CHAPTER 2

LITERATURE REVIEW

A brief literature review pertaining to the present work in ferrocement, ferrocement RC composite construction, Finite Element techniques are presented in this chapter.

2.1 GENERAL

Rapid development of innovative and fast track construction techniques and application of ferrocement (FC) is increasingly becoming common in various structural engineering applications. This leads to the research on ferrocement with considerable volume of technical information regarding design, construction, maintenance and rehabilitation techniques on ferrocement are available. Many researches have been carried out and listed the property and behavior of thin composite element ferrocement on flexure, impact, durability etc. Further it is required to evaluate the behavior of ferrocement composite in shear, to ensure the structural stability in shear strength also. The matrices used for casting the ferrocement elements are mostly normal cement mortar. A very few research works have been done on the usage of self compacting mortar for the ferrocement mortar. The selection of self compacting mortar for ferrocement will reduce corrosion and increase the durability of the structure due to uniform dispersion of mortar. Evaluation of ferrocement formwork systems in flexure and the composite action between
the RC and the ferrocement formwork interaction with various shear connectors were studied in this research. The literature survey on self compacting mortar and use of ferrocement as permanent formwork in flexure and shear were discussed below.

2.2 TENSILE TEST ON WIRE MESH FOR FERROCEMENT

Naaman & Shah (1971) proposed the tension test for ferrocement, which makes use of layers of reinforcement that are most often in the form of welded or woven wire mesh and expanded metal. They also recommended yield strength of weld mesh for the specific types of mesh. Prande & Gaidhakar (2014) reported in their study that the increase in tension due to increase in contact area between wire meshes and mortar by increasing the number of layers of meshes.

An experimental study on tension behavior of ferrocement in direct tension test reported by Phalke & Gaidhakar (2014) in addition of fibers shows that the panels with more number of layers exhibits greater tensile strength as compared with same panels having less number of layers of mesh as well as panels with fiber mesh shows less elongation. Phalkel (2014), describes the same nature of results with the flat panel casted with mortar using 1% super plasticizer.

Hossain et al. (2005) conducted an experimental investigation on the flexural behavior of thin cement composite ferrocement with geogrid mesh and chicken mesh by varying percentage of reinforcement and reported the load-deflection smooth curve for geogrid-mesh-cement composites.
2.3 SELF COMPACTING MORTAR (SCM)

Memon et al. (2007) studied the performance of high workability mortar mix, applicable for casting of thin ferrocement elements by using slag as cement replacement and super plasticizer as water reducing agent. The results showed that the high workability slag cement mortars are having reasonably high strength, low water absorption and exhibiting early strength. Rathish (2010) reported that the use of high range water reducing super plasticizer reduces the pore structure and increases the compressive strength and thereby increasing the durability. It was concluded from the study that the addition of an optimum dosage of superplasticizer improved the workability and strength characteristics of silica fume mortars. In order to propose a simplified mix proportion for ferrocement works Sivakumar et al. (2011) describes a conceptual approach for Optimum dosage of hyper plasticizers using Marsh cone studies and a good stability and uniform spread of concrete without segregation of aggregates or mortar were observed. S. Thenmozhi (2012) presented a flexural behavior of self compacted concrete with fiber reinforced slab. The test result indicates the reduction of crack width and SCC ferrocement hybrid polypropylene fibers indicates delay in crack growth.

Rajkumar & Vidivelli (2010), reported the investigations on the mechanical properties of mortar through difference in polymer content and also by ferrocement with three different volume fractions of mesh reinforcement modified with styrene Butadiene Rubber Latex. The test results confirm that polymer modified ferrocement laminates can be used to significantly increase the flexural capacity of RC beams.
2.4 FERROCEMENT FORMWORK SYSTEM

Kadir et al. (1997) proposed the technique for using ferrocement concept to produce in situ permanent formwork as a viable alternative for traditionally used wooden forms. Then Mays & Barnes (2010) studied the feasibility of using precast ferrocement as a low permeability cover layer to the subsequently poured in situ reinforced concrete members, where there is a high risk of reinforcement corrosion. The use of permanent ferrocement formwork provided an increase in strength of 15% over the conventional reinforced concrete. He also presented the test result on the flexural behavior of reinforced concrete beams with ferrocement permanent formwork. The beams incorporating ferrocement formwork contributed from 16 to 75% to the flexural strength of the composite beams depending on steel area and the use of shear connectors.

Based on the observation made by Desayi & Nandakumar (1995) assuming physical models on the formation of flexural shear crack and web-shear crack and the best-fit semi-empirical equations have been developed. Abdel Tawab, Alaa (2006) expressed the results of an investigation aiming at the development of U-shaped ferrocement permanent forms can be used for construction of reinforced concrete beams as a viable alternative to traditionally used wooden and metal formwork. Shaheen et al. (2013) studied the behavior of ferrocement concrete composite channels, reinforced with various types of reinforcing materials under failure load. The results showed that high ultimate and serviceability loads, crack resistance control, high ductility, and good energy absorption properties could be achieved by using the proposed permanent ferrocement forms.
Mansur et al. (2000) studied the behavior of ferrocement in shear by conducting flexural tests on simply supported beams under two symmetrical point loads. The major variables of the study were the shear span-to-depth ratio a/h, volume fraction of reinforcement, strength of mortar, and the amount of reinforcement near the compression face. Test results indicate that the diagonal cracking strength of ferrocement increases as the a/h ratio decreases and the amount of reinforcement near the compression face are increased. Nassif & Najm (2004) studied the overall performance of structures, such as composite bridge decks, beams, bearing walls, etc. Various types of beam specimens with various mesh types (hexagonal and square) were tested under a two-point loading system up to failure. Experimental results were compared with nonlinear analysis as well as a finite element model for overall non-linear behavior. Results show that the proposed composite beam has good ductility, cracking strength and ultimate capacity.

Chandrasekhar Rao et al. (2008) presented an experimental study on the strength and behavioural aspect of voided ferrocement channel type units for precast beams. The flexural strength of the voided channels was compared with that of solid channels too. The test results indicate that the drop in flexural strength with the voids is very negligible compared to the decrease in the weight of the member. The Moment curvature response of the voided members under flexural loading improved with the post ductility of the member with increase in the number of layers.

Al-Rifaie & Jomaah (2010), presented, prefabricated ferrocement panels for composite floor and wall panels. The measured values of deflections and the observations made indicated that ferrocement can be used in construction of buildings.
Abasolo et al. (2009), focused on the fabrication and the maximum moment capacity of a Ferrocement beam. The Ferrocement beams specimen shows higher ultimate moment capacity than the benchmark specimen. This means that the beams are safe for using as a floor joist beams in residential and commercial structures.

### 2.5 FERROCEMENT WITH SHEAR CONNECTORS

Hammoud & Naaman (1998) conducted an experimental investigation to study the behavior of ferrocement bolted shear joints. Three failure modes, net tensile section failure, cleavage failure, and crushing compression failure of the bolt were observed and were compared with the equations developed based on the Lower Bound Theorem.

Hassan & Awal (2011) have done an experimental study on simply supported ferrocement plates having a span/depth ratio of 2.0. A good agreement between the classical shear equations prediction and the experimental values was obtained.

The experimental result on ferrocement concrete composite channels reinforced with various types of reinforcing materials by Shaheen & Hanesh (2015) resulted high crack resistance, high deformation characteristics, high strength, high ductility and energy absorption. Bansal et al (2008), explains the various retrofitting techniques using ferrocement due to its easy availability, economy, durability, and their property of being casted into any shape without need of significant formwork.
Ghosh et al. (1978), have experimentally verified and suggested that the wire mesh can be used as shear reinforcement for RC members, as a replacement for the conventional stirrups.

2.6 FERROCEMENT AT TENSION ZONE

Al-Kubaisy & Jumaat (2000) presented a study on the flexural behavior of reinforced concrete slabs with ferrocement tension zone cover. The effect on percentage of wire mesh reinforcement, cover layer, thickness and the type of connection between the ferrocement layer and the reinforced concrete slab on the ultimate flexural load, first crack load, crack width and spacing and the load deflection relationship were examined. The results indicate that the use of ferrocement cover slightly increases the ultimate flexural load and increases the first crack load. The first crack load increased with the increase in the percentage of mesh reinforcement and the ferrocement layer thickness. Considerable reduction in cracks width and spacing was observed for specimens with a ferrocement layer.

Paramasivam et al. (1998) reviewed the repair and strengthening of reinforced concrete beams using ferrocement laminates attached onto the surface of the beams. The result shows that ferrocement is a viable alternative as strengthening component for the rehabilitation of reinforced concrete structures. Zamin et al. (2010) presented a new approach for flexural modulus of laminated composites derived from the analysis of a flexural-section composed of several ductile and brittle layers of different module.

Sakthivel & Jagannathan (2012) have made an attempt to experimentally investigate the ultimate flexural load of ferrocement slabs reinforced with PVC coated steel weld mesh and galvanized ion weld mesh.
The flexural load of slab with PVC coated weld mesh is 90% that of specimens with galvanized iron weld mesh. Increasing the number of mesh layers substantially increases the flexural load as well as improving the ductility behavior of ferrocement slabs.

Ranković & Drenić (2002), have reviewed the most important analytic expressions, on the basis of strength of shear connectors in steel-concrete composite beams. Mohammed & Assi (2012), have carried out tests on fibrocement discs to measure tensile stress-strain relationship including testing wide ranges of matrix strength. The analysis based on the proposed tensile model was found to be accurate for ferrocement beams and slab strips provided that the span/depth ratio less than 2.

Shah (2011) tested the parameters such as cement mortar thickness, gage-wire spacing and bond at the interface of ferrocement and brick columns. It was found that the first crack load and ultimate load of a ferrocement encased masonry column was increased by 119% and 121% respectively. Al-Rifaie et al. (2014) analysed the prefabricated ferrocement cavity wall and roof panels to produce very energy efficient dwellings. Savale et al. (2013) studied the behavior of ferrocement plate with various mesh patterns. The result gave increase in volume fraction (VF) of wire mesh layer subsequently increases the shear carrying capacity of the plate. The stress intensity is determined using FEM (ANSYS) and compared with the available results.

Nandhini et al. (2012) carried out tests on GFRP sandwiched ferrocement slabs of 50mm thick to evaluate the performance under static and dynamic loading conditions. In both loading the ductility behavior of GFRP
composite ferrocement slab was found to be drastically improved compared to ferrocement slabs.

Masood et al. (2003) tested the potential of ferrocement in normal, moderate, and hostile environments. The result shows an increase in the load carrying capacity of panels with 20% addition of fly ash. Ahmad et al. (1995) have tested thin wall webbed sections under transverse load. The result indicates that the ultimate shear increases with increase in the volume fraction of wire mesh. Also an empirical expression has been developed for the same for ease in direct design application.

Quek & On (1991), emphasizes on the mathematical models used for predicting the ultimate and first crack moment capacities of ferrocement structural elements. The result indicates that the mechanism approach and the equilibrium method are comparatively more reliable. Mansur & Ong (1987) have conducted flexural test on the simply supported rectangular beam by varying the shear span to depth ratio and the volume fraction of reinforcement. The result shows that the ferrocement with small shear span to depth ratio are more prone to shear failure even with the increase in volume fraction of reinforcement.

Paramasivam & Sri Ravindrarajah (1988) have studied the behavior of bundled reinforcement in ferrocement element under tension and bending by placing it in top, bottom and middle. The result concludes that by placing the reinforcement near the surface reduces the first crack.

Sasiekalaa & Malathy (2012) conducted flexural test on 500mm x 150mm x 25mm, by including silica fume (SF) and fly ash (FA) with superplasticizer. From the experimental results it was found that the
combination of 5% silica fume, 20% fly ash and 0.6% super plasticizer reinforced with volume fraction 2.823% and 3.770% leads to significantly improved flexural behaviour in terms of strength, toughness with increase in shear resistance and cracking.

Mourad (2000) discussed the different techniques to increase the existing column capacities. Investigation on the efficiency of confining plain concrete with different layers of Welded Wire Fabric (WWF) resulted the strength gain.

Sakthivel & Jagannathan (2011), Ravindrarajah et al. (1996), studied the importance of using ferrocement in swimming pools and water tanks, silos, corrugated roofs, shell and dome structures, and also in the repair of RC structures. Hossain & Awal (2011) carried out experimental and analytical investigations for modulus of elasticity of thin cement composite and observed that the flexural modulus of elasticity of thin cement composite depends on the elastic modulus of mortar.

2.7 NUMERICAL MODEL USING ANSYS

Aboul-Anen et al. (2009), emphasize on the composite action between the ferrocement slab (0.8m x 0.8m x 0.025mm thick) and the steel sheeting. The experimental results were compared for the ferrocement slab with and without steel sheeting and their numerical models were developed using ANSYS software package.

Analysis was done using the finite element software ANSYS V. 11 by Mohammed (2012), with 8-node iso-parametric brick elements, to represent mortar, the wire mesh layers were considered as smeared layers
elastic-perfectly plastic materials embedded within the brick elements by assuming perfect bond between the mortar and steel. As well as increasing number of wire mesh layers increase the load capacity by 18% and 28% respectively. The increase in the thickness and variation in diameter cause decrease in deflection to 20% and 10% alternately.

Saleem & Ashraf (2008), have focused on developing a design for small size, low cost earthquake resistant house. Earthquake resistance was ensured by analysing the structure on ETABS for seismic zone 4. The structure shows satisfactory behavior under earthquake loading.

Mohamad (2012), has developed a procedure to analyse ferrocement slab. Computational model has been compared with numerical and experimental results. The result shows that the computational model is adequate for predicting non-linear behaviour of ferrocement slab.

Singh et al. (2014) presented the non linear behavior of RC beam-column joints using Finite Element Modeling under the static load has been carried out, to study the response and load carrying capacity of exterior RC beam-column joints using non-linear finite element analysis with software ATENA-3D. The results showed a significant improvement in the ultimate load carrying capacity.

Shaheen & Eltaly (2013), investigated the possibility of using ferrocement in constructing water supply pipe. Finite element models were developed to stimulate the behavior of the pipes through nonlinear response and up to failure, using the ANSYS Package. Shaheen et al. (2013), presented the damage in ferrocement tank was detected experimentally by changing its dynamic parameters. A theoretical models using ANSYS finite element
software were developed to find the modal parameters of the healthy and damage tank. The results showed that the theoretical models give accurate results in comparing with the theoretical results. Also the experimental modal analysis is quick, easy and inexpensive method to detect the damage in the ferrocement tank.

Kulkarni & Chhabra (2014) report deals with the shear strength of simply supported ferrocement rectangular beam subjected to two point loading. The stress intensity was determined using ANSYS and compared with the available test results and analytical calculations.

Ibrahim & Mahmood (2009) presented an analytical model for reinforced concrete beams externally reinforced with fiber reinforced polymer (FRP) laminates using finite elements method adopted by ANSYS. The results obtained from the ANSYS finite element analysis were slightly stiffer than that from the experimental results. The maximum difference in ultimate loads for all cases is 7.8%.

2.8 CONCLUSION FORM LITERATURE

2.8.1 Tensile test on wire mesh for ferrocement

The wire meshes are not indented to be used for engineering applications and there is no standard test procedure to determine the mechanical properties of wire mesh. In 1987 Nanni, A & Zollo, RF have developed some standard procedure to determine the relative modulus, tensile strength of the wire. The characteristic of wire fabrics varies from manufacturer to manufacturer. Hence there must be some standardization for each manufacturer and therefore properties of wire fabrics must be tested for
each project. Tensile strength of ferrocement increases as the contact area between mortar and wire mesh increases. The flexural strength increases and deflection decreases as the wire mesh layer increases. The test on weld mesh has to perform with the standard procedure when it is used for engineering applications.

2.8.2 Self Compacting Mortar (SCM)

Ferrocement is a thin composite made of wire mesh and mortar with the effective cover of 1.5mm – 2mm. The probability of corrosion is more due to very less cover thickness which will reduce the lifespan of the member. Hence the performance of the mortar plays an important role in ferrocement elements. In the initial stage of ferrocement construction, conventional mortar of 1:2 to 1:3 with water cement ratio 0.35 to 0.5 has been used. With the availability of chemical admixtures it is easy to prepare a self compacting mortar for the ferrocement. The self compacting mortar possess low permeability, high workability and high compressive strength. Many research works have been conducted to optimize the dosage of admixtures to get high workable and high strength mixes with various mineral admixtures. The selection mix proportion of mortar is to decide based on the purpose of ferrocement element and its application.

2.8.3 Ferrocement

Use of ferrocement as a permanent formwork system for beam element provides an increase in strength of 15% over the conventional beam. Compared to wooded and steel formworks, “U” shaped ferrocement formworks showed higher ultimate strength, crack resistance, high ductility, good energy absorption and serviceability loads. When the ferrocement is
introduced only at the tension cover zone there is a slight increase in the ultimate flexural capacity and first crack load. The slip at the cold joint (cold joints are formed primarily between two batches of concrete where second batch is delayed and placed) between reinforced concrete slab and ferrocement layers lowered the ultimate flexural strength by 34% but reduced the crack width. Systems incorporating shear connectors exhibited higher flexural strength upto 10% and reduced deflection compared to the system without the shear connectors. The behavior of ferrocement when shear span to depth ratio (a/h) decreases diagonal crack strength increases. When the volume fraction of wire mesh and the strength of mortar are high and the shear span to depth ratio is small, then it is susceptible to shear failure. Ferrocement with various types of element (hexagonal and Square) with the non linear analysis and finite element method of analysis model result shows, proposed component has good ductility cracking strength and ultimate capacity. In the repair and rehabilitation works ferrocement is a very good viable alternate strength component for reinforced concrete systems.

2.8.4 Finite Element modeling

The results obtained from the finite element analysis software ANSYS results are slightly differ from the experimental results but it is with in the limit. Hence Complex models can be done using finite element software to save the time and cost invested for experimental work.

2.9 STRUCTURE OF THE THESIS

The details of the work done in this investigation are arranged in the following sequence
Chapter 1 emphasizes the history, significance and characteristics of ferrocement technology. It also describes the application of ferrocement in various field, advantage and disadvantage of using ferrocement.

Chapter 2 briefs the literatures pertaining to the present work in ferrocement, ferrocement RC composite construction, Finite Element techniques are presented in this chapter.

Chapter 3 describes the development of self compacting mortar using various admixtures and the hardened properties.

Chapter 4 elaborates the effect of shear span to depth ratio of ferrocement channel section under flexural loading. The influence of volume fraction of reinforcement on the bending strength of the beam is also focused. The ferrocement channel section in-filled with RC composite under flexural loading is compared with the finite element technique using ANSYS software modeling.

Chapter 5 presents the use of various types of shear connectors to enhance the interaction between the ferrocement and RC components. It also elaborates the flexural behavior of ferrocement in-filled RC composite beam. The experimental results have been verified with the finite element software ANSYS 14.5.

Chapter 6 presents the flexural strength of RC beam with ferrocement placed at the tensile side. The load deflection was compare with those observed from the finite element software ANSYS 14.5. The moment curvature relation and strain values are also presented.

Chapter 7 gives the general conclusions and specific conclusions on each category of the beams.