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GEOPOLYMER CONCRETE WITH FRP CONFINEMENT

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ABSTRACT

Given the recent attention towards renewable and environmentally friendly technologies, usage of geopolymer concrete, a greener substitute for traditional Ordinary Portland Cement (OPC) concretes is becoming more prevalent than ever. However, unconfined Geopolymer concrete exhibits much higher levels of brittleness compared to that of OPC concretes. Ductility of geopolymer concrete can be increased by lateral confinement. Fibre Reinforced Polymer (FRP) confined concrete, demonstrates a major gain in ductility and strength compared to that of steel confined concrete.

This research investigates the structural performance of geopolymer concrete with FRP wrapping (Carbon Fibre Reinforced Polymer and Glass Fibre Reinforced Polymer). Experimental program included twenty geopolymer concrete samples (ten 100 x 200 mm and ten 150 x 300 mm). Test variables were the type of confinement (GFRP and CFRP), number of confinement layers (one and two) and specimen size. It is observed that both CFRP and GFRP confinement are effective in improving the strength and ductility of geopolymer concrete. FRP confinement is equally as effective on large geopolymer cylindrical samples as the smaller counterparts. The outcomes of this study can be used to improve the design and development of geopolymer concrete and FRP technologies, ultimately aiding sustainable construction methods whilst promoting carbon neutral design.

KEYWORDS

Geoolymer concrete, GFRP, CFRP, confinement, ductility.

INTRODUCTION

The need for this study has stemmed from the realisation and increased awareness of the derogatory effects of non-renewable and carbon-positive technologies. Given this recent advancement towards renewable and environmentally friendly technologies, usage of geopolymer concrete as a greener substitute for traditional Ordinary Portland Cement concrete is becoming more prevalent than ever. As it stands today, typical Portland cement production within the construction industry accounts for approximately 3.9 to 7.0% of the global CO_2 emission. One such way to effectively reduce this carbon footprint is through substitution with that of a green concrete. Studies have concluded that by using geopolymer concrete as a replacement for traditional concreting methods, CO_2 emission figures can effectively be reduced by up to 80% (Fitzgerald, 2010).

The term 'geopolymer' refers to that of synthetic alkali alumina silicate which, occur through the reaction between 'either a concentrated aqueous silicate or solid alumina silicate or concentrated aqueous alkali hydroxide with that of solid alumina silicate (Duxson et al., 2006). This reaction results in a rigid chain geopolymer network. The formed 'synthetic alkali alumina silicate' or simply 'Geopolymer' network provides a wide range of benefits for usage as an alternative binder in cementitious materials (Alliance, 2013). In the short history of geopolymer construction products a multitude of benefits for its usage have arisen. One reason that geopolymer cement products are considered as a greener alternative is the fact that fly ash is a primary constituent of geopolymer concrete. Fly ash is produced as a by-product in the burning of coal, in which approximately 73% of power generated in Australia is produced through coal fuelled power stations. Statistics show that approximately 12 million tons of fly ash is produced per annum within Australia while 6.5 million tons of fly ash remaining unused (Hardjito, 2005). Studies have accordingly shown that when compared to that of OPC the carbon footprint of geopolymer concrete is reduced anywhere from 26% – 45%.

Properties of geopolymer concrete family varies significantly depending on the source material (Sofi, 2007) and are superior to their OPC counterparts in terms of early strength gain, sulphate (Wallah et al., 2005) and fire resistance (Pan and Sanjayan, 2010) and very little shrinkage (Hardjito, 2004; Olivia, 2012). In addition, geopolymer concrete has a strong resistance to high temperatures and thus subsequently reduces the risks associated with spalling and strength loss (Kong, 2010). Sofi et al. (2007) concluded that the mechanical properties of geopolymer concrete depend on the mix design and curing method. Having investigated geopolymer and OPC paste and concrete, Pan et al. (2011) concluded that differences in the pastes are consistent with the differences in the concretes. While the tensile strength of geopolymer concrete is higher than that of its counterpart (Sofi et al., 2007, Pan et al., 2011, Olivia and Nikraz, 2012), elastic modulus (Pan et al., 2011, Olivia and Nikraz, 2012) and flexural strength (Olivia and Nikraz, 2012) of the same is reported to be lower. Equations for tensile strength, flexural strength and modulus of elasticity for geopolymer concrete have been proposed in the past (Diaz-Loya, 2011; Sofi, 2007). However since geopolymer concrete exhibits higher brittleness than OPC concrete, careful consideration given in the structural design of high strength concrete (HSC) should be continued for the structural design of geopolymer concrete (Pan, 2011).

Despite having a multitude of associated benefits, geopolymer concrete products also come hand in hand with a fair share of problems. Unconfined geopolymer concrete has been found to exhibit much higher levels of brittleness compared to that of OPC concretes (Pan and Sanjayan, 2010). In the past decades, the use of fibre reinforced polymer (FRP) composites as the method of confinement has been gaining increasing popularity. The FRP reinforcement can provide significantly higher confinement stresses than the conventional steel reinforcement and therefore provide good level of ductility to high strength concrete (Lokuge et al., 2010). Same method of confinement can be applied to improve the ductility of geopolymer concrete. Thus as a direct result of this shortfall, this study aims to make and test the structural performance of geopolymer concrete samples with confinement provided by FRP wrapping (CFRP and GFRP).

EXPERIMENTAL PROGRAM

An experimental program was designed to effectively address the aim of this research. Within the program there were three test variables: the type of confinement (GFRP and CFRP), number of confinement layers (one and two) and specimen size (100 mm diameter and 200 mm high, 150 mm diameter and 300 mm high). In total 20 specimens were tested, which comprised of 16 confined specimens of differing test variables and 4 unconfined control specimens. It should duly be noted that all samples were produced in duplicate to ensure accuracy in results when testing for compressive strength, and axial strain.

Fly ash used in the investigation was Type F (low calcium) fly ash of approximately 15 µm. It was sourced from Pozzolanic Millmerran in Queensland, Australia. Density of fly ash was found to be 1100 kg/m^3. Ground Granulated Blast Furnace Slag (GGBFS) was received from Australasian (iron & steel) Slag Association, Wollongong, Australia. GGBFS was approximately 45 µm and had a relative density of 2.88. Fine dry sand used in the investigation had a bulk density of 1494 kg/m^3, water absorption of 8% and particle size smaller than 425 µm. Two different sizes of coarse aggregates were used (7.5 mm and 10 mm maximum aggregate size). Alkali activators used to make geopolymer concrete included sodium silicate and sodium hydroxide solutions. Sodium silicate solution is available in different grades. Alkali silicate used in this research was Grade D sodium silicate solution with a modulus ratio (Ms) of 2 (Ms = SiO_2/Na_2O and Na_2O = 14.7% and SiO_2 = 29.4% and water = 55.9% by mass) and specific gravity of 1.5. Sodium hydroxide with 90% purity in the pellet form was used to prepare sodium hydroxide solution. Plain carbon fibre cloth weave used is a one over one under weave pattern with a weight of 200 g/m^2. Glass fibre cloth had a weight of 250 g/m2. The tensile strength of carbon fibre and E-Glass used were 3530 MPa and 2000 MPa respectively. Five parts epoxy with one part hardener was used to prepare epoxy resin mix and 230 g epoxy resin mix was used for 1 m^2 of fibre cloth.

Mix Design

The mix design utilised within the experimental program is outlined in Table 1. It was based on the research conducted by (Zhao, 2011). However the amount of fly ash in the original research was reduced to 50%, replacing that amount by GGBFS. Aggregate weights shown in Table 1 represent the saturated surface dry quantities.

Table 1. Mix proportions

Material	Quantity (kg/m^3)
Alkaline liquid/fly ash	0.45
NaOH solution (8M)	49
Na_2SiO_3 solution (Grade D)	122
Fine aggregate	554
Coarse aggregate	
7.5 mm	647
10 mm	647
Fly ash	190.5
GGBFS	190.5

Sample Preparation

At least one day before the sample preparation, sodium hydroxide pellets were mixed with distilled water to get the sodium hydroxide solution with the required molarity. This was mixed with the sodium silicate solution to prepare the alkaline solution. On the day of sample preparation, sand, coarse aggregates, slag and fly ash were initially dry mixed for about a minute in a 120 litre mixer. The pre-prepared alkaline solution was then introduced in the dry mix and further mixed for 4 minutes before casting into greased cylindrical moulds. The fresh geopolymer concrete was stiff until compacted using a vibrating table. Samples were cured in room temperature for 24 hours and then placed in a constant temperature room (23^{0}C and 50% humidity) until the time of testing. Seven days prior to testing, samples were then wiped down with methylated spirits and paper towel to remove residual oil left from the casting process. Required amounts of both the carbon fibre and glass fibre cloth were measured and cut to shape allowing for a 2-3 cm overlap of the weave. Epoxy resin/hardener blend was mixed up in a ratio of 5 parts epoxy to 1 part hardener. The epoxy resin blend was then applied with a paintbrush to the exterior of a sample taking care to ensure even and generous coverage, whilst ensuring all voids were completely saturated with the solution. The corresponding pre-cut fibre reinforcement sheet was then laid out and epoxy resin was generously applied to the sheet ensuring that complete saturation of all fibres within the sheet was achieved. The samples were then wrapped with the saturated reinforcement sheets. The samples were then left to sit and thus allow for the resin to dry and reach full strength One day prior to testing excess fibre reinforcement was trimmed. Two strain gauges were then applied vertically and equidistantly around the marked midpoint. Samples thus prepared are shown in Figure 1.

Figure 1. Sample preparation

Details of the samples tested are shown in Table 2.

Table 2. Details of samples

Sample number	FRP type	Layers	Sample size
1, 2	CFRP	1	100 mm diameter and 200 mm high
3, 4		2	
5, 6	GFRP	1	
7, 8		2	
9, 10	Unconfined		
11, 12	CFRP	1	150 mm diameter and 300 mm high
13, 14		2	
15, 16	GFRP	1	
17, 18		2	
19, 20	Unconfined		

Testing

The fibre wrapped specimens were then tested in a Sans compression testing machine with 1500 kN loading capacity at a constant cross head speed of 2 mm/min. Axial strains were measured using platen to platen method and two longitudinal strain gauges glued diagonally opposite in the middle third of the specimen height. A commercially available data logging system named “System 5000” was used as the data acquisition system, which required a host computer for entering commands, reading the returned data and for managing the output channels. Compression testing was performed as per AS1012.9 (Australia, 1999). Samples failed in compression are shown in Figure 2.

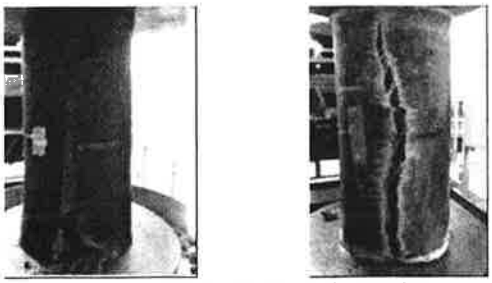


Figure 2. Tested samples

RESULTS AND DISCUSSIONS

Most of the samples were failed with the rupture of FRP while the others failed due to the delamination in the overlapping zone of FRP. Figure 3 shows the 28 day compressive strengths for small and large geopolymer concrete samples wrapped with CFRP and GFRP. Samples 7 and 8 with 2 layers of GFRP show less compressive strength compared to other samples. Densities of these 2 samples are also less than other samples which might be the reason for this poor behaviour.

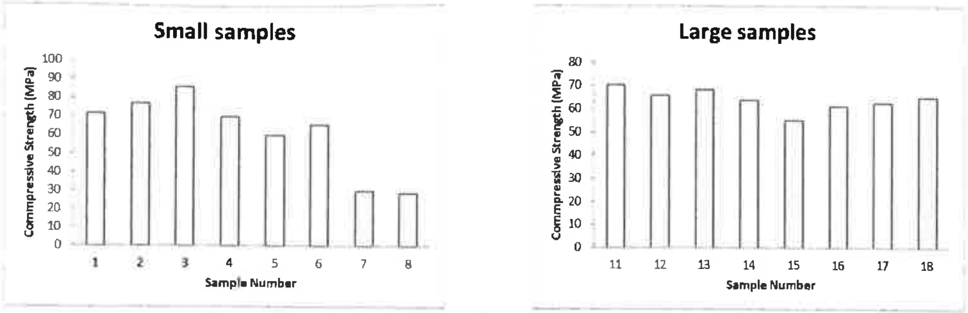
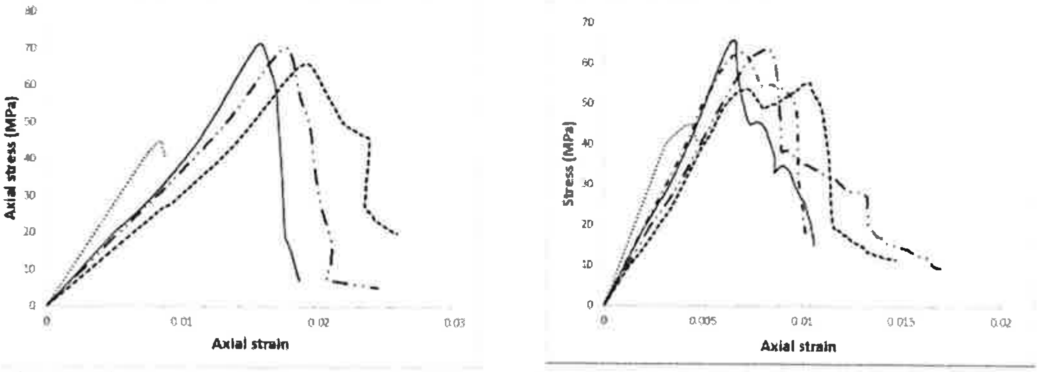


Figure 3. 28 day compressive strength for the tested samples

The unconfined compressive strength at 28 days had an average value of 45 MPa. Figure 4 shows the stress-strain relationships obtained from the experimental program for selected samples due to the space limitation for this paper. It can be seen from Figures 3 and 4 that the confinement has been more effective in the large samples than the small samples. For small samples the peak strength has marginal variations with the varying type/level of confinement. However the axial strain corresponding to the peak axial stress increased with the increasing level of confinement for CFRP. Ultimate strain and ductility also increase with the increasing level of confinement. All the curves shown in Figure 4 show the strain softening which is inconsistent with the FRP confined HSC reported in the literature (Lokuge, 2005). Strain hardening can be observed in the stress-strain relationships when the level of confinement is higher. However if the level of confinement provided by the FRP is not so strong, the stress starts to reduce after the peak strength of unconfined geopolymer concrete and the specimen will fail with FRP rupture. Strain softening can be observed in this situation.



(a) 100 mm diameter and 200 mm high samples (b) 150 mm diameter and 300 mm high samples

—— CFRP 1 layer — · · CFRP 2 layers ·········· Unconfined

·········· GFRP 1 layer – · – · GFRP 2 layers

Figure 4. Axial stress- axial strain relationships for CFRP and GFRP confined geopolymer concrete

It can be concluded that both CFRP and GFRP are effective means of improving both strength and ductility benefits to unconfined geopolymer concrete products, which are typically brittle in nature.

CONCLUSIONS

The research program resulted in conclusive results that state the multitude of ductility and strength benefits associated with wrapping the geopolymer concrete samples with FRP. The results of the study concluded that FRP confinement techniques are equally effective upon large geopolymer samples, as small geopolymer samples.

Whilst the study effectively showcases that both CFRP and GFRP confinement technologies are effective techniques in improving the strength and ductility of geopolymer concrete, it was found that CFRP was more effective in improving the strength and GFRP was more effective in improving the ductility than the corresponding counterparts. All things considered the outcomes of this study can be used for improvement in the design and development of geopolymer concrete and FRP technologies ultimately aiding sustainable construction methods and promoting carbon neutral design.

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REFERENCES

Geopolymer Alliance (2013) The Geopolymerization Process, viewed April 10, <http://www.geopolymers.com.au/science/geopolymerization>.

Standards Australia (1999) Method of testing concrete, Method 9: Determination of the compressive strength of concrete specimens, Standards Australia, Australia.

Diaz-Loya, EI, Allouche, E.N. and Vaidya, S. (2011) "Mechanical properties of fly ash-based geopolymer concrete", ACI Materials Journal 108: 300-6.

Duxson, P, Fernandez-Jimenez, A, Provis, L, Lukey, G, Palomo, A and Van Deventer, J (2006) "Geopolymer technology: the current state of the art.", Advances in Geopolymer Science & Technology 42: 2917-33.

Fitzgerald, J 2010, What is Geopolymer Concrete?, viewed April 2, <http://www.homeimprovementpages.com.au/article/Geopolymer_concrete>.

Hardjito, D, and Rangan, B.V. (2005) Development and properties of low-calcium fly ash based geopolymer concrete, Faculty of Engineering, Curtin University.

Hardjito, D, Wallah, S.E., Sumajouw, D.M.J., and Rangan, B.V. (2004) "On the development of fly ash-based geopolymer concrete", ACI Materials Journal 101: 467-72.

Kong, DLY, and Sanjayan, J.G. (2010) "Effect of elevated temperatures on geopolymer paste, mortar and concrete", Cement and Concrete Research 40: 334-9.

Lokuge, W, Setunge, S and Sanjayan, JG (2010) "Stress-strain model for high strength concrete confined by FRP", In Proceedings of the 21st Australasian Conference on the Mechanics of Structures and Materials: Incorporating Sustainable Practice in Mechanics of Structures and Materials (ACMSM21) Melbourne, Australia: 481-6.

Lokuge, WP, Sanjayan, G.J. and Setunge, Sujeeva (2005) "Stress strain model for laterally confined concrete", Journal of Materials in Civil Engineering, ASCE 17: 607-16.

Olivia, M, and Nikraz, H. (2012) "Properties of fly ash geopolymer concrete designed by Taguchi method", Materials and Design 36: 191-8.

Pan, Z and Sanjayan, JG (2010) "Stress-strain behaviour and abrupt loss of stiffness of geopolymer at elevated temperatures", Cement and Concrete Composites 32: 657-64.

Pan, Z, Sanjayan, J.G., and Rangan, B.V. (2011) "Fracture properties of geopolymer paste and concrete", Magazine of Concrete research 63: 763-71.

Sofi, M, Deventer, J.S.J., Mendis, P.A. and Lukey, G.C. (2007) "Engineering properties of inorganic polymer concretes (IPCs)", Cement and Concrete Research 37: 251-7.

Wallah, SE, Hardjito, D, Sumajouw, DMJ and Rangan, BV (2005) "Sulfate and acid resistance of fly ash-based geopolymer concrete" [online], In Proceedings of the Australian Structural Engineering Conference Sydney, N.S.W.: Engineers Australia: 733-42.

Zhao, R and Sanjayan, J.G. (2011) "Geopolymer and portland cement concretes in simulated fire", Magazine of Concrete research 63: 163-73.