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Experimental analysis of composite push test integrating geopolymer concrete

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Abstract

This paper primarily focuses on implementing constructions practises that are sustainable, and that can also meet the current demand for infrastructure development around the world. The cement industry is one of the largest industries in the world, as result current construction practices are causing adverse environmental issues ranging from the excessive utilisation of natural resources, emission of greenhouse gases and producing an excessive amount of waste. Thus, to tackle the problem one encouraging solution is to use alkali activated Geopolymer concrete that utilises waste product such as fly ash and grounded slag as a 100% replacement of Portland cement. Subsequently, this paper presents experimental testing and discusses the behaviour of six (6) steel-concrete composite push test specimens incorporating Geopolymer concrete and OPC concrete. A total of three (3) specimens were fabricated using steel profiled Bondek Sheeting and remaining three (3) specimens had a conventional concrete slab. From the result obtained, it was found that push test specimen with conventional slab outperformed specimens fabricated with Bondek profile sheeting due to the reduced amount of concrete surrounding the shear studs cause by Bondek flanges. Also, the results showed that geopolymer concrete has great potential as it achieved almost identical results as compared to control OPC push test specimens.

Keywords: *Geopolymer Concrete; Fly Ash; Alkaline Solution; Push Test; Headed Shear Studs.*

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1. Introduction

Over the last century, concrete has become the most manufactured product on earth in terms of volume ,and it is second most consumed substance after water [1] with a current consumption of 1 m^3 per person per annum [2]. Concrete mainly consists of three main components: aggregate, water and cement. Despite, aggregates occupies a larger fraction of concrete, it is the cement that is accountable for extensive emission of carbon dioxide (CO_2) into the atmosphere.

World-wide, the production of cement contributes at least 5-7% of CO_2 emission [2], [3], whereas in Australia, production of cement accounts for approximately 1.3% of CO_2 emission [4]. In addition to that, due to high demands of cement production globally, the cement industry could represent up to 10% of total CO_2 emission in the near future. The key cause of extensive CO_2 emission from the production of cement is when the limestone is heated and decarbonised to from lime which is the fundamental ingredient to produce cement followed by high energy fuel required such as coal for the chemical process that allows calcination of limestone [5].

Since 1950 the production of cement has gone by a factor of 25 and China has used more cement from 2011-2013 than the USA during the entire 20th century. As a result in 2010, the cement industry was responsible for 2823 million metric tons (Mt) of CO_2 emission into the atmosphere. Furthermore, the global cement production has increased by over 73% between 2005 and 2013 from 2310 Mt to 4000 Mt, respectively [3].

Consequently, due to devastating environmental impacts from the immense production of cement has led to increasing awareness to engage in new technologies that are sustainable and meets the current demand of concrete or cement for infrastructure development world-wide. Thus, to tackle the presented situation this research study focuses on the benefits of utilising supplementary cementititous material such as fly ash and grounded furnace slag as an alternative to Portland cement to develop geopolymer concrete for structural applications.

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. The chemical composition of fly ash, slag and cement is presented in Table 1. For conventional concrete, locally available all general purpose cement was used.

Alkaline Solution (AS) was used to activate the green binder to develop geopolymer concrete. The AS is a mixture of Sodium Hydroxide (SH) solution (NaOH) and Sodium Silicate (SS) solution (Na_2SiO_3). The ratio of SH to SS solution by mass is taken to be 2.5. The SH used to prepare the solution is commercial grade in pellets with 99% purity and SS solution used is commercially available D-grade with SiO_2 to Na2O ratio of 2.0, that is the solution was comprised of 55.9% of water and 44.1% of sodium silicate (Na2O =14.7% and SiO_2 = 29.4%). The AS solution was prepared to have NaOH concentration of 10M. Normal tap water was used to prepare SH solution. The AS was prepared 24 hours before concrete mixing for both SS and SH solutions to mix thoroughly.

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. Table 2 presents the material proportion for each concrete mix.

Table 1. Chemical composition of fly ash and slag

Binder	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**Na_2O**	**MgO**	**K_2O**	**SO_3**	**LOI**
Fly Ash	52.2	24.0	13.7	3.18	0.65	1.32	0.8	0.2	1.1
Slag	32.6	13.4	0.35	43.0	0.20	5.5	0.3	3.4	0.1
Cement	18.2	4.9	2.6	60.7	0.2	1.0	0.4	2.2	3.0

Table 2. Concrete mix design

Mix ID	**Mix Proportion (kg)**							
	C*	FA	Slag	CA	SD	AS	EW	SP
GPC	-	92	10	312	184	45.91	3	2
OPC	85	-	-	248	184	-	-	-

C* = Cement, FA = Fly Ash, CA = Coarse Aggregate, SD = Sand, AS = Alkaline Solution, EW= Extra water and SP = Superplasticiser

2.2. Experimental test

2.2.1. Concrete mixing

The preparation of the geopolymer concrete involved the mixing of all the dry material 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. Meaning, 50% of AS was added in the concrete mixer and mixed for 2 minutes followed by 50% of SP was added and mixed for additional 2 minutes. The remaining 50% AS and 50% SP was poured into the mixer and mixed for another 2 minutes. Finally, extra water was added and mixed for 5 minutes. The concrete was mixed in 300L Baron concrete mixer.

2.2.2. Test Specimen design specification

A total of six (6) push test specimens were fabricated and tested. The dimensions configuration of all the specimen were identical in such that concrete slab was comprised of 600x600x130 mm, and 200UB29.8 steal beam consists of a 700mm long section was joined to the concrete slab by the mean of 19mm diameter headed shear stud. A total of 8 shear head connectors were welded per push test specimen. For Bondek specimen 1mm thick galvanized steel profile sheet was used. Figure 1 illustrates the design specification both conventional concrete slab and Bondek push test specimens.

To study the mechanical properties such as Compressive Strength and Modulus of Elasticity of concrete, 200x100 mm cylinder specimens were poured and cured for 28 days. Also, unreinforced beams size of 400x100x100 mm was cast to determine the Modulus of Rupture. The gravitational compaction test was carried out to determine the workability of the geopolymer concrete.

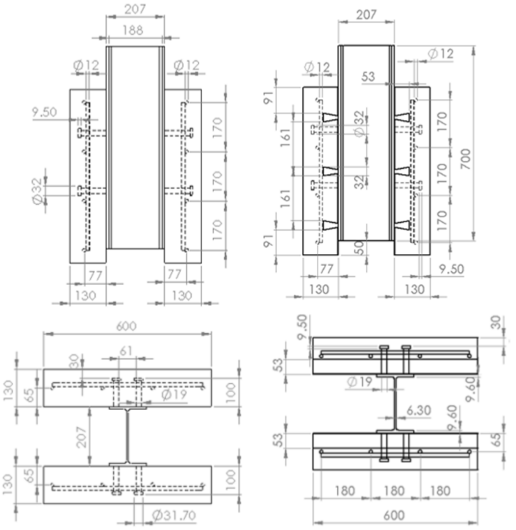

Fig. 1. Specimen design specifications

2.2.3. Curing conditions

To determine the effect of the change in temperature on geopolymer concrete at ambient temperature, one pair of push test specimen was cured in different curing condition. This was achieved by curing one pair of push test specimen in open environment and another pair under inclosed environment. The fluctuations of daily temperature for both curing conditions were observed and recorded as seen in Figure 2. It can be seen that specimen cured under open environment experienced greater temperature fluctuation in comparison to those within the indoor (close) curing conditions. Similar to push pest specimens, corresponding cylinder samples were cured identically.

2.2.4. Testing rig and procedure

The test rig configuration for push Test specimens was consists of Hydraulic Oscillator with load capacity of 1000kN. The boundary condition for push test specimens consisted of roller support on the south end and fixed support on the north end of the specimens. Regarding loading conditions, the push test specimens will be tested in accordance with loading conditions specified in Eurocode 4 (Annexure B2.4). Subsequently, all the specimens will be subjected to 40% of the expected failure load which will be cycled twenty-five (25) times. Once 25 loading cycle is completed, then specimen will be subjected to increasing load until failure occurs.

The cylinder tests were performed in accordance with Australian Standard (A.S) 1012.8.1:2014.Modulus of Rupture test was carried out in accordance with A.S 1012.11:2002. Furthermore, the gravitational compaction test was carried in accordance to test procedure specified in AS 1012.3.2:2004. The compressive test was carried out for curing cycle of 7, 14, 21 and 28 days whereas Modulus of Elasticity and Rupture test was carried out on 28 day curing cycle.

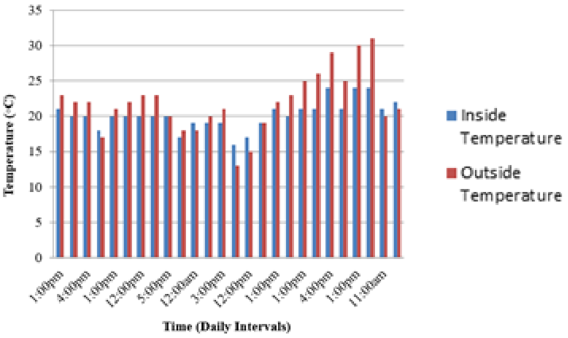

Fig. 2. Curing conditions

3. Results and discussion

3.1. The mechincal properties of concrete

From the test results obtained as shown in Figure 3, it can be seen that GPC-IS mix cured in inclosed (controlled) environment has achieved lower compressive strength throughout the curing cycle as compared to GPC-OS which was kept under open environment subjected to significant change in temperature and humidity at ambient conditions. The outdoor curing condition achieved a maximum temperature of 31°C as compared to 24°C for the indoor curing conditions which allowed for an improved geopolymerisation reaction to occur within GPC-OS, hence the reason for GPC-OS achieving higher compressive strength. Therefore, change in temperature and humidity at ambient condition does play a vital role in strength development of geopolymer concrete. In regards to OPC mix, it was designed for 32 MPa in accordance to British Standards and it achieved 36.87 MPa for 28 days curing period.

Since Modulus of Elasticity is directly related to the compressive characteristic of concrete mix, therefore similar pattern to compressive strength was observed where GPC-OS achieved higher elasticity as compare to GPC-IS concrete mix. For 28 days Modulus of Elasticity achieved by GPC-OS and GPC-IS is 33625 MPa and 32806 MPa, respectively. Overall, as expected OPC concrete has achieved the highest modulus of elasticity of 45161 MPa as compare to geopolymer concrete.

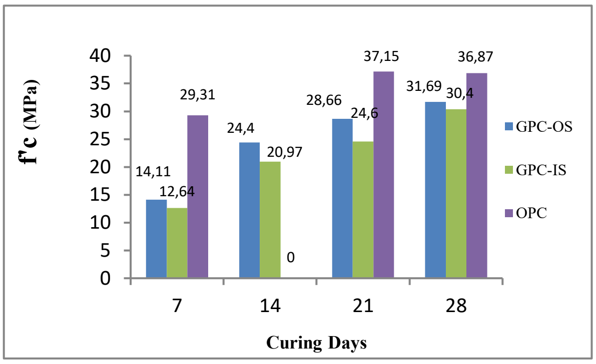

Fig. 3. Compressive strength vs curing days

The result for Modulus of Rupture showed that geopolymer concrete achieved higher tensile strength as compared to OPC concrete. However, GPC-OS achieved the highest value of 4.66 MPa whereas GPC-IS and OPC achieved the value of 3.96 MPa and 3.87 MPa, respectively.

The workability of geopolymer concrete was observed by performing gravitational compaction test. The procedure of the test was carried out according to AS 1012.3.2 (2004) where, poor and excellent workability level corresponds to compaction factor value of ≤ 0.7 and ≥ 0.95, respectively. From the test, the flowability of the geopolymer concrete looked very good and, correspondingly the concrete achieved the compaction factor of 0.90 which according to standard is classified as good workability.

3.2. Push test

Table 3 illustrates the maximum shear resistance achieved by each push test specimen along with the governing specimen failure. It can be seen that the performance comparison between conventional slab (CS) and Bondek slab (BS) specimens can easily be distinguished since all the conventional slab specimen achieved higher shear resistance as compare to Bondek specimens. The main reason can be attributed to the presence of embossments, which significantly reduces the amount of local concrete surrounding the shear studs. Hence, causing the BS to become increasingly prone to conical type concrete failure and allow significant separation of the concrete from the steel beam. As a result, all the interaction between the BS and steel beam as a composite section is eradicated, and the specimen is less effective in resisting shear load as compare to CS specimens. Ultimately, the presence of Bondek is unable to resist larger shear.

Furthermore, it was very clear that change in curing condition of geopolymer concrete plays a vital role which was reflected by the variation of maximum shear resistance obtained push test specimens. The temperature range for both outdoor and indoor was recorded using temperature data logger; every three hours the temperature was observed and recorded. It was observed that outdoor temperature range was from 13 C to 31 C, whereas indoor temperature range was from 16 C to 24 C. As expected, specimens CS-GPC-OS cured in outdoor condition outperformed specimen CS-GPC-IS, where CS-GPC-OS and CS-GPC-IS achieved maximum shear resistance per stud of 115.95 kN and 91.30 kN, respectively. Similarly, the effect of change in temperature was observed for Bondek specimens.

In regards to the failure mode of push test specimen, it was observed that the dominant failure mode for both CS and BS is constant amongst all test specimens. As shown in Table 3 that the conventional slab specimens all failed from concrete splitting type failure, and the Bondek specimens failed from conical type failure. Figure 4 illustrates conventional and Bondek specimens failure mode.

Overall, the push test specimen (CS-OPC and BS-OPC) with conventional concrete achieved the highest value of maximum shear resistance but in comparsion to GPC push test specimens especially GPC-OS the difference was insignificant. Therefore, geopolymer concrete has great potential as a substitude to conventional concrete for sturctural applications.

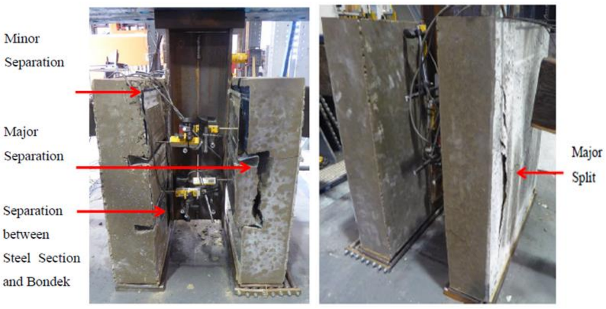

Fig. 4. Occurrence of concrete cracking

Finally, the test results obtained from the experiment was compared to Eurocode 4 and Australian Standard AS2327.1:2003. Using the formulas specified in each of the respective codes, it was found that the expected calculations in accordance with Eurocode were too conservative for conventional slab push test specimens. However, for Bondek specimens, the calculated values were reliable and close to tested values. On the other hand, the calculated values for Bondek Push test specimens according to Australian Standard was too conservative and very reliable for conventional slabs specimens. The comparison between calculated and test values from both standards can be found in Table 3.

Table 3. Push test result summary

Specimen ID	Shear resistance per stud (kN)	Failure mode
CS-GPC-OS	115.95	Concrete Splitting Failure
BS-GPC-OS	44.47	Conical Type Failure
CS-GPC-IS	91.30	Concrete Splitting Failure
BS-GPC-IS	41.23	Combination of Conical and Splitting Failure
CS-OPC	118.43	Concrete Splitting Failure
BS-OPC	57.29	Conical Type Failure

Table 4. (cont.)

Specimen ID	Eurocode (kN)	Australian Code (kN)
CS-GPC-OS	74.4	93.25
BS-GPC-OS	52.08	93.25
CS-GPC-IS	74.4	93.25
BS-GPC-IS	52.08	93.25
CS-OPC	74.4	93.25
BS-OPC	52.08	93.25

4. Conclusions

In conclusion, the research study was conducted to determine the behaviour of shear connector integrated within geopolymer concrete for steel-concrete composite push test specimens. Following points summarise the reseach study:

1) Push test specimens with conventional slab significantly outperformed specimens incorporating Bondek specimens.

2) Conventional slab specimens all failed due to concrete splitting type failure whereas, Bondek specimen all failed from conical type separation.

3) The greater temperature exposure of geopolymer concrete improves the geopolymerisation reaction which leads to improved strength development and concrete duability.

4) The difference in maximum shear resistance achieved by OPC and GPCspecimen was insignificant. Hence geopolymer concrete can be great substitute for conventional concrete.

5) Eurocode 4 and Australian standard calculated values were too conservative for conventional slab and Bondek specimen, respectively.

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