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Shear Behaviour of Hybrid Fibre Reinforced Geopolymer Concrete Beams

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ABSTRACT

Concrete is the most common material for construction. The demand for concrete as a construction material leads to the increase of demand for Portland cement. Concrete is known as a significant contributor to the emission of greenhouse gases. The cement industry is the second largest producer of the greenhouse gas. The environmental problems caused by cement production can be reduced by finding an alternate material. One of potential material to substitute for conventional concrete is geopolymer concrete. Geopolymer concrete is an inorganic alumino-silicate polymer synthesized from predominantly silicon, aluminium and by product materials such as fly ash, GGBS (ground granulated blast furnace slag). Geopolymer concrete does not contain cement. Hybrid fibres were used in this study. Hybrid fibre is the combination of steel fibre and basalt fibre with different volume fractions. When these fibres are added to this special concrete it improves the ductile behaviour and energy absorption capacity. This is due to the property of steel and basalt fibre to bridge the crack development inside the concrete. The main objective of the study is to look into the shear behaviour of hybrid fibre reinforced geopolymer concrete beams.

Test specimens of 1200×150×100 mm size were used for the study. 20-30% of Fly ash by the mass was replaced by GGBS. The variable used were percentage of steel fibre volume fraction viz. 0.0%, 0.5%, and 1%, and basalt fibre volume fraction viz. 0.0%, 0.15%,and 0.3%. The concentration of sodium hydroxide was 12Molar and 14 Molar in geopolymer concrete. For curing, temperature was fixed as 60^0 C for 24 hours. The geopolymer specimens were cured by using steam curing chamber. The specimens were cured after the rest period of three days. A trail and error process was used to obtain proper mixture proportion for geopoymer concrete. The specimens were tested after the age of 7 days. The obtained results of Fly ash and GGBS -based hybrid fibre geopolymer concrete (F&GHGPC) specimens were compared with the only Fly ash-based hybrid fibre geopolymer concrete (FHGPC) specimens.

Test results shows that first crack load, ultimate load, energy absorption capacity, experimental shear strength and ductile characteristic of F&GHGPC geopolymer concrete specimens were higher than the FHGPC geopolymer concrete specimens.

INTRODUCTION

GENERAL

The global use of concrete is second only to water. As the demand for concrete as a construction material leads to the increase of demand for Portland cement. Concrete is a mixture of Portland cement, aggregate, and water. Concrete is the most commonly used material in the world because of its outstanding strength, durability and availability. The worldwide consumption of concrete was estimated to be about 8.8 billion tons per year. Due to increase in infrastructure developments, the demand for concrete would increase in the future.On the other hand, the climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2), to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming. The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere (Davidovits, 1994).Several efforts are in progress to supplement the use of Portland cement in concrete in order to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, granulated blast furnace slag, and alkaline solution to development of alternative binders to Portland cement.In this respect, the geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of global warming, the geopolymer technology could significantly reduce the CO_2 emission to the atmosphere caused by the cement industries.

GEOPOLYMER

Geopolymers are chains or networks of mineral molecules linked with co-valant bonds. Geopolymer concrete is the result of the reaction of materials containing alumina silicate with concentrated alkaline solution to produce an inorganic polymer binder. Geopolymer concrete is proven to have excellent engineering properties with reduced carbon foot print. Geopolymer concrete is not only reduces the greenhouse gas emission but also it utilizes a large amount of industrial waste materials. There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminum (Al). Geopolymer concrete can be manufactured by using the low-calcium (ASTM Class F) fly ash obtained from coal-burning power stations.

Alkaline solution is used as the biding material for geopolymer concrete. Alkaline solution is made using sodium hydroxide (NaOH) and sodium silicate (NaCl) solutions. Due to this attribute it becoming an increasingly popular material for construction.

The term ‘geopolymer’ was first introduced by Joseph Davidovits in 1978. He proposed that binder could be produced by a polymeric reaction of alkaline solution and the aluminium in source materials of geological origin or by-product materials such as fly ash. Because the chemical reaction take place in this case is a polymerization process, davidovits coined the term ‘geopolymer’ to the represent these binder.

In this work, low calcium (ASTM CLASS F) fly ash with GGBS (ground granulated blast furnace slag) based geopolymer is used as the binder. Fly ash GGBS based geopolymer paste binds the loose coarse aggregate, fine aggregate and other un-reacted materials to form the geopolymer concrete with or without presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in case of opc concrete, the aggregates occupy about 75-80% by mass, in geopolymer concrete.

FORMATION OF GEOPOLYMER

Geopolymers are members of the family of inorganic polymers formed by the reaction between an alkaline solution and an aluminosilicate source. The name geopolymer was formed by a French Professor Davirdovits in 1978 to represent a broad range of materials characterized by networks of inorganic molecules. The geopolymers depend on thermally activated natural materials like Metakaolinite or industrial by products like fly ash or slag to provide a source of silicon (Si) and aluminum (Al). These silicon and Aluminium is dissolved in an alkaline activating solution and subsequently polymerizes into molecular chains and become the binder.

Professor B. Vijaya Rangan (2008), Curtin University, Australia, stated that, “the polymerization process involves a substantially fast chemical reaction under alkaline conditions on silicon-aluminum minerals that results in a three-dimensional polymeric chain and ring structure”. The ultimate structure of the geopolymer depends largely on the ratio of Si to Al (Si:Al), with the materials most often considered for use in transportation infrastructure typically having an Si:Al between 2 and 3.5. The reaction of Fly Ash with an aqueous solution containing Sodium Hydroxide and Sodium Silicate in their mass ratio, results in a material with three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds (Davidovits, 1994).

HYBRID FIBRE REINFORCED GOPOLYMER CONCRETE

Hybrid Fiber Reinforced Concrete (HFRC) is formed from a combination of different types of fibres which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. The combining of fibers, often called hybridization.

Addition of fibres have an enormous potential in crack arresting and therefore fibre reinforced concrete has an enormous potential in crack arresting. As the fibres in to concrete structures have been effective in improving structural performance under gravity loads, improve the structural strength, ductility, as well as in increasing shear strength, energy absorption capacity , and damage tolerance in members subjected to several loading conditions. In

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this work Basalt fibre and Steel fibre with different volume fractions are used to made hybrid fibres.

ANALYSIS OF TEST RESULTS

INTRODUCTION

In this chapter an attempt is made to analysis the experimental results obtained from the testing of specimens and are discussed.

The results obtained from the shear test on the beams are tabulated below. The values shown in the Table.4.1 are average of results obtained from the test on two identical beams under same type of loading.

Table.4.1 Test results of shear specimens

Beam Designation	First crack Load (kN)	Ultimate Load (kN)	Deflection at ultimate load (mm)
F&GHGPC1	20	43	4.25
F&GHGPC2	21	46	4.50
F&GHGPC3	22	47	4.65
F&GHGPC4	30	55	5.00
F&GHGPC5	31	57	5.20
F&GHGPC6	31	57	5.22
F&GHGPC7	35	60	5.25
F&GHGPC8	35	62	5.40
F&GHGPC9	35	62	5.60

LOAD AND DEFLECTION BEHAVIOUR OF F&GHGPC BEAMS

Using the data obtained from the experiment, load deflection plots were drawn and comparison of these plots is shown Fig.4.4. All the plots show linear behavior till the formation of first crack. This could be termed as pre-cracking stage. Beyond this stage, the slope of the curve decreases. This indicate the formation of multiple cracks and hence reduction in flexural rigidity of the beam specimens. In this stage, deflection increases nonlinearly with the load. Beyond this stage, plots became more or less flat and the specimens without fibres showed a sudden drop in the load beyond the peak load. On the other hand F&GHGPC with fibre exhibits more or less flat descending portion, which indicate improvement in ductility due to the fibres and enhancement of stiffing effect of concrete in between cracks in the tension zone.

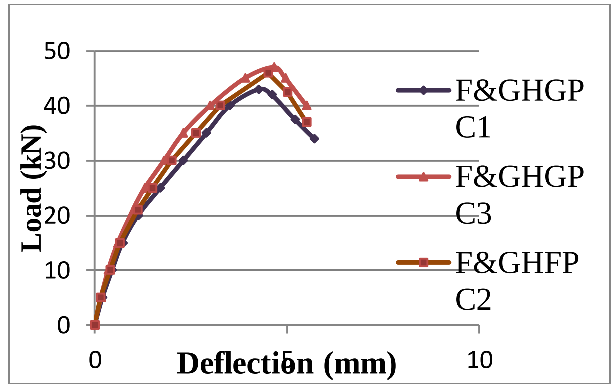

Fig.4.1 Comparison of load vs deflection of F&GHGPC1, F&GHGPC2 and F&GHGPC3

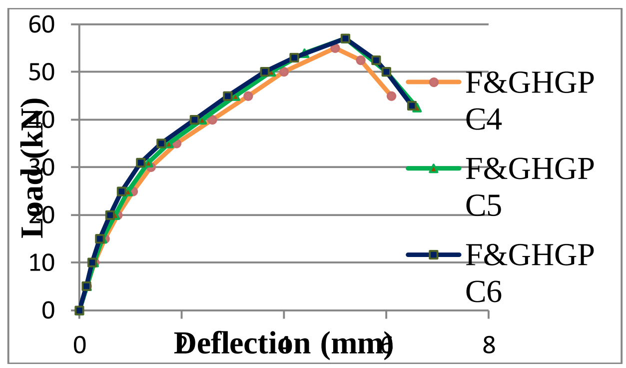

Fig.4.2 Comparison of load vs deflection of F&GHGPC4, F&GHGPC5 and F&GHGPC6

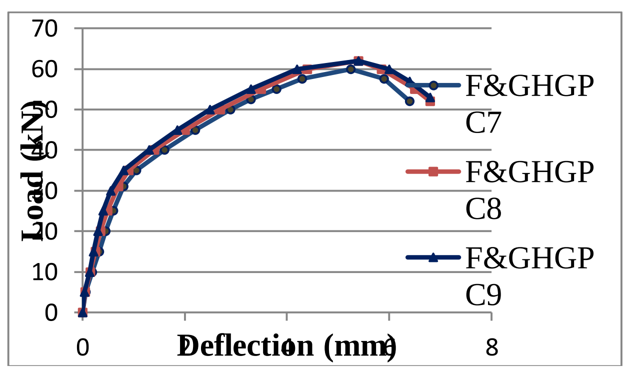

Fig.4.3 Comparison of load vs deflection for F&GHGPC7, F&GHGPC8 and F&GHGPC9

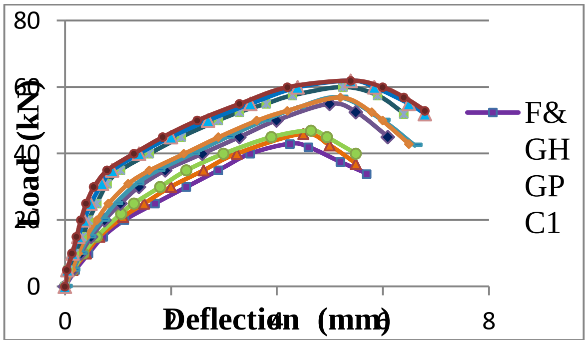

Fig.4.4 Comparison of load vs deflection for all the F&GHGPC specimens

FIRST CRACK LOAD AND ULTIMATE LOAD OF F&GHGPC BEAMS

Average values of test results of two specimens for each percentage of fibre are given in above Table.4.1. First crack load was determined from the load deflection plot corresponding to the point on the curve at which curve deviated from linearity. Referring the above Table.4.1, addition of fibres to GPC beams showed an increase in the first crack load than the beams without fibres. This may be due to the increase in the tensile strain carrying capacity of concrete in the neighbourhood of fibre.

Ultimate load also increase s with the addition of steel fibres to the GPC beams when compared with beams without fibres. When fibres are added to the concrete, they intercept the cracks and this causes deviation of cracks from its initial propagation. This result in the demand of more energy, which in turn improves the load carrying capacity. Comparison of first crack load and ultimate load for shear specimens is shown in Fig.4.5. Comparison of deflection at first crack load and ultimate load for the shear specimens is shown in Fig.4.6.

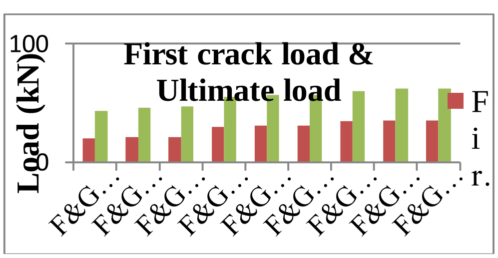

Fig.4.5 Comparison of first crack load and ultimate load for shear specimens

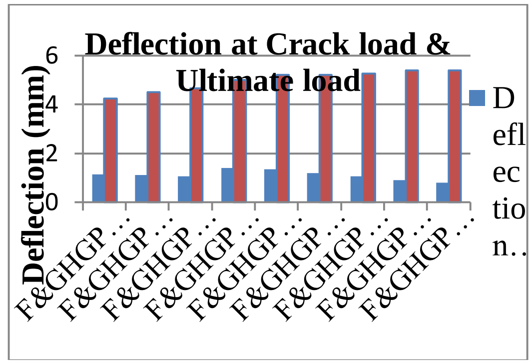

Fig.4.6 Comparison of deflection at first crack load and ultimate load

ENERGY ABSORPTION CAPACITY OF F&GHGPC BEAMS

The energy absorption capacity of the beam could be obtained from the area under the load deflection plot. The area under the load deflection curve shown in Fig.4.4 indicates the energy absorption capacity of the F&GHGPC specimens. Due to sudden shear failure full load deflection plot could not be obtained. Therefore area up to peak load was taken to compare the energy absorption capacities as shown in the Table.4.2

Table.4.2 Energy absorption capacity for F&GHGPC specimens

Beam Designation	Energy Absorption Capacity	
	Absolute (kNm)	Relative
F&GHGPC1	0.173	1.000
F&GHGPC2	0.191	1.104
F&GHGPC3	0.215	1.240
F&GHGPC4	0.249	1.437
F&GHGPC5	0.272	1.572
F&GHGPC6	0.272	1.572
F&GHGPC7	0.315	1.809
F&GHGPC8	0.332	1.919
F&GHGPC9	0.332	1.956

The energy absorption capacity of the beams F&GHGPC8 (1% steel fibre and 0.5% basalt fibre) and F&GHGPC9 (1% steel fibre and 0.3% basalt fibre) is more than other F&GHGPC beams. The volumetric percentage of hybrid fibre is more in these beams due to that the energy absorption capacity of

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these beams is higher than the other F&GHGPC beams.

Table.4.3 Experimental shear strength of F&GHGPC beam specimens

Beam Designation	τ_v (N/mm^2)
F&GHGPC1	2.80
F&GHGPC2	3.06
F&GHGPC3	3.13
F&GHGPC4	3.67
F&GHGPC5	3.80
F&GHGPC6	3.80
F&GHGPC7	4.00
F&GHGPC8	4.13
F&GHGPC9	4.13

rom the above table we can see that for the beams F&GHGPC7, F&GHGPC8 and F&GHGPC9 have high shear strength values compare to the other beams. This is because of the volumetric percentage of steel fibre content is more than the other beams. Beams F&GHGPC5 and F&GHGPC6 has shown same shear strengths, F&GHGPC8 and F&GHGPC9 shown same shear strength values. Further increase of volume percentage of basalt fibre has not shown much effect on shear strength of beams

Load deflection behaviour for FHGPC Beams:

Load deflection behaviour of FHGPC beams is same as the load deflection behavior of F&GHGPC beams. Using the data obtained from the experiment, load deflection plots were drawn and all comparison of these plots is shown Fig.4.11. All the plots show linear behavior till the formation of first crack. Beyond this stage, the slope of the curve decreases. As load increased deflections are also increased.

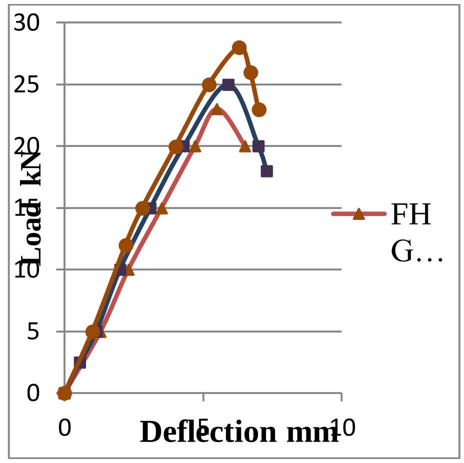

Fig.4.8 Comparison of load vs deflection of FHGPC1, FHGPC2 and FHGPC3

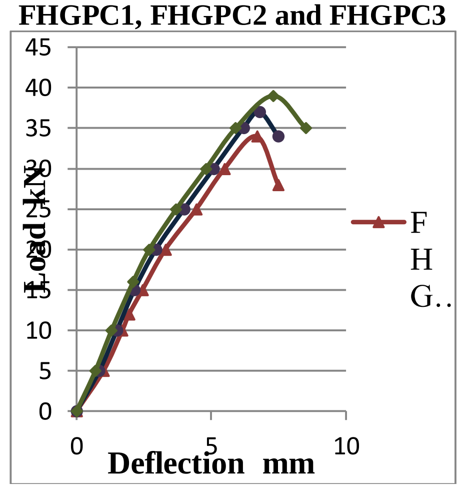

Fig.4.9 Comparison of load vs deflection for FHGPC4, FHGPC5 and FHGPC6

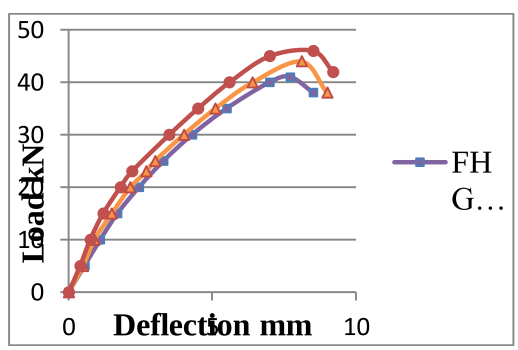

Fig.4.10 Comparison of load vs deflection for FHGPC7, FHGPC8 and FHGPC9

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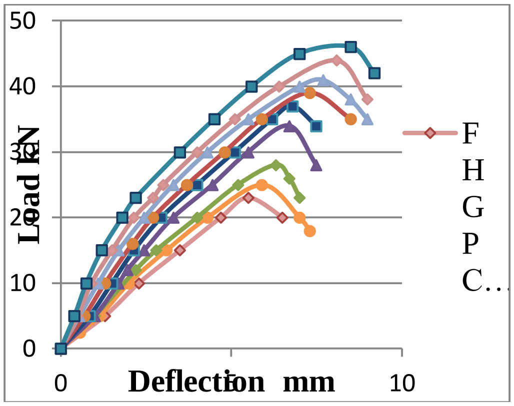

Fig.4.11 Comparison of load vs deflection curves for all the FHGPC specimens

Table.4.5 Comparison of Experimental shear strength of F&GHGPC beams with FHGPC beams

SI.No.	Volume fraction (%)	Experimental shear strength τ_v (N/mm^2)	
		F&GHGPC	FHGPC
1	S0B0	2.80	1.53
2	S0B0.15	3.06	1.66
3	S0B0.3	3.13	1.86
4	S0.5B0	3.67	2.27
5	S0.5B0.15	3.80	2.48
6	S0.5B0.3	3.80	2.60
7	S1B0	4.00	2.73
8	S1B0.15	4.13	2.90
9	S1B0.3	4.13	3.06

Shear strength of all the beams in F&GHGPC and FHGPC is increasing gradually. This is due to the effect of fibres introduced inbeams. We can absorb that experimental shear strength values are increasing significantly in all the beams.

Compare to FHGPC1, shear strength of F&GHGPC1 increased by 83%. The shear strength of F&GHGPC9 is 47% more than the F&GHGPC1 and 40% more than the F&GHGPC4

Table.4.6 Comparison of Energy absorption capacity of F&GHGPC beams with FHGPC beams

SI.No.	Volume frraction (%)	Energy absorption capacity (kNm)	
		F&GHGPC	FHGPC
1	S0B0	0.173	0.085
2	S0B0.15	0.191	0.110
3	S0B0.3	0.215	0.116
4	S0.5B0	0.249	0.147
5	S0.5B0.15	0.272	0.165
6	S0.5B0.3	0.272	0.211
7	S1B0	0.315	0.246
8	S1B0.15	0.332	0.279
9	S1B0.3	0.332	0.296

from the above results we can see that th energy absorption capacity for the beams in case of fly ash and GGBS based hybrid fibre geopolymer concrete (F&GHGPC) and only fly ash based hybrid fibre geopolymer concrete (FHGPC) is increasing. Addition of fibres to the geopolymer concrete has increased the ductility factor of beams thus increase in enegry absorption capacity of beams. Compared to fhgpc beams f&ghgpc beams have more energy absorption capacity. This is due to the effect of GGBS which repalced the 30% of fly ash by mass.

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