ISSN (Online) : 2348 - 2001

International Refereed Journal of Reviews and Research

Volume 5 Issue 5 September 2017

International Manuscript ID : 23482001V5I5092017-03

(Approved and Registered with Govt. of India)

Lightweight Composite Ferrocement Structural Elements: A Review

Farhaz Ahmed[1], Yati Aggarwal[2], Sunita Bansal[3]

Corresponding Author 1

M.Tech Research Scholar, Department of Civil Engineering, FET(Faculty of Engineering and Technology), Manav Rachna International University, Faridabad, India

E-mail: farhaz021@gmail.com

Author 2

Assistant Professor, Department of Civil Engineering, FET, Manav Rachna International University, Faridabad, India

Author 3

Associate Professor, Department of Civil Engineering, FET, Manav Rachna International University, Faridabad, India

Abstract: Construction of lightweight structures is a prerequisite to disaster risk reduction, low cost housing and economical viability. Ferrocement has extensive applications in lighter, low cost housing, architecture and insulation work. But its structural applications from both load bearing and non-load bearing aspects are still unharnessed. The main objective of this study is to conduct a review of Lightweight Composite Ferrocement panels. Though many experimental studies have been conducted but few actually give the metrics of weight vs. strength appraisal for optimum light construction. The performance metrics of ferrocement greatly depends on the characteristics of the reinforcing mesh and the mortar mix. Optimum range of properties of mesh, number of layers, fillers and strength of mortar needs to be standardised. Also, the Indian Standard Codes of practice is very isolated in its approach as it covers only the specifications of precast ferrocement tanks. More experimental studies are required on the behaviour and the performance of LWF (lightweight ferrocement) composite plates with lightweight materials like polystyrene sheets as filler in flexure and shear.

Keywords: Ferrocement, sandwich panels, ferrocement mortar mix, lightweight composite ferrocement panels

1. **Introduction:**

In India there are around 250 million housing units out of which about 90 percent use masonry work for walls but main drawbacks include huge weight and thermal discomfort. To make any structure light proper designing is necessary. The dead load and supported live load ratio should be small to make structure lighter. The lightweight design uses maximum accessible resources regarding minimum weight and the strength capacity. The allowable strain and stiffness in working condition has to be given due consideration. Since, there is large number of determinants such as material, assembly, fabrication, maintenance etc., Engineers have to deal with different situations to reach optimum light structure. Ferrocement has proven to be a construction technique which is lighter and economical. State-of-the-Art Report on Ferrocement reported by American Concrete Institute(ACI) Committee 549 in year 1975 defined ferrocement as "*Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials*" (1997).

ISSN (Online) : 2348 - 2001

International Refereed Journal of Reviews and Research

Volume 5 Issue 5 September 2017

International Manuscript ID : 23482001V5I5092017-03

(Approved and Registered with Govt. of India)

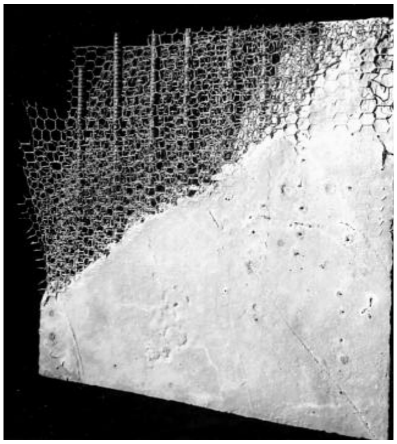


Figure 1: Ferrocement Panel, Source:(1997)

Joseph-Louis Lambot was the first person to use cement mortar with small size wire mesh to make water tank. In 1848 he constructed first boat using cement mortar and wire mesh.

Almost after hundred years in 1940-1950, an Italian engineer and architect *Pier Luigi Nervi* recognized that ferrocement's advantage are not only restricted to boat building but can also be utilize in terrestrial work, and performed experiments on them (2012).

Fisheries Department of the Food and Agriculture Organization (FAO) in 1968 began constructing boats of ferrocement in Latin America, Asia and Africa. In 1972, United States National Academy of Sciences assembled a team to collect data on ferrocement's application in developing countries which recommended to constitute a global hub to assemble, process and distribute data on ferrocement (2012). In 1975, National Science Foundation checked the ferrocement's behavior in bending under static loading and cyclic fatigue loading (1997). In the second phase (1988) ACI committee developed "Guide for the Design, Construction and Repair of Ferrocement" that became famous globally and gives us the basics of local codes on ferrocement. Since ferrocement is found to have some distinctive properties like lightweight, superior cracking behavior, moldability to any shape, high tensile strength-to-weight ratio. It has good potential in the construction industry, especially in developing countries where light weight and low cost housing is required. Use of locally associable resources like materials and partial skilled labor can provide wide range applications, for example pre-fabricated house units, construction of boats, biogas structures and for the purpose of strengthening and repairing of structures. Ferrocement is very flexible material possessing effective performance characteristic, predominantly in crack load, ductility and strength. As reinforcement is equally spread in transverse as well as longitudinal direction which is closely spaced throughout the section, ferrocement lends itself to precasting to meet the strength and serviceability conditions. There is a sufficient scope for standardization and mass production with the economy in construction (2014b). Many experimental work have outlined the mechanical and physical properties of ferrocement, and a lot of data is available to explain its behavior for further research (2012g).

2. Use of Ferrocement Layers:

In 1994 Gregson and Dickson innovated a combination of Reinforced concrete and ferrocement to form distinctive structure of Schlumberger Cambridge Research building. at the same time Al-Rifaei and Hassan studied channel shaped ferrocement behavior in one-way bending elements theoretically as well as experimentally and found out that the element gives large deformation before failure and is acceptable for susceptible structures (2012h).

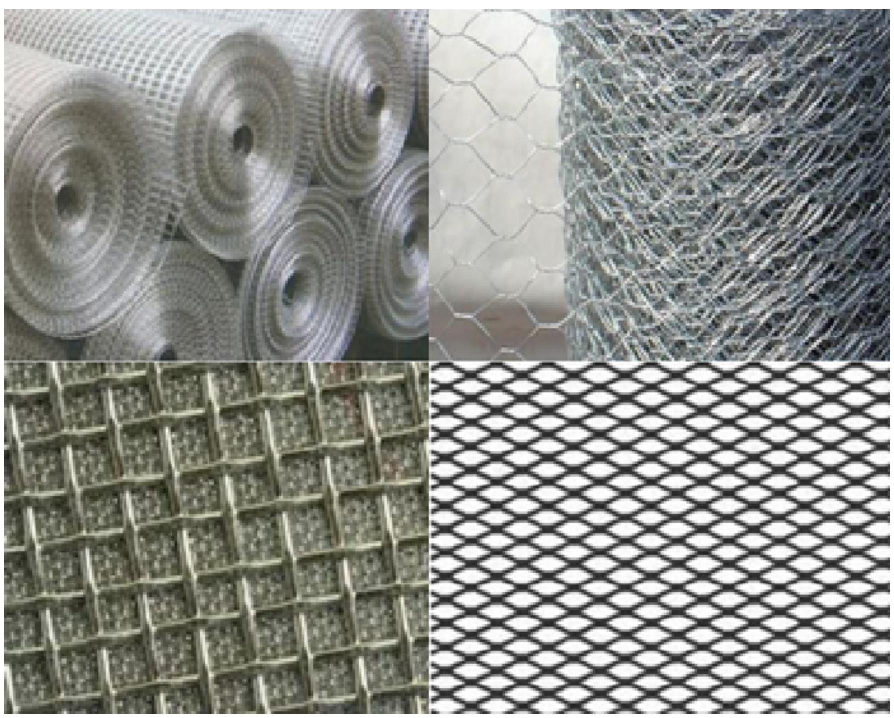


Figure 2: Types of wire mesh

ISSN (Online) : 2348 - 2001

International Refereed Journal of Reviews and Research

Volume 5 Issue 5 September 2017

International Manuscript ID : 23482001V5I5092017-03

(Approved and Registered with Govt. of India)

In 1995 Barnes and Mays used low permeability cover layer of ferrocement on reinforced concrete element which is placed in reinforcement corrosion prone areas. It was found out that the use of styrene butadiene rubber between the ferrocement forms and the reinforced concrete can be precast and also used as formwork which give an increase in strength of about 15 percent as compared to traditional reinforced concrete (2012h). Chandrasekhar Rao et al. (2012) conducted tests on voided ferrocement channels to study the behavioral aspects and strengths of precast beams. They found flexural strength decreases in voided channel when equated to solid channel but the fall in strength is very less when compared with weight of the beam. They concluded that cracking load capacity does not get affected by change in percentage of steel but ultimate strength does change significantly. By increasing the number of layers, crack width decreases but stiffness and load carrying capacity increases. Further to this, in another experimental study, Chandrasekhar Rao et al. (2006) studied 60 ferrocement plates of rectangular shape by changing number of layers and doing variation in shear span to depth ratio (a/d). Results show the shear behavior is predominant till shear-span to depth (a/d) ratio of 3 but flexural behavior is more important for design of the element beyond this value. They also generated an empirical equation to estimate ferrocement plate's shear capacity.

ISSN (Online) : 2348 - 2001
International Refereed Journal of Reviews and Research
Volume 5 Issue 5 September 2017
International Manuscript ID : 23482001V5I5092017-03
(Approved and Registered with Govt. of India)

Figure 3: Two point loading arrangement, Source:(1982)

S.K. Kaushik et al. (2014) gave the idea to change the orientation of wire mesh at 0º, 45º and 60º stressed beams (upto safe load of 75 percent) which retrofitted with ferrocement jackets. It was observed that mesh at angles 45º showed the maximum load carrying capacity when compared with the control specimen. All tests proved fall in deflection, crack width but rise in energy absorption capacity. Retrofitted beams with wire at 0º were most effective because they had least cost to strength ratio. Besides orientation, some studies varied the number of layers and size of opening. Jalal A. Saeed et al. (1997) did experimental work to study the ultimate load and flexural strength of 9 one way ferrocement

ISSN (Online) : 2348 - 2001

International Refereed Journal of Reviews and Research

Volume 5 Issue 5 September 2017

International Manuscript ID : 23482001V5I5092017-03

(Approved and Registered with Govt. of India)

slabs and tested them under two point loading. It was observed that as the size of wire mesh increases flexural strength and ultimate load decreases while when number of layers of mesh increase both increases remarkably. They also suggested empirical equation for ultimate load and cracking load. A. Jagannathan (2012) studied the comparison of Galvanized Iron-coated steel welded mesh and Polyvinyl Chloride coated steel welded mesh and observed their ultimate flexural load by varying number of layers from 1 to 3. Special flexure loading frame was made to test slab of size 700 x 200 x 15 mm with galvanized iron-coated steel welded mesh and polyvinyl chloride coated steel welded mesh under four point loading. By raising the number of layers ductility and flexure load increases. They also found that polyvinyl chloride coated steel welded mesh have flexural load 90 percent than that of galvanized iron-coated steel welded mesh which reasons polyvinyl chloride coated steel welded mesh to be superior to galvanized iron-coated steel welded mesh for slabs of ferrocement.

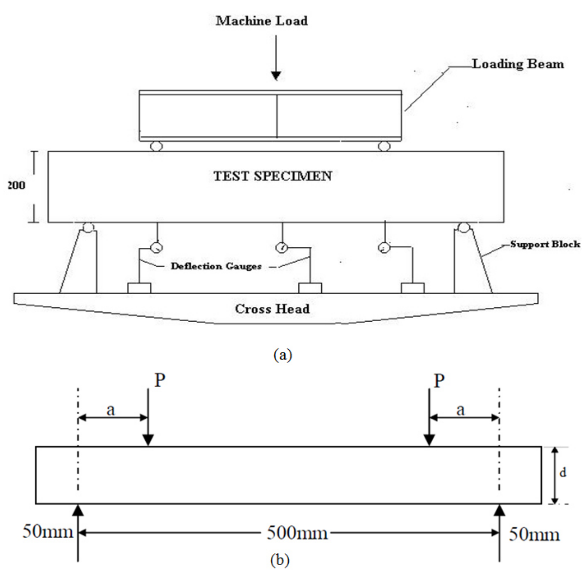


Figure 4:(a) Typical two point loading arrangement, (b) a/d ratio for shear capacity, Source:(2006)

The research study by A. Jagannathan (2011) was performed with an aim to find out effect of polymer mesh Reinforcement in Ferrocement Panels experimentally as well as theoretically. Panels of size 700 x 300 x 25 mm were cast with varying number of polymer mesh and even replacing them by chicken mesh also then tested under 4 point loading. Outcome of the test show that there is a significant relation between the experimental and theoretical values of first crack moment its deflection. When the number of mesh increased there was a slight deduction in deflection at ultimate load and increase in modulus of elasticity while it does not show much change modulus of elasticity in chicken wire mesh.
Mohamad et al. (2009) examined flexural behavior of folded and flat panels of ferrocement. The parameters they varied were number of layers of wire mesh and thus observe its effects on ultimate strength and ductility. They found in folded panel by change in number of layers, there is not much effect on cracking load but flexural strength and energy absorption capability and ductility of both flat and folded panel changes by introducing new wire mesh.

3. Lightweight Ferrocement Structural Elements:

Many experimental studies have been published on ferrocement structural elements like channel beams, cored beams and sandwich slab panels. The structural elements are fabricated in different combinations with two or more layers of meshes at top and bottom tied up with steel loops and various materials as fillers. P. Poluraju et al. (2014f) made a comprehensive review of state of art on 3D slab panels and their behavior under general loading. They observed shear strength depend on diagonals number (100-200 diagonal per square-meter) while axial compressive strength on aspect ratio and concrete's compressive strength. Degree of composite action and shear span have remarkable effect on 3D panel's flexural strength. Abhijit Mandlik et al. (2015b) worked on Expanded polystyrene, it is lightweight material which have compressive strength comparable to medium clay and good thermal insulation. Expanded polystyrene is cheaper than traditional aggregate which is use concrete and have unit weight of 1200-2000 kg/m^3. In this paper, parameters under consideration were modulus of elasticity, drying shrinkage, compressive strength of Expanded polystyrene. Result shows that on increasing the number of expanded polystyrene concrete have negative effect on tensile and compressive strength. Research study by T.C. Rao et al. (2008) on voided channel beams where the flexural strength of solid channel sections was compared with that of voided channels. It was observed that by increasing the no of wire mesh layers voided channel's moment-curvature response is upgraded. Fall in flexural strengths of voided channels is very small as compared to its corresponding weight reduction. T.C. Rao et al. (2009) tried to examine the behavior of voided ferrocement beam in shear and compared it with solid ferrocement channels in shear. They casted 24 channels, for each voided and solid. Parameters varied were number of wire mesh layers and shear-span to depth ratio, and tested them under four-point loading. Results show ultimate shear strength and cracking of both voided and solid rise with fall in shear-span to depth ratio falls and rise in volume fraction of mesh. They found shear behavior is superior up to shear-span to depth (a/d) ratio of 3 and above it flexural behavior is superior for voided as well as solid. Post cracking ductility also rises as the number of layers of wire mesh is increased.

T. Chandra Sekhar Rao et al. (2012) carried out an experimental study on the strength and behavioral aspects of cored Ferrocement box-beams for precast purposes and proposed an empirical formula based on the layers of wire mesh for the ultimate moment capacity of box-beam. As the number of layers increases cored specimen's moment-curvature response ameliorates. Ade S. Wahyuni et al. (2012) conduct experiment to observe the behavior of lightweight sandwich reinforced concrete which is prefabricated by autoclaved aerated concrete block. In total four slab were casted three with varying the quantity of autoclaved aerated and one is solid, eight type of test were performed on them. Slabs showed different shear capacity according to the filler material of autoclaved aerated but when these value compared with codal provisions it comes under codes safety predictions. A. Kumar (2005) suggested box sections of ferrocement for slab, beam and flat slab work. Ferrocement box sections

ISSN (Online) : 2348 - 2001

International Refereed Journal of Reviews and Research

Volume 5 Issue 5 September 2017

International Manuscript ID : 23482001V5I5092017-03

(Approved and Registered with Govt. of India)

were found to be 56.2percent less in weight and 15.6percent lower cost than conventional construction whereas flat slabs were 58.2percent lesser in weight and 17.7percent lower in cost. Experiments conducted by S. Grija et al. (2014) to study behavior of lightweight Ferrocement wall panels. They casted wall panels of size 1000 X 1000 X 150 mm and tested them under axial load. They observed weight of wall panel made by ferrocement is 31.11, 37.33, 49.12, 54.9 and 66.66 percent lighter than Solid brick masonry, hollow block masonry, concrete brick masonry, fly ash brick masonry and brick masonry. Ferrocement wall panels were 78.91 percent less in cost than traditional wall of brick masonry. They also found out that the wall panels of ferrocement have remarkable high ratio of strength to weight than conventional reinforced concrete element.

Yousry B.I. Shaheen et al. (2010) observed the behavior of filler material on the lightweight composite Ferrocement panels under 3 line loading. Parameters varied under consideration were type of filler material, thickness of plate, number and types of layers of meshes. 15 panels were casted, out of which 12 were light weight and 3 were traditional RC (Reinforced Concrete) plates. Results show that as the thickness increases there is a rise in initial and ultimate load. Also, there is a fall in initial and ultimate load as we use filler material but deflection increases by using them. Initial cracking and ultimate loads have great impact on the type of mesh is used. Highest energy absorption capacity (958.54KN.mm) was shown by welded galvanized steel sheet panel while maximum ductility ratio (53.32) is by welded plastic pipes panel when compared with lightweight composite Ferrocement panels.

ISSN (Online) : 2348 - 2001

International Refereed Journal of Reviews and Research

Volume 5 Issue 5 September 2017

International Manuscript ID : 23482001V5I5092017-03

(Approved and Registered with Govt. of India)

Figure 5: Placing the wire mesh, Source: (2013)

Yousry B. Shaheen, et al. (2012) also inspected the behavior of composite reinforced ferrocement concrete plates by varying thickness, shape of mesh and number of layers. Testing of 18 reinforced ferrocement plates was conducted which have sizes of 1100 X 550 mm with variable thickness of 60,80 and 100 mm. Plates also were provided with 6mm dia. steel bars, 6 number of bars in transverse direction and 4 number of bars in longitudinal direction. Two types of steel meshes were used, expended wire mesh of size 33 X 16.5 mm and welded wire mesh of size 12 X 12 mm. Number of layers was varied. All the plates tests' were conducted under three line loading. Conclusion of test was that cracking load mildly increases when the volume fraction of reinforcement increases and it does not depend on the type of mesh. Expanded steel mesh gives high number of cracks than welded mesh for ultimate load. Welded mesh depicted brittle failure under tensile loading without warning. When light weight brick core was put inside plates and flexural loading applied, as the number of opening increases it was observed that there is a increment in ductility ratio, energy absorption ratio and ultimate load.

ISSN (Online) : 2348 - 2001

International Refereed Journal of Reviews and Research

Volume 5 Issue 5 September 2017

International Manuscript ID : 23482001V5I5092017-03

(Approved and Registered with Govt. of India)

Yousry B. Shaheen et al. (2004) in their second phase research work on ferrocement constructed hollow core panels and ferrocement sandwich to see energy absorption, ductility, crack resistance control, serviceability and ultimate loads. They casted 17 sandwich and 24 cored panels 380mm width 1000mm height, thickness 25mm for single layer 35mm for double layer, welded wire, woven and expanded metal mesh, used total thickness 120 to 240 mm and hollow core have 3 holes in circular shape of 75mm dia. throughout specimen length which is filled with same mortar mix. All specimens were tested under axial and flexural loading. Outcome of tests was that all the above parameters under consideration increase with increase in volume fraction. For same thickness, welded wire mesh shows higher ultimate load in flexure than with woven and expended steel mesh and light weight bricks core have lesser strength for axial and flexural loading than ferrocement core panels.

Thermocol or polystyrene when used as filler material in structural members, thermocol provide good bending stiffness at low density because it have very small flexural as well as compressive strength. It can be consider as construction material for structural framework because it easily resist external loads. Pradeepa.S et al. (2016) conducted investigations on lightweight web sandwich panel's strength efficiency. They tested panels under one point as well as under three point loading by considering these panels as floor. They also tested these panels as wall by applying axial loading. It was observed that the cost of construction by Reinforced Thermocol technology was cheaper than the traditional quarried stones construction. qNahro Radi Husein et al. (2013) carried out experimental study on lightweight web sandwich panel. Thirteen panels were casted of size 500 mm X 400 mm X 100 mm having core size 450 mm X 105 mm X 60 mm and special three core prism in every panel. Out of thirteen, three panels had core material of thermocol while remaining ten had aerated concrete. Shown result were in terms of flexural load, ultimate flexural load, failure mode and load-deflection curve and it was observed that unit weight of lightweight web sandwich panel having thermocol was 1250 to 1300 Kg/m^3 and with aerated concrete it was 1850 to 1950 Kg/m^3.

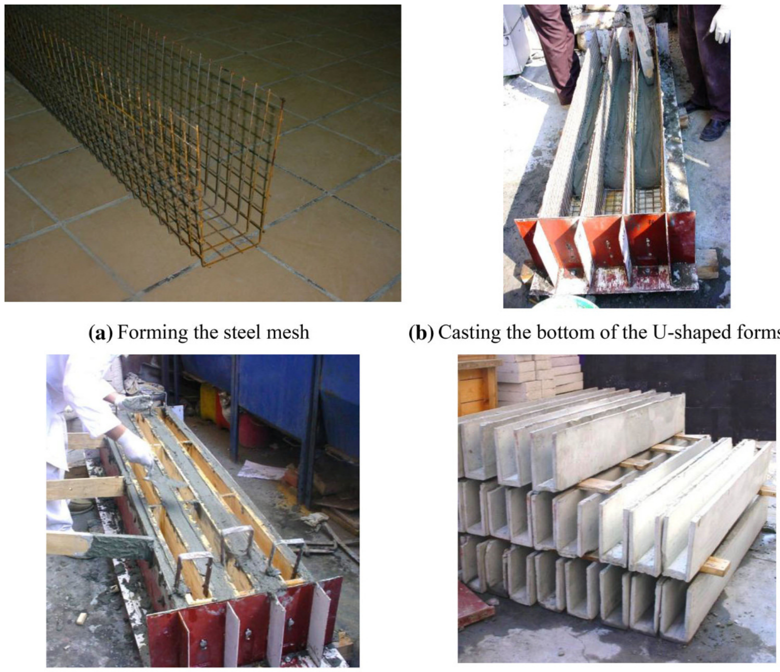
ISSN (Online) : 2348 - 2001

International Refereed Journal of Reviews and Research

Volume 5 Issue 5 September 2017

International Manuscript ID : 23482001V5I5092017-03

(Approved and Registered with Govt. of India)



(a) Forming the steel mesh **(b)** Casting the bottom of the U-shaped forms

(c) Casting the sides of the U-shaped forms **(d)** The U-shaped ferrocement forms

Figure 5: U-shaped Forms, Source:(2014)

4. Different Mixes of Mortar in Ferrocement:

According to World Business Council for Sustainable Development "Cement poses several sustainability issues that need to be managed: Cement production emits CO_2 and other air emissions, and the quarrying of raw materials produces local impacts such as noise and dust. Also, water use needs to be carefully looked at in locations where water is scarce" (n.d.). With the contemporary aims of sustainability in construction, cement is being replaced by lower embodied energy materials. Lot of research has been done to achieve same strength and properties of cement composites when cement content is varied by adding pozzolanic materials like fly-ash, silica fumes, ground blast furnace slag etc. Some additives like fibers; polystyrene or different types of aggregates have also been tried and

ISSN (Online) : 2348 - 2001
International Refereed Journal of Reviews and Research
Volume 5 Issue 5 September 2017
International Manuscript ID : 23482001V5I5092017-03
(Approved and Registered with Govt. of India)

tested. It is possible to achieve considerable improvements in various properties of this Ferrocement slabs by substituting regular materials in mortar.

Yousry B. Shaheen et al. (2016) investigated the effect of silica fumes on the concrete's properties and to find out optimum percentage of silica fumes for replacement of cement. 12 composite slabs of size 1200 X 1200 X 140 mm were cast in which one layer of polystyrene is sandwich between layers of ferrocement. Result incorporate comparisons between first crack load, crack pattern, flexural strength, and deflection at different loading. Results show that Optimum silica fumes percentage for replacement of cement was 10percent based on tests of tensile and compressive strength. Block of polystyrene increases the ultimate shear punching load of the composite slab. The volume fraction of steel bars have great impact on energy absorption, resisting moment and ductility, more the steel ratio more will be the ultimate moment. Salihuddin Radin Sumadi et al. (2008) experimental work was in 2 phase, in first phase ferrocement slab were casted of high workability slag-cement mortar mix and test were done in according to observe the compressive strength and optimum replacement of cement by slag of about 50% to 60%. In second phase, 600 elements of aerated concrete sandwich ferrocement wall were casted. Results showed change in Flexural strength, load-deflection behavior, water absorption by variation in number of layers.

In 2012, Naveen et al. (2012) used blast furnace slag in place of fine aggregates to make specimen lightweight. They studied blast furnace slag's variation (0, 10, 20 and 30 percent) effect in ultimate strength and first crack, also the ferrocement behavior under repeated monolithic flexural loading. They observed 10 percent of sand replacement by slag gives maximum value of ultimate strength and first crack. By increasing number of wire mesh (volume fraction) high number of repetitions is taken by specimen due to increase in strain carrying capacity.

M.Amala and Dr. M.Neelamegam (2015) compared and studied the behavior of ferrocement on the variation in ratio of cement and copper slag. 4 point static loading was used to examine the samples. Results showed that ferrocement slabs of copper slag have better flexural strength than the traditional ferrocement slabs and copper slag also improved the impact strength. Further, it is observed that as copper slag increases, kinetic energy also increases.

Mohana Rajendran et al. (2013) tried to make a geopolymer ferrocement slab in which they added geopolymer instead of cement and varied sodium hydroxide's concentration as 8M, 10M, 12M and 14M. Total 30 slabs were casted of size 1000 × 200 × 25 or 30mm (varying thickness) and examined under flexural loading. After investigations, it was found that as percentage of geopolymer and thickness of slab increases, stiffness and load carrying capacity increases and crack width decreases. Energy absorption properties and deformation at ultimate load also increased by the use of geopolymer.

J. Sridhar et al. (2014) examined the behavior of composite reinforced ferrocement beam with replacement of fine aggregates with steel slag in which they varied volume fraction of mesh as 1.88 percent and 2.35 percent and replaced fine aggregate by steel slag as 0 percent and 30 percent. Flexural tests under two-point loading were done on 5 RCC beams of size 1220 X 100 X 150 mm and 4 ferrocement beams of size 1220 X 100 X 25 mm by varying above parameters. Epoxy resin was also used in ferrocement laminates for bonding. From the results it was found out that 30 percent of steel slag and 2.35 percent of volume fraction gives increased value of load carrying capacity, energy absorption capacity and ductility.

The research study by M. Jamal Shannag (2007) to observe the outcome of mixing discontinuous fibers in mortar specimen with steel mesh. Parameter under consideration were changing number of wire mesh, type of fiber, glass and steel and wire's transverse spacing form small to large. Test results showed that by adding glass fibers in closely spaced mesh gives significant rise in energy absorption to failure, and rise in flexural strength. Keeping everything the same, use of brass coated steel fibers leads to significant rise in energy absorption capacity with only slight increase in flexural strength and reduction in crack width. Main Aim of research by S. Deepa Shri et al. (2012) was to find out ferrocement fiber reinforced panel's flexural behavior which have self-compacting concrete. They studied effect of varying number of meshes, thickness of slab and fiber content, Flexural loading test

ISSN (Online) : 2348 - 2001
International Refereed Journal of Reviews and Research
Volume 5 Issue 5 September 2017
International Manuscript ID : 23482001V5I5092017-03
(Approved and Registered with Govt. of India)

were conducted on 24 slabs of size 700 X 300 X (25 and 30mm) varying thickness. It was found that SCC ferrocement slab with hybrid polypropylene fibers give increased energy absorption, load carrying capacity, deformation at ultimate load and number of cracks but decrease in width of cracks.

R. J. Phalke et at. (2014) studied the ferrocement slabs behavior under flexure by varying the number of welded square meshes as 2, 3 and 4, also adding steel fibers as 0 and 0.5 percent. 2 point loading test were conducted on slabs of size 500 X 200 X 25 mm. It was observed that by increasing welded square mesh numbers, energy absorption capability and ductility increases remarkably, plus as the number of welded square mesh increases with addition of steel fibers, load carrying capacity rises by 58percent and deflection falls by 33 percent.

Waleed et al. (2010) investigated ferrocement brick composite floor slab panel's behavior by flexural loading test. They found slabs with three truss type shear connector and discontinuous brick layout shows much effective ductility than the slabs with two shear connector and continues brick layout. Hago et al. (2005) examined the ferrocement roof slab for its behavior under service and ultimate loads by introducing beams of ferrocement and monolithic shallow edge. They observed that this type of roof slabs have high ultimate load carrying capacity.

5. Discussion:

Much of research work and experimental studies conducted in different parts of the world have highlighted the flexural and shear capacities of ferrocement structural panels. The energy absorption capacity also tends to improve with use of different cores in between ferrocement and mortar layers. The design flexibility thus offers a range of building elements such as load bearing walls, partition walls, pavement elements etc. and also can be shaped to any geometric requirement. They are also compatible with all other construction systems due to easy anchorage possible. Many studies have also appraised the strength to weight ratio parametric. Panels made using two sheets of reinforced plaster enveloping light cores are both light weight and rigid with ease of handling and transportation.

Buildings made using ferrocement panels are particularly light weight, have a low seismic mass with enhanced disaster resilience. Polystyrene cores are likely to offer light weight, thermal insulation in addition to fire resistance due to its self extinguishing behavior. The thickness of core, its density and material can be customized to deliver good thermal insulation. Indoor thermal comfort greatly reduces energy consumption thus promotes energy efficiency. But standardization with respect to size of panel, number of layers and type of mortar to the strength achieved needs to be done by the regulatory authorities. The manufacture of these panels can be industrialized resulting in optimization of assembly process along with reduction in labour and construction time. Compared to traditional products, ferrocement panels deliver versatility and sustainability in construction and achieve better results at reduced costs.

6. Conclusion:

This review has summarized that ferrocement is a versatile but unharnessed material. The ease of construction with mere materials makes it suitable for low cost light construction especially in developing countries. The applications of ferrocement in both cast in situ as well as precast construction have been explored in all areas of civil engineering but there is a dearth of enough research and a coded rationale for design. The standardisation of procedures and applications as load bearing and non-load bearing elements is lacking. The regulatory authorities need to publish the codes as for reinforced concrete structures. The performance of ferrocement elements greatly depends on the number and characteristics of the reinforcing mesh, fillers, and mortar mix. Optimum ranges for these parameters need to be specified. The light weight sandwich panels offer a good potential towards good energy efficiency and disaster resilience. This review study emphasizes more experimental research with sustainable building materials, combinations of meshes, fibers and fillers. Considering the economics, simplicity and versatility, ferrocement can prove to be a potential alternative to RCC in elemental light construction.

ISSN (Online) : 2348 - 2001
International Refereed Journal of Reviews and Research
Volume 5 Issue 5 September 2017
International Manuscript ID : 23482001V5I5092017-03
(Approved and Registered with Govt. of India)

References

1. ACI Committee 549. (1997a). State-of-the-Art Report on Ferrocement. *Aci 549R-97*, 1–26.

2. Alwash, A. S. A. (1982). Flexural behaviour of ferrocement, *85*, 273. https://doi.org/10.2495/HPSM06010

3. Amala, M., & Neelamegam, M. (2015a). Experimental Study of Flexure and Impact on Ferrocement Slabs. *IOSR Journal of Mechanical and Civil Engineering*, (1), 62–66.

4. Bansal, P. P., Civil, B. E., & Structures, C. (2014a). Effect Of Wire Mesh Orientation On Strength Of Beams Retrofitted Using Ferrocement Jackets. *International Journal*, *5*(2), 8–19.

5. Banu, P. S., Dharmar, S., & Nagan, S. (2014b). Flexural Behavior of Trough Shaped. *International Journal of Innovative Research in Science, Engineering and Technology*, *3*(6), 14010–14017.

6. Chandrasekharrao, T., Gunneswararao, T. D., Ramanarao, N. V, & Rambabu, C. (2012a). an Experimental Study on Ferrocement Box-Beams Under Flexural Loading. *International Journal of Emerging Technology and Advanced Engineering*, *2*(9), 138–144.

7. El-wafa, M. A., & Fukuzawa, K. (2010a). Flexural Behavior of Lightweight Ferrocement Sandwich Composite Beams. *Journal of Science and Technology*, *15*(1), 69–92.

8. Fahmy, E. H., Shaheen, Y. B. I., Abdelnaby, A. M., & Abou Zeid, M. N. (2014c). Applying the Ferrocement Concept in Construction of Concrete Beams Incorporating Reinforced Mortar Permanent Forms. *International Journal of Concrete Structures and Materials*, *8*(1), 83–97. https://doi.org/10.1007/s40069-013-0062-z

9. Fahmy, E. H., Shaheen, Y. B., Zeid, M. N. A., & Gaafar, H. (2004). Ferrocement Sandwich and Cored Panels Ferrocement Sandwich and Cored Panels.

10. Grija, S., Sivakumar, P., Lakshmikandhan, K. N., Ravichandran, R., & Karthikeyan, B. (2014d). Novel ferrocement light weight wall panels. *International Journal of Applied Engineering Research*, *9*(18), 4645–4658. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-84904497985&partnerID=40&md5=27946c8c6550a29714586f048a058c85

11. Hago A W, Al-Jabri K S, Alnuaimi A S, Al-Moqbali H, and A.-K. M. A. (2005a). Ultimate and service behavior of ferrocement roof slab panel. *Construction and Building Materials*, *19*(1), 31–37.

12. Jagannathan, A. (2012b). Study of flexural behavior of ferrocement slab reinforced with PVC coated weld mesh. *IJERD*, *1*, 50–57.

13. Jagannathan, A., & Investigations, A. P. (2011). Flexural Behaviour OF Polymer Mesh Reinforced Ferrocement Panel. *International Journal on Recent Trends in Engineering & Technology*, *5*(3), 1–6.

14. Jalal A. Saeed, P. H. M. & I. H. A. (1997b). Behavior and Flexural Strength of Ferrocement One Way Slabs with Square Openings. *Journal of Zankoy Sulaimani*, *1*(1), 57–67.

15. Kumar, A., & Division, S. E. (2005b). Ferrocement Box Sections-Viable Option for Floors and Roof of Multi-Storeyed Buildings, *6*(6), 569–582.

16. Mandlik, A., Sood, T. S., Karade, S., & Naik, S. (2015b). Lightweight Concrete Using EPS, *4*(3), 2013–2016.

17. Mohamad N, Mahmood A, Majeed K. (2009a). Flexural Behavior of Flat and Folded Ferrocement Panel. *Construction and Building Materials*, *24*(9), 222–229.

18. Mohammed N. Mahmood, H. S. (2013a). Flexural Strength of Reinforced Concrete Slabs

Strengthened and Repaired by High Strength Ferrocement at Tension Zone. *Al-Rafadain Engineering*, *21*(2), 78–89.

19. Naaman, A. E. (2012c). Evolution in Ferrocement and Thin Reinforced Cementitious Composites. *Arabian Journal for Science and Engineering*, *37*(2), 421–441. https://doi.org/10.1007/s13369-012-0187-4

20. Nahro Radi Husein, V. C. Agarwal, A. R. (2013b). An Experimental Study on Using Lightweight Web Sandwich Panel as a Floor and a Wall. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, *3*(7), 2278–3075,.

21. Naveen, G. M., & Suresh, G. S. (2012d). Experimental study on light weight ferrocement beam under monotonic and repeated flexural loading. *International Journal of Civil and Structural Engineering*, *3*(2), 294–301. https://doi.org/10.6088/ijcser.201203013028

22. Phalke, R. J., & Gaidhankar, D. G. (2014e). Flexural Behaviour of Ferrocement Slab Panels using Welded Square Mesh by Incorporating Steel Fibers. *International Journal of Research in Engineering and Technology*, *3*(5), 756–763.

23. Poluraju, P., & Rao, G. A. (2014f). BEHAVIOUR OF 3D-PANELS FOR STRUCTURAL APPLICATIONS UNDER GENERAL LOADING : A STATE-OF-THE-ART, 173–181.

24. Pradeepa, S., Anitha, J., Selvi, N. T., Pranav, P., & Jaketia, A. (2016a). A Study on use of Reinforced Thermocol Panels as an Alternate Building Material, *4*(3), 113–117.

25. RADIN, S. S., & RAMLI MAHYUDDIN. (2008a). *DEVELOPMENT OF LIGHTWEIGHT FERROCEMENT SANDWICH PANELS FOR MODULAR HOUSING AND INDUSTRALIZED BUILDING SYSTEM*.

26. Rajendran, M., & Soundarapandian, N. (2013c). An experimental investigation on the flexural behavior of geopolymer ferrocement slabs. *Journal of Engineering and Technology*, *3*(2), 97. https://doi.org/10.4103/0976-8580.113047

27. Rao, T. C. (2008b). An Experimental Study on Ferro Cement Channel Units Under Flexural Loading. *International Journal of Mechanics and Solids*, *3*(2), 195–203.

28. Rao, T. C., & Gunneswararao, T. D. (2012e). Flexural Behaviour of Thin-Webbed Ferrocement Channel Sections, *7*(7), 707–716.

29. Rao, T. C., Rao, T. D. G., & Rao, N. V. R. (2006). an Appraisal of the Shear Resistance of Ferrocement Elements, *7*(6), 591–602.

30. RAO T. C. S., RAO T. D. G., R. N. V. R. (2009b). Investigation on voided Ferrocement Channel Beams in Shear. *Journal of The Institution of Engineers*, *90*, 38–44.

31. S.Deepa Shri, R. T. (2012f). An Experimental Investigation On The Flexural Behaviour Of SCC Ferrocement Slab Incorporating fibers. *International Journal Of Engineering Science and Technology (IJEST)*, *4*(5).

32. Shaheen, Y. B. I., C, Z. A. E., & Ramadan, A. G. (2012g). Pre- and Post-Fire Strength Assessment of Ferrocement beams. *International Journal for the Science and Engineering of Concrete and Building Materials.*, *3*(3).

33. Shaheen, Y. B. I., Safan, M. A., & Abdalla, M. A. (2012h). Structural Behavior of Composite Reinforced Ferrocement Plates. *International Journal for the Science and Engineering of Concrete and Building Materials.*, *3*(3), 477–490.

34. Shaheen, Y. B., Nasser, A. A., & El-habashy, W. S. (2016b). Behaviour of Ferrocement Sandwich

Panels Slabs under Shear, *7*(March), 11–23.

35. Shannag M.Jamal. (2007). Flexural response of Ferrocement with fibrous Cementitious Matrices. *Construction and Building Materials*.

36. Sridhar, J., Malathy, R., & Sangeetha, R. (2014g). Flexural Strengthening of Reinforced Concrete Beams using Ferrocement Laminates with Partial Replacement of Fine Aggregate by Steel Slag. *Journal of Engineering and Technology*, *4*(2), 125. https://doi.org/10.4103/0976-8580.141205

37. The Cement Sustainability Initiative (CSI) - Sustainable Construction. (n.d.). Retrieved September 30, 2017, from https://www.wbcsdcement.org/index.php/cn/key-issues/sustainability-with-concrete

38. Wahyuni, A. S., Vimonsatit, V., & Nikraz, H. (2012i). Shear Behaviour of Ligthweight Sandwich Reinforced Concrete Slabs. *Advances in Structural Engineering*, *15*(10), 1705–1715. https://doi.org/10.1260/1369-4332.15.10.1705

39. Waleed A, Yavuz Y, Jaafar M S, Noorzaei J. (2010b). Structural behaviour of ferrocement–brick composite floor slab panel. *Construction and Building Materials*, *24*(6), 2224–2230.