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Experimental study of Steel-Concrete Composite Beams comprised of Fly ash based Geopolymer concrete

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Abstract

To combat the present situation of greenhouse gases emission from cement production, a promising solution is to utilise supplementary cementitious by-product materials such as fly ash to produce green concrete known as Geopolymer concrete (GPC). However, despite fly ash based concrete is a promising substitute for ordinary Portland cement (OPC) concrete, it is not yet being utilised to its full potential for structural applications. And so, to utilise green concrete to its full potential, this paper aim is to conduct an experimental study that will integrate fly ash based concrete within steel-concrete composite beams. The research will include casting of composite beams with GPC mix, and an OPC concrete as a reference mix designed according to British Standards. To determine the ultimate moment capacity, a total of Four (4) composite beams comprised of coventional and Bondek steel profile concrete slab are designed and tested according to Australian Standards. From the test results, it was found that composite beam with conventionalconcrete slab outperformed the beams with Bondek profile sheeting. Also, regarding of ultimate bending moment capacity, the composite beam with geopolymer concrete experienced almost identical to OPC composite beam.

Keywords: *Sustainability; Geopolymer concrete; Fly ash; Steel-concrete composite beam.*

1. Introduction

The Portland cement is one of the major used building materials and has been incorporated virtually in all the infrastructure development around the world. According to [1], the global production of cement is over four billion tonnes per annum and, China has become the leading cement producer followed by India contributing the total production of cement globally up to 57.3 % and 6.6 %, respectively. However, due to excessive production, the cement industry contributes up to 5-7% of greenhouse gas CO_2 emission [2]. Consequently, to mitigate the presented situation great efforts are made to study the benefits of incorporating by-products or waste materials as a binder to produce the concrete.

One major advantage of using Fly ash as a primary concrete binder is that it's abundantly available and due to lack of utilization, it is considered as waste and dumped into the landfill. Only 26 % of total fly ash produced annually in the United States has been used for construction practices and, rest of it is being disposed of as a waste material [3], causing further environmental damages.

Introduced in 1970's by Joseph Davidovits, Geo-polymer concrete encompass the reaction of aluminosilicate binders that are rich in silica (Si^{4+}) and alumina (Al^{3+}) such as fly ash combined with highly concentrated alkaline solution (typically Na or K-based solutions). The reaction of these elements results in polymeric chains with a three dimensional amorphous to semi-crystalline microstructure [4]. Despite proven to exhibit excellent compressive strength, low drying shrinkage, resistance to sulphate attack and good acid resistance [5], fly ash based geopolymer concrete has not been used to its full potential. Because the relatively high temperatures are beneficial for overcoming the activation barrier of fly ash [6], which has become a major obstacle for it to be widely accepted for larger structural applications. And, for cast-in-place applications, geopolymer concrete requires to be cured at ambient temperatures. Thus, for the purpose of this study fly ash based geopolymer concrete mix is designed particularly to be cured and cast in ambient temperature and incorporated into steel-concrete composite structure to experimentally determine the ultimate flexural behaviour of the beams.

2. Experimental Program

2.1. Materials

The primary binder used for geopolymer concrete is a low calcium Class-F fly ash obtained from coal power plant in Queensland, Australia. Grounded Blasted Furnace Slag (GBFS) was utilised as an additive that is known to cure geopolymer concrete at ambient temperatures. The binder ratio of 90:10 was applied, that is 90% fly ash and 10% slag content. For conventional concrete, locally available all general purpose cement was used. The chemical composition of fly ash, slag and cement is presented in Table 1.

The aggregates used within the concrete mix designs consisted of both Fine aggregate (Nepean river sand) and Coarse aggregate (20mm Basalt rock also know as Blue Metal). To improve the flowability of Geopolymer concrete, superplasticiser (SP) known as SIKA Visco Crete PC-HRF-2 was utilised.

2.2. Experimental Test

2.2.1. Concrete Mixing

The geopolymer concrete was mixed and poured on site and cured at ambient temperatures. To begin concrete mixing, all the dry component (Fly Ash, GBFS, Fine and Coarse aggregate) was mixed completely before adding any liquid component. Once the dry material was thoroughly mixed, then the liquid components were added to the concrete mix using 50:50 method. That is, 50% of AS was added in the concrete mixer followed by 50% of SP was added and mixed. Then the remaining 50% AS and 50% SP was poured into the mixer and mixed and finally extra water was added to the concrete mix until the good consistency was achieved.

The OPC concrete was designed and mixed according to British Standards. Table 2, provides concrete mix design.

Table 1. Chemical composition of binders

Binder	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	SO_3	LOI
Fly Ash	52.2	24.0	13.7	3.18	0.65	1.32	0.2	1.1
Slag	32.6	13.4	0.35	43.0	0.20	5.5	3.4	0.1
Cement	18.2	4.9	2.6	60.7	0.2	1.0	2.2	3.0

Table 2. Concrete Mix design

Mix ID	Mix Proportion (kg)							
	C*	FA	Slag	CA	SD	AS	W	SP
GPC	-	292	35.52	995	584	146.33	9.79	6.50
OPC	308	-	-	248	678	-	170	-

C* = Cement, FA = Fly Ash, CA = Coarse Aggregate, SD = Sand,

AS = Alkaline Solution, W= water and SP = Superplasticiser

2.2.2. Test Specimens design specifications

A total of four (4) steel-concrete composite beam specimens were fabricated and tested according to Australian Standard AS 2327.1:2003. The geometry of all the specimen are identical in such that concrete slab was comprised of 4600x600x130 mm and 200UB29.8 steal beam 4600 mm in length was conjoined to the concrete slab by the mean of 19mm diameter headed shear stud. To achieve full shear connection, a total of 30 shear studs were welded onto steel beam with the spacing of 200mm centre to centre. Also, N12 steel reo bars were used to form steel mesh to provide flexural reinforcement in the concrete slab. Also, for each concrete mix one conventional and one composite concrete slab was designed. For the composite concrete slab, 1mm thick galvanised Bondek steel profile sheet were laid perpendicular to the beam. Fig. 1. illustrates the design specification both conventional concrete slab and Bondek slab composite beam specimens.

To study the mechanical properties such as Compressive Strength and Modulus of Elasticity of concrete, 200x100 mm cylinder specimens were poured and cured wrapped in plastic film.

2.2.3. Testing Procedures

The test rig was comprised of Hydraulic Oscillator with load capacity of 1000kN. The beam was simply supported at 4000 mm, and both ends of the specimens was roller support as seen Fig.2. A loading plate with a mass of 38 kg was placed in the middle of the beam and downward axial loading was applied at the constant rate of 0.027 mm/sec. At the beginning of the test initial loading of 30kN and 20 kN was applied to conventional and bondek specimen, respectively, to check all the instruments attached are functioning correctly.

The testing machine for cylinder testing involved Intron Universal Testing machine with a 1000kN capacity and loading rate of 20 MPa/min was adopted.

3. Results and Discussions

3.1. The Mechanical properties of Concrete

The cylinder tests for compressive strength and Modulus of Elasticity was performed in accordance with Australian Standard (A.S) 1012.8.1:2014. Modulus of Rupture (MOR) beam test was carried out in accordance with A.S 1012.11:2002. The compressive test was carried out for curing cycle 28 days and on the day of beam test whereas Modulus of Elasticity was carried out on 28 day curing cycle.

The test results for conventional concrete and Geopolymer concrete is summarised in Table 3. From the test results, it can be seen that geopolymer concrete achieved compressive strength of 32 MPa for 28 days according to its design strength. Whereas, OPC achieved slight higher compressive strength of 43 MPa. Furthermore, compressive strength on the beam test day for both OPC and GPC had very similar strength of 43MPa and 41 MPa, respectively.

Regarding Modulus of Elasticity, since its directly related to compressive strength behaviour of the concrete thus similar pattern was observed where the result obtained by OPC was higher in comparison to geopolymer concrete. The result obtained by OPC and GPC is 36776 MPa and 22941 MPa, respectively.

Table 3. Mechanical properties of concrete

Concrete type	Compressive Strength (MPa)		Modulus of Elasticity (MPa)
	28 Days	Test Day	28 days
OPC	42.9	43	36776
GPC	32.34	41.50	22941

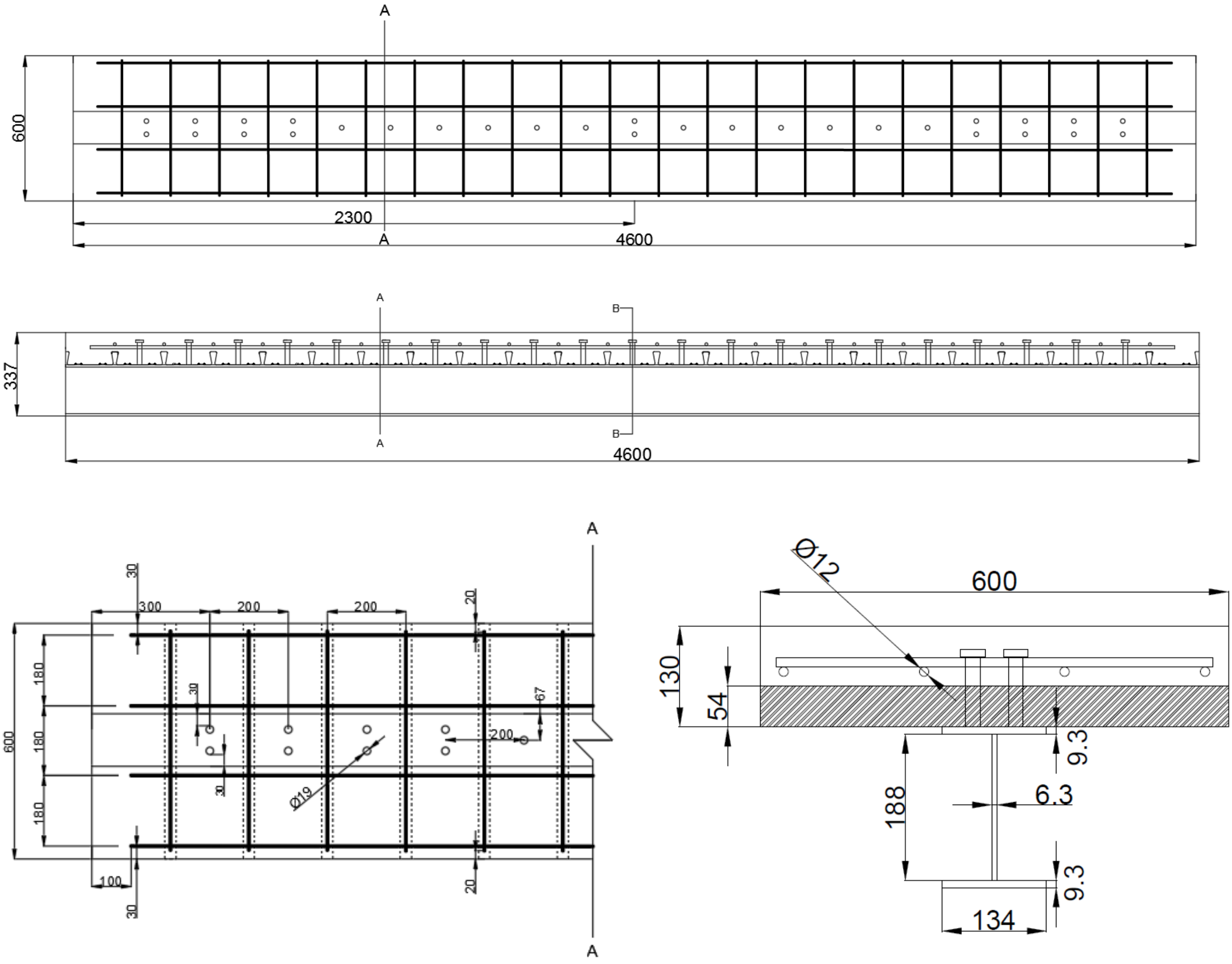

Fig. 1. Composite beam specifications

3.2. Composite Beams

The result obtained from beam testing is summarised in Table 4. Overall, it can be seen that the beams with conventional concrete slab outperformed the beam with composite concrete Bondek slab for both OPC and GPC. That is, specimen OPC-C experienced load capacity of 270 kN with deflection of 164 mm in comparison to OPC-B which achieved load capacity of 229 kN with deflection of 123 mm. Similarly, specimen GPC-C experienced higher load capacity as compare to specimen GPC-B. This is due to the presence of embossments which reduced the amount of concrete within the concrete slab, therefore, reduced the overall beam's capacity.

Also, comparing only conventional concrete beams for both concrete types then it can be seen that both experienced almost the same load capacity whereas OPC achieved only 1.85 % higher than GPC-C. However, on the contrary GPC beam with Bondek experienced higher load capacity than specimen OPC-B. But due to sudden failure of specimen GPC-B achieved the least amount of mid-span deflection as seen in Fig. 3.

Fig. 2. Composite beam test set-up

Table 4. Beam test result summary

Specimen ID	Max Load Capacity (kN)	Mid Span Deflection (mm)	Ultimate Moment (kN.m)	Maximum Curvature (x 10^{-6} mm^{-1})
OPC-C	270	164	270	198
OPC-B	229	123	229	204
GPC-C	265	157	265	257
GPC-B	250	75	250	253

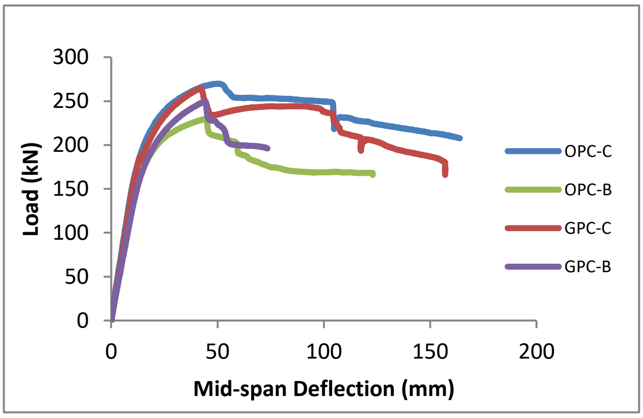

Fig. 3. Load vs Mid-span deflection

Furthermore, the moment vs curvature of all beams specimens is shown in Fig. 4. It can be seen that initial stiffness for all the beams are very similar and until the moment of 200 kN.m all the beams are within the elastic region, and from there onwards the beams are behaving differently to one another. regarding ductility specimen with geopolymer concrete were more ductile as compare to the specimen with normal concrete. Overall, comparing conventional concrete slab specimens, GPC-C achieved 23% higher flexural capacity then OPC-C. A Similar result is seen when comparing specimens with the Bondek profile concrete slab. That is GPC-B achieved 19% higher flexural capacity in comparison to OPC-B. Another important observation is that all the beams except OPC-C experienced sudden drop after achieved its ultimate moment capacity due to flexural concrete cracking.

4. Conclusion

In conclusion, the experimental study was conducted to determine the ultimate flexural capacity of the steel-concrete composite beams incorporating enviromental friendly geopolymer concrete. Overall, it was observed that the beam specimens with conventional slab outperformed specimens incorporating Bondek concrete slab for both concrete types that is due to the presence of profile sheet flanges that reduces the amount of concrete within the concrete slab hence reducing its ultimate capacity. Also, it was observed that geopolymer concrete achieved the higher flexural capacity for both conventional and composite concrete slab. At last, it can be concluded that environmental friendly geopolymer concrete has great potential and can be a great substitute for larger structural application as compared to normal cement concrete that contributes a significant amount of greenhouse emission globally.

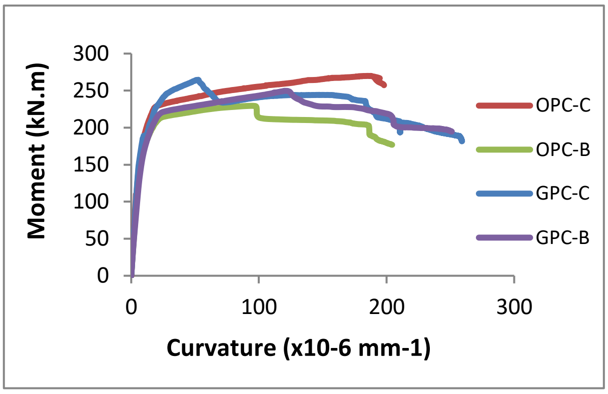

Fig. 4. Moment vs Curvature

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