

# Analytical Research on Ferrocement : Design, Strength and Servicability Aspects

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## ABSTRACT

Ferrocement or Ferro-concrete is a system of reinforced mortar or plaster applied over layers of metal. It consists of closely spaced, multiple layers of mesh or fine rods completely embedded in cement mortar. It has a wide range of uses including sculpture and prefabricated building components. Ferro concrete is relatively a new material and has good strength and resistance to impact. When used in house construction in developing countries, it provided better resistance to fire, earthquake, and corrosion than traditional materials such as wood, adobe and stone masonry. Depending on the quality of construction and the climate of its location, houses may pay for themselves with almost zero maintenance and lower insurance requirements. The main objective of this research is to investigate the possibility of using ferrocement concrete in different types of advanced construction. The current work presents the comparison between the performance of ferrocement and reinforced concrete under static load.

**Keywords:** Ferrocement, Mortar Matrix, Mesh Reinforcement, RCC, Servicability, Durability.

## I. INTRODUCTION

Ferrocement is principally the same as reinforced concrete (RCC), but has the following differences:

- Its thickness rarely exceeds 25 mm, while RCC components are seldom less than 100 mm.
- A rich Portland cement mortar is used, without any coarse aggregate as in RCC.
- Compared with RCC, ferrocement has a greater percentage of reinforcement, comprising closely spaced small diameter wires and wire mesh, distributed uniformly throughout the cross-section.
- Its tensile-strength-to-weight ratio is higher than RCC, and its cracking behavior superior.
- Ferrocement can be constructed without formwork for almost any shape.

Ferrocement is quite a new material, which was first used in France, in the middle of the 19th century, for the construction of a rowing boat. Its use in building construction began in the middle of the 20th century in Italy. Although its application in a large number of fields has rapidly increased all over the world, the state-of-the-

art of Ferrocement is still in its infancy, as its long-term performance is still not known.

There are basically three types of methods of Ferrocement construction:

1. Armature System
2. Closed Mould System
3. Integrated Mould System

*Armature system:* In this method the skeleton steel is welded to the desired shape on either of sides of which are tied several layers of stretched meshes. This is strong enough, so that mortar can be filled in by pressing for one side and temporarily supporting from the other side. Filling in of mortar can also be administered by pressing in the mortar from both the sides. In this method the skeletal steel (bars) are at centre of the section and as such they add to the dead weight of without any contribution to strength.

*Closed mould systems:* Several layers of meshes are tied together against the surface of the mould which holds them in position while mortar is being filled in. The mould may be removed after curing or may remain in position as a permanent part of a finished structure. If

the mould is to be removed for reuse, releasing agent must be used.

*Integrated mould system:* Using minimum reinforcement any integral mould is first to be considered to act as a framework. On this mould layers of meshes are fixed on either side and plastering is done onto them from both sides. As the name suggests, the mould remains permanently as an integral part of the finished structure (E.g. double T-sections for flooring, roofing etc.). Precaution should be taken to have firm connection between the mould and the layers filled in later, so that finished product as a whole integral structural unit.

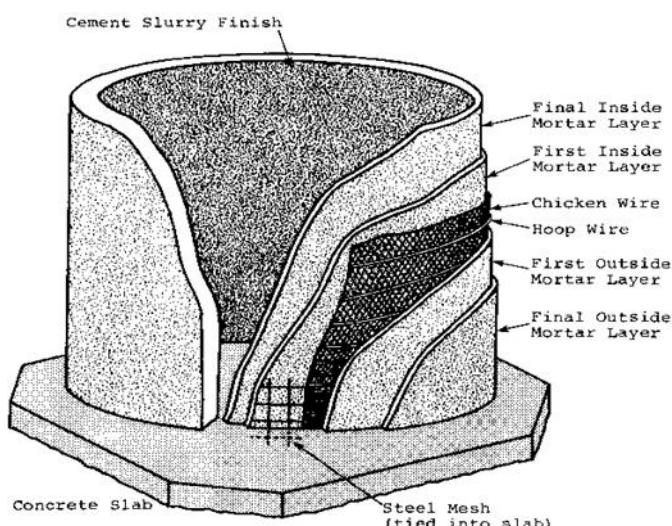


Figure 1: Detailed View of Ferrocement Construction

## II. METHODS AND MATERIAL

### A. Constituent Materials of Ferrocement

- Cement
- Fine Aggregate
- Water
- Admixture
- Mortar Mix
- Reinforcing mesh
- Skeletal Steel
- Jointing compounds
- Admixtures

#### Mortar Composition

- The essential ingredient of the mortar which represents about 95 % of ferrocement is Portland

cement, sand, water, and in some cases an admixture.

- Most locally available, standard cement types are suitable, but should be fresh, of uniform consistency and without lumps or foreign matter. Special cement types are needed for special uses, eg sulphate-resistant cement in structures exposed to sulphates (as in seawater).
- Only clean, inert sand should be used, which is free from organic matter and deleterious substances, and relatively free from silt and clay. Particle sizes should not exceed 2 mm and uniform grading is desirable to obtain a high-density workable mix. Lightweight sands (eg volcanic ash, pumice, inert alkali-resistant plastics) can also be used, if high strengths are not required.
- Fresh drinking water is the most suitable. It should be free from organic matter, oil, chlorides, acids and other impurities. Seawater should not be used.
- Admixtures can be used for water reduction, thus increasing strength and reducing permeability (by adding so-called "super plasticizers"); for waterproofing; for increased durability (eg by adding up to 30 % fly ash); or for reduced reaction between mortar and galvanized reinforcements (by adding chromium trioxide in quantities of about 300 parts per million by weight of mortar).

#### Mix Proportioning

The recommended mix proportions are: sand/cement ratio of 1.5 to 2.5, and water/cement ratio of 0.35 to 0.5, all quantities determined by weight. For water tightness (as in water or liquid-retaining structures) the water/cement ratio should not exceed 0.4. The moisture content of the aggregate shall be considered in the calculation of required water. Quantities of materials shall preferably be determined by weight.

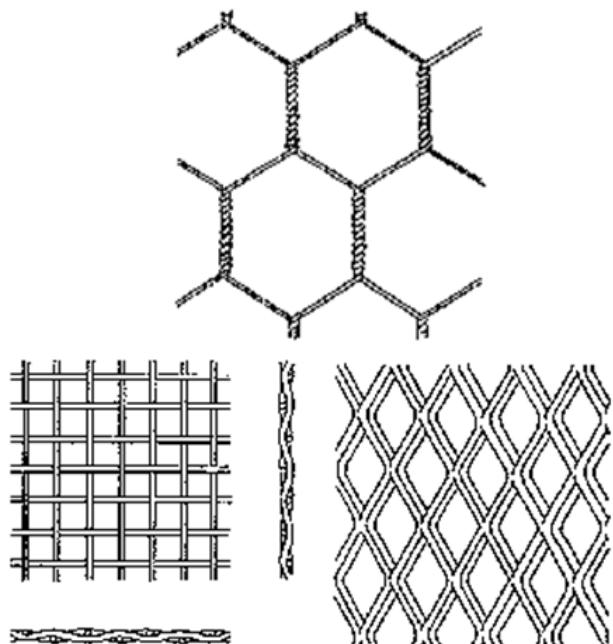
The mix shall be as stiff as possible, provided it does not prevent full penetration of the mesh. Normally the slump of fresh mortar shall not exceed 50 mm. For most applications, the 28 day compressive strength of 75 by 150 mm moist cured cylinders shall not be less than 35 N/mm<sup>2</sup>.

## *Reinforcement Details*

- The reinforcing mesh (with mesh openings of 6 to 25 mm) may be of different kinds, the main requirement being flexibility. It should be clean and free from dust, grease, paint, loose rust and other substances.
- Galvanizing, like welding, reduces the tensile strength, and the zinc coating may react with the alkaline environment to produce hydrogen bubbles on the mesh. This can be prevented by adding chromium trioxide to the mortar.
- The volume of reinforcement is between 4 and 8 % in both directions, ie between 300 and 600 kg/m<sup>3</sup>; the corresponding specific surface of reinforcement ranges between 2 and 4 cm<sup>2</sup>/cm<sup>3</sup> in both directions.
- Hexagonal wire mesh, commonly called chicken wire mesh, is the cheapest and easiest to use, and available almost everywhere. It is very flexible and can be used in very thin sections, but is not structurally as efficient as meshes with square openings, because the wires are not oriented in the principal (maximum) stress directions.
- Square welded wire mesh is much stiffer than chicken wire mesh and provides increased resistance to cracking. However, inadequate welding produces weak spots.
- Square woven wire mesh has similar characteristics as welded mesh, but is a little more flexible and easy to work with than welded mesh. Most designers recommend square woven mesh of 1 mm (19 gauge) or 1.6 mm (16 gauges) diameter wires spaced 13 mm (0.5 in) apart.
- Expanded metal lath, which is formed by slitting thin gauge sheets and expanding them in the direction perpendicular to the slits, has about the same strength as welded mesh, but is stiffer and hence provides better impact resistance and better crack control. It cannot be used to make components with sharp curves.
- Skeletal steel, which generally supports the wire mesh and determines the shape of the ferrocement structure, can be smooth or deformed wires of diameters as small as possible (generally not more than 5 mm) in order to maintain a homogenous reinforcement structure (without differential stresses). Alternatively, skeletal frameworks with

timber or bamboo have been used, but with limited success.

- Fibers, in the form of short steel wires or other fibrous materials, can be added to the mortar mix to control cracking and increase the impact resistance.



**Figure 2:** Types of Steel Reinforcement used in Ferrocement

## *Mechanical Properties of Ferrocement*

The mechanics of ferrocement is very complex because of the almost infinite variety of size, geometry, fabrication methods, orientation, yield and ultimate stress of the steel wire mesh reinforcement available. The specific surface area of the wire mesh appears to correlate well with the first crack strength, spacing and number of cracks.

The tensile, flexural and compressive strengths depend on the orientation of the mesh, technique of fabricating the mesh and its ultimate strength. It appears that the conventional methods of analysis for reinforced concrete can be used to calculate the flexural strength of ferrocement. Ferrocement has superior impact properties, but its fatigue strength may limit the high allowable stresses to which it could be subjected. Our everyday experience is that big bulky things are stronger than thin things. Ferrocement is a special material called ‘thin membrane’ that is quite strong despite being thin. It's

strong under both stress and strain, because it is both strong and thin in nature, many things can be constructed at low cost.

Making of ferrocement articles uses more manpower than machines. This makes it especially suitable for India where manpower is relatively cheap. However, for long life, certain precautions must be taken during ferrocement construction.

#### *Strength Requirements of Ferrocement*

Ferrocement structures and structural members shall have design strength at all sections at least equal to the required strengths for the factored load and load combinations. Design strength provided by a member or cross-section in terms of axial load, bending moment, shear force, or stress shall be taken as the nominal strength calculated multiplied by the strength reduction factor  $\phi$  to satisfy the general relationship.

$$U \leq \Phi n$$

Where  $U$  is the factored load equal to the minimum required design strength,  $N$  is the nominal resistance, and  $\phi$  is a strength reduction factor.

Design strength for the mesh reinforcement shall be based on the yield strength  $f_y$  of the reinforcement but shall not exceed 690 N/mm<sup>2</sup>. Design yield strengths of various mesh reinforcement are shown in Table 1. These shall be used for design only when test data are not available.

**Table 1:** Minimum Values of Yield Strength and Effective Modulus for Steel Meshes and Bars Recommended for Design

		Woven Square Mesh	Welded Square Mesh	Hexagonal Mesh	Expanded Metal Mesh	Longitudinal Bars
Yield Strength	$f_y$ N/mm <sup>2</sup>	450	450	310	310	410
Effective Modulus	( $E_r$ ) <sub>Long</sub> N/mm <sup>2</sup>	138000	200000	104000	138000	200000
	( $E_r$ ) <sub>Trans</sub> N/mm <sup>2</sup>	165000	200000	69000	69000	----

**Table 2:** Recommended Design Values of the Global Efficiency Factor of Reinforcement for Member in Uniaxial Tension or Bending

		Woven Square Mesh	Welded Square Mesh	Hexagonal Mesh	Expanded Metal Mesh	Longitudinal Bars
Global Efficiency Factor	Longitudinal	0.50	0.50	0.45	0.65	1.0
	Transverse	0.50	0.50	0.30	0.20	0
	At 45°	0.35	0.35	0.30	0.30	0.70

## B. Service Load Design

### *Flexure*

For investigation of stresses at service loads, straight line theory (for flexure) shall be used with the following assumptions:

- a) Strains vary linearly with distance from the neutral axis.
- b) Stress strain relationships of mortar (concrete) and reinforcement are linear for stresses less than or equal to permissible service load stresses.
- c) Mortar (concrete) resists no tension.
- d) Perfect bond exists between steel and mortar (concrete).

To compute stresses and strains for a given loading, the cracked transformed section can be used. The effective area of each layer of mesh reinforcement is determined. The value of modular ratio  $n_r = E_r/E_c$ , may be used for both tensile and compressive reinforcement. Once the neutral axis is determined, the analysis shall proceed as for reinforced concrete beams or columns having several layers of steel and subject to pure bending.

### *Allowable Tensile Stress*

The allowable tensile stress in the mesh reinforcement under service conditions shall be taken as 0.60  $f_y$  where  $f_y$  is the yield strength. For liquid retaining and sanitary structures, the allowable tensile stress shall be limited to 200 N/mm<sup>2</sup>. Consideration shall be given to increase the allowable tensile stresses if crack width measurements on a model test indicate that a higher stress will not impair performance.

### *Allowable Compressive Stress*

The allowable compressive stress in either the mortar (concrete) or the ferrocement composite shall be taken as where is the specified compressive strength of the

mortar. Measurements of the mortar compressive strength shall be obtained from tests on 75 mm x 150 mm cylinders.

### C. Serviceability Requirements

Ferro cement structures shall generally satisfy the intent of the serviceability requirements except for the concrete cover.

#### *Crack Width Limitations*

The maximum value of crack width under service load conditions shall be less than 0.10 mm for noncorrosive environments and 0.05 mm for corrosive environments and/or water retaining structures.

#### *Fatigue Stress Range*

For ferrocement structures to sustain a minimum fatigue life of two million cycles, the stress range in the reinforcement shall be limited to 200 N/mm<sup>2</sup>. A stress range of 350 N/mm<sup>2</sup> shall be used for one million cycles. Higher values may be considered if justified by tests.

#### *Corrosion Durability*

Particular care shall be taken to ensure a durable mortar matrix and optimize the parameters that reduce the risk of corrosion.

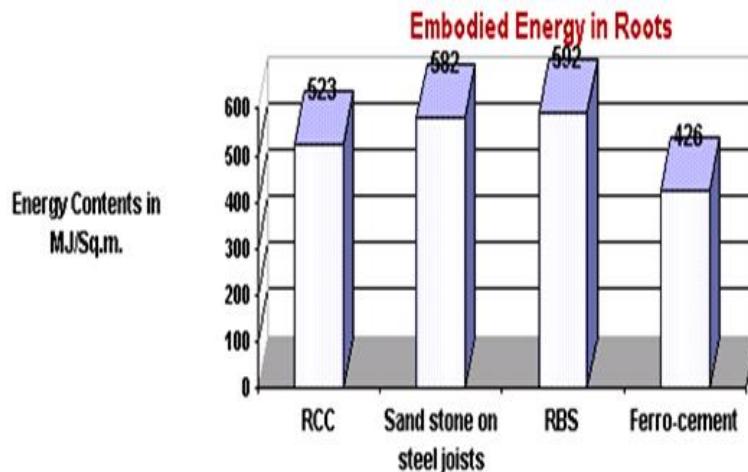
#### *Deflection Limitation*

Since ferrocement in very thin sections is very flexible and its design is very likely to be controlled by criteria other than deflection, so no particular deflection limitation is recommended for it.

## III. RESULTS AND DISCUSSION

**Table 3:** Comparative Analysis of Ferrocement and other Building Materials [4]

Parameters	Reinforced Cement Concrete (RCC)	Stones	Reinforced Brick Cement (RBC)	Ferrocement
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
Cost range (Rs.) for 1 M span	450-600	400-500	400-550	375-450



**Figure 3:** Comparison of Embodied Energy of Different Building Materials

#### *Limitations*

- Structures made of it can be punctured by collision with pointed objects.
- Corrosion of the reinforcing materials due to the incomplete coverage of metal by mortar.
- It is difficult to fasten to Ferrocement with bolts, screws, welding and nail etc.
- Large no of labors required.
- Cost of semi-skilled and unskilled labors is high.
- Tying rods and mesh together is especially tedious and time consuming.

#### *Applications of Ferrocement*

- Tanks, containers and silos
- Floors and roofs
- Waterproofing
- Manhole covers
- Anticorrosive membrane treatment
- Rehabilitation of structures
- Chemical resistant treatment
- Fire resistant structures
- Marine applications



**Figure 4:** Ferrocement used in curved structures



**Figure 5:** Ferrocement used in making boats



**Figure 6:** Ferrocement used in sewage pipes

## IV. CONCLUSIONS AND FUTURE SCOPE

The goal of the current research is studying the feasibility of ferrocement concrete in design and construction of structures. This study has brought out that ferrocement construction is an innovative and advanced technique, its readily available materials and ease of construction make it suitable in developing countries for housing, water and food storage structures. Ferrocement is found to be a suitable material for repairing or reshaping the defective RCC structural

elements and enhancing its performance. The applications of ferrocement are capturing almost all the fields of civil engineering but there is a dearth of research backing and a rational design base to construction of ferrocement structure. Nowadays there is great improvement in ferrocement construction techniques. Ferrocement structures have advantage over the conventional materials like RCC steel, wood and plastic as these are durable, strong, waterproof and also competitive in price generally. The Quality of ferrocement works are better assured because the components are manufactured on machinery set up. Moreover, the execution time at work site is reduced, contributing least shutdown. Maintenance cost of ferrocement structures is almost negligible.

Considering its unique features, no doubt ferrocement will be one of the most important structural alternatives for RCC and a repair material in the future and thus has a great potential for developing and developed countries alike.

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