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Original Research Paper

Engineering

INVESTIGATION ON LIGHT WEIGHT FERROCEMENT BEAMS UNDER MONOTONIC AND REPEATED LOADING

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ABSTRACT A Light weight ferrocement is a composite material consisting of cement-sand mortar (matrix) along with light weight fine aggregate (In this research blast furnace slag is employed as light weight fine aggregate) as a replacement of sand in some quantity and reinforced with layers of small diameter wire meshes . These studies mainly attempt to determine the first crack strength, ultimate strength and the influence of mesh wires on some of these properties. This work has been proposed to investigate on the Load-Deflection and Moment-Curvature characteristics of lightweight ferrocement in monotonic and repeated loading. These results are expected to be useful in a better understanding of the flexural behaviour of lightweight ferrocement and in the design of such members subjected to monotonic and repeated loading.

KEYWORDS : Blast furnace slag, Light weight ferrocement,Monotonic load,,Repeated load and wire mesh.

I.INTRODUCTION

A Light Weight Ferrocement is a Composite material in which the filler material is cement mortar and Blast Furnace Slag. It is brittle in nature, and the reinforcement consists of wire meshes and/ or steel bars of small diameter. Since ferrocement units are thin, ranging from 20mm to 50mm, thermal comfort is one of the aspects to be borne in mind while designing or adopting ferrocement for building construction. Replacement of sand by lightweight aggregate (L.W.A) would improve the thermal comfort inside the building with such ferrocement elements.

Ferrocement has high resistance against cracking, also many of its engineering properties such as toughness, fatigue against resistance, and impermeability etc, are improved when compared to reinforced concrete. Light Weight Ferrocement has been successfully used in water tanks, sunshades, secondary roofing slabs, shells, boats, pipes, marine structures etc.

A ferrocement hull can prove similar to or less weighty than a fiber reinforced plastic (fiberglass), aluminum, or steel, hull. New methods of laminating layers of cement and steel mesh in a mould may bring new life to ferrocement building.

II.RESEARCH SIGNIFICANCE

Light weight Ferrocement elements are generally more strength when compared to the conventional reinforced concrete elements due to the fact that, reinforcement is uniformly distributed over the entire section of the elements. But the post peak portion of the load- deflection curve of bending test of ferrocement elements reveals that the failure occur either due to mortar failure in compression or due to the failure of extreme layers of mesh . So, an attempt has been made to study the Strength behavior of ferrocement Beam with the ferrocement concrete materials and Blast furnace slag..This paper provides information regarding Deformation characteristics such as Load Deflection and Moment Curvature of ferrocement Beam.

III. EXPERIMENTAL INVESTIGATION

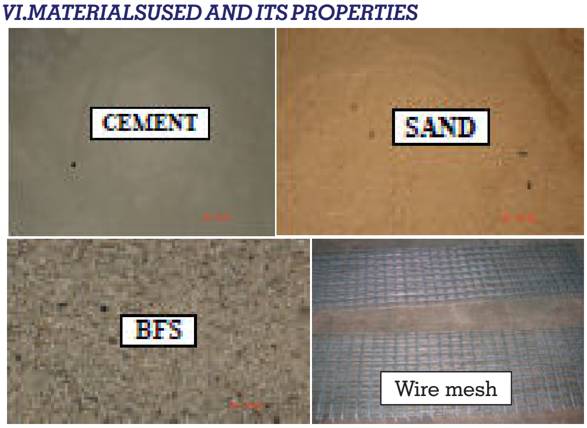
Variable Parameters

The primary variables considered in the Work included i) Number of Layer of square mesh reinforcements 2 layers and ii)Effect of Blast furnace slag in concrete by replacing sand by 0%, 10%,20%&30%. Under monotonic and repeated loading

Test specimens

A total of 24 Number of specimens of Light Weight Ferrocement Beams were cast and are tested. All specimens have a dimension of 100mmX1000mm with a thickness of 50mm each. The thickness of slab were kept constant and the parameters such as number of layers of wire mesh reinforcement (2 - layered reinforcement), and the concrete mix with and without Blast furnace slag (0 to 30%). The specimens were designated as show in Table 1 shows the details of the varying parameters used in the Ferrocement Beam in the present investigation work. The supplementary specimens such as each three numbers of 70.6mm cubes with and without the Blast furnace slag were cast along with the Ferrocement Beams specimens and are tested for its compressive strength. Table: 2 gives the characteristic compressive strength of the 70.6mm size cu bes.

VI.MATERIALSUSED AND ITS PROPERTIES



Cement: Ordinary Portland cement of grade 43 conforming to IS: 8112-1989 , which was stored in a cool and dry place before used. physical properties of cement is found given in the table 3.

Sand: Fine aggregate used in the light weight ferrocement is taken from Narsipura river bed near Kudala sangama. This river sand is totally free from all impurity and organic matters. physical properties of sand is found given in the table 4.

Water: Ordinary potable water was used for mixing. The mixing water should be fresh, clean, and potable

Blast Furnace Slag (BFS): The blast furnace slag used to replace sand was obtained from Visvesvaraya Iron and Steel Plant, Bhadravathi. It is non-metallic by product of steel manufacturing, consisting essentially of silicates and aluminum silicates of calcium that are developed in a molten condition simultaneously with iron in a blast furnace. It is mixed in different proportions in mortar. The chemical composition of this BFS given by the supplier and the physical properties are as shown in Tables5 and Tables6.

Wire mesh: wire meshes have square openings 4x22 gauge (0.55 mm average dia at 4.17 mm c/c) are used. Meshes with square openings are available in welded or woven form. Welded-wire mesh is made out of straight wires in both the longitudinal and transverse directions.

V.CASTING & TESTING OF SPECIMEN

Casting of specimens

Parameters considered in this study are, the percentage of sand replacement and mesh wires. Four percentages of replacing sand by lightweight aggregate (L.W.A.) viz., 0%, 10%, 20% and 30% by weight and mesh wires in terms of number of mesh layers per specimen viz., 2. A total of 24 ferrocement specimens have been cast. 3 specimens were cast at a time of dimension as shown in fig 2 & 3, using of teak wood moulds as shown in Fig 1. The layer of mesh was held in position at required spacing in the moulds by means of suitable aluminum spacers, which were removed while casting. In each casting about 3 mortar cubes 70.6 of mm side were also cast as control specimens. A plate vibrator was used for compacting the specimens. Moulds were dismantled 24 hours after casting and cured under water up to age of 28 days. After curing the specimens were removed from water and kept in a cool and dry place till they were tested. All the specimens were white washed before applying the load to notice the cracks clearly. Three cubes were tested for their composition strength after testing each set of specimens in each group.

Instrumentation and Loading Procedures

All the specimens were tested in a 25kN- loading frame, which is fixed over a strong floor. The beams were simply supported with an effective span of 600mm c/c. Two point loads were applied transversely at one third distances from support using a cross beam. Along with it, 25kN capacity proving ring was used for the load application. Dial gauges of sensitivity 0.01mm were used to measure the deflection of the beams. The dial gauges were kept at mid span of the beam and other two were kept at one third distances from supports. In addition to deflectometer, the curvature meter was fixed at a specific gauge distance so as to measure the top and bottom strains. The behaviour of the beams was keenly observed from the beginning till collapse. The propagation of initial cracks due to the increase of load was also recorded. The loading was continued till the verge of collapse.

In each set six specimens were cast, out of which three specimens were tested under monotonic loading and other three under repeated loading. A reaction frame was fabricated for testing specimens under monotonic and repeated load as shown in figure 3.The specimen was seated in between two supports spaced 600mm apart center to center in reaction frame. Loading was applied from top upwards such that the tension face of specimen is on bottom as shown in fig 3. This was done to facilitate marking of cracks in the flexure zone. Rubber padding was used both that supports and at load points, to ensure that the load was applied uniformly across width of the specimen. Loads were applied at one fourth span points, ie at 150mm from supports using a mechanical screw jack of 250kN capacity through a distribution steel high beam shown fig 3.Applied load was measured using a proving ring of 50KN capacity.

VI.TEST RESULTS AND OBSERVATIONS

Load vs Deflection curves

Behavior of Average of three Specimens for each percentage of Blast Furnace Slag replacement under monotonic load, represented by the load deflection curves show in fig 4

For all the specimens under monotonic loading, the load deflection curves show generally two portions. The first portion is a rising portion up to first crack load. & second is horizontal portion near ultimate showing an increase in deflection.

Cracking behavior

All the Beams exhibit a fairly ductile behavior and the failure pattern is as shown in Figure: 5 The failure of Beam specimens results from the yielding of wire mesh reinforcement followed by the crushing of concrete. Initially fine flexural cracks appeared at the bottom of the specimen, with further increase in the load, regularly spaced vertical cracks were observed and they extended from the bottom of the specimen towards the top fibre. The load was increased up to ultimate stage and cracking pattern is observed.

Behavior of Average of three Specimens for each percentage of Blast Furnace Slag replacement under repeated load, represented by the load deflection curves show in fig 6.

Form all the specimens under repeated loading, the Load-Deflection curves shown in fig6, the 10 % of slag replacement specimens carry a more load compare to other replacements & it is felt that increase in stiffness in the initial cycles may be due to the closure of shrinkage cracks present in the specimens before loading.

Determination of first crack strength

Moment at first crack (M_{cr}) for all the specimens tested under monotonic and repeated loading has been given in column 4 of tables of tables 7 and 8 respectively. Modulus of rupture at first crack,f_{cr} is calculated based on the gross section as

$$fcr = \frac{M_{cr}y}{I_g} \quad \text{..........................(1)}$$

Where, fcr is the crack strength (Mpa)
Mcr is the cracking moment (N-mm)
y is the depth of neutral axis(50 mm for the specimen tested)
Ig is the gross moment of inertia (mm^4)

First crack strength (fcr) obtained using test data and Eq. 1 has been tabulated as fecr in column 5 of Tables 7 and 8.Values of fcr computed using equations of Table 9 has been tabulated as f^c_{cr} in column 7 of Tables 7 and 8.

The ratio of $\frac{f^e_{cr}}{f^c_{cr}}$ are determined separately for all the specimens under monotonic and repeated load.

These values are tabulated in column 8 of tables 7 and 8.They have mean value and coefficient of variation of 1.065 and 0.055 for specimens under monotonic loading and 1.085 and 0.034 respectively for specimens under repeated loading.

Determination of experimental Modulus of rupture at Ultimate (fu)

Using the test data, extreme fiber stress at ultimate has been calculated from the simple bending theory as

$$f_u = \frac{6M_u}{bh^2} \quad \text{.........................(2)}$$

Where, f_u = Modulus of rupture in flexure, Mpa
M_u = Ultimate bending moment, N mm b = Breadth of beam, mm
h = Overall depth of the specimen, mm

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Values of M_u for all the specimens tested under monotonic and repeated loading has been given in column 4 of table 10 and table 11 respectively.

Ultimate strength (f_u) obtained using test data and Eq. 2 has been tabulated as feu in column 5 of Tables 10 and 11.

The ratio of $\frac{f_u^c}{f_u^c}$ are determined separately for all the specimens under monotonic and repeated load. These values are tabulated in column 8 of tables 10 and 11.They have mean value and coefficient of variation of 1.002 and 0.137 for specimens under monotonic loading and 1.11 and 0.108 respectively for specimens under repeated loading.

APPENDIX

Table 1 : Ferrocement Beam details and varying parameters

No. of mesh layers	Percentage replacement of B.F.S. of 1:2 cement mortar			
	0	10	20	30
2	LMN21-0% LMN22-0% LMN23-0%	LMN21-10% LMN22-10% LMN23-10%	LMN21-20% LMN22-20% LMN23-20%	LMN21-30% LMN22-30% LMN23-30%
2	LRP21-0% LRP22-0% LRP23-0%	LRP21-10% LRP22-10% LRP23-10%	LRP21-20% LRP22-20% LRP23-20%	LRP21-30% LRP22-30% LRP23-30%

Table: 2 Characteristic compressive strength

SL.No	Cube ID	BFS (%)	Average Compressive Strength (N/mm^2)
1	0% C1-3	0	43.5
2	10% C1-3	10	56
3	20% C1-3	20	48
4	30% C1-3	30	44

Table-3 Physical Properties of Cement

Physical property	Results obtained	IS specifications
Standard consistency (%)	30	Not specification
Initial setting time	45 mins	Not less than 30 mins
Final setting time	434 mins	Less than 600 mins
Fineness of cement	1.95%	Not more than 10%
Specific gravity	3.14	3.15
Compressive strength 28-days	44.10 N/mm2	43.0 N/mm2

Table-5 Properties of BFS

Fineness modulus	3.58
Density (kN/m^3)	1.12
Water content (%)	0.05
Specific gravity	2.41
Grading zone	I

Table-6 Chemical Properties of BFS

Constituents	Compositions (%)
SiO_2	30-33
Al_2O_3	20-22
CaO	33-35
MgO	9-10
S	Traces
Others	3-5

Fig.1 Teak wood mould

Table-4 Properties of Sand	
Fineness modulus	2.85
Density (kN/m^3)	1.53
Water content (%)	0.5
Specific gravity	2.61

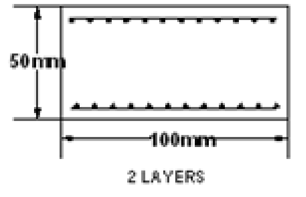


Fig 2 Details of Reinforcement in Specimen

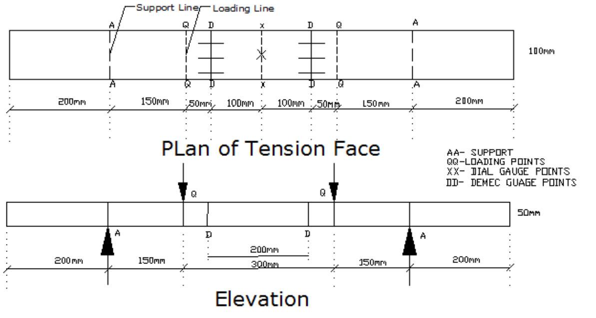


Fig3 Details of Demec & Dial Gauge points specimens

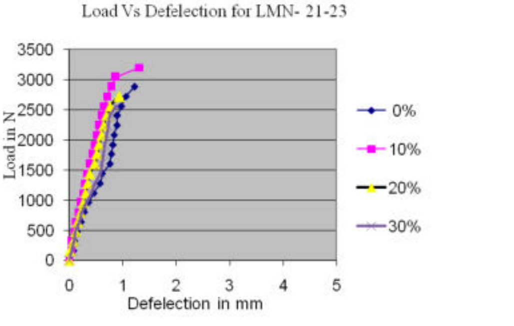
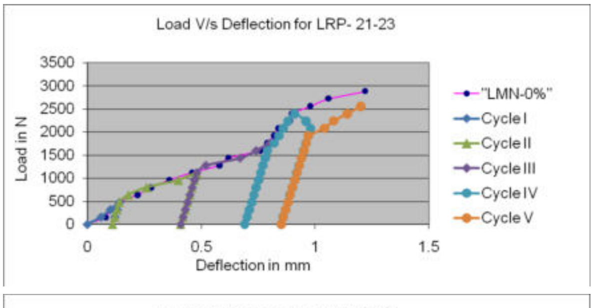
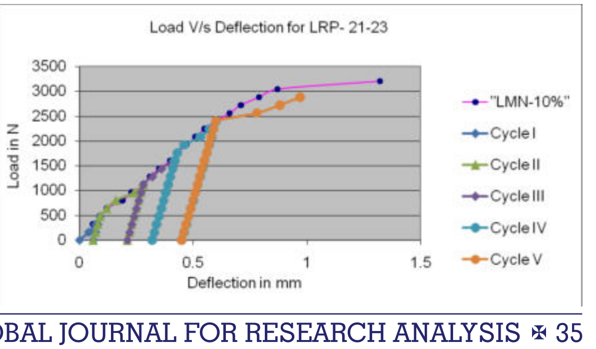


Fig 4: Load Vs Deflection

Fig 5 – Failure of Specimens in 0% replacement of BFS





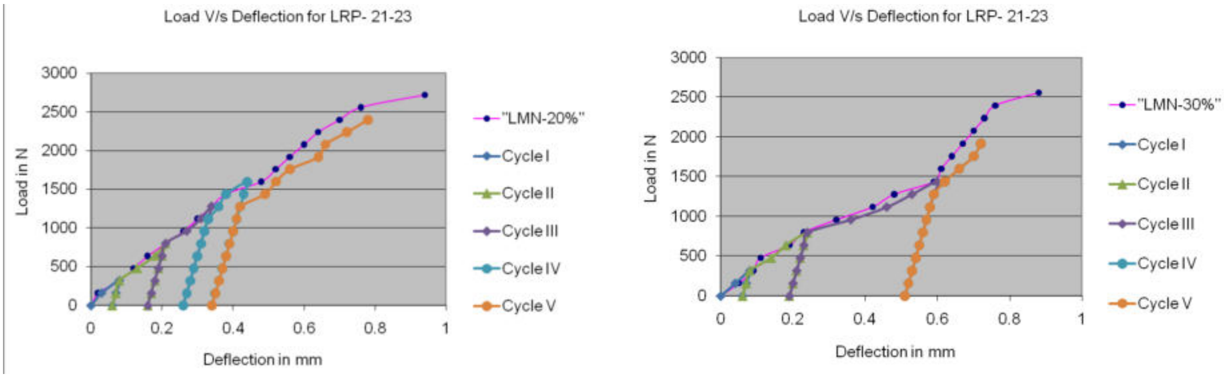


Fig 6: Repeated Load (N) Vs Deflection(mm)

Table 7 First Crack Strength Of Specimens Under Monotonic Loading

Specimens	No of Layers	Cube Strength f_{cu} (Mpa)	Cracking Moment M_{cr} (N-m)	Experimental cracking strength f^e_{cr} (Mpa)	$\frac{f^e_{cr}}{\sqrt{f_{cu}}}$	Calculated cracking strength f^c_{cr}(Mpa)	$\frac{f^c_{cr}}{f^e_{cr}}$
LMN-21-23-0%	2	43.5	204	4.90	0.74	5.08	1.03
LMN-21-23-10%	2	56	228	5.47	0.73	6.21	1.13
LMN-21-23-20%	2	48	204	4.91	0.71	5.33	1.01
LMN-21-23-30%	2	44	192	4.61	0.69	5.04	1.09

Table 8 First Crack Strength Of Specimens Under Repeated Loading

Specimens	No of Layers	Cube Strength f_{cu} (Mpa)	Cracking Moment M_{cr} (N-m)	Experimental cracking strength f^e_{cr} (Mpa)	$\frac{f^e_{cr}}{\sqrt{f_{cu}}}$	Calculated cracking strength f^c_{cr}(Mpa)	$\frac{f^c_{cr}}{f^e_{cr}}$
LRP-21-23-0%	2	43.5	144	3.46	0.52	3.83	1.10
LRP -21-23-10%	2	56	180	4.32	0.58	4.86	1.12
LRP -21-23-20%	2	48	168	4.03	0.58	4.23	1.04
LRP -21-23-30%	2	44	153	3.67	0.55	3.98	1.08

Table 9 Variation of fcr

Replacement percentage of L.W.A of 1:2 cement mortar	Load Type	Equation for f_{cr}
0	Monotonic Repeated	$f_{cr} = 0.77\sqrt{fcu}$ $f_{cr} = 0.58\sqrt{fcu}$
10	Monotonic Repeated	$f_{cr} = 0.82\sqrt{fcu}$ $f_{cr} = 0.65\sqrt{fcu}$
20	Monotonic Repeated	$f_{cr} = 0.79\sqrt{fcu}$ $f_{cr} = 0.61\sqrt{fcu}$
30	Monotonic Repeated	$f_{cr} = 0.76\sqrt{fcu}$ $f_{cr} = 0.60\sqrt{fcu}$

Table 10 Modulus of rupture at ultimate of specimens under monotonic Loading

Specimens	No of Layers	Cube Strength f_{cu} (Mpa)	Cracking Moment M_{cr} (N-m)	Experimental cracking strength f^e_u (Mpa)	$\frac{f^e_u}{\sqrt{f_{cu}}}$	Calculated cracking strength f^c_u (Mpa)	$\frac{f^c_u}{f^e_u}$
LMN-21-23-0%	2	43.5	216	5.18	0.79	5.03	0.97
LMN-21-23-10%	2	56	240	5.76	0.77	6.86	1.19
LMN-21-23-20%	2	48	204	4.9	0.71	4.89	0.99
LMN-21-23-30%	2	44	192	4.61	0.69	3.97	0.86

Table 11 Modulus of rupture at ultimate of specimens under monotonic Loading

Specimens	No of Layers	Cube Strength f_{cu} (Mpa)	Cracking Moment M_{cr} (N-m)	Experimental cracking strength f^e_u (Mpa)	$\frac{f^e_u}{\sqrt{f_{cu}}}$	Calculated cracking strength f^c_u (Mpa)	$\frac{f^c_u}{f^e_u}$
LRP-21-23-0%	2	43.5	192	4.60	0.7	4.49	0.97
LRP-21-23-10%	2	56	216	5.18	0.69	5.63	1.08
LRP-21-23-20%	2	48	132	3.17	0.46	3.84	1.21
LRP-21-23-30%	2	44	108	2.59	0.39	3.07	1.18

VII.CONCLUSION

From the results of the experimental study reported herein, the following conclusions can be drawn.

1. Blast furnace slag is an industrial waste material, which can be used for construction purpose.
2. The compressive strength of the 10 % replacement of BFS mortar is about 30% higher than that of the conventional mortar.
3. Replacement of 10% of BFS has shown increase in first crack strength & Ultimate strength and other replacement of 20 % and 30 % of Blast furnace slag has shown decreases in marginal.
4. The light weight ferrocement specimens could sustain greater number of repetitions.
5. The Blast furnace slag ferrocement Beams show a good load carrying capacity

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