Structural Applications of Ferro-cement

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Abstract

Ferrocement is ideally suitable for structures with thin wall as the uniform dispersion and distribution of reinforcement, better cracking control provided, impact resistance and ductility, better tensile strength-to-weight ratio. By applying available mechanised manufacturing methods and correct choice of reinforcements it can be cost competitive in developed countries. Research and development works of ferrocement, at many countries done, has resulted in several applications such as roofs, sunscreens, secondary roofing slabs, water tanks, biogas digesters, repair and strengthening members in the building industries. The notable features of the materials, application and performance of some of these ferrocement structural applications are explained in this report.

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FERROCEMENT

1-INTRODUCTION

1.1- DEFINITION

Ferrocement is another type of reinforced concrete which is different from ordinary reinforced or pre-stressed concrete principally by the style in which the reinforcing elements are dispersed and arranged. It consists of closely, multiple spaced layers of fine rods or mesh completely submerged in cement mortar or concrete. It can be formed into thin sections or panels, generally less than 25mm (1 in.) thick, with only a thin mortar cover over the outermost layers of reinforcement. Finally, ferrocement can be defined as "*Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials.*" [1]

1.2- FERROCEMENT TRENDS

Wide use of ferrocement in the construction industry has developed during the last 25 years. The main uses of ferrocement construction in worldwide to date have been for mainly boats, silos, roofs and tanks. The construction of ferrocement can be divided into four steps:

1. Constructing the steel rods to form a framing system;
2. Covering rods with mesh to build the skeletal framing;
3. Plastering using cement mortar.
4. Curing.

Reminder that relatively low level technical skill labours are required for steps 1 and 3, though step 2 is very important. Therefore, skilled labour is required. This is a mark for industrially developed nations but an advantage for countries where unskilled labor is relatively plentiful. In developed countries where labour is relatively expensive. (as shown in Fig. 1.1)

Fig.1. 1Wire mesh covered by mortar using shotcreteing to form a shell.

1.3-HISTORY

The idea of submerging reinforcement into fresh concrete to form what we now recognize as reinforced concrete almost simultaneously to three persons. A French gardener Joseph Monier (1823-1906), merged a mesh of iron rods into large planting pots in 1849. Wilkinson, an Englishman, made reinforced concrete beams for buildings using old mining ropes in the tension zone of the beams. [2] And finally, J. L. Lambot made a concrete rowing boat in which the reinforcement was in the form of a network (or basket) of wires and interwoven thin rods. [3,4]. (as shown in Fig.1.2)

This was the birth of reinforced concrete, but subsequent development differed from Lambot's concept. The technology of the period could not provide accommodations the time and power needed to make reinforcement mesh of hundreds of wires. In its place, large rods were used to make that is now called normal reinforced concrete, and the concept of ferrocement was almost forgotten for about 100 years.

Reinforced concrete for building boats reappeared briefly during the First World War, when a lack of steel plates forced a search for other materials for building boat. [5] However, the conventional use of steel rods with large-diameter to reinforce the concrete required thick hulls, making the vessels less applicable to operate than lighter wood or steel ships.

Pier Luigi Nervi resurrected the original ferrocement concept in the beginning of 1940s when he saw that reinforced concrete with layers of wire mesh formed a material having the mechanical characteristics of an almost homogeneous material and capable of resisting effect impact. [6,7]

During the late 1960s and early 1970s, the importance of the technical and scientific community turned to the materials science of ferrocement as a productive field of study. Technical papers appeared in the speculation and literature about the use of ferrocement as a structural material began to increase. An important development was the founding of the “International Ferrocement Information Center” (IFIC) at the “Asian Institute of Technology”, Bangkok, Thailand, in October 1976. In association with the “New Zealand Ferro Cement Marine Association” (NZFCMA), the IFIC publishes a quarterly journal, “*The Journal of Ferrocement”*. Another publication, “*The International Journal of Cement Composites”*, later renamed “*Cement and Concrete Composites”*, regularly covers papers about ferrocement.

Fig.1. 2- This is a model of the ferrocement boat that Lambot built in 1856.

It is in the Museum of Brignoles in France.

1.4-COMPOSITION

1.4.1—General

Ferrocement contains a Portland cement mortar mixture, steel rods and wire mesh reinforcement, admixtures, and coatings. This chapter studies the properties of the basic materials and contains a short explanation of the construction procedure.

1.4.2—Matrix

The mortar matrix mainly used in ferrocement contains hydraulic cement and inert filler material. Portland cement is commonly used, sometimes mixed with a pozzolan. Usually the filler material is a well-graded sand passing a No. 8 (2.36 mm) sieve. However, depending on the characteristics of the reinforcing material (mesh opening, distribution, etc.), a mortar contains some small-size gravel.

The physical characteristics and microstructure of mortar matrix depend upon the chemical composition of the cement, the water-cement ratio, the nature of the sand, and the curing conditions of the completed structure. Then the matrix represents approximately 95 percent of the volume of ferrocement, its characteristics have a great effect on the final properties of the product. There are frequent references relating to detail of the effects of various mix of matrix proportion parameters on the properties and microstructure of hydraulic cement mortars. [8,9]

The use of portland cement in ferrocement matrix is considered to have some tensile strength. It gives the idea that composite action between the reinforcement and matrix the is more noticeable in ferrocement than in ordinary reinforced concrete with steel bars. The use of various types of fibers will also have an effect on the tensile properties of the producing matrix. The used water should be clean and somewhat free from organic matter. Water-cement ratios in ferrocement matrix changes between 0.30 and 0.55, by weight. In general, a workable mix will totally penetrate and embed the wire mesh reinforcement and will have satisfactory amounts of porosity and shrinkage. Admixtures may be used to reduce water-cement ratio and improve mix plasticity

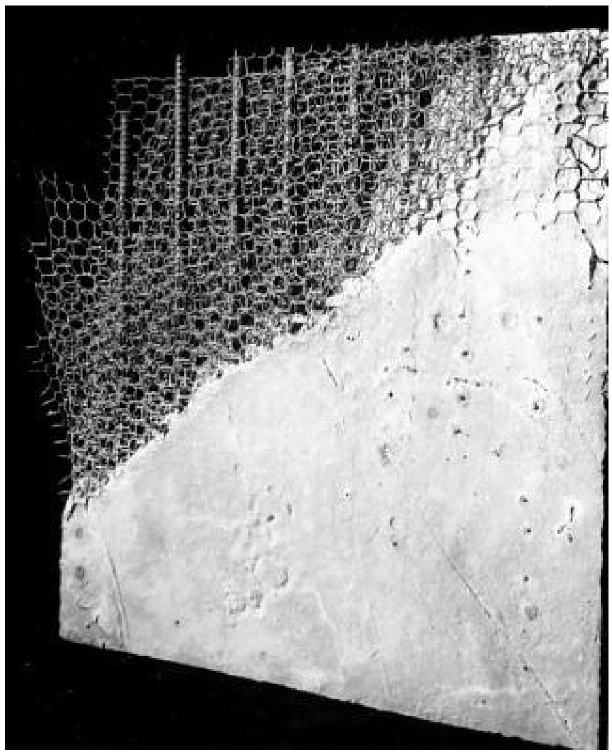


Fig.1. 3—A typical ferrocement section.

1.4.3—Reinforcement

Commonly layers of continuous mesh made from single strand filaments used as a reinforcement for ferrocement. Specific mesh types as woven or interlocking mesh (like chicken wire mesh), woven cloth mesh in which filaments are interwoven and their connections are not tightly connected, welded mesh in which a rectangular arrangement is formed by intersecting wires perpendicularly welded together at their joints, two other shapes of mesh reinforcement are in use as expanded metal lath produced by slitting thin gage steel plates and stretching them in perpendicular direction to the slits [10,11]. Several examples of welded and woven wire mesh are shown in (Fig. 1.4 to Fig. 1.9).

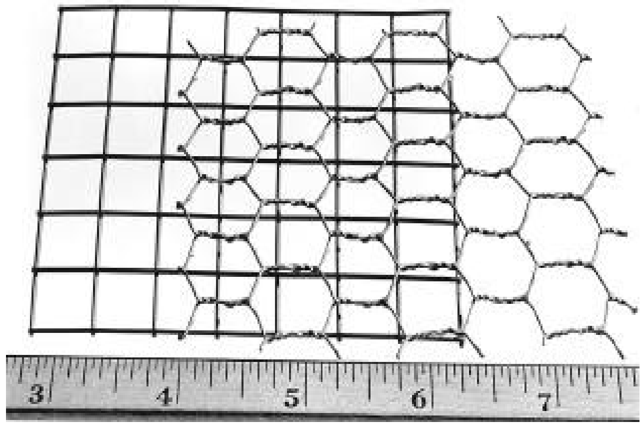


Fig.1. 4—Types of reinforcing mesh commonly used for ferrocement.

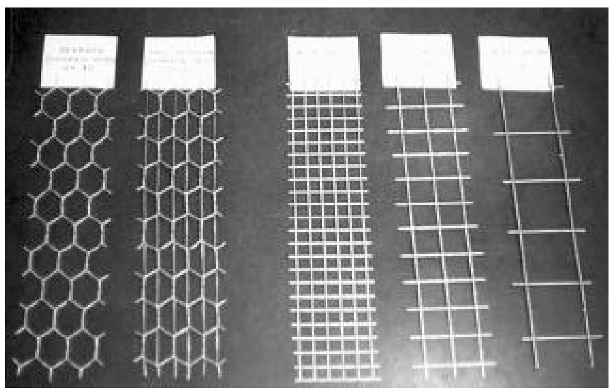


Fig.1. 5—Samples of hexagonal and welded wire mesh

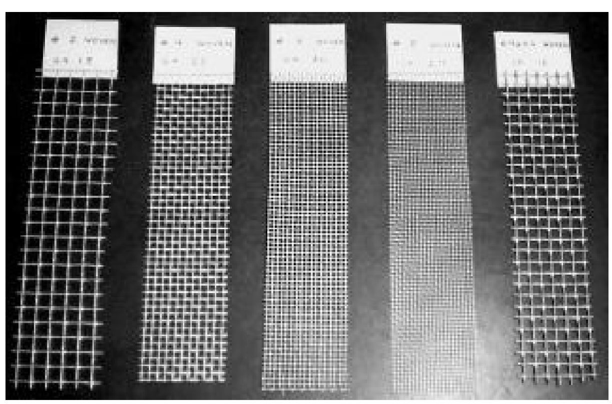


Fig.1. 6—Samples of woven wire mesh

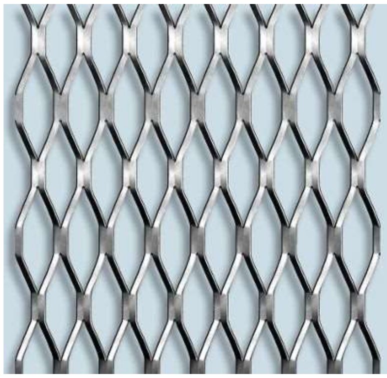


Fig.1. 7—Samples of expanded metal wire mesh

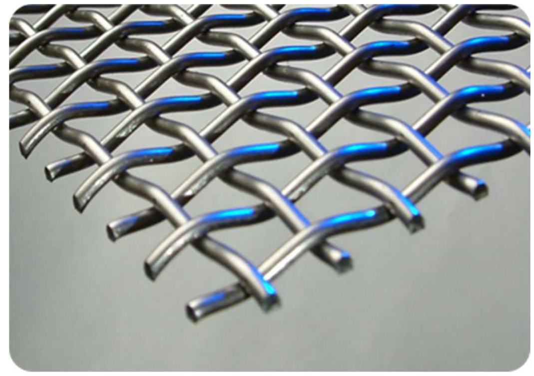


Fig.1. 8 —Samples of woven wire mesh

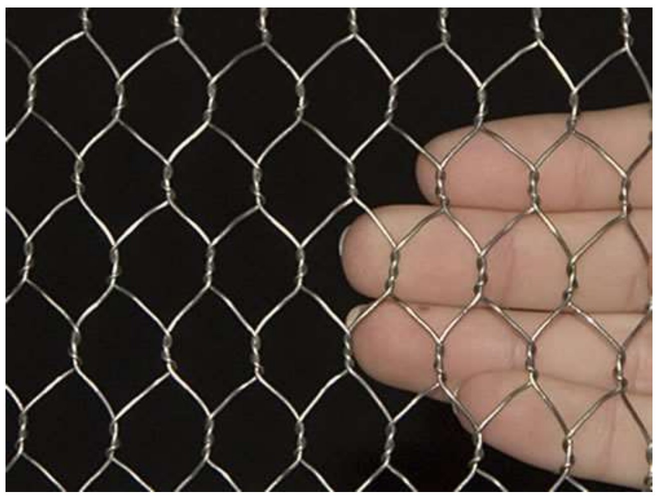


Fig.1. 9—Samples of checken wire mesh.

Table.1.1—Table of chicken wire mesh .

stainless Steel Chicken Wire Netting					
mesh			Min. Gal.v. G/SQ.M	Width	Wire Gauge (Diameter) BWG
Inch	mm	Tolerance(mm)			
3/8"	10mm	±1.0	0.7mm - 145	2' - 1M	27, 26, 25, 24, 23
1/2"	13mm	±1.5	0.7mm - 95	2' - 2M	25, 24, 23, 22, 21
5/8"	16mm	±2.0	0.7mm - 70	2' - 2M	27, 26, 25, 24, 23, 22
3/4"	20mm	±3.0	0.7mm - 55	2' - 2M	25, 24, 23, 22, 21, 20, 19
1"	25mm	±3.0	0.9mm - 55	1' - 2M	25, 24, 23, 22, 21, 20, 19, 18
1-1/4"	31mm	±4.0	0.9mm - 40	1' - 2M	23, 22, 21, 20, 19, 18
1-1/2"	40mm	±5.0	1.0mm - 45	1' - 2M	23, 22, 21, 20, 19, 18
2"	50mm	±6.0	1.2mm - 40	1' - 2M	23, 22, 21, 20, 19, 18
2-1/2"	65mm	±7.0	1.0mm - 30	1' - 2M	21, 20, 19, 18
3"	75mm	±8.0	1.4mm - 30	2' - 2M	20, 19, 18, 17
4"	100mm	±8.0	1.6mm - 30	2' - 2M	19, 18, 17, 16

1.4.4—Admixtures

Ferrocement may need chemical additives for reduction of the reaction between the galvanized reinforcement and matrix while addition to the frequent admixtures normally used in the producing ferrocement and normal reinforced concrete. Adding chromium trioxide to the mix water has been reported to be useful in this regard. [12,13] Solution concentration recommendation depends upon the water-cement ratio used.

1.4.5—Matrix mix proportions

Mix mortar for ferrocement proportioned as:

1- Sand-cement ratio (1.4 to 2.5) by weight.

2- Water-cement ratio (0.30 to 0.5) by weight.

Minimum water should be used to consist compactibility. This is normally reached by using a rounded well-graded, natural sand with a maximum size about one-third of the smallest opening in the reinforced ferrocement to ensure appropriate penetration. A sand passing a No. 16 (1.16 mm) sieve has given acceptable results in many applied applications

1.4.6—Coatings

Many coating types and suitable surface treatments available for use with normal concrete and reinforced concrete installations, can be applied to ferrocement. These include treatment by polymer, and the use of latex, acrylic, and cement-based coatings. They are applied to control surface deterioration, reduce porosity, or provide a particular functional surface of a design. [1]

2 - APPLICATIONS OF FERROCEMENT

2.1—Boats

Ferrocement boats have been built in almost every country of the world. Some knowledge of the extent of ferrocement boat manufacture is given in [14], which lists the countries of the Asian-Pacific region for boat construction. Ferrocement boats have been introduced on a large scale only in the Republic of China. In other countries, ferrocement occupies a fraction of a percent of the total ferrocement boat-building market.

Ferrocement boat construction has been found gorgeous for many countries developed industrially because:

1- Availability of its basic raw materials in most countries.
2- It's fabrication into nearly any shape traditional and design can be improved or reproduced.
3- It is durability more than most woods and economically better than imported steel.
4- Construction of ferrocement skill labours can be learned easily.
5- Ferrocement erection is more labor-intensive and less capital-intensive.
6- Except for highly stressed designs like those in deep-water vessels, a qualified supervisor can complete the necessary amount of quality control using fairly unskilled labour [1]. (as shown in Fig.2.1 and Fig.2.2).

Fig.2. 1— A ferrocement house boat designed by (Ricky's Ferrocement Barge Co.) in Guernsey 2013 (under construction) .

Fig.2. 2— A ferrocement boat designed by (Ricky's Ferrocement Barge Co.) in Guernsey 2013 (completed).

2.2—Silos

Less enough storage facilities for grains in most developed countries and villages was a real case that solved by constructing silos. It has been reported that up to 25 percent of rice is lost to birds, rodents, fungi, and insects in Thailand. [15] Ferrocement silos with capacity of storing up to 30 tons of grain appear quite economical and suitable for developing nations. Ferrocement offers appropriate sealants with low permeability and can be manufactured airtight. In an airtight ferrocement box, micro-organisms cannot subsist to harm the stored product. [15] (as showen in Fig 2.3 and Fig.2.4)

Fig.2. 4 —Ferrocement silos in India (under construction

Fig.2. 3 —Ferrocement silos in India

2.3—Tanks:

The previous remarks regarding the need in developing countries for grain storage apply equally to the storage of drinking water. Thus, the use of ferrocement is also being used in developing nations for constructing water tanks. [16,17]

Financed by the "International Development Research Centre of Canada", two model water tanks with cylindrical shape were designed, built, and tested to be used in the rural areas Philippines for the collection of rain- water. [18] (Fig. 2.5) Several hundred tanks, made with ferrocement which have been in use for the past several years, have been built on a self-help basis in many regions in the Philippines. An elevated ferrocement water tank with capacity 46 m^3 (12,500 gal) capacity was productively constructed In Bangladesh in 1989. It includes some unique design structures, well-suited with the local circumstances, that simplified the construction process and also resulted in considerable economy.

A study found that ferrocement tanks to be less costly than fiberglass or steel tanks. This study includes the design detail, methods of construction, and detailed drawings for the ferrocement tanks are given in the final report submitted by the "Science Museum of Virginia" to the "U. S. Energy, Research and Development Administration". These conclusions are based on the study:

1. For the construction of water storage tanks for keeping energy collected by a solar system, ferrocement is an economically probable material.
2. Ferrocement is flexibile in shape, possibility of hot storage, no corrosion occurs, relatively less maintenance required, it has a ductile failure mode. These are significant advantages of ferrocement against other materials usually used for low to medium pressure [up to 345 kPa (50 psi)] storage of fluids.
3. Less energy required for production of ferrocement tanks than steel tanks. [1]

(show Fig.2.5 and Fig.2.6).

Fig.2. 5 – Ferrocement tanks for rain water collection

Fig.2. 6 —Rain-water ferrocement tank in India

2.4—Roofs

Economical materials for building roofs are necessary for industrially developing countries especially for single family dwellings. For building floors and walls of a residence house local materials can be used. However, in past manufacturing roofs with local materials to be economic, durable, resistant to fire, insects, flood, and earthquakes have not been actually successful. As a result, many developing nations constructed using galvanized iron sheets or asbestos cement sheets. These two materials used for roofing may cost as much as 60 percent of the total price of a house. [19]. Ferrocement develops to be an economic alternative material for roofing. (Show Fig.2.7 to Fig.2.9).

Ferrocement roof can be used as a precast product which is easy to install or it can also be fabricated in situ in villages. In Italy large ferrocement roofs have been constructed. A recent design and construction of six ferrocement shells for a roof to shelter animals is described in [20]. The roofs have a span of 17 m (56 ft) and a thickness of 30 mm (1.2 in.). The performance of other geometrical shapes for use as roofs has also been investigated at the "National University of Singapore". [1] Note that since the dead load produces a critical stress in the design of roofs.

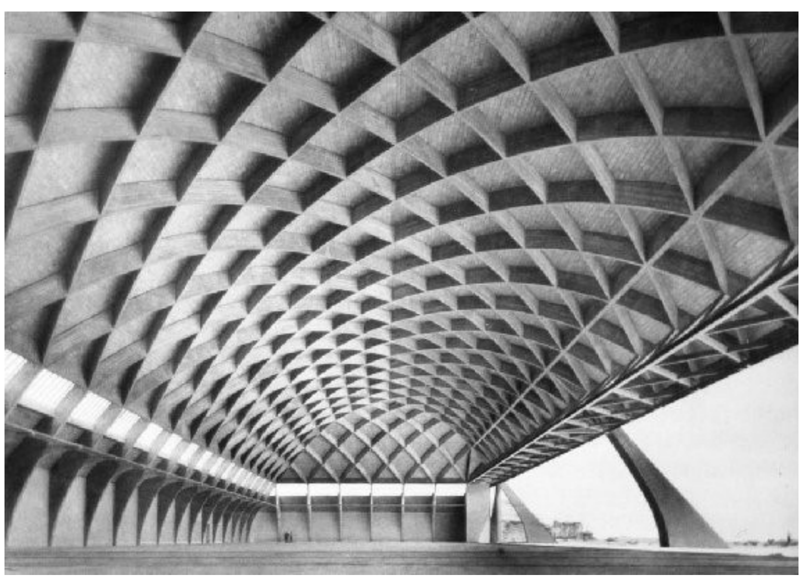


Fig.2. 7 -Turin Exhibition Hall in Metropolitan City of Turin, Italy by Architect Pier Luigi Nervi (1950).

Fig.2. 8 - Precast ferrocement panels for roofing.

Fig.2. 9- Conical ferrocement roof

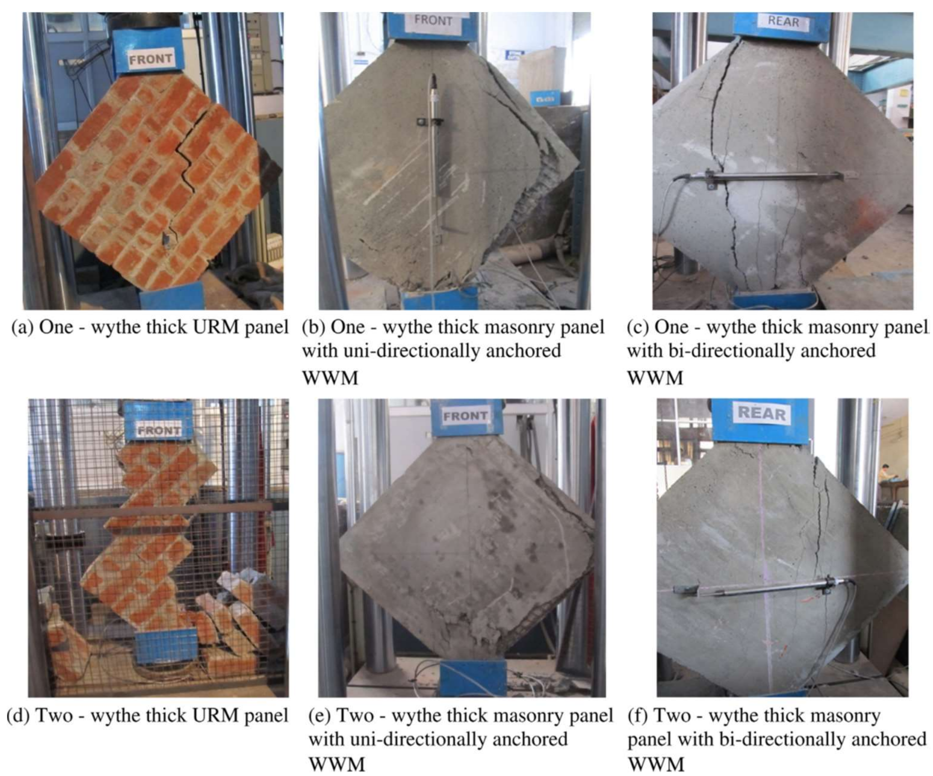
2.5 – Ferrocement for strengthening

Most commonly used building materials is unreinforced masonry (URM) in many developing countries. Most URM buildings are built with no consideration or little for effect of seismic loading, and these are not capable of resisting the expected seismic actions. The major part of the loss of human lives and property during past earthquakes, has been attributed to poorly built URM buildings. In spite of important developments in earthquake engineering during the past years, the URM buildings continue to be the major cause of economic and human losses during earthquakes, as observed during Bhuj (2001), Kashmir (2005) and Ankara (2007) earthquakes. During earthquake, the masonry walls are subjected to both in-plane as well as out-of-plane action. URM walls are very weak in out-of- plane bending action due to extremely low tensile strength of the mortar-brick interface and resist the lateral load primary in in-plane action [21]. Ferrocement can be used for strengthening URM walls which is known as (bandages and splints, respectively). (as shown in Fig.2.10 to Fig.2.12)

Fig.2. 10 - Strengthening using ferrocement in India

(a) Construction of URM wallette
(b) Wrapping of WWM over first layer of rich cement-sand (1:4) plaster
(c) Micro-concreting of URM panel
(d) Finished strengthened masonry wallette

Fig.2. 11- Strengthening using ferrocement



(a) One - wythe thick URM panel
(b) One - wythe thick masonry panel with uni-directionally anchored WWM
(c) One - wythe thick masonry panel with bi-directionally anchored WWM
(d) Two - wythe thick URM panel
(e) Two - wythe thick masonry panel with uni-directionally anchored WWM
(f) Two - wythe thick masonry panel with bi-directionally anchored WWM

Fig.2. 12- Testing specimens of strengthened URM with ferrocement

2.6 - Biogas digesters

Biogas is an energy source can be renewed with several types of production ways and various brilliant chances to use. Biogas refers to a production of gas by anaerobic digestion (AD) or fermentation of organic material including sewage manure, sludge, municipal solid waste, energy crops, biodegradable waste, or other biodegradable feedstock. Biogas application have a long history. Evidence submits that biogas was used from 3000 years ago for heating water for bath in Assyria. Marco Polo reported that, the earliest Chinese literature indications covered sewage tanks built to produce biogas some 2000–3000 years ago. The biogas technology production returns to a long time. In the seventeenth century, Jan Baptita Van Helmont first found out that flammable gases could improve from decompose organic matter. In 1776, Count Alessandro Volta proposed that there was a direct relation between the quantity of flammable gas generated and the quantity of putrefying organic matter. In 1808, Sir Humphry Davy developed that methane occurs in the gases generated during the AD of cow's droppings. In 1859, the first sewage plant was built in modern times in Bombay.

Biogas plants constructed with ferrocement can be applied either as an earth-pit lining or self-supporting shell. Typically, cylindrical vessel is acceptable. Very small plants (Volume less than $6m^3$) can be manufactured. As in the case of a plant with fixed-dome, the ferrocement gas-holder needs special sealing measures. Convenient models of family type biogas plants must be selected on the source of preference of the beneficiaries and bearing in mind technical requirements, such as distance between the kitchen and cattle shed, location, Water availability and raw materials like dung, kitchen, sanitary, loose and leafy biomass, and other biomass wastes [22]. (as shown in Fig.2.13 to Fig.2.16).

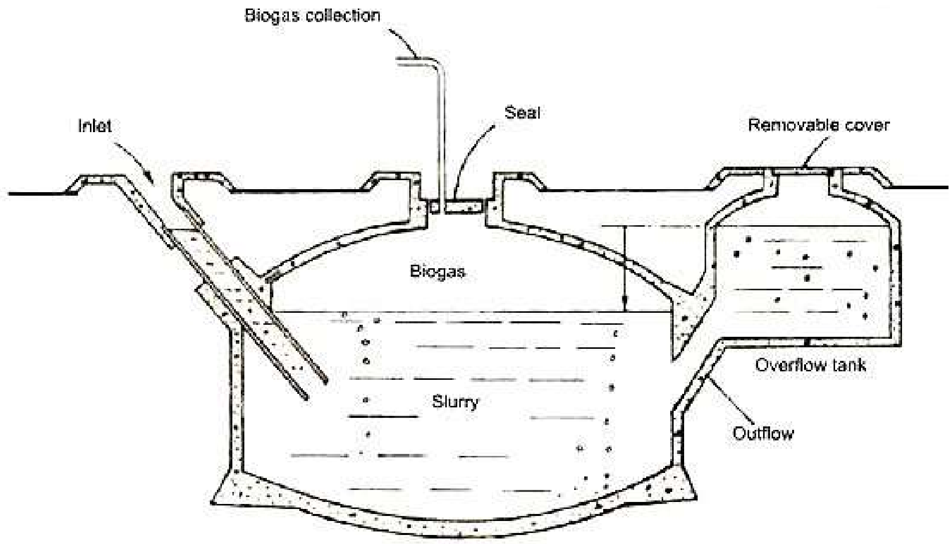


Fig.2. 13 -Section detail of biogas plant

Fig.2. 14 -Ferro-cement biogas plants (Construction of a biogas plant in Mirpurkhas Sindh Pakistan 2012)

Fig.2. 15 - Ferrocement biogas digesters comlpeted

Fig.2. 16 - Ferrocement biogas digesters under construction

2.7 - Small deck bridges

This type of small bridges constructed in gardens especially over water passages. Paul Spooner is a mechanical engineer and an artist, he lives in the state of California. Spooner built a small deck bridge in his parent's garden with dimensions approximately (150*75) cm, (as shown in Fig.2.17 to Fig.2.20)

Fig.2. 17 -Spooner's deck bridge (steel bars with chicken wires).

Fig.2. 18 -Spooner's deck bridge (while plastering).

Fig.2. 19 -Spooner's deck bridge (covered with cement mortar).

Fig.2. 20 -Spooner's deck bridge (completed).

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