# POLITECNICO DI TORINO

**Department of Environment, Land and Infrastructure Engineering**

**Master of Science in Petroleum Engineering**

# MASTER THESIS

## FERRO-CEMENT TECHNOLOGY AND PROSPECTIVE DEVELOPMENTS IN DURBAILITY AND SUSTAINABILITY

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# I ABSTRACT

Ferro-cement concrete is different from the conventional reinforced concrete on the basis of its composition and characteristics. In the composition of Ferro-cement concrete we replace steel bars with the Skelton meshes wire/welded which can be dispersed and arrange in different layer and completely emerged in the cement mortar. The emerging role of the Ferro-cement technique is its: durability, crack resistance, impact resistance, toughness, light weight, sustainability and flexibility. These qualities are mainly due to its geometrical properties like uniform distribution of reinforcement meshes over the surface and short cross-section area of reinforcement.

Moreover, literature overview on its flexural properties, corrosion impacts, durability improvement, laminations technique and ultimate strength. Different types of meshes and their impacts on the strength, General procedure to cast Ferro-cement element as per American Concrete Institute (ACI) codes have been discussed. Little attention has been given to the durability and environmental diffusions on Ferro-cement and major part has covered the sustainability of Ferro-cement structure over resistance of fire, corrosion, earth quake and aggressive environment. Small part of its uniqueness from conventional reinforcement concrete has been covered also enlighten some different engineering techniques which give importance to Ferro-cement in its worldwide utilization. Ferro-cement has various applications in different part of construction field like Buildings, Marine and maintenance.

This thesis endeavors to review the previous study on Ferro-cement and highlighted the notable construction developments, material properties and particular technique of merging reinforced meshes into cement mortar. This study highlights the importance of Ferro-cement use for boat, silos, swimming pools, folded roofs and also in the maintenance/repairing reinforced cement concrete (RCC) sectors.

## II ACKNOWLEDGEMENTS

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# III DEDICATION

This thesis is dedicated to my Parents, Behram Khan and Rubina BB.

For their endless love,

Support and encouragement

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# 1 INTRODUCTION

## 1.1 General

In today's world concrete is only substance which has 2nd most consumption after water. It is a heterogeneous material which is generally used for construction purpose. Today the use of concrete is much higher as it was 40 years ago. The consumption of concrete on approximately estimates in all over the world is 11 billion metric tons every year. As we all know concrete is a ductile material and it is not as strong as steel so here question comes in mind that: why is concrete the most widely used engineering material? Prof. Povindar K. Mehta (Mehta & Monteiro, 2006) identified three main reasons. First reason is concrete has ability of excellent water resistance, which makes it the ideal material for building structures to control the sustainability of store, and water transport. The second reason is the possibility to mould structural concrete element into a variety of shapes and sizes. The third reason is that concrete is usually the cheapest and most readily available material on the job. There are many more like: low maintenance, fire resistance, and resistance to cyclic loading. Many years ago, most of the heritage structures were built with wood masonry. Although, the start of reinforced in the end of 19th century gave it lime light to construct buildings and bridges to enhance its use all around the world. Composite material in which steel used with the concrete matrix called reinforced concrete. Steel reinforcement is utilized in flexural member to overcome the weakness of concrete in tension. As steel has excellent strength in compression than concrete so it can also use to support the compressive strength. I.e. Column. In 20th century many architectures and engineers captured the advantages of reinforced concrete and built their significant building which today known as their cultural symbols. Now a day's reinforcement is broadly acknowledged and used. Specialized data on the reinforcement concrete can be gotten from American concrete institute (ACI) and many similar national centers. It has future scope on agriculture, Rural, Urban structures due to exceptional elasticity, flexibility, strength.

## 1.2 Ferro-Cement

### 1.2.1 Introduction of Ferro-cement

The term Ferro-cement is the combination of two words that means reinforcement which is embedded in the cement-sand matrix. Ferro-cement is a unique invention of reinforced concrete with a few contrasts in which the principle aspect is in size of the specimen. In Ferro-cement technique instead of using large size of steel rods we use small size reinforcement meshes such as: woven wire meshes, welded wire meshes and expended metal meshes or fine rods which are totally embedded in the mortar matrix. Unlike concrete, in Ferro-cement technique instead of using coarse aggregate only cement sand mortar use as a bonding material. Ferro-cement term usually used to portray a steel meshes. Furthermore, mortar composite material which can form thin panels in thickness of 1 inch (25mm) with thin cover to protect the reinforcement from corrosion.

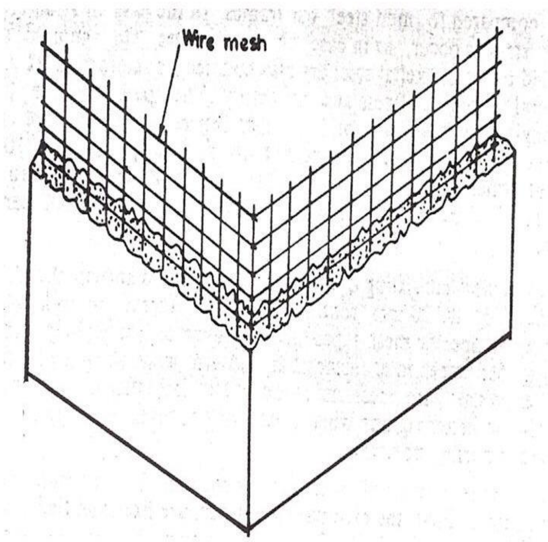
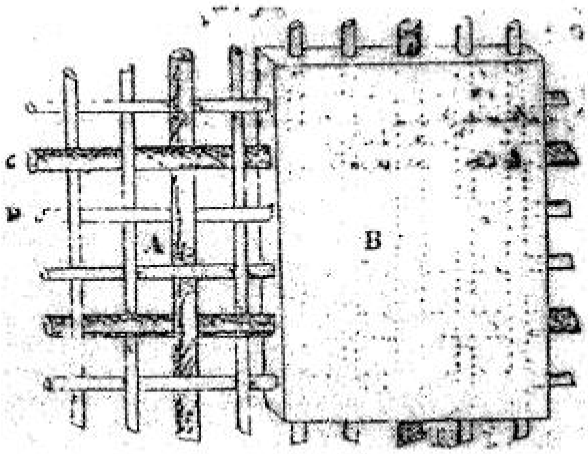



**Figure1. 1:** Typical section of Ferro-cement element

### 1.2.2 History of Ferro-cement

In 1848 a Frenchman Mr. Joseph-Louis Lambot invented the Ferro-cement. Lambot described his patent in 1855 with the following words: (which are translated from French to English language)

*"My innovation demonstrates new products that help to replace wood that is exposed to moisture, such as wood floors, water containers, flowerpots, and so on. As with the articles I want to create, the new material consists of a metal mesh that is connected or formed by wire or rod. I give this net a shape that looks the best possible way like flexible woven mat. Then I put hydraulic cement or similar bituminous tar or mixture to fill the joints."*




French Patent Summary: *(22120. 30 mars 1855.) Combinaison de fer et de ciment, destinee a remplacer le bois dit fer-ciment succedant du bois de construction. Reseau metallique ou carcasse d'un bateau, d'une caisse a eau ou a orangers.*

**Figure1. 2:** Lambot's patent on "fer-ciment"

Lambot built two rowboats in 1848 and 1849, in length respectively about 3.6 m and 3 m (12 and 9 foot) and 38 mm (1.5 in.) thick and disclosed his patent at the Paris exhibition in 1855 (Figure 1.2). Detailed description of Lambot's original boat, depicted in Figure 1.3, has been given by Morgan and Morgan in the Proceedings of Ferrocement 6, the Sixth International Symposium on Ferrocement (Naaman, 1998), and dedicated to Lam-bot.


**Figure1. 3:** Original 1848 Lambot's boat preserved in Brignoles Museum

After the first Ferro-cement development in 1848 until the second half of the 20th century, the development of Ferro-cement stopped due to the improvements of reinforced concrete. In fact after its invention Ferro-cement was almost forgotten for 100 years, just because of more increasingly development of RCC. Only in early 40's of 19th century Pier Luigi Nervi, a noted Italian engineer-architect revived the original concept of Ferro-cement as with layer of wire meshes exhibits mechanical conduct so unique in relation to ordinary reinforced concrete execution and potential application which classed as a different material. Ferro-cement as characteristics of split excellent qualities of crack resistance, affect obstruction and sturdiness which are achieved because of the nearby separating and uniform distribution of meshes in a composite. But today the application of Ferro-cement increases due to its properties such as, easy to build and cost effectiveness over the reinforced concrete technology. Ferro-cement has been used in a wide range of applications such as: boats, buildings, bus shelters, food and water storage tanks, irrigation structures and bridge decks also more suited as the rehabilitation element in the RCC structures.

So now a day's we can say Ferro-cement is generally acknowledged and used technique. Technical information on the Ferro-cement can be acquired from the international Ferro-cement information centre (IFIC), American concrete institute (ACI).

## 1.3 Definition of Ferro-cement

### 1.3.1 ACI committee 549

In the state of art report on Ferro-cement, the definition of Ferro-cement was given by ACI committee 549 which was first published in 1980.

*"Ferro-cement is a type of thin wall reinforced concrete commonly constructed on hydraulic cement mortar reinforced with closely spaced layer of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials." [2]*

### 1.3.2 Suggested Revised Definition

By the time many engineers start doing work on this technology and get some experience and knowledge from previous work and advancement of Ferro-cement NAMAAN suggested the definition by extending the ACI definition with following two lines (NAMMAN, 2012)

*"The fineness of the mortar matrix and its composition should be compatible with the mesh and armature system it is meant to encapsulate. The matrix may contain discontinuous fibers."*

The main reason to adding these two lines in the ACI definition is to form a sound composite and helps in use of fiber to improve development in hybrid composition.

Although Ferro-cement is one of the old technology (more than 160 years), It is eco-friendly and has many improved features such as strength, toughness, water-tightness, lightness, durability, fire resistance and stable environment which cannot be matched with other thin constructional material. Ferro cement is a building material with obvious advantages of spatial structure of this type of thin member and material. Recommended for use on the curve of those properties and also Ferro-cement can be a thin folded construction element because of its stiffness quality.

## 1.4 Objectives

In the prospect of Ferro-cement objectives the thesis intention is to increase the knowledge of the engineers and architectures with the importance, application and sustainability of Ferro-cement.

- To overview the preliminary study of Ferro-cement

- To discuss material and experimental procedures of Ferro-cement
- To discuss the sustainability of Ferro-cement.
- To discuss the application of Ferro-cement

## 1.5 Characteristics of Ferro-cement

The specimens are thin and light weighted. Easy to produce and cost effective. It can be produced into multiple shapes and sizes. Environmentally sound i.e. approved strength against seismic activities. It is water tight, durable and resistance to rust if meshes are properly encapsulated. It is a ductile material which can attain its shape after removing the load.

Pier Luigi Nervi stated notable description about the characteristic of Ferro-cement is: “The maximum subdivision and distribution of reinforcement meshes in the cement mortar give great elasticity and resistance too cracking.”

## 1.6 Difference between Ferro-cement and Reinforced Concrete (NAMAAN, 2000)

There are many similarities in Ferro-cement and reinforced concrete as Ferro-cement is the type of reinforced construction but also there is some of differentiation in the behavior of these two techniques.

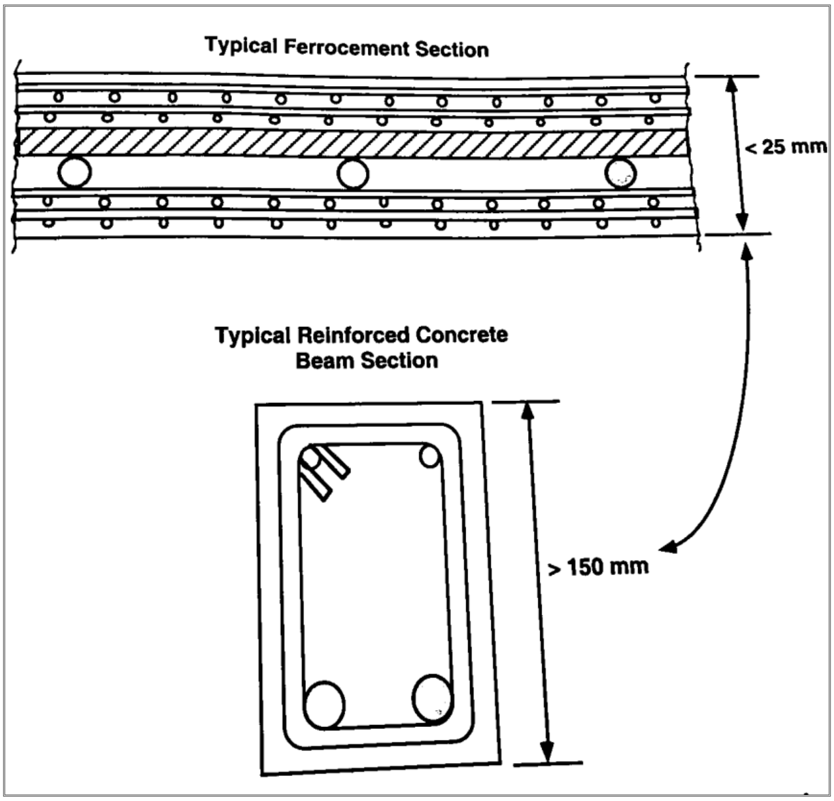



**Figure1. 4:** Typical cross section of Ferro-cement VS reinforced concrete

### 1.6.1 Physical

It is thinner material and has reinforcement meshes throughout the distribution of the element. It can be reinforced in both directions like transverse and longitudinal. Unlike concrete for the matrix of Ferro-cement we don't use coarse aggregate. For the binding material we can use cement and fine grains mortar.

### 1.6.2 Mechanical

In difference of reinforced concrete Ferro-cement can have isotropic properties in two way action and in indeterminate system it has high level of redundancy. Ferro-cement has high tensile strength as it can have same order of its compressive strength because of it's throughout distribution of meshes and high specific surface of reinforcement. Ferro-cement cracking behavior in tension is different from standard reinforcement due to the presence of transverse reinforcement. Ferro-cement is more ductile material than reinforced concrete because of the increased number of layers of meshes used which can increase in the volume fraction and specific surface of reinforcement. Because of its small width cracking it is more sustainable for water tanks and during pressure increment Ferro-cement stretches to avail the properties of higher leakage and behave as a safety valve to counter its failure. Because of it's throughout surface reinforcement Ferro-cement has high impact resistance and punching shears resistance.

**Table1. 1:** Comparison between Ferro-cement and other construction Materials [3]

| **Parameters** | **Reinforced Cement Concrete (RCC)** | **Stones** | **Reinforced Brick Cement (RBC)** | **Ferro-cement** |
|---|---|---|---|---|
| Strength to weight ratio | Low | Very Low | Medium | High |
| Performance | High | Medium | Medium | High |
| Durability | High | Medium | Medium | High |
| Equipments for roof | Shuttering required | No Shuttering | Shuttering required | No Shuttering |
| Skills required | Skilled | Highly skilled | Highly skilled | Semi skilled |

## 1.7 Thesis Organization

First chapter, "Introduction" describes the introduction to Ferro-cement and objectives of present study.

Second chapter, "Literature Review" covers the summary of past work done on Ferro- cement by different researchers.

Third chapter, "Material and Experimental Methodology" describes the material and testing procedures for the production of Ferro-cement specimens.

Fourth chapter, "Sustainability of Ferro-cement" covers the aspects of sustainability

Fifth chapter, "Applications of Ferro-cement" it covers the applications of Ferro-cement in different aspects and their flexibility of use.

Sixth chapter, "Conclusions and Future Recommendations" describes the conclusion of this project, scope of work and recommendation for future on Ferro-cement.

To achieve the objectives of present study, work of different researchers is required to explore. With the help of past work, we can get the idea about work on Ferro-cement which gives enough information to know the behavior of Ferro-cement on different field of work.

# 2 LITERATURE REVIEW

## 2.1 General

This chapter carried out the different investigations done by different researchers discussed regarding different properties like in flexural and durability with and without admixtures used for preparation of Ferro-cement. First part reviews the historical development of Ferro-cement and work of different committee and institute to recognize it to the worked. Second part discuss about the different research and progressive work on different properties of Ferro-cement.

## 2.2 Historical Review of Ferro-cement

**Joseph Aspdin:** In 1824, he familiarized Portland cement to the world. In 1835 and onward a series of concrete buildings were constructed but reinforcing the material was not so common in that period. After a period of time when they faced the weakness in tensile strength of concrete the concept of reinforcement was carried out in an effort to conquer the low elasticity of cement by using a bronze rod and strip. In a short period of time utilization of reinforced concrete was increased. However the maximum rate of warm extension of the bronze due to its crack. Joseph Monier [1849] constructed huge garden tubs, Francois Coiquet [1852] cast concrete inside the wooden shutter around an iron skeleton and William Wilkinson [1854] picked a concept to embed an arrangement of flat iron bars in the concrete beams. He is known as the builder of a new castle.

During the same period, Joseph-Louis Lambert who is known as horticulturist lived in his town in Miraval which is in the vicinity of the brignoles. He was doing different experiments by using reinforcement meshes arrangement which are plastered of cement sand matrix and develop pots, seats and bathtubs. In 1855 He referred to these materials as "Ferciment".

Lambot's boat is still on display at the Brignoles museum in France. An Italian Engineer-Architect **Pier Luigi Nervi** adopted Lambert's ideas in the early1940's when he investigated that reinforcing the concrete with metal mesh layers it produced materials which hold the uniform mechanical properties and great resistance to loading then Nervi gave name to this material "FERRO-CEMENT" after about a hundred years of its concept invention.

The national academy of sciences of USA (United States of America) established a group on the use of Ferro-cement in developing countries and that meeting was chaired by Prof. James P. Romualdi of Carnegie-Mellon University, U.S.A in 1972. The report was published in early

1973 and outcome of this report was likely that the people can understand the properties and application of Ferro-cement and started using them.

In November 1974, the Asian Institute of Technology (AIT) and the National Academy of Sciences PAS hosted the case study “Asia Ferro-cement and Technology Introduction Workshop” in Bangkok, Thailand. In October 1976, under the mission of “South-East Asia Regional Economic Development” International Ferro-cement information Centre (IFIC) was established at AIT in Bangkok, Thailand. Which were supported by the International Development Research Centre (IDRC) Canada, United States Agency for International Development (USAID) and government of New Zealand.

By the start of 1977 the American Concrete Institute (ACI) had set up advisory group 549 on Ferro-cement to audit and plan a code of training for this material. ACI Committee 549 originally classified the clarity of Ferro-cement in 1980 which was in this way modified in 1988, 1993 and 1997. The International Ferro-cement Society (IFS) formed a Committee (1FS-10-01) the suggestions of which were distributed as "Ferro-cement Model Code" (FMC) in January 2001. The definition in the above model code mirrors the advances in Ferro-cement as well previous experiences too.

**Mansur and Paramasivam:** [6]. In 1986, they proposed a technique to describe the definitive quality of the Ferro-cement with bending based on the idea of plasticity test. In his analysis, ferro-cement is considered to be a homogeneous, elasto-plastic material. Experimental investigations were likewise led to consider the conduct and quality of Ferro-cement in flexure. It was discovered that a definitive strength increment with expanding in network review (w/c proportion) and volume portion of reinforcement.

**Kausik and others:** [7]. In 1987, During their research, it was seen that the efficiency of mesh overlap of Ferro-cement specimen was investigated by changing the thickness of cover in square woven lattices with varying wire diameters and mesh opening also flexural tests were carried out by changing the number of mesh layers. For the investigation of above mentioned experiments, cement sand mortar with ratio (1: 1.5) and (1: 2) were cast-off. They obtained a systematic formula for the lap length (Lp) on the basis of mesh overlap concept that it is enough to get perfect bonding strength around the surface and to prevent slippage while permitting stress. They carried 350 test sample of 400x200 mm dimensions, with 5 mm coverage on all the sides having w/c = 0.4 and samples were tested at an essential issue stacking on a just bolstered range of 300 mm. From all above experiments it was resulted that: (1) the influence of some factors like strength of mortar, width of reinforcing wire, and effect of mesh opening disturb the overlapping span. (ii) Overlap slippage can be the reason of bond failure.

**Vijay Raj:** [8]. In 1988, they studied on development of durability of Ferro cement by using lime. for the experiment of this project cement-sand mortar 1:3 was prepared in a concrete mixer with w/c ratio 0.45 and admixture fresh hydrated lime powder 15% were added. This mix design was used to carry out a slump test to find workability. Durability properties in Ferro-cement specimen were examined by changing the concentration of sulfuric acid for 30 days in specimen of Ferro-cement with lime. From experiment it was concluded that durability can improve by reducing permeability and lime addition can help in mortar workability improvement.

**Austriaco and Pama:** [9]. In 1988, there were many factors that influence the durability of Ferro-cement here austiaco and pama gave some namely: mortar composition, permeability, erosion of reinforcement and construction projects. He concluded his experimental results as by reducing the permeability we can get improvement in durability and erosion can be prevented by providing cover on all four side to reinforcement with mortar.

**Gupta and others:** [10]. In the period of 1972-78 they examined the corrosion development of Ferro-cement structures, where they casted specimen in different compaction mechanism by hand and industrialize bunched forms and used pique or un-galvanized steel meshes. These specimens had been exposed to different non-industrial natural states of changing degrees. In the period of 1983-1990, to examine the extension of corrosion, wire meshes specimen were drawn from structure. A couple of the structures were broken and presented to same conditions for comparison. In the wire samples the influences of corrosion were taken as the weigh lose of specimen. The samples were completely analyzed additionally it is discovered that Ferro-cement specimens of 12 to 15 mm stubby were observed to be outstanding in erosion opposition oversaw time of 14 to 15 years. It is additionally prescribed to utilize machine-driven impel process, galvanized reinforced meshes, excellent classified sand for matrix of mortar, water repellent covering to fabricate the solid and vigorous Ferro-cement structures. It is likewise seen that poor pressed and bad handiwork results in smaller scale spots and increment in the ratio of erosion.

**Alrifaie and Trikha:** [11]. In 1990, they had investigated uniformly loaded Ferro-cement specimens (500x500 mm) in which three distinct courses of action in particular, (1) all Layers should be arranged in one direction (2) other different layers situated in orthogonal way and

(iii) in case of twin courses each twin course constitute of two orthogonal arranged meshes in contact with one another were analyzed. Under uniform load mechanism a total of square specimens (20mm and 30mm thick) were tested. In light of the above experiments they reported that the course of action consisting of two courses with two meshes orthogonal way and set in contact is better than two courses plans comprising of the considerable number of meshes in unidirectional way. They suggested that specimen below biaxate condition of leaning the meshes must have organized in twin courses.

**Al-Rifaie and Hassan:** [12]. In 1991, they had analyzed a test based hypothetical structural performance of low thickness Ferro-cement one-way leaning specimen. Components of various length & width were tested their comparative practically for reception to roofing of small size private living houses. Total nine collapsed plate specimens were developed and tested to their ultimate strength. In all of these models, the cross-sectional thickness and web depth were stored consistent whether the range length and the brim wide fluctuated. Two different loading conditions were applied on these models, point loads and four symmetrical point loads. The outcomes showed the good performance of Ferro-cement for the development of specimen of a horizontal spreading in sense of one-way leaning. They have seen that the Ferro-cement sample experience huge resistances in deflection till its failure.

**Clarke and Sharma:** [13]. In 1991, they had examined the lamination impacts in the Ferro-cement specimen and presented the experiments and results as: they utilized 23 square specimens of Ferro-cement and tested up to failure point under biaxial flexure test and they concluded that on the off chance that the point of introduction of the placed meshes with respect to the edges of the specimen is 45 degree we accomplish minimum toughness under biaxial flexure and if the edge of the direction of the meshes with respect to the edges of the specimen is 0 degree we can attain maximum strength under biaxial flexural test.

**Karunkar Rao:** l991 [14]. In 1991, they had introduced a strategy for computing extreme flexural strength of a whole structure having elements of pre-cast Ferro-cement joined with the specimen of reinforced concrete slab. The improvement and use of the compound framework including the utilization of pre-cast Ferro-cement components and cast in-situ concrete slab section material essentially included arranging of reasonably formed pre-cast Ferro-cement unit of structures. They were tested separately and used in conjunction with on-site concrete to establish and evaluate the effects of the composite. He concluded that the load deflection data of the basic system under working load conditions can be used to understand its structural performance.

**Onet and others:** [15]. In 1992, they had examined the performance of Ferro-cement specimen's plate and beam in bending. In plate and beam specimens different arrangements of mesh layers were considered. There were six specimens having dimension (100x250x3200 mm) and strengthened with meshes reinforcement in hexagonal arrangement were experimented under simply supported conditions and examined The first fracture appearance, maximum strength, fracture width on the specimen. They have presumed that Ferro-cement specimens of plate and beam types have an excellent performance under loading condition because of width of the fractures appear on the testing specimen are shorter than in standard reinforced specimen. The great performance at failure in regards to the part of the durability and failure strength of the specimen demonstrates the ability of developing Ferro-cement effectively in the construction industry.

**Onet and Magureanu:** [16]. In 1993 they had worked on the cracking and bending of Ferro-cement specimen under the impact of load direction. The tests were done on beam element. They reported that Ferro-cement is commonly an adaptable material and an entirely flexible one is reinforced section. The long time deflection parameter set up a theory by means of deformation showing that the long haul deflection influence the performance of beams significantly more than the abrupt one.

**Ramesh and Nedwell:** [17]. In 1994, they completed exploratory examinations to acquire more precise data with respect to mesh tensile strength and to look at the conceivable impact of having multiple strands with mutual action. Galvanized meshes were utilized with four and six layers, which were uniformly spaced and situated in centre and equally spaced among top and bottom be that as it may all the meshes had a similar length (i.e.325 mm). Flexural test of three points loading with simply supported span of 300 mm on specimens (350x120x38 mm) were done. In view of the experiment it has been reasoned that the yield quality and a extreme rigidity get for meshes reinforcement with at least two Longitudinal wires of a similar diameter which can be more prominent than others like those with a single wire mesh no prominent affects occurred in the steel quality and maximum rigidity of lattices because of expanding the quantity of longitudinal wires, in this manner be considered while breaking down Ferro-cement under flexural and tensile test.

**Ramesh and Vickridge:** [18]. In 1996, they had worked on the development prediction of ultimate strength of Ferro-cement under flexural and purposed different methods. One such method was utilized as the premise of the PC program FAOFERRS (program for analysis of Ferro-cement in flexure) which has been functioned to contrast the forecasts and the trial results for having different meshing arrangement. It was fundamental that not only the behavior of used material also mesh arrangement in specified element to be incorporated into the investigate information detailed. All the tests by them clearly demonstrate that ACI technique for investigation of Ferro-cement samples in flexure gives solid estimation to a maximum loading capacity.

**Ranjbar and others:** [19]. In 1998, they led examinations by leading of welded mesh and its effect on the tensile and twist development of Ferro-cement. The main goal of these experiments was to obtain more information about the mechanical properties of the mesh and its effect on the tensile and twisting behavior of the ferro-cement component. Following parameters were reviewed in these tests: classification of wire (galvanized, un-galvanized and stainless steel) mesh size. Flexure test under two concentration line loads were carried out on Ferro-cement simply supported slab and tensile testing of Ferro-cement specimen was completed in a Universal testing machine (UTM). It is resulted that multiple strands presence in specimen seems to enhance the development of mesh strength and furthermore increment the tensile and flexural strength against failure.

**Nassif and others:** [20]. In 1998, they did investigation and worked on flexural performance of the composite concrete beam which was laminated with the thin section of Ferro-cement. The arrangement of meshes in laminated specimen of the Ferro-cement was hexagonal and square. The concrete beams were examined under two point stacking framework and results from the test were contrasted with Ferro-cement laminated reinforced concrete beams. The conclusion of the investigation was reported as lamination of a thin course of Ferro-cement to a concrete beam upgrades the toughness and additionally the cracking resistance composite element reinforced with square meshes gave preferable outcomes over hexagonal meshes and increments as the number of mesh course build the fracturing resistance of the concrete beam.

**Mehdi and Ahmed:** [21]. In 1999, they had analyzed test examinations by leading accelerated laboratory tests on structural performance of Ferro-cement in sea water. Dumbbell and rectangular type of Ferro-cement samples were casted these samples having w/c proportion of 0.45 and two layers of meshes (expended metal 18 gauges). After 10days of healing, the investigated specimen was kept at room temperature. After the accelerated test flexural and tensile tests were carried out at the specimens. From the outcomes it has been inferred that the tensile and flexural strength of Ferro-cement samples gradually decreased due to the sea water and the cracking designs were very comparative in all of the samples and externally there was no sign of corrosion influence.

**Balaguru and others:** [22] carried work on lamination of specimen with inorganic polymer for flexural performance of specimen high strength. The development of mesh reinforcement panels and carbon panels made of woven cross sections, unidirectional sheets and glass was compared. The bending test center point stack is performed at a simple support distance of 100 mm. It was found that the plate with four layers of hardened steel wire played a role as a bright composite material. In the ductile failure mode, the carbon fiber content increased and the modulus and fiber content increased to obtain higher torque and later yielding performance can be expected to be very precise.

**Ohama and others:** [23] contemplated flexural performance of vinylon fiber-reinforced polymer modified mortars (VFRPMM). VFRPMM were prepared with different w/c proportions, polymer-cement proportions and fiber content. These prepared VFRPMM then investigated for their twist performance. The samples were tried with third-point stacking mechanism on Universal testing machine (UTM) and bending examined by utilizing dial gauge. It is resulted from the test outcomes that, VFRPMM demonstrates enhancement in quality, strength, and disfigurement with increment in the fiber substance and polymer-bond proportion. From above mentioned results it is concluded that Workability and performance of VFRPMM diminished with increment in fiber content regardless of the polymer cement ratio and w/c proportion. In can be concluded in a way that excellent reinforcement for polymer modified mortars we can use vinylon fibers.

# 3 MATERIAL AND EXPERIMENTAL METHODOLOGY

## 3.1 Materials

Material used in Ferro-cement should meet all the standard requirements which are mentioned in ACI codes like conventional RCC. All the materials should be locally available in the market. The mortar matrix has great impact on the performance of the Ferro-cement element because it has the part of 95 percent in construction.

### 3.1.1 Mortar Matrix

A homogeneous mix mainly composed by Portland cement, sand, and water known as mortar matrix. To improve its workability and strength there are some admixture can add like fly ash and silica fume. Ingredients of mortar matrix, cement and fine aggregate has different chemical composition so the ratio of cement-sand and cement-water are more important for the strength of binding.

### 3.1.2 Mesh Reinforcement

Steel work is a pre-manufactured or non manufactured support made by persistent steel wire or steel ties, framing a customary shape system or grid. Strengthening networks in Ferro-cement will be assessed for their sensitivity to take and hold shape just as for their strength execution in the composite framework. Reinforcement of meshes should be spotless and there are not any hazardous material, i.e. dust, paint spots, oil and rust. Here are general types and size of mesh reinforcement utilized in Ferro-cement. (ACI 549)

#### 3.1.2.1 Mesh Opening

Mesh opening is the size of spacing between joints of wire meshes. Mesh opening size vary according to their diameter.

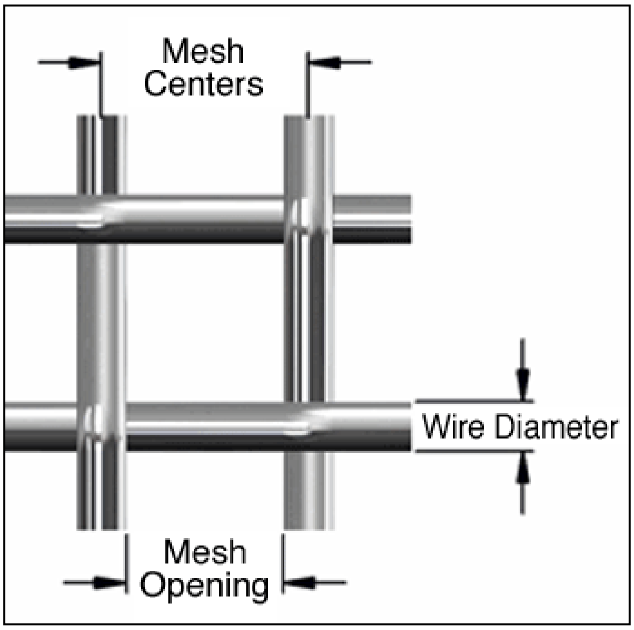



**Figure3. 1:** Mesh openings close view

#### 3.1.2.2 Expanded Steel Mesh

These types of meshes are manufactured with the steel strips which are gotten from the thin steel sheets expansion and shearing as per characteristics mentioned in ASTM C 847.Its manufacturing process is supported as cutting the thin diameter steel sheet and expending them in perpendicular direction of that cutting area. If systematic and suitable construction procedure is adopted then expanded steel mesh is appropriate for frames and tanks. In the ordinary introduction these meshes provide approximately equal strength to welded wire meshes. Expanded steel mesh has a great resistance impact and crack control. Even though, with all these suitability and good performance this type of reinforcement is not suitable for many applications as its flexibility is not excellent so specially it cannot be used in the folded and sharp curve panels construction.

**Figure3. 2:** Expended steel mesh close view

### 3.1.2.3 Welded Steel Mesh

Welded steel work is a pre-assembled work produced using wires welded at their convergences, as characterized by ASTM A185. Welded wire networks are made out of straight wire in the both direction of longitudinal and transverse. Consequently there thickness is high like two wire diameter thickness. These meshes are known as stiffer than the woven meshes because of its high modulus. The behavior of the deformation curve in the welded steel is different from other meshes because at initial loading it leads to smaller crack width. The fundamental grids of welded meshes are commonly square or rectangular.

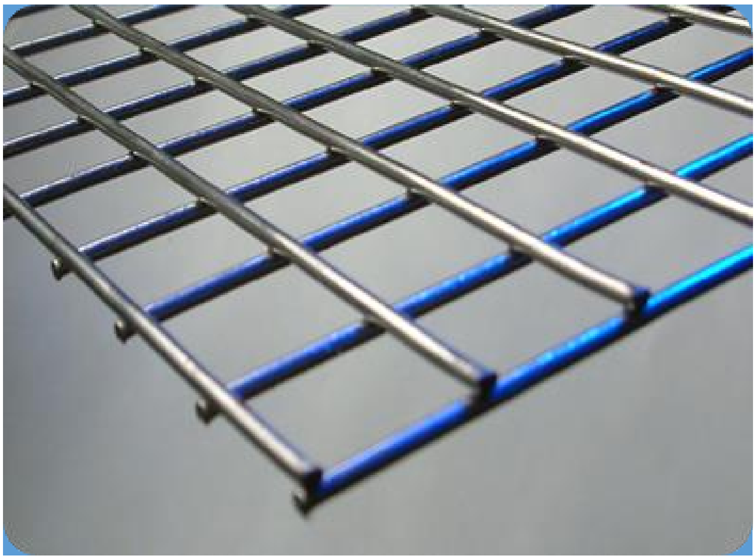


**Figure3. 3:** Welded steel mesh close view

#### 3.1.2.4 Woven Steel Mesh

These types of steel meshes are manufactured by machine as characterized by ASTM E2016-99. These are manufactured in specific orientation as, around the transverse wire there are longitudinal wires woven. Their thickness dependent upon the thickness of the weave and it might be up to three wires diameter. The fundamental grid of woven mesh is commonly square or rectangular.

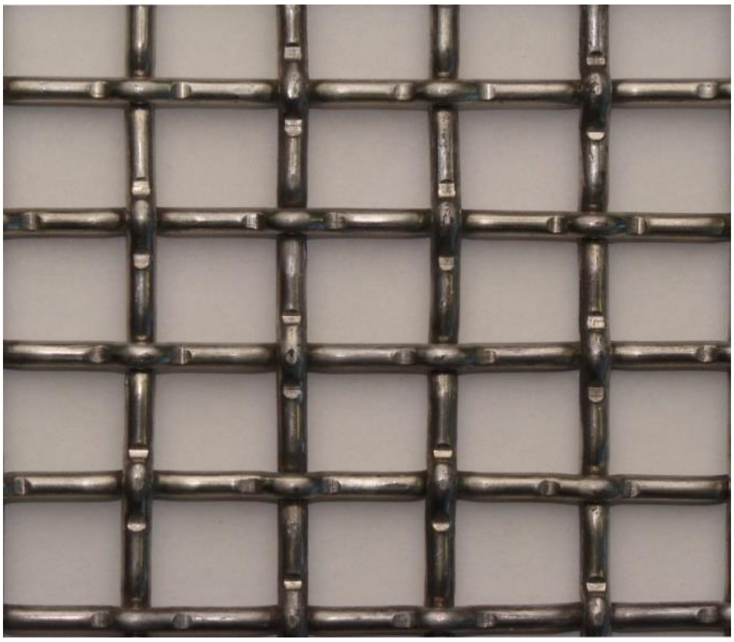


**Figure3. 4:** Woven steel mesh close view

#### 3.1.2.5 Hexagonal Steel Mesh

These types of steel meshes are also known as the chick wire meshes. In structural term they are not basically as adequate as other meshes like steel meshes with the square openings in light of the fact that the wires are not constantly arranged toward principle stress or vertical stresses. Anyway they are entirely adaptable and can be utilized in doubly bended elements. Hexagonal steel mesh is shown in figure.

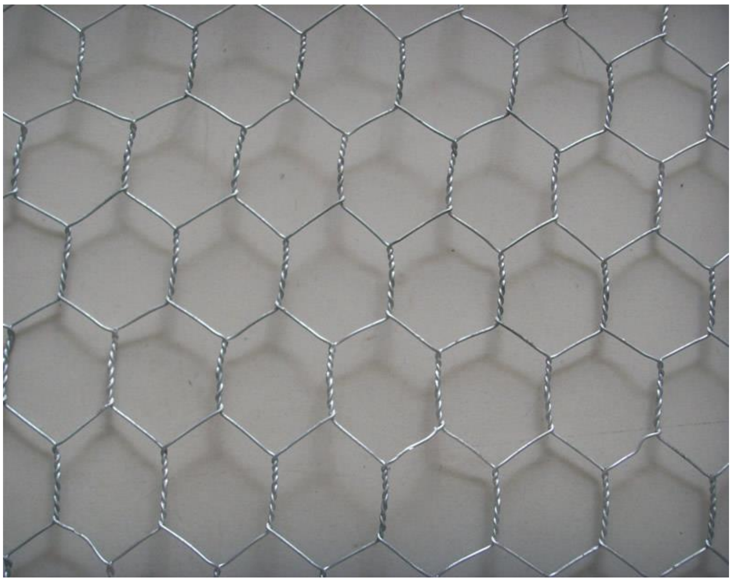


**Figure3. 5:** Hexagonal steel mesh close view

### 3.1.3 Cement

Cement acts as a hydraulic binder binding particles of sand, steel and wire mesh into one compact and strong mass. It is hence essential that only fresh cement of uniform consistency and free from lumps or other foreign matter should be used. There are five type of cement: type-1 is Ordinary Portland cement conforming to ASTM C-150 which is commonly used. Portland cement speaks to the reason for the vast majority of cement-based materials utilized now-days, and it is gotten by mixing clinker and a small amount of gypsum. Portland cement clinker delivered through the grinding inside and high temperature kiln of calcareous and siliceous raw materials containing components, typically communicated as oxides, Cao, Sio2, Al2o3, Fe2o3 and some amount of other materials. Since calcium silicates are the essential constituents of Portland cement, the raw must give calcium and silica in suitable form and proportions. Temperature of around 1,450 ºC (2,640 ºF), a revolving furnace called kiln is utilized to achieve the sintering.

Type-2 cement produces less heat amid hydration and is likewise reasonably protection from sulfates. Type-3 is fast solidifying cement which gets early stage strength more quickly than type-1 cement. Type-4 cement mostly used for mass concrete because of its low heat and is rarely consider in design of Ferro-cement. Type-5 cement is known as the sulfate resisting cement and mostly consider for specific buildings which are exposed to sulfate. The decision of specific kind of cement ought to rely upon service and environmental condition.

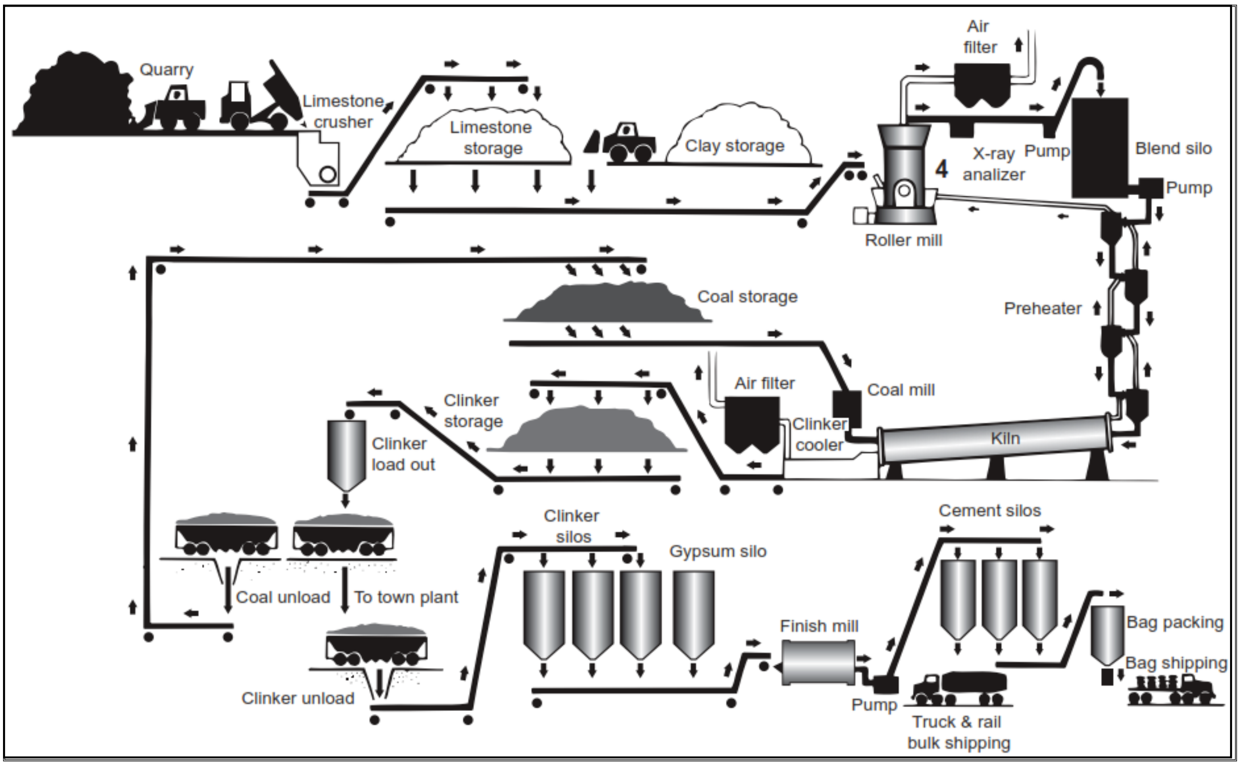



**Figure3. 6:** Flow diagram of the dry process for Portland cement manufacture (Mehta & Monteiro, 2006)

### 3.1.4 Sand

Sand which we select for the Ferro-cement must be standardized on requirements which are mentioned in ASTM C33 for fine aggregates that sand should be dormant, clean and free from natural matters and free from injurious substances and generally free from silt and clay. In figure 3.7 you can see the standard set of sieves with mechanical shaker for performing the sieve analysis to remove coarser particle from sand. In Ferro-cement we should use the fine aggregates passed from Sieve #8 (2.36mm) which has capability to achieve results in form of well-graded sand. However, a sand passing from sieve #16 (1.18mm) has been reported a satisfactory in results of enhancing the workability of mortar mix (ACI committee 549, 1997). Small size coarse aggregates might be added to the sand whenever allowed by the size, opening and distance between layers of the meshes. ACI 549, 1R-93 (ACI committee 549, 1993) gives a progression of imperatives that cement, aggregates, water and chemical admixtures should confirm to be utilized in Ferro-cement development. Sand is the most widely recognized aggregate used in Ferro-cement. Grading requirements for sand, provided by ASTM C 33 are following.

**Table3. 1:** Grading requirements for sand, provided by ASTM C 33

| Sr. No. | Sieve No. | Sieve size (mm) | Percentage Passing by Weight (%) |
|---|---|---|---|
| 1 | #4 | 4.75 | 100 |
| 2 | #8 | 2.36 | 80-100 |
| 3 | #16 | 1.18 | 50-85 |
| 4 | #30 | 0.60 | 25-60 |
| 5 | #50 | 0.30 | 10-30 |
| 6 | #100 | 0.15 | 2-10 |
| 7 | Pan | - | - |

**Figure3. 7:** Sieve set

#### 3.1.4.1 Gradation Curve

Gradation curve is a chart between sieve size and cumulative percentage of passing of standard set of sieves for any fine material.

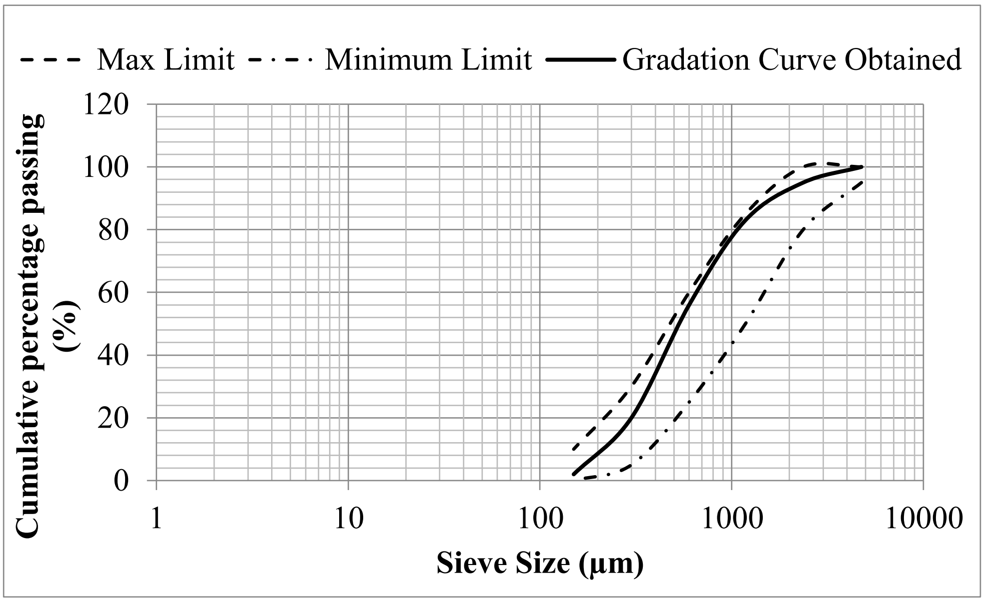



**Figure3. 8:** Gradation curve for sand

Gradation of sand is determined by grain size distribution curve produced for experimental work. The chart of gradation curve shows the obtained gradtion curve lies between the ASTM limiting values. In the graph x-axis shows sieve size and y-axis shows commulative passing percentage. The upper curve shows the max. range of gradation curve and the most lower shows the min. range of gradation curve according to ASTM standard. The obtained gradation curve is shown in middle.

#### 3.1.4.2 Fineness Modulus

Fineness modulus is used to measure the fineness of sand particles used. And absorption is a process by which water is enter into and tends to fill the permeable pores of the sand.

**Table3. 2:** Different sieves and sizes for sieve analysis

| Sieve number | Sieve size (mm) |
|---|---|
| 4 | 4.75 |
| 8 | 2.36 |
| 16 | 1.18 |
| 30 | 0.60 |
| 50 | 0.30 |
| 100 | 0.15 |

#### 3.1.4.3 Test Procedure of Fineness Modulus

Fineness modulus can determine according to ASTM standard C136 test for sieve analysis of fine and coarse aggregates.

Aggregate should sieve using the appropriate sieves size and note on each sieve the aggregate weight retained then calculate the weight of aggregate on each sieve cumulatively then at the end calculate the aggregate retained cumulative percentage by adding the aggregate cumulative weight and divide the sum by 100.

Fineness Modulus Can Be Calculated By Given Formula

$$F.M. = \frac{\text{sum of cumulative \%age weight retained on sieve \# 100}}{100}$$

### 3.1.5 Water

The mixing water should be fresh, clean and potable. The water must be free from organic matter, silt, oil, sugar, chloride and acidic material with pH $\geq$ 7. There is no any kind of salt in water. Water mixed with sugar has deleteriously affected the setting of cement and ought to be maintained a strategic distance from at whatever point is conceivable.

### 3.1.6 Admixtures

Admixtures in the Ferro-cement composite enhance its strength and durability because of following three reasons: 1- reduction in use of water which helps to reduce permeability, 2- prevention from air entering which helps to resist freezing and defrosting phenomena, 3- concealment of response in the composite of Ferro-cement. In exposure condition serviceability of the structure can be improved through coating or admixtures. Admixtures like fly ash and silica fume should be up to the regulations which are mentioned in ASTM C-618.

## 3.2 Equipments

### 3.2.1 Testing Machine

There are many testing machines which are used for compression and flexure test. Here i am describing one of testing machine with all its specification.


**Figure3. 9:** Compression Testing Machine with flexural arrangement

### 3.2.2 Moulds

For the specimen tests in laboratory we cast different samples in the moulds and get different results respective to different days. Here are some pictures to show the molds for the casting of beams and cubes to get the result on the testing of compression for the cubes and flexural for the beams. In the picture steel moulds for cubes are 6 x 6 x 6 (inches) for compression specimens and moulds for beams are 4 x 4 x 18 (inches) for flexural specimens.

You can also use wooden panel for casting of Ferro-cement elements. But it is not common because of the roughness on the edges of the panels due to the surface of wood. The size of the panel is 6 x 18 (inches) and thickness is 12.5mm, 15mm and 20mm, with steel plates on both sides, and office clamps to tighten the steel plates to hold the specimen from both sides.

**Figure3. 10:** Different sizes of Moulds, cubes and panels

### 3.2.3 Trowels, Trays and Tamping Rods

In the following picture you can see many equipment which you can use during the casting of specimen as for the preparation of cement mortar we can use tray and to mix the mortar use trowel and brush can use to clean the mould from inside to remove any cement particles before casting of the specimen and while filling. After filling the moulds the standard compaction should carry in the way that is 25 blows with 25mm steel rod with three successive layers.

**Figure3. 11**Trowels, trays and tamping rods

### 3.2.4 Weighing Balance

Weighing balance should use to measure the required weights of sand and cements for the mix.


**Figure3. 12:** Weighing machine

### 3.2.5 Curing Tanks and Burlaps

There are different techniques for the curing. Curing tanks can be used for the curing purposes and burlaps were used for curing the sensitive specimens like cement mortar beams.

**Figure3. 13:** Burlaps and laboratory curing tank

## 3.3 Experimental Procedure

Ferro-cement is the composition of cement sand mortar and steel meshes reinforcement. There are some standards which regulate this construction technique like: ASTM, EN, ISO and other equivalent. These standard regulations communicate about the testing procedure, deformation response, compressive and tensile strength, elastic plastic modulus, shear and impact resistance, quality control, and other problems of curing and casting.

After selection of the type of meshes and sand samples which passes through sieve #8 and discovered as a fine aggregate. We need to do Preliminary tests on sand (Fineness Modulus and moisture content). Preliminary test should perform regarding water/cement ratio. After testing the specimens testing the different specimen we need to select or choose one w/c ration which assures us the suitable workability for casting the samples.

### 3.3.1 Process of Ferro-cement Construction

The procedure of constructing Ferro-cement is very considerable job as this technology has different procedure to cast and has low weight and thin material in thickness of about 10-25 mm with a minimum cover of 3mm. It needs consideration in placing reinforcement in layers and excavation according to design.

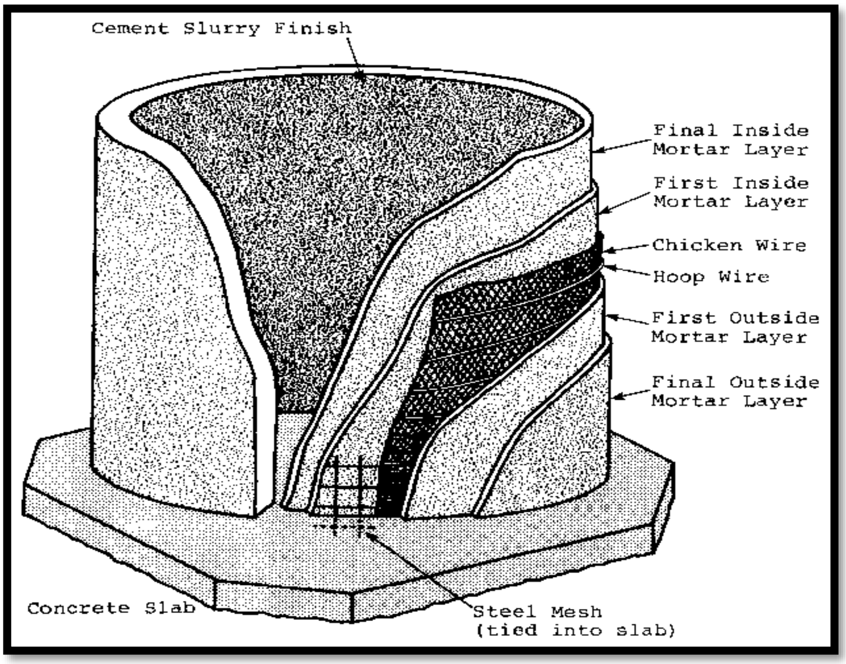



**Figure3. 14:** Detailed View of Ferro-cement Construction

#### 3.3.1.1 Small Site

For evaluating the design of Ferro-cement we don't need much space as we need for the construction of conventional reinforcement concrete (RCC). On construction site we don't need the number of big steel reinforcement to store but we can easily get the wire meshes in rolled form and we don't need to make space for the coarse aggregates, bamboos/steel pipes for scaffolding and planks of wooden framework because in Ferro-cement technique we assemble the structural element on the ground. (Divekar, 2011b)

#### 3.3.1.2 Labors

It is one of the uniqueness in Ferro-cement that for the construction of Ferro-cement we don't need known skilled labor to evaluate any design project. For Ferro-cement construction we need just three types of worker to execute. 1) A steel fabricator who can cut the meshes reinforcement for desired shape. 2) A welder who can connect/weld the reinforcement with the steel Skelton whenever we need. 3) A mason who can plaster and cast Ferro-cement. The manufactured and mesh reinforced tied steel bar confine for Ferro-cement cavity wall of 10sq.m territory weighs just 50 kg and can without much of a stretch be lifted and take up by two people (Divekar, 2011).

#### 3.3.1.3 Tying of Reinforcement Meshes

In the Ferro-cement project there are number of layer of meshes we use for the construction, for executing the project as per design we should cut and bind the meshes inward. It is important that meshes reinforcement should be ties and welded with each other as when we splash/penetrate cement mortar forcefully it should not move from their position (Sakthivel and Jagannathan, 2011).

#### 3.3.1.4 Mix Proportioning

Mix proportion is very important for engineers to evaluate any project or casting any specimen in the library. Mix design tells us about the gradient proportions in composite matrix. Here if we see the Ferro-cement case the mix proportioning recommended for this application are: cement/sand by weight is 1.5 to 2.5 and water/cement ratio by weight 0.35 to 0.50 for a suitable workability. If we have high sand content then for maintaining the same workability we increase the water content. Fineness modulus of sand, sand/cement and water/cement ratio ought to be resolved from trail batches to guarantee a mix that can invade the reinforcement and performed an excellent and dense. The wetness of the total substance should be considered in the assurance of required water. Amounts of materials should ideally be calculated by weight. The designed mix proportioning should be as firm as could reasonably be expected, if it doesn't anticipate complete penetration of the reinforcement. Typically, slump value for fresh mortar should not surpass 50mm.

#### 3.3.1.5 Mortar Placement

Mortar placement in Ferro-cement technique is very unique than the conventional reinforcement. It has a very important role in the durability and functioning of the Ferro-cement element. Mortar placement can be by hand and through spray gun (shotcreting) to achieve homogeneous distribution of mixture throughout out the distribution of an element and meshes must be covered by the mortar matrix properly. An engineer from California Martin Iorns gave us a different technique to place the reinforcement meshes in the mortar matrix instead of placing mortar in the meshes. He placed the meshes in layer the freshly sprayed mortar to make sure that meshes are not out and they are properly cover with the mortar matrix. In this way he placed the thin mortar cover generally in 3mm thick and then placed the layer of reinforcement but did not allow to dry completely and primarily placed another mortar and successively layer of meshes. The importance of this technique is you can easily see each and every layer to be covered properly and if there are any gap you can immediately cover by the mortar (NAMAAN 2000). The edges of the meshes which are pressed by the hand can be placed in a right position so by this technique we can get the proper covering to the edge of meshes and mechanical vibration ensure us the durability in Ferro-cement element (Doshi et al. 2011).

#### 3.3.1.6 Curing

After the 24 hours of casting Ferro-cement element we go for their curing to avoid their shrinkage crack. This step is very important to get full properties of the mortar. Generally we do cure for 28 days to ensure full strength but for the comparison of results in strength we can do curing for 7 days and 14 days as well.

### 3.3.2 Compressive Strength

Compressive strength is the strength of a specimen which describe about the load carrying capacity of an unreinforced specimen by assuming a uniform stress distribution of 0.85 $f'c$. Here $f'c$ is the compressive strength of design mortar matrix. Moreover the reinforcement like square or rectangular reinforcement meshes in matrix can boost its strength. The most important thing in Ferro-cement for compressive strength is the slenderness ratio as Ferro-cement is a thin material it can reduce its compressive strength below the designed load carrying capacity. In Ferro-cement application the desirable compressive strength is up to 70 MPA.

### 3.3.3 Flexural Strength

Flexural strength can also be known as the tensile strength of concrete. In this test our main target is to know the failure point of concrete slab or beam by using the central point loading machine with crack mouth opening displacement as the information source. It can likewise be known as Modulus of Rupture in Psi and can be controlled by standard test techniques ASTM C78 (third-point loading) or ASTM C 293 (center point loading).

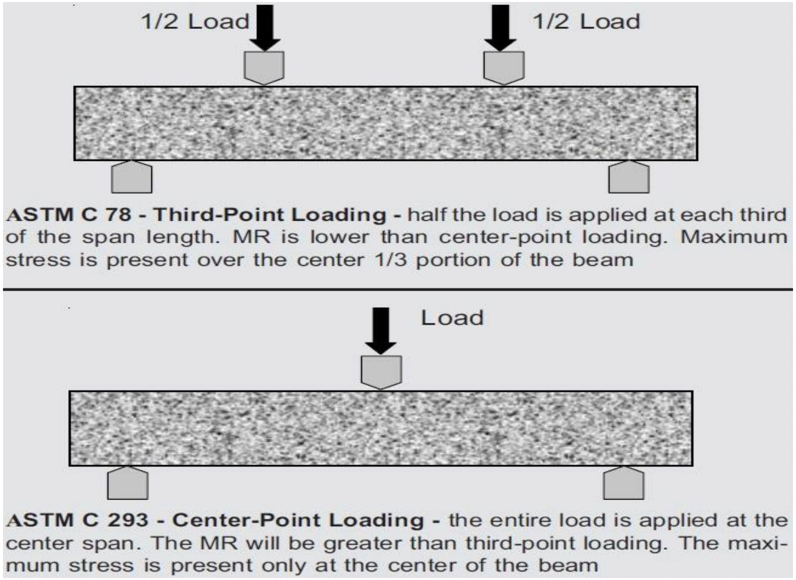



**Figure3. 15:** Third Point Loading

Flexural Strength is around 10 to 20 percent of compressive strength. However, the best relationship for explicit materials is acquired by research facility tests for given materials and mix design of structure. Flexural tests are amazingly concentrated amid preparation, taking care of, and relieving techniques. Beams are extremely overwhelming and can be damaged when casting and transported from the activity site to the testing in lab. Enabling a beam to dry will yield lower qualities. Try not to enable the example to dry for more or shorter periods. Short time of drying can create a sharp drop in flexural quality and vice versa.

# 4 SUSTAINABILITY OF FERRO-CEMENT

## 4.1 General Introduction:

Meeting the needs of present without compromising the potential of future generation to fulfill own needs is known as sustainability. Raising the scale of sustainability in construction directed to decrease of negative natural effect and asset utilization for the duration of the existence cycle of manufactured facilities with a synchronous increment in life quality. Ferro-cement is a material that is these days progressively utilized worldwide absolutely in light of the likelihood to meet the various prerequisites which concern the biological nature of structures. The method of construction structure and arranging needs long haul manageability as their foundations intended to support the greater part century. As like ordinary cement, Ferro-cement is one of the new advancement materials continuously called upon to fill in as a monetary construction material for outrageous conditions. In spite of the fact that, Ferro-cement is commonly used for marine condition as for example: ships, barges, floats and numerous other sort of gliding structures. The purpose for this wonder might be on the grounds that Ferro-cement is a thin basic component with a normal thickness of in the middle of 12mm to 50 mm may appear to be very unseemly for such employments. Not with standing, with the critical enhancement for Ferro-cement material, particularly with the utilization of some aroused cross sections and polymers in mortar material. Ferro-cement enhances its supportability and turn into the most appropriate material of development in separate condition.

Ferro-cement high toughness execution is outstanding in extraordinary condition, quake zones and its effective use in this structure might be an advantage for real designing applications. In the goals of supportability of Ferro-cement, the imperative things to accomplish are high quality, toughness, accessibility of material, impermeability and financial components. Shape this perspective, obviously the task to be created to address the development difficulties later on.

Ferro-cement as a rule acts uniquely in contrast to standard reinforced concrete in execution of solidarity and potential application due to its high surface zone to volume proportion in a concrete mortar grid which improves Ferro-cement to reinforce its designing properties as for example: rigidity, flexural quality, affect opposition, impermeability and sturdiness. From numerous points of view of utilizations Ferro-cement has been utilized in everywhere throughout the world, both in developing and developed nations. The noticeable qualities of Ferro-cement like high quality and adaptability empower the material to increase wide acknowledgment in auxiliary applications. The monetary creation, strong thin shell structure for agribusiness and lodging applications are the regular instances of its accessibility and adaptability in development as a large portion of which uses on the accessibility of neighborhood materials and least talented labor. Many watercraft manufacturers are pulled in to Ferro-cement material on account of its solidness and water snugness to utilize the material widely for business and specialties, for example, skimming docks, sea canal boats, gliding houses, barge, floats, and so on.

In India Ferro-cement innovation is regularly utilized in building houses on account of its neighborhood accessibility and adaptability in construction and as a result of its flexural quality on high surface region to weight. It is likewise earthquake safe contrasted with working of typical cement and steel structures. The sensible cost and accessibility of material at neighborhood level builds its interest to use in development innovation. Indeed, even a beginner could build the structure as a matter of course. What's more, Ferro-cement construction would give lighter structure which brings down upkeep expenses and longer lifetime in correlation with steel development and RCC construction. Most huge advantage of Ferro-cement is in its thin shell structure, which typically in the scope of 30 to 50mm thickness, that can oppose bigger avoidance and higher break load for comparative load conveying ability to that of concrete. Ferro-cement has noteworthy maintainability in development setting as it is solid, monetary, flame resistant, earthquake safe, sans rust and does not decay or blow down in tempests. Ferro-cement can't entirely be delegated a feasible material, yet it is very proficient and financially knowledge.

## 4.2 Durability of Ferro-cement

The word durability can be defined as the resistance. In term of forro-cement characteristics durability is the resistance of failure of ferro-cement properties when it is under service loading or expose to environment. The measurements to achieve durability for ferro-cement according to standard are same as for standard reinforcement. For example such measure are provided by ACI 201.2R (ACI committee 201, 2016). Moreover from different experimental work we come to know that there are two things that influence the ferro-cement durability (ACI committee 549, 1997): 1) Aggressive substances can influence the reinforcement in ferr-cement due to small cover of the element (1 to 2mm). 2) The distribution of reinforcement meshes throughout the area and have large contact can be the reason of high corrosion. But despite all these points from the literature review we don’t have strong chances for critical corrosion in ferro-cement as we can use galvanized reinforcement to counter it. We have to focus on the cover thickness to make sure the durability as per sustainable material.

### 4.2.1 Cracking Behavior

Ferro-cement is material with the low thickness and less cover but despite all these things it has a very good cracking behavior in comparison of reinforced concrete. The maximum crack width in ferro-cement is much lower than the standard reinforcement concrete. As per standard for corrosive and hydraulic environment maximum width crack should be 0.05 mm and 0.1 m for other structures. (IFC Committee 10, 2001: NAMAAN Ferro-cement & laminated cementitious composites, 2000).

Ferro-cement under service load because of its small width crack it provides excellent leakage characteristics. As this property can exhibit ferro-cement application for water tank

### 4.2.2 Corrosion

As in the composition of ferro-cement we use steel meshes with smaller diameter than the conventional reinforcement and those meshes distributed throughout the distribution of the element surface which give us high specific surface. The main important thing in the ferro-cement is the small diameter meshes which loss the cross section of wire meshes. If we see the corrosion impact on reinforcement, it induces the internal tensile stress which can be smaller than the conventional reinforcement due to the smaller diameter of meshes.

If we see in the literature: kosa et al. worked on the deformation of the steel fibers and mortar due to corrosion in drying and wetting condition in laboratory atmosphere and in 3.5 percent standard soadium chloride solution. (Kosa, NAMAAN. And Hansen, 1991; Kosa and NAMAAN 1990). Reinforcement fibers, 0.5 mm diameter and 30 mm long were used in this investigation. They concluded that all the experimental elements suffered from severe corrosion with ranging 5.4 to 70 percent reduction in steel diameter but there were no any cracks appeared on the surface of specimen. We can say that in ferro-cement due to the multiple layers of the meshes in a short space can have severe effect of corrosion in the composite.

## 4.3 Techniques to Improve Durability of Ferro-cement

Any type of structures either conventional reinforced concrete or ferr-cement thay are always in the exposure of the environment. Specific structures can be in aggressive environment. Two researchers Drochytka and Petranek investigated and determine following protective measure to increase the service life of the reinforced concrete structures. 1) Developed the physical properties of concrete and the material which can be repairable. 2) Electrochemical behavior of the steel reinforcement should be alternative. 3) Surface treatment should be applied (Drochytka & Petranek, 2002).

Fully compacted material composition can assure durability of the structure. Beside this we can improve the durability of ferro-cement by adding fly ash and other pozzolanic materials, it helps to develop the resistance from sulfate and sea water attack in a same manner as it works for conventional concrete (ACI committee 549, 1997). In aggressive environment and for restoring material a protective layer is good for existing ferro-cement building. ACI committee 515 describes different effect by many substances on untreated buildings and gives us solution in form of "traditional technique" and "electrochemical technique" to protect them (ACI committee 515, 2013).

### 4.4 Diffusion of Ferro-cement

Diffusion is the arbitrary movement of free atoms or particles in a soaked pore system affected by a focus inclination (Concrete Society;, 1988; Feldman and Sereda, 1968). The diffusion can be in either vaporous or ionic structure. A commonplace case of vaporous dispersion is the diffusion of CO2 into the cementitious material, while a run of the mill case for ionic dispersion is chloride diffusion (Nanukuttan, 2007).

In the composition of matrix for the ferro-cement element we use different ingredients like cement, sand, water and meshes. These all have different impacts which are affected by the aggressive environment so the diffusion of severe impacts for example gases like O2 and CO2 and molecular ions like CL- and SO4= can happened. About the gaese their molecules can move freely rapidly in the open pores than through water saturated, and in case of ions it can diffuse when they dissolved in the water saturation. However diffusion have great impact in saturated one instead of partially saturated pore.

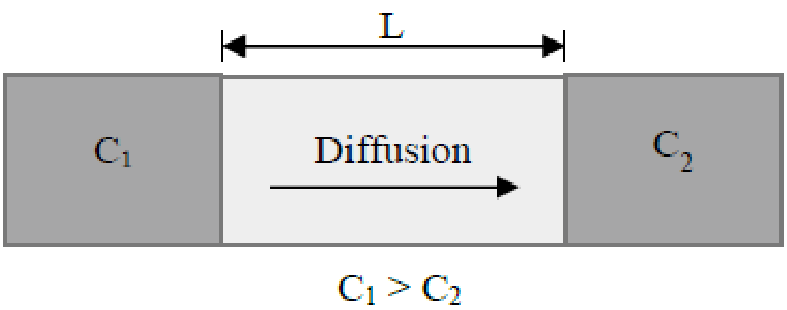



**Figure4. 1:** Schematic representation of the diffusion process (Bertolini, 2006)

As I mentioned in above paragraph about the ingredients of ferr-cement the impacts of diffusion in the concrete can sustain for a certain degree with components of cement matrix. Such as chlorides can attach with the aluminum ions as C-S-H, however CO2 can react with alkaline species, especially carbon hydroxide. With the passage of time the gradual increase of these impacts can affect the diffusion phenomena.

### 4.4.1 Carbonation

Carbonation is the consequence of the disintegration of CO2 in the solid pore fluid and this responds with calcium from calcium hydroxide and calcium silicate hydrate to shape calcite (CaCO3). The carbonization profundity of a solid exposed to 15 years of ordinary indoor introduction is roughly equivalent to 5mm so the disapproval of ferro-cement by and by may be because of its generally less thick cover around the meshes reinforcement, which can resist erosion.

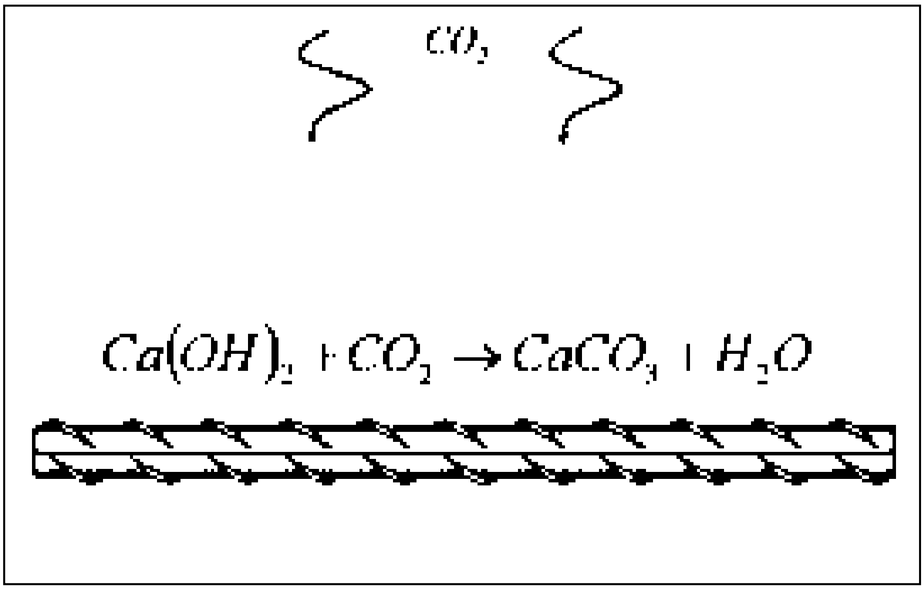



**Figure4. 2:** Diffusion process of CO2

### 4.4.2 Chloride diffusion

Passage of chloride from sea water is the essential driver of depassivation of steel and coming about mischief to marine reinfoced concrete structures, explicitly in the sprinkle zone. High chloride penetration experience may be gotten by including pressure driven or pozzolanic minerals to the matrix of cement. Points of reference are blast furnace slag (BFS) which has been used in concrete in the Netherlands at high swap levels for France various decades, and different minerals like silica smoke and fly fiery debris which are being used in various countries.

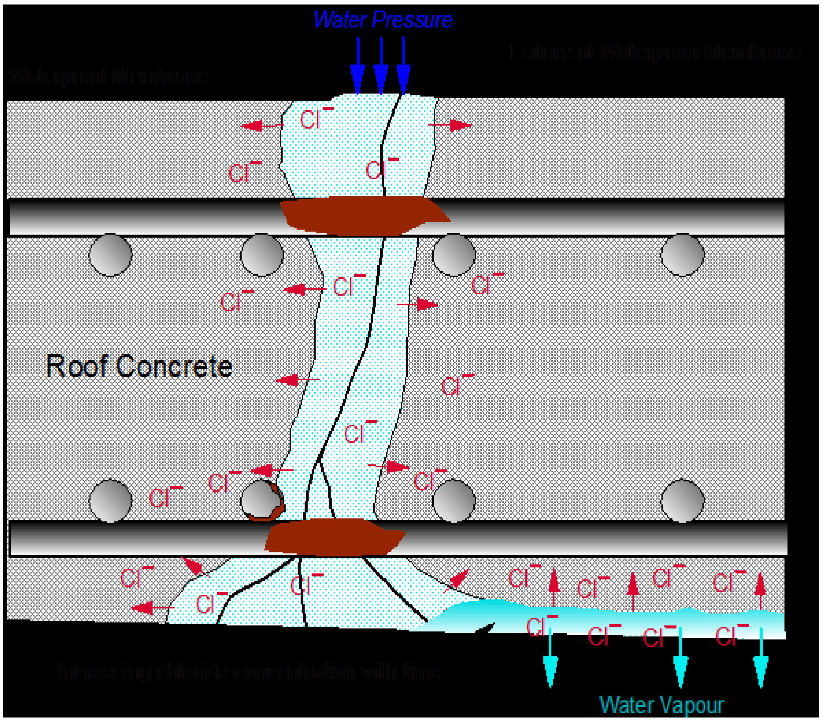



**Figure4. 3:** Chloride diffusion due to salt water

## 4.5 Sustainability of Ferro-cement

### 4.5.1 Impact Resistance of Ferro-cement

Ferro-cement because of its high effect vitality engrossing capacity is exceptionally sufficient to oppose the effect as contrasted and regular strengthened concrete is especially limited at the effect zone rather than entire zone. Effect obstruction parameter is exceptionally helpful in applications identified with seaward structures and water crafts. This following specimen is carried out from the laboratory of civil engineering department at the University of Nottingham, UK

**Figure4. 4:** impact resistance of Ferro-cement sample

### 4.5.2 Rehabilitation Technique by Ferro-cement

Sustainability of concrete enhanced by including Ferro-cement plates around typical strengthened. The Ferro-cement plating around RCC controls the negative perspectives as water sealing and fixing of strengthened cement concrete. On the off chance that a building is compelling in expanding the splitting it is inferred that by utilizing restoration procedure of Ferro-cement component, we can fortify a definitive load and increment the effect opposition of reinforced concrete component.

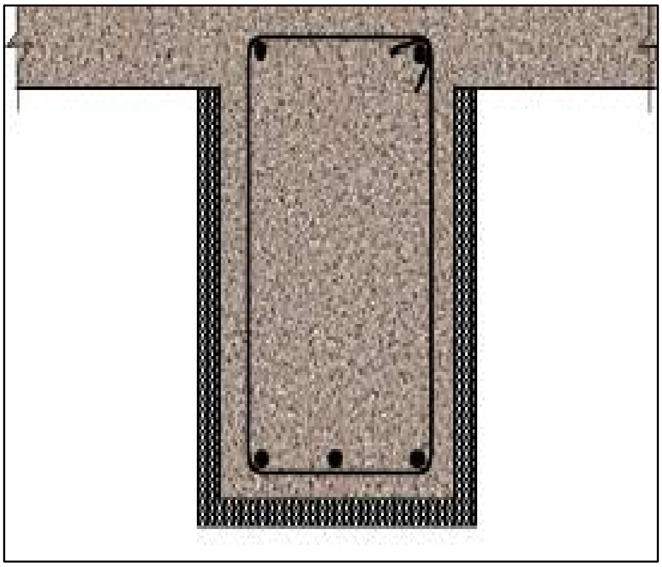


**Figure4. 5:** Section of T beam is platted with Ferro-cement

### 4.5.3 Fire Resistance

Imperviousness to fire is essential for manageability of any building to continue its designed life, in this setting one of the tests was completed at Ferro-cement building segment in Baghdad, Iraq. The outcome came as Ferro-cement building part can endure coordinate fire with a maximum temperature esteem up to 756o C for a time of 2½ hours with no isolation in the outside of components confronting the fire.

**Figure4. 6:** Fire resistance of Ferro-cement compartment

### 4.5.4 Crack-Arrest Mechanism

There are two delicate elements that support the transportation of forceful specialist in to concrete, and impact its planned life and safety. These are breaking profundity and nature of cover to steel. Outer forceful specialists, for example, water, air and chloride particles can enter through breaks and rust the reinforcement. Notwithstanding the little cover, Ferro-cement displays phenomenal breaking conduct, which prompts little split widths under administration stack. Regarding usefulness limit state, most extreme split widths in Ferro-cement are much lower than that of conventional reinforced concrete. Indeed, the most extreme break width ought not surpass 0.05 mm for destructive conditions and additionally water holding structures, and 0.1 mm for different structures. Ferro-cement has leeway of split obstruction on account of its high surface region to volume proportion and being a solid material have less measure of solid, it help to limit the breaks on the building so the restoration and fixing of the building each year won't be required.

### 4.5.5 Earthquake Resistance

Ferro-cement has a nature of flexibility. In light of its high flexibility Ferro-cement plated structure has high obstruction of seismic earthquake and can swing a couple of centimeters amid quake and be back in its unique position with our any harm to the human lives and structures. This preferred standpoint of Ferro-cement empowers it a supportable material in earthquake zones.

### 4.5.6 Economic Sustainability:

Finance related factor is imperative in the plan of any engineering project. In the perspective of Ferro-cement structures there will spare in the material as the cement and steel prerequisite lessen about 10% to 15%. The formwork for building slab, beams and other basic structural component isn't required. Sparing in the consumptions of the waterproofing and fixing in correlation of RCC structures.

### 4.5.7 Explosive protection:

Blast protection for structures under immediate or circuitous risk from touchy dangers regularly requires retrofit arrangements with negligible or impermanent natural effect while giving basic protecting from stun waves. Ferro-cement framing gives a secluded and viable latent arrangement. The fuse of ceaseless steel wire reinforcement loans pseudo-malleability under effect stacking which help auxiliary honesty contrasted and ordinary strengthened concrete and amasses harm at the effect zone.

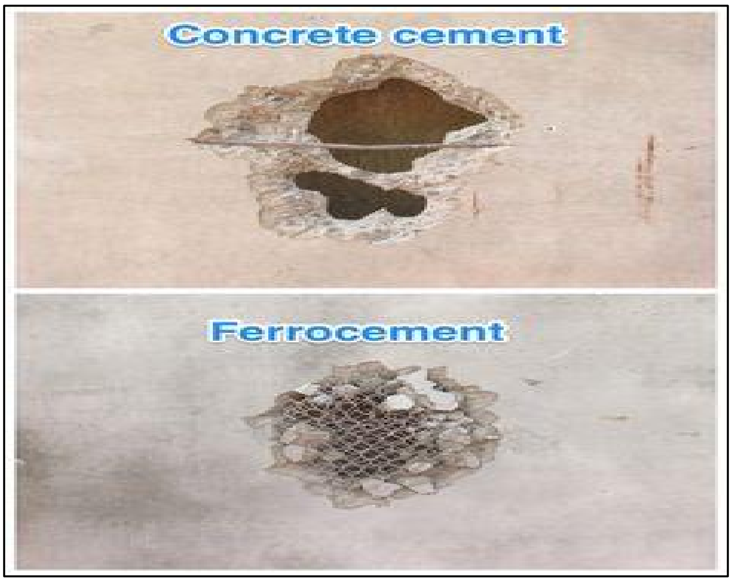



**Figure4. 7:** Explosive protection of RCC and Ferro-cement

### 4.5.8 Corrosion Resistance

Ferro-cement has known as an incredible material for minimal effort lodging, its toughness keeps on involving concern attributable to the erosion affectability of the little diameter metallic wire networks. Assurance of support in Ferro-cement is normally accomplished as the reinforcement work is appropriated all through the thickness, is portrayed by high explicit surface and is made out of little distance across electrifies wires networks and expanded compelling spread. Also, if there should be an occurrence of erosion, the far reaching consumption items will prompt inside elastic anxieties that are relied upon to be littler than that of rebar in customary reinforced concrete.

### 4.5.9 Environmental Sustainability

Environmental maintainability is essential for the social effects as with regards to natural advantages, Ferro-cement can be made of nearby assets and items, decreasing the effects of transport. The environmental advantage of building structures dependent on Ferro-cement and ordinary reinforced concrete is the decrease of the measure of waste amid construction stage, because of the likelihood of disposal of wooden formwork, which makes up an impressive piece of the created waste. The vitality amid the building's utilization stage can be diminished, in light of the fact that the Ferro-cement basic components have long administration life, with at least upkeep. Ferro-cement fixes are done physically, with low utilization of materials and vitality.

A few focal points of Ferro-cement as a construction material might be outlined as pursue:

1. Higher quality control.
2. Pre-Fabricated products.
3. Availability of basic materials for construction
4. Easiness in production and installation.
5. Shading devices to protect the buildings from day
6. Mean time construction.
7. Labor easily trained at site.
8. Improved the performance of structure.
9. Economical as 15-50% cheaper than standard construction.
10. Required less maintenance.
11. Reduction in dead weight, 50-75% lighter than standard techniques.

# 5 APPLICATIONS OF FERRO-CEMENT

## 5.1 Introduction

Ferro-cement's development technique is becoming worldwide useable because of its durability and this motivation make the world to decide to use it for many kind of elements which are used as; street furniture, decoration element, drainage pipes, gutters, sculptures and storage tanks for food and water. Now a day we can find its many applications in the building construction development. And because of its thin element characteristics we can use it as a repair material. In the construction techniques, building materials should be sustainable structurally as well as environmentally, economically and can perform as per requirement (Akhtar et al. 2009). Ferro-cement material is thin and can be molded in any shape; with all of these aspects it has also esthetical view and strength to overcome the load (PushyamitraDivekar, 2011) which gives the strong selection and good solution to roofing construction (Abdullah and Takiguchi, 2003). Ferro-cement material use as storage tanks on large scale worldwide. Storehouses made of Ferro-cement can store grains, fertilizer, pesticide and cement up to limit of 10 metric tons (22400 lb) (Naaman, 2000). Before Ferro-cement technique wood and steel were utilized for storage purpose but Ferro-cement replaced these techniques because of more durability than wood and financially economic than steel (Hago et al 2005). In India the test was carried out on Ferro-cement cylindrical bins which have 3 metric ton capacity and size of (1*1.20 m) and resulted as Ferro-cement bins are more economical than steel bins and reinforced concrete bins (RCC) or aluminum (ACI 549 R97) (Sharma et al. 1979). There were some studies carried out: which resulted as in the wind tunnel construction the cost of Ferro-cement development is more economical than the steel and fiberglass (Report JABE-ARC-07, 1976). In 1984 a Ferro-cement precast panel's swimming pool with size of (25*12.5 m) was constructed in Vila Loma Jibacoa with the depth and thickness of 1.80m and 25mm respectively. In the cost estimation it was seen that Ferro-cement panels swimming pool almost seven times less cost than RCC of the same size swimming pool.

## 5.2 Ferro-cement Nervi's Technique

In the period of 1888-1942 application of Ferro-cement construction was not much developed. After 40's, PIER LUIGI NERVI an Italian architect engineer had done number of experiments on Ferro-cement to know about its properties and applications. On the results of that experiment it was concluded that in case of reinforcing the concrete with layers of meshes, it can be characterized as homogeneous material that has enough strength to overcome the impact load. Nervi additionally developed the Ferro-cement idea to civil engineering structures and utilized the possibility of layering for the top noteworthy structures including the rooftop framework crossing 98m for the Turin exhibition hall. Due to the economic factor and flexibility at large scale Ferro-cement is now considered as the structural material in many areas of construction application like houses. In numerous points of view Ferro-cement is regarded to be an augmentation of RCC and it is preferred over conventional RCC because of its durability, mechanical properties and elastic behavior due to its homogeneity at some point of loading.

In Nervi's technique: he took some important changes in the construction system. He gave a patent of prefabrication which means he wanted to cast each element of the building on the ground and eliminated wooden formwork from the construction site. From his technique every element which is fabricated on the ground must be enough light weight, small size to lift and assembly very easily. He gave specific shape to each element as it can have enough strength and stiffness to assemble and to sustain service life. He divided the construction yard into two main sections which could be worked in parallel. One side is the construction site and on the other hand there were fabrication site for the labor used to assemble the elements of the structure (Iori& Poretti, 2013). To test the first experiment of this technique was adopted in between 1939 and 1942 when he was worked for the construction of airplane hangars for Italian air force.

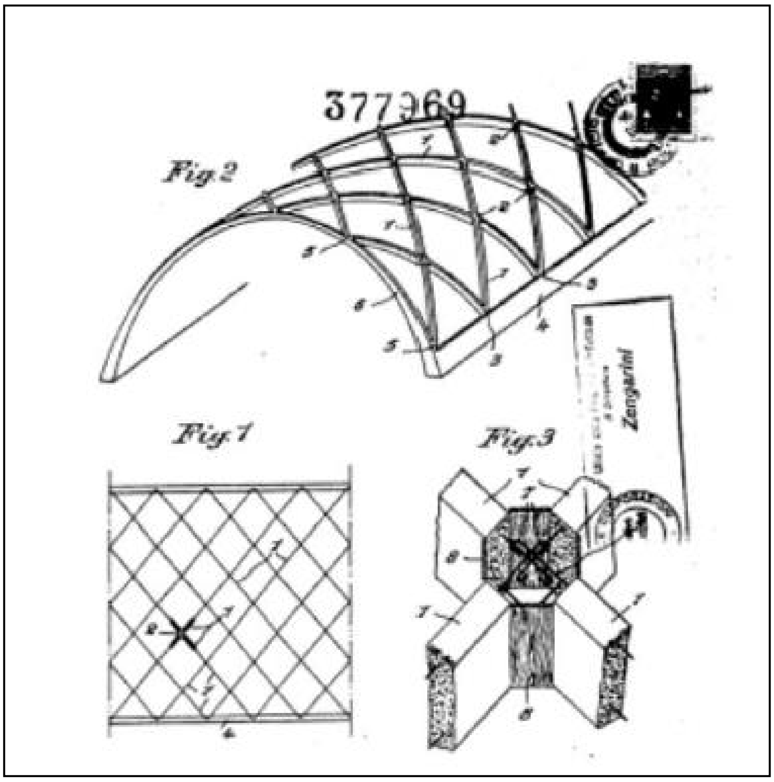



**Figure5. 1:** Italian patent n. 377969, "Structural prefabrication technique", 1939

**Figure5. 2:** Aircraft Hangar, Orbetello. Pier Luigin Nervi & Bartoli, 1939-1941

## 5.3 Ferro-cement Raichvarger and Tasta technique

They described many techniques to assemble the single and double Ferro-cement element from flat shape to curved shape. In one technique they assembled the flat Ferro-cement and then bend it in to U shape section. The important thing to remember is we have to bend the element while it is in plastic stage and also the mould should be designed properly to allow a perfect development.

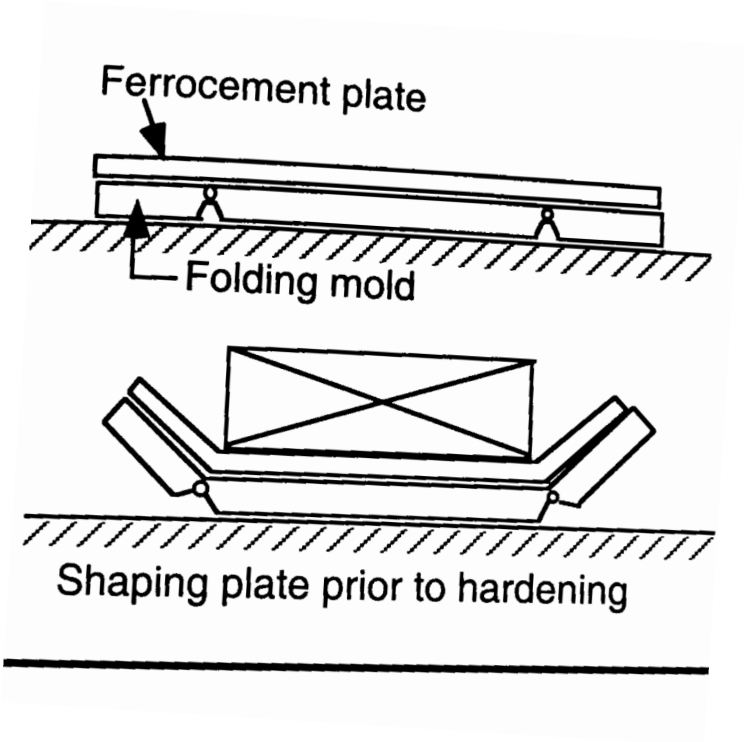



**Figure5. 3:** Moulding of flat plate to U shaped section (NAMAAN 2000)

With the same technique another operation was carried out on Ferro-cement element to form square, rectangular and curved shape. In this technique they casted a flat Ferro-cement element while its edges were on a rigid frame and then the rigid support were lifted up slightly while the element was in plastic stage then towards hardening it deform due to its own weight.

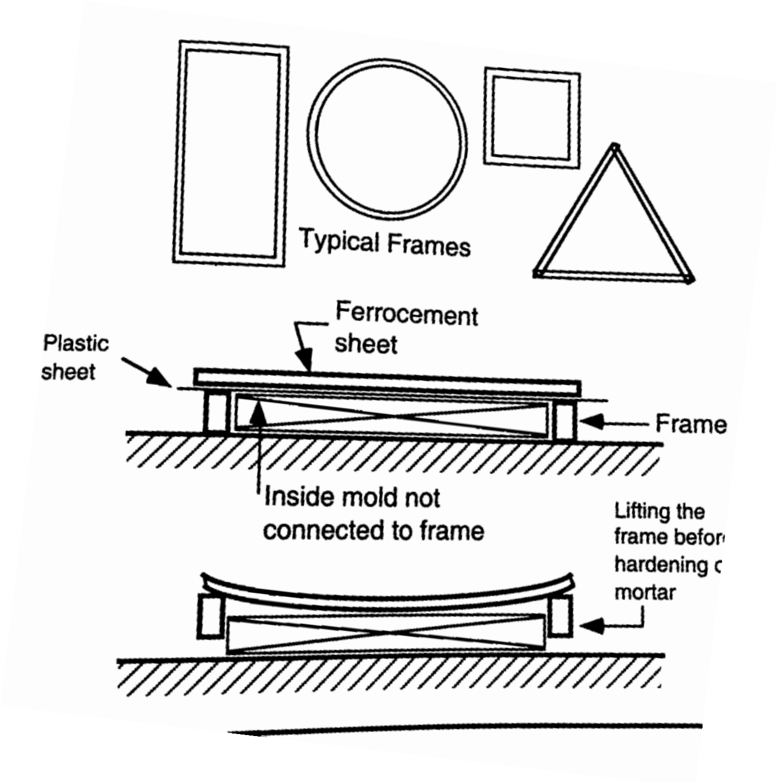



**Figure5. 4:** Shell shaped elements (NAMAAN 2000)

### 5.4 Ferro-cement Douglas Alexander Technique

The new technique of Raichvarger and Tasta recognized worldwide and then in New Zealand an engineer Douglas Alexander used this technique in a different way. He was construction the wall of cylindrical water tank, in that operation he made Ferro-cement sheet and in plastic stage he bend it by cylindrical drum. The problem he was faced is the cracking during the bending but those cracked was healed in curing.

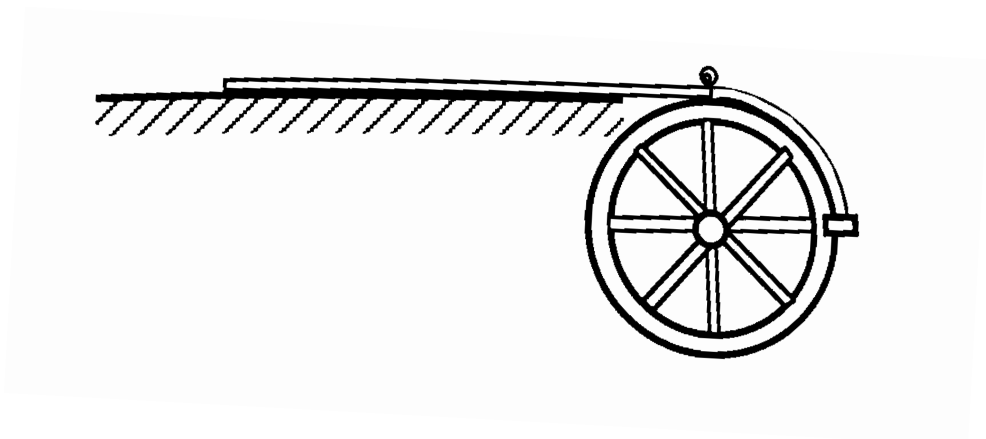


**Figure5. 5:** Cylindrical Element (NAMAAN 2000)

## 5.5 Ferro-cement Wainshtok Rivas Technique

He did work on the different technique to mould the flat Ferro-cement sheet into U-shape, W-shape and V-shape. In his technique he placed the series of flat plates mould and each mould were connected through the mesh strips. When the specimens get hardened they were easily can lift and can be moulded into different shapes with the help of meshes strips.

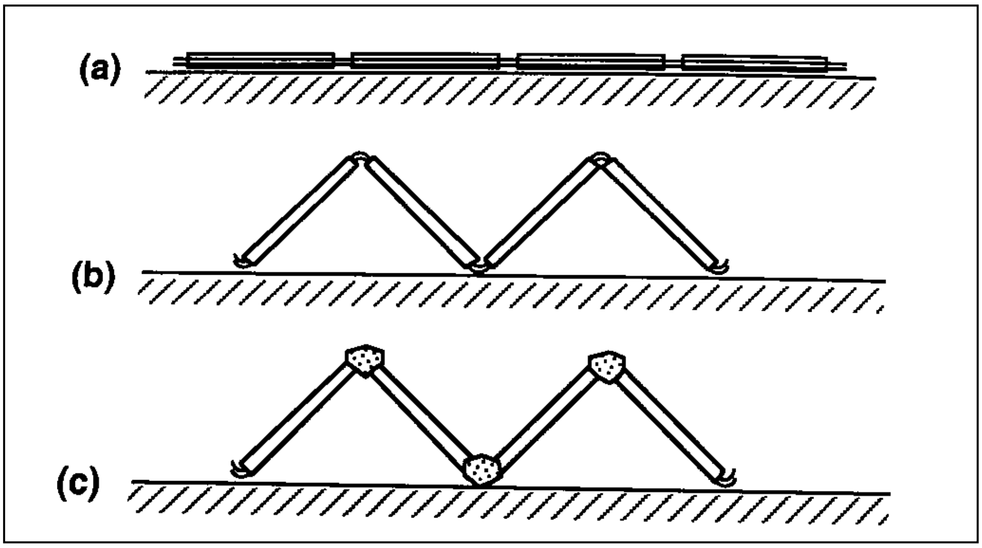



**Figure5. 6:** Typical production of Ferro-cement W-shaped elements from Flat sheet (NAMAAN 2000)

## 5.6 Ferro-cement World-wide Techniques

Ferro-cement panels are widely used in the structural construction like rooftops, storage tanks, pools, biogas digesters, stockpiling houses and some particular applications for the sea such as boats and floating houses. For all of these Ferro-cement applications, RCC is too heavy and cannot utilize for these purposes over weight and economical factors so Ferro-cement is preferable over the RCC construction (reinforced cement concrete). (Naaman 2000, Hago et al 2005, Abasolo et al 2009).

Ferro-cement world widely accepted and utilized in early 1960s. Countries like United Kingdom, New Zealand and Australia utilized it on a large scale. After that, number of other countries built their structure by using Ferro-cement. Israel used Ferro-cement to develop and repair their existing structures (Adajar et al., 2006).

In Bangladesh, Indonesia and Papua for the construction of houses, reinforcement replaced with bamboo or bush sticks by using Ferro-cement technique because of their locally availability. Ferro-cement structures were constructed in Sri Lanka has ability to overcome the impact of whirlwind and some folded sheets were examined by the structure inquire about foundation and state designing enterprise Colombo, Sri Lanka, it was resulted that these Ferro-cement folded sheets can developed over the cement folded sheet as an rooftop material (Naaman and Shah, 1976; ACI Committee 549R-97).

In India Ferro-cement structures are developed by the institute Auroville center for scientific research (CSR) Tamil Nadu India after the satisfactory investigation on the durability of Ferro-cement elements (CoP, 1997). In Malaysia, Brazil, India, Papua, Venezuela, Philippines and Pacific Ferro-cement precast elements have been used for the rooftop and distribution walls. In Singapore, India, Indonesia, Zimbabwe and Peru Ferro-cement technique developed as to replace the galvanized iron sheet and asbestos sheet with the precast folded rooftop panels which were reinforced with locally available materials (Robles-Austriaco, 1992).

Ferro-cement technique developed in Singapore on a large scale as it used in the construction of different aspects like shades, roofs aesthetic as gracing the ceiling, water storage tanks and as the faces of the buildings (Paramasivam, 2011). More work on the behavior of wave action has to be done on the Ferro-cement element in the civil engineering laboratory at the NUS (national university of Singapore) and it was resulted that Ferro-cement has great durability to sustain and resistance the earth quake actions (Paramasivam et al. 1985).

## 5.7 Applications

Because of extraordinary flexibility nature, durability, easily accessibility of material, unskilled labour and less machineries for the construction of Ferro-cement structure Ferro-cement has extensive variety of utilization in construction development. Either there are marine structures or ground structures Ferro-cement has great impact to sustain the development. Now a day's applications of Ferro-cement in construction rapidly increase worldwide. Here are some of the applications listed below:

- Storage Tanks and silos
- Floors tiles and Rooftops
- Manhole covers
- Ferro-cement buildings
- Ferro-cement ducts
- Rehabilitation of structures
- Rural applications
- Marine applications
- Fire resistance structures
- Pipes

- Foot bridges
- Strengthen the RCC structures
- Precast Ferro-cement structure

### 5.7.1 Boat-Building

Ferro-cement is world known due to its durability and flexibility so it can be molded in any shape so this constructional property gives an attraction in design of some traditional building construction. In point of boats design Ferro-cement is more economical, durable and has high resistance to fatigue and impact load than the wooden material. Lambot's (the father of Ferro-cement) made an application of Ferro-cement in the construction of boats to replace the timber.


**Figure5. 7:** Lambot's boat in France Museum

### 5.7.2 Storage Tank

In the rural areas under ground and over ground water strange tank constructed with the Ferro-cement because of its high quality of water-tightness and impact resistance. Ferro-cement water tank can sustain more due to its durability and have very less leakage in comparison to the conventional RCC tanks.

**Figure5. 8:** Water tank with rounded reinforced wall

### 5.7.3 Food Storage Facilities

The issue of nourishment storage in the under develop countries is rising as a noteworthy subject of consideration from specialized organization. In developed countries Ferro-cement technique for the food silos developed in high range at local condition by replacing the steel and wooden silos. Because Ferro-cement food storage tanks don't need a lot of attention during construction as well in maintenance and also help in the resistance of bird, insects, water and weather interaction to the food.

**Figure5. 9:** Ferro-cement Food Storage Drum

### 5.7.4 Repair & Confinement of RCC Structures

RCC (reinforced cement concrete) is a composite material in which concrete has low ductility and steel has high tensile strength so under loading condition RCC behavior is totally different as it shows cracking which become deepen under continues loading condition for this reason with the passage of time RCC require some maintenance to sustain. With the maintenance, structure can improve its service life in the context of strength and stiffness and also some surface textures improve the weathering and resist the aggressive species to damage steel. RCC structures that become progressively worse can be repaired with Ferro-cement because this technique can improve the strength up to 30% and also has great resistance in formation of cracks. In any structure column is the main element to support the load so deterioration of column can be confined by the Ferro-cement which help to improve its strength, durability and energy absorption and sustain the column to support the load of structure. This Ferro-cement confinement not just to improve the strength but also can give the water tightness and resistance to the aggressive substances to enter and corrosion the reinforcement.

Because of the great flexibility and different mechanical behaviors, Ferro-cement has extensive variety of applications. For the maintenance of some structural element the determination of Ferro-cement should be done after the proper investigation and analysis according to the provision of criteria in ACI. In addition Ferro-cement ought not been selected as contender to RCC or supplement to it. There are some studies carried out in the context of replacing the wire meshes with the reinforced plastic meshes and high cementations matrices which can give the high performance to the structure in future.

**Figure5. 10:** Matgliana warehouse Restoration work

### 5.7.5 Ferro-cement Wall

Ferro-cement wall over the brick masonry wall is more reasonable substitute due to its light weight and easy way of construction. More added also Ferro-cement wall is modest than the brick one. In the composition of Ferro-cement wall there are two or three layers of meshes are connected with the rod skeleton in vertical and horizontal direction with the diameter from 6 mm to 8mm depend on the thickness of the wall. In Bangladesh there was government project name PalliJonoped adopted the Ferro-cement wall technique and built some houses.

**Figure5. 11:** Ferro-cement wall of a House

**Figure5. 12:** Ferro-cement Model Curly wall

### 5.7.6 Storage Dam of Ferro-cement

There are certain types of dam which can use to store water. The rapid adoptions of Ferro-cement technique in many countries expended to construct storage dam. For the water retaining purpose the number of steel meshes reinforcement provides strength and water tightness. In the construction of Ferro-cement storage dam it is not much cost effective as conventional because of the base work and pipelines work. But in comparison of earthen dam it is more economical and easy to construct with armature labour.

**Figure5. 13:** Ferro-cement Storage Reservoir

### 5.7.7 Ferro-cement Folded and Corrugated Panels for Roofing

Ferro-cement has increased broad use of folded unit as a roofing material as it is best economical alternative of conventional concrete slabs. This material can be folded in to any shape due to the versatility of meshes. For an esthetical look mostly people prefer their houses with conjugated panels and folded plates. These panels can be manufactured with composite of cement mortar and 18 gauge woven wire roofing. In the rural context it can be more reliable in term of maintenance and economic than corrugated galvanized iron sheet. Flat and corrugated roofing systems are generally popular ACI Committee 549-R97).

**Figure5. 14:** Ferro-cement folded plate

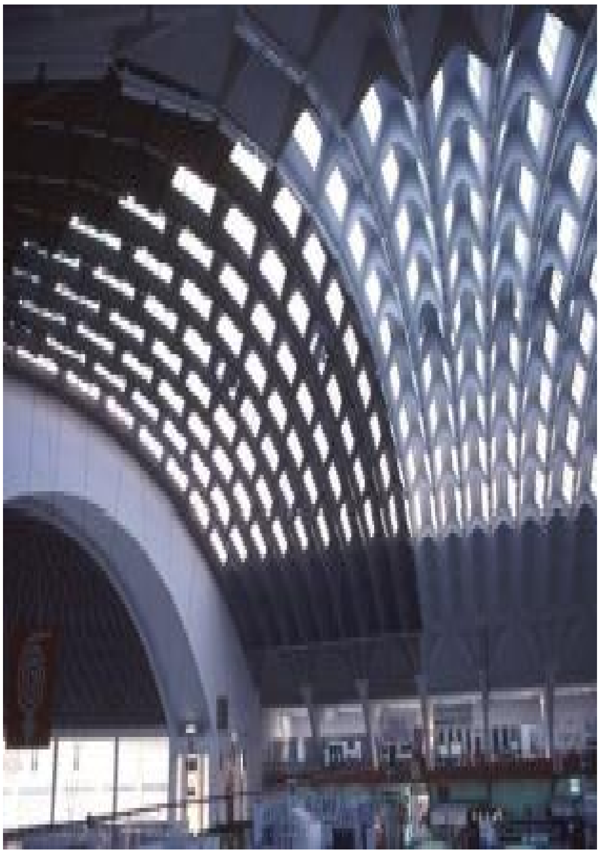


**Figure5. 15:** Palazzo del lavoro, Turin

**Figure 5. 16:** Palazzo dello sport, Rome

### 5.7.8 Ferro-cement Stairs

Ferro-cement has a great impact in the use of building components. In the construction of stair case we can use the Ferro-cement panel as a slab step which can be hold by the RCC support. This technique of construction is more economical than the conventional reinforced concrete.

**Figure5. 17:** Ferro-cement stairs case

### 5.7.9 Furniture

Commonly furniture’s manufactured with wood and steel but now Ferro-cement also developed in this context because of its flexibility, reliability, durability, resistance to impact and resistance to fire damage. Ferro-cement furniture’s technique mostly used to build benches for public parks. Government of Bangladesh initiated this technique in rural areas school due to its durability against disaster prone areas.

**Figure5. 18:** Ferro-cement Bench

### 5.7.10 Planter

In the composition of Ferro-cement we use wire meshes which have high flexibility as we can mold them into any desirable shape. This versatility of Ferro-cement gives scope to different aesthetic design. Circular and square design models are the most common and suitable examples.

**Figure5. 19:** Ferro-cement Flower planters

### 5.7.11 Sculptures

There are some studies and experiments are undergoing on the production of Ferro-cement sculptures. Most concerning Ferro-cement development part is the sculpturing design in public places like in gardens and parks to make them more attractive. Because of its flexibility it can be mould in any shape.

**Figure5. 20:** Ferro-cement Sculpture

**Figure5. 21:** Ferro-cement sculpture in park, Chili

# 6 CONCLUSION AND FUTURE RECOMMENDATIONS

The main focus of the thesis work is to study the Ferro-cement technology in the field of construction. Ferro-cement technology was invented and implemented by Lambot's in 1848 to manufacture boats by replacing timber with metal bar meshes merged in hydraulic cementation, as it is highly resistant to water. After this development, Ferro-cement technique was further used in the construction of buildings during 1940's by an Italian engineer-architect Pier Luigi Nervi. The major concern in developing a project is its strength, sustainability and economy.

In terms of physical and mechanical properties, Ferro-cement and conventional reinforced concrete differs in its composition and has a higher tensile strength, as Ferro-cement has a distributed mesh throughout the high specific area with a small cover. Ferro-cement has been used worldwide in the different sectors of construction because of its unique characteristics in strength, weight and size. The main properties of Ferro-cement are its durability, cementations lamination impacts, cracking behavior under test, sustainability and strengths phenomena to withstand service load and aggressive environment.

Further investigation has been done in studying the Ferro-cement's behavior, and it was seen that Ferro-cement can mold into any shape due to its layers of double meshes which thus enhances its flexibility and durability. Cement mortar resists the load applied on the elements and in case of failure in its resistance, reinforcing meshes helps in resisting the load because of its yielding capacity. Thus, it is concluded that ductility of the Ferro-cement increases with an increase in the number of mesh layers.

Regarding strength of Ferro-cement, it was seen from the previous work that with an increase in the content of minerals admixtures (such as silica fume, fly ash) into an equal proportion of Water to Cement, the strength of Ferro-cement increases in single and double meshes. It was further seen that the strength of Ferro-cement element depends also on the thickness of element along with cement content and number of reinforcing mashes layer. The flexural loads at first crack and ultimate loads depend on number of reinforcing mesh layers used in Ferro-cement. Flexural strength of beams will always lesser than the reinforcement meshes slab panel because meshes are provided to have good energy absorption capacity. The material of Ferro-cement is cheap and readily available in market.

With respect to the sustainability of Ferro-cement, as with the passage of time there are many changes occur in the social environment with the growth of population, engineering and industrial technologies. There is huge impact of these global changes on construction industry as this industry is linked with the energy, environment and sustainability. A sustainable development of cement concrete can avoid the degradation of environment and enable us to maintain a good life. The sustainability in Ferro-cement can be achieved with the durability and corrosion prevention and due to these qualities Ferro-cement is good for impact resistance, fire resistance, earth quake and crack arresting. There are many applications of Ferro-cement such as building applications, marine applications, and Repair and maintenance applications.

It is recommended that further researches should be taken with the consideration of:

- Due to good ductility it is good for earth quake areas
- Due to its light weight it can sustain with the total weight of structure.
- Ease of construction makes it suitable in under-developing countries for housing, water and food storage structures.

# 7 REFERENCES


1. Cassie W. (1967) Lambot's Boats: A Personal Discovery. "Concrete (London), 1(11)". Pp. 380-382.
2. ACI Committee 549. (1982). "State-of-the-art report on ferro-cement". Farmington Hills: American Concrete Institute.
3. Nassif HH. & Najm H. (2004). "Experimental and analytical investigation of ferro-Cement Concrete Composite Beams." Pp. 787-796
4. ACI Committee 549 (1997). ACI 549R-97: "Report on ferro-cement". American Concrete Institute.
5. Disenbacher A. & Brauer F. (1984). Material development design, construction and evaluation of ferro-cement planning boat. "Marine Technology". Pp. 277-296.
6. Mansur M.A. & Paramasivam P. 'Cracking behavior and ultimate strength of ferro-cement in flexure', Journal of ferro-cement Vol.l6, No.4. 1986. pp. 405-415.
7. Kaushik S.K. Gupta V.K. & Rahrnan M.K. 'Efficiency of mesh overlaps of ferro-cement elements'. Proceedings of the symposium on building materials for low cost housing held at United Nations building and organized by RILEM international series, January 1987, Bangkok, Thailand. Pp. 11-18.
8. Vijay Raj. 'Utilization of lime for improving durability of ferro-cement'. Proceedings of third international symposium on ferro-cement by Kaushik, S.K and Gupta, V.K. University of Roorkee, India. December 1988, Published by TMH, New Delhi. pp. 153-158.
9. Austriaco L.R. & Pam R.P. 'Durability of ferro-cement'. Proceeding of third international symposium on ferro-cement. Kaushik S.K and Gupta V.K. University of Roorkee, India. December 1988, Published by TMH, New Delhi. Pp. 225-229.
10. Gupta V.K, Kaushik S.K & Shanna P.C. 'Corrosion performance of ferro-cement', proceeding of third international symposium on ferro-cement. Kaushik S. K and Gupta V.K. University of Roorkee, India. December 1988, Published by TIVIH, New Delhi. pp. 142-152.
11. Al-Rifaie W.N & Trikha D.N. 'Effect of an arrangement and orientation of hexagonal mesh on the behavior of two-way ferro-cement slabs'. Journal of Ferrocement.Vo1.20, No.3. July 1990. pp. 219-930.

12. Al-Rifaie W.N & Hassan A.H. ‘Structural behavior of thin ferro-cement one-way bending elements’. Journal of ferro-cement. Vo1.24, No.2. April 1991. pp. 115-126.
13. Clarke R.P & Sharma A.K 'Experimental behavior of ferro-cement flat plate under bi-axial flexure’. Journal of ferro-cement. Vol.21, No 2. July 1991. pp. 127-136.
14. Karunakar Rao P. 'Ultimate flexural strength of a composite slab of precast ferro-cement and reinforced concrete elements'. Indian concrete journal, Vo1.65, No.10. October l991. pp. 517-520
15. Onet T, Magureanu C & Vescan V. ‘Aspects concerning the Behavior of Ferro-cement in Flexure’. Journal of Ferro-cement. Vol. 22, No.1. January 1992. pp. 19.
16. Onet T & Magureanu C. 'Flexural behavior of ferro-cement beams in long-term loading'. Journal of ferro-cement. Vo1.23, No.3. July 1993. pp. 199-206.
17. Ramesht M.H. & Nedwell P.J. ‘Influence of transverse wires on yielding and ultimate strength of ferro-cement in flexure’. Journal of ferro-cement. Vo1 24. 3 July 1994. pp. 225-237.
18. Ramesht M.H. & Vickridge I.G. ‘FAOFERRS a computer program for the analysis of emergent in flexure’. Journal of ferro-cements. Vo1 26. 1January 1996. pp. 21-31.
19. Ranjbar, M. Nakassa A. and Nedwell, P.J. "Some investigations into the behavior of welded mesh and its effect on the tensile and flexural performance of ferro-cement". Proceedings of the sixth international symposium on ferrocement. Naaman, A.E. (Eds.), University of Michigan. Ann Arbor. June 7-10. 1998. Pp267-276.
20. Nassif H., Chirravuri G. & Sanders M.C. ‘Flexural behavior of ferro cement/concrete composite beams', Proceedings of the sixth international symposium on ferro-cement, Naaman, A.E. (Eds.), University of Michigan. Ann Arbor, June 7-10, 1998. pp. 251-258.
21. Mehdi M.R. & Ahmed M.A. ‘Durability of ferro-cement in Sea water by accelerated laboratory tests’. Journal of ferro-cement. Vol. 29. No. 1. 1999. pp. 35-38.
22. Balaguru P. Giancaspro I. & Lyon R. ‘Flexural behavior of high strength laminates with inorganic polymer’ Proceeding of the seventh international symposium on ferro-cement and thin Reinforced cement composites Mansur. MA. Org. K.C.G. (Eds.), National University of Singapore, June 27-29, 2001. pp. 239-246.
23. Ohama Y., Shirai A. & Sato, F. 'Flexural behavior of Vinylon fiber reinforced polymer-modified mortars 'Proceeding of the seventh international symposium on ferro-cement and thin reinforced cement composites, Mansur, MA.Org. K.C.G. (Eds.), National University of Singapore, June 27-29, 2001. pp. 143-150.

24. Berkowski P. & Dmochowski G. (2014). Examples of concrete structural elements in early 20th century buildings in Wrocław (Poland) – Case studies. In M. Grantham, P. Muhammed Basheer, B. Magee, & M. Soutsos (A cura di) Concrete Solutions: Proceedings of concrete solutions, 5th International Conference on concrete repair, Belfast, Northern Ireland, 1–3 September 2014 (p. 699-706).
25. Chiorino M. (2012). Art and science of building in concrete: The work of Pier Luigi Nervi. Concrete international 34(3). Pp. 32-40.
26. ACI committee report 549. IR-93: 'Guide for the design 1993'. Construction and maintenance of ferro-cement. Reported by ACI Committee 549
27. ACI 544.3: Guide for specifying, mixing, placing and finishing steel fiber reinforced concrete.
28. ACI committee 549 R, "State-of-the-art report" ACI 549 R-97, in manual of concrete practice, American concrete institute, Farmington hills, Michigan, 1997. Pp. 1-26.
29. ACI committee 116 (2000). ACI 116R-00: Cement and concrete terminology (Reapproved 2005). American concrete institute.
30. ACI committee 201 (2016). ACI 201. 2R-16: Guide to durable concrete. American concrete institute.
31. Disenbacher A. & Brauer F. (1984). Material development construction design and evaluation of ferro-cement planning boat. Marine technology 11(3). Pp. 277-296.
32. ACI Committee 211 (1991). ACI 211. Pp. 1-91: Standard practice for selecting proportions for normal, heavyweight, and mass concrete (Reapproved 2009). American concrete institute.
33. ASTM (2009), ASTM C876: Standard test method for Half-Cell potentials of uncoated reinforcing steel in concrete. West Conshohocken. American society of testing and materials.
34. ASTM (2016), ASTM C125: Standard terminology relating to concrete and aggregates. West Conshohocken. American society of testing and materials.
35. Balaguru P., Naaman A. & Shah. (1977). Analysis and behavior of ferro-cement in flexure. V103, ST10. (pp. 1973-1951). ASCE
36. IFS Committees 10, 2001. "Ferro-cement model code". Building code recommendations for ferro-cement (IFS 10-01)
37. ACI Publication SP.61, 1979. "Ferro-cement -materials and applications". Pp. 1-195
38. ACI committee 549, 1980. "Guide for the design, construction and repair of ferro-cement". ACI Structural Journal, May. June. Pp. 325-351

**39.** Shah S.P. & W.H. 1972. "Impact resistance of ferro-cement". Journal of the structural division proceedings of the American society of civil engineering, January. Pp. 111-123

**40.** Al-Rifaie W.N. & Al-Lami M.S. "Structural behavior of ferro-cement exposed to oil". Journal of engineering and technology, University Of Technology, Vol. 19. No.2. 2000 Iraq

**41.** Al-Tayyib A. J. & Khan M. S. Concrete deterioration problems in the Arabian Gulf - a review, Durability of building materials, 4. 1987

**42.** Mansur M.A. 1996. "Durability of ferro-cement case study", Journal of ferro-cement Vol. 26. No. 1. pp. 11-19

**43.** Iorns M.E. 1987. "Prevention of ferro-cement corrosion", Proceedings of the international correspondence symposium. pp. 91-94. Bangkok: International information centre.

**44.** Wiebenga J.G. 1980. Durability of concrete structures along the North Sea coast of the Netherlands, in performance of concrete in marine environment, ASTM special publication SP-65, paper 24. Pp. 437-452

**45.** Guang Jing Xiong, 1996. "Influence of cover thickness in the behaviour of ferro-cement" Journal of ferro-cement Vol. 26 No.1. pp. 181-190

**46.** IASS JOURNAL Pier Luigi Nervi. Vol. 54, 2013. Pp. 2-3

**47.** Ahmed M. & Haque K. A. 1983. Pre-cast building components for costs saving, proceedings of the seminar on low cost housing (Construction and Materials). Housing and building research institute, Dhaka, pp. 59-79.

**48.** Anonymous, 1978. Ferro-cement water tank, do it yourself series, Booklet no.2. International ferro-cement information centre. Asian institute of technology, Bangkok, Thailand.

**49.** Ferro-cement structural applications. P. Paramasivam, Singapore: our world in concrete & structures, August 200. pp. 27 -28

**50.** Abdullah & Takiguchi, K. (2003). An investigation into the behavior and strength of reinforced concrete columns strengthened with Ferro-cement jackets. Cement and concrete composites. pp. 233–242.

**51.** ACI Committee 549-R97: State-of-the-art report on ferro-cement, ACI 549-R97, in manual of concrete practice. American concrete institute, Farmington Hills, Michigan 1997. pp. 26 pages.

**52.** Bulletin CP-10 (1968). Ferro-cement tanks and utility buildings. New Zealand Portland cements association, Wellington, pp. 5.

**53.** Collins J.F. & J.S. Claman "Ferro-cement for marine application and engineering evaluation," SNAME, New England section (March 1969).

**54.** Alexander, D.J. “Newer technique in the construction of pre-stressed concrete barges and pre-stressed Ferro-cement Vessels,” Journal of ferro-cement. Vol. 4, No. 6, 1975.

**55.** Raichverger, Z., and Tasta, E.Z., “Manufacturing technology of structural elements Made of Ferro-cement,” Journal of Ferro-cement. Vol 8, No. 4, 1978. pp. 259-266