TOUGHNESS OF GEOPOLYMER FERROCEMENT TROUGH PANEL – AN EXPERIMENTAL STUDY

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Abstract— **This paper deals with the study of impact resistance and energy absorption properties of Geopolymer Ferrocement Trough Panel under impact load. Geopolymer is an eco-friendly binding material alternative for Ordinary Portland Cement (OPC). In the last decade fly ash based geopolymer has emerged as a promising new cement alternative in the field of building and construction materials. Ferrocement is a thin composite made with a fly ash based mortar matrix reinforced with closely spaced layers of relatively small diameter wire mesh. Over the years, applications involving Ferrocement have increased due to its properties such as strength, toughness, water tightness, lightness, ductility and environmental stability. This project aims to study and compare the structural behaviour of Ferrocement trough panel and its mechanical properties. These panels were subjected to impact loading by drop weight test method. It is concluded that Geopolymer Ferrocement Trough Panels with 10M NaOH solution using higher impact energy absorption capacity as compared other geopolymer mixes.**

*Keywords— **Ferrocement, Geopolymer, Wire mesh, Impact load.***

I. 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.

a) Drop weight single or repeated impact test,
b) Constant strain rate test
c) Weighted pendulum charpy type impact test,
d) Explosion- impact test,
e) Projectile impact test,
f) Instrumented pendulum impact test,
g) Split Hopkinson bar test.

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. Reported work on the impact behavior of Ferrocement slabs relates to the use of conventional reinforcement (chicken mesh and M.S. skeletal) and drop-weight method (instrumented/ordinary falling weight). 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 manufacturing process itself. 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 ton ordinary Portland cement consumes 4GJ energy and produces about 1 ton of carbon dioxide (Co_2) to the atmosphere. About half of the Co_2 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. Geopolymers prepared by using the low calcium fly ash exhibit high compressive strength, low creep, minimal drying shrinkage, good acid resistance, fire resistance. 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.

II. LITERATURE REVIEW

In the experimental work carried out by **S. Nagan and R.Mohana (2014)**[1], they found the resistance of geopolymer mortar slabs under impact load by dropping a steel ball from a considerable height. For this study, they used specimens of size 230 x 230 x 25 mm with different combinations of chicken mesh and rectangular weld mesh and are subjected to impact load by drop weight test and the impact energy required for first crack and final crack were calculated. They found that the combination of chicken mesh and rectangular weld mesh together showed better performance in case of energy absorption and residual impact strength. The compressive strength, flexural strength and split tensile strength of 10M geopolymer mortar specimens are found to be 36.05%, 33% and 27.7% more when compared to cement mortar specimens respectively. Also with increase in volume of reinforcement, energy absorption of geopolymer ferrocement specimen increases compared to cement mortar specimen.

In this experimental investigation **P.Saranyabanu (2014)**[2]**,** The geometry of ferrocement panel is trough shape with dimensions of 1000 mm x 350 mm x 30 mm. For the panels with single wire mesh, the mesh was placed at mid depth of the panel and the mortar mix was prepared using sand-cement ratio and water-cement ratio by weight of 1:1 and 0.3, respectively. After 24 hours from casting, the samples are removed from the mould and the cured in water for 28 days. The flexural behavior of trough shaped ferrocement panels reinforced with skeletal steel and wire mesh with varying number of wire mesh layers is presented. The slab panels are tested under flexural loading by applying line loads at 1/3rd points. The cracking load was not significantly affected by the number of the wire mesh layer particularly for the Trough panel. From the experimental result, the flexural strength of the trough shaped panel with single layer wire mesh is 81% more than flat panel and 50% lower than folded panel. And the deflection is 61.18% less than flat panel and 44.68% more than folded panel. And trough shape panel with double layer wire mesh is 77.95 % more than flat panel and 53.81% lower than folded panel. And the deflection is reduced by 56.36% and 6.17% respectively when compared of flat panel and folded panel. Finally increasing the number of layers of wire mesh from 1 to 2 layers, significantly increase the ductility and capability to absorb energy of both types of the panel.

III. RESEARCH SIGNIFICANCE

In this investigation, the experiments were conducted to understand the structural behavior of Geopolymer Ferrocement Trough Panels under impact loading. The tests were mainly focused on the impact load test of geopolymer Ferrocement Trough Panels with all the four edges in fixed condition by drop weight test. This paper presents the no. of blows required for first crack stage, ultimate stage, impact load and energy absorption at first crack and ultimate stage.

IV. MATERIALS

a. Fly Ash

Fly ash is the most abundantly used mineral admixture as replacement for cement in mortar. It is also the main ingredient for geopolymer mortar due to its active participation in the geopolymerization process. Pozzolanic material exhibits cementitious properties when combined with calcium hydroxide. Fly ash is used as the pozzolana in many concrete applications. Fly ash is used as cement replacement.

b. Fine Aggregate

Locally obtained trichy river sand is used as the fine aggregate in the mortar mixes. The sieve analysis result indicates that the sand confirms to zone-II as per IS: 383- 1970.

c. Sodium Hydroxide

Generally, NaOH is available in market in pellets or flakes form with 96% to 98% purity where the cost of the product depends on the purity of the material. The solution of NaOH was formed by dissolving it in water based on the molarity required. It is recommended that the NaOH solution should be made 24 hours before casting and should be used with 36 hours of mixing the pellets with water as after that it is converted to semi-solid state.

d. Sodium Silicate

It is also known as water-glass which is available in the market in gel form. The ratio of SiO_2 and Na_2O in sodium silicate gel highly affects the strength of geopolymer mortar. Mainly it is seen that a ratio ranging from 1 to 1.5 gives a satisfactory result.

e. Wire Mesh

Steel wire meshes are considered as primary reinforcement. This include square woven or welded meshes, chicken (hexagonal/aviary) wire mesh, etc. Except for expanded metal mesh, generally all the meshes are used galvanized. Galvanizes chicken wire mesh with a hexagonal opening of size 12 mm and wire thickness of 1.29 mm was used in this study.

V. MIX PROPORTION AND EXPERIMENTAL INVESTIGATION

a. Geopolymer Mix Design

Sodium hydroxide concentration	= 10 M
Na_2SiO_3 to NaOH ratio	= 1:1.50
Fly ash to Sand ratio	= 1:1
Alkaline activator to Fly ash ratio	= 0.45
Curing type	= oven curing
Curing period (oven)	= 24 hrs@72°c -75°c

b. Preparation of Alkaline Activator Solution

The mixture of Na_2SiO_3 solution and NaOH solution can be used as the alkaline liquid. The Alkali activator solution has to be prepared before 24 hours of use because at the time of mixing Na_2SiO_3 and NaOH solution it generates a huge amount of heat and the polymerization takes place by reacting with one another, which will act as a binder in the geopolymer mortar. It should be used within 36 hours of mixing the pellets with water as after that it is converted to semi-solid state. The Sodium hydroxide, available in small flakes, is dissolved in water at different proportions as required molarity of solution.

c. Geometry of mould

Geometry shape of Ferrocement trough panel will be casted using geopolymer mortar and the size of panels. The tested ferrocement panels consist of two Trough panels. The dimensions of the trough are shown in Fig. (1) which depicts that the horizontal projection of the trough panel is (350x200mm) dimensions. The thickness of the panels is 30mm.The panels are constructed using the conventional ferrocement materials, which is composed of cement mortar and Galvanizes chicken wire mesh with a hexagonal opening.

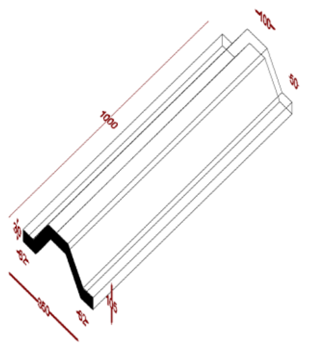

Figure 1. Dimensions of the Trough panel

d. Casting of geopolymer ferrocement panels

Special mould was fabricated in metal sheet to match the required geometry of the trough panel. Each sample is molded after fixing the required wire mesh and skeletal steel in its proper position. For the panels with single wire mesh top of the skeletal steel. Then the panels were cast in sodium hydroxide concentration 10M, sodium hydroxide to sodium silicate ratio 1:1.50, fly ash to sand ratio of 1:1 and alkaline activator to fly ash ratio of 0.45 with proper compaction**.** The moulds were coated initially with oil so as to enable easy removal of the moulds. The moulds were placed on an even surface. The surface was painted with waste oil. Cover blocks were used to ensure a clear cover of 5 mm. Normal mild steel bars steel bars (nominal diameters 6 mm) were used as the reinforcing material. The steel reinforcement mat with required spacing was placed inside the moulds.

e. Impact machine set-up

Geopolymer Ferrocement trough panels were tested under drop weight impact load the impact was conducted using 4.5 kg hammer that was allowed to fall freely from a constant height of 460mm through a guide at the center of the panel for all the specimens with the simple support conditions as per ASTMD 2794.Specimens were placed in their 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 was also recorded. For each panels 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 the point, corresponding number of blows were noted. The no. of impact blows required to develop first visible crack was used to calculate the first crack impact strength. The schematic diagram of impact test experimental setup is shown in Figure 2.

Figure 2. impact machine set-up

VI.RESULTS AND DISCUSSION

a. Energy absorption

The mass was then dropped repeatedly and the number of blows required to cause first crack was recorded. Then the number 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 panels 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.

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

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' (Irs). The energy absorption capacities of Ferrocement slab specimens at first crack and at ultimate failure stages are presented.

Table 1 Impact Resistance of Geopolymer Ferrocement Trough Panels

S. No.	Specimens ID	First Crack Resistance – FCR (No. of blows)	Ultimate Resistance – UR (No. of blows)	Percent increase in Resistance from FCR to UR
1	GFP TH 01	8	22	1.75
	GFP TH 02	9	25	1.74

Table 2 Impact Energy of Geopolymer Ferrocement Trough Panels

S. No	Specimens ID	Impact Energy Absorbed (Joules)		Impact Strength Ratio (I_{rs})
		At First Crack	At Ultimate	
1	GFP TH 01	165.60	455.40	2.75
	GFP TH 02	186.30	517.50	278

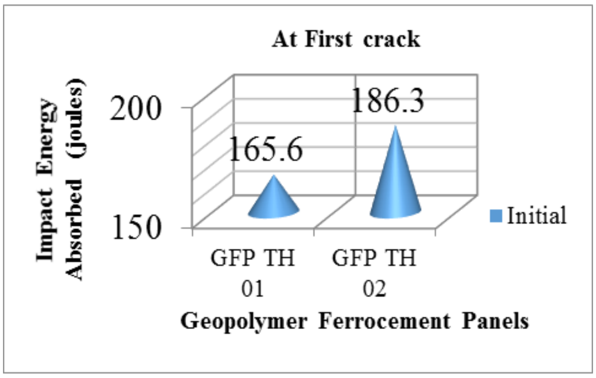

Figure 3 At first crack

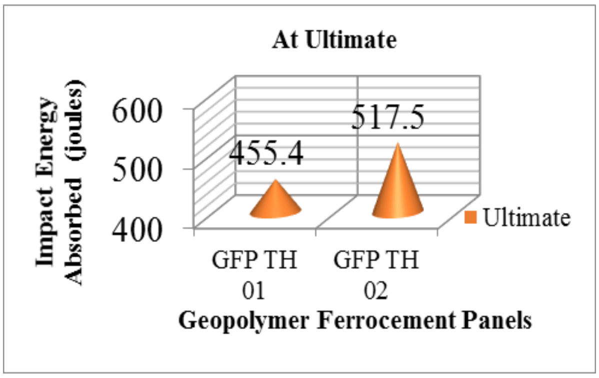

Figure .4 At Ultimate

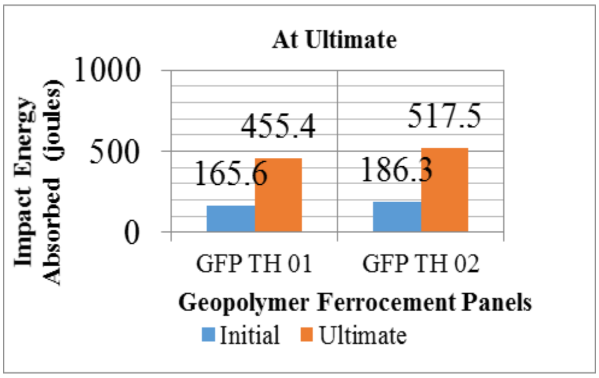

Figure 5. Impact Energy of Geopolymer Ferrocement Trough Panels

b. 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 panels. The impact energy absorbed by the geopolymer panels 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 panels, 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 panels is shown in the Fig 6 and 7.

Figure 6. Geopolymer Ferrocement Trough Panels at First crack

Figure 7. Geopolymer Ferrocement Trough Panels at failure

V. CONCLUSIONS

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

1) Increase in the volume of reinforcement the energy absorption is also increased when compared to the control mix.

2) The failure pattern in the impact tested panels is found to be punching shear due to higher reinforcement. Only pure cracks are propagated up to the edge.

3) The energy absorbed at failure is directly proportional to the volume of the reinforcement provided in the Geopolymer Ferrocement panels.

4) Increase in molarity of NaOH also increases first crack impact strength and ultimate impact strength of Geopolymer concrete panels.

5) Geopolymer Ferrocement Trough Panels exhibit excellent impact resistance characteristics, in terms of higher energy absorption and higher I_{rs} values, indicating excellent post-cracking behavior.

6) Geopolymer Ferrocement Trough Panels exhibits higher impact strength, while compared with geopolymer Ferrocement Flat panels based on the experimental test results.

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