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FLEXURAL BEHAVIOUR OF GEOPOLYMER BASED FERROCEMENT PANELS

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Abstract

Ferrocement is special form of reinforced cement concrete (RCC) without coarse aggregate and reinforced with closely spaced multiple layers of mesh encapsulated in rich cement mortar. Ferrocement sections are relatively thin in construction and requires comparatively less reinforcement. They can be moulded into any shape and size, which may not be the case with conventional RCC elements. The construction dosen't necessarily requires shuttering, formwork, etc. And are highly versatile material possessing a high degree of ductility, durability, strength, crack resistance that is greater than that of RCC structural elements. This type of construction facilitates precast systems, as the ferrocement sections are not only thin, but also light weight enough for ease of handling. Applications of ferrocement are numerous. Since, ferrocement appears to be an economic alternative material, here in this research study, it is envisaged to utilise it as primary precast roof panel elements of a proposed prefabrcicated roofing system.

Geopolymer, a novel binder, a type of inorganic polymer synthesised from room temperature by using industrial waste or by-products as source materials to form a solid binder, is also used as binder for complete replacement of Ordinary Portland cement (OPC). The main objective of this research work is to study the comparative flexural behaviour of precast panels containing weld mesh and (chicken) wire mesh reinforcement grill, packed / cast in both types of conventional OPC mortar/geopolymer mortar. The precast panels of cement mortar are conventionally designated as 'FERROCEMENT PANELS', whereas the precast panels of geopolymer mortar are innovatively termed as "GEO-FERROCRETE PANELS". The geo-ferrocrete panels were air-cured under ambient temperature conditions and ferrocement panels were cured under water for 28 days. The sizes of the precast roofing panels were fixed at 1000 mm long, 600 mm wide and 30 mm thick. Comparative flexural performance shows Ferrocement panels have good flexural behavior compared with geo-ferrocrete panels.

Keywords: Flyash, GGBS, Ferrocement, Roof slab, Deflection, flexural test

INTRODUCTION

Portland cement is popularly used as the basic raw-material (as a primary binder) in concrete mixes, for all the construction works. Reinforced cement concrete (RCC) structural elements of typical construction projects, consume huge quantities of cement. Very high cement consumption for RCC constructions not only shoots-up the economic costs of the project, but also would hugely increase the ecological pollution issues associated with cement production plants. In this context, engineering research projects were taken-up, across the globe, on technological development for alternative construction technologies (to replace popular RCC construction techniques), towards the objective of relatively reducing the cement consumption. Prestressed structures, precast technologies, ferrocement construction, etc., have been emerged as viable engineering practices in this direction.

Ferrocement was considered as one of the construction technologies, by American Concrete Institute committee 549. Ferrocement elements are reinforced composites, those differ from normal conventional reinforced cement concrete (RCC) elements. According to ACI committee, Ferrocement are the thin walled reinforced elements generally constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small sized diameter wire mesh. When compared to conventional reinforced cement concrete (RCC) elements, the ferrocement has structural advantages of, higher tensile strength / high modulus of rupture / homogeneous properties / high resistance to punching shear failure and impact loading/ lesser crack widths, etc. Ferrocement is used in many construction applications [13]

LITERATURE REVIEW

According to N.P. Rajamane, the compressive strength of geopolymeric mortar were higher in which the geopolymeric materials was activated by sodium hydroxide and sodium silicate solutions [1]. In Madeshwaran C. K's research work explains about the compressive strength of GGBS and flyash with varying percentage and varying the molarities of Alkaline solution and also specified that concentration of NaoH increases strength and greater strength achieved with 100% replacement of GGBS [2]. Sreevidya. V research work explains about the curing of geopolymer mortar specimens it explains that strength gain at ambient curing conditions gaved less strength when compared with curing at higher temperature curing conditions [3].

Hago.K. studied about the service behavior of Ferrocement roof panels with incorporating different layers of chicken mesh and rectangular mesh and also explains about the cracking and ultimate flexural behavior of Ferrocement specimens [4][5]. Swapnil and Aathinavi, studied about different shaped panels in Swapnil's research work shows the results related to Ferrocement segmental elements and studied about the load behavior and load bearing capacity of the elements [6]. In Aathinavis research studied about the folded panels and were subjected to different loading and cost parameters were also studied for the Ferrocement elements [7]. Amruthas research paper studied about the through shaped panels with different layers of mesh and varying percentage of SBR polymers and studied about load bearing capacity and crack width studies [9]. Suresh R research work says that Ferrocement elements are flexible and strong due to the even distribution of reinforcement. And studied about the flexural behavior of panels with partial replacement of flyash and incorporating weld mesh and chicken mesh as reinforcement; under flexural loading it showed that Ferrocement were good in bending and had good crack resistant [8]. In Suhail H experimental research work showed that Ferrocement elements witn double layer of mesh gaved good flexural strength comparedwith single layer of mesh and geopolymer mortar had good strength compared with Ferrocement elements [10].. In Ranjith K and Murali G explains about the ferrocemnt elements cast cement mortar and geopolymer mortar incorporating wire mesh and hexagonal mesh with different layers showed good flexural behaivour and higher stiffness and ductility under loading and also had higher energy absorbent when subjected to impact loading and flexure. [13] [14].

MATERIALS USED

The cement used for casting all experimental specimens, is the ultra tech brand of OPC 53- grade. Its properties were studied according to IS:4031(part 2)-1988. Geopolymeric materials used for producing geo-ferrocerete panels are, flyash and Ground Granulated Blast Furnace Slag (GGBS). Flyash and GGBS were brought from Ennore power plant and steel plant, respectively. The fine aggregate used was of standard size of less than 4.75mm, and it is the locally available river sand. The distributed reinforcement consists of square weld mesh of 30mm*30mm opening and diameter of 2.5mm in both longitudinal and transverse direction and chicken mesh of 36-gauge chicken mesh of 10mm opening were used. The preliminary studies are performed according to the IS code recommendations.

PROPERTIES OF CEMENT MORTAR

The cement used to find the properties are Ultratech brand cement of OPC 53 grade and the properties are studied according to specified IS codal provision.

Table 1 Physical properties of OPC

Physical properties	OPC Cement
Standard consistency of cement	30%
Specific gravity of cement	3.14
Initial setting time (Minutes)	55
Final setting time (Minutes)	215

FINE AGGREGATES

Tests were also conducted to find the specific gravity of the fine aggregates using pycnometer as per IS 2386-1963 (Part- 3).

Table.2 Properties of fine aggregate

Specific gravity	2.5
Fineness modulus	3.1
The river sand falls under Zone II according to IS 383-1970	
Bulk density	1647kg/m^3

PREPARATION OF ALKALINE SOLUTION

The alkaline solution is prepared 24 hours before the casting. It is prepared by mixing sodium hydroxide in liquid /pellets form in water and after the temperature come down the sodium silicate solution is added to the mix before 30 minutes of casting.

GROUND GRANULATED BLAST FURNACE SLAG AND FLY ASH

The fly ash is fiery debris obtained from the warm power plant. It is a decent pozzolano and remains either dark or grey. The fly ash used in the study was obtained from Ennore thermal power plant, Tamilnadu. Ground granulated blast furnace slag is a hydraulic binder obtained from the blast furnaces of iron and steel plants. The physical properties of flyash and GGBS are studied by weighing required quantity of flyash and GGBS and using Vicat apparatus mould. To determine the normal consistency, initial and final setting time of geopolymer mix which includes 60% of GGBS and 40% Flyash is taken and alkaline solution made of sodium hydroxide and sodium silicate is used to prepare the geopolymer paste. The normal consistency is started initially by added 28% of solution by weight of binder and tested as per the procedure specified by IS 4031-1988 (Part 4), until the needle penetrates to a depth of 33 to 35 mm from the top.

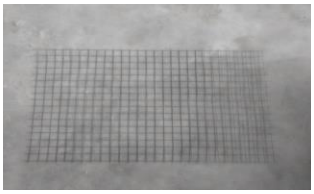
Table 3 Physical properties of flyash and GGBS

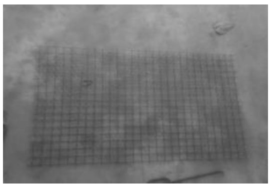
Physical properties	Flyash and GGBS
Standard consistency of fly ash and GGBS	31.5%
Specific gravity of fly ash	1.966
Specific gravity of GGBS	2.74
Initial setting time (Minutes)	40
Final setting time (Minutes)	150

REINFORCEMENT PROVIDED

Square weld mesh:. The weld mesh was cut to a required dimension of 1000mm*600mm. Single layer of weld mesh is provided in the specimen panels. The mesh which can be distributed evenly in both directioms.

Chicken mesh: It is known as chicken mesh or hexagonal mesh. It is generally used in the poultry forms. Due to its thin dimension and strength properties it is being used as a reinforcing material. It is provided in 2 layers above and below the square weld mesh.





(a) **(b)**

Fig 1 (a) Weld mesh (b) Weld mesh with 2 layers of chicken mesh

Table.4 Specification of hexagonal mesh

Sl.No	Properties	Values
1	Shape of opening	Square
2	Length	1000 mm
3	Width	600 mm
4	Mesh opening	30 mm*30 mm
5	Thickness of joint	5 mm
6	Diameter of mesh	2.5 mm
7	Available form	Rolls

Table.5 Specification of chicken mesh

Sl.No	Properties	Values
1	Shape of opening	Hexagonal
2	Length	1000 mm
3	Width	600 mm
6	Diameter of mesh	0.2 mm
7	Available form	Rolls

MIX PROPORTIONS

The mix ratio of both cement mortar mix and geopolymer mortar mix used in the present study adopted is 1:3.

Table.6 For water cement ratio 0.45

Cement	Fine aggregate	Water
435kg	1310kg	200kg
1	3	0.45

Table 3.7 Constituents of geopolymer mortar

Geopolymer binder		Fine aggregate	Alkaline solution
Fly ash	GGBS		
140kg	210kg	1060kg	215kg
1		3	0.61

EXPERIMENTAL INVESTIGATION

Experimental investigation consists of study of flexural behavior of test panels and study of deflection under constant loading and also consists of strain behavior of the panels under loading.

DETAILS OF TEST SPECIMENS

The cross sectional dimensions of the ferrocement and geo-ferrocrete panels were adopted by standard principles. Total of 8 panels were cast which includes4 geo- ferrocrete panels and 4 ferrocement panels. The overall dimension of the panels is 1000 mm length, 600 mm width and 30 mm thick. These panels include single layer of weld mesh and double layer of chicken mesh, and the reinforcement is placed at the mid span.

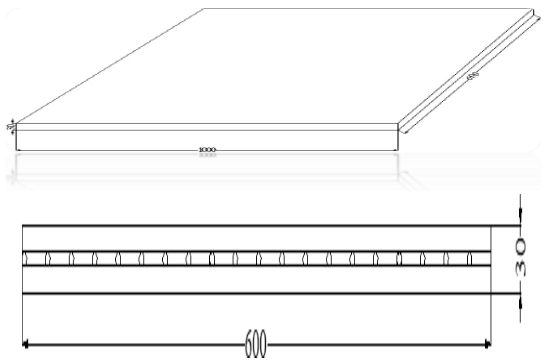


Fig 4.1 Details of test specimen Table 4.1 details of the specimen

CASTING AND CURING OF FERROCEMENT AND GEO-FERROCRETE PANEL

For Casting of test panels, the mortar was spread on steel mould and a layer of mortar is spread through the mould and single layer of weld mesh and double layer of mesh prepared is placed at the mid span of the mould after the placement of mesh the next layer of mortar is laid and surface is finished, same procedure is carried foe geo-ferrocrete panel and Ferrocement panels. The panels were demoulded after 24 hours of casting and cured it with gunny bags for 28 days, whereas geo-ferrocrete panles cast with geopolymer mortar were cured under room temperature. For casting the materilas were weighed, dried and mixed in a concrete mixer, before casting oil were applied on the surface of the mould and mortar was laid in layers' care was taken to ensure motar was laid properly and compacted.

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Fig.2 preparation of mould for casting EXPERIMENTAL TEST SETUP

The primary investigation of this experimental investigation is to study the comparative flexural behaviour of ferrocement with that of geo-ferrocrete panels; The panel specimens were tested at the facture and fatigue laboratory of CSIR-SERC. Testing was done using multipurpose servo hydraulic universal testing machine of 500KN capacity. The mode of control of the machine is displacement control. The stroke length of UTM is

±75mm. The panels were placed over the specially fabricated supporting system. All the specimens were tested by providing simply supported condition. The load is applied as two point placed concentrated loads, at one-third span and two-third span. The slab is kept on the prepared test set-up which includes a L- shaped beams on both the sides, as pedestals. Above these pedestals, one side hinge support and other side roller support were provided for freely allowing moment and to attain a good deflection.

(a) (b) (c)

Fig .3 (a) Testing machine (b) Flexural test setup (c) Test setup after placing slab

INSTRUMENTATION

The slab was instrumented with single linear variable differential transducer (LVDT) to measure the deflection at the mid-point of span. First a sand-paper is used to prepare the surface of substrata to be smooth. Acitone clear splint is used to remove the inert particles from the panels. Two strain gauges were fixed, one at 1/3rd span and the other at 2/3rd span, to measure the strain at particular points. They were marked using meter scale. Both instruments, the LVDT and strain gauges were connected to data acquisition system. LVDT's were used to measure axial deformation of maximum 50mm. The strain gauges were fixed for the measured gauge length of 60mm. CN- adhesive was used to paste the strain gauges. Both instruments, the LVDT and strain gauges were given initial corrections and verified before the applying the load. Static load application was administered on the specimen panels.

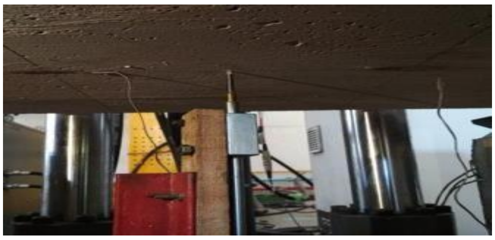


Fig.4 Instrumental setup

EXPERIMENTAL OBSERVATION OF GEO- FERROCRETE PANELS

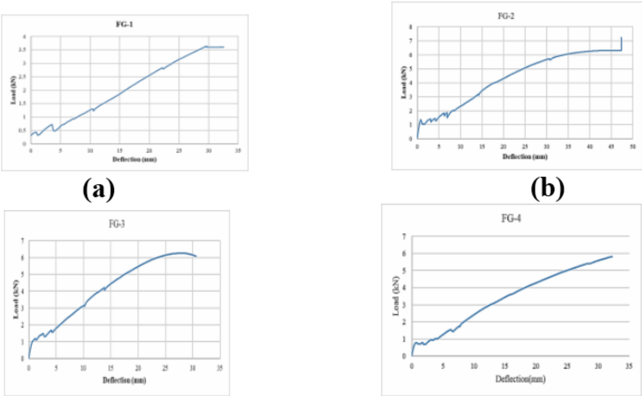
The behaviour of panels under flexure was observed by using LVDT and stain gauges. The initial loading was started from 0 and displacement rate of loading was 0.01mm/min. The behaviour of panels was recorded until the ultimate cracking.

(a) (b)

Fig.5(a) Testing of geo-ferrocrete panel (b) Tested specimen

Table 5.1 Experimental test results

Specimen designation	Reinforcement	Specimen ID	Cracking load		Ultimate load		Remarks
			Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	
Geo-ferrocement Panels (FG)	Single layer of weld Mesh and double layer of chicken mesh	FG-1	0.5	10.00	3.59	32.53	The Initial cracking at b0.5k N was observed due to the improper cover in the FG-1 specimen
		FG-2	2.68	16.80	6.31	47.28	
		FG-3	2.01	22.44	6.25	28.52	
		FG-4	1.81	23.48	5.93	33.51	



(a) (b)

(c) (d)

Fig.6 (a), (b), (c) and (d)-Load and deflection behaviour of Geo-ferrocrete panels

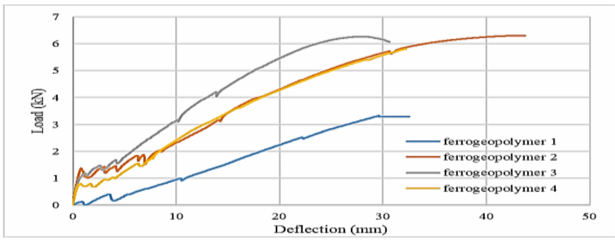


Fig.7 Result of geo-ferrocrete panels

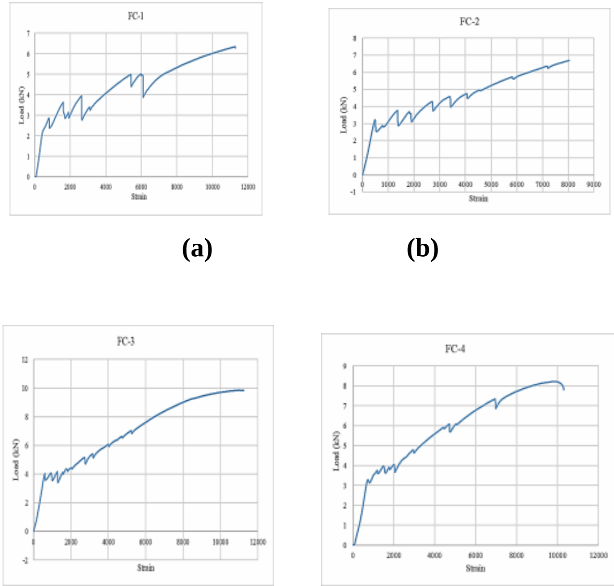
EXPERIMENTAL OBSERVATION OF FERROCEMENT PANELS

(a) (b)

Fig.7 (a) Flexure test of ferrocement panel (b) Behaviour of specimen

Table.6 Experimental test results

Slab designation	Reinforcement	specimens ID	Cracking		Ultimate load	
			Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
Ferroc ement (FC)	Single layer of weld mesh and double layer of chicken mesh	FC-1	4.0	22.88	6.274	26.152
		FC-2	4.5	18.82	6.685	20.024
		FC-3	5.09	21.05 5	9.849	26.549
		FC-4	6.30	15.90	8.156	22.856



(a) (b)

(c) (d)

Fig.8 (a), (b), (c), (d)-Load and deflection behaviour of ferrocement panels

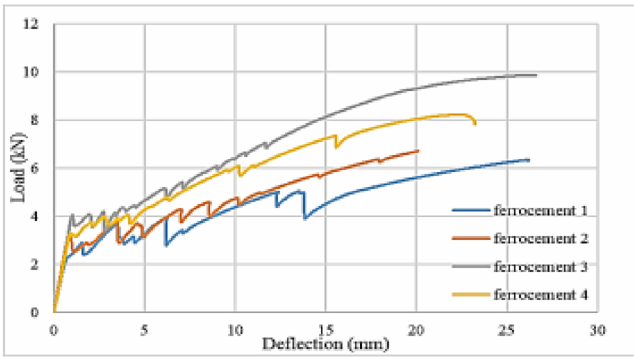


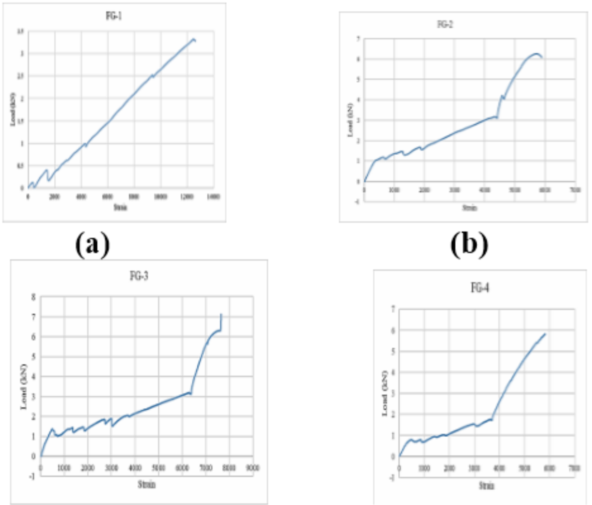
Fig.9 Result of Ferrocement panels

STRAIN OF THE FERROCEMENT AND FERRO-GEOPOLYMER PANELS WERE OBSERVED

Strain gauge readings from the testing are observed. The strain gauges were used to record the strain pattern. The average strains of the both the strain gauges were worked-out and listed in the following tables. The strain values of geo-ferrocrete panels were more compared with Ferrocement panels it shows that Ferrocement panels are good in deformation compare to geo-ferrocrete panels

Table.7 Strain values of Geo-ferrocrete panels

Slab designation	Reinforcement	Specimen s ID	Strain	
			Load(kN)	Strain
Geo-Ferrocrete panels (FG)	Single layer of weld mesh and double layer of chicken mesh	FG-1	3.28	12657
		FG-2	6.294	7624
		FG-3	6.21	5810
		FG-4	5.79	5798

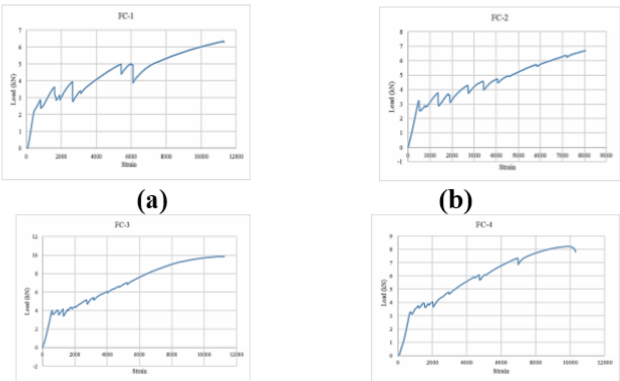


(a) (b) (c) (d)

Fig.10 (a), (b), (c), (d) strain plot for geo-ferrocrete panels
Table.8 Strain values for Ferrocement panels

Table.8 Strain values for Ferrocement panels

Slab designation	Reinforcement	Specimens ID	Strain	
			Load (kN)	Strain
Ferrocement (FC)	Single layer of weld mesh and double layer of chicken mesh	FC-1	6.27	11295
		FC-2	6.639	7902
		FC-3	9.84	11226
		FC-4	8.084	10202



(a) (b) (c) (d)

Fig.11 (a), (b), (c), (d) Strain behavior of Ferrocement panels

COMPRESSIVE STRENGTH TEST

It is a mechanical property to measure the maximum load the cube can undergo before failure. The test was conducted according to IS codal provision. The compressive strength of geopolymer mortar and cement were studied and results are plotted. It shows that geopolymer mortar has early strength development and also good in compression loading.

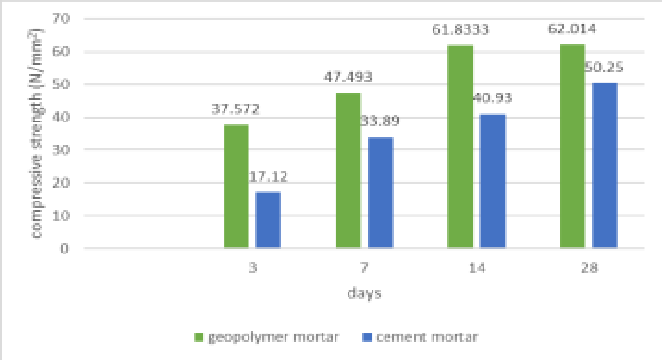


Fig.12 compressive strength test result

SPLIT TENSILE STRENGTH TEST

The split tensile test is believed to give more uniform results compared with other tension test. The split tensile test is done according to IS:5816-1999 codal recommendations. The split tensile strength of geopolymer mortar has greater strength compared with split tensile strength of cement mortar specimens.

Table 9. Split tensile test for cement mortar

Description	Split tensile strength (MPa)
Days of curing	28
Cylinder of 100 X 200mm	2.1

Table 10. Split tensile test for geopolymer mortar

Description	Split tensile strength (MPa)
Days of curing	28
Cylinder of 100 X 200mm	3.55

CRACKING

In both ferrocement panels and geo-ferrocrete panels the cracking occurred around the mid span point. As the load is gradually increased, the crack width started percolating through ribs and many cracks were observed adjacent to the center line crack. The cracking behavior also shows that the maximum deflection of the panel was occurred at the mid span.

(a) (b) (c)

Fig.13 (a) cracking of ferrocement panel (b) cracking of ferro-gopolymer panel specimens after testing

RESULTS and DISCUSSION

- The geopolymer mortars gain more than 95% of its 28-day strength within 14- days. Comparatively the cement mortar gains about 80% of its 28-day strength within 14-days. This point concludes that the geopolymer mortars gain strength rapidly, unlike the case of cement mortars.
- According to the experimental works carried out, the compressive strength of geopolymer mortar specimens gave greater compressive strength at the age of 14 days of more than 60Mpa, when compared with cement mortar specimens with 50Mpa at the age of 28days. It means the performance of geopolymer mortars against compression are quite better than OPC mortars.
- The split tensile strength of geopolymer mortar specimens at the age 28days was found to be 3.55Mpa and cement mortar was 2.1Mpa. In this type of mechanical strength also the geopolymer performance is comparatively better.
- However, the flexural behaviour of ferrocement panels were shown to be better when compared to that of geo-ferrocrete panels.
- The load bearing capacity of ferrocement panels were found to be relatively more and the initial cracking was observed at 5.09kN with deflection 21.055mm. The ultimate failure was for ferrocement panel was observed at 9.849kN for FC-3 specimen.
- Thus it gives a technical conclusion that the performance of ferrocement panels are good in bending, though the cement mortar matrix performance has been moderate against direct compression

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CONCLUSION

- The geopolymer mortar is cured under ambient temperature conditions it doesn’t require water curing.
- As water is a precious material, for the construction purpose cement mortar requires more amount of water and day by day there is reduction the water quantity to overcome that geopolymer mortar can be replaced with cement mortar.
- Even though geo-ferrocrete panels are good in compression and split tensile strength they are not more resistant against bending when compared with Ferrocement panels. As Ferrocement panels were good in bending.
- Maintaining of cover places a important role in strength gain, and load bearing capacity. Even though the crack was developed at lesser load. The increase in load was observed due the distributed reinforcement.
- About 97% of strength development was observed in geopolymer mortar at early ages of 14 days which is not observed in cement mortar specimens. The geo-ferrocrete panels were not good in bending even though there was not much difference in the ultimate load when compared with Ferrocement elements.
- Delay of initial crack is observed in Ferrocement panels compared with geo-ferrocrete which shows greater crack resistance behavior.
- Due to the simple cross section and flexibility and the panels are useful in precast construction with low cost housing schemes and emergency shelter housing for disaster affected areas.

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