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Development of New Binder Matrix in Ferrocement Studies

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ABSTRACT
Ferrocement is a light weight structural thin member, Suitable for substituting wood and for structural elements of exotic shapes such as shells, chimneys, boats, etc. Ferrocement is proved as highly durable and ductile, but because of reinforcement distributed uniformly within the volume of matrix and very rich cement mortar is used, ferrocement tend to have very high Embodied Energy and Embodied Carbon dioxide Emission. These defects are completely eliminated in the innovative study presented in this paper. Portland cement is substituted with geopolymeric binders made from fly ash and slag powder. Ferrocement specimens produced with this new binder were found to have adequate strengths. In the present study, it was found that new ferrocement without Portland cement has almost similar or even sometimes superior properties in terms of strength, durability, etc. Compared to conventional ferrocement with Portland cement as binder very high durability of this new material was proved by accelerated corrosion test in SRM University. Even after 60 days of severe corrosion condition tests by alternate wetting (salt water) and drying cycle there was no measurable corrosion. These new composites can be used for making precast elements such as casting of water tanks, innovative architectural aesthetic constructions, faster low cost durable houses, corrosion resistant pipes for sewage lines, tunnel linings in metro rail, roads and irrigation techniques. The present development of new ferrocement can become an apt substitute for conventional ferrocement, but with very low carbon footprint.

Keywords
Ferrocement, Geopolymer, Corrosion, Durability, Carbon footprint.

1. INTRODUCTION
Ferrocement is a versatile structural material possessing unique properties of strength and serviceability. It is made with closely – knit wire mesh or chicken mesh and reinforcing bars (welded mesh) filled with rich cement mortar. The materials required for marking it, namely, cement, sand, wire mesh or chicken mesh and welded mesh are easily available in the market. It is possible to fabricate a variety of structural elements using ferrocement, which are thin, light in weight, durable and possess a high degree of impermeability. Ferrocement combines with lightness and mould ability of concrete and can be cast to any shape.

Ferrocement is a OPC based rich mortar, But OPC is not an eco-friendly binder material, Nearly 1 tonne of carbon dioxide is emitted while producing 1tonne of cement (High Embodied CO2 Emission content) Embodied Energy is also high. Hence there is a need for alternate eco-friendly binder system.

1.1 Geopolymer
A new binder material, known as geopolymer was first introduced by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure . He utilised silica (SiO2) and alumina (Al2O3) available in the specially processed clay (metakaolin) to get inorganic polymeric system of alumino-silicates. Unlike Ordinary Portland Cement, geopolymers do not need calcium-silicate-hydrate (C-S-H) gel for matrix formation and strength, but utilise the polycondensation of silica and alumina precursors to achieve required mechanical strength level.

Two main constituents of geopolymer (GP) are: geopolymer source materials (GSMs) and alkaline activator liquids. The GSMs should be alumino-silicate based and rich in both silicon (Si) and aluminium (Al) and thus, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc can form GSMs the processing conditions for GPCs are almost similar to Conventional Concretes (CCs) except that during mixing operations of GPCs, instead of water, a premixed alkaline solution, known as ‗Alkaline Activator Solution' (AAS), is added. Following materials were used to produce GPCs
(i) Fly ash,
(ii) Ground Granulated Blast Furnace Slag (GGBS),
(iii) Fine aggregates (in the form of river sand),
(iv) Alkaline Activator Solution (AAS) - a mixture of alkali silicates and hydroxides, besides distilled water.

2. MATERIALS AND METHODOLOGY
2.1. Materials
2.1.1 Cement
The cement used for this study is Portland Pozzolanic Cement is conforming to Indian Standard IS 12269 – 1987 of grade 53.

2.1.2 Fine Aggregate
The sand is used as fine aggregate and it is collected from nearby area. The sand has been sieved in 4.75 mm sieve.

2.1.3 Ground-granulated blast-furnace slag (GGBS)
It is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The chemical composition of a slag varies considerably depending on the composition of the raw materials

in the iron production process. Silicate and aluminate impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the blast furnace the slag floats on top of the iron and is decanted for separation. Slow cooling of slag melts results in an unreactive crystalline material consisting of an assemblage of Ca-Al-Mg silicates.

2.1.4 Fly ash

In the present study, Class F fly ash was used to function as part of the cement, though, it is commonly often used as a conventional Supplementary Cementing Material. The cementitious action of fly ash in the present study is due to the fact that the new matrix envisaged to be developed was likely to have very high W/C ratio and very low cement content, thereby, the fly ash can act more as a filler.

Table 1. Chemical composition of GSM

Chemical composition	Fly Ash Class F	GGBS
CaO	1.3	40.3
SiO_2	60.3	43.4
Al_2O_3	25.5	12.5
Na_2O	0.4	0.9
K_2O	0.8	0.6
MgO	0.8	1.5
Fe_2O_3	7.8	0.3
Specific Gravity	2.21	2.91

2.2. Alkali activated solution

The alkali activator solution is made from

10% - Sodium hydroxide solution.

20% - Sodium silicate solution.

70% - Distilled water.

Table 2. Properties of NaOH solution

% NaOH content	50% (by mass)
Density	1.5 Kg/l
Nature	Hygroscopic

Table 3. Properties of SSS solution

Chemical Formula	Na_2OxSiO_2
Appearance	Liquid
Colour	Light Yellow
Molecular Weight	184-254

2.3 Cement mortar

The basic cement mortar had a Cement: sand ratio of 1:2 with 0.45 water cement ratio (w/c). The amount of water used should be the minimum consistent with compatibility.

2.4. Geopolymer mortar

The basic materials required for preparing the geopolymer mortar is GGBS or Fly ash and the GSM: sand of 1:2 ratio with 0.45 ASM/GSM ratio is used in the present study.

3. STRENGTH CHARACTERISTICS

The study presents the compressive strength and structural behavior of ferrocement matrix.

3.1. Compressive strength

Table 4. Compressive strength of mortar

Specimen	% FA	28 days compressive strength
OPC	0	29.51
OPC	25	29.44
OPC	50	18.9
GPC	0	32
GPC	25	34
GPC	50	38

3.2. Flexural strength of Ferrocement panels

Ferrocement panels of size 500 X 100 X 25 mm is made with both conventional mortar and geopolymer mortar. The weld mesh of 3mm diameter is used with 2 and 4 layers of chicken wire mesh as shown in figure.

Figure 1. Ferrocement panels

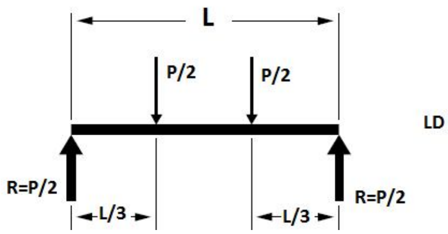

Figure 2. Two point loading on panels

Table 5. Flexural test of Ferocement panels

Specimens	% FA	No. of layers	Load at 1st crack (kN)	Load at 2nd crack (kN)
OPC	0	2	3	5
		4	3	5
GPC	0	2	3	6
		4	4	7
GPC	25	2	2	4
		4	3	5

Figure 3. Initial crack and Failure of panels

3.3. Structural load test of Ferrocement

Ferrocement slabs (1000 mm x 300 mm x 25 mm) is made with 2 and 4 layers of mesh.

Figure 4. Test setup of Ferrocement slabs

Table 6. Structural load test of slabs

Specimens	OPC		GPC (0% FA)		GPC (25% FA)	
No. of layers	2	4	2	4	2	4
Load (Kg)	Deflection (mm)					
100	1.11	1.42	0.23	0.28	0.14	1.32
200	1.96	2.61	0.41	0.49	0.34	2.08
400	3.8	4.23	0.69	0.72	0.73	4.28
600	5.88	6.68	1	1.09	1.18	6.16
800	7.65	8.58	1.29	1.33	1.65	8.4
1000	9.25	10.7	1.58	1.65	2.38	10.35
1200	10.7	12.7	1.88	1.92	2.98	12.57
1400	12.2	14.9	2.18	2.23	3.48	14.74
1600		16.9	2.49	2.51	3.9	16.5

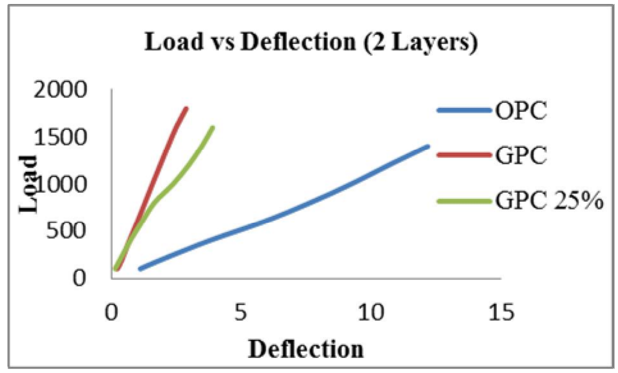

Figure 5. Load vs Deflection graph of slabs with 2 layers.

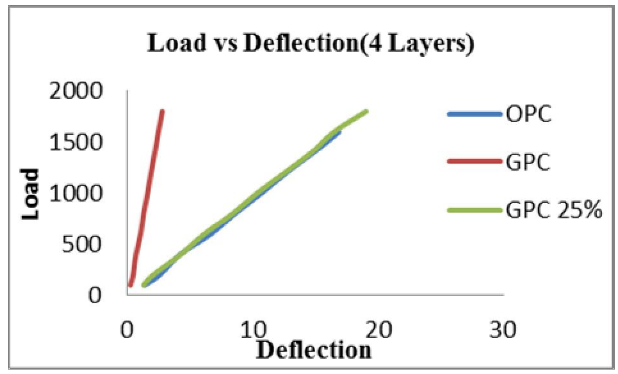

Figure 6. Load vs Deflection graph of slabs with 4 layers.

4. CORROSION TEST IN FERROCEMENT

Corrosion is the phenomena which causes deterioration of steel. The menace of corrosion has been increasing along with the increasing use of steel for various purposes such as building and construction, automobiles, ship building, transmission line and telecommunication towers, substation structures, bridges and jetties, irrigation structures like gates, water supply lines and pipes. This is a negative aspect of the use of steel. Against all these odds, a material called ferrocement has been developed, and it helps prevent corrosion. The most significant contribution of ferrocement is that most of the structures that are made of steel can also be constructed in ferrocement. Structures constructed in ferrocement will resist corrosion fully with nil/negligible maintenance. Ferrocement has been proved to be corrosion resistant material of construction when it is made skilfully with rich mortar low water- cement ratio and proper curing.

4.1 Corrosion specimens

OPC and GPC panels(150 mm x 150 mm x 25 mm) with 0%,25%,50% Fly ash. Meshes were treated by Soaking in AAS solution for 15 minutes and then drying for 24 hrs. The OPC specimens are cured in water for 3 days and Then oven dried at 60̊c for 24 hours, the specimens are Soaked in 5% Nacl solution to initiate the corrosion Process. The GPC specimens are cured in room temperature for 7 days and then soaked in 5% Nacl solution to initiate the corrosion process.

Figure 7. Ferrocement panels left for drying

The specimens are left for Alternate Wetting and Drying cycle (AWD). The AWD cycle is done by allowing the specimens to oven dry at 60°c for 8 hours and then soaking in 5% Nacl for 16 hours. The corrosion in the specimens are observed by visual observation and by measuring electrochemical potential.

4.2. Visual observation

Table 7. Visual observation of OPC

Specimen	OPC					
Mortar	1:2			1:4		
% FA	0	25	50	0	25	50
Type of mesh	Treated					
1st corrosion spot	9 days	20 days	25 days	3 days	20 days	28 day
Corrosion after 60 days	8 big spot	2 spots	2 spot	Major spots		

Table 8. Visual observation of GPC

Specimen	GPC					
Mortar	1:2			1:4		
% FA	0	25	50	0	25	50
Type of mesh	Treated					
1st corrosion spot	17 days	17 days	30 days	After 30 days		
Corrosion after 60 days	minute spot			Very minor spots		

Figure 8. Corrosion spots formed in specimens

4.3. Electro Chemical Potential measurement

Electro Chemical Potential measurement is done on the ferrocement specimens by using calomel electrode.

Table 9. Electro Chemical Potential- OPC

Specimens	OPC (1:2)			OPC (1:4)		
% FA	0	25	50	0	25	50
Mesh	Treated					
Potential on 60th day (mV)	-280	-220	-215	223	223	-44

Table 10. Electro Chemical Potential- GPC

Specimens	GPC (1:2)			GPC (1:4)		
% FA	0	25	50	0	25	50
Mesh	Treated					
Potential on 60th day (mV)	-246			46	49	

Higher –ve values of OPC martix indicates high rate of corrosion in the mesh.

Low –ve or more +ve values of Geopolymer matrix indicate the specimens are capable of resisting corrosion.

5. CONCLUSION

[1] Geopolymer is formed from industrial wastes such as Fly ash and GGBS (Ground Granulated Blast Furnace Slag).

[2] Geopolymer mortar can have strength simillar to conventional portland cement mortar.

[3] Strength behaviour of ferrocement with geopolymer mortar is almost simillar or higher than the portland cement mortar.

[4] The time of failure is high in GPC matrix, hence it is a highly ductile material.

[5] Ferrocement with cement mortar has more deflection than the ferrocement with geopolymer mortar, hence geopolymer matrix is a stiffer material.

[6] Ferrocement with geopolymer mortar do not have corrosion spot even after 60 days of severe AWD cycle.

[7] Ferrocement with geopolymer matrix is proved to be a highly corrosion resistant matrix than conventional cement matrix.

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