

BEHAVIOUR OF GEOPOLYMER FERROCEMENT SLABS SUBJECTED TO IMPACT*

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Abstract– This paper presents the experimental investigations of the resistance of geopolymer mortar slabs to impact loading. For this, specimens of size 230mmx230mmx25mm with 4 layers of chicken mesh 2 layers of rectangular weld mesh and combination of single layer of weld mesh and four layers of chicken mesh were cast and subjected to impact loading by drop weight test. The results obtained show that the addition of the above mesh reinforcement has increased the impact residual strength ratio of geopolymer ferrocement by 4-28 that of the reference plain ferrocement mortar slab. The combination of 1 layer of weldmesh and 4 layers of chicken mesh of geopolymer ferrocement specimens show the best performance in the test, i.e. energy absorbed, residual impact strength ratio (I_{rs}). It was concluded that the increase in volume fraction of reinforcement V_r , increases the energy absorption and also residual impact strength ratio of geopolymer ferrocement than that of ferrocement specimens.

Keywords– Geopolymer, impact loading, ferrocement, chicken mesh, weld mesh

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. (i) Drop weight single or repeated impact test, (ii) Constant strain rate test (iii) Weighted pendulum charpy type impact test, (iv) Explosion- impact test, (v) Projectile impact test, (vi) Instrumented pendulum impact test, (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 [2]. Reported work on the impact behaviour of ferrocement slabs relates to the use of conventional reinforcement (chicken mesh and M.S. skeletal) and drop-weight method (instrumented/ordinary falling weight) [3-6]. Hence, in the present study drop-weight method was selected and used to study the impact characteristics of slab specimens.

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. Portland cement is the most common type of cement used in construction applications, but it is an expensive binder due to the high cost of production associated with the high energy requirements of the

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manufacturing process itself. [7, 8]. The contribution of ordinary Portland cement production worldwide to greenhouse gas emission is approximately 7% of the total greenhouse gas emission to the atmosphere. The production of 1 tonne ordinary Portland cement consumes 4GJ energy and produces about 1 tonne of carbon dioxide (CO₂) to the atmosphere. About half of the CO₂ emissions from Portland cement production are due to calcination of limestone, while the other half are due to combustion of fossil fuel. For the above reasons, recent research works are focusing on the feasibility of replacing cement with different types of waste products. Fly ash has gained prominence as the most commonly used waste material for partially replacing cement.

A promising research outcome developed in the last decade is low calcium fly ash based geopolymer cement and concrete [9-11]. Geopolymers prepared by using the low calcium fly ash exhibit high compressive strength, low creep, minimal drying shrinkage, good acid resistance, fire resistance [12]. The authors have conducted impact test to study the properties of geopolymer ferrocement prepared with 10 molarity (M) geopolymer mortar which show excellent properties compared with the ordinary cement mortar. This paper describes the impact behaviour such as the first crack load, ultimate impact load, residual impact strength ratio of the geopolymer ferrocement slab panels using 10 M geopolymer mortar and their toughness behaviour is compared to that of ordinary ferrocement slab panels.

2. EXPERIMENTAL INVESTIGATIONS

a) Materials used

The following materials are employed in this work:

- ❖ Ordinary Portland Cement (53 grade)
- ❖ Fine aggregate (Sand)
- ❖ Geopolymer
- ❖ Wire meshes (Chicken Meshes and Weld meshes)

1. Ordinary Portland cement- Ramco 53 grade according to IS 4031-1988 [13] is used to prepare control specimens. Some of the properties of the cement are given here,

- ❖ Specific Gravity = 3.156
- ❖ Standard Consistency = 32 %
- ❖ Initial Setting time = 45 mins
- ❖ Final Setting Time = 255 mins
- ❖ Compressive strength = 56.75 N/mm² (28 days)

2. Fine aggregate used is the ordinary river sand passing through sieve no.8 (2.36 mm) with a specific gravity of 2.72, dry density of 1.6 g/cc and having a fineness modulus of 2.56 as per I.S: 383-1970 [14].

3. Geopolymer is a combination of the following compounds,

- ❖ Pozzolans (fly ash, silica fumes, GGBS etc.,)
- ❖ Fine aggregate
- ❖ Activator solution (Hydroxides and Silicates of sodium or potassium)
- ❖ A high – range water reducing Glenium B233 Super Plasticizer
- ❖ Distilled water.

The pozzolan used here is the low calcium fly ash of class F obtained from the Tuticorin thermal power plant. The chemical composition of the fly ash, as determined by X-Ray Fluorescence (XRF) analysis is given in Table 1. In this research, analytical grade sodium hydroxide in pellet form (NaOH With 98%

purity) and sodium silicate solutions ($\text{Na}_2\text{O}=14.7\%$, $\text{SiO}_2=29.4\%$ and $\text{Water}=55.9\%$ by mass) were used as the alkaline activators. In order to avoid the effect of unknown contaminants in the mixing water, the sodium hydroxide pellets were dissolved in distilled water. The activator solution was prepared at least one day prior to its use. To improve the workability of fresh mortar, commercially available Superplasticiser based on modified polycarboxylic ether formulation GLENIUM B233 was used. The constituents of geopolymer mortar are shown in Fig. 1.

Table 1. Chemical composition of fly ash

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	TiO_2	SO_3	MgO
Mass (%)	65.43	20.67	6.18	1.26	-	-	-	Trace	0.82



Fig. 1. Composition of geopolymer

4. Wire meshes: The wire woven chicken meshes (Fig. 2) with a hexagonal opening of size 12 mm, wire thickness of 0.72 mm (20 gauge) are used. The welded weld mesh (Fig. 3) having a rectangular grid opening of size 76.2 mm x 38.1 mm, with a thickness of 2.45 mm in transverse direction and 3.45 mm in longitudinal direction are used. Ultimate strength of weld mesh and chicken (hexagonal) mesh are 440 N/mm^2 , 270 N/mm^2 .



Fig. 2. Chicken mesh



Fig. 3. Weld mesh

b) Volume fraction of reinforcement

When the same square or rectangular wire mesh is used throughout the depth of a ferrocement element then the volume fraction of reinforcement can be calculated from Eq. (1) [15]

$$V_r = \frac{N\pi d_w^2}{4h} \left[\frac{1}{D_l} + \frac{1}{D_t} \right] \quad (1)$$

[V_r - Volume fraction of reinforcement, N - Number of layers of mesh, π - 3.14, d_w - diameter of mesh wire, h - Thickness of ferrocement element, D_l - Distance center to center between longitudinal wires, D_t - Distance center to center between transverse wires.]

For other types of mesh (hexagonal or chicken wire, expandable metal, fibre reinforced plastic – FRP or irregular meshes) Eq. (2) [15] is recommended to be used.

$$V_r = \frac{Nw_r}{h\delta_r} \quad (2)$$

[V_r -Volume fraction of reinforcement, N - Number of layers of mesh, w_r - Unit weight of reinforcing mesh, h - thickness of ferrocement element, δ_r - density of reinforcement material]

c) Mortar

The geopolymer mortar used in this study is composed of low calcium fly ash and alkaline solution composed of Sodium hydroxide, sodium silicate combinations. Sodium hydroxide is mixed with deionized water at a concentration of 10M and kept for at least 24 hours prior to casting. All geopolymer mortar specimens were made with sand to fly ash ratio by equal proportion. The hydroxide to silicate ratio is kept constant as 1:1. The fly ash and the fine aggregates were dry mixed together in mixer machine for 5 minutes, followed by the addition of activator solution containing hydroxide and silicate and super plasticiser to the mixture, and mixed for another 10 minutes (as shown in Fig. 4). The mixing was carried out at room temperature of approximately 25-30 °C. Cement mortar is prepared by mixing OPC 53 grade cement and graded river sand at a weight ratio of 1:1. Water is then added to the cement to give a water to cement ratio of 0.3. The mortar mix detail is shown in Table 2.



Fig. 4. Mixing of materials using Hobart mixer

Table 2. Mortar mix details

Specimen	Cement	10- Molarity
No. of Specimens	3	3
Cement(Kg.)	4.17	-
Sand(Kg.)	4.17	4.72
Fly ash(Kg.)	-	3.96
Sodium hydroxide(Kg)	-	0.79
Sodium silicate(Kg.)	-	0.79
Water(Kg)	1.251	-
Super Plasticizer(kg)	0.08	0.11

d) Method of specimen preparation

Total 24 square slabs (4 series – 3 in each series), each of size 230mm (length) x 230mm (width) x 25mm were cast in steel moulds with open tops (Fig. 5). Details of the test parameters and specimen identifications are given in Table 3. The moulds were made in a form such that each of the four side walls and the base of the formwork were detachable so that the mould could be easily separated from cast element after its initial setting. The contact surfaces of the steel moulds to the mortar were greased before casting the specimens to ease the demoulding process. The 2 layers of weld mesh, 4 layers of chicken mesh, combination of one layer of weld mesh and 4 layers of chicken mesh were bundled with binding wire without spacing in-between them and placed in the mould (Fig. 6) keeping a minimum cover of 5mm. Then Geopolymer mortar is poured into the mould. For each specimen type, 3 mortar cubes of size 70.7 x 70.7 x 70.7 mm, 3 mortar cylinder specimens of size 75 mm diameter and 150 mm height, and 3 mortar beams of standard size 100 mm x 100 mm x 500 mm long are cast to test the characteristic strength, split tensile strength and flexural strength of Geopolymer mortar (Fig. 7).

All these Geopolymer mortar and Geopolymer Ferrocement specimens were heat cured for 48 hours at 75 °C in heat curing chamber (Fig. 8) and Ferrocement specimens were cured under water for 28 days.



Fig. 5. Slab mould

Table 3. Test parameter and specimen identification

Set	Specimen Identification	Number of layers of mesh	Volume fraction of Reinforcement, V_r
1	FC GF	Without mesh	0%
2	FC1 GF1	4 layers of Chicken mesh	0.8%
3	FC2 GF2	2 layers of weld mesh	1.5%
4	FC3 GF3	1 layer of weld mesh&4 layers of chicken mesh	1.6%

Note: FC, GF corresponds to Ferrocement, Geopolymer Ferrocement.



Fig. 6. Casting of geopolymer ferrocement slab specimen



Fig. 7. Mortar mould for compressive strength, flexural strength and split tensile strength



Fig. 8. Heat curing chamber under operation mode

e) Impact test set-up

Twenty four, (230X230X25) mm slab specimens were tested under drop weight impact load. The impact was conducted using 0.6 kg steel ball that was allowed to fall freely from a constant height of 400mm through a guide at the centre of the slab for all the specimens with the simple support conditions as per ASTM D 2794 [16]. Specimens were placed in their position in the testing frame (Fig. 9) with the finished face up. The guiding pipe was then placed in position. The mass was then dropped repeatedly and the number of blows required to cause first crack was recorded. The number of blows required for failure (no rebound) was also recorded. For each slab specimen, the number of blows required to cause the first crack was noted. Then the process was continued further, till the crack propagated further and appeared at the top surface of the specimen. At that point, corresponding number of blows were noted. The impact energy absorbed in Joules was computed using the relation $(n \times W \times h \times 9.81)$, whereas n = No. of blows, W = weight in N, h = drop height in meters (0.40m). The various strength properties of the mortar such as, compressive strength, flexure strength, split tensile strength were determined by standard I.S. test procedures at 28 days of curing. The test results obtained are given in Table. 4.



Fig. 9. Impact setup

Table 4. Properties of mortar

SI. NO	Properties	Age of testing in 28days	
		Cement mortar	Geopolymer mortar
1	Cube compressive strength (MPa)	35.67	48.53
2	Flexural strength(MPa)	1.0	1.33
3	Split tensile strength(MPa)	1.8	2.3

3. RESULTS AND DISCUSSIONS

a) Impact energy

From the impact test, the number of blows required for the initiation of first crack was based on visual observation and the ultimate failure was determined based on the number of blows required to open the crack in the specimen sufficiently and for the propagation of the crack through the entire depth of the specimen [17]. 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 (2.35 J). The impact energy absorbed/required to cause the first crack, the impact energy absorbed/required to cause the final crack; failure of the geopolymer ferrocement specimens was compared with that of the reference ferrocement specimens (Table. 5). It was observed that the mesh reinforced mortar specimens do not break into distinct pieces, whereas plain mortar slab specimens were broken into distinct pieces (Fig. 10). From the results, it is seen that due to incorporation of mesh in mortar the impact resistance of the slab has increased 1.8 -19.5 fold (in terms of impact energy absorbed), depending on the type of mesh and volume fraction of reinforcement. Moreover, the ultimate crack resistance generally increases with increase in volume fraction of reinforcement. Of the three types of volume fraction of reinforcement, combination of 1 layer of weld mesh and four layers of chicken mesh have absorbed higher energy, when compared to the other two types, and the highest impact energy absorbed was 108.28J (Fig. 11). This may be due to the higher ductility and lesser susceptibility to embrittlement of reinforcement. Slab specimens which appear to possess a relatively low impact resistance at the appearance of first crack were found to improve and obtain high impact resistance at failure. The ratio of energy absorbed up to failure of specimen to the energy absorbed at initiation of first crack is defined as the 'residual impact strength ratio' (I_{rs}). The I_{rs} value for various ferrocement slab and geopolymer ferrocement slab was computed and given in Table 5. The residual impact strength ratio (I_{rs}) lies in the range of 2.5 to 3 and 2.6 to 3.2 for ferrocement and Geopolymer Ferrocement specimens reinforced with chicken mesh and weld mesh and a combination of 4 layers of chicken mesh and 1 layer of weld mesh specimens of Geopolymer Ferrocement have the highest residual impact strength ratio among the other types of meshes. The impact residual strength ratio of Geopolymer Ferrocement specimens increased by 4-28 times that of the reference plain Geopolymer mortar specimens.

b) Failure pattern

It was observed during testing that the Ferrocement, Geopolymer Ferrocement 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 unlike the case of plain slab (without any reinforcement) where the fragments detached/separated and fell into pieces (Fig. 10). It can be thus inferred that meshes used as reinforcement play a major role in not only improving the impact energy absorption, but also help to retain/hold the various fragments together, after full damage has occurred to the specimens due to impact loading.

Table 5. Impact energy absorbed

S. No	Specimen	Impact energy absorbed (Joules)		Residual impact strength ratio(I_{rs})
		Initial	Final	
1	FC	-	9.47	-
	GF	-	11.77	-
2	FC1	18.83	47.08	2.5
	GF1	21.18	56.49	2.6
3	FC2	23.54	61.20	2.6
	GF2	28.25	70.63	2.7
4	FC3	28.24	77.68	3.0
	GF3	32.95	108.28	3.2

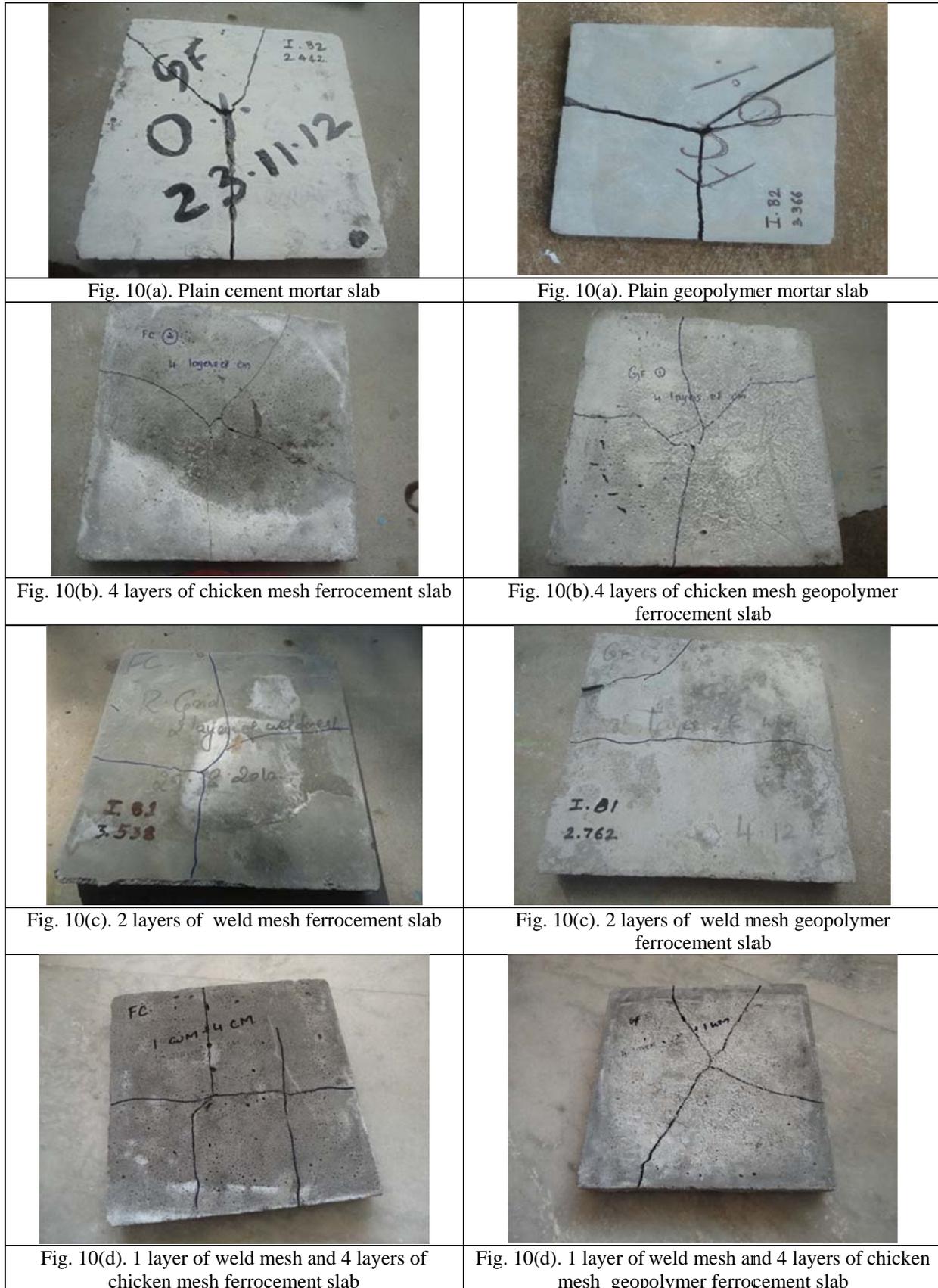


Fig. 10. Typical crack pattern of (a) Plain mortar slab (b) 4 layers of Chicken mesh slab (c) 2 layers of weld mesh layers slab (d) 1 layer of weld mesh and 4 layers of chicken mesh slab of Ferrocement and Geopolymer Ferrocement slab (assembled after impact)

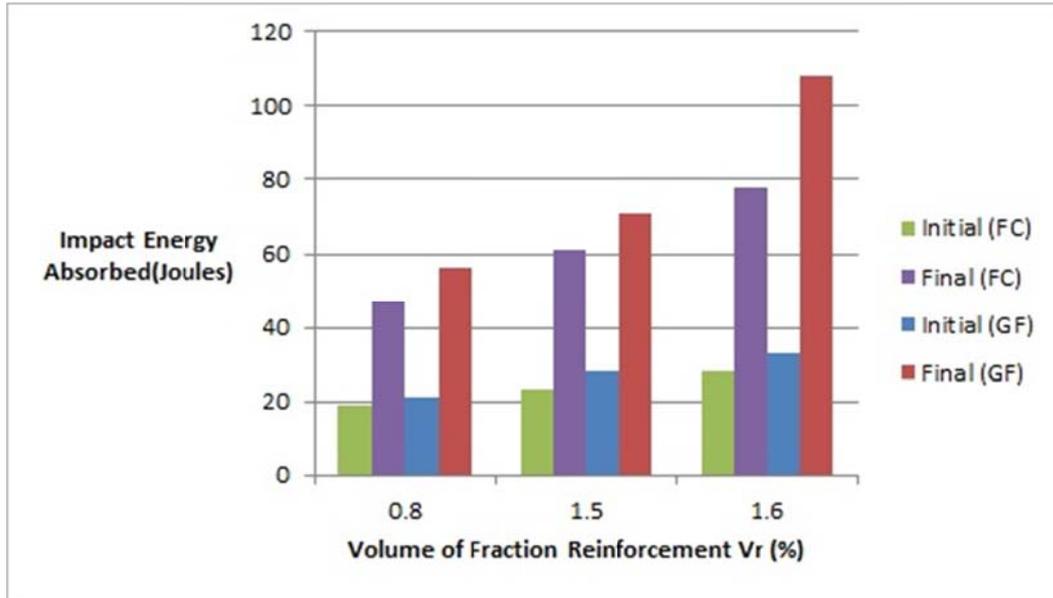


Fig. 11. Initial and final energy absorption of the specimen for various volume fraction of reinforcement

4. CONCLUSION

Following are the salient conclusions based on the experimental investigations reported in this paper.

1. In all the impact test specimens, the damage is found localized, i.e. at the point of impact of load, and the failure is characterized by formation of cracks initially at the bottom surface of the specimen, propagating to the top surface and then widening further.
2. The percentage increase in compressive strength, flexural strength, Split tensile strength compared to control cement mortar specimen for 10M Geopolymer mortars are 36.05%, 33% and 27.7% respectively.
3. Increase in volume fraction of reinforcement, V_r increases the energy absorption, residual impact strength ratio of both Ferrocement and Geopolymer Ferrocement. Increase in volume fraction of reinforcement V_r increases the energy absorption of geopolymer ferrocement specimen GF, GF1, GF2, GF3 by 24.28%, 496%, 645% and 1043% respectively than that of plain cement mortar slab.
4. Identical failure patterns were observed in Ferrocement and Geopolymer Ferrocement slab specimens and it is independent of the type of reinforcement (i.e. chicken mesh/weld mesh) adopted.
5. Geopolymer Ferrocement slabs exhibit excellent impact-resistance characteristics, in terms of higher energy absorption and higher I_{rs} values, indicating excellent post-cracking behavior. The above unique characteristics can be effectively utilized for geopolymer ferrocement elements subjected to impact loads.
6. Performance of geopolymer ferrocement slab is the highest when the volume fraction is 1.6% and the number of layers of reinforcement is 5 (1 layer of weld mesh & 4 layers of chicken mesh), within the range of parameters considered.
7. The energy absorbed at failure is directly proportional to the volume fraction of reinforcement provided in the geopolymer ferrocement slab.
8. Higher energy absorption found in Geopolymer Ferrocement specimens can be used for applications like small channel lining, open terrace roof finish, pavement slab etc.

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