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Study on Ferrocement Panels for Use in Secondary Roofing

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Abstract: In tropical climatic conditions the terrace slab is subjected to direct sunlight and subsequent heat radiation in to the dwelling units. The conventional weathering coarse adopted in the industry to offer thermal insulation, such as laying of brick bat tiles, application of heat reflective coating, laying of light weight concretes and tiles, etc. has other negative consequence although it offers minimal thermal comfort. The secondary roofing concept involves laying of Ferro cement panels one foot above the original RCC slab is an viable option. There is a need for developing a Ferro cement panel which offers excellent strength and durability properties for use in secondary roofing application.
This investigation studies the flexural performance of ferrocement panels with different mesh types, configurations and mix ingredients. The mesh types employed in the study includes galvanized wire mesh and crimped wire cloth mesh. The variations in the mix ingredient are ordinary mortar and flyash modified mortar (40%). Fresh mortar and hardened mortar properties including water absorption test were also found as per Indian standards for control and flyash modified mortar. In each category three ferrocement panels are cast and subjected to flexure strength test as per BIS 516-1968(Methods of Tests for strength of concrete) by four point loading method. The test was conducted in a 40 ton capacity universal testing machine with special fixtures for supporting specimens. The load is applied at a lower rate, continuously without shock during entire test period. The performance indicates such as first crack load, ultimate load carrying capacity, crack region, crack pattern including load-deflection behavior was observed. Flexure strength results on ferrocement panels exhibited that panel with single layer crimped wire cloth mesh and in combination with galvanized mesh offer significant increase in ultimate load carrying capacity of the order 40-50% as compared galvanized wire mesh panel irrespective of no. of layers.
It is also found that there is an improved ductility ratio of 60% for crimped wire cloth panels and combination of crimped cum galvanized panels as compared to galvanized wire mesh panels. The load-deflection behavior clearly indicates that there is a manifold improvement in the energy absorbing capacity of crimped wire mesh panels and crimped cum galvanized wire mesh panels. It is concluded that crimped wire mesh panels made of ordinary and flyash modified mortar offers appreciable flexural strength properties and will be a viable option for mass production of Ferro cement panels for use in secondary roofing.

I. INTRODUCTION

A. General

The concept of ferrocement, of reinforcing cement mortar by closely spaced layers of fine wire mesh, was originally conceived one and a half centuries ago by Lambot for boat building. The use of this material was subsequently promoted for civil engineering structures by Nervi one century later in the 1940s. Ferrocement material has since been extensively studied and the basic technical information on various aspects of design, construction, and application is now available. Ferrocement is a form of reinforced concrete that differs from conventional reinforced or prestressed concrete primarily by the manner in which the reinforcing elements are dispersed and arranged. It consist of closely spaced, multiple layers of mesh or fine rods completely embedded in cement mortar. A composite material is formed that behaves differently from conventional reinforced concrete in strength, deformation, and potential applications, and thus it is classified as a separate and distinct material. It can be formed into thin panels or sections, mostly less than 1 in. (25 mm) thick, with only a thin mortar cover over the outermost layers of reinforcement. Unlike conventional concrete, ferrocement reinforcement can be assembled into its desired shape and the mortar can be plastered directly in place without the use of a form. The following definition was adopted by the ACI Committee 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.”

B. Ferrocement Roofings

Roof is an important building fabric in housing, which requires proper design and construction, as it is most exposed to climatic elements. In tropical climate, roof is the main heating element of a house. The external surface of the roof is often subjected to the largest temperature fluctuations. It is possible to build walls and floors of a dwelling using local materials. Past attempts are made to manufacture (from local materials) roofs which are economical, durable, and resistant to fire, insects, flood, and earthquakes have not been very successful. As a result, many developing countries import galvanized iron sheets or use asbestos cement sheets. These two roofing materials may cost as much as 60 percent of the total cost of a house. Ferrocement appears to be an economical alternative material for roofing. The previously described advantages of ferrocement for boats apply equally well to roofs. Ferrocement roofing materials can be factory mass-produced in prefabricated form, a process best suited to the concentrated demands of the urban area, or it can also be fabricated in-situ in villages.

The use of ferrocement as roofing for large span structures has been successfully used in many European and South American countries. Construction of hundreds of ferrocement roofs for poorer areas of Mexico has been well documented; most of these ferrocement roofs were dome shaped with a span of 3 to 6m (10 to 20 ft. large ferrocement roofs have been constructed in Italy. A recent design and construction of six ferrocement shells for a roof to shelter animals is a classic example. The performance of other geometrical shapes for use as roofs has also been investigated at the National University of Singapore. Since the stresses produced by dead load are critical in the design of roofs, thin ferrocement. Shells should be economical for roof structures.

Many researchers have done investigations to improve the flexural behaviour and durability of ferrocement using modified mortar matrices. Corrugated ferrocement sheets have been developed and tested by the Building Research Institute, State Engineering Corporation, Colombo, Sri Lanka. These sheets are developed as a replacement for asbestos cement corrugated sheets which are widely used as a roofing material. It has been reported that ferrocement sheets are less expensive and require less capital investment and foreign exchange. These ferrocement sheets are designed so that their weight, dimensions, and load-carrying capacities are similar to the widely used asbestos cement sheets. In addition, it has been observed that ferrocement sheets are more ductile than asbestos cement sheets. Thus, since the supply of asbestos fibers is limited and since they are carcinogenic, ferrocement may be a very suitable replacement.

C. Secondary Roofings

In tropical countries, 30-40% of heat is gained through roof in a building and diurnal temperature variation is medium to high, it is essential to look into the thermal performance of any roofing system before it is adopted. Ferrocement is also an attractive material for secondary roofing which facilitates heat insulation in buildings. After a detailed investigation at the National University of Singapore, the building authority of Singapore is convinced of the improved performance of ferrocement and gave permission for implementation in projects. As a result there has been a large scale replacement of traditional lightweight concrete units by ferrocement slabs. Thermal insulation on roof is essential to improve the building comfort and to increase the energy conservation (i.e. to reduce the air conditioning load). Ferrocement panels laid over sequentially erected dummy pillars on the existing RCC roof serve the purpose of secondary roof and can greatly enhance the thermal insulation.

D. Need For The Study

The traditional weathering proof methods adopted in the industry includes laying brick bat coba with tiles, application of heat reflective coating, laying light weight aggregate concrete, etc. The major disadvantage with these methods is that the insulation cracks up due to temperature variation and Water ingress into the insulation and roof causing dampness in building and subsequent reduction in durability. It is necessary to evolve a system which dissipates the heat before it reaches roof slab. Alternatively, ferrocement panels can be used for secondary roofing which is laid over dummy brick pillars constructed in the existing roof. By this way, vacuum to the height of one foot is created between the existing roof and the secondary roof to dissipate the heat energy. Since the secondary roof is subjected to nominal live load and exposed to atmospheric conditions, it is necessary to develop a ferrocement panels which offers excellent strength and durability characteristics.

E. Objectives And Scope Of The Project

The main objective is to develop ferrocement panels for use in secondary roofing taking in to consideration of the expected live load and durability requirements.

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1) To study the different types of configurations of mesh for possible use in ferrocement panels.
2) Selection of suitable meshes such that the developed ferrocement roof panels resist the level of stress expected.
3) To develop ferrocement panels using various combination of meshes
4) To conduct flexural strength test on ferrocement panels as per
5) IS 516-1968 (Methods of Tests for strength of concrete) by four point loading method.
6) To optimize the developed ferrocement panel based on flexural behavior in terms of ultimate load carrying capacity, first crack load, formation of cracks, crack region and crack pattern.

II. REVIEW OF LITERATURE

The literatures related to development, testing and optimization of ferrocement panels were collected for the last two decades and presented in this chapter.

Sudhakumar (2001) carried out an experimental investigation to study the thermal behavior of hollow and in filled ferrocement roofing panels, under steady state heat flow conditions. The materials used for infilling the ferrocement panels were insulating materials like vermiculite, celcrete and thermocole. These materials were mixed with cement and/or sand in the correct proportions and then used for filling up. Several such units were cast and tested under steady state heat flow conditions using a plate heater and a constant temperature water bath circulator. Test results indicate that the hollow ferrocement panels have less thermal inertia and heat capacity, and they have a very good thermal damping capacity. Similarly, the thermal inertia and heat capacity of these hollow panels can be increased by infilling the air space with the low conductivity materials

Masood et al. (2003) investigated the performance of ferrocement panels in different environments. The study investigated the performance of ferrocement panels under normal, moderate, and hostile environments. The conditions were created using potable and saline water for mixing and curing. Fly ash, a waste material, was also used as partial replacement of cement. The ferrocement slab panels cast with varying number of woven and hexagonal mesh layers were tested under flexure. Compressive and tensile strength of control specimens and load-carrying capacity of the panels under flexure with and without fly ash were investigated. Result showed that addition of fly ash in different environments affects the flexural strength of panel for both woven and hexagonal wire fabric.

Nassif and Najm (2004) conducted an experimental and analytical investigation of ferrocement-concrete composite beams. In this study, method of shear transfer between composite layers was examined. Various types of beam specimens with various mesh types (hexagonal and square) were also tested under two-point loading system up to failure. Results showed that the proposed composite beam has good ductility, cracking strength and ultimate capacity.

Milon et al (2013) have examined the flexural performance of ferrocement panels under normal and saline water exposure was investigated. For this rationale, a series of thin mortar plate specimens of 275 mm × 275 mm (width× length) in size were casted with varying number of mesh layers, thickness and immersed condition. For the expedition of the effect of saline water, accelerated constant current corrosion test was performed. Mid-point loading test was done to measure the flexure performance of the specimens. Test results revealed that the flexural performance of ferrocement wall panel reduces due to the effect of saline water.

III. BASIC MATERIAL STUDY

A. Details Of Materials

The materials used in the experimental study include:

1) 53 grade Ordinary Portland Cement (OPC)
2) Locally available river sand as Fine Aggregate
3) Galvanized wire mesh and crimped wire cloth
4) Flyash as partial replacement with cement

Table 3.1& 3.2 gives the properties of cement and fine aggregate to be used in the study. The general guide lines about properties and types of constituent materials used in ferrocement is outlined in table 3.3.

Table 3.1 Properties of Cement

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S.No	Description		Observed value
1.	Cement	Standard Consistency	27%
		Specific gravity	3.1
		Initial setting time	72 min
		Final setting time	330 min

B. Types Of Meshes

1) Ferrocement Construction

Materials	Range
Wire mesh	
Diameter of wire (□)	0.5 □ 1.5 mm
Type of mesh	Chicken wire or square woven or welded galvanized mesh
Size of mesh opening (S)	6 S 25 mm
Volume fraction (V_R) of reinforcement in both directions	2% V_R 8%
Specific surface (S_R) of reinforcement in both directions	0.1 S_R 0.4 mm^2/mm^3
Elastic Modulus (E_R)	140 - 200 N/mm^2
Yield strength ($□_{Ry}$)	250 - 460 N/mm^2
Ultimate tensile strength ($□_{Ru}$)	400 - 600 N/mm^2
Skeletal Steel:	
Type	Welded mesh, steel bars, strands
Diameter (d)	3 mm d 10 mm
Grid size (G)	50 mm G 200 mm

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Yield strength	250 - 460 N/mm^2
Ultimate tensile strength	400 - 600 N/mm^2
Mortar Composition:	
Cement	Any type of Portland cement (depending on application)
Sand to cement ratio (s/c)	1 s/c 3 by weight
Water cement ratio (w/c)	0.3 w/c 0.5 by weight
Gradation of sand	5 mm to dust with not more than 10%* passing 150 □m BS test sieve
Compressive strength (cube)	Not less than 35 N/mm^2

B. Study On Strength And Durability Properties Of Mortar Mix

2) *Compressive Strength Test:* The compressive strength test was carried out as per IS 516 -1968 (Methods of Tests for Strength of Concrete) on 100mm cube specimens to find the strength of the developed mortar mix. Compressive strength of mortar was found at the age of 7 days and 28 days. Totally 9 mortar cube specimens were tested. Compression Testing Machine of capacity 1000kN was used for the test. The 100mm cube specimen was placed between upper and lower platens such a way that finished surface form the side of the specimen and exactly placed on the central axis. The load was applied gradually without shock at 140 Kg/cm^2/minute. Test was continued and the failure load was noted. Table3.4 shows the observation on compressive strength for control mortar cubes. The average 7 day, 28 day compressive strength was found to be 24Mpa and 35Mpa respectively. The compressive strength of the specimen was calculated as follows.

Compressive strength = **P/A** (N/ mm^2)

P - Failure load**;** A – c/s area of concrete specimens in mm^2

Table 3.2 Compressive Strength of control mortar cubes

Sl.No	Cube Identification	Ultimate Load (kN)		Compressive Strength(N/mm^2)	
		7 days	28 days	7 days	28 days
1	F1	207	327	20.7	32.7
2	F2	236	352	23.6	35.2
3	F3	270	366	27.0	36.6

	Average			23.76	34.8

Table 3.3 Water Absorption test for control mortar cubes

Sl.No	Specimen Identification	Initial Weight (kg)	Weight after 24 hour immersion in water (kg)	Water Absorption (%)
1	S-1	2.209	2.250	1.82
2	S-2	2.211	2.253	1.86
3	S-3	2.212	2.253	1.82
			Average	1.83

Table 3.4 Water Absorption test for 40% flyash modified mortar cubes

Sl.No	Specimen Identification	Initial Weight (kg)	Weight after 24 hour immersion in water (kg)	Water Absorption (%)
1	F-1	1.840	1.891	2.69
2	F-2	1.845	1.889	2.32
3	F-3	1.839	1.887	2.54
			Average	2.51

IV. EXPERIMENTAL INVESTIGATION

A. Introduction

Eighteen ferrocement roof slab panels made from different mesh configurations and mortar mix are subjected to flexure test. The mesh types employed in the study includes crimped wire cloth mesh, galvanized mesh and crimped wire cloth cum galvanized wire mesh. The mortar mixes varied are ordinary mortar and flyash modified mortar ferrocement panels were subjected to flexural strength test. The following are the details of the specimens subjected to flexure test as per BIS 516-1956 (Methods of Tests for strength of concrete) by four point loading method.

B. Specimen Preparation

The ferrocement slab panels of size 900mm x 300mm x 25mm were cast with embedded wire mesh in cement mortar. In case of single wire mesh, it is placed such that it forms a center in the 25mm thick slab panel whereas in case of double mesh layer, thick mesh was placed 8mm above bottom surface (proposed tension zone) and thin mesh is placed 8mm beneath top surface. Figure 4.1 shows the various stages involved in fabrication and casting of ferrocement panel.

C. Test Procedure

Hydraulically operated universal testing machine of 40 tons capacity was used to conduct the flexure test. The load - deflection behavior of ferrocement roof panels was obtained by placing the slab panel in the specially made seating assembly.

V. RESULTS AND DISCUSSION

A. General

Flexural strength behavior of 18 ferrocement roof slab panels made from crimped wire cloth mesh; crimped wire cloth cum galvanized wire mesh; galvanized wire mesh and flyash incorporated panels were obtained and analyzed in this chapter. The evaluation criteria includes mesh types, mix proportion first crack load, ultimate load, crack type and crack pattern.

B. Flexural Strength Test

Table 5.1 Details of First Crack Load And Ultimate Load Of Ferrocement Panels

S.no	Type of specimen	First crack load (KN)	Ultimate load (KN)	Physical observation	Remarks
1.	FCC1	8.8	10.64	Evenly distributed cracks in the mid 1/3rd region. appreciable	Appreciable ductility

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				deformation of panel during testing	
2.	FCG1	4.4	5.20	Breaking of specimen after Fcr without forming crack patterns. No appreciable deformation of panel	Poor ductility
3.	FCG2	5.2	6.40	Breaking of specimen after Fcr load. Moderate hair crack formed in mid 1/3rd region.	Poor to moderate ductility

4.	FCCG	7.20	12.72	Well distributed patterned cracks in the mid 1/3rd region. Significant deformation of panel during loading.	Improved ductility and good load carrying capacity
5.	FAG1	10.40	10.80	Breaking of specimen after Fcr load. No formation of cracks in the mid 1/3rd region.	Poor ductility and good load Carrying capacity
6.	FAC1	6.56	10.08	Well patterned cracks in the mid 1/3rd region with significant deformation. Upon relieving of load, tendency for original shape	Significant ductility property and good load carrying capacity.

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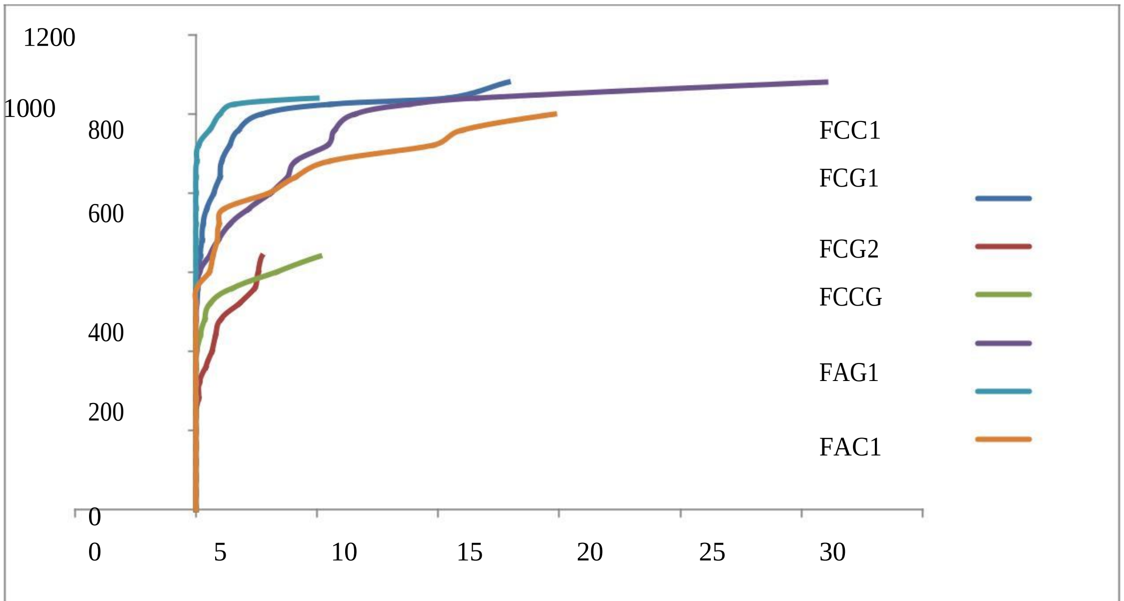
6 ferrocement panels were made of crimped and galvanized wire mesh three in each category in which 40% replacement of flyash with cement has been made. These panels are subjected to flexure test after 28 days of curing period. Figure5.2 shows load-deflection behavior of flyash incorporated ferrocement panels. FAC1 shows excellent load-deflection behavior. Deformation of panel slowly increases with gradual increment in load. Whereas FAG1 exhibits 27% higher resistance against deformation as compared to FAC1. And FAG1 panel breaks immediately after the first crack load and there is no appreciable deflection and crack pattern formation.



DEFLECTION(mm)

Figure 5.1 Load-Deflection Behaviour Of Ferrocement Panels With Control Mortar And Flyash Incorporated Mortar

Figure 5.1 shows Load-deflection behaviour of ferrocement panels with control mortar and flyash incorporated mortar**.** FCCG exhibits excellent load-deflection behavior and very good load carrying capacity when compared to all other panels. FAC1 shows resistance against deformation up to 800kg. After that, a large deflection takes place with just 200kg increment in load and also upon relieving of load there is a tendency to regain original shape. FCG1, FCG2 and

FAG1 broke immediately at the middle one-third region after the first crack load which shows poor yielding capacity of the galvanized wire mesh. No appreciable deflection and crack pattern is found in the galvanized mesh panels irrespective of no. of layers. FCG2 shows very slight improvement in load carrying capacity when compared to FCG1.

Figure 5.2 evenly distributed crack pattern in FCCG

VI. CONCLUSIONS

A. Compressive strength test result and water absorption test indicated the adequacy of using ordinary mortar and flyash modified mortar in ferrocement panels.

B. Flexure strength results on ferrocement panels exhibited that panel with single layer crimped wire cloth mesh and in combination with galvanized mesh offer significant increase in ultimate load carrying capacity of the order 40-50% as compared to galvanized wire mesh panels irrespective of no. of layers.

C. It is also found that there is an improved ductility ratio of 60% for crimped wire cloth panels and combination of crimped cum galvanized panels as compared to galvanized wire mesh panels.

D. Single and double layer galvanized wire mesh panels exhibits poor ultimate load carrying capacity and brittle failure takes place immediatelyafter the first crack resistance load.

It is concluded that ferrocement panels made of ordinary mortar or flyash modified mortar reinforced with crimped wire mesh in single layer or in combination with galvanized wire mesh offers appreciable flexure strength properties and will be a viable option for mass production of ferrocement panels for use in secondary roofing.

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