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Experimental Investigation on Ferro-Geopolymer Flat Panel

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ABSTRACT: Ferrocement is regarded as highly versatile material possessing a degree of roughness, ductility, durability, strength, crack resistance that is greater than that found in other forms of concrete construction. Various researchers have conducted the studies to investigate the characteristics of mortar mix to use in ferrocement elements. Recently there has been a growing trend towards the use of supplementary cementitious materials, whether natural, waste or by-products, in the production of composite cements because of ecological, economical and diversified product quality reasons. To investigate the properties of concrete and mortar with fly ash as complete replacement of cement is remained active area of research. The present study is aimed to investigate the compressive strength, load verses deflection behaviour, crack width and stiffness of Ferro-Geopolymer slabs by replacing cement completely by fly ash.

KEYWORDS: Crack Width, Deflection, Ferrocement, Ferro-Geopolymer, fly ash, stiffness.

I. INTRODUCTION

Climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2), to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming [8]. It is estimated that the production of cement will increase from about 300 million tons in 2010 to 550 billion tons in 2020, as per the estimates by the Cement Manufacturers Association (CMA).

The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere [2].In view of this, there is a need to develop sustainable alternatives to Portland cement utilizing the industrial by products such as fly ash, ground granulated blast furnace slag which are pozzolonic in nature.

Ferrocement is a thin walled reinforced concrete commonly consists of cement mortar, reinforced with closely spaced layers of continuous and relatively small wire meshes [12]. Thus, the properties of mortar mix like compressive strength, water absorption are very important to consider during the design of thin ferrocement structural elements. To reduce the heat of hydration and due to economic reasons now a day's cement is being replaced partially with the pozzolans which are usually industrial by products such as metakaolin, silica fume and fly ash etc., Durability of mortar in general is controlled by sand cement ratio, w/c ratio, and casting and compaction techniques. Fly ash has positive effects if used in an environment friendly way, preserving natural resources, and above all it could produce concrete of better quality.

Geopolymer has the potential to replace ordinary Portland cement and can produce fly ash-based geopolymer mortar with excellent physical and mechanical properties. In order to produce geopolymer, low-calcium fly ash needs to be activated by an alkaline solution to produce polymeric Si-O-Al bonds. Fly ash when in contact with alkaline solutions forms inorganic alumino-Silicate polymer product known as Geopolymer. These novel geopolymer cements, which

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have unique properties such as high early strength, low shrinkage, sulphate and corrosion resistance could become a viable alternative to conventional cement and hence substantially reduce CO_2 emission caused by the cement and concrete industries. Water in a geopolymer mixture, therefore, plays no role in the chemical reaction that takes place and thus provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement concrete mixture during the hydration process. There are two main constituents of geopolymer, namely the source materials and the alkaline liquids. The source materials for geopolymer based on alumina-silicate should be rich in silicon (Si) and aluminum (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, the by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. could be used as source materials. In present study Fly ash based Ferro-Geopolymer (FGP) and cement based Ferrocement (FC) slab panels are cast and tested under flexural loading.

II. EXPERIMENTAL INVESTIGATION

2.1 Material Properties

2.1.1 Fly Ash

Fly ash used was obtained from bituminous coal. Chemical composition is as shown in table (1).

Table (1) Chemical composition of fly ash (Mass %)

SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	TiO_2	MgO	P_2O_5	SO_3	H_2O	LOI*
48.0	29.0	12.7	1.76	0.39	0.55	1.67	0.89	1.69	0.5	-	1.61

2.1.2 Cement

Ordinary Portland cement (OPC) of 53 grades, conforming to Indian standard specifications is used for making the cement mortar and test specimen. Some of the properties of cement are:

Consistency = 34%,
Initial Setting Time = 90 min,
Final Setting Time = 212 min,
Specific Gravity = 3.11,
Fineness by dry sieving method = 2.2%.

2.1.3 River Sand

The type of fine aggregates used in this study is brought from locally available quarries and places. Fine aggregates used are 4.75mm down with Specific gravity of 2.38, Bulk Density 1670 Kg/m^3, water absorption 2.11% and having fineness modulus of 3.31(IS 383-1971 Zone II).

2.1.4 Water

Ordinary potable water is used for experimental investigations, considered in this study.

2.1.5 Sodium Hydroxide

Generally, the sodium hydroxides are available in solid state in the form of pellets and flakes as shown in Figure 2.1.In this investigation, the sodium hydroxide pellets in 14 molar concentrations are used. The manufacturers data related to physical properties are given in Tables (2).

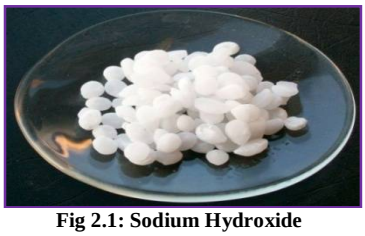

Fig 2.1: Sodium Hydroxide

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Table (2) Physical Properties of Sodium Hydroxide

Physical properties	**Values**
Colour	Colour-less
Specific Gravity	1.47
pH	14

2.1.6 Sodium Silicate

Sodium silicate, shown in Figure 2.2 is available in aqueous solution and in solid form and is used in cements, passive fire protection, refractories, textile and lumber processing, and auto mobiles. In present investigation, aqueous sodium silicate solution is used. As per the manufacturer, silicates are supplied to the detergent company and textile industry as bonding agent. Same Sodium silicate is used for the making of geopolymer mortar. The manufacturers data related to physical and chemical properties are given in Tables (3).

Fig 2.2: Sodium Silicate

Table (3) Chemical and Physical Properties of Sodium Silicate

Chemical Formula	Na_2O	SiO_2	H_2O	Appearance	Colour
Values	27.60%	32.08%	40.32%	Liquid (Gel)	Light yellow Liquid (Gel)

2.1.7 Wire Mesh

In this project square, welded wire mesh is used to find the flexural strength and deflection of slab. Square welded mesh is used in single layer and double layer. The diameter of wire used is 1.5 mm and mesh opening is 25 mm. The mesh used in the study is shown in Figure 2.3.

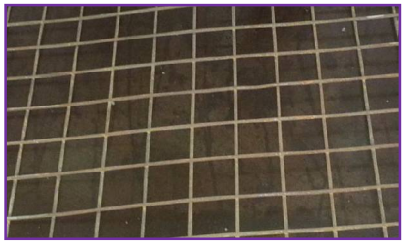

Fig 2.3: Square Welded Wire Mesh

Mesh shape = Square welded
Length (mm) = 740 mm
Width (mm) = 440 mm

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Mesh opening size (mm) = 25 × 25 mm
Thickness at joint (mm) = 7.22
Diameter of wire (mm) = 1.5
Ultimate tensile strength (MPa) = 345

2.2 Mixing
2.2.1Geopolymer Mortar:
The quantity of (fly ash+ solution) and (fine aggregate) for making the geopolymer mortar is taken as 33% and 66% respectively. Fine aggregates used are river sand. The alkaline liquid to binder ratio is taken as 0.4. Since fly ash shows very low binding property, a binder solution has to be prepared in order to enhance the binding property in the fly ash mortar. The binder solution consists of a combination of Sodium hydroxide and Sodium silicate solution in the ratio of 2.5 and sodium hydroxide pellets in 14molar concentrations are used.

Fig 2.4 (a): Composition of Geopolymer Mortar

Fig 2.4 (b): Geopolymer Mortar mix

The materials used for preparing the geopolymer mortar mix and freshly prepared geopolymer mortar are shown in Figures 2.4(a) and 2.4(b).

2.2.2 Cement Mortar:
The ratio of cement to fine aggregate for making the cement mortar is taken as 1:2. Fine aggregate used is river sand. A water cement ratio of 0.4 is adopted. The proportion of the constituents is so adjusted that the mortar gives the required strength, workability, water tightness and finish. All ferrocement slabs is cast with a nominal mix of 1:2 and a water cement ratio of 0.4.

2.3 Geometry of the specimens
The cross-sectional dimensions of the ferrocement and ferro-geopolymer slabs are adopted by applying the standard principles. The overall dimensions slabs are given below.

Fig 2.5 (a): Details of Slab Panel

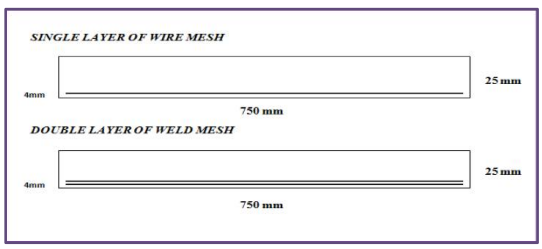

Fig 2.5 (b): Geometry of Slab Panel

Figure 2.5 (a) shows the details of slab specimens cast for the study. Length of panel= 750mm Width of panel= 450mm Thickness of panel= 25mm. Figure 2.5 (b) shows the detailing of slabs for single and double layer mesh. Both the slabs

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are with same size 750 X 450 mm and the thickness of the slab is 25 mm. In the single layer slab the mesh is provided at distance of 4mm (cover) and in the double layer slab both the layers are bundled with binding wires and placed at distance of 4mm from bottom.

2.4 Casting of control specimens

Compressive strength is a qualitative measure of the properties of hardened mortar. For compression test, mortar cubes of 70mm X 70 mm X 70mm are tested. All the cubes are tested in saturated condition, after wiping out the surface moisture in the of cement mortar specimen.

Fig 2.6: Testing of Mortar Cubes

For each mix combination, three cubes are tested for compressive strength at the age of 28 days of curing for cement mortar specimens and 48 hours after steam curing for geopolymer mortar specimens at room temperature using universal testing machine of 600 kN capacity. The tests are carried out as per IS 516-1959. Figure 2.6 represents testing of mortar cubes.

2.5 Casting and curing of slab panels

2.5.1 Casting of ferro-geopolymer panels

Sodium hydroxide solution was prepared by dissolving sodium hydroxide Pellets with water at least one day prior to mixing. The sodium silicate solution is added to the above solution before 1 hour of mixing. Fly ash is first mixed with fine aggregate for 5 minutes, after which activator solution is slowly introduced and further mixed for another 5 minutes. Mixing is carried out in a room temperature of approximately 25^0C-30^0C. A steel mould of size 750mm x 450mm x 25mm is made and is placed on the level platform of casting yard after applying a thin coat of oil. 4mm of mortar, equal to the cover of reinforcement laid over the oiled surface. The wire meshes are placed over this mortar layer inside the steel mould. Then mortar is laid over the cage and finished to exact dimensions by using trowel and straight edge for making slab with single layer of mesh. The same procedure is carried out to make slabs with double layer of mesh. The meshes are bundled with the help of binding wires in the case of slab with double layer of reinforcement. Slight vibration is given to the specimen after laying first and second layer of mortar with the help of steel hammer to eliminate pores from the mixture. The casting of all Ferro-Geopolymer slab panels is carried out at railway sleeper's factory Vishal Nirmiti Pvt. Ltd. Mohol, Dist. Solapur.

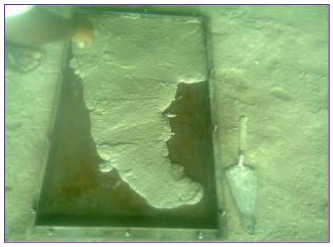

Fig 2.7: Casting of geopolymer slab pane

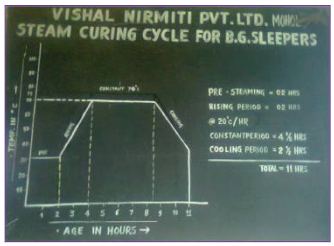

Fig 2.8 (a): Steam curing cycle

Fig 2.8 (b): Placing of slab panel in steam curing Chamber

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The casting of slab elements is shown in Figure 2.7.The type of curing adopted in this study for Ferro-Geopolymer slabs is heat curing with the help of steam. Steam curing of all Ferro-Geopolymer slabs is performed at railway sleeper's factory Vishal Nirmiti Pvt. Ltd. Mohol, Dist. Solapur. The slabs are steam cured in the chamber for 11 hours with standard steam curing cycle generally used for the curing of railway sleepers into the factory. The steam curing at the sleeper's factory is such a way that it is divided into four numbers of cycles as given below. Figure 2.8 (a) shows steam curing cycle and Steam curing of Ferro-Geopolymer slab specimens is shown in Figure 2.8 (b).

2.5.2 Casting and curing of Ferrocement slab

A steel mould of size 750mm x 450mm x 25mm is made and is placed on the level platform of casting yard after applying a thin coat of oil. Cement is first dry mixed with fine aggregate for 5 minutes after which water is slowly introduced and further mixed for another 5 minutes till the mixture becomes homogeneous; mixing is carried out in a room temperature of approximately 25^0C-30^0C. 4mm of mortar, equal to the cover of reinforcement laid over the oiled surface. The wire meshes are placed over this mortar layer inside the steel mould. Then mortar is laid over the cage and finished to exact dimensions by using trowel and straight edge for making single layer of mesh. Same procedure is used to make slabs with double layer of wire mesh. The meshes are bundled with the help of binding wires in the case of slab with double layer of mesh. Vibration is given to the mould after laying first and second layer of mortar with the help of mechanical vibrator to eliminate pores from the mixture.

Fig 2.9 (a): Placing of reinforcement

Fig 2.9 (b): Casting of ferrocement Slab panel

Fig 2.10: Curing of ferrocement specimen

Figure 2.9 (a) & (b) shows the placing of reinforcement in the panel and casting of ferrocement slab panels. Specimens were removed from their molds 24 hours after casting, cured in wet gunny bags for 28 days, and then left in laboratory environment until testing. Curing of specimens is shown in Figure 2.10.

Fig 2.11: Curing of Ferrocement Slab Specimen

Specimens were removed from their moulds 24 hours after casting, cured in wet gunny bags for 28 days, then left in laboratory environment until testing. Curing of specimens is shown in Figure 2.11.

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2.6 Flexure Test Set – up

The primary focus of the experimental investigation is to evaluate the flexural behavior of rectangular slab panels reinforced with mesh. Considering the testing facility fabrication and the ease of handling, slab panels of size 750 x 450 x 25 mm with thickness 25mm are selected for studying the flexural strength behavior. The panel thus prepared is placed over the specially fabricated supporting system. All the specimens are tested by simulating simply supported condition the load is applied as two symmetrically placed concentrated loads. Loading is done using universal testing machine. A ball bearing arrangement is provided between loading frame and universal testing machine to attain uniform loading the slab is kept on the frame and the dial gauge of 0.01mm least count is fixed at central bottom to measure the maximum deflection. Load is applied gradually on the slab, for every 200N of load application; the corresponding deflection is taken through dial gauge. The first crack load and the corresponding deflection are noticed. The ultimate load and the corresponding deflection are also noted. The Load vs. deflection behavior is examined. The crack pattern of various slabs is also studied. Schematic view of the test set up is shown in Figure 2.12.

Fig 2.12: Flexural Test Setup for Rectangular Slab

III. RESULTS AND DISCUSSION

The experimental results for tested rectangular slab specimens are given in Tables 4.

Table 4: Experimental Results for Slab Panels

Slab Designation	Reinforcement	Cracking		Ultimate		Compressive Strength of Mortar used (MPa)
		Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	
FC	Single Layer	1.77	4.06	7.57	28.66	45.104
	Double Layer	2.37	3.51	10.37	31.08	
FGP	Single Layer	3.57	1.29	5.17	3.89	70.473
	Double Layer	3.97	5.77	12.97	32.61	

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2.6.1 Load Vs Deflection Curves

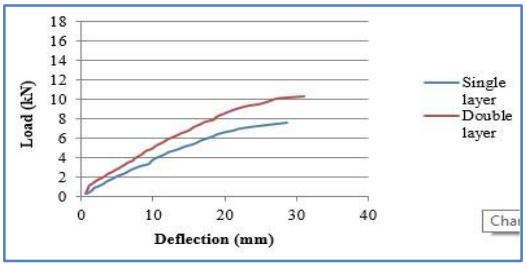

Fig 2.13 (a): Load vs. Deflection Behavior for FCS Slabs with Single and Double Layer of Mesh

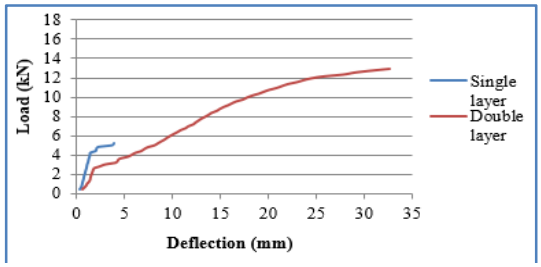

Fig2.13 (b): Load vs. Deflection Behavior for FGPS with Single and Double Layer of Mesh

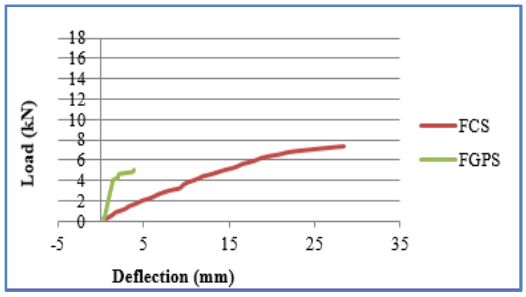

Fig 2.13 (c): Load vs. Deflection Variations for Different Slabs with Single Layer of Mesh

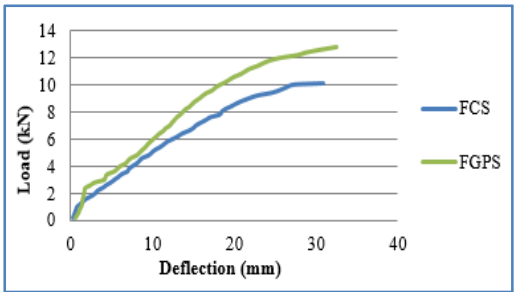

Fig 2.13 (d): Load vs. Deflection Variations for Different Slabs with Double Layer of Mesh

Figure 2.13 (a) to 2.13 (d) shows the load deflection curve for single and double layer of welded slabs with different mortar mixes. The comparison between different materials indicates that the load carrying capacity of slabs increases with increase in number of mesh layers.

2.6.2 Bottom Surface Crack Pattern

The failure of slab specimen results from the yielding of wire mesh reinforcement is followed by the crushing of mortar. Initially fine flexural cracks appeared at the bottom surface of the specimen. With further increase in the load, regularly spaced vertical cracks are observed and they extended from the bottom of the specimen towards the top. The load is increased up to ultimate stage and cracking pattern is observed.

Fig 3.5 (a): Bottom Surface Crack Pattern of Ferrocement Slab

Fig 3.5 (b): Bottom Surface Crack Pattern of Ferro-Geopolymer Slab

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2.6.3 Crack Width

The average central crack width is measured at ultimate load for all slabs. The measurement of maximum crack width is achieved with the help of Brinell microscope as shown in figure 2.14, Table 5 shows details of average central crack width observed in slabs.

Figure 2.14: Reading Crack Width Using Brinell Microscope

Table 5: Average Central Crack Width Observed in Slabs

Slab ID	Average Maximum Crack Width (mm)	
	Single Layer	Double Layer
FCS	0.8	0.667
FGPS	0.35	0.15

2.6.4 Stiffness (k)

Stiffness is the rigidity of an object, the extent to which it resists deformation in the response to the applied load. In this study, the stiffness of the test slabs is observed by calculating the ratio of load at first crack, P_1 to corresponding deflection, Δ_1.

The stiffness is defined by the Equation:

$$k = P1/\Delta 1$$

Table 6: Stiffness of Test Slabs

Slab ID	Stiffness (kN/mm)	
	Single Layer	Double Layer
FCS	0.435	0.675
FGPS	2.767	0.688

IV. CONCLUSIONS

The following conclusions were drawn from the detailed experimental investigations carried out on basic strength properties of geopolymer and cement mortar and flexural strength of ferro-geopolymer and ferrocement flat slabs.

- Compressive strength of steam cured geopolymer mortar specimens is higher than cement mortar specimens.
- The flexural strength of ferrocement specimen's increase with the addition of fly ash.
- The ultimate load carrying capacity of both Ferro-geopolymer as well as Ferrocement slabs increases with increase in layers of meshes. Slabs cast with two layers of welded mesh carried the maximum load.
- All slab specimens mostly have failed due to flexural cracks i.e., cracks are initiated at the bottom of the mid span which are mostly in flexure zone.

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- The ferrocement structural elements evolved in this study are having a simple cross section and it can be fabricated easily with the help of simple formwork.
- The use of weld mesh in the slab structure gives more strength.
- The flexural strength of double layer of ferro-geopolymer slab made by using river sand as a fine aggregate is 25% more than the ferrocement slab made by using same configuration.
- Delay in first crack load is observed in Ferro-geopolymer specimens as compared with Ferrocement slab specimens.
- Increase in the number of mesh in both ferrocement and ferro-geopolymer flat slabs increased the ductility and decreased the crack width.

V. ACKNOWLEDGMENTS

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