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FLEXURAL BEHAVIOUR OF FERROCEMENT PANELS WITH SILICA FUME AND CHINA CLAY AS CEMENT REPLACEMENT MATERIALS

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ABSTRACT

In this experimental investigation, an attempt is made to study the flexural behaviour of ferrocement panels of dimensions 600mm × 100mm × 25mm with the incorporation of mineral admixtures such as Silica fume and China clay in mortar matrix. Condensed Silica fume is used as a Cement Replacement Material (CRM) in various proportions (4%, 6%, 8%, 10% 12% and 14%). China clay is also used as a Cement Replacement Material in various proportions (5%, 10%, 15%, 20%, 25% and 30%). Both the cementitious materials are used separately in mortar. Galvanized Weld mesh and Woven mesh were used as reinforcements for the preparation of ferrocement panels. The flexural response of the ferrocement panels with Silica fume (SF)/China clay(CC) will be tested and compared with that of their control specimens. So, this study involves the determination of flexural load carrying capacity, load-deflection relationship, number of cracks, maximum deflection and mode of failure of ferrocement specimens. Two line loads were applied along the spans of all specimens at one-third points. Loads are applied in steps and corresponding deflections were recorded for each increments of load.

Keywords: *China clay, deflection, Flexural response, Replacement, Silica fume, weld mesh.*

INTRODUCTION

Ferrocement can be suitably used as a strengthening material because of its better cracking behavior and improvement in its mechanical properties with economy in cost. Ferrocement is a composite material comprising of rich cement mortar and continuous reinforcement mesh in the form of small diameter steel rods and wires. Even-though the Ordinary Portland Cement mortar matrix for ferrocement has satisfied for standard performance requirements, it is deficient with regard to some of the properties such as tensile strength and chemical resistance. So, in this study, supplementary materials such as silica fume and china clay were used as Cement Replacement materials with an aim to improve the characteristics of conventional ferrocement panels.

LITERATURE REVIEW

Paramasivam P, Mansur M.A and Ong, K.C.,[1] (1985) investigated the flexural behavior of ferrocement slabs made up of cellular matrix and reported that use of lower grade mortar yields higher flexural ductility. The cracking strength of reinforcement panels decreases with decreasing density of mortar because of a reduction in mortar strength. Walkus. B. R [2] (1986) made an attempt to determine the deformations and cracking of ferrocement specimens. He has presented the complete details of moulds to be used for the preparation of ferrocement. Mansur M.A and Paramasivam P., [3] (1986) reported the results of the investigations conducted on ferrocement to study the cracking behavior and ultimate strength in flexure. Both first crack and ultimate moment increased with increasing matrix grade and increasing volume fraction of reinforcement.

Irons M. E.,[4] (1986) discussed all the major types of meshes in ferrocement and mentioned that the lowest cost and high specific surface of expanded metal compared to wire mesh makes it the most cost effective reinforcement. Paramasivam P and Sri Ravindrarajah R.,[5] (1988) reported that under direct tension and simple bending, ferrocement having reinforcement bundled and placed near the surfaces showed reduced crack width and increased intensity of cracking at failure compared to other arrangements of reinforcements. The first crack strength of ferrocement having reinforcement bundled and placed near the top and bottom surfaces is about 16 percent higher than that having evenly distributed reinforcement arrangements. Randhir J. Phalke., and Darshan G. Gaidhankar.,[6] (2014) studied and compared the effect of varying the number of wire mesh layers and use of steel fibres on the ultimate strength and ductility of ferrocement slab panels. Their test result showed that panels with more number of layers exhibits greater flexural strength and less deflection as that compared with panels having less number. Based on the literatures collected [7-12], the percentages of Silica fume and China clay are proportioned in the mortar matrix.

MATERIALS USED IN THE FERROCEMENT PANELS

FINE AGGREGATE

The fine aggregates used for the preparation of ferrocement panels are conforming to IS 383 – 1970, Zone III sand is used as shown in table 1.

Table 1 Physical properties of fine aggregate

Sl. No.	properties	Test results
1.	Specific gravity	2.63
2.	Fineness modulus	2.21
3.	Grading	Zone III

CEMENT

The cement used for all ferrocement panels are conforming to IS 269 – 1976. Ordinary Portland cement of grade 43 (Zuari brand) is used and is tested for its properties as shown in table 2.

Table 2 Physical properties of cement

Sl. No.	Properties	Test result
1.	Specific gravity	3.12
2.	Normal consistency	31%
3.	Initial Setting time	50 mins

WATER

Potable water, clean and free from harmful salts or foreign materials which may impair the strength and resistance of the mortar is used in this study.

REINFORCEMENTS

Galvanized weld mesh and woven mesh were used as main reinforcements in ferrocement panels. The cumulative volume fraction of reinforcement is calculated as 3.27%. Also, the reinforcing steel wire mesh has openings large enough for adequate bonding, closer distribution and uniform dispersion of reinforcement to transform the brittle mortar into a high performance material distinctly different from reinforced concrete.

Figure 1 Tensile strength test on weld mesh

The meshes used in this study were weld mesh of thickness 1.2mm and woven mesh of thickness 0.6mm. The weld meshes have a square openning of 10mm. The weld mesh is tested for its tensile strength in the Universal testing machine as shown in figure 1 and the ultimate tensile strength was found to be 476.86 N/mm^2 and that of woven mesh was 687.20 N/mm^2.

MINERAL ADMIXTURES

Supplementary cementitious materials are added to mortar as part of the total cementitious system. They may be used in addition to or as a partial replacement of Portland cement. They are used to improve a particular mortar property, such as workability, compressive strength and permeability. An overdose or under-dose can be harmful to achieve the desired effect. It also reacts differently with different cements. Traditionally, fly ash, slag, calcined clay, calcined shale, and silica fume were used in mortar/concrete individually. In this experimental study, Silica fume is used as an admixture and replacement for cement individually in various proportions.

SILICA FUME

Silica fume has a spherical shape and is extremely fine with particles less than 1 μm in diameter and with a specific surface area of 15,000 – 30,000 is used in this study. The relative density of silica fume is generally in the range of 2.20 to 2.5. The bulk density of silica fume varies from 130 to 430 kg/m^3.The specific gravity of Silica fume used in this study is 2.23. The chemical composition of silica fume used in this study is shown in table 3.

Table 3 Chemical composition of Silica fume

Sl. No.	Properties	Content
1.	SiO_2 content (%)	85 – 97
2.	CaO content (%)	< 1
3.	H_2O (moisture)	Max 1.0% (when packed)
4.	C (Carbon)	Max 2.5%
5.	LOI (Loss On Ignition)	Max 4.0%
6.	Specific surface area (m^2/kg)	15,000 – 30,000
7.	Bulk density (kg/m^3)	600-700 (when packed)
8.	Specific gravity	2.23

CHINA CLAY

China clays are used in general purpose concrete construction much the same as other pozzolana. They can be used as a partial replacement for the cement, typically in the range of 15% to 35%, and to enhance resistance to sulphate attack, control alkali-silica reactivity, and reduce permeability. China clays are hexagonal platy crystals ranging from 0.1μm to 10μm and have a relative density of between 2.40 and 2.61 with bulk density ranging from 650 m^2/ kg to 1350 m^2/ kg. The chemical composition and specific gravity of china clay used in this study is shown in table 4.

Table 4 Chemical composition of China clay

Sl. No.	Properties	Content
1.	SiO_2 content (%)	45 – 48
2.	Al_2O_3 content (%)	33 – 39
3.	Fe_2O_3 content (%)	0.6
4.	CaO content (%)	0.06
5.	MgO content (%)	0.50
6.	TiO_2 content (%)	0.50
7.	K_2O content (%)	0.1
8.	Specific gravity	2.56

SUPER-PLASTICIZERS

A control mortar with a flow value of 107mm is used in this study. Ten different types of mortar were prepared with almost same workability of control mortar by adjusting the dosage of super-plasticizer and water-binder ratio. The super-plasticizer reduces the water content required to give suitable workability for placing and compaction. In this study CONPLAST 430 from FORSOC which has the properties as shown in table 5 is used, to decrease the water-cement ratio.

Table 5 Properties of Super-Plasticizers

Sl. No.	Properties	Value
1.	Specific gravity	1.220 to 1.225 at 35^{o}C
2.	Chloride content	NIL as per IS 456 and BS 5075
3.	Air-entrainment	Approximately 1% additional air is entrained
4.	Compatibility	Can be used with all types of cements except high alumina content

OBJECTIVE OF EXPERIMENTAL STUDY

The main objective of this experimental work is to study the flexural response of ferrocement panels under flexural loading. The varying parameters in this study are:

a) Percentages of Silica fume as CRM in ferrocement panels.
b) Percentages of China clay as CRM in ferrocement panels.

EXPERIMENTAL WORK

FLOW TABLE TEST

The mortar in the ratio of 1:3 prepared with river sand as fine aggregate and a water-cement ratio of 0.45 is tested using the flow table apparatus as per IS 5512 – 1983 which is shown in figure 2. The super-plasticizer (Conplast 430) is added with the mortar by trial and error method to get a good workability condition. 15 rotations were applied with uniform speed for all trials. The flow of the mortar spread on the flow table is measured in the two mutually perpendicular directions and the average value is taken as the flow of the sample. Thus the workability of the control mortar specimens is determined as 107mm. The same workability (± 0.5mm) will be maintained in all the mortar specimens with and without silica fume/china clay.

Figure 2 Flow test apparatus for cement mortar

COMPRESSIVE STRENGTH TEST

Compressive strength test was conducted on the mortar cube specimens with 1:3 cement-sand ratio using river sand. The mortar cubes were placed in the compression testing machine co-axially and the loads were applied gradually up to their failure stage. The maximum load carrying capacities of three mortar cube specimens were observed and tabulated as shown in table 6. The mean of the three compressive strength values is taken as the ultimate compressive strength of the control mortar specimens.

Table 6 Compressive strength test results of control mortar cubes (1:3)

Sl. No.	Specimen code	Compressive load after 28 days curing (N)	Compressive strength after 28 days curing (N/mm^2)
1.	C – 1	232919	46.73
2.	C – 2	230426	46.23
3.	C – 3	237056	47.56
Mean			46.84

DETAILS OF FERROCEMENT PANELS

Ferrocement panels of dimensions having length 600mm, breadth 100 mm and thickness 25mm were cast and used for testing their flexural behavior. One layer of weld mesh and one layer of woven mesh tied with each other were placed at top as well as at the bottom zone of all ferrocement panels. Weld mesh of wire diameter 1.20 mm with a square opening of 1.50 cm and woven mesh with a wire diameter 0.6 mm were used as reinforcement.

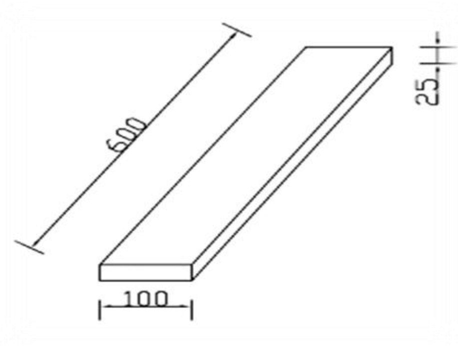

Figure 3 Ferrocement panel dimensions in mm

ARRANGEMENT OF REINFORCEMENTS

Arrangement of reinforcements with bundled meshes in the compression and tension zone exhibits reduced crack-width and increased intensity of cracking at failure compared to other arrangements of reinforcements. Totally, two weld mesh and two woven mesh were used in each ferrocement panels. The arrangements are made in such a way that the weld meshes are located at both the surfaces of the panels and the woven meshes are located nearer to the neutral axis of the panel. A clear outer cover of 5mm is maintained on both the surfaces of the panels. One layer of weld mesh and one layer of woven mesh were tied with each other is shown in figure 4.

Figure 4 Tied layers of meshes

CASTING OF FERROCEMENT PANELS

All the ferrocement panels were cast using suitable steel moulds with spacer bars. The prepared mortar with and without silica fume/ china clay of good workability is used for casting the panels. After cleaning and oiling the mould, the mortar layer of 5mm thick was spread at the base of the form work, and on this base layer the first mesh was laid. Spacers were used to maintain the required cover. Slight manual compaction was given to each layer of mortar. Totally 39 ferrocement panels were cast using 11 varieties of the mortar, three of each mix. The cement mortar with 1:3 mix ratios were used in all ferrocement panels. The casting process of the ferrocement is shown in the figure 5. To ensure compatibility, all panels were prepared using the same workability measured using flow-table tests according to IS: 5512-1983. Some of the prepared ferrocement panels were shown in figure 6. The panels were de-moulded after 24 hours and cured by immersing in curing tank for 28 days.

Figure 5 Casting of ferrocement panels in progress

Figure 6 Prepared ferrocement panels

TESTING OF FERROCEMENT PANELS

Flexure test was conducted on all ferrocement panels with various proportions of Silica fume and China clay respectively. One end of the panel is simply supported and the other end is on roller support with two concentrated line loads over a span of 500 mm leaving an overhang of 50 mm on each support as shown in figure 7 and 8 is adopted in this study. A sensitive elastic proving ring of 5 kN capacity is used to apply and observe the loads on the panels. The verticality and eccentricity of the complete system is verified thoroughly before starting the test. Third point loads were gradually applied through a hand operated reaction frame. Deflectometer is mounted on the magnetic base having a least count of 0.01 mm was used to obtain mid-span deflections at various stages of loading. Deflection readings were taken at 0.2 kN increment of load. At each load increment, the number of cracks with the central one-third span of specimens was noted.The first crack load, ultimate load, maximum deflections, number of cracks and their flexural strengths were recorded and presented in table 7 to 9.

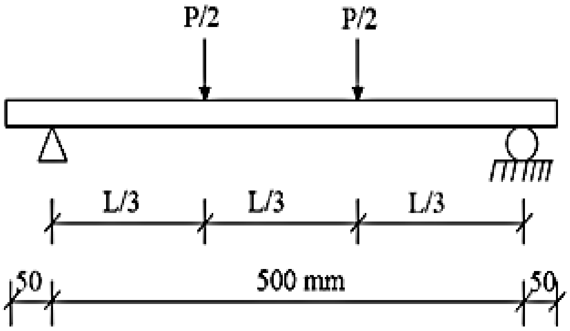

Figure 7 Flexure test set up

Figure 8 Actual Test set up of ferrocement panel

Table 7 Flexure test results of ferrocement panels with Silica fume as CRM

Sl. No.	Specimen code	% of CC	Ultimate Load in N	Maximum deflection in mm	No. of cracks
1.	C	0	2061	12.78	5
2.	CC5%	5	1961	10.13	5
3.	CC10%	10	2084	16.27	6
4.	CC15%	15	2206	22.4	7
5.	CC20%	20	1716	16.57	8
6.	CC25%	25	1471	10.73	8
7.	CC30%	30	1226	10.19	10

Table 8 Flexure test results of ferrocement panels with China clay as CRM

Sl. No.	Specimen code	% of SF	Ultimate Load in N	Maximum deflection in mm	No. of cracks
1.	C	0	2061	12.78	5
2.	RSF4%	4	1471	12.01	9
3.	RSF6%	6	1471	12.32	10
4.	RSF8%	8	1961	13.15	7
5.	RSF10%	10	2206	10.82	9
6.	RSF12%	12	2452	10.90	9
7.	RSF14%	14	2206	10.12	11

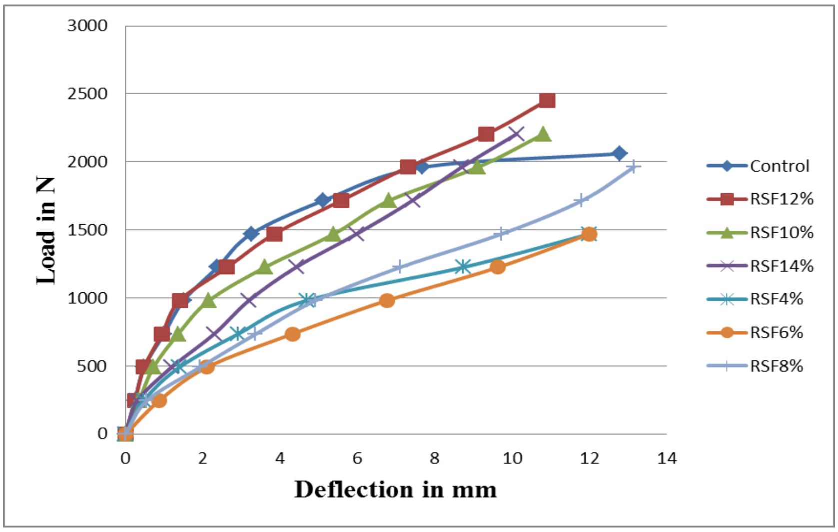

Figure 9 Load – deflection relationship of ferrocement specimens with silica fume as CRM

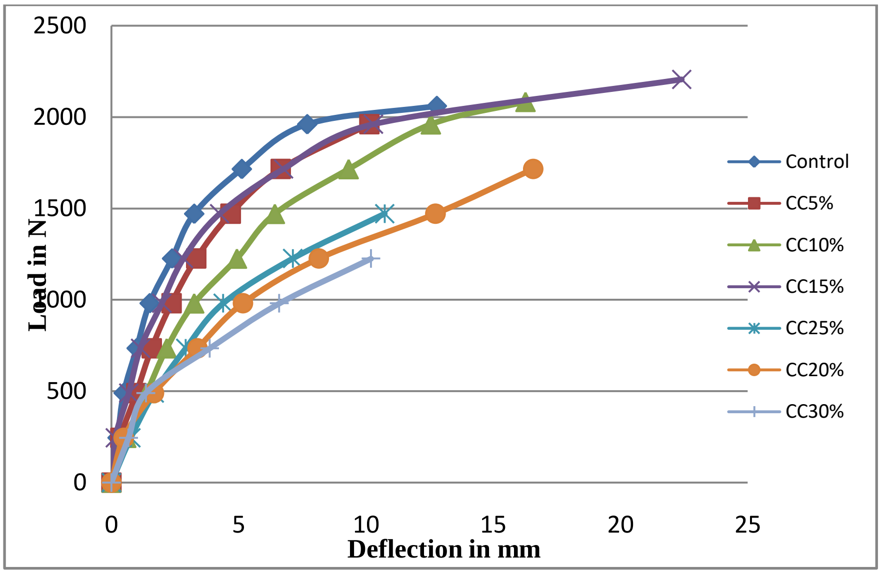

Figure 10 Load – deflection relationship of ferrocement specimens with China clay as CRM

RESULTS AND DISCUSSION

The flexural strength test result indicating the ultimate load, maximum deflection, number of cracks and flexural strength were presented in the table 7 to 8. The load-deflection relationships were presented in figure 9 and 10. The ferrocement panels with 12% SF as CRM achieved a maximum ultimate load of 2452 N which is 12% higher than that of control ferrocement panels. The ferrocement panels with 10% and 14% SF as CRM achieved a maximum load of 2206 N which is 7.04% higher than that of the control ferrocemnt panels. The ferrocemnt panels with 4%, 6% and 8% SF as CRM exibit a significant decrease in their ultimate load. As far as deflections are concerned the ferrocement panels with 8% SF as CRM exibit a maximum deflection of 13.15 mm which is 2.90% higher than that of the control ferrocement panels with 4%, 6%, 10%, 12% and 14% exibits a significantly lesser deflections at their ultimate load stage. The ferrocement panels with 15% CC as CRM achieved a maximum ultimate load of 2206 N which is 7.04% higher than that of control ferrocement panels. The ferrocement panels with 10% CC as CRM achieved a maximum ultimate load of 2084 N which is 1.12% higher than that of control ferrocement panels. The ferrocement panels with 5%, 20%, 25% and 30% CC as CRM exibit a significance decrease in their ultimate load. As far as deflections are concerned, the ferrocement spanels with 15% CC as CRM exibit a maximum deflection of 22.40 mm which is 75.27% higher than that of control ferrocement panels.

SALIENT CONCLUSIONS

The following conclusions were made based on the experimental studies:

- Out of all the thirteen sets of ferrocement panels, the panels with 12% SF as CRM increased the flexural strength upto a maximum of 12%.
- The replacement of OPC by 15% CC increased the flexural strength of ferrocement panels by 7%.
- All other specimens (RSF4%, RSF6%, RSF8%, CC5%, CC20%, CC25% and CC30%) have no significant increase in their flexural strength when compared with control ferrocement panels.
- By the presence of suitable proportions of SF and CC in ferrocement panels, the ductility of the panels have been improved significantly.
- All the ferrocement panels exhibited flexural mode of failure only.
- Since, the replacement of cement by 12% SF and the replacement of cement by 15% CC have improved the flexural strength of ferrocement panels, the effective utilization of industrial wastes (Silica fume and China clay) can also be achieved by incorporating them in cement.

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