CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Many scientists and researchers have studied the aspects of causes of damages in structures and the required remedial measures to bring it into the satisfied level. The assessments of damages due to various causes and the novel rehabilitation techniques can be made in many ways. A brief review of the works done by various authors is presented in this chapter.

2.2 STUDIES ON EPOXY BONDED STEEL PLATES

MacDonald and Calder (1982), studied the behaviour of concrete beams externally reinforced with steel plates bonded to their tension flanges. They tested a series of beams under four point loading. Results showed that full composite action was provided by the adhesive and that significant improvements in performance could be achieved in terms of load, crack control, and stiffness. Exposure tests were carried out on unreinforced concrete beams with steel plate bonded to one face. Results showed that significant amounts of corrosion of the steel plate may take place due to natural exposure. Also loss in bond strength at the steel-epoxy interface was observed resulting from the corrosion of the steel plate. The reduction in the overall strength of the exposed beams was attributed to the corrosion.

Van Gemert and Vanden Bosch (1985), reported the results of durability tests on concrete beams with epoxy bonded steel reinforcements. They studied the effects of long term exposure, fatigue, and temperature loading and concluded that the effects of atmospheric corrosion depended for the greater part on the preparation of concrete and steel plate surfaces and on the workmanship of the repair crew. Therefore more specialized personal and a careful control of the preparation work would be necessary.

Swamy et al. (1987), studied the strengthening of reinforced concrete structures by adhesive bonding of external reinforcement in the form of steel/ composite plates. The external bonding had been the subject of considerable research and it had proved to be an effective technique of restoring, upgrading the serviceability and strength of reinforced
concrete flexural members. Plate bonding technique was found to be less invasive and could be easily carried out without causing any additional structural damage.

Neelamegam et al. (1998), carried out an experimental investigation on RC beams strengthened by external bonded steel plates. The parameters like the plate thickness, plate length, type of end anchorage, and the effect of pre-cracking were considered. The test results were discussed with reference to the available theoretical and empirical approach. They concluded that by proper analysis and careful design it was possible to enhance adequately the strength and serviceability characteristics of RC beams by plate bonding technique and overcome possibilities of premature failure due to plate separation and also the ultimate strength and ductility of plate bonded RC beams were improved by the provision of end anchorages.

Gehlers and Moran (1990), studied the effect of flexural peeling stresses on the serviceability and ultimate strength of upgraded concrete beams with bonded plates. The failure of beams caused by large cracks in the concrete region between the plates and the longitudinal steel re-bars was categorized in terms of forces that were present near the end of plates. That paper focused mainly on the problem of flexural peeling and the effect of shear forces which had no flexural peeling to the formation of diagonal shear cracks. Equations were developed to predict the ultimate peeling moment that caused the initial formation of peeling cracks. It was concluded that the peeling strength depended on the flexural rigidity of the cracked plated section, the tensile strength of the concrete, and the thickness of the plate.

Hamoush and Ahmad (1990), investigated the behaviour of damaged concrete beams strengthened by external bonded steel plates, using linear-elastic fracture mechanics and the finite element method. The study investigated the failure by interface de-bonding of the steel plate and the adhesive layer as a result of interfacial shear stresses. Simply supported concrete beams under monotonically increasing symmetric loads were considered in the study. They reached the conclusion that the strain energy release rate for an interface crack between steel plate and adhesive layer was negligibly small and the steel plate-strengthened beams had high interface bonding load and the strain energy
release rate initially reached a maximum value when the length of the interface crack was approximately equal to the length of the flexural cracks.

2.3 STUDIES ON EPOXY BONDED FRP PLATES

Hamid Saadatmanesh and Ehsani (1996), experimentally investigated the static strength of reinforced concrete beams strengthened by gluing glass fiber reinforced polymer (GFRP) plates to their tension face of the beams. The measured load versus strain in GFRP plates, steel rebar, extreme compression fiber of concrete, and the load versus deflection for the section at mid span of the beams were plotted and compared to the predicted values. The results indicated that the flexural strength of RC beams could be significantly increased by gluing GFRP plates to the tension face. In addition the epoxy bonded plates had improved the cracking behaviour of the beams by delaying the formation of visible cracks and reducing crack widths at higher load levels.

Garden and Hollaway (1998), studied and reported that carbon fiber reinforced polymer (CFRP) materials were all suited to the rehabilitation of civil engineering structures due to their corrosion resistance, high strength to the weight ratio, and high stiffness to weight ratio. The anchorage system for the plate had more structural benefit under low shear span/depth ratio.

Houssam Toutanji and Yue Zhang (2000), studied external bonding fibre reinforced polymer (FRP) sheets with epoxy matrix which had an effective technique for strengthening and repairing reinforced concrete beams under flexure. The variables in that study were the reinforcement ratios the type of epoxy matrices and the concrete-FRP interface conditions. All the beams were subjected to four point bending test under load control while the crack width, deflection, and mid span strain at both compression and tension faces were measured. An analytical method for predicting the ultimate moment and moment strain curves of the strengthened beams were developed. Both experimental and theoretical results were presented and compared. Results showed that there was a good agreement between the experimental and analytical result. They concluded that externally bonded CFRP sheets significantly enhanced the flexural strength capacity of RC beams by 50%.
Arockiasamy et al. (2001), presented some studies on the long-term behaviour of the beams reinforced with carbon-epoxy FRP under uniform sustained loading. An analytical method was developed to predict the long-term behaviour of CFRP internally reinforced concrete beams. The calculated deflections, strains, and curvatures agreed reasonably with the experimental values. A simplified equation for calculating the long-term deflection was proposed for CFRP reinforced concrete beams.

2.4 STUDIES ON EPOXY BONDED FERROCEMENT COMPOSITES

Suryakumar and Sharma (1976), presented a comparison of the results of tests of thirty-five specimens with the theoretical values of ultimate strength, predicted by the conventional reinforced concrete theory. They concluded from the study that, conventional reinforced concrete theory could be adopted for predicting the ultimate flexural strength of ferrocement. The ultimate strength and first crack strength of ferrocement was found to increase linearly with increase in the percentage area of reinforcement.

Perumalsamy et.al (1979) carried out experiments on ferrocement beams reinforced with volume fraction varying from 2% to 6% with variety of square steel meshes which were subjected to fatigue flexure with three levels of loading corresponding to approximately 40%, 50% and 60% of static yield load. Based on the observed experimental results linear regression equations were proposed by them to predict fatigue life of ferrocement as a function of the stress range in the outermost layer of steel mesh. Also, an exponential relation with two parameters was built to predict the increase in deflection, average and maximum crack widths as a function of applied load and number of loading cycles. The proceeding relations established by them are carefully adaptable to reinforced concrete subjected to fatigue flexure.

Desayi and Ganesan (1984), proposed a method to determine the maximum crack width in ferrocement flexural elements. The constants appearing in the proposed method were evaluated using test results of eight prototype channel shaped ferrocement flooring elements. The width of crack which appears in a ferrocement member was an important limit state to be considered in the serviceability of such structural elements. Extensive studies on the determination of maximum crack width in reinforced concrete members
have been reported. Very few investigations were available for the determination of maximum crack width in ferrocement flexural elements. The test programme consisted of casting and testing of nine channel shaped ferrocement flooring elements. The specimens were tested under two equal loads at third points. The loads were applied in stages and at each stage of loading the surface strains and widths of cracks after they appeared were noted. The experimental crack widths were compared with the theoretical crack widths calculated. The computed maximum crack width and average crack width values were close to the observed maximum and average crack widths and compare satisfactorily for all the stages of loads. They concluded that a method had been proposed to determine the maximum crack width in ferrocement flexural members of channel cross sections used for flat roofs or floors. The constants appeared in this method were determined from a statistical analysis.

Neelamegam et.al (1984), discussed the flexural behaviour of polymer ferrocement using various polymer mortars as matrices. The polymer ferrocement with five kinds of reinforcements were prepared using latex cement mortar, resin mortar and polymer impregnated mortar and tested for flexural behaviour. Conventional ferrocement as a control was also tested by the same method. From the test result, it was concluded that the ultimate moment and flexural toughness of the polymer ferrocement were markedly improved with an increase in the specific surface area of the reinforcements regardless of the type of polymer matrix. The flexural load at the first crack of resin ferrocement and polymer impregnated ferrocement was considerably higher than that of ordinary ferrocement and latex ferrocement.

Naaman and Mc Carthy (1985), studied the flexural behaviour of ferrocement beams reinforced with hexagonal meshes. The variables include the compressive strength of mortar, the number of mesh layers and the mesh orientation. Results were compared with similar tests using square meshes and were used to derive efficiency factors of reinforcement for hexagonal meshes. It was found that the efficiency of hexagonal meshes placed parallel to the loading direction was almost as good as that of square meshes, provided differences on yield strength of reinforcement were accounted for. The cost of mesh reinforcement often represents the single largest cost component of the cost of ferrocement not only in labour intensive countries but in industrialized countries.
Hence, savings on the cost of reinforcement may have a significant impact on the total cost of ferrocement structures and their application. They concluded that the strength of ferrocement beams reinforced with hexagonal meshes placed parallel to the loading direction was of the same order as that of beams reinforced with square meshes of the same yield strength. The observed average ultimate strength of ferrocement beams reinforced with hexagonal meshes placed transverse to the loading direction was about 69% that of similar beams with meshes placed parallel to the loading direction.

Mansur and Paramasivam (1985), reported the results of an experimental investigation conducted on three ferrocement sections under combined bending and axial loads. Each section had identical dimensions but contains different volume fraction of reinforcement. Based on the conventional reinforced concrete analysis, a method was presented for predicting the ultimate load capacity and hence the interaction behaviour of a ferrocement section. The experimental data were in good agreement with theoretical predictions. Ferrocement as a construction material had gained considerable attention because of its adaptability, high strength to weight ratio, superior cracking characteristics, ductility and impact resistance compared to conventional reinforced concrete. This experimental program consisted of testing forty eight specimens under different combinations of bending moment and axial loads. All the specimens were 100 mm wide and 25 mm thick. Two different lengths were used to limit the effective length to depth ratio to 12. The specimens for direct compression tests were 300 mm long while the length of the remaining specimens were 380 mm. The specimens were subjected to direct tension, tension and bending, pure bending, bending and compression and direct compression. They investigated the interaction behaviour of ferrocement sections under combined bending and axial loads. The test results indicated two distinct modes of failure: primary compression and primary tension. The former type of failure occurred under predominant axial loads, while the latter was caused by a moderate compressive load or tension. The interaction relationship as obtained from the present tests was similar to that of a conventional reinforced concrete sections.

Singh et.al (1986), described a programme of flexural fatigue tests on ferrocement slabs with four different types of reinforcement. They concluded that most fatigue failures were occurred by fracture of the wires. It was considered that the comparison of test results
should be based on the stresses in the reinforcement rather than the composite materials. Some of the wires in the ferrocement composites failed due to brittle fatigue fracture however the remaining wires in the same composites showed some degree of necking under a combination of fatigue and static overloading.

Desayi and Ganesan (1986), investigated the fracture properties of ferrocement using double cantilever beam specimens. The fracture behaviour of ferrocement had been studied using contoured double cantilever beam specimen. The influences of different percentages of mesh reinforcements and initial crack length on the fracture behaviour were investigated. The specimens were subjected to monotonic loading until complete failure and unloading-reloading technique. Thirty nine double cantilever beams specimens were cast. The influence of different percentages of mesh reinforcement and initial crack length on the fracture of double cantilever ferrocement specimens had been investigated. They concluded that the fracture energy calculated was found to increase with crack extension continuously and the curve was convex towards the crack extension axis. This was due the effect of increasing number of wires bridging the crack as the crack extends. The wires resist the load even after the crack had reached the end of the specimen.

Naaman and Homrich (1986), developed a simple design aids to predict the flexural resistance of ferrocement beams reinforced with equally spaced layers of any type of reinforcing mesh. These aids were also valid as a first approximation for ferrocement beams in which the layers of mesh were lumped equally in the upper and lower half of the section. The methodology proposed for the analysis and design of ferrocement in flexure was based on a widely accepted rational approach, yet it was very simple and extremely efficient. It was shown to be sufficiently accurate for most common sections configurations.

Mansur (1987), proposed a design of ferrocement under combined bending and axial loads. The uniform dispersion of ferrocement reduced the otherwise brittle mortar into a composite material of high ductility. As a result, ferrocement deformed plastically at ultimate load. They had also presented the rigid plastic concept that could be conveniently used for the construction of non-dimensional design charts of ferrocement subjected to
combined bending and axial loads. The rigid plastic approach was found to be satisfactory for predicting the strength of ferrocement under combined bending and axial loads.

Prakash and Rao (1988), suggested the probabilistic analysis of tensile strength of ferrocement. The upper and lower limits for ultimate load of ferrocement specimens in direct tension were obtained and were compared with experimental results. A comparison of computed bounds on ultimate load with the experimental results showed that generally the estimated bounds enclosed the observed spread in the experimental results. The estimated upper bound ultimate loads agreed well with experimental values. However, the experimental lower bound loads were underestimated. They concluded that the methodology developed in this paper could be used to estimate reasonably the range of spread of the experimental ultimate loads of ferrocement specimens subjected to tension.

Mansur (1988), conducted an experimental investigation to study the ultimate load behaviour of ferrocement in which the member thickness was systematically varied for an equal volume fraction of reinforcement. The reinforcement was furnished by either welded or woven wire mesh. In this paper, he presented the analytical and experimental investigation of the ultimate load behaviour of ferrocement in flexure. The experimental program comprised a series of tests in which the thickness of the member was systematically varied for an equal volume fraction of reinforcement. The test results indicated that the ultimate rotation capacity of the member decreased with increasing thickness and that the welded wire mesh reinforcement provided better curvature ductility than an equivalent amount of woven weld mesh. However, within the practical range of member thickness, both types of reinforcement furnished sufficient ductility to justify a rigid plastic analysis at collapse.

Walkus (1988), studied the behaviour of ferrocement elements subjected to uni-axial long term tension. Based on the experimental results, deformations of ferrocement under short term and long term loads were compared. It was shown that in ferrocement during long term loading the number of micro cracks with crack width 20 microns to 100 microns were constant.

Al-Sulaimani and Ahmad (1988), presented the flexural rigidity and deflection characteristics of ferrocement flanged beams (I beams and hollow box beams). For all
ferrocement beams, tested load Vs central deflection and moment Vs curvature were plotted from the recorded and reduced data. From this study the conclusions drawn were, the flexural rigidity in the uncracked stage could be calculated theoretically as the flexural elastic modulus of ferrocement multiplied with the uncracked moment of inertia of the flanged cross section. The number of wire mesh layers had no significant effect as the flexural rigidity in the uncracked stage. However, as the member of wire mesh layers in the cross section increases, the flexural rigidity in the cracked stage increases.

Tatsa (1991), presented a method for design and analysis of components made of ferrocement in bending. It was based on the approach that ferrocement may be considered as a form of reinforced concrete and therefore the limit state procedure was used in a manner similar to the design and analysis of reinforced concrete elements. It should be stressed that although similar to reinforced concrete in many ways, the unique properties of ferrocement as have been discovered in the extensive research carried out in recent years. That must be taken into consideration in order to achieve an effective design. These include the dependence of the tensile strength of the ferrocement laminates on the depth of the cross section. The contribution of rectangular-shaped meshes, welded or woven for which the yielded strength could verified by tests and the modulus of elasticity was found to be reduced by 30% compared with regular steel. It was more complicated to define the properties of other types in a manner suitable for the analysis process.

Basunbul et.al (1991), studied the flexural behaviour of ferrocement sandwich panel. The parameters considered in the experimental investigation were the number of wire mesh layers, the skeletal steel, the web mesh reinforcement and the number of webs. The ultimate moment capacities were computed analytically using conventional reinforced concrete theory and these results were compared with experimental results by tests on 12 sandwich panels. Cracking behavior and failure pattern for all panels were also obtained and compared. The successful and wider acceptance of these panels was greatly influenced by their strength, serviceability, durability, and availability of rational design procedures. They concluded that the increasing the number of ribs between three and five does not seem to improve flexural strength and ductility. The number of ribs and the presence of web mesh reinforcement played an important role in developing full moment capacities. Increasing the number of wire mesh layers and using skeletal steel in the
tension plate improved the ductility in the working range and also the ultimate strength. The number of wire mesh layers had no significant contribution to stiffeners and rigidity in the uncracked stage. The conventional reinforced concrete theory predicts the ultimate moment capacities.

Ser-Tong and Seng-Hooi (1991), examined the uncertainty in the mathematical models used for predicting the ultimate and first crack moment capacities of ferrocement structural elements. They cast rectangular ferrocement slabs having nominal dimensions 700 mm x 300 mm x 30 mm reinforced with two layers of galvanized wire mesh separated by a layer of skeletal steel placed nominally at mid-depth with the aid of spacers. The accuracy and uncertainty of five ultimate moment models and two first crack moment models for predicting the flexural capacities of ferrocement structural elements were investigated. The results showed that even though the first crack moment capacity models have lower systematic biases than the ultimate moment capacity models, the uncertainty in the predicted first crack moment capacity was higher than that of the ultimate moment capacity.

Ahmed et.al (1991), presented the rehabilitation technique for reinforced concrete structural beam elements using ferrocement. This technique involved strengthening of the reinforced concrete beams by application of hexagonal chicken mesh and skeletal steel combined by ordinary plastering. The basic parameters involved were the amount of wire mesh applied, its geometrical configuration and the degree of distress in the beams. The test results found were in good compliance with the original design capacity of the beam. A number of rehabilitation methods had been developed. The use of ferrocement as a rehabilitation material was comparatively a new approach and was relatively a better method due to the various inherent properties of this method. They concluded that ferrocement laminates was used as an alternative material in rehabilitation of distressed structural elements. It could also effectively control the cracks and mid-span deflections. The dead weight of the rehabilitation material was almost negligible and hence it did not require any catering for the additional dead weight as in most of the other rehabilitation materials.
Prakash Desayi and Veerapa Reddy (1991), studied the strength of light weight ferrocement in flexure. Light weight ferrocement had been made by replacing sand in the cement mortar by foamed blast furnace slag from 0% to 100% in step of 20%. Ferrocement specimen was of rectangular section 200 mm width 25 mm thick have been cast using this light weight mortar. A total of 54 specimens were tested under four point loading on an effective span of 900 mm and the modulus of rupture computed at first crack and its ultimate. A strength density parameter had been introduced to represent the effect of varying strength and density of the light weight mortar. The test specimens were rectangular in section 200 mm wide and 25 mm thick with an overall length of 1000 mm. A total of fifty four specimens comprising nine specimens for each replacement of sand were cast. These specimens were tested in flexure on an effective span of 900 mm and under four point loading. The load was applied from the bottom so that tension face was on the top which permitted easy working of crack and a measurement of crack width. They concluded that the density and compressive strength of light weight mortar was found to decrease linearly with the percentage of replacement of sand by foamed blast furnace slag. The extreme fibre stress of light weight ferrocement at the first crack was found to be independent of the amount of mesh reinforcement but linearly varying with strength density parameters. These conclusions apply to ferrocement which had symmetrically distributed measures.

ON et.al (1992), investigated the reliability of ferrocement slabs subjected to cyclic thermal shock loading induced by rain drops during service. The datas were obtained experimentally by subjecting specimens to heating and welding cycles and monitoring the residual first crack strength at different periods. The imposed thermal shock loads simulated actual service conditions were estimated by monitoring the temperature of typical roofing slabs just before the commencement of rain over a period of time. The results indicated that the ferrocement slab poses good flexural resistance with respect to the cyclic loadings studied and were suitable for use as roofing elements. Exterior structural elements were subjected to repeated wetting and drying caused by the sun and rain inducing cyclic stresses throughout their period of service. Their cracking strength may deteriorate with time due to the induced cyclic loadings, especially when the temperature difference between the surface of the element and the raindrops was
significant. They examined the durability of ferrocement roofing slabs with respect to thermal shock loadings arising from raindrops under service conditions. They concluded that the durability of ferrocement roofing slabs in relation to the cyclic thermal shock loadings induced by raindrops had been studied experimentally using a residual strength approach. Results of reliability analysis indicated that the ferrocement roofing slabs considered in this study will have at least 62% of their original strength after 50 years of service.

Prakash Desayi and Nanda Kumar (1992), presented the behaviour and strength of ferrocement in shear. An experimental investigation on the shear strength of ferrocement was described. Tests were conducted on 155 simply supported rectangular ferrocement specimens under four point loading. The variables of the study were the number of layers of wire mesh, two mesh layouts strength of the mortar and shear span to depth ratio. Two types of shear cracking and failure, namely those due to flexure-shear and web shear were noticed. The test results indicate that for both of the mesh layouts considered, the shear strength was increased as the shear span to depth ratio decreased. The shear stress at which the flexure shear crack formed for the uniformly disturbed mesh layout was higher than the shear stress at which the same kind of crack formed for the lumped mesh. This could be due to the fact that the meshes when distributed uniformly in the depth of specimen offered greater resistance to crack formation than when lumped at the two edges. They have concluded that two types of shear cracking and failure, namely those due to flexure-shear and web shear were observed. The strength of ferrocement in flexural shear cracking and web shear cracking increases as the (a/h) ratio was decreased and the volume fraction of mesh wire was increased for all mortar mixes and the two mesh layout were studied.

Singh and Xiong (1992), presented the behaviour of interactions between the various phases of the ferrocement composite. Simpler and reliable models had been developed which led to economical design of singly and uniformly reinforced ferrocement incorporating weld mesh. They compared their model with other models developed by researches and concluded that the debonding between steel and mortar makes the actual moment capacity of the weld mesh reinforced section higher than the calculated value. This was based on the plane deformation assumptions of the various ultimate moment
capacity models. This appeared to be the most reliable and simple for a singly reinforced section. For uniformly reinforced sections, a new model was proposed which was shown to be more reliable and relatively simple. The ultimate moment capacity model based on ultimate strength of steel for singly reinforced section showed the best agreement with test results. For a uniformly reinforced section, a model based on ultimate steel strength was proposed which gives the best results.

Ong et.al (1992), investigated the flexural strengthening of reinforced concrete beams using ferrocement laminates, attached onto the tension face of the beams. Eleven simply supported beams of rectangular cross section were tested to failure under concentrated loads. The parameters that were varied were the method of attachment, volume fraction of reinforcement of the ferrocement laminates and the level of damage of the beams. Their performances were compared with the control beams with respect to cracking, deflection and ultimate strength. They tested eleven rectangular beams. Eight of these beams were strengthened with a 20 mm thick ferrocement laminate attached on the tension face. The latter was reinforced with two smooth mild steel bars of 6 mm diameter sandwiched between two layers of galvanized welded wire mesh of 1.2 mm diameter and 25 mm square grid size. They carried out the investigation with the intention of furnishing additional data on the performance of reinforced concrete beams strengthened and repaired with ferrocement laminate. The effect of volume fraction of the ferrocement laminate and the level of damage of the beam were also studied. The performances of the strengthened beams were compared to the control beams with respect to cracking, deflection and ultimate strength. The results showed that all the strengthened beams exhibited higher ultimate flexural capacity and greater stiffness. Use of epoxy resin adhesive and ramset nails at closer spacing as shear connection were able to ensure composite action. A decrease in the volume fraction of reinforcement of the ferrocement laminates from 3.55% to 2.36 % resulted in a reduction in strength. The presence of the ferrocement laminates had an inhibiting effect on the tensile cracks and crack width was reduced after strengthening.

Rao (1992), investigated and presented the load – deformation data in the form of stress-strain relationship pertaining to structural mortar prisms of size 150 mm x 50 mm x 25 mm, with and without mesh reinforcement of varying percentage. Analysis of the test
data revealed that for all group of specimens tested, the common feature was that there was initial and final non-linearity of stress strain plots with linearity in between. It was noted that the range of linearity in the stress strain plot decreases up to a reinforcement percentage of about one percent and beyond that a fairly greater length of stress strain plot was linear. It was seen that the modulus of elasticity in compression for plain mortar specimens was fairly high compared with moduli values obtained for ferrocement specimens suggesting that the reinforcement in the cement mortar had radically altered the behaviour of the material from that of a relatively rigid to a near elasto-plastic material. Compression tests were conducted on solved prisms of size 150 mm x 50 mm x 25 mm reinforced with galvanized chicken mesh and or weld mesh. They concluded that the stress strain behaviour of elements sandwiched by ferrocement laminates improved under compression.

Hughes and Evbuomwan (1993), investigated that the strength of reinforcement concrete beams enhanced due to polymer modified ferrocement. This paper reported some of the results of on-going research in the development of the reinforced repair mortar to be used in enhancing the strength of downgraded reinforced concrete beams. One of the main problems faced by the buildings and construction industries was the deterioration of concrete structures. The high level of spending within the industries for concrete repairs showed that the degree of concerns that had arisen due to the number of structures in need of repair. The common techniques employed in the repair of concrete structures were resin injection, shortcretting and patch repairs. They concluded that there was an increase in ultimate and cracking loads and ductility of the enhanced beam in comparison with the controlled beam. They also concluded that the beams enhanced with reinforced materials exhibited a much higher ultimate flexural strength than the controlled beams. The beams enhanced by the material were absorbed to exhibit both higher cracking and ultimate loads compared with the enhanced beam. The use of the material also led to increased stiffness and ductility.

Onet and Magureanu (1993), investigated the flexural behaviour of ferrocement beams in long term loading. The test was conducted on three beams of size 100 mm x 250 mm x 3200 mm. The beams were simply supported with two concentrated loads applied on the third span. From the test results, they concluded that the value of the long term
deformation factor established by means of strains or deflections indicates that the long
term deflections influence the behaviour of beams much more than the instantaneous one.

Gurdev and Guang (1995), had given their findings of flexural fatigue characteristics of
ferrocement for reliable design, as for designing ferrocement against fatigue by using the
probability-stress-life (P-S-N) plot. Ferrocement specimens of size 350 mm×125 mm×30
mm were used. Six layers of weld mesh were used as reinforcement to give a nominal
percentage of reinforcement of 1.2%. The use of S-N relationships for predicting fatigue
behaviour leads to an unreliable design, however the proposed method for producing P-S-
N relationships, incorporating the probability aspects was more appropriate. Finally, they
concluded that rectangular stress distribution was relatively more reliable and economical
for predicting steel stress when designing ferrocement against fatigue by using the P-S-N
relationship of wire tested in the air.

Ezzat Fahmy et.al (1997), presented a proposed method for repairing concrete beams
using ferrocement laminates as a viable alternative to steel plates which were directly
 glued to the cracked tension face of the beam by epoxy resins. The results of both
experimental and analytical investigations to examine the effectiveness of this method
were reported and discussed including strength, deflection, and cracking characteristics of
the repaired specimens. Twenty seven reinforced concrete beams were tested over simply
supported one meter span. Each specimen was first loaded with a central line load till
collapse or upto 85% of the ultimate load of the control specimen. After unloading, the
damaged beam specimens were repaired by either one layer at the tension face, two layers
at the tension face or u-shaped layer around the beam cross section. The finite element
 technique was used to analytically investigate the effectiveness of the proposed repair
method. Based on the results and observations of both the experimental and analytical
investigations presented, they concluded that under short term loading conditions,
reinforced concrete beams failed due to overloading could be restored with enhanced
strength and performance using ferrocement laminates. After repairing, all the repaired
tested specimens showed large deflections at ultimate load and significant increase in the
ductility ratio. Repairing reinforced concrete beams with a u-shaped layer around the
beam cross section, increased the gain in the ultimate moment about three times. This was
obtained only when one laminate was attached to the tension face.
Fahmy et.al (1999), presented a method for repairing reinforced concrete columns using ferrocement laminates as a viable economic alternative to the highly expensive conventional jacketing methods by reinforced concrete or steel jackets. The results of an experimental investigation to examine the effectiveness of this proposed method were reported and discussed including strength, deformation, ductility and energy absorption characteristics of the reported specimens. Twenty four reinforced column models were tested under concentric compression load. Each specimen was first loaded till failure or upto either 67 % or 85 % of the ultimate load of the control specimens. After unloading the damaged column specimens were repaired by jacketed completely by using 10 mm thick ferrocement around the four sides of the specimens. Three different types of reinforcing steel meshes were used. The experimental results of the repaired columns demonstrated that irrespective of the pre-loading level or the mesh type better behaviour and load carrying capacity for all test specimens could be achieved compared to their original behaviour. Under short term loading conditions all repaired specimens restored more than their original ultimate strengths. It was found that the ultimate load of the repaired column specimens was affected by the level of damage sustained prior to repairing. They concluded that under concentric loading conditions, reinforced concrete column damaged due to over loading could be restored with enhanced strength and performance using ferrocement jackets. The repaired specimens showed higher deformation at ultimate load, increase in the ductility ratio and considerable increase in the energy absorption during testing. The higher the volume fractions, the higher the gains in ultimate load and lower the gain in ductility ratio and energy absorption. Based on the comparison between the theoretical gains in the load carrying capacity with the experimental ones, it was obvious that ferrocement jackets provided the repaired column specimens with strong confinement effect.

Mohammed Arif et.al (1999), investigated the behaviour of materials reinforced with varying number of mesh layers and orientation and developed a set of elastic and inelastic material properties. It was observed that the conventional empirical relation based on mortar crushing strength overestimated the mortar modulus. The elastic module obtained using the rule of mixture compared well with the values evaluated from the tests on ferrocement specimens. The primary intent of the experimental program discussed here
was to evolve a set of material properties that could be subsequently used to analytically simulate the mechanical behaviour of ferrocement under a wide range of loading conditions. The experimental program included testing of ferrocement specimens in tension, compression and flexure. Similar specimens of mortar were also tested in tension, compression and flexure. They concluded that 45 degree orientation emerged as the weakest configuration because of the lowest volume fraction of wire mesh in the direction of loading.

Prem Pal Bansal et.al (2000), studied the effect of wire mesh orientation on strength of beams retrofitted using ferrocement jackets. Various retrofitting techniques were used in field and out of all plate bonding technique was considered the best. Ferrocement sheets were most commonly used as retrofitting material due to their easy availability, economy, durability and their property of being cast to any shape without needing significant formwork. In this work, the effect of wire mesh orientation on the strength of stressed beams retrofitted with ferrocement jackets had been studied. The beams were stressed up to 75% of safe load and then retrofitted with ferrocement jackets with wire mesh at different orientations. The results showed that increase in load carrying capacity of beam retrofitted with ferrocement jackets. A considerable increase in energy absorption also took place. Beams rehabilitated with ferrocement jackets showed better performance in terms of ultimate strength, first crack load, crack width, ductility and rigidity of the section. To carry out the investigation, eight prototype beams of size 127 mm × 227 mm ×4100 mm were cast and tested for two points loading. On conclusion, the beams retrofitted with wire mesh at different orientations did not debond when loaded to failure. After retrofitting all the test specimens, the researchers had found reduced crack widths, large deflection at the ultimate load, a significant increase in the ductility ratio and considerable increase in the energy absorption.

Mansur et.al (2001), reported the results of punching shear tests on thirty one square ferrocement slabs. The slabs were simply supported on all four sides and tested under a central concentrated load. The parameters investigated include the width of the square loaded area, mortar strength, volume fraction of reinforcement, depth of slab and the effective span. Both cracking load and punching shear load increased with an increase of parameters except the effective span. The critical perimeter for punching shear failure
was found to be located at a distance of 1.5 times the depth of the slab from the edge of the loading plate. They had proposed an equation for predicting the punching shear strengths of ferrocement based upon the test data as well as the data available in the literature.

Pankaj et.al (2002), developed numerical simulations to predict the mechanical behaviour of ferrocement composites. They proposed anisotropic elasto-plastic models to simulate the mechanical behaviour of ferrocement plates. These models used the elastic and inelastic proportion derived from simple in plane tension and compression experiments. Two different mathematical models, the homogeneous layered model and the mortar ferrocement layered models were considered. The analytical predictions were found well in comparison with the experimental results. They found that the mortar ferrocement layered model with the orthotropic ferrocement layers performed best. It was concluded that a single set of material properties could be used to simulate the behaviour of ferrocement plates under in plane as well as out of plane loading. They concluded that the model that involved complete homogenization was capable of simulating experimental results under homogeneous stress conditions such as those that exist in plane tension tests. This model also performed well with changed mesh orientation. However, under flexural conditions, the homogeneous layered model had a tendency to overestimate peak loads. Therefore, homogenization of properties in the entire thickness of the section could not be recommended. Both variations of the mortar ferrocement layered model performed well under in plane as well as in flexural loading conditions. This happened as long as the principal stress directions were aligned with the principal mesh direction. However, with the change in the mesh orientation the transtropic variation showed considerable drift from the experimental results.

Miguel Lara and Bolander (2004), studied the effects of reinforcement positioning on the flexural behaviour of ferrocement. An experimental program was conducted to study the cracking behaviour of lightly reinforced ferrocement panels subjected to four point bending. Specimens with identical dimensions and boundary conditions exhibited different cracking and load deflection responses due to unintended variations in the positioning of the reinforcing mesh over the constant moment region of the specimen. The specimens were cast in steel forms and had dimensions 350 mm × 76 mm × 12.7
mm. Two layers of welded wire square mesh were placed in each form before casting. The loading apparatus for four point bend testing was designed and constructed. In this paper, the author reported the experimental study of the variations in reinforcement positions and its effect on specimen strength and cracking performance. A series of lightly reinforced ferrocement panels were produced and then loaded in four points loading. During testing, the tension face of the specimen was continuously monitored. The specimens load-deflection response and cracking behavior were correlated with the positioning of the reinforcement at the section when failure occurs. They concluded that the design of ferrocement for flexure shared common features and principles with that of reinforced concrete.

Vidivelli et.al (2004), studied the repair and rehabilitation of reinforced concrete beams by ferrocement. The reinforced concrete structures may be distressed due to impure materials, environment, improper workmanship, over loading and structural deficiency. A damaged or distressed reinforced concrete beam could be repaired or re-strengthened to a satisfactory level of performance at a reasonable cost by different methods. Ferrocement was an ideal material for rehabilitation and restrengthening of structure because it improved crack resistance confirmed with high toughness, the ability to be cast into any shape, rapid construction with no heavy machinery, small additional weight and low cost of construction. All these properties were achieved with a thickness of 20 mm. A total of three beams were cast and tested. One beam (Parent beam) was tested to ascertain the load deflection behaviour and ultimate load. The remaining two beams were damaged by overloading. After unloading, the damaged beam specimen was repaired with ferrocement laminates with single layer at the tension face and U-shaped single layer around the beam cross section with epoxy. Static test was conducted on all the beams to determine the load deflection behaviour and ultimate load. A comparison was made between parent beam, damaged and repaired beams on crack width, deflection and ultimate strength at different load stages.

Masood et.al (2005), investigated experimentally the rehabilitation of RC and FRC beams by ferrocement. The experimental investigation consisted of casting and testing of 21 beams of size 115 ×170 × 3350 mm. The beams were tested by two-point loading. After testing the beams, the parent beams were rehabilitated by applying Epoxy resin on the
four faces exposed to form a good bond between old and new concrete before fixing square welded mesh to the main reinforcement in the tension zone. It had been observed that the rehabilitated beams were able to attain the same level of strength and stiffness as the virgin beams. The average load deflection values for parent/virgin and rehabilitated beams were reasonably close. The rehabilitated beams were able to attain the same level of strength and stiffness as the virgin beams with the restrengthened beams showing appreciable improvement in the load deflection behaviour apart from successfully sustaining the same ultimate load as the virgin beams. Thus, the suggested repair and re-strengthening method adopted for the damaged beams could be safely carried out.

Kumar (2005), studied the use of ferrocement box sections for floors and roof of multi-storied buildings. A comparison was made between ferrocement box sections, flat slab and conventional beam slab construction. He found that ferrocement box sections being light in weight need less strong supporting structures. The floors and roofs of most buildings were constructed with reinforced cement concrete. The various options available for flooring and roofing purposes were the beam slab systems, channel sections, T sections, ribbed sections, flat slabs and box sections. They concluded that ferrocement box sections supported on RCC beams were found to be cheaper than beam and slab construction and flat slab option. When compared with weight, the ferrocement box sections were lighter weight than the beam-slab construction. The use of ferrocement box sections would economize on the supporting structures. At service load conditions, ferrocement showed a large number of smaller crack width compared to a few wide cracks in reinforced concrete. The ferrocement box sections with higher ductility would make the structure less prone to seismic damage.

Ganesan and Thadathil (2005), investigated the rehabilitation of reinforced concrete flexure element using ferrocement jacketing. An experimental investigation had been carried out to study the effect of ferrocement jacketing and the strength and behavior of distressed reinforced concrete flexural elements. The reinforced concrete specimen of size 100 mm wide 150 mm depth 1200 mm length were subjected to different stages of loading viz 0.7, 0.8, and 0.9 times ultimate load carrying capacity. The distressed specimen was strengthened by ferrocement having different values of volume fraction of mesh reinforcement viz 0.26%, 0.52% and 0.78%. The test results indicated that the
strengthening of damaged reinforced concrete element using ferrocement jacketing improves the load carrying capacity significantly. The other mechanical properties such as ductility stiffness and energy absorption capacity were found to increase with percentage of volume with fraction mesh reinforcement.

Rathish Kumar and Rao (2005), in their investigation dealt with the study of ferrocement in biaxial tension – tension based on hollow cylindrical specimens. An interaction curve was proposed to estimate the strength of ferrocement in biaxial tension-tension. The use of high performance mortar as the matrix for ferrocement improved the strength and durability characteristics such as permeability and cracking of the composite. The closer distribution and uniform dispersion of reinforcement transforms the brittle mortar into a distinctly different material from reinforced cement concrete. The commonly adopted specimens for conducting tests in biaxial stress state were cubes, solid cylinders, hollow cylinders and plate. In the present investigation, they used hollow cylindrical specimens to investigate the strength of high performance ferrocement in biaxial tension-tension, because hollow cylinder could be tested easily in all biaxial stress combinations. They concluded that the stress in one direction was found to be beneficial to strength in the orthogonal direction as observed from the normalized interaction diagram. The trend of the interaction diagram was not affected by the specific surface factor whereas the individual values of strength were dependent on surface factor. An interaction curve and hence a mathematical model was developed for the high performance ferrocement which could be used as a criterion for design of ferrocement surfaces under biaxial tension-tension. From the crack pattern, it was concluded that there was adequate ductility in ferrocement as these specimens confirmed to resist load even after the total propagation of cracks. High performance ferrocement was ideal for use in stressed skin surfaces owing to its superior performance in strength, ductility and crack resistance.

Vidivelli and Antony Jeyasekar (2005), summarized the results of a multiphase experimental programme and did an analytical study to investigate the viability of using externally bonded ferrocement laminates to rehabilitate erosion damaged reinforced concrete beams. Eighteen reinforced concrete beams of size 125 mm × 250 mm × 3200 mm were cast and damaged the reinforcement by subjecting to corrosion, and the beams were repaired by rehabilitating with ferrocement laminates. All the beams were tested in
flexure under a four point bending regime. The overall performance of the rehabilitated beams was evaluated by considering the equivalent elastic force using energy and deflection approaches. Results from experimental data were compared with the results from non linear analysis and it was seen that the proposed composite beams have better ductility, cracking strength and ultimate capacity. Damaged beams rehabilitated with 3% volume fraction of ferrocement laminates exhibited better performance when compared to other volume fractions. A non linear finite element modeling adopted proved to be an acceptable predictive tool for the analysis of reinforced concrete beams rehabilitated externally with ferrocement laminates.

Chandresekar Rao et.al (2006), investigated the shear strength of simply supported ferrocement rectangular plates subjected to four points loading. They conducted tests on ferrocement elements by varying the shear span to depth ratio and different layers of ferrocement mesh reinforcement. They observed that increase in the volume fraction of the mesh reinforcement (number of layers of mesh) increased the shear capacity of the member. They also found that up to shear span to depth ratio 3, shear behaviour was predominant. Beyond shear span to depth ratio 3, the flexural behaviour was predominant and the design of the elements based on flexure was sufficient. The experimental investigation consisted of casting and testing six series of plates. The six series of plates were tested for different shear span to depth ratios. All the plates were tested in a two point symmetrical load. They concluded that the load carrying capacity and ductility of plain ferrocement elements improved by several folds with the inclusion of aligned wire mesh. The increase in the number of mesh layers increases both the shear load carrying capacity as well as the ductility of the composite. The shear behavior of ferrocement elements was similar to that of reinforced concrete elements.

Noor Ahmed Menon et.al (2006), investigated the strength and behaviour of light weight ferrocement aerated concrete sandwich blocks. The primary variables investigated were the type of wire mesh, and the number of wire mesh layers in the ferrocement box. The response variables considered include compressive strength, overall unit weight and failure mode. The results were compared with control block specimens made solely of the aerated concrete. The results showed significant increase in compressive strength due to the encasement of aerated concrete. Structural sandwich panels were frequently used in
modern lightweight construction due to their low thermal conductivity and high strength to weight ratio. A typical structural sandwich element consisted of two thin high strength and high density facings or skins which were adhesively bonded to or encased in a thick core layer made of low strength and low density material. The facings or skins consisted homogeneous metallic material or of cement based composites. Cement based composites exhibited much better performance as compared to plain concrete. The common materials used for core were foam, non-metallic honeycombs or cellular concretes. The introduction of new materials such as laminated composites like ferrocement as the facing or skins and low density materials like aerated concrete as the core presented new possibilities in designing a sandwich system. In that study, this type of composite was referred to as ferrocement– aerated concrete sandwich composite. Ferrocement had been regarded as a highly versatile construction material having unique properties of strength and serviceability. The experimental study involved casting and testing of 24 block specimens of standard size 400 mm×200 mm×100 mm as per recommendations. The core size of the sandwich specimens was maintained as 376 mm ×200 mm ×76 mm. Ferrocement box of 12 mm thickness was produced over four sides of the core to fabricate sandwich block of standard size. After 28 days of curing, the specimens were tested for compressive strength. All the sandwich specimens showed significant enhancement in compressive strength compared to the control specimens. Failure modes of all specimens were observed during compressive strength tests and all the specimens failed in a brittle manner. They concluded that ferrocement encasement result in significantly higher compressive strength of the sandwich blocks.

Antony Jeyasekar and Vidivelli (2006), presented a method for repairing and rehabilitating damaged reinforced concrete beams above the original capacity level using ferrocement laminates which were directly glued into the cracked tension face of the beam by epoxy adhesives. A total of sixteen beams of size 125 mm wide 250 mm depth and 3200 mm length with effective span 3000 mm were cast and tested. The damage due to overloading was achieved in terms of ultimate load carrying capacity of perfect beams. The damaged beams were repaired and rehabilitated by using ferrocement laminates with three different volume fraction of reinforcement. Static and dynamic tests were conducted on all the beams to evaluate flexural and dynamic properties. Based on the experimental
and dynamic studies, they concluded that the ferrocement laminates properly bonded to the tension face of reinforced concrete beams could enhance the flexural capacity substantially. At any given load level, the deflections and the rebar strains and the crack width in the rehabilitated beams had reduced significantly compared to the perfect beams. The rehabilitated beams exhibited an increase of 75% in its overall performance compared to the respective perfect beams. The numerical solutions showed good correlations with the experimental results.

Jamal and Tareq (2006), had conducted bending tests on ferrocement specimens with steel meshes and fibres. They had investigated the effects of combining reinforcing steel meshes with discontinuous fibres as reinforcement in thin mortar specimen. They investigated the number of mesh layers, transverse wire spacing and type of fibres. For this purpose they cast 72 ferrocement plates of size 300 mm x 75 mm x 125 mm with two and four layers of woven steel square wire mesh with 3 replications. Each specimen was tested in center point loading bending tests. They varied mesh geometry including spacing of wires forming the mesh, number of mesh layers, discontinuous fibres including glass fibres and brass coated steel fibres. They concluded that the increase in number of steel mesh layers from two to four caused a substantial increase in flexural strength and energy absorption. They had also concluded that addition of brass coated steel fibres to the matrix of ferrocement lead to a significant increase in the flexural strength and that the addition of discontinuous fibres to the matrix effectively prevented the spalling of the mortar cover at the ultimate load.

Mohd. Zamin Jumaat et.al (2006) in their study discussed the causes of deterioration of concrete as well as repairing by cement grout, mortar, concrete, shortcrete, epoxy, ferrocement with mortar, fibre reinforced polymer and spray gel fibre reinforced polymer. The techniques of applying those materials and also some resin based materials for bonding agent between interface of old concrete and new concrete were also reported by them. The advantages and disadvantages of those materials, causes of debonding between concrete substrate and new concrete applied on substrate and preventive measures were discussed and suggested by them that the cement based materials were more suitable. They established a fact that the effectiveness of a repair work depends upon the quality of the material, implementation techniques, and effective supervision.
Elavenil and Chandrasekar (2007), analyzed the reinforced concrete beams strengthened with ferrocement laminates using ANSYS. The validity of the results was compared with the experimental results reported. Finite element models were developed to simulate the behaviour of full size beams through non linear response and failure using the ANSYS program. In this paper, they presented the numerical study to simulate the behaviour of beams strengthened in flexure with ferrocement and two control specimens without being strengthened. They concluded that the general behaviour of the finite element models represented by the load deflection plots at mid span shows good agreement with the experimental and theoretical results reported. They found that the load carrying capacity of the flexure strengthened beam predicted by finite element analysis was higher than that of the control beam. They found that the ferrocement strengthened beam had a higher ultimate load than the control beam.

Rathish Kumar et.al (2007), studied the behaviour of RC and ferrocement jacketed columns subjected to simulate seismic loading. Ductile behaviour was hence essential to prevent complete structural collapse under sustained loading. The structural response during earthquake had indicated that the majority of the column failure was caused by high shear stresses, insufficient transverse reinforcement rendering those members ineffective at dissipating seismic energy and inadequate ductility rapidly leading to failure. This work formed a part of experimental investigations aimed at developing an efficient and economical method of retrofitting existing reinforced concrete structure for enhanced shear resistance. The shear strength of reinforced concrete members under inelastic loading was affected by a number of parameters including the axial load ratio. This research was aimed at examining the effect of axial load on the hysteretic response and energy absorption capacity of RC and ferrocement confined columns. The experimental program consisted of three scale model bridge pier specimens designed as shear deficient specimens tested under different axial loads before and after retrofitting with ferrocement jackets. The three RC columns were strengthened with six layers of ferrocement jackets, after their failure. They concluded that the external confinement using ferrocement resulted in enhanced stiffness, ductility, and strength and energy dissipation capacity. The mode of failure could be changed from brittle shear failure to
ductile flexural failure. The axial loads influenced the hysteretic response of columns and energy absorption capacity.

Prakash and Patil (2007), investigated the effect of sustained temperatures on the strength properties of fibrous ferrocement containing steel fibres. They had adopted different temperatures as 200° C, 400° C, and 600° C. They had conducted compression test, flexural test and impact strength test. It had been observed that the compressive, flexural and impact strengths of fibrous ferrocement increased as the percentage of steel fibres in it increases. They also observed that all the strengths of fibrous ferrocement increased with increase in the amount of welded mesh and chicken mesh. They concluded that the compressive strength, flexural strength and impact strength of fibrous reinforcement could be enhanced either by increasing percentage of steel fibres or by increasing specific surface areas of welded mesh and chicken mesh. There was a reduction in strength properties of fibrous ferrocement when subjected to high temperatures such as 200° C, 400° C, and 600° C. The percentage decrease was very high at 400° C and 600° C. But compared to ferrocement, fibrous ferrocement showed better fire resisting capacity.

Kondraivendhan and Balu Pradhan (2009), presented their finding on the effect of ferrocement confinement on the behaviour of concrete. In this study, the use of ferrocement as an external confinement to concrete specimen was investigated. The effectiveness of confinement was achieved by comparing the behaviour of retrofitted with that of conventional specimens. For this investigation they considered plane cement concrete specimens with different compressive strength. A total of 42 cylindrical specimens with a diameter of 150 mm and a height of 900 mm were cast. The plane cement concrete specimens were wrapped with ferrocement laminates. A rich cement mortar was applied on the roughened surface of the specimen and then chicken mesh of constant thickness was wrapped around the specimen. The specimen was placed on the loading frame and tested. After testing they concluded that the ferrocement could be effectively and efficiently used as a confinement of concrete. Owing to confinement of concrete with ferrocement the strength increased compared with the control specimen.

Prem Pal Bansal et.al (2011), presented their findings in their paper that the effects of number of layers of wire mesh in the ferrocement jackets, type of section and initial stress
level on the strength of retrofitted stressed reinforced cement concrete beams had been studied. They had tested 28 beams of size 127 mm x 227 mm x 4100 mm. Out of 28 beams 14 beams were under reinforced and remaining beams were balanced. Four control beams and 24 retrofitted beams had been tested under a 2-point loading system with simply supported end conditions which had an effective span of 3750 mm. The control and retrofitted beams had been loaded to failure. They concluded that for all the cases of the beams retrofitted with ferrocement jacketing reinforced with two or three layers of woven wire mesh, the maximum load carrying capacity as well as safe load carrying capacity increases appreciably. They had concluded that the deflection ductility ratio and toughness increased with increase in percentage of reinforcement in ferrocement jackets. They finally concluded that retrofitting of beams with ferrocement jackets should be preferred where the strengthening of beams were required to take care of the deficiency of the beams in flexure.

2.5 STUDIES ON CAST INSITU BONDED FERROCEMENT COMPOSITES

Paramasivam et.al (1994), investigated the flexural behaviour of reinforced concrete Tee beams strengthened with thin ferrocement laminates attached to the tension face. Twelve simply supported beams were tested under concentrated loads at mid span. The ferrocement laminates were attached using L-shaped mild steel round bars as shear connectors. The parameters that were varied include the spacing of the shear connectors, method of surface preparation and volume fraction of reinforcement was the ferrocement laminates. Performance was generated in terms of cracking characteristics, mid span deflection, stiffness, and ultimate load capacity. The shear connector used comprised 8 mm diameter smooth mild steel bars. They were inserted and anchored into pre-drilled holes at the soffit of the beams using epoxy resin adhesive. The free ends were then bent and secured to reinforcement in the ferrocement laminates. A total of twelve simply supported T-beams were tested under concentrated loads applied at mid-span. A 30 mm thick strengthening ferrocement laminates consist of two smooth mild steel bars of diameter 6 mm sandwiched between two layers of galvanized welded wire mesh. They concluded that the addition of the ferrocement laminate to the tension face of reinforced concrete beams using L-shaped bar connectors could substantially improve the performance of the beams. The appearance of the first crack was delayed by the presence
of the ferrocement laminate. The flexural rigidity of the strengthened beams was higher than the unstrengthened beams. The increase in flexural capacity was dependent on the amount of additional reinforcement and preservation of full composite action until failure.

Paramasivam et.al (1998), studied the strengthening of reinforced concrete beams using ferrocement laminates attached onto the surface of the beams were reviewed. Investigations into the transfer of forces, across the concrete ferrocement interface, the effects of the level of damage sustained by the original beams prior to repair and the results of repeated loading on the performance of the strengthened beams were discussed. They suggested that ferrocement was a viable alternative strengthening component for the rehabilitation of reinforced concrete structures. They had suggested that the strengthening of beams in flexure, prefabricated ferrocement reinforcements were attached onto the beams soffit (tension face) before the ferrocement matrix was cast to complete the laminate. Shear connectors were introduced for the dual purpose of securing the ferrocement reinforcement during fabrication and to promote composite action between concrete substrate and the ferrocement laminate during loading. They have also investigated the use of mechanical shear connectors in flexural strengthening of beams. They examined two types of anchorage systems namely power driven nails of diameter 3.8 mm and anchor bolts of diameter 15 mm. The possible use of epoxy resin adhesive in place of the mechanical anchorages was also examined. Epoxy resin adhesive was first applied onto the beam soffit after which the ferrocement reinforcement was placed onto the beam soffit and the mortar was applied. All the strengthened beams were then tested to failure under simply supported conditions. They found that composite action between the ferrocement laminates and the concrete substrate were sustained in the beams strengthened with laminates attached to a power drives nails at a spacing of 100 mm and that attached using epoxy resin adhesive. All other beams, despite the use of mechanical anchorages exhibited localized horizontal cracks along concrete ferrocement interface. They had concluded that the addition of ferrocement laminates to the soffit (tension face) of the beams tested statically, substantially delay the first crack load, restrained cracks from further widening and increase the flexural stiffness and load capacities. Further improvements in mid-span deflections and load carrying capacities were noticed.
Hani Nassif and Husam Najm (2004), in the paper, suggested that the use of cementious composites for infra-structure applications was becoming more popular with the introduction of new high performance materials. Ferrocement laminates were introduced to enhance the overall performance of structures as composite bridge decks, bearing walls, beams etc. This article presented the results of an experimental and analytical study done on composite beams made of reinforced concrete over laid on a thin section of ferrocement. Various types of beams specimens with various mesh types (hexagonal and square) were tested under a two point loading system to failure. Bridge deck rehabilitation was emerging as an increasingly important topic in the effort to deal with the deteriorating structure. This paper introduces ferrocement laminates with high compressive strength at the bottom of the concrete deck. The beam specimens were cast in two groups. The dimensions were reduced geometrically from an actual bridge deck. A total of 24 simply supported composite beams were tested under a two point loading system. From the results, they concluded that full composite action between both layers cannot be attained based on rough surfaces without shear studs. They observed that a minimum number of five studs were needed to provide full composite action between both layers. Beams having shear studs with hooks exhibited better pre-cracking stiffness as well as cracking strength than those with L shaped studs.

Mohd Zamin Jumaat and Ashraful Alam (2006), investigated the strengthening of reinforced concrete beams using ferrocement laminates with skeletal bars attached onto the soffit of the beam. Investigations into the methods of anchorage of the ferrocement laminates in the strengthened beams, methods to increase the ultimate load of the original beam using ferrocement laminate and control the cracking behaviour of the beams and the effect of damage of the original beams prior for repair. In that study, nine rectangular beams were fabricated and tested. They concluded that the beam strengthened by using ferrocement laminates have performed better in cracking behaviour, reduction in mid-span deflection and increase in the ultimate load carrying capacity. The additions of the ferrocement laminates with skeletal bars to the soffit of the beam substantially delayed the formations of first crack, restrained the crack width and increase the flexural stiffness. Mild steel bars of diameter 6 mm and anchorage length 200 mm were found to be adequate to ensure full composite action at the concrete and ferrocement interface. The
crack pattern for both the original and repaired beam were similar in nature. They also suggested based on the results of the investigations, ferrocement could be shown to be a viable alternative material for the repair and strengthening of reinforced concrete beams.

2.6 SUMMARY

Based on the review of the available literature, the following points had been taken note of:

- Most of the rehabilitation and retrofitting works had been done on FRP as a rehabilitation material.
- Most of the works had been carried out on the rehabilitation of structures undergone short term failure.
- Many researchers had used steel plates or fibre laminates for retrofitting purpose.
- The study of ferrocement as a rehabilitation material was few in number and some of the ferrocement rehabilitation study had dealt with number of layers of ferrocement reinforcement and few of them in terms of volume fraction of ferrocement reinforcement upto 3.53% with single type of mesh.
- There were very limited studies on plate bonding technique for rehabilitation and retrofitting of structures and very limited studies on cast insitu bonding technique for rehabilitation and retrofitting of concrete structures.
- Only limited studies have dealt with the prediction of ultimate load carrying capacity.

2.7 NEED FOR THE RESEARCH

From the literature review, it is clear that most of the works have been done on retrofitting and rehabilitation of structures by FRP plates or steel plates and limited studies have been carried out on different composite plate bonding techniques and cast insitu bonding techniques. Most of the studies reported the behaviour of structural elements subjected to different types of damages. The present work aims at studying the effect of ferrocement laminates used as rehabilitation material by adopting plate bonding technique and cast insitu bonding technique on undamaged and predamaged reinforced concrete beams, and also to examine the effect of three different volume fraction of ferrocement reinforcement $V_r=2.192\%$, $V_r=4.386\%$ and $6.576\%$ in ferrocement laminates.
This has been planned to be achieved by conducting extensive experimental and analytical studies on reinforced concrete beams, under undamaged laminated and predamaged rehabilitated status.