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Structural Applications of Ferrocement for Water Harvesting Concrete

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ABSTRACT
This study Examines the possibility of solving problem based on the effect of using different numbers of wire mesh layers on the flexural strength of the flat ferrocement panels and to compare the effects of varying on the ductility and the ultimate strength of ferrocement structures, with common problems such as poor flexural strength, poor load bearing capacity, doubt of durability, brittle failure when a break point occurs due to exceeding and physical cohesion of the ferrocement materials. The assignment on the application of ferrocement was done in order to solve problems of construction challengers such as high costs of construction difficulties and materials in the society. The study also provided other option for the design of different structural elements such as Beams, Slabs, etc in structural design.
Keywords: Structural Applications, Ferrocement, Water Harvesting

INTRODUCTION
The modern medium mostly used to make reinforced concrete in the world today is concrete and steel combined; similar applications are in high-rise buildings, roadways and highway bridges. Yet, the first known example of reinforced concrete was a ferrocement boat. Joseph-Louis Lambot's original French patents on wire-reinforced boats were invented in 1847 not long after the development of portland cement. (See Figures 1.1) This was the birth of reinforced concrete, but subsequent development differed from Lambot's concept. The technology of the period could not cater for the time and effort needed to make mesh of thousands of wires. Instead, large rods were used to make what is now referred to as standard reinforced concrete, and the concept of ferrocement was almost forgotten for a hundred years. Reinforced concrete evolved as the material familiar today in fairly massive structures for which formwork to hold the fresh concrete in the wide gaps between reinforcing rods and a fairly thick

cover over the rods nearest the surface are to be used.

Reinforced concrete for boat building was also used during the First World War, when a shortage of steel plates forced a search for other boatbuilding materials. The U.S. and U.K. governments, among others, commissioned ship builders to construct seagoing barges and concrete ships, some of which continued in use after the war. A similar occurrence took place in the United States during the Second World War. However, the frequent use of large-diameter steel rods to reinforce the concrete required thick hulls, making the vessels less practical to operate than lighter wood or steel ships.

Figure 1.1: Lambot's original ferrocement boat built in 1848 now rests in the Brignoles Museum in France. (Brignoles Museum, France)

Construction Techniques for Ferrocement Water Storage Tanks

Ferrocement water storage tanks have been found to be safe, economical and easy to construct and maintain even in very difficult remote areas. Various site and problem specific construction techniques have been developed by various R&D groups for making ferrocemnt tanks of small and medium capacities. This review presents few of these techniques. Three casting methods developed at SERC, Ghaziabad in India have become very popular among field engineers/contractors and are being used on large scale in actual field projects and the structures constructed are performing their functions for which they were designed very well.

The importance of storing drinking water in safe and hygienic structures is now being realized in a much better way in many countries. In India, the programme of providing safe drinking water to all rural citizens by the year 1991 has been taken up by the Department of Rural Development, Government of India under a National Technology Mission on Drinking Water. Besides finding and development of other water sources, it has been felt necessary to collect effectively and store the rain water at an appropriate season and utilize it judiciously so that the requirement of water,, Vi for drinking purpose, is met with in a sustained manner for a reasonable period. Quite large area of the country, such as North--*1-2S* Eastern hills, coastal belt and islands, plain areas of central and North India, normally get sufficient rain fall. The Mission has accorded a very high priority for taking up rain water harvesting schemes and ferrocement water storage tanks. In the process of collection and storage of rain water, the role of a safe and hygienic water storage reservoir/tank is very important. It holds the collected water in a hygienic environment for preventing its getting contaminated during storage. It also, forms a major component expenditure-wise for any rain water harvesting system.

Several types of reservoirs/tanks are in use for storing of water in various parts of the world. Tanks of various shapes are being adopted. Some of the popular shapes are, rectangular, cylindrical and spherical. Tanks are constructed using:

(1) Brick/ stone/R.C.C. block masonary

(2) Reinforced cement concrete (R.C.C)

(3) Steel/G.I. sheets

(4) Ferrocement

(5) Bamboo reinforced concrete

(6) Fibre reinforced plastic

(7) Composite construction using brick and R.C.C./ferrocement, and

(8) High density pothythelene.

Detailed studies carried out at various research organizations, experiences in field and long term behaviour studies on ferrocement tanks have established that F.C. tanks have an edge over the other alternatives. "Ferrocement is a construction material which is ideally suited for construction of water storage tanks due to its higher resistance against cracking, impact, shock and moisture migration. It can be moulded in any shape and does not require formwork" (as this is thus the main application of ferrocement in this project work). Structures made with ferrocement are thinner than that of R.C.C (reinforced concrete)., lighter in weight hence need lighter supporting structure. Ferrocement construction does not require any heavy plant or machinery or highly skilled labour as needed for fabrication of steel or R.C.C. structures (reinforced concrete structures). These do not get damaged with normal impact, shock loads or fire as in the case of masonry and plastic tanks.

These are economical in comparison with RCC, masonry, steel and plastic tanks. With Its advantages and easy availability of its constituent materials in most of the places, ferrocement is an ideal construction material for water storage tanks in rural and urban areas for large type of water supply and minor irrigation schemes. Tanks can be installed in underground, part underground and part above ground and overhead conditions.

In India, the Structural Engineering Research Centre, Ghaziabad has been a pioneer institution in the field of Research & Development on ferrocement. The Centre is one of the main institutions working on rain water harvesting system for the National Technology Mission in India. The Centre has done considerable work on development of ferrocement structures and many techniques, for production of ferrocement applications such as water tanks, storage bins, septic tanks, roofing units, wall panels irrigation channels, manhole covers, leak proofing treatment for masonry and RCC structures, biogas digesters, check dams have been developed.

Uses of Ferrocement

Ferrocement can be used as food-processing equipment
Ferrocement can also be used for Low-Cost Roofing
Ferrocement in Disaster Relief (i.e prevention of flooding e.t.c)
Ferrocement Training Facilities
Ferrocement used for Food-Storage Facilities
For manufacturing Indigenous Boats
Gas tanks (for liquid and natural gas)
Cooling towers
Sewage troughs, lagoons, septic tanks, and other treatment facilities

Ferrocement is a strong, versatile, light weight, durable building material which is simple in composition, requires almost no formwork, labour intensive with minimum skill and of low cost of construction. It is made from a wire reinforced mixture of sand, water, and cement which was first discovered in France by Jospeh Lambot in 1848 and patented by him in 1852. He is the first, who introduced applications of ferrocement in civil engineering field. A ferrocement structure is a much thinner and lighter structure and consists of closely, but uniformly distributed layers of wire meshes which provide greater tensile strength, flexibility and better crack resistance than ordinary concrete. It is effectively used in fabrication of boats, silos, water tanks, roofs, miscellaneous building components like sun – breakers, pergola, e.t.c

MATERIALS AND METHODOLOGY

Raw Materials and Preparation

In this chapter we will be considering the various methods of ferrocement application, the materials being used and how those materials will be applied. Ferrocement, also called reinforced concrete is also obtained by mixing cement with sand mortar and applying the mixture over some layers of woven or welded wire mesh with small diameter holes. Ferrocement is widely recognized because of the availability of its raw materials around the world. It is fire resistant and easy to shape and make.

Materials

The materials used are:
Ordinary Portland cement (OPC)
Wire mesh of small diameter holes
Binding wire (2 lenghts)
Water
Sand
Hand trowels
Steel rods (8 mm)
Paper

1. Cement

The cement for general construction is to be ordinary Portland cement of 43-grade conforming to IS: 9112-1989. It should be compatible with the admixture used.

2. Sand

Sand shall be obtained from reliable supplier. It should be clean, hard, strong, and free of organic impurities and deleterious substances. It should be inert with respect to other materials used and of suitable type with regards to strength, density, shrinkage and durability of the mortar made with it. Grading of the sand is to be such that a mortar of specified proportions is produced with a uniform distribution of the aggregate, which will have a high density and good workability of the aggregate, which will have a high density and good workability and which will work into position without segregation and without use of high water content. The grading of the sand shall be as given in Table 1.

Table 3.1: Desirable Sand Grading

I.S. Sieve	Percentage passing by weight
2.36 mm	100
1.18 mm	50 – 70
600 Micron	25 – 45
300 Micron	10 – 20
150 Micron	2 – 5

3. Water

Water used for making and curing shall be clean and free from injurious amounts of oil, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to mortar or steel. Potable water is generally considered satisfactory for making cement: sand mortar and its curing.

4. Reinforcing Mesh

One of the essential components of ferrocement is wire mesh. Different types of wire meshes are available almost everywhere. These meshes consist of thin wires, either woven or welded into a mesh, but the main requirement is that it must be easily handled and flexible enough to be bent around sharp corners. For the general construction 20 gauge 12 mm x 12 mm galvanized wire mesh may be used which comes into size of 1 x 30m roll.

PHASES OF CONSTRUCTION

The main application of ferrocement worked on is " the construction of a ferrocement rain water harvesting tank" accompanied with tests such as grain size analysis, compressive strength test, cylindrical test, split tensile test , Flexural test and water absorption test.

How to Construct a Ferrocement

Fig 3.1: Rain Water harvesting tank
Making a 5,000-liter tank: a typical ferrocement construction

Fig. 3.2: Making the reusable mold:

Fig. 3.3: Drawing the rebar patterns

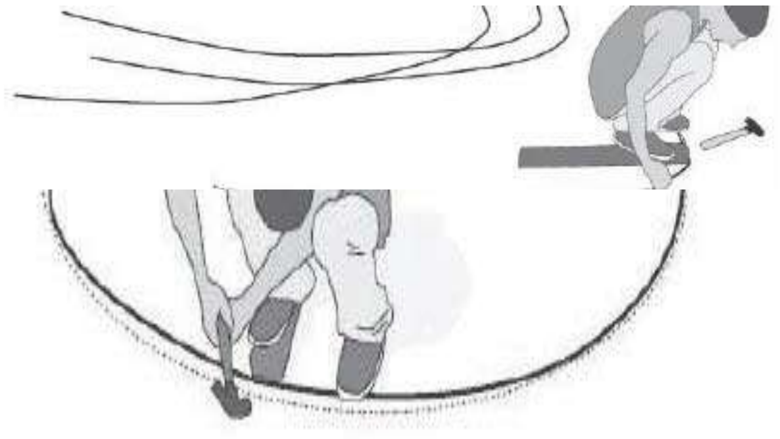


Fig. 3.4: Cutting and bending the Rebars for the molds

Fig 3.5: Welding the Rebars together to form the mold

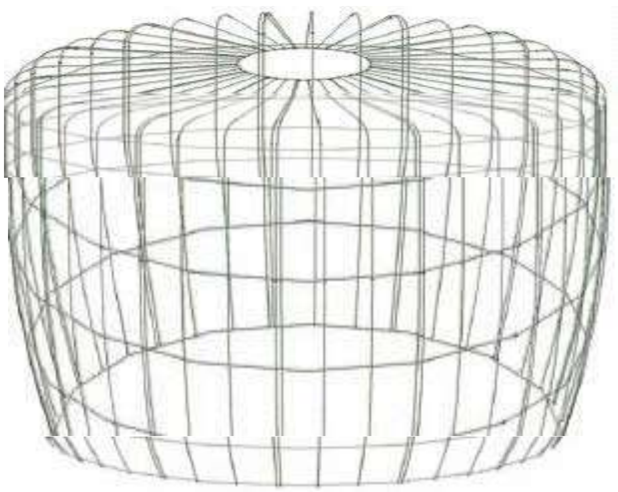
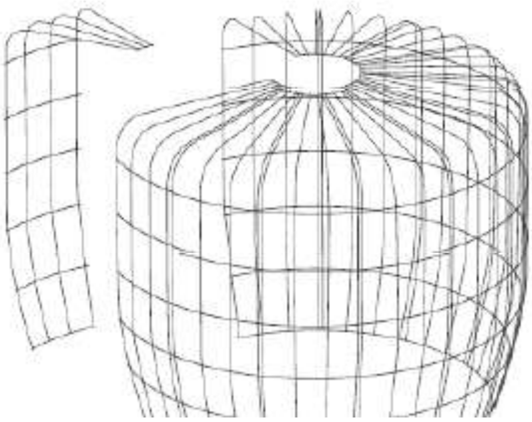


Fig. 3.6: Cutting the mold into panels



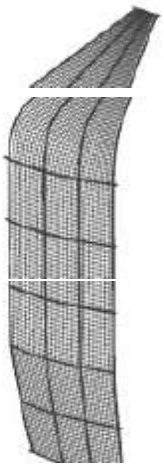
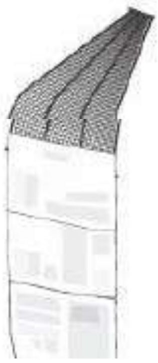


Fig 3.7: Cladding the panels with wire mesh

MAKING THE TANK (CONT'D): PREPARING THE MOLD FOR USE

Fig 3.8: Papering over the mold panels Fig 3.9.1: Assembling the panels together over the **Tank Base**.



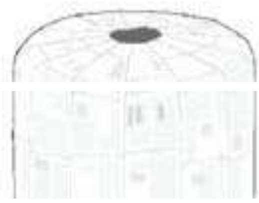


Fig3.9.2: Assembling the panels together

Making the Tank Base

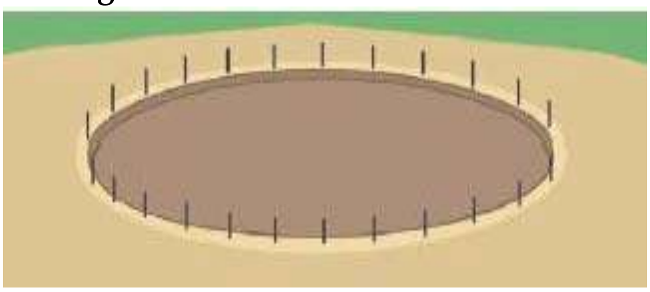


Fig 3.10: The ground is leveled and staked

Fig 3.11: Plain GI strips and rebar ring comprise the base mold; a base course of gravel is laid

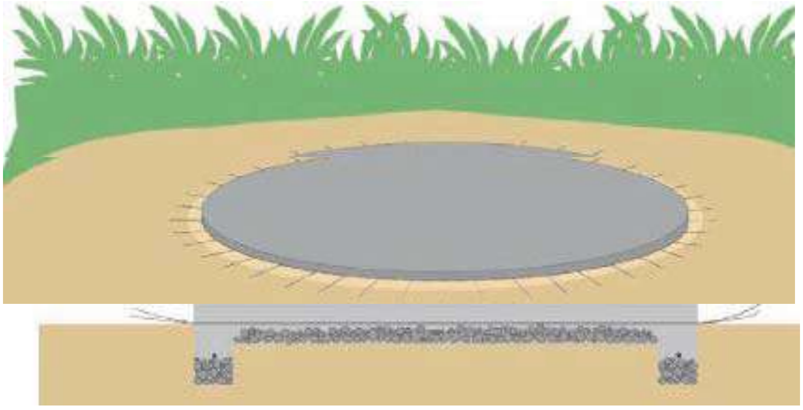


Fig 3.12.1 & 3.12.2: A reinforcing grid of tie wire is laid; concrete is troweled in

Constructing the Tank

Fig. 3.13: Winding some wire around the tank to hold the paper

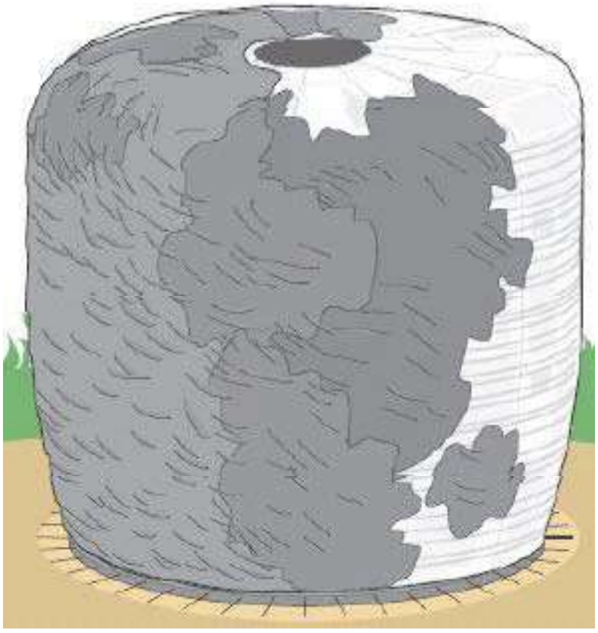


Fig. 3.14: One or two mortar coats


Fig. 3.15: Vertical wire reinforcement

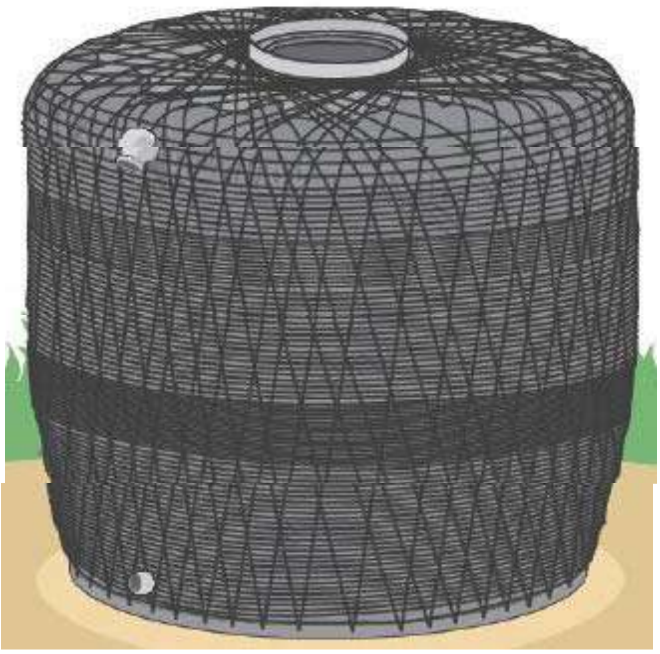
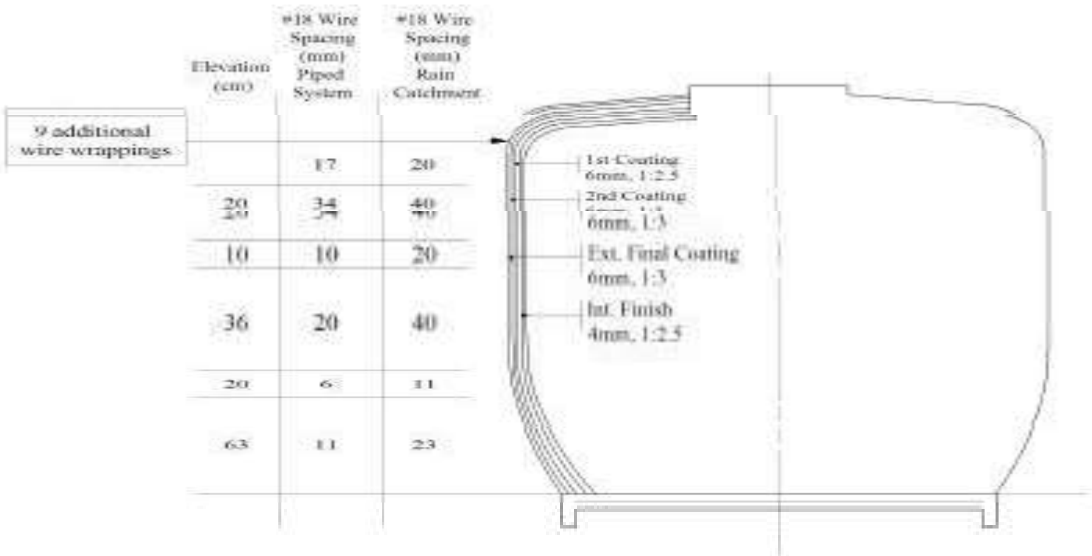


Fig. 3.16: Horizontal wire reinforcement to resist the water pressure

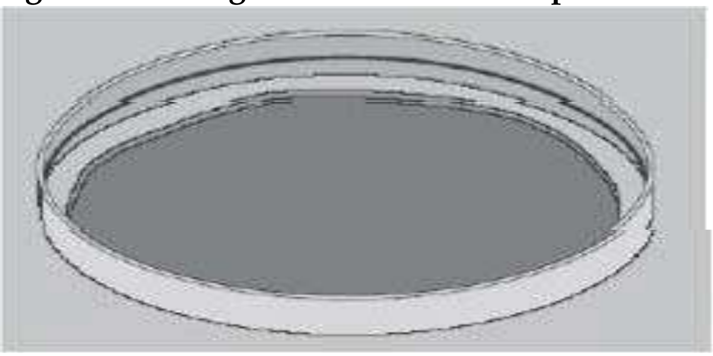
Constructing the Tank

Fig. 3.17: Wire positions and spacing



Example of horizontal wire spacing for a 5,000 liter tank

Fig. 3.18: Making the Tank (cont'd): Lip Construction Details



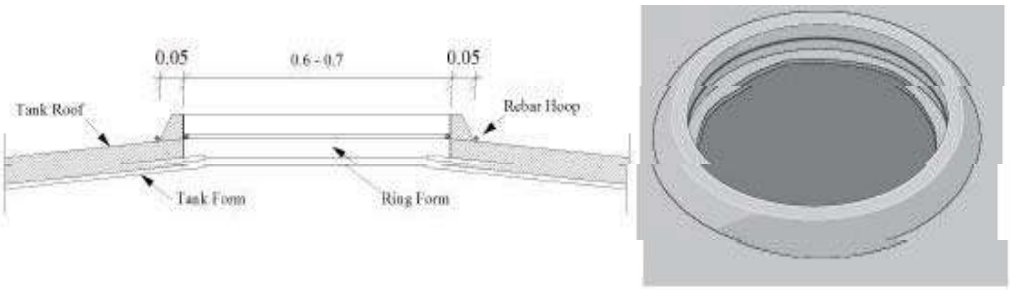
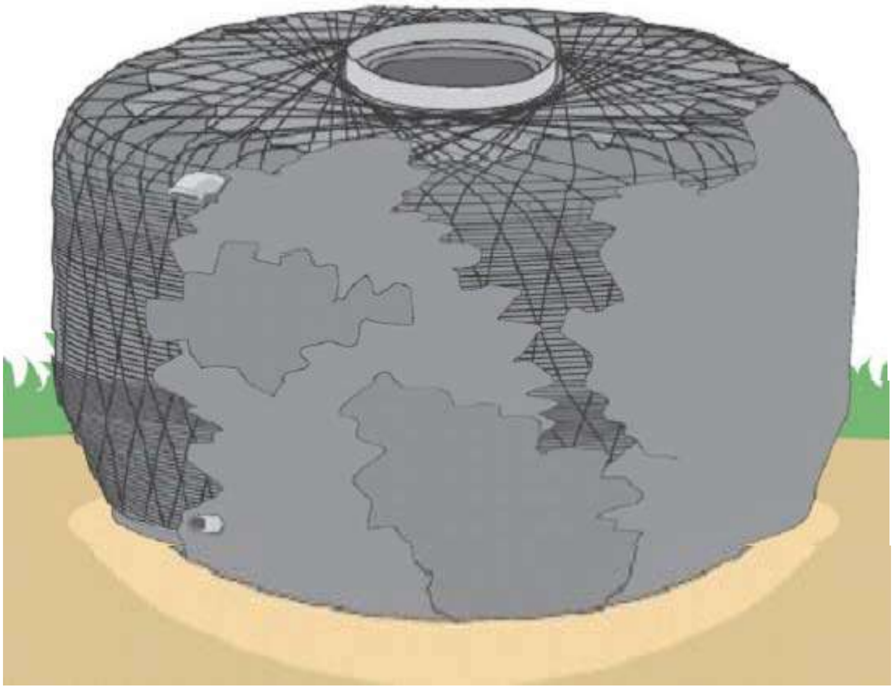


Fig. 3.19: Lip mold details

Fig. 3.20: Finishing the tank exterior with more mortar



Finishing the Interior

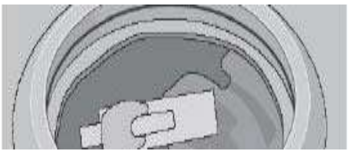


Fig. 3.21: Interior finish of mortar then a final flooring layer

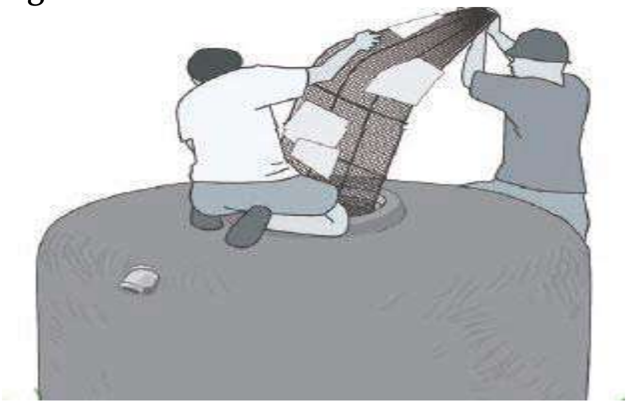


Fig. 3.22: De-molding the following morning

Fig. 3.23: Making a manhole lid

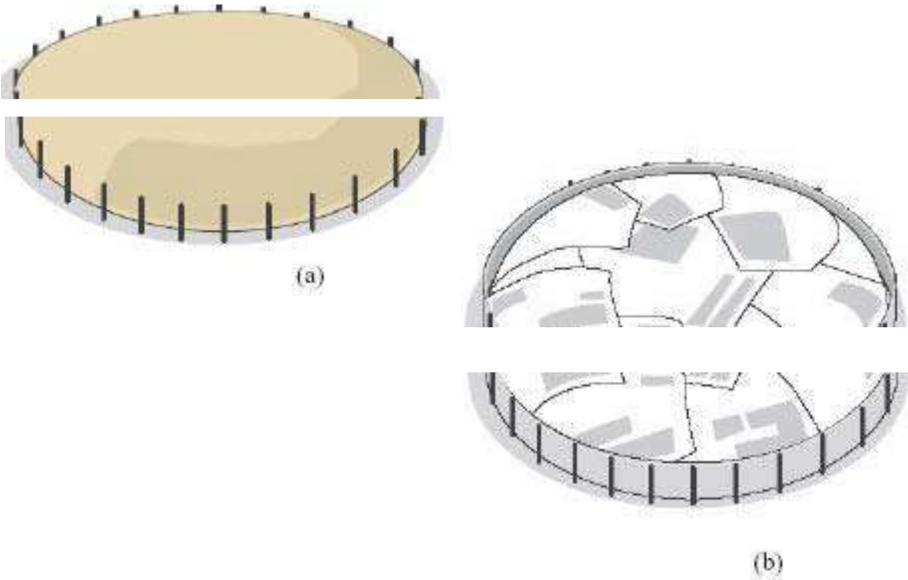
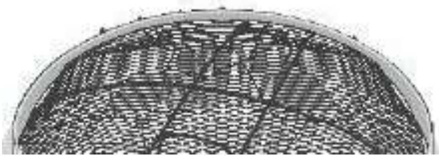
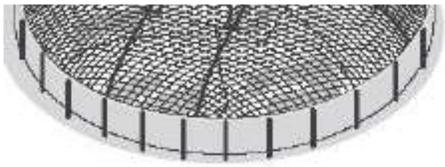
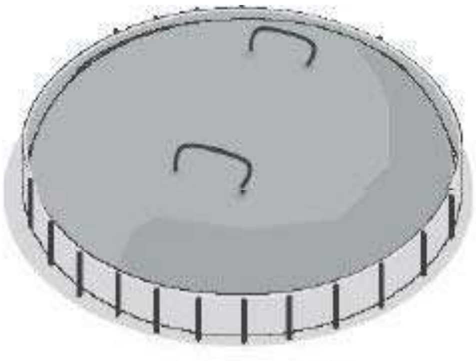


Fig. 3.24: Making a manhole lid

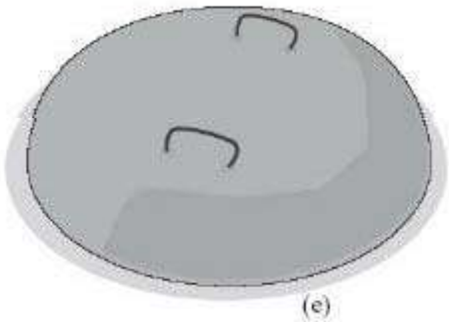




Shape earth
Stake. Line with news papers. Place lid mold and reinforcement
Fig 3.25



(d)



(e)

Fig 3.26 & 3.27: Emplace mortar; Demold

Fig. 3.28: A finished Rainwater Harvesting Tank

MIX FOR BASE COURSE

For 6 mm thin layer of base course, the sand should be as given in Table 1.

The mix ratio of Cement

Sand should be 1: 3. Free water / cement ratio maximum 0.45. The mixing water admixed with liquid water proofing compound at a dosage of 140 ml/50 kg of cement. However at some locations due to bad shape of main roof slab thicker base course may be required to give proper slope towards the drain. In such cases the maximum size of aggregates may be as per the requirement of base course thickness. Suppose a thickness of 25mm is required for the base course, then the mix ratio will be Cement: Sand 1 : 3, sand 100% passing on 8 mm.

Free water / cement ratio maximum 0.4. The dosage of liquid waterproofing compound will be the same.

Mix for Ferrocement Mortar

The sand gradings shall be as given in Table 1. The cement: sand ratio will be 1:2.5. Free water /cement ratio maximum 0.4. The mixing water shall be admixed with liquid water proofer and plasticizer for mortar at a dosage of 10 ml / 50 kg of cement.

The mix proportions are given by weight. However, sand may be taken by volume. Mix ratio of sand by weight may be converted by volume by dividing its ratio by the room dry bulk density of actual site sand. The bulk density of cement may be taken as 1.44 kg/lt

RESULTS AND DISCUSSION

Results and Analysis

Introduction

This chapter consists of various tests carried out to examine the workability of different ferrocement mixes and how they can affect the flexural ability, compressive strength, splitting tensile ability o f the ferrocement specimens. It also consists of methods for making and curing test specimens for strength tests.

Flexural Strength Test

$f_s = \frac{3Pa}{2bd^2}$

Where,

f_s= flexural strength in, megapascals i.e. MPa (N/mm^2).

P = maximum load at failure, in newtons;

a = distance between the supporting rollers, in millimetres

L = length of beam (400mm)

b = width of beam (100mm)

d = depth of beam (100mm)

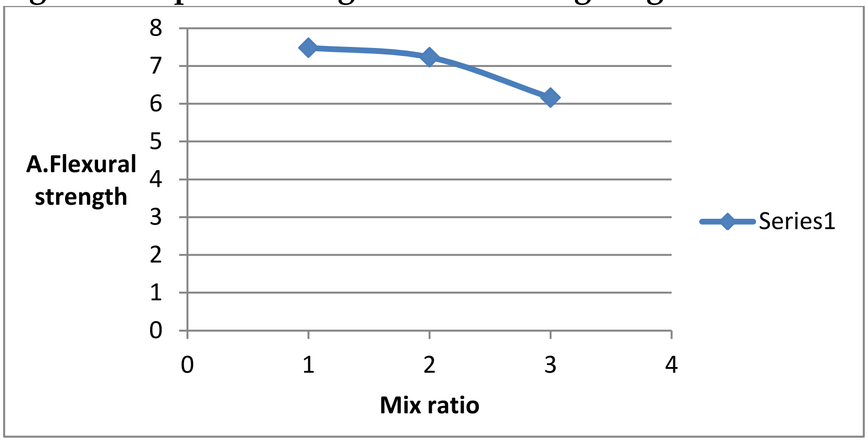
Fig. 4.1: Cracked Beam during flexural strength test

Table 4.1: Results for flexural strength for ferrocement components

Mix	Surface Area mm2	Mass (KN)	Flexural Strength(N/mm²)	Average Flexural Strength (N/mm2)	Load (P)
1.1	10000	7832.0 7830.5 7862.25	6.99 7.34 8.12	7.48	23.30 23.90 17.75
1.2	10000	7860.5 7800.0 7694.2	7.18 6.58 7.93	7.23	24.30 21.90 19.75
1.3	10000	7595.0 7593.5 7349.25	5.32 5.92 7.24	6.16	27.10 26.40 24.20

From the table above the optimum is 7.93 N/mm² for a 14 day curing period. This shows a decreasing trend of flexural strength.

Fig. 4.2: Graph of average flexural strength against the mix ratio



Density Test

Density = M/ V

Where:

M= mass (KN)

V= Volume of cube (150×150×150)

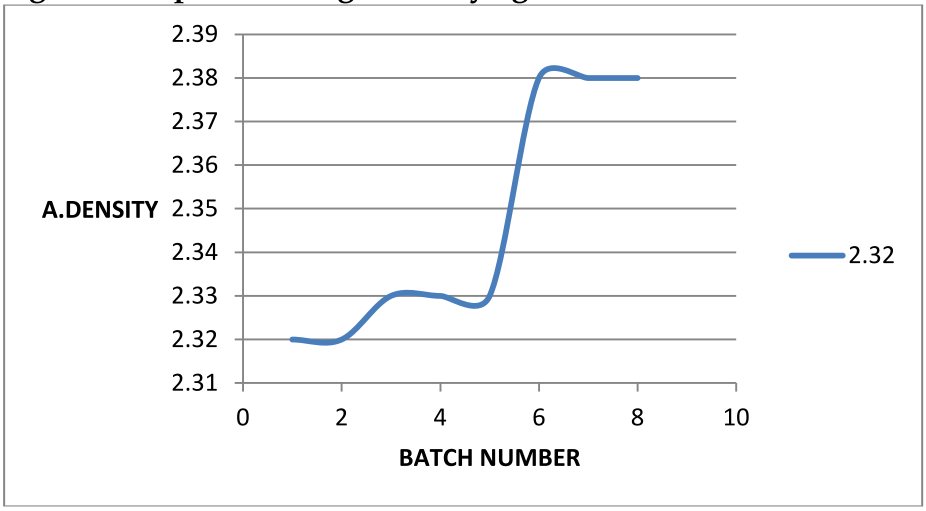
Fig. 4.3: Using cube to carry out density test

Table 4.2: Results of Average Density (kg/m³)

Batch cube No.	Mass (KN)	Volume	Density (M/V)	Average Density (kg/m³)
1 2 3	7902.5 7780.0 7878.0	337500 337500 337500	2.34 2.31 2.32	2.32
4 5 6	7552.2 8065.0 8030.0	337500 337500 337500	2.24 2.38 2.37	2.33
7 8 9	7941.2 7829.4 8298.4	337500 337500 337500	2.35 2.32 2.46	2.38

From the table above the optimum density occurs at cube 5 and optimum average density at batch 3, which shows an increasing trend. The optimum density is therefore 2.38 (kg/m³) which is still within the density of design mix criteria (i.e. 2.36 kg/m³)

Fig. 4.4: Graph of average density against batch number



Compressive Strength Test

$f_{ck} = \frac{P}{A}$

Where,

f_{ck}= compressive strength, in mega pascals i.e. MPa

P = maximum load at failure, in kilo newtons (kN);

A= area of the specimen on which the compressive force acts of the specimen (EN 12390-1)

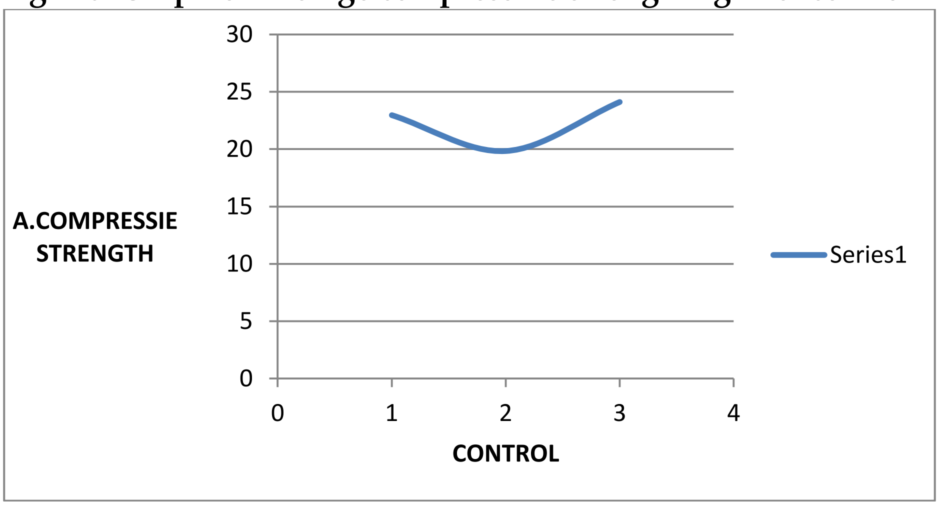
Fig. 4.5: crushed ferrocement cubes during compressive strength tests

Table 4.3: Results showing the compressive strengths for their corresponding mix ratios resulting in different masses when weighed and also having a standard surface area

Mix	Surface Area (mm^2)	Mass load (kN)	Compressive Strength (P/A)	Average Compressive Strength (MPa)	Control
1.1	22500	451.65 533.55 564.90	20.07 23.71 25.10	22.96	2290.5
1.2	22500	426.60 485.325 426.60	18.96 21.57 18.96	19.83	2532.0
1.3	22500	426.75 565.05 635.85	18.97 25.11 28.26	24.11	2540.0

From the above table, the ferrocement components have and undulating trend of compressive strength in correspondence to their different mixes, as further shown in the graph below. Also, the optimum compressive strength is 28.26 MPa at mix ratio 1.3.

Fig. 4.6: Graph of average compressive strength against control



Splitting Tensile Strength Test

Splitting tensile strength test was carried out on a total of ferrocement cylindrical specimens. Three cylinders from each pervious ferrocement batch mix were tested after 7, 14, and 28 days of curing. The mathematical expression for splitting tensile strength test is given as follows;

$$f_t = \frac{2P}{\pi H d}$$

f_t= tensile splitting strength, in newtons per square millimetre i.e. (N/mm^2).

P = maximum load at failure, in newtons (N);

H = height of the cylinder, in mm (300mm);

d = diameter of the cylinder, in mm (150mm)

π = 3.142

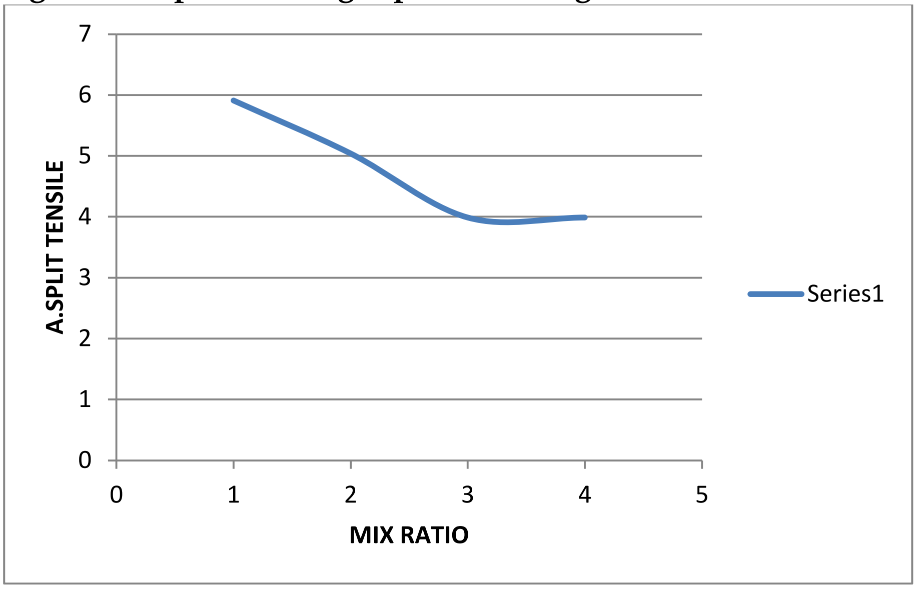
Fig. 4.7: Cylinder after Split Tensile Test

Table 4.4: Results of the split tensile strength tests after 7, 14 and 28 days

Mix	Surface Area (mm2)	Mass	Load (P)	split tensile strength (N/mm^2)	Average split tensile strength
1.1	176700	12502.5 12436.2 12428.5	362.00 418.50 468.50	5.12 5.97 6.63	5.91
1.2	176700	12424.25 12410.0 12419.2	299.00 385.00 387.00	4.23 5.43 5.47	5.04
1.3	176700	12329.5 12333.2 12325.5	194.5 327.00 321.00	2.75 4.63 4.59	3.99

From the above table the optimum split tensile strength is 6.63 at 28 days was obtained for ferrocement, as it was within the mix ratio of 1.1.

Fig. 4.8: Graph of average split tensile against mix ratio



Comparison

Comparison of 7, 14 and 28 days Test Results

Fig. 4.9: Flexural Strength Comparison

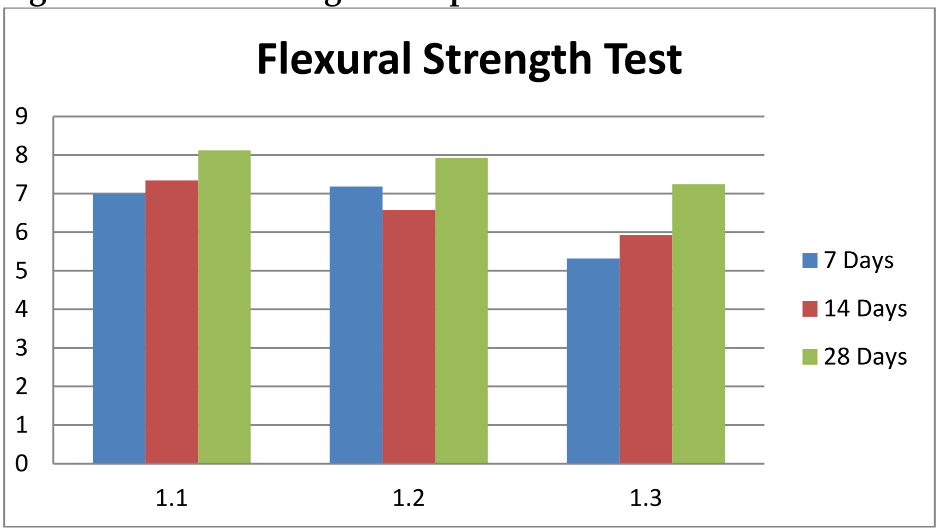
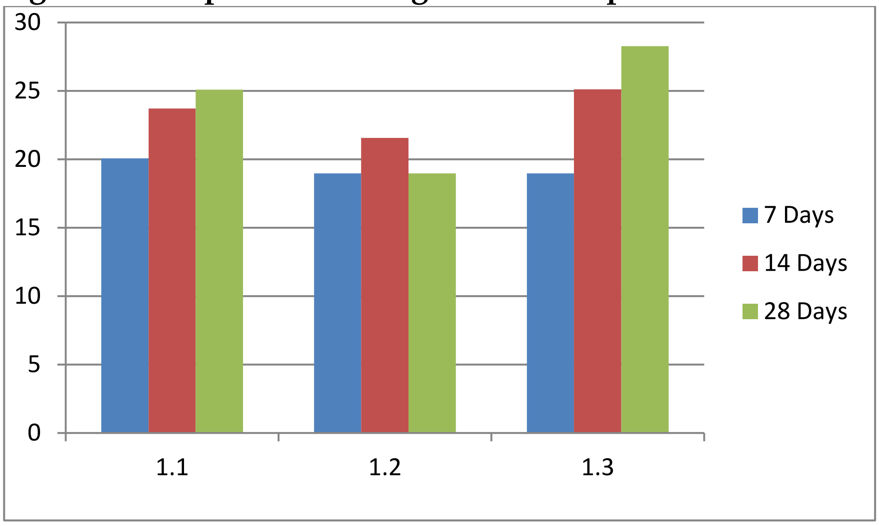


Fig. 4.10: Compressive Strength Test Comparison



CONCLUSION AND RECOMMENDATION

Conclusion

The optimum density for the ferrocement sample was within the density design mix of 2.36 kg/m^3 which makes it standard for use.When mixing my cement mortar with sand and some other aggregates i at some point had to increase the water to cement ratio in order to improve the workability of the mix.

Casting was carried out in different molds for different experimental purposes e.g cube mold for density and compressive strength tests, cylindrical molds for splitting tensile tests and beam molds for flexural strength tests.

The water-cement ratio was also increased during the casting process for cylindrical and beam molds as wire mesh was used as reinforcement. Thus this is to enable the proper casting around and in between the gaps of the wire mesh.

The flexural strength of ferrocement when compared with normal rebar concrete was higher due to the use of wire mesh reinforcement and a standard cement sand ratio. Also, the splitting tensile strength of ferrocement is higher compared to normal concrete mainly because of the wire mesh reinforcement in this project

Recommendation

Due to machine failure, the results of my laboratory tests where a little bit altered as a result of curing an extra day unlike as planned. I therefore recommend proper and regular servicing of the equipments in order to yield perfect results in laboratory tests.

I also recommend additional laboratory staffs for proper cleaning of equipments and the laboratory at large. There should be proper laboratory tests before using a particular ferrocement mix for design construction to prevent unforeseen circumstances from occurring e.g cracking due to poor water-cement ratio e.t.c

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