An Experimental Study on Behaviour of GGBS in Ferro-Cement Wall Panel

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***Abstract:* - The uses of prefabricated Ferrocement components increase engineering properties of the structure and reduce the cost of construction and completion time. Ferrocement is a versatile structural construction material possessing unique properties of strength and serviceability. It is made with closely-knit wire mesh steel reinforcing bars filled with rich cement mortar. Welded mesh may also be used in place of reinforcing bars. The materials required for making it such as cement, sand, wire mesh and mild steel reinforcing bars are easily available everywhere.Water permeability coefficient of the concrete mixed with ground granulated blast-furnace slag (GGBS) was investigated.**

***Keywords:* Ferro cement; Ground granulated blast-furnace slag**

I. INTRODUCTION

The shelter is one of the core needs of human being. With the use of locally available materials incorporate with the upgraded skills and technology without sacrificing strength, performance and life of the structure, we can implement new concept known as Low-cost housing which deals with effective cost controlling technique which deals in reducing the cost construction. There is huge misconception that low-cost housing is suitable for only substandard works and they are constructed by utilizing cheap building materials of low quality. The reality is that by proper management of resources the Low-cost housing is executed. Ferrocement can be adapted to many different functions or activities of structural construction material possessing unique characteristics of strength and serviceability. With closely tightened wire mesh steel reinforcement impregnated with rich cement mortar. Cement, aggregate, wire mesh are easily available everywhere for its construction. It is possible to fabricate in Ferrocement a variety of structural elements which are thin, light and durable and possessing a high degree of impermeability. It can be cast into any shape due to the lightness of steel and mouldability of mortar. No level of earthquake resistance can guarantee that an earthquake will not blemish a building. Good seismic resistant design will minimize structural damage and the most importantly, protect the lives of the occupants during a major seismic circumstance.

Fig 1 Ferrocement House

Ground-granulated blast-furnace slag (GGBS) is a cementitous material residue obtained by carefullyquenchingmolten iron slagfrom a blast furnace in waterto produce a glassy, granular product that is then dried and ground into a fine powder.

II. OBJECTIVE

- To study strength behaviour of normal Ferrocement wall panel with cement partially replaced by GGBS.
- To compare durability behaviour of normal mortar with cement partially replaced by GGBS by Water permeability Test.
- To study thermal efficiency of normal mortar with cement partially replaced by GGBS mix wall panel.

III. SCOPE

The wall panel samples were of size 1mX1mX0.05m with the single layer of two types of welded steel wire meshes. Loading is applied to wall panels of capacity 50 tonnes after 56 days by the uniformly distributed load on top and bottom supports. Water permeability and thermal coefficient of normal OPC mortar and 50% GGBS replaced mortar are analyzed.

IV. JOURNAL REVIEW

Lakhan Murari and Elson John (2015) studied the performance of prefabricated Ferro-cement wall panels. In present condition time and price is one of the major factors in the construction industry. Buildings have to construct with sufficient capacity in the maximum short period and in cheaper price. In such conditions, different construction techniques will be applied to obtain the goals like Ferrocement used for construction solves the problem of cost while prefabrication solves the problem of speedy construction. It was also observed that the use of wire mesh as reinforcement in Ferrocement increases the crack pattern in the case of slabs. Based on results obtained from the study, it can be concluded that the prefabricated Ferrocement hollow wall panels may be used for the construction of low-cost housing and it is also cheaper compared to RCC elements of similar size. With use of Ferro cement elements, the dead load can be reduced for a building.

This research work is mainly focused on developing a small single room house. Muhammad Ali Zafar (2015), Ferrocement beams and wall panels are recommended as the main structural elements. Based on the analysis on ETABS software and experience it is stated that this type of structure will not only be suitable for temporary use but for permanent construction as well. Its behaviour under a major seismic activity is satisfactory. It can bear the shock with little or no damage. By minimizing the loss of life and property, direful failure can be avoided in any case.

Wail N. Al-Rifaie et al. (2014), proposed modern method of Eco-Housing Construction (Ferro cement System). Urban development is a key consumer of energy, a structural system based on generic services facilities are introduced by Al-Rifaie and prefabricated Ferro-cement cavity wall and roof panels within the proposed system present a series of possibilities for the solution of building construction at the maximum reduction of the electrical energy. The energy required to run the building using the proposed Ferrocement construction system and the use of the traditional method of construction is determined. It is concluded that the Ferro-cement eco-housing system method is able to produce very energy efficient dwellings.

In this paper, Kantharaju et al. (2001) had made an attempt to promote the substantial use of Ferrocement components as a substitute to conventional concrete components for application in the housing suitable for developing countries. Ferrocement products are an ideal substitute for wood and they can be extensively used in various components of a housing like a door, roofing etc. In India, by using Ferrocment products in place of conventional wood or reinforced cement concrete components the cost of construction has been reduced to 20 to 40%. Developing countries where mass social housing projects are being taken up the use of Ferro cement components would go a long way in helping them to build houses at an economical cost and also at a faster rate.

In this study, Yasutaka Sagawa et al. (2010) the specimens which include normal strength concrete and high strength concrete were examined by changing water to binder ratio. The effectiveness of GGBS on strength and chloride ion diffusion coefficient was measured by migration test. Moreover, the application of GGBS for pre-stressed concrete bridge superstructures was presented. GGBS can increase the resistance to water penetration and chloride penetration and thus the durability of concrete structures can be improved. Also, the use of GGBS for concrete material contributes to the saving the natural resources and energy in cement manufacturing process and to reducing CO2 emissions and environmental impact. Due to the increase in the strength of GGBS concrete at the early stage is smaller, they are rarely used for bridge superstructure construction. While some applications to pre-tensioned concrete have been reported, the application to post-tensioned concrete has been very few. The more positive use of GGBS has been required.

D. Suresh and K. Nagaraju (2015) studied that the GGBS mixes are highly resistant to aggressive environments such as silage pits. Due to the movement of moisture of GGBS mixes, probably due to the dense and strong microstructure of the interfacial aggregate to binder transition zone the property has attained. The mineral composition of GGBS cement paste like fewer aluminates and portlandite than Portland cement probably contributes to this resistance. The GGBS is a good replacement for cement in some cases and serves effectively but it can’t replace cement completely. But even though it replaces partially it gives very good results and a greener approach to construction and sustainable development which we are engineers are keen about today.

V. MATERIALS USED

CEMENT

A cement is a binding material used for construction that sets, hardens and cling to other materials. They are rarely used on its own but rather to bind aggregates together. Cement is used with fine aggregate to produce mortar for masonry and with coarse aggregates to produce concrete. Portland cement is the most common type of cement in general use. It is a basic ingredient of concrete, mortar and most non-speciality grout. They may be grey or white in colour. Due to high alkaline nature of cement, cement bags are printed with health and safety warnings on them. But it is exothermic. As a result, wet cement is strongly caustic and can easily cause severe skin burns if not promptly washed off with water. Severe respiratory and eye irritations occur when dry cement powder is in contact with them. Cement users need to wear appropriate gloves and protective clothing.

Fig 2 Ordinary Portland Cement

GROUND GRANULATED BLAST FURNACE SLAG

GGBS is one of the greenest of construction materials. Its only raw material is a very specific slag that is a byproduct from the blast furnaces manufacturing iron. Manufacturing of GGBS utilizes all of the slag and produces no significant waste. As well as the environmental benefit of utilizing a byproduct GGBS replaces something that is produce by a highly energy intensive process. By comparison with Portland cement, manufacture of GGBS requires less than a fifth the energy and produces less than a fifteenth of the carbon dioxide emissions. Further green benefits are that manufacture of GGBS does not require the quarrying of virgin materials and if the slag was not used as cement it might have to be disposed of to tip. Mortar containing GGBS is less permeable and chemically more stable than normal concrete. This enhances its resistance to many forms of deleterious attack.

Fig 3 Ground Granulated Blast Furnace Slag

FINE AGGREGATE

The fine aggregate is an accumulation mineral grains derived from the disintegration of the rocks. The fine aggregate is different from the clays which contain organic particles in it. The gravel is only distinguished by the size of its grains. By using the water current or using the wind across the land passing on to the sand, it will be washed and been sorted out to uniform grain size. Mainly the commercial sand is obtained from river beds originally formed by wind actions. The sands are usually quartz or siliceous materials. The 98 % silica sand is the most useful commercial sand.

WATER

Water is also an essential ingredient in the mortar as it actively participates in the chemical reaction with cement. The water used should have pH value lying in between 6 and 8, and it should be free from organic matter. The water used for mixing and curing was clean and free from impurities. Potable water is generally considered satisfactory for mixing. The minimum water/cement ratio required is 0.30. The water/cement ratio is the key factor that determines the strength of concrete. Portable clean drinking water available in the water supply system was used for casting as well as for curing of the test specimens. Here we adopted 0.45 W/C for mortar mix.

STEEL WELDED MESH

Welded steel wire mesh of two aperture sizes were used for the specimen casting.

Fig 4 Steel Welded Mesh 1

Fig 5 Steel Welded Mesh 2

VI. METHODOLOGY

MATERIAL TESTING

CEMENT

The cement used for study is Chettinad Cement (OPC) and its properties are studied. All the tests are carried out in accordance with the procedure given by Indian standard specifications. The specific gravity of cement are shown in Table 1

Table 1: Specific gravity of OPC

Sl. No	Characteristics	IS Specification	Values Obtained
1	Specific Gravity	As per IS 2780-Part 3, the specific gravity of cement is in between 3.1 – 3.15	3.12

GGBS

The GGBS used for study is JSW GGBS and its properties are studied. All the tests are carried out in accordance with the procedure given by Indian standard specifications. The specific gravity of cement are shown in Table 2

Table 2: Specific gravity of GGBS

Sl. No	Characteristics	IS Specification	Values Obtained
1	Specific Gravity	As per IS 2780-Part 3, the specific gravity of cement is in between 3.1 – 3.15	2.87

FINE AGGREGATE

The fine aggregate used was M-Sand in the cement mortar. The physical properties of fine aggregate are shown in Table 3

Table 3: Specific gravity of Fine aggregate

Sl. No	Characteristics	IS Specification	Values Obtained
1	Specific Gravity	As per IS 2386-1963, Part 3, the specific gravity of cement is in between 2.6-2.7	2.67
2	Fineness modulus	According to IS 383-1970 clause 4.3, the fineness modulus of fine aggregates ranges from 2.2 to 2.6 for fine sand	2.93
3	Grading Zone	As per IS 383-1970 Table 4, the fine aggregate is divided into four zones namely Zone I, Zone II, Zone III and Zone IV	Zone I, were the fine and coarse aggregate ratio is reduced.

WELDED MESH

(i) Gauge thickness

Gauge of welded meshes are measured by Screw Gauge Test. Screw Gauge is an instrument which is used for measuring accurately the diameter of a thin wire or the thickness of a sheet of a metal. Screw driver consists of a U-shaped frame fitted with a screwed spindle which is attached to a thimble. Parallel to the axis of the thimble, a scale graduated in mm is engraved. The gauge values are shown in table 3.2.

(ii) Centre to centre Spacing

Centre to centre spacing of welded meshes are measured using Verinier calliper test. A vernier caliper is a measuring device used to precisely measure linear dimensions. It is a very useful tool to use when measuring the diameter of round objects, spacing of meshes etc. because the measuring jaws can be secured on either side of the circumference. The center to center spacing of welded meshes are shown in Table 4.

Table 4: Center to center spacing of welded mesh

	Reading Along Longitudinal Direction		Reading Along Transverse Direction	
	Mean of Gauge value, (mm)	Centre to centre spacing of mesh, (mm)	Mean of Gauge value , (mm)	Centre to centre spacing of mesh, (mm)
MESH 1	1.28	17.55	1.23	17.57
MESH 2	2.20	18.20	2.04	38.49

(iii) Tensile Strength

The tensile test on the steel was done and the ultimate tensile load of the steel was obtained. The tensile strength was calculated from the tensile load. The tensile strength specimen was prepared such that the specimen has the maximum length between 38- 45 cm. The steel has the total cross section of 1.24mmϕ, 1.28mmϕ, 2.21mmϕ and 2.04mmϕ. A total of 3 specimens were tested and the specimen was tested using the Hydraulic UTM available in the laboratory. The ultimate tensile load of the specimen and the corresponding strength of the steel was calculated and is given in Table 5

Fig 6 Two types of mesh steel for tensile test

Fig 7 UTM for tensile test

Table 5 Tensile Strength of steel of welded mesh

Type of Mesh	Sl. No.	Diameter of Steel (mm)	Cross sectional Area of steel (mm^2)	Average Tensile Strength (N/mm^2)
Mesh 1	1.	1.24	1.95	772.65
	2.	1.28	2.01	769.49
Mesh 2	1.	2.21	3.47	870.32
	2.	2.04	3.20	864.59

Fig 8 Steel of Mesh 1 break after limit

Fig 9 Steel of Mesh 2 break after limit

MIX PROPORTIONS AND COMPRESSIVE STRENGTH

Mortar cubes of size 70.6mm x 70.6mm are casted and tested at 7 and 28 days for finding compressive strength. Mortar mixes with 6 specimens of normal OPC and different proportions of GGBS like 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% are added to replacement of cement are done.

Fig 10 Specimens of mortar mixes after casting

According compressive strength of cement mortar are compared with different grades and the optimum content of GGBS in cement mortar is found out. Tests are carried out by Compression Testing Machine (CTM) with capacity of 2000kN.

Fig 11 Compression Testing Machine

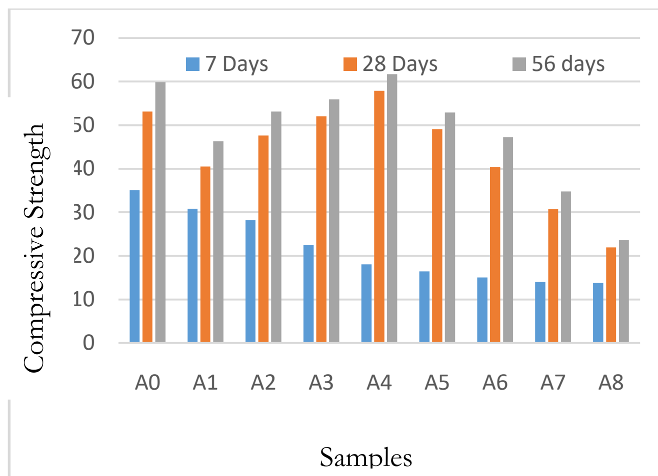

Fig 12Analysis on Compressive Strength results

Compressive strength of mortar cubes for 28 days curing are done and sample A4 got maximum compressive strength of 57.92 N/mm^2. So optimum condition of GGBS in cement mortar is 50% partial replacement.

(i) CASTING OF SPECIMENS

(a) Mortar Mix

One of the main constituents of Ferro-cement is cement mortar. The cement mortar impacts the compressive strength to the Ferro cement structure. The ratio of binder to fine aggregate was 1:3 and the water/cement ratio was taken as 0.45.

(b) Details of Specimen

The size of the Ferro cement wall panel sample is taken as 1000mm x 1000mm x 50mm based upon LakhanMurari and Elson John (2015) in order to find its load carrying the capacity. Three specimens were casted- Ferro cement wall panel and Ferro cement wall panel with cement partially replaced by GGBS of two types of welded wire meshes. Each of three samples are casted and its average strength value is considered.

Wall panels with Mesh 1 are casted with 1.28mm thick at 17.55mm center to center spacing and 1.23mm at 18.20mm spacing.

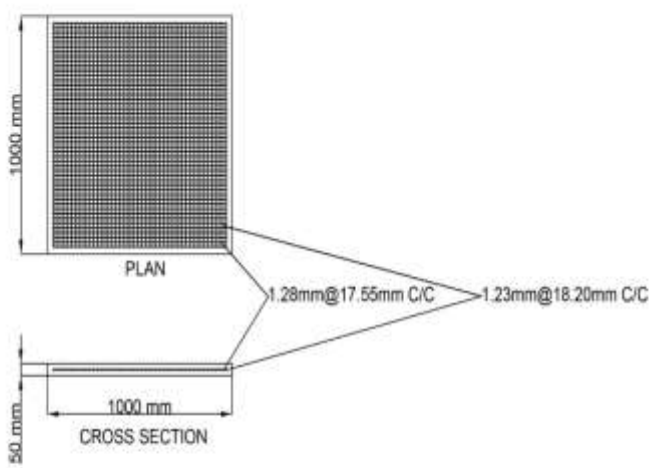

Fig 13 Wall panel details with Mesh 1

Wall panels with Mesh 2 are casted with 2.20mm thick at 18.20mm center to center spacing and 2.04mm at 38.49mm spacing.

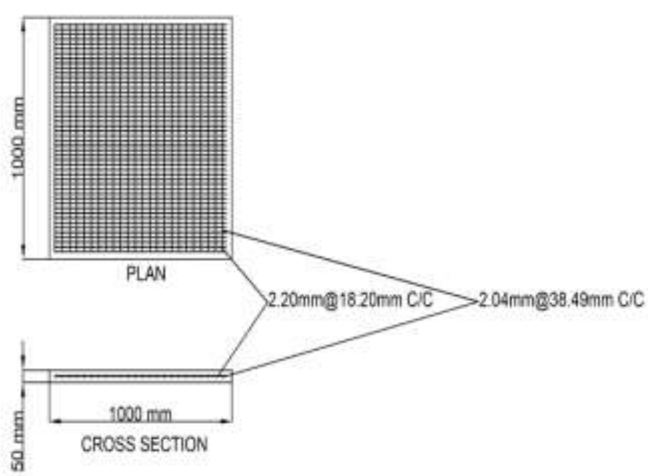

Fig 14 Wall panel details with Mesh 2

(c) Casting of Specimens

Before casting specimens, first of all we have to prepare the mould according to specified shape and size. Moulds are made by12mm thickness plywood with the help of external supports.

Fig 15 Preparation of mould

For preparing cement mortar every material was weighed and 20% extra was taken for any case of wastage and shrinkage of mortar. Mixer machine is using for mixing the materials; the mixer is first cleaned and kept wet in order not to allow the absorption water added to the concrete. For mixing, the mixer is first loaded with fine aggregate and then with cement. Then water is added slowly in order to obtain a uniform mix. The resulting cement mortar is uniform in appearance. Then the mortar is transferred to the moulds.

Fig 16 Placing first layer of mortar

For casting of wall panels, the first layer of mortar was filled up to half portion of thickness required, ie 25mm with the help of trowel.

Fig 17Placing the steel mesh

Then steel mesh was placed and over which another layer of mortar was placed over it. This was done in order to arrange the steel mesh uniformly between the mortar layers.

Fig 18Placing the last layer of mortar

Finally levelled surface is finished evenly such that no water is ponded to any particular area of wall panel.

Fig 19Finishing the outer surface of slab

Proper curing is done after 24 hours of casting with help of covering panels surfaces with sack fabric. Thus the exposed surface is prevented from drying out. These are periodically wetted. It is ensured that the surface of panel is not allowed to dry even for a short time during the curing period.

Fig 20Curing process of Wall panels

After the curing period, specimens are shifted very carefully without any damage for testing on loading frame.

Fig 21 Wall panels after curing

(d) TESTING OF SPECIMENS

- *Loading Frame*

The specimens casted were tested for their break load capacity using Universal testing machine of capacity 500kN after 56 days. The apparatus used for testing the specimen is a loading frame of capacity 50 tons. The loading frame consisted of steel frames to transfer the load to foundation and pumps and jack to apply the load to specimen.

Fig 22 Loading Frame

- *Breaking Load Capacity*

The specimens casted were tested for their breaking load capacity. The specimens were placed on the loading frames of UTM vertically. The load was applied at a constant rate without shocks and increased continuously in uniform distributed loading. Load applied was measured using dial gauge with 0.1 ton accuracy.

Fig 23 Wall panel placed in loading frame for testing

(e) WATER PERMEABILITY TEST

As per IS 3085-1965 Water permeability tests are carried out. The test consists in subjecting the mortar specimen of known dimensions, contained in a specially designed cell to a known hydrostatic pressure from one side measuring the quantity of water percolated through it during a given interval of time and computing the coefficient of permeability. The test permits measurement of water entering the specimen as well as that leaving it.

Fig 24 Water permeability testing apparatus

Mortar cubes with two types of specimens- normal OPC mortar and 50% GGBS (optimum content) partial replaced mortar of size 150mm x 150mm x150mm are casted and tested after 56 curing days.

Fig 25 Cubes casting on vibrating table

Cubes are casted on vibrating table confirming Indian standards such that uniform vibration are applied to mould surfaces frequently. Three mortar cubes for each specimens are casted simultaneously.

Fig 26Cubes before demoulding

The mortar cubes are allowed for curing process after 24 hours of casting. Curing is allowed for 56 days. After the curing period cubes are shifted from curing tank and allowed to dry before water permeability test is started.

Fig 27 Curing of Cube

This test consists in subjecting the mortar specimen of known dimension, contained in a specially designed cell, to a known hydrostatic pressure from one side, measuring the quantity of water percolating through it during a given interval of time and computing the coefficient of permeability.

Fig 28 Cubes after curing

Then the specimen has thoroughly cleaned with stiff wire brush to remove all dust particles. They are surface dried, centered in the cell.

Fig 29 Cell after placing and centering of cube

Fig 30 Preparation of Bee wax

Pure Bee-wax is collected from beekeeper and melted into liquid state using induction cooker. The wax is heated such that it is not over burned.

Fig 31 Pouring process of Bee wax into cell

A mixture of bees-wax and cotton is melted and poured in extra space remaining in the cell in three layers and are allowed to cool. However the wax is cooled, it shrinks. Special care is taken in pouring process such that no wax is poured over the mortar cube. Because we have to check water permeability test. Wax is good insulator for water. So wax over specimen can reduce its water permeability. Thus the wax is poured into gap after placing thick paper over top surface of cube.

Fig 32 Melted Bee-wax after cooling

The seal has been checked very conveniently by bolting on the top cover plate, inverting the cell and air pressure of $1 kg/cm^2$ has been applied.

Fig 33 Cell placed after sealing of specimens

When wax is found to be fully sealed, all the three cells are assembled for testing. Compressed water inlet hose from water reservoir is connected to top of cells after top covers are fixed tightly. Three measuring cylinders are placed below each cells. It gives quantity of water which are penetrated through the specimens. Test temperature should be $27^0 \pm {}^0C$ with the system completely filled with water, desired pressure of $5kg/cm^2$ for 100 hours. The test permits measurement of the water entering the specimen as well as that leaving it.

Coefficient of permeability, $K = \frac{Q}{AT\frac{H}{L}}$

where

K = coefficient of permeability, cm/sec

Q = quantity of water percolating over entire period of test after steady state has been reached, mm

A = area of specimen face, cm^2

T = time over which Q is measured, sec

H/L = ratio of head to thickness of specimen

(f) Thermal Conductivity Test

Measurement of thermal conductivity is done at transient condition. Here a square prism specimen of size 10cm x 10cm x 5cm was used for finding the thermal conductivity of the Ferrocement. The experimental setup consists of heating unit, power supply and display unit as shown in figure. Here one end of the specimen was heated using a source and the heat supplied can be found out from the sensors attached to the heating element. At a particular distance two sensors were placed in order to find out the temperature difference between those points. From the heat supplied, temperature difference and the area of specimen the thermal conductivity can be found out using the below equation.

$$k = \frac{q * d}{A(T_1 - T_2)}$$

where

k = thermal conductivity of the specimen, W/mK;

q = quantity of heat passed (W);

d = distance between the sensors (m);

A = area of the specimen (m^2);

T_1 = temperature at first point (K);

T_2 = temperature at second point (K).

Fig 34 Experimental setup for thermal conductivity

First of all mould of size 100mmX100X50mm is prepared and cleaned. Then first layer of well mixed mortar is placed and levelled. Welded mesh of size after reducing 10mm cover from all four sides are placed over it.

Fig 35 Placing mesh after first layer of mortar

Compaction is made by surface vibrator. Second layer of mortar is well levelled and finished. After 24 hours, panels are demoulded and placed for 56 curing days.

Fig 36 Panel specimen for thermal conductivity testing

VII. RESULTS AND DISCUSSION

In the present investigation, an attempt has been made to determine the performance of GGBS Ferro cement wall panels for the purpose of prefabrication by examining their breaking load capacity. For this specimen were cast and tested. To check the practicality of GGBS Ferro cement wall panels are casted and the strength and cost analysis were done to compare them with normal Ferro cement panels. The compressive strength of the cement mortar gives idea about mortar characteristics. By the result of this single test we can judge that whether this casting has been done in a proper manner or not. The compressive strength of the mortar cubes depends on the factors such as mortar strength, quality of raw materials, water cement ratio and the quality of mortar during production.The results obtained from the testing of the specimens were tabulated and analysis of the strength was done.

(a) COMPRESSION STRENGTH RESULTS

The compressive tests for the specimens were done and the compression yield load after failure was obtained from the dial gauge. The compressive tests were done for 3 sets of mortar cubes with 0%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% of replacement of OPC with GGBS. The specimens were loaded at a rate of 0.14 to 0.32 MPa per second. The compressive strength of the specimens were calculated using the equation,

$$Compressive\ strength = \frac{\text{Compressive load after failure}}{Area\ of\ specimen}$$

Table 6 Mix Proportions and Compressive strength of Mortar cubes

Sample Mixture	OPC	GGBS	Quantity of materials required for one mortar cube (70.6mmx70.6mm) in grams				Compressive strength at 7 days curing	Compressive strength at 28 days curing	Compressive strength at 56 days curing
			OPC	GGBS	Fine Aggregate	Water			
A0	100%	-	200	-	600	90	35.04	53.10	59.86
A1	80%	20%	160	40	600	90	30.84	40.53	46.28
A2	70%	30%	140	60	600	90	28.18	47.62	53.10
A3	60%	40%	120	80	600	90	22.47	52.04	55.91
A4	50%	50%	100	100	600	90	18.06	57.92	61.73
A5	40%	60%	80	120	600	90	16.45	49.09	52.90
A6	30%	70%	60	140	600	90	15.05	40.40	47.28
A7	20%	80%	40	160	600	90	14.05	30.77	34.78
A8	10%	90%	20	180	600	90	13.78	21.91	23.61

A graph is plotted between Compressive strength of mortar cubes for different mixes with curing period of 7, 28 and 56 days are evaluated.

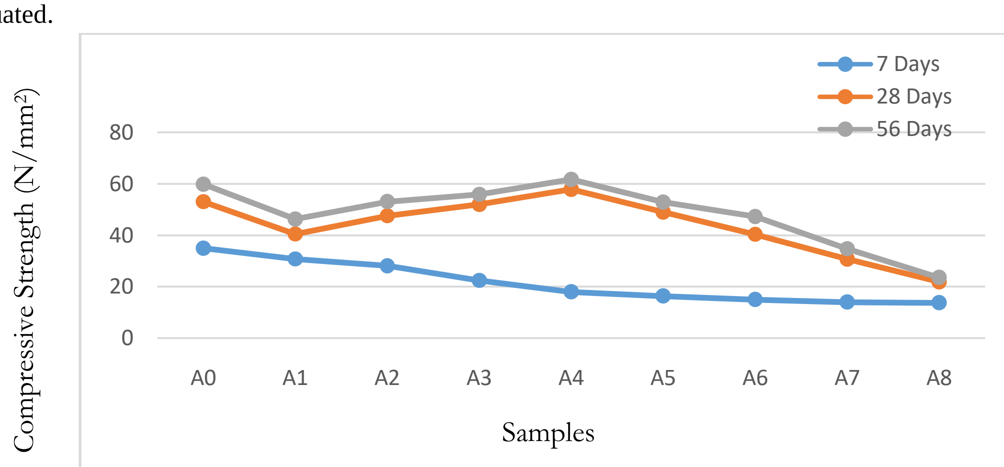

Fig 37 Compressive strength of Mortar

The compressive strength test was done and the results were tabulated. From the analysis of the results obtained, it was concluded that the specimen with 50 % replacement of OPC with GGBS achieved more strength than other replacements. The mineral composition of GGBS cement paste probably contributes to this resistance. As we have seen GGBS is a good replacement to cement in some cases and serves effectively but it can't replace cement completely. But even though it replaces partially it gives very good results and a greener approach in construction and sustainable development which we are engineers are keen about today.

(b) BREAKING LOAD CAPACITY

The specimens were casted in the laboratory. The wall panel samples of size 1mX1mX0.05m with the single layer of two types of welded steel wire meshes. Three samples of each specimens were prepared, cast, tested and results are noted. The samples were tested using Universal Testing Machine of 50 tonnes capacity after 56 curing days. The load carrying capacity of wall panels obtained after testing is as given in table 7. Crack pattern after testing is as shown below from figure 38 to figure 41.

Fig 38 Mesh 1 OPC mix wall panel

Fig 39 Mesh 2 OPC mix wall panel

Fig 40 Mesh1 A4 mix wall panel

Fig 41 Mesh2 A4 mix wall panel

Table 7 Test results of wall panels

TYPE OF WALL PANEL	DESIGNATION	INITIAL CRACK (kN)	FAILURE LOAD (kN)
OPC mortar mix wall with Mesh 1	OPC S	287.5	297.5
A4 mortar mix wall with Mesh 1	A4 S	305.5	319
OPC mortar mix wall with Mesh 2	OPC B	391	400.5
A4 mortar mix wall with Mesh 2	A4 B	435	440.5

From test results, it is clear that use of Mesh 2 will increase wall panel strength from 25% to 28%. Due to high gauge thickness and tensile strength of Mesh 2 is major reason. And also use of GGBS played another supreme role in increasing 10% its strength.

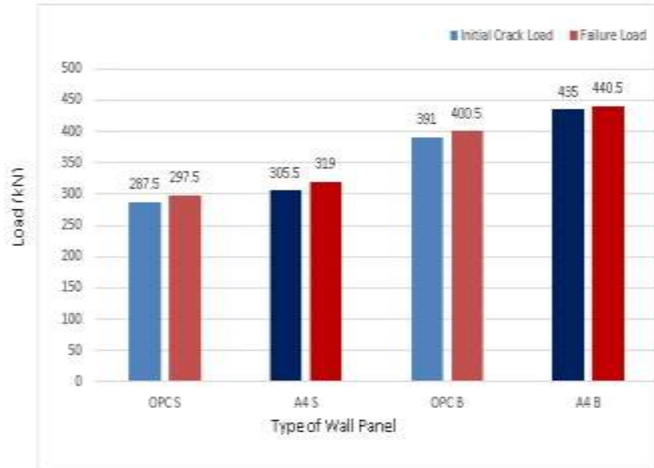

Fig 42 Load carrying capacity of Wall panels

(c) COEFFICIENT OF PERMEABILITY

Property of a material that lets water to diffuse through it to another medium without being chemically or physically affected is known as permeability of a material. Thus we are testing water permeability of different types of mortar cubes using water permeability test. After removing pressurized cubes from the cell, they allowed for testing procedure.

Fig 43 Mortar cube placed in CTM for permeability depth check

Finally mortar cubes are placed in Compression testing machine (CTM) for finding depth of permeability of water. Two round rods are placed on top and bottom surface of cube.

Fig 44 Mortar cube after splitting in CTM

A slow steady load is applied to split cube into two. After splitting specimens are placed depth of percolation of water is measured using a measurement ruler

Fig 45 Water permeability of normal OPC mortar mix

The quantity of water percolated through the normal OPC mortar mix is found to be 15mm.

Fig 46 Water permeability of A4 mortar mix

The quantity of water percolated through the normal OPC mortar mix is found to be 5mm. From this result itself, we can say that water permeability of GGBS replaced mortar mix is lesser than that of normal OPC mortar mix.

Table 8 Coefficient of Permeability

Type of Mortar mix	Coefficient of Permeability
OPC Mortar mix	$1.811x10^{-6}$
A4 Mortar mix	$5.761x10^{-6}$

Coefficient of water permeability of A4 mortar mix has reduced upto 3.5 times that of normal OPC mortar mix. Mortar containing GGBS is less permeable and chemically more stable than normal mortar. This enhances its resistance to many forms of deleterious attack. The reaction between GGBS, Portland cement and water are complex. When OPC reacts with water, the insoluble hydration products form close to the cement particle. The more soluble product of hydration (Calcium hydroxide) migrates through the pore solution and precipitates as discrete crystals surrounded by large pores. When GGBS particles are mixed, both the GGBS and OPC hydrate to form calcium silicate hydrates. Additionally, the GGBS react with the excess of calcium hydroxide to form a finely dispersed gel which fills the larger pores. The result is a hardened cement paste which contains far fewer calcium hydroxide crystals and therefore has fewer large capillary pores. The reduction in free calcium hydroxide makes concrete chemically more stable and the finer pore structure limits the ability of aggressive chemicals to diffuse through the concrete.

(d) THERMAL CONDUCTIVITY

Thermal conductivity testing apparatus is used for measuring thermal conductivity of normal OPC mix wall panel and A4 mix wall panels with the two types of welded meshes. It was found out by specimens of size 100mmX100mmX50mm.

Table 9 Thermal conductivity results

Type of Wall panel	Average Thermal Conductivity (K/Mk)
OPC S	0.33
A4 S	0.29
OPC B	0.41
A4 B	0.37

The thermal conductivity of normal OPC mix Ferrocement wall panel is found to be more thermal conductive as compared with A4 mix Ferrocement wall panel. Due to high silica and aluminate content thermal coefficient of GGBS mixed mortar panels have reduced upto 25%. When we are adopting Mesh 2, its thermal transfer is increased. Quantity if steel per unit are mesh 2 is higher than mesh1.

(e) COST COMPARISON OF WALL PANELS

Cost Comparison of raw materials required for two types Ferrocement wall panels are shown in Table 10

Table 10 Cost Comparison

Type of Mix	Total Cost (Rs.)
OPC Mix	2463/-
A4 Mix	2340/-

From table we can say that A4 Mix is 6% more economic as compared with normal OPC Mix Ferrocement wall panels.

VIII. CONCLUSIONS

Literature reviews are done. Tests on materials and their results are tabulated. Mix proportioning is done for normal control mix OPC mortar (1:3) for water-cement ratio 0.45. By comparing the compressive strength of different grades like 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% replacement of GGBS with OPC of cubes, the optimum condition is confirmed and Ferro-cement wall panel samples are casted.

Ground granulated blast furnace slag (GGBS) is one of the greenest of construction materials. From test results, it is clear that use of Mesh 2 will increase wall panel strength from 25% to 28%. Due to high gauge thickness and tensile strength of Mesh 2 is major reason. And also use of GGBS played another supreme role in increasing 10% its strength. Mortar containing GGBS is less permeable and chemically more stable than normal concrete. Coefficient of water permeability of A4 mortar mix has reduced upto 3.5 times that of normal OPC mortar mix. This enhances its resistance to many forms of deleterious attack. The thermal conductivity of A4 mixed wall panel have reduced upto 12%. Ferrocement wall panels made by A4 Mix is 6% more economic as compared with normal OPC Mix panels.

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