International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 06 | June -2017 www.irjet.net p-ISSN: 2395-0072

A Review study of Application of Ferro-Cement

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Abstract – *Ferro cement is one the advancement that is happening in the field of civil engineering. It has low self-weighted, and thus gives fewer loads on to the structures. In this paper, we have studied different properties of the Ferrocement like tensile behavior, cracking, compression, fire resistance and impact Resistance. Based on Tests performed, various applications and its benefits over normal cement will be identified.*

Key Words: Ferrocement, cement, tensile behaviour, Material, Sustainable Development.

1. INTRODUCTION

Reinforced concrete is the most widely used construction material in present age. Ferro-cement can be considered as the origin and the first application of reinforced concrete. Ferro-cement also called as Ferrocement was invented by a Frenchman, Joseph Louis in 1848. Basically at that time Joseph wanted to create urns, cisterns and planters without the expense of kiln firing. Ferro-cement relates to type of thin reinforced concrete consisting of large amount of small diameter wire meshes distributed uniformly throughout the cross section and cement mortar. Ferro-cement is a highly versatile form of reinforced concrete possessing unique qualities of serviceability and strength which cannot be matched with any other thin construction material. Though being the oldest and first of its kind use of Ferro-cement was limited and not widely accepted. One of the reasons it was not adopted widely was that the production technology which was available at that time (19th century) was not efficient to produce small diameter wires and meshes. There production was more expensive as compared to large diameter iron rods and thus a setback was created. During world war reinforced concrete was used to manufacture boats due to shortage of materials, particularly steel. As the amount (volume) of steel required in Ferro-cement is more as compared to reinforced concrete and as a result its use was completely forgotten. During 1940's a known Italian architect Luigi Nervi revived the original concept of Ferro-cement, he found out components of Ferro-cement produced material which have approximately homogeneous mechanical properties and high resistance to impact. And with time the durability and serviceability of Ferro-cement ascertained and finally started achieving acceptance.

2. COMPONENTS OF FERRO-CEMENT

Ferro-cement primarily consists of cement, sand, wire meshes and various admixtures. The main difference between reinforced concrete and Ferro-cement is the scale. Reinforced concrete uses larger size reinforcing bar as compared to wire/meshes in Ferro-cement. Reinforced concrete consists less volume of the metallic part as compared to that of the Ferro-cement. It does not contain large size aggregate as used in reinforced concrete only cement mortar is used. Sometimes depending on the requirement Ferro-cement may consists of large size bars along with wire mesh. The number of layers of wire mesh to be provided depends on the applications for which it is going to be used. Typical cross sections of Ferro-cement are shown in (fig. 1)

2.1 Mortar Composition

Portland cement is generally used in Ferro-cement. But the type of cement to be selected should depend on its application where to be used and in which environment to be used. The sand to cement ratio is usually in the range of 1 to 2.5 by weight. And water to cement ratio is in the range of 0.4 to 0.6 by weight. In order to enhance the properties of cement in wet and hardened state fly-ash, slag and silica fume should be used. These minerals will also act as fine filler material. Well graded sand from salt free source should be used. In order to make sand penetrate in the reinforcement mesh the maximum size of the sand particle should be one third of the opening of the mesh. I

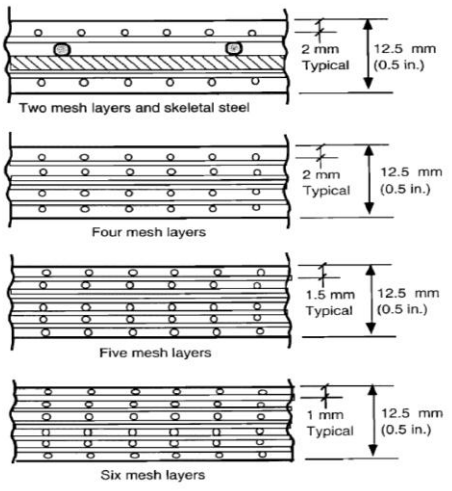


Fig. 1: Typical cross sections of Ferro-cement

2.2 Mess reinforcement

Ferro-cement along with mortar uses layers of small diameter wire mesh as reinforcement. The volume and the specific surface area of the reinforced wire are considerably higher for Ferro-cement as compared to that of normal reinforced concrete. Different types of wire meshes are available like woven or welded mesh, perforated sheet products and expanded metal lath. Even the shape of the wire mesh varies from square to hexagonal. All the meshes which are used as reinforcement in Ferro-cement are galvanized except expanded metal mesh. Mesh made from vegetable fibres and alkali resistant glass fibres are also used.

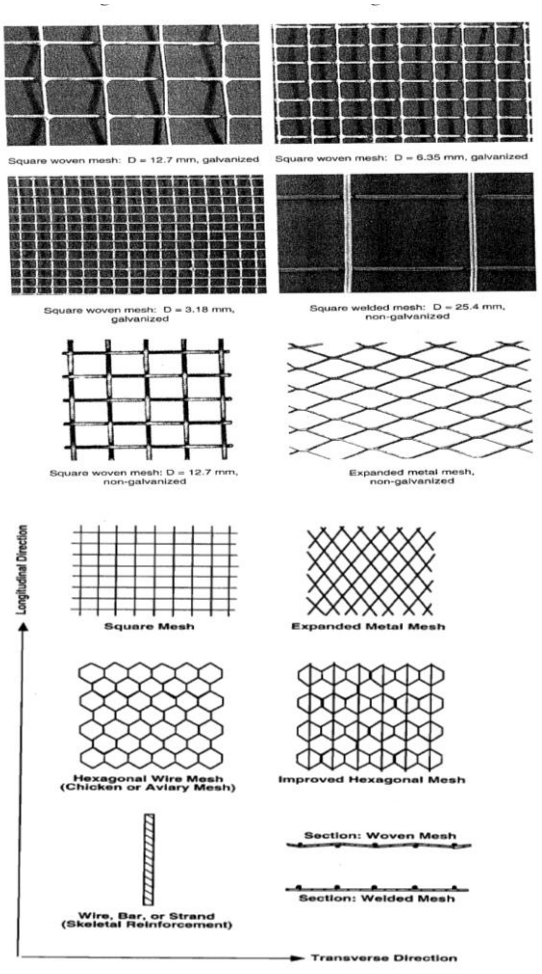


Fig 3: Typical steel meshes used in Ferro-cement

Wire Diameter	0.5 mm to 1.5mm
Type of Mesh	Woven, expanded metal, perforated sheet products, galvanized mesh
Shape of Mesh	Square, hexagonal
Number of Mesh Layers	Up-to 12 layers (1 layer per 2mm)
Mesh Openings Size	6mm to 25mm
Volume of Reinforcement	2 – 8 % of total volume

3. CONSTRUCTION METHODS OF FERRO-CEMENT

The constituent materials of the Ferro-cement are selected according to the use for which it is required. The sand to cement ratio usually varies between 1.5 to 2, the water to cement ratio should be between 0.35 to 0.6. The fineness of the sand particles to be used should depend on the reinforced cage to be encapsulated (opening of wire mesh).

3.1 MORTAR PLACEMENT

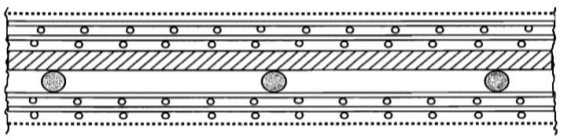
Mortar can be placed either by using hands or by using shot Crete technique. In both the process mortar is forced trough the mesh. Another technique called as "Lay-Out Technique" can also be used. The main difference between the later and the former technique is that in later mesh is placed in mortar instead of mortar in mesh. Successive layer of mesh are placed on freshly placed mortar layer. Major advantage of this technique is that each layer is placed under visual control and thus it can be ensured that no voids or any gaps are left behind in the matrix.

3.2 CONSTRUCTION PROCEDURE

While producing Ferro-cement it must be ensured that proper encapsulation of multiple layers of wire mesh reinforcement is made with the mortar. The mortar used should be sufficiently compacted which ensures minimum air voids present in the matrix. Construction process of Ferro-cement can be carried out by three methods namely:

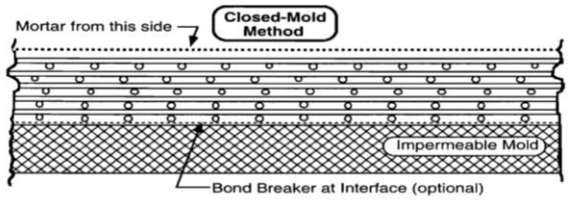
- Armature system
- Closed mould systems
- Integrated mould systems

Skeletal armature systems: In this method layers of wire meshes are tied on either side around the skeleton steel which is welded to get the desired shape. Mortar is then applied preferably from one side and forcing it to penetrate through the wire mesh openings of many layers till the time slight excess quantity of mortar appears on the other side. After that the excess mortar is pressed back and the remaining quantity is struck off. The skeletal steel is placed in both the directions. They are not considered as structural reinforcement, they just add to the dead weight of structure. Skeletal steel act as spacers rods to the wire mesh reinforcement.

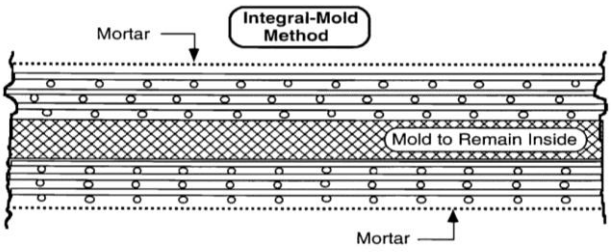


Closed mould systems: In this method of construction of Ferro-cement layers of wire mesh are tied together against the surface of the mould. These moulds hold the wire mesh in position while mortar is being filled from one side. The mould may remain in the position as permanent part of the

structure or it can be removed for future use. If the mould has to be removed then proper pre-treatment has to be done before laying the mesh layers. For the lay-out technique this method of construction is adopted.

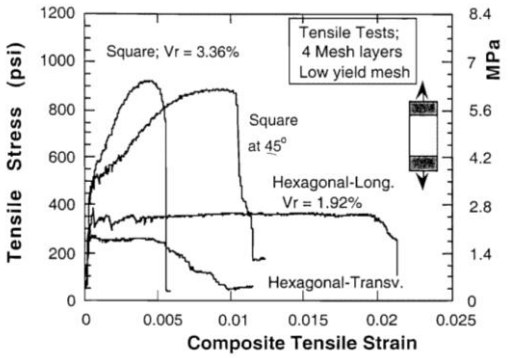


Integral mould systems: As the name implies in this method the mould used becomes integral part of the Ferro-cement. A semi-rigid framework with some minimum layer of wire mesh or by using rigid foam insulation material such as polystyrene or polyurethane can act as the integral mould. After the placing of the mould wire meshes are fixed from both the sides and mortar is applied.



4. PROPERTIES OF FERRO-CEMENT

Ferro-cement is an extremely thin reinforced member versatile material with depth of around 25mm but the properties which it has got it has with respect to material behaviour and its suitability for structural application is quite unique. Compared to other form of concrete construction Ferro-cement possesses greater degree of toughness, durability, strength& crack resistance.



4.1 Tensile Behaviour

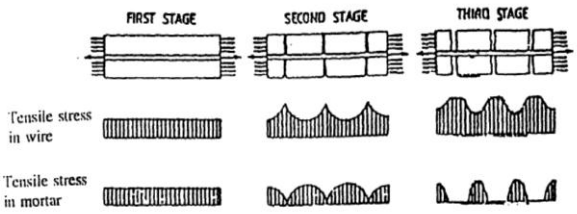
Tensile strength (behaviour) of Ferro-cement is depended on wire mesh system which it has. Tensile strength of Ferro-cement varies depending upon number of layers of wire mesh, spacing between the mesh, shape of the wire mesh, orientation of wire mesh in it. Tensile behaviour of Ferro-cement is entirely different as compared to that off normal reinforced concrete, specific surface area of reinforcement is larger as small diameter bars (wires) which are distributed uniformly. Tensile strength of Ferro-cement is limited to the tensile strength of reinforcement taken alone the direction of loading as mortar layer above itself has very less tensile strength. Tensile strength in Ferro-cement is of same order as that of compressive strength in it.

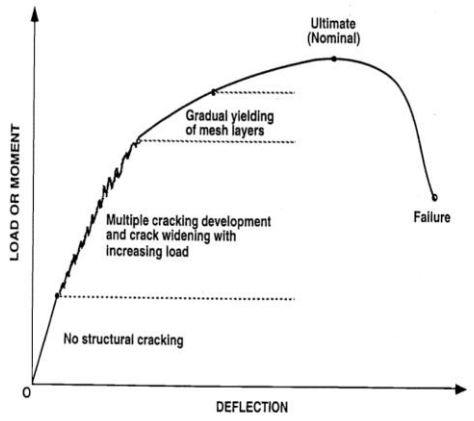
Depending upon the orientation of the wire mesh tensile strength of the Ferro-cement varies. Square mess at 0° or 90° is equally efficient, while the efficiency of square meshes in tension get reduced upto 50% if the wires are arranged at 45° to the loading axis. Meshes with smaller opening decreases the size of the cracks formed and thus indirectly helps out in obtaining high strength concrete. The tensile strength of Ferro-cement is directly depended on the volume of reinforcement present in it. More the reinforcement (wire meshes) higher is the tensile strength. Transverse reinforcement helps in increasing tensile strength and safety of structure.

4.2 CRACKING

Crack formation in Ferro-cement depends upon the type of matrix wire interfacial bond. First cracking is one of the important parameter on which the cracking pattern of ferro-cement depends on. First cracking can be subjective and it depends upon how the cracks are viewed through microscope or through naked eyes. The first crack width may range anything between 0.005 mm to 0.1 mm depending upon how they are noticed (viewed). First cracking basically means the first deviation which occurs in the load deflection curve of the Ferro-cement material. The first cracking strength required to develop crack depends upon the specific surface of reinforcement. It increases with increase in specific surface area of reinforcement.

The Ferro-cement composites first behave as linear elastic until the first crack is appeared. After the first crack appears the multiple cracking stage starts, number of cracks starts to form but the crack width remain constant and propagates in the direction where the matrix starts to fail. Now the reinforcement starts to yield and will continue till fatigue failure occurs, during this number of cracks formed are few but the width of cracks already formed starts increasing.

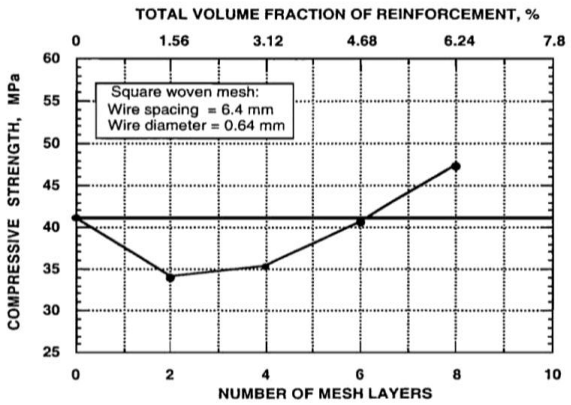




The crack developed in Ferro-cement also depends upon the thickness of mortar layer, orientation of wire mesh. The crack width usually increases with increase in the mortar covering. Wire mesh at 0° to the load applied has lesser cracking compared to wire mesh at any other orientation.

4.3 COMPRESSION

The compression characteristics of the Ferro-cement is mainly due to high compressive strength of cement mortar, though reinforcement also contribute in bit of compression strength to Ferro-cement but majority of it is provided by mortar. But with the increase in the number of layers of wire mesh (volume of reinforcement) the compressive strength increases. Compressive strength ranges from 30 Mpa to 70 Mpa for typical Ferro-cement products.



The loss (reduction) of compression strength in Ferro-cement is mainly due to buckling of wire mesh reinforcement and delamination (splitting of laminate in layers). This affects can be minimized by tying the reinforcements in different layers across the depth of the element which creates kind of tri-axial confinement. Type of wire used also affects the compressive strength of the Ferro-cement; welded wire mesh provides higher strength as compared to that off expanded or hexagonal mesh. Up-to 50-60% of the ultimate compression strength Ferro-cement behaves linearly, the behaviour becomes non-linear beyond this limit.

4.4 DURABILITY

The durability of any material depends upon the type of environment under which it is placed/used. Successful performance of any material depends upon its durability as than that of it strength properties. The durability issues related with Ferro-cement are quite similar to those of reinforced concrete like permeability, corrosion, external causes from outside which can be in any form physical, chemical or mechanical and due to internal causes like differential temperature, alkali aggregate reaction and so on. The most important property (constituent) which determines the durability of Ferro-cement in any kind of environment is the cement mortar used. More impervious the mortar layer is, the Ferro-cement is more durable. The measures required to be applied in reinforced concrete to insure its durability should also be applied to Ferro-cement. But Ferro-cement being a thin reinforced structure there are certain unique factors which affects it durability properties.

 The cover in Ferro-cement is abnormally low and thus it is relatively easy for the corrosive agents to reach the reinforcement.

 Ferro-cement consists of greater volume of small diameters wire mesh as compared to reinforced concrete. The specific surface area of the wire mesh is unusually high and thus providing large area of contact on which corrosion can take place hence potentially increasing the rate of corrosion in it.

 Most of the reinforcing meshes used in Ferro-cement are galvanized to prevent corrosion but the zinc coating can have some adverse effects from gas bubble formation.

In order to reduce the corrosion risk in Ferro-cement and make it more durable the mortar which is used should have low water to cement ratio. Porosity and permeability of the mortar should be reduced. Proper compaction of the mortar should be carried out. And use of mineral additives and admixtures in Ferro-cement should be made. Depending on the condition coating layer should be applied.

4.5 LIQUID RETAINING CAPACITY

Ferro-cement has got wide application in retaining water like in liquid storage tanks. Leakage starts in the tank made up of Ferro-cement after the first cracking has occurred. The leakage increases in the cracked reinforcement as average crack width increases and with decrease in the wall thickness. With increase in the volume or specific surface area of the wire mesh theleakage decreases as the crack width and number of cracks formed decreases. The crack widths formed in Ferro-cement are much smaller in size as compared to those formed in normal reinforced concrete as a result of it the leakage occurring in Ferro-cement is comparatively less.

4.6 FIRE RESISTANCE

Fire resistance can be defined as the ability of structural elements to resist fire. Fire severity, materials of the element, geometry etc are the factors on which resistance of concrete elements depend on. Based on various studies carried on Ferro-cement by different researchers on its fire resistance capability different results were obtained. Most of the scholars agreed on that by providing a Ferro-cement jacket on reinforced structures there resistance to fire increased. This property of Ferro-cement was due to its specific heat capacity which was slightly higher than those of concrete cover and thus it can absorb more heat as compared to that of concrete cover. Structure members are weakened when exposed to high temperatures causing the structures to collapse. It was found from the studies that by using thin layer of Ferro-cement as jacketing to the reinforced members the surface spalling reduced due to reinforcing wire mesh. Increase in wire mesh content in Ferro-cement significantly improved flexural and toughness under normal conditions, after fire exposure the wire mesh content had no longer significance on the two mechanical properties. Moreover, by increasing the wire mesh content the insulation property becomes poorer which is basically due to decrease in specific heat capacity of Ferro-cement. On the other hand increasing the mortar covering resulted in improved insulation performance. Ferro-cement behaviour under fire is still in its formative years more number of experiments is needed to be carried out before concluding properties of Ferro-cement relating resistance to fire.

4.7 Impact resistance

Amount of energy absorbed during impact loading is referred as resistance from impact. Due to its higher ability of absorbing impact energy Ferro-cement is very adequate to resist the impact as compared to that of conventional reinforced concrete. The reason for high impact energy of Ferro-cement is due to high specific surface area and large volume reinforcement in it. With addition of fly-ash and silica fume to the matrix energy absorbing capacity due to impact increases. Thickness of Ferro-cement also affects the impact resistance. Impact damage is generally localised and occurs at the point of contact. Spalling of internal mortar layer and delamination of the mesh layers may occur due to the impact. Punching failure may occur in Ferro-cement having high impact energy due to highly reinforcement with wire mesh.

5. ADVANTAGES OF USING FERRO-CEMENT

- Easy availability of constituents required for Ferro-cement.
- Cost effective
- Ferro-cement can be fabricated in any desired shape
- Durable and resistant to the environment
- Application in wide range of construction techniques
- Low level technology and unskilled labour
- Reduction in use of formwork\
- Reduction in self-weight
- Flexibility in cutting, jointing & drilling
- Cost effective
- Repairs usually easy and inexpensive
- Watertight
- Endearing insulation
- Fire resistance
- Joint less structure

6. DISADVANTAGES OF FERRO-CEMENT

- Risk of corrosion if the mortar in the initial stage is not compacted properly leaving behind air voids which can act as pool of water and cause corrsosion of the wire mesh.
- Labour intensive
- Structure made out of Ferro-cement can be punctured by forceful collision with pointed objects.
- Fastening not possible

7. APPLICATION OF FERRO-CEMENT

Ferro-cement has got wide range of applications in construction industry. Due to its extreme versatile nature and easy availability of the constituent materials. It can be constructed with minimum of skilled labour and very less machineries. Some of the applications of Ferro-cement are listed below:

- Tanks, containers & silos
- Floors & Roofs
- Floor tiles
- Manhole covers
- Ferro-cement building
- Ferro-cement ducts
- Rehabilitation of structures
- Rural applications
- Marine applications
- Fire resistant structures

- Soil stabilisation
- Pipes
- Bridges
- Foot Bridge
- Strengthening of RCC structure
- Pre-cast Ferro-cement structure

7.1 BOAT-BUILDING

Construction of Ferro-cement boats has been found attractive because it can be fabricated into any shape and traditional designs could be reproduced and often improved, besides being more durable and cheaper than wooden boats. Ferro-cement is preferred for boat construction as it has got high impact resistance. Use of Ferro-cement in boat building was one of its first applications.

7.2 RESERVOIRS

Ferro-cement can be used for the storage of water or other liquid as it is strong, durable & water-tight. Leakage in such type of tank is very less as compared to that or normal reinforced concrete structure.

7.3 FOOD STORAGE FACILITIES

The problem of food storage in the developing countries is emerging as amajor subject of attention from technical assistance organizations. Advantage of Ferro-cement in building food-storage facilities indeveloping countries is its adaptability to an almost unlimited range of curvedshapes and local conditions. Ferro-cement silos require little maintenance,and they offer protection against rodents, birds, insects, water, and weather.

7.4 REPAIR & CONFINEMENT OF RCC STRUCTURES

Cracking and spalling are some of the major reasons for the deterioration of RCC structures. With time the cracks get deepen and peeling of concrete starts. A good repair improves the function and performance of structures, restore and increase its strength and stiffness, enhances the appearance of the concrete surface, provides water tightness and prevents ingress of the aggressive species to the steel surface durability. Ferro-cement can be used for repair purpose of deteriorated RCC structures. Use of Ferro-cement can increase the strength up to 30% and along with that it prevents formation of cracks. Confinement of Ferro-cement around defective columns can enhance the strength, ductility and energy absorption capacity of the existing structure. This confinement work also protects the existing reinforcement, provides water tightness and prevents ingress of the aggressive species to the surface of original concrete or steel surface.

Ferro-cement has got wide range of applications due to its extremely versatile behaviour. Selection of Ferro-cement for some work should be done only after carrying out proper analysis and considering all the different criteria's available.

Moreover Ferro-cement should not been seen as competitor to RCC or complement to it. The labour intensive nature of conventional Ferro-cement has been detrimental to its use in developed countries. This is one of the reasons why Ferro-cement is overlooked by architects & engineers. Study on use of reinforced plastic meshes and high performance cementious matrices are carried out with the help of which improved structural performance at low cost can be obtained in future.

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