrete CFRP interface for flexural strengthening were presented. The results were compared with experimental results of sixteen full-scale beams for the load-deformation relationship. For the perfect bonding model, CFRP elements were smeared into solid elements, and for the non-perfect bonding model, bonding elements were used for sensitivity analyses. The experimental and finite element analysis results were matching well. The results of the FEA perfect and non-perfect bonding models differed by 1 to 7% from the experimental test result. The ultimate load values calculated based on the ACI 440 equations differed by up to 22%. The failure modes of the FEA models were in good agreement with those of the experimental beams.

**Santhakumar et al (2004)** simulated the behavior of retrofitted RC beams and analysed numerically. They analysed the control beam and retrofitted beams with
CFRP sheets. The software package ANSYS was used for this study. The load deflection curves obtained from FEM analysis compared with the experiment carried out by Tom Norris et al (1997). The ANSYS show good agreement with the experimental values. Their modeling helped in knowing the crack formation and propagation in retrofitted beams in which the crack pattern could not be seen by the experimental study due to wrapping of CFRP sheets.

Thomsen et al (2004) conducted tests on CFRP and GFRP strips strengthened RC beams in flexure. They studied the failure mode of beams and found that the failure pattern of strengthened beams based on the length of FRP plate length.

Zhichao Zhang et al (2004) investigated the shear failure occurred in deep beams. They found that the deep beams can be improved in load carrying capacity by bonding CFRP reinforcements externally. Deep beams strengthened with CFRP strip and fabric were tested without shear reinforcements. The CFRP strip and fabric with different orientations with axis of beams were tested. The beams were designed as under reinforced beam as per ACI code. They found that decrease in ratio of shear span to effective depth leads to increase in shear capacity of CFRP laminated deep beams. The CFRP fabric and U-shaped CFRP laminate strengthened deep beams showed as decrease in shear span to effective depth ratio decreases in shear capacity of beams. But in double layer CFRP laminated beams showed increase in shear capacity of beams

Maaddawy and Soudki (2005) investigated the corrosion damaged RC beams strengthened with CFRP laminates. They tested the beams with different degrees of corrosion upto 31% and strengthened the beams by 1mm thick CFRP laminate. In their tests, the failure of beams took place as crushing of concrete in control and corroded beams. They observed rupture of CFRP laminates causes failure of beams preceded by yielding of tensile reinforcement. They also found that deflection in CFRP laminated repaired beam reduced significantly when compared to control and corrosion damaged beams. The deflection in corrosion damaged and repaired beams with CFRP laminates reduced by 46% when compared to the control beams.

different reinforcement ratios with dimensions 150 mm wide, 200 mm depth and 2000 mm length were cast and tested. Out of twelve beams, three beams were kept as control beams and remaining nine beams were strengthened with CFRP sheets, with different width, length and number of CFRP sheets. All the beams were tested in flexure by four-point bending. They measured deflection and compressive strain in mid-span of beams. The load carrying capacity and stiffness of strengthened beams were increased when compared to control beams. They compared the experimental results with ACI 440.2 R-02 (2002) and ISIS Canada (2001) and it was found that they overestimated the CFRP sheet strengthened beams in flexural strength.

Jayaprakash et al (2007) found the externally bonded fibre reinforced polymer was a good technique for improving strength of RC structures. A series of ten large scale rectangular beams of size 120 mm x 340 mm x 2980 mm were cast in four series. In each series one was kept as control beam and remaining beams were precracked and strengthened with CFRP fabric strips. The test procedure consisted of two faces. The first face, precracks were developed by applying two cycles of loading and tested the CFRP strengthened beams in the second face. This study confirmed that the shear capacity of CFRP beams increases with increase in spacing of CFRP strips. They have used bi-directional CFRP strips and found this technique very effective to upgrade the strength of beams. They also stated that bi-directional CFRP strip controlled the debonding of CFRP strips from bottom face of the beams.

Toutanji et al (2007) conducted a study on organic and inorganic resin based CFRP strengthened RC beams. This study was divided into two categories of beams such as strengthened using organic and inorganic resin. The organic resin was containing two component system such as resin and hardener. In inorganic resin, aluminosilicate powder was blended with water. In the first category, beams were strengthened with two, three and four layers of CFRP sheets, whereas in second category, two, three, four and five layers of CFRP sheets used for strengthening of beams. They tested both categories of beams in flexure and found that inorganic resin system was very effective in load carrying capacity and increase in stiffness of beams when compared to beams with organic resin system. They also stated that the load transfer mechanism of organic and inorganic matrix system is different. The
beams with inorganic resin based CFRP sheets showed micro cracks and failure occurred by rupture of CFRP sheets, whereas organic resin based CFRP sheet failed by delamination. Both systems significantly reduced deflection. The ultimate load capacity was similar but the yield load was different in both systems.

**Lijuan Li et al (2008)** evaluated the performance of FRP strengthened RC beams bonded with CFRP and GFRP sheets. They tested three types of beams such as control beam, polypropylene fibre reinforced concrete beam and hybrid fibre reinforced concrete beam containing polypropylene and steel fibres. The strengthening method of beams carried out using single layer of CFRP sheet, single layer of GFRP sheet and bi-layer using GFRP and CFRP sheets. They found that these three different strengthening methods possessed different effects on stiffness and load carrying capacity of beams. The CFRP sheet strengthened beams showed an improvement in ultimate load carrying capacity and stiffness in fibre reinforced concrete beams. The GFRP sheet strengthened beams showed reduced load carrying capacity and increase in ductility whereas stiffness and strength of beams increased in beams strengthened by combining CFRP and GFRP sheets.

**Mohammad Reza Aram et al (2008)** investigated the different modes of failure in debonding of FRP plates in flexural strengthened beams. They conducted four points bending test on beams strengthened with FRP laminated beams and compared with analytical and finite element solution. Results were compared with existing international codes. They have recommended the limiting shear stress to tensile strength of concrete and strain is limited to 0.08 to prevent debonding of plates.

**Costa and Barros (2010)** conducted the study on CFRP strengthened RC beams both experimentally and numerically. They found a decrease of 10% in load carrying capacity of beam when there was a cut in bottom arm of steel stirrups. Shear failure was predominant due to high effectiveness of FRP strengthening system. They used U type wrapping of CFRP sheet to avoid shear failure of beams.

**Shanmugam et al (2010)** investigated the study of influencing parameters such as carbon and glass fibre wrapped over the bottom of RC beams. The size of beams were 100 mm x 200 mm with three varying length of 900, 1200 and 1500 mm (three series). Beams were tested in flexure under four points load condition. In each
series, five types of beams such as control beams, beam with GFRP fabric, beam with CFRP fabric, beam loaded up to ultimate and strengthened with CFRP and GFRP fabrics are cast. The first crack load increased in three series of CFRP strengthened beams are 47-95, 43-78 and 39 percentage respectively compared to control beam and strengthening of beams increases the percentage of yield loads are 67, 63-83 and 43-126 in three series of beams compared to control beams. The ultimate load at failure was increased in strengthened beams considerably.

Sheth and Gajjar et al (2010) conducted the study of strengthening using FRP in RC beams to increase the strength in flexure. The cross section of the beam was 230 x 450 mm and length of 5 m. After completing the retrofitting for RC beams for flexural with FRP and steel plate, the cost of material for FRP strengthened beam was 10% less than the retrofitted beam with steel plate. They compared IS code and ACI code for flexural capacity of with and without FRP strengthened beams and found that IS code design estimated 24% less than ACI code in flexural strength of beams.

El-Ghandour (2011) investigated beams strengthened for flexure and shear by CFRP sheets. He used different shear and flexure sheet ratios and tested in three point bending. Longitudinal CFRP sheets were used for flexure and U type wraps used for shear. The size of beam was 120 mm x 300 mm x 2000 mm. The mode of failure, crack pattern and load carrying capacity were based on geometry of beams and scheme of strengthening pattern. He found an increase of 33.3% load at first crack and improvement of crack pattern of beams. The width and spacing of cracks were reduced with increase in stiffness of beams.

Jung Deng et al (2011) conducted test on CFRP strengthened beam and found improvement in strength and stiffness of beam. An analytical solution developed for composite beams using FEM modelling on CFRP strengthened beams. Both analytical and the finite element models (ANSYS, 2003) were used to validate the experimental work carried out by Tavakkolizadeh and Saadatmanesh (2003). The result showed that Hognestad theory, the AASHTO method, proposed method and finite element, all provided conservative prediction for the flexural capacity by 9.3%, 11.1%, 4.6% and 5.7% respectively.
Yasmeen Taleb Obaidat et al (2011) conducted a study on CFRP strengthened RC beams for flexure and shear. They have tested twelve RC beams in four point loading. The mechanical properties of concrete, steel and CFRP laminates were found out. The stiffness of RC beams strengthened by CFRP laminates got increased when compared to control beam. The load carrying capacity of CFRP strengthened beam increased by 23% compared to control beam and width of crack also increased in strengthened beam. The strengthened beams were failed due to debonding of CFRP plates.

2.2.2 Studies on Rehabilitated Beams with Stainless Steel Plates

Irwin (1975) performed tests on two reinforced concrete beams in flexure. One beam had external bonding of steel plates using epoxy resin on tension face and the other was without external reinforcement. The test results indicated that (i) highly localized stresses in the concrete and adhesive layers might be produced (ii) when bonding was increased progressive failure of the bond might began at a crack bridged by the steel plates and (iii) the bond strength of the epoxy resin might be affected by static loading and long term creep.

Solomon et al (1976) conducted tests on seventeen sandwich beams (steel plate on both the faces of concrete core) in which all the beams collapsed due to debonding between the tensile steel plates and the concrete core. The surface of the bottom plates showed that a thin layer of concrete remained stripped off from the concrete core during debonding.

MacDonald (1978) conducted tests on four RC beams strengthened with steel plates at the bottom face of beam with epoxy resin adhesive. The beams were tested for flexural behaviour of RC beams. The results showed that all the beams failed by horizontal shear in the concrete adjacent to the steel plate. It was noted that the calculated interface shear stress between the concrete and the steel at failure (ignoring the thickness of adhesive) was less than the normal shear strength of the concrete used.

Cusens et al (1980) tested plain concrete beams with external steel plate reinforcement. The failure was primarily due to bond failure at the interface of the
concrete and the steel plate. The steel plates yielded first and crushing of concrete in compression took place in the immediate vicinity of the load and the steel plate debonded.

**Jones et al (1982)** tested eight RC beams with steel plates at the bottom of beams. They tested beams of length of 2.25 m by four point bending system. The results indicated that the external plate increased the bending stiffness and the load carrying capacity of beams. They found the debonding of steel plates occurred when the shear stress reached to maximum level at the interface.

**Rao et al (1995)** conducted tests on RC beams strengthened with stainless steel plates using newly developed epoxy adhesive resin. The ultimate load capacity was increased by bonding stainless steel plates at the bottom of the beam by using epoxy resin. They cast seven beams of size 150 mm x 150 mm thereby keeping one as control beam and remaining beams for retrofitting purpose. Three beams were strengthened with epoxy bonded steel plates whereas the remaining three beams were strengthened with mild steel plates attached with three different type of expanding bolts. The beams were simply supported and tested by two-point loading applied at one-third positions. The beam strengthened with epoxy bonded plates yielded a higher ultimate load carrying capacity, accompanied by a reduction in deflection and crack width. The beams strengthened with mechanically attached plates exhibited a better ductility behaviour thus providing adequate warning before the impending failure.

### 2.2.3 Studies on Rehabilitated Beams with Ferro Cement Laminates

**Anwer et al (1991)** conducted experiments on RC beams strengthened with ferrocement laminates. Hexagonal chicken wiremesh and skeletal steel combined with ordinary plastering were applied on tension face of the RC beams. They tested the strengthened beams and developed a design chart to determine the parameters for rehabilitation of beam elements.

**Onet et al (1992)** tested the behaviour of ferrocement in flexure. The tested ferrocement elements of plate and beam types had a good behaviour under working load due to the fact that the width of cracks appeared to be very small when
compared to reinforced concrete. The impermeability, stiffness, and durability of the ferrocement elements were much improved.

**Ong et al (1992)** investigated the load carrying capacity of RC beams strengthened by ferrocement laminates at the bottom of beams. They found that the load carrying capacity of beams increased with increase in stiffness of beams. The strength of beam reduced by reducing volume fraction of reinforcement in ferrocement laminates. They also found that the spacing and width of crack reduced in the beams strengthened by ferrocement laminates.

**Paramasivam et al (1993)** conducted test on damaged and repaired beams using ferrocement laminates. The overloading damage cracks were filled by injecting epoxy resin. Then the beams were rehabilitated with thin ferrocement sheets. The ferrocement laminated RC beams were tested for flexure and found increase in load carrying capacity of beams when compared to control beams.

**Paramasivam et al (1998)** conducted a study on T-beams strengthened with ferrocement laminates at the side face of web of beams. The reinforcement cages were prefabricated and attached to the side of the web by mild steel dowel bars. They found this technique performed well when compared to other types of shear strengthening methods. The ferrocement laminate bonded at the soffit of the beam delayed the first crack load and reduction in crack width with increase in flexural stiffness and load carrying capacity of beams.

### 2.2.4 Studies on Patch Mortar / Concrete Repairing

**Manjrekar (1995)** argued that polymer modified cement concrete/mortar were best suited for repair and rehabilitation works. The use of polymer called Styrene Butadiene Rubber (SBR) has been discussed in detail. The author also mentioned the International codes available on standards of materials / chemicals used for rehabilitation works.

**Folic and Radonjanin (1998)** studied the effect of polymer modified concrete by adding styrene butadiene rubber latex with 2.5, 5, and 7.5 percent on the cement mass. To find out the mechanical properties of polymer modified concrete, they cast and tested about 180 concrete samples of cubical, prismatic, and cylindrical shapes.
They found the increase in tensile strength, ductility, bond between reinforcement and concrete, improvement of properties contributing the durability of reinforced concrete structures.

Ali et al (1998) carried out the investigation of repair mortar ranging between simple plain cement mortar to complex formulation containing SBR latex, silica fume, methylcellulose, accelerator and carbon or glass fibres. They studied the characteristics including compressive, tensile, flexural and flexural bond strengths. They concluded that addition of SBR latex to modify plain cement mortar at the rate of 10% solid content by weight of cement was found to be most advantageous. The workability, tensile, flexural and flexural bond strength were found improved while a slight reduction in compressive strength was noticed. It was not significant for repair applications.

Rio et al (2005) presented the behaviour of patch – repaired RC beams, after subjecting them to corrosion in steel reinforcement at mid span due to chloride penetration. They used polymer mortar with cement based, epoxy as binder for repairing the damaged portions. They found that the ductility coefficient in deflection was increased due to reduction area of reinforcement due to corrosion. The repaired beams with polymer mortar showed an increase in load carrying capacity of beams when compared to corrosion damaged beams but decrease in capacity of beam when compared to control beams. The results showed that the load carrying capacity decreased with increased degree of corrosion. The steel reinforcement in tension zone yielded at lower loading when compared to control beams. The patch repair on RC beams is found to be a cost effective method when compared to other repair techniques used in the construction industry.

2.3 SUMMARY

The review of the available literature is summarized below:

1. Most of the repair, rehabilitation and retrofitting works have been done on FRP material.

2. Some researchers have used polymer based repair techniques.
3. Some of the works studied the rehabilitation methods using steel plates by plate bonding technique.

4. The study of FRP sheet / laminate strengthening process carried out for damaged beams.

5. Some researchers presented FEM modeling for predicting the study of FRP strengthened beams.

6. The effectiveness of strengthened beams carried out with limited number of experimental studies.

The various systems of the strengthening techniques carried out on beams are well understood from the above literature study. The GFRP and CFRP sheet strengthening technique was used and found as an effective method of repair system of beams. Most of the studies are based on their country environment with their own materials. Those studies may not be reflected on the study carried out with the Indian environment. It is concluded that an experimental study is necessary to know the behaviour of beams with varying strength retrofitted with the locally available GFRP and CFRP sheets.