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Impact Study on Ferrocement Slabs with Different Types of Mortar Matrices

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Abstract: This paper presents the experimental investigation of Ferrocement slabs subjected to impact test. A total of 24 slabs were tested that includes varying materials (ingredients) and different number of reinforcing weld mesh layers. The mix proportions include variable additive materials for the specimens preparation and compared with the conventional slab. From the drop weight impact test, it is observed from the results that the number of reinforcing layers improve the impact energy absorption and also have influence in confining the fragments mix together. From the comparison the mix containing cement, sand and 10% addition of Fumed Silica and 40% replacement of cement with GGBS to the volume of cement. These specimens showed increase in the energy absorption compared to other mixes

Keywords: *Ferrocement Slabs, Impact Testing, Impact Energy, Galvanised meshes*

1. Introduction

The capability to absorb energy, often called 'toughness', is of importance in actual service conditions of mesh reinforced composites, when they may be subjected to static, dynamic and fatigue loads. Toughness evaluated under impact loads is the impact strength. Impact resistance of any reinforced composite can be measured by using a number of different test methods, which can be broadly grouped into the following categories.

(1) Drop weight single or repeated impact test,
(2) Constant strain rate test,
(3) Weighted pendulum charpy type impact test,
(4) Explosion- impact test,
(5) Projectile impact test,
(6) Instrumented pendulum impact test,
(7) (vii)Split Hopkinson bar test [1].

Several methods have been reported to evaluate the impact characteristics of concrete/cement composites. Of these, the simplest and most widely used test is the drop-weight test, which can be used to evaluate the relative performance of composites.

The characteristics of the impact load are different from those of static and seismic loads. Since the duration of loading is very short, the strain rate of material becomes significantly higher than that under static and seismic loading. Also structural deformation and failure modes will be different from those under static and seismic loading. In construction industry, strength is a primary criterion in selecting a concrete for a particular application. Concrete used for construction gains strength over a long period of time after pouring. Therefore, rapid and reliable prediction for the strength of concrete would be a great significance [2].

Ferrocement is a thin composite, made up of cement-based mortar matrix reinforced with closely spaced layers of small diameter weld mesh. The mesh may be made of metallic or other suitable materials. These slabs are more ductile, when compared to the conventional reinforced concrete elements, but the post-peak behaviour of ferrocement elements reveals that the failure occurs either due to mortar failure in compression or due to the failure of extreme layers of mesh [2]. So here an attempt has been to study the impact behaviour of the ferrocement slabs by varying the percentage reinforcement. Ferrocement has been used for various offshore and marine structures, roofing, water tanks, grain silos and biogas plants. Even though conventional ferrocement using ordinary cement mortar as matrix satisfies most general requirements, ferrocement products which have higher ultimate moment and toughness are required for some special applications in ocean engineering and the chemical industry [1].

2. Experimental Investigation

The ferrocement slabs were cast in moulds of dimension 300mm x 300mm with thickness varying from size 25mm to 30mm. The moulds are made from wood. Before casting of the slabs, the moulds are properly cleaned and applied with one coat of oil as mould releasing agent and to get better surface finish.

3. Materials Used

3.1 Cement

The cement used in this work was Ordinary Portland cement conforming to the requirement of IS: 12269-

1987. The results of various tests on cement properties are given in Table 1.

***Table 1**: Properties of Ordinary Portland cement*

Characteristics	Obtained Values
Normal Consistency	30%
Initial Setting Time	45 mins
Final Setting Time	255 mins
Fineness	0.085 %
Specific Gravity	2.781

3.2 Fine Aggregate

Fine Aggregate used was river sand passing through 4.75mm sieve obtained from a local source. The Properties of Fine Aggregate are presented in Table 2.

***Table 2:** Properties of Fine Aggregate*

Characteristics	Value
Specific Gravity	2.61
Fineness Modulus	2.78
Grading Zone	II
Moisture Content	NIL

3.3 Fumed Silica

Fumed Silica (CAS number 112945-52-5) also known as pyrogenic silica was used (Fig 1). It consists of microscopic droplets of amorphous silica fused into branched, chain like three - dimensional secondary particles which then agglomerate into tertiary particles. Primary particle size is 5-50nm. The particles are non-porous and have a surface are 50-600m^2/g. The density is 160 - 190 kg/m^3.

***Fig 1** Fumed Silica*

3.4 Fly Ash

Fly ash, also known as "pulverized fuel ash", is one of the coal combusted products, and is composed of the fine particles that are driven out of the boiler with the flue gases. When used in Portland cement, Class F fly ash can be used as a Portland cement replacement ranging from 20-30% of the mass of cementitious material. Hence, in the present study 30% replacement of cement has been done with Fly ash.

3.5 Ground Granulated Blast Furnace Slag

Ground-granulated blast-furnace slag (GGBS or GGBFS) 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. The main components of blast furnace slag are CaO (30-50%), SiO2 (28-38%), Al2O3 (8-24%), and MgO (1-18%). The physical properties of the materials are presented in Table 3.

***Table 3:** Physical Properties of cement replacement materials*

Materials	Specific gravity	Dry density Kg/m^3
Fumed silica	1.25	35.82
Fly ash	1.97	760
GGBS	2.85	930

3.6. Wire Mesh

Galvanised weld mesh with square opening of size 60mm x 60mm (Fig 2) are used with a diameter of 2.44mm. Wire mesh with square opening of 10mm x 10mm (Fig 3) with a diameter of 0.8mm was used. The percentage elongation of weld mesh and wire mesh is 18% and 28%, respectively.

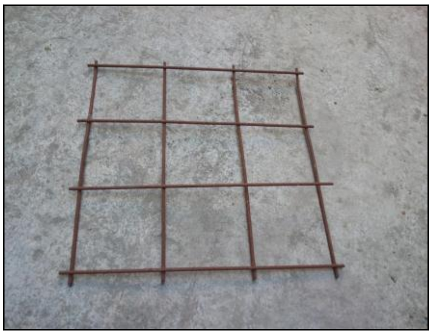

***Fig 2** Weld mesh (60mm x 60mm)*

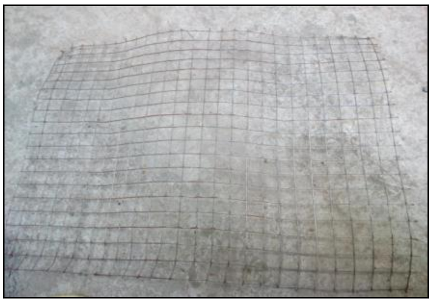

***Fig 3** Wire mesh (10mm x 10mm)*

3.7 Water

Water is an important ingredient as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. Potable water is generally considered satisfactory. In the present investigation, tap water was used for both mixing and curing purposes.

4. Mix Proportions

In this study, mix proportions of the specimens are calculated according to nominal mix. The mixture proportions for the cement and fine aggregate are kept nominally same, except for replacement of cement with various materials depending upon desired replacement percentage. Depending upon the selected replacement percentage, direct substitution of cement with an equal weight of Fumed Silica, Fly ash and GGBS was carried out. The mortar mix proportions and the corresponding mix designations are presented in Table 4.

Table 4: *Proportions of components of materials*

Materials	Mix Name			
	A	B	C	D
W/C ratio	0.4			
Cement (kg/m^3)	792	792	554.4	475.2
Fumed Silica (kg/m^3)	- - -	72.9	72.9	72.9
FA (kg/m^3)	1188	1188	1188	1188
Flyash	- - -	- - -	237.6	- - -
GGBS (kg/m^3)	- - -	- - -	- - -	316.8
Water	316.8	316.8	316.8	316.8
Effective W/C	0.4	0.45	0.43	0.43

5. Casting of Slabs

A weld mesh of size 300mm x 300mm as a single layer was placed and the wire mesh is placed on each side and tied tightly. In the same way double and triple layers were places and the wire mesh is wound around it. The slabs were filled with fresh mortar and compaction has been done. A total of twenty four slabs have been cast. The Slabs are named as below:

A - 100% Cement (Control mix)
B - 100% Cement + 10% Fumed Silica
C - 70% Cement + 30% Fly ash + 10% Fumed Silica
D - 60% Cement + 40% GGBS + 10% Fumed Silica

6. Test Setup and Testing

Impact test was conducted on the square slabs after 28 days of curing by using a drop weight and the test setup is shown in Fig 4. It consisted of a rigid welded steel frame square in plan and supported by short columns. The specimen was laid flat resting on four 75 mm diameter bars to provide line support along the four edges. The test setup consists of a cylindrical ball of 60mm dia, 150mm height (the plunger) with hemispherical blunt tip to a height of 50mm. The height of the drop was kept as 250mm. The plunger which loads the panel has a spherical tip enabling a point contact to be made. A rope and pulley arrangement with a pipe guide, which enables a central impact in the vertical direction, was used to manually raise the hammer to the required height for repeatedly dropping it on the specimen surface. Grease was applied on the rollers to reduce friction and to ensure a smooth fall. The various strength properties of the mortar such as, compressive strength, Flexure Strength, Split Tensile Strength were determined by standard IS test procedure at 28 days of curing. The Test results are obtained as given in Table 5 and Fig 5, Fig 6 and Fig 7.

Fig 4 *Impact Machine Setup*

Table 5: *Properties of mortar (28 days)*

Properties	Mix Name			
	A	B	C	D
Compressive Strength (MPa)	55.3	60.47	31.47	29.8
Split Tensile Strength(MPa)	2.22	1.73	2.32	2.17
Flexural Strength(MPa)	6.50	5.66	5.01	7.47

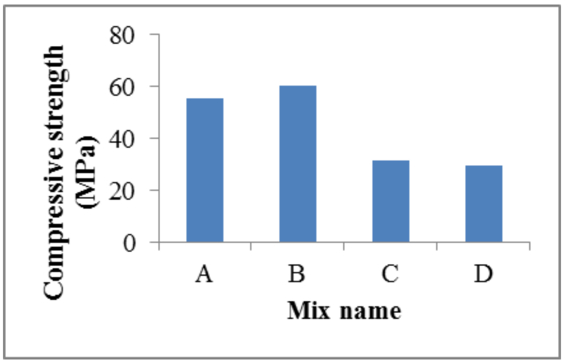

Fig 5 *Shows the Compressive Strength of Mortar Mix at 28 days*

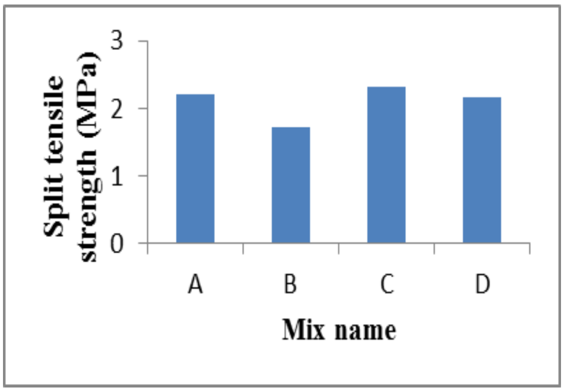

***Fig 6** Shows the Split Tensile Strength of Mortar Mix at 28 days*

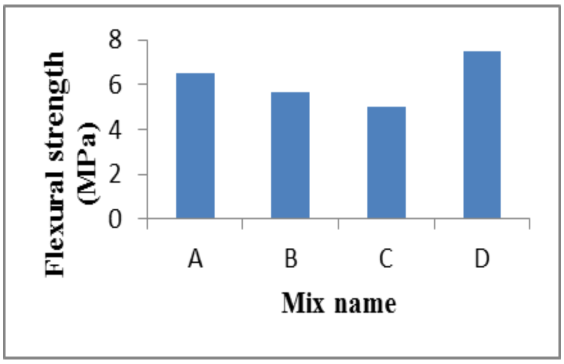

***Fig 7** Shows the Flexural Strength of Mortar Mix at 28 days*

7. Results and Discussion

7.1 Energy Absorption

The mass was then dropped repeatedly and the number of blows required to cause first crack was recorded. Then the numbeo of blows required for the failure is also recorded. Then the process was continued further, till the crack propagated further and appeared at the sides of the specimen. The number of blows required to cause the crack width of 2mm were also noted down. The total energy absorbed by the ferrocement slabs when struck by a hard impactor depends on the local energy absorbed both in contact zone and by the impactor. The energy absorption can be obtained by using the following formula [2].

$$E = N \times (w \times h) \text{ joules} \quad (1)$$

Where

E= energy in joules
w= weight in Newton
h= drop height in meter
N= blows in numbers

The ratio of energy absorbed up to the failure of specimens to the energy absorbed at initiation of first crack is defined as the 'Residual Impact Strength Ratio' (I_{rs}). The energy absorption capacities of Ferrocement slab specimens at first crack and at ultimate failure stages are presented in Table 6 and Fig 8.

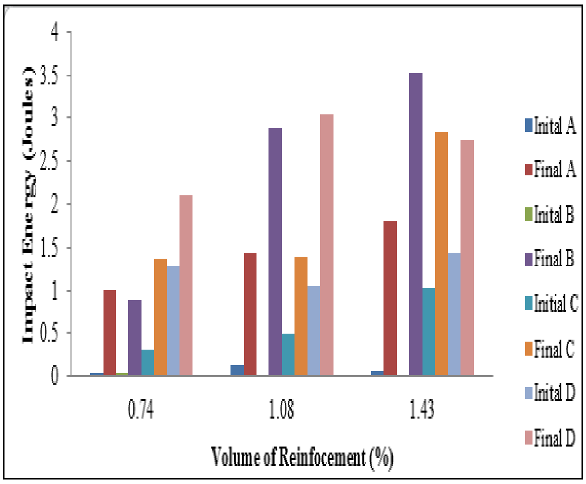

***Fig 8** Energy absorption capacity of First crack and Ultimate stage of slabs*

***Table 6:** Energy absorption capacity of Ferrocement Slabs*

Mix ID	Impact energy observed (Joules)		Residual impact strength ratio (I_{rs})
	Initial	Final	
A1	0.043	0.996	23.163
A2	0.123	1.446	11.756
A3	0.067	1.817	27.119
B1	0.035	0.896	25.600
B2	0.015	2.893	192.867
B3	0.023	3.538	153.826
C1	0.306	1.370	4.477
C2	0.502	1.382	2.753
C3	1.020	2.829	2.774
D1	1.283	2.694	2.100
D2	1.040	3.164	3.042
D3	1.442	3.969	2.752

7.2 Failure Pattern

From the impact test number of blows required to initiation of first crack was based on visual observation and the ultimate failure was determined based on the number of blows required for the crack to propagate to sides of the slab. The impact energy absorbed by the mortar slab specimens were computed based on the number of blows required to cause ultimate failure and impact energy per blow. Moreover, the ultimate crack resistances generally increase with increase in volume fraction of reinforcement. Of the three types of reinforcement, combination of three layer weld mesh and two layer of wire mesh with GGBS mix have absorbed higher energy compare to the other types. This may be due to the higher ductility and lesser susceptibility to embrittlement of reinforcement. It also observed that the failure pattern of the specimens exhibited localized failure at the point of contact of the drop-weight and no fragments detached from the specimens as the various layers of the mesh reinforcement helped to hold the different fragments together. It can thus infer that meshes used as reinforcement play a major role in not only improving the impact energy absorption, but also retain/hold the various fragments together. The Failure pattern of slabs is shown in the Fig 9, Fig 10, Fig 11 and Fig 12.

7.3 Mode of Failure

Slabs with mortar mix A and B (Fig 9 and Fig 10) showed 4 to 6 cracks with larger crack width propagated upto the side of slabs in single layered mesh slabs at failure stage. All the cracks reached from centre to edge of the slabs. In two layered mesh slabs, multiple cracks with small crack width propagated upto the edge and cracks are interconnected like network. Punching shear failure was observed and very small crack width cracks reached upto the edge of the slabs. Slabs with Fly ash (mix C) (Fig 11) and GGBS based mix (mix D) (Fig 12) showed punching shear mode of failure. Micro-cracks are developed and reached to the edge of the slab.

8. Conclusions

Based on the above experimental results, the following conclusions are arrived.

1) Mechanical properties of four types of mortar matrices for ferrocement application are studied. Compared to control mix A the compressive strength of mix B increases by 9.3% whereas mix C and mix D decreases by 43.1% and 46.1% respectively. The Split Tensile strength of Mix C increases by 4.5% whereas mix B and mix D decreases by 22.07% and 2.25% respectively when compared with control mix A. The Flexural Strength of mix D shows an increase by 15% but mix B and mix C decrease by 13% and 23%.
2) By increasing the layers of weld mesh, the width of the cracks are reduced and only few cracks are propagated upto the edge of the slabs. Higher reinforcement content restrict the cracks to propagate and create localised failure i.e., at the point of impact of load, and the failure is characterized by formation initially at the bottom surface of the specimen, propagating to the sides and then widening further.
3) Increase in the volume of reinforcement the energy absorption is also increased when compared to the control mix.
4) The failure pattern in the impact tested slabs is found to be punching shear due to higher reinforcement. Only pure cracks are propagated upto the edge.
5) The energy absorbed at failure is directly proportional to the volume of the reinforcement provided in the Ferrocement Slabs.
6) Even though the compressive strength of mortar mix C and D are very lower than the mix A and B, their impact resistance are higher because the mix C and D are ductile than mix A and B.

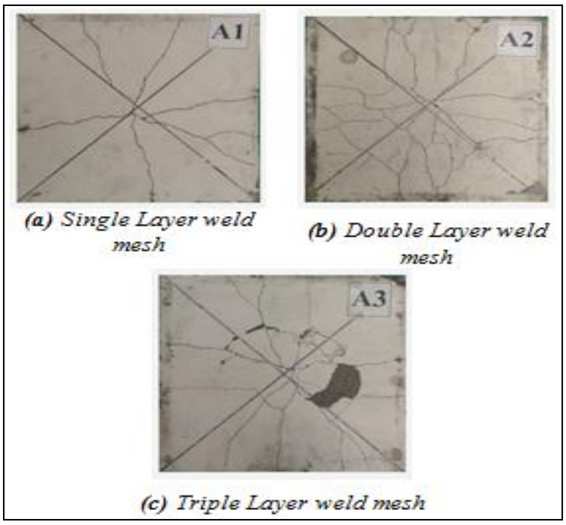

Fig 9 *Failure Pattern of Ferrocement slabs of Control Mix*

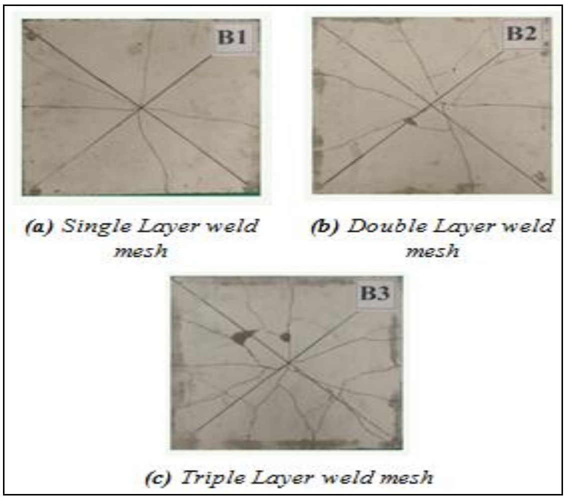

Fig 10 *Failure Pattern of Ferrocement slabs with addition of 10% Fumed Silica*

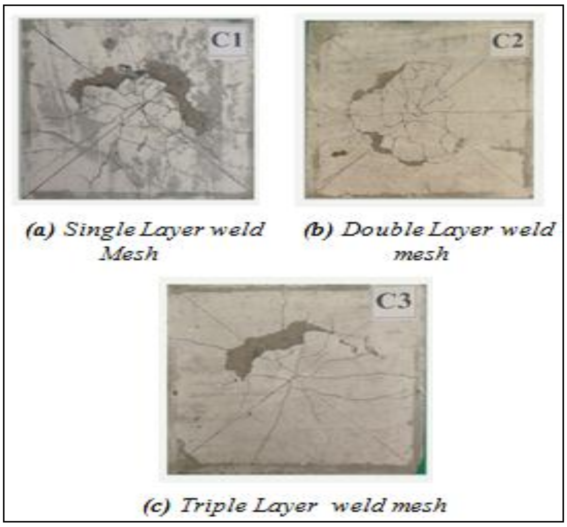

Fig 11 *Failure Pattern of Ferrocement slabs of 30% replacement of cement by Fly ash and addition of 10% Fumed Silica*

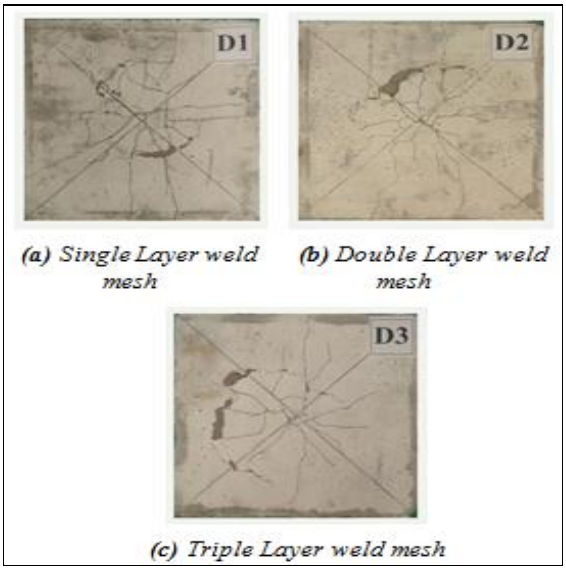

Fig 12 *Failure Pattern of Ferrocement slabs of 40% replacement of cement by GGBS and addition of 10% Fumed Silica*

9. Acknowledgement

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