Geopolymer concrete with FRP confinement

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ABSTRACT: Geopolymer concrete has become a potential candidate to replace Ordinary Portland Cement concrete in the construction industry due to its lower greenhouse gas emissions. It further proves to be environmentally friendly because it uses fly ash which is a by-product of coal that would otherwise end up as landfill. Its use is, however, limited by a concern regarding increased brittleness and a lack of understanding of its behaviour under multi-axial loadings. Ductility of geopolymer concrete columns can be increased by lateral confinement. The conventional confinement with steel reinforcement may not always be adequate to provide the ductility levels desired by the engineer. Confining pressure applied by FRP is a function of the lateral strain of concrete. The proposed project aims at understanding the complete deformational behaviour of this greener material with different levels of carbon fibre reinforced polymer (CFRP) and glass fibre reinforced polymer (GFRP) confinement.

1 INTRODUCTION

At the moment there is overwhelming scientific consensus to prove that climate change is happening. Climate change due to global warming is one of the biggest social, political, economical and environmental issues that have an effect on all of us. Global warming is caused by the emission of greenhouse gases such as carbon dioxide, methane and nitrous oxide into the atmosphere. It is reported that the production of cement contributes about 5-7% of CO_2 emissions globally while in 2008, Australia reported 1.3% of green house gas emissions are due to the production of cement (McLellan et al. 2011). Producing of one ton of Ordinary Portland Cement (OPC) releases approximately one ton of CO_2 into the atmosphere (Rangan 2008, Wallah 2010). Nevertheless, the overall use of concrete is second only to the use of water around the world (Rangan 2008). With the introduction of carbon tax in Australia, it is a timely concern to investigate and replace/reduce cement in the hugely used construction material, concrete.

Decades ago, Davidovits (1988) suggested that an alkaline solution could be used to react with silicon and aluminium of a material and produce binders similar to cement binder. Since this chemical reaction is a polymerisation process, Davidovits (1988) named this new binder as “geopolymer”. The source materials used to produce geopolymer concrete mainly comes from industrial waste materials such as fly ash, granulated blast furnace slag, rice husk. A recent research (Deevasan & Ranganath 2010) shows that there is a possibility of using industrial effluent as a partial replacement for commercially available alkaline solutions. Majority of the geopolymer studies in Australia are based on low calcium fly ash while the international researchers investigated the material made of high calcium fly ash (Chindaprasirt et al. 2007, Rattanasak et al. 2011, Guo et al. 2010). However it is documented that low calcium fly ash is preferred because of the fast setting associated with the high calcium fly ash (Olivia & Nikraz 2012). Although there is no difference in the cost of producing OPC concrete or geopolymer concrete (Hardjito et al. 2004), introduction of carbon tax will definitely pave the way for geopolymer concrete to outperform economically than its counterpart OPC concrete. Properties of this inorganic polymer concrete family varies significantly depending on the source material (Sofi et al. 2007) and are superior to their OPC counterparts in terms of early strength gain, sulphate (Wallah 2005) and fire resistance (Pan & Sanjayan 2010) and very little shrinkage (Hardjito et al. 2004, Olivia & Nikraz 2012). 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 & Nikraz 2012), elastic modulus (Pan et al. 2011, Olivia & Nikraz 2012) and flexural strength (Olivia & 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 (Sofi et al. 2007, Diaz-Loya et al. 2011). 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 et al. 2011).

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.

2 EXPERIMENTAL PROGRAM

An experimental program was designed to prepare geopolymer concrete. There were three test variables, namely the compressive strength of concrete, the type of FRP and the level of confinement provided. Two compressive strengths (Mix 1 and Mix 2), two types of FRP (CFRP and GFRP) and two levels of confinement (1, 3 wraps) were investigated. Tests were performed in duplicate for each wrapping configuration, each type of FRP and each mix. All together 16 specimens were tested with confinement and 4 specimens were tested for unconfined compressive strength in the experimental program.

2.1 *Materials*

Fly ashes used in the investigation were Type F (low calcium) fly ash of approximately 15 µm. It was sourced from Pozzolanic Millmerran. The chemical composition of the fly ashes is given in Table 1. Density of fly ash was found to be 1100 kg/m^3.

Table 1. Chemical constituent: percentages

SiO_2	$A1_2O_3$	Fe_2O_3	CaO	Mg0	Na_2O	K_2O	SO_3
51.8	24.4	9.62	4.37	1.5	0.34	1.41	0.26

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 in this mix (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 (M_s) of 2 (M_s = SiO_2/Na_2O and Na_2O = 14.7% and SiO_2 = 29.4% and solids = 44.9% by mass) and specific gravity of 1.5. Sodium hydroxide with 90% purity in the pellet form was used to prepare sodium hydroxide solution. The concentration of sodium hydroxide solution used to make 40 MPa mix is 8 Molar. In order to make 8M solution, 262 g of NaOH pellets were mixed to make a kilogram of NaOH solution (Rangan 2008).

Plain carbon fibre cloth weave 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/m^2.

2.2 *Mix design*

The mix design used in this research was based on the work reported by Zhao & Sanjayan (2011) and is shown in Table 2.

Table 2. Mix proportions.

Material	Quantity (kg/m^3)
Alkaline liquid/fly ash	0.45
Fly ash	381
NaOH solution (8M)	49
Na_2SiO_3 solution (Grade D)	122
Fine aggregate	554
Coarse aggregate	
7.5 mm	647
10 mm	647

Aggregate weights shown in Table 2 are in the saturated surface dry condition. Two batches of geopolymer concrete were prepared (Mix 1 and Mix2) using the same mix design. However the curing time for Mix 1 was 3 hours and the same for Mix 2 was 6 hours in the same curing condition, 80^0C.

2.3 *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. During our trial batches it was concluded that the condition of the aggregates play an important role during the mixing process. Aggregates should be in the saturated surface dry (SSD) condition so that they will neither absorb chemicals nor contribute more water to the mix. Aggregates thus prepared are shown in Figure 1.

Figure 1. SSD condition of aggregate

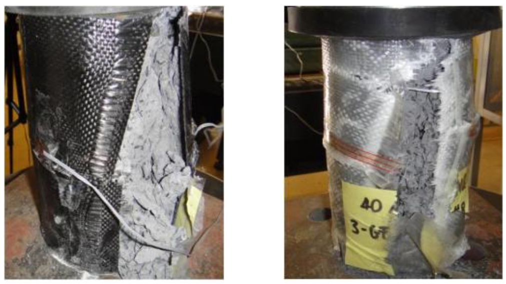
Sand, coarse aggregates and fly ash were initially dry mixed for about a minute in a 120 litre mixer. The pre-prepared alkaline solution was then introduced in the dry mix and further mixed for 4 minutes before casting into greased 100 mm diameter and 200 mm high cylindrical moulds. The fresh geopolymer concrete was stiff until compacted using a vibrating table. Concrete thus cast were covered with a polyethylene sheet before putting them in the oven for curing at 80^0C. Mix 1 and Mix2 batches were first cured in the oven for 3 hours and 6 hours respectively and then in a constant temperature room (23^0C and 50% humidity) until the time of testing.

The cylindrical specimens were allowed to air dry for a day after taking out of the fog room. Any surface pores were filled with a quick setting filler. Having applied an epoxy-based primer onto the concrete surface, it was allowed to cure for about 30 minutes before applying the wrap. The required length of fibre wrap was cut with an allowance of 30 mm for overlapping. Laminating resin of equal mass as the weight of the fibre wrap was applied on the surface of the fibre wrap using a soft brush. Distributing laminating resin and squeezing any excess resin out was performed. The composite fibre was then wrapped tightly around concrete specimen and allowed to cure for three days. The concrete specimens were wrapped in one, or three layers of carbon fibre or glass fibre composite. Two strain gauges of 90 mm gauge length were placed laterally at the middle third in two diametrically opposite sides. All the specimens were prepared using this method and selected 2 samples ready to be tested are shown in Figure 2.

(a). CFRP (b). GFRP

Figure 2. Fibre wrapped specimens

3 TESTING



(a). CFRP (b). GFRP

Figure 3. Tested specimens

The fibre wrapped specimens were then tested in Sans compression testing machine with 1500 kN loading capacity at a constant cross head speed of 2 mm/min. Samples failed in compression are shown in Figure 3.

4 RESULTS AND DISCUSSION

4.1 *Stress-strain relationships*

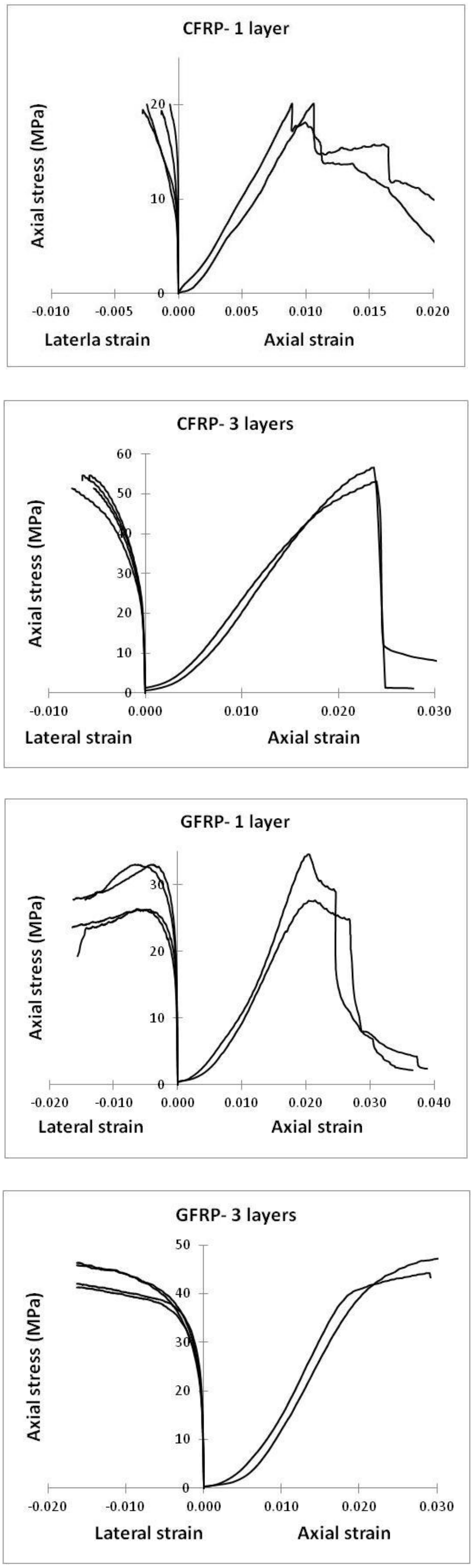


Figure 4. Stress-strain relationships for Mix 1

The stress-strain relationships obtained for geopolymer concrete using platen-to-platen method and strain gauges are shown in Figure 4 and Figure 5 for Mix 1 and Mix 2, respectively.

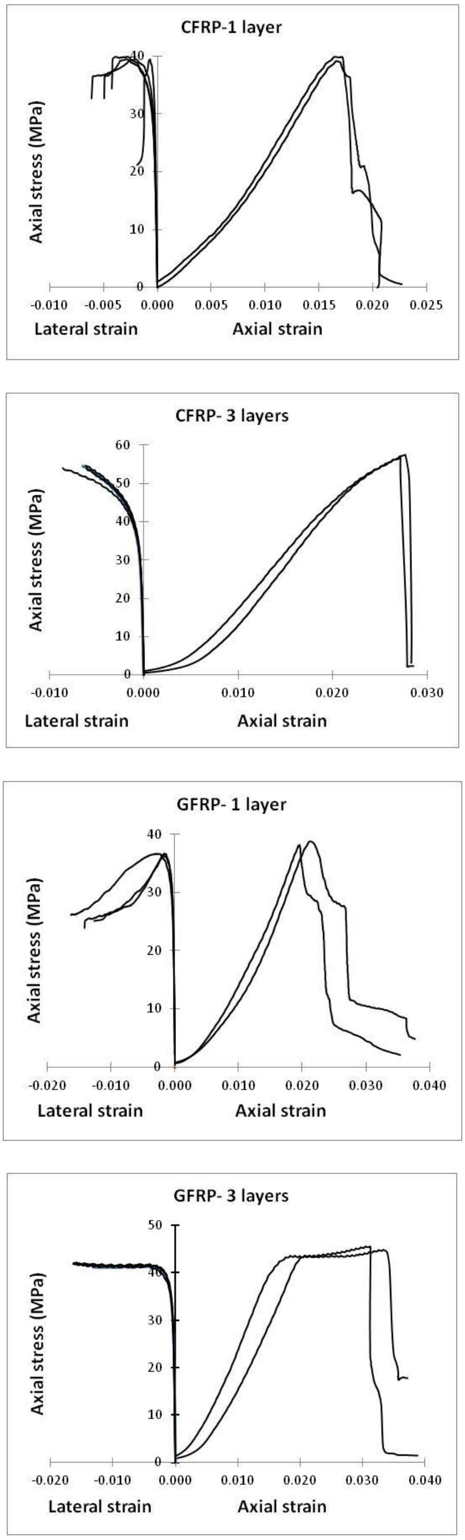


Figure 5. Stress-strain relationships for Mix 2

Axial strains were measured using platen to platen method while the lateral strains were measured using strain gauges. Mix 1 and Mix 2 had 28 day compressive strengths of 23.2 MPa and 33.8 MPa, respectively. Therefore, with increased curing time the unconfined compressive strength increases which is similar to the observations reported in the literature. Both mixes showed an increase in the compressive strength with the increased level of lateral confinement while CFRP outperforms GFRP marginally. Three layers of FRP showed improved ductility compared to one layer of FRP confined geopolymer concrete. Most of the specimens showed a bond failure between the geopolymer concrete and CFRP and GFRP.

When geopolymer concrete is subjected to axial compression, the confinement provided by the FRP wrapping is related to the lateral dilation of the material. Therefore, the lateral strains reported in this paper will be useful for the modelling of the FRP confined geopolymer concrete.

5 CONCLUSION

The influence of parameters such as curing time and CFRP and GFRP confinement on geopolymer concrete was investigated in this research. The experimental investigation was based only on the compressive strength of geopolymer concrete. It was observed that increased heat curing time enhanced the unconfined compressive strength. Ductility levels can be improved with the increased levels of confinement. However the bond between the geopolymer concrete and FRP needs further investigation. The experimental results for the lateral dilation can be used for the modelling of geopolymer concrete subjected to FRP confinement.

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