Section A-Research paper

ISSN 2063-5346

Statistical Comparison of durability aspects of Geopolymer Concrete and Cement Concrete using ANOVA Analysis

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Abstract

Geopolymer, a folio which can go about as an option in contrast to Portland concrete. The characteristics of substantial utilizing geopolymer based on fly ash as the fastener were displayed in late investigations. Nonetheless, the majority of the past investigations zeroed in on the characteristics of geopolymer substantial examples relieved at higher temperature. In this review, geopolymer concrete based on fly ash reasonable for restoring was planned at surrounding temperature. Two unique blends (series A and B) with 39% and 36% antacid activating agent and GGFS in various FA extents has been utilized for substantial examples of geopolymer using a Single Factor analysis of Variance ANOVA. 6 GC (4 combinations for series A and 2 for B) and 2 substantial blends of Ordinary Portland Cement were ready in research facility to concentrate on the characteristics of geopolymer concrete. The mechanical characteristics of the substantial were researched by flexural strength, rigidity and compressive strength. The researched sturdiness characteristics were the sorptivity, impacts of the openness of various forceful conditions, drying shrinkage and volume of penetrable voids (VPV) for example, sodium sulphate arrangement, drying and elective wetting in salty water climate. The compressive strength of geopolymer concrete at 28 days fluctuated from 25.6 to 28.2 MPa. A definitive strength of slag mixed geopolymer cements based on fly ash came to up to 31.9 MPa. The geopolymer cements displayed sorptivity, VPV esteems and drying shrinkage practically identical to the comparable compressive strength of OPC cement. Also, the slag mixed geopolymer concrete based on fly ash showed an incredible protection from sulphate assault and substitute wetting and drying impact. The protection from forceful climate expanded with the expansion of slag content in the blends. There was not any indication of break or any huge mass difference of the geopolymer substantial examples later openness to the forceful climate. The geopolymer substantial examples showed low extensions in sulphate arrangement.

Keywords*: Compressive strength; Durability; Flexural strength; Fly ash; Geopolymer concrete; Properties; Anova analysis*

Introduction

Geopolymer is a rising field of research for utilizing by-products. It has paved the way for finding new alternatives for the replacement of cement in the concrete industry and may be utilized by cement producers to offer a broader range of cementitious products to the market. The geopolymer material shares a chemical makeup with natural zeolitic materials, but its microstructure is amorphous. The polymerisation process is generally accelerated at higher temperatures.

Heat-relieved geopolymer concrete based on fly ash has high compressive and rigidities, and low powerful consistence that are for the most part useful for concrete. The greater part of the past examinations were directed on geopolymer substantial that relieved heat which is viewed as great for precast substantial individuals.

ISSN 2063-5346

In this task, GGBFS is utilized along with fly ash like a piece of all-out cover. The GGBFS mixed geopolymer based on fly ash glue ties the composites to shape the GC, with or without the existence of compounds. GGBFS was included with low Ca FA in surrounding temperature to speed up the relieving of GC.

The assembling of GC is completed utilizing the typical procedure in substantial innovation. Solidness related characteristics are significant contemplations for plan of cement. Porousness attributes are examined as the main characteristics to administer solidness of concrete. Lesser porousness imparts extreme protection from the entrance of forceful particles in the substantial and consequently diminishes the degree of weakening of cement. Thus, the strength characteristics of GGBFS mixed geopolymer concrete based on fly ash relieved at surrounding conditions were concentrated in this exploration.

Analysis of variance (ANOVA) is used: to compare means if the number of samples exceeds two, or to identify factors that affect the results of the experiment. The analysis of variance is based on the idea of comparing the variances of experimental results caused by experimental errors and the influence of a factor. To estimate the dispersion of results caused by experimental errors, the spread of values is estimated at a fixed level of the factor. The difference between the group averages for the levels of the factor and the overall average is used to estimate the variance brought on by the influence of the factor.

Literature Review

GC can be assumed as an indispensable part with regards to manageability and ecological issues. Around 5% of worldwide CO2 emanations start from the assembling of concrete. As indicated the development of 1 ton of Cement delivers around 1 ton of Carbon dioxide to climate(Poon, Azhar, Anson, & Wong, 2003).

Past investigations Research Sufian et al.(2014) stated that geopolymer concrete is better than conventional concrete in terms of resistance to acid attack, has good ability when facing sulfate settlement, and is quite stable when temperatures rise significantly.

It was reported by Criado et al.(2007) that the durability and strength of the GPC improved along with time regardless of the kinds of chemical solutions

Experimental Work

Particle Size Distribution

Sieve analysis was used to determine the proportion of particles of different sizes within a particular aggregate product. The test used a tower of interlocking sieves with apertures that decreased in size from top to bottom. Sieve analysis was conducted as per the AS 1289.3.6.1-2009 (Standard Australia, 2009).

Fine Aggregate

- The test sample (1kg) was dried to a constant weight at a temperature of 110 ± 5^{o}C and weighed.
- 500gm of fine material that had been oven dried were used for the sieve analysis.The sand sample was separated in two parts as the mass of the tested sample was exceeding than the recommended value outlined in AS 1289.3.6.1 (Each part not less than 150gm). At the end of the test the retained weight of particles on each sieve was recombined and considered these as single sieve functions.

ISSN 2063-5346

- The sample was than sieved by using a mechanical shaker. A set of sieves (2.36mm, 1.18mm, 600µm, 300µm and 150 µm) were used.
- On completion of sieving, the material on each sieve was weighed and cumulative weight passing through each sieve was calculated as a percentage of the total sample weight.
- Finally, the fineness modulus was obtained by adding cumulative percentage of aggregates retained on each sieve and dividing the sum by 100.

Absorption, % = ((S- A)/A) ×100 -- (3-1)

Relative density (specific gravity) (OD) = A/ (B+S – C) -------------- (3-2)

Relative density (specific gravity) (SSD) = S/ (B+S – C) --------------(3-3)

Where,

A = oven-dry test sample mass, gm. S= mass of the saturated surface dry sample, gm,

B = mass of pycnometer filled with water, gm, and

C = mass of pycnometer filled with specimen and water, gm.

Coarse Aggregate

Similar procedure as in the fine aggregate was applied for sieve analysis of the coarse aggregate. The procedure is follows:

- The sample was dried at a temperature of 110 ± 5°C to a constant mass in accordance with the AS 1289.3.6.1 (Standard Australia, 2009) and the result was quantified to the closest 0.1 percent of the sample mass, or 0.1 gm.
- The sieve used for coarse aggregate sieving were 26.5mm, 19mm, 9.5mm, 4.75mm, 2.36mm and 1.18mm. The Sieves were placed in the mechanical shaker and shaking for approximately 10 minutes.
- Finally, it was noted how much aggregate was kept.

Mixture	**Geopolymer Concrete GPC – 1**	**Geopolymer Concrete GPC – 2**	**Geopolymer Concrete GPC – 3**	**Geopolymer Concrete GPC – 4**	**Ordinary Portland Concrete OPC – 1**	**Ordinary Portland Concrete OPC – 2**
Label	A35 S00 R2.5	A35 S00 R1.5	A35 S10 R2.5	A35 S10 R1.5	OPC – 1	OPC – 2
Course Aggregate	1222	1222	1216	1216	1054	1054
Sand	658	658	655	655	768	740
Fly Ash	400	400	360	360	-	-
GGBFS	-	-	40	40	-	-
Cement	-	-	-	-	446	376
SH[b]	40	56	40	56	-	-
SS[c]	100	84	100	84	-	-
Water	-	-	8	8	165	151
SP[d]	6	6	6	6	-	4.2

ISSN 2063-5346

Table 1 : Mixture Proportions of the concrete mixtures

- Absorption and relative density of the coarse aggregates were calculated by the equations 3-4 and 3-5 respectively.

Absorption, % = ((B - A)/A) ×100 -- (3-4)

Relative density (Specific gravity) (OD) = A / (B – C) ------------------ (3-5)

Where,
A = oven-dry test sample's mass in gm, in air.
B = saturated-surface-dry test sample's mass in gm, in air.
and
C = apparent mass of saturated test sample in water, gm

ANOVA results of the slump test.

An increase in the density of the fresh mix was established, increasing with the amount of modifier. This picture is explained by the filling of voids with binder micro particles, which are formed in the process of chemical contraction of the raw mixture, resulting from a decrease in volume in the process of hydration. These results are supported by data of the relevant literature, which showed a decrease in flow ability properties, both from Fly ash, GGBFS and Without GGBFS.

Experimental Results & Discussions :

1. Mechanical properties of Concrete
   a. Compressive Strength Test
   b. Indirect Tensile Strength Test
   c. Flexural Strength Test
2. Durability properties of Concrete
   a. Dry Shrinkage Test
   b. Sorptivity Test
   c. Sulphate Resistance
      i. Visual Resistance
      ii. Mass Change
      iii. Change in Compressive Strength
   d. RCPT Test & Results

Mechanical Properties of Concrete :

Testing of Compressive Strength Test

The compressive strength's assurance has been performed on Cube shaped examples of 150mm X 150mm X 150mm. Every example for GC is being placed in surrounding restoring situations of 15 - 20°C till tried. At last, testing of compressive strength and the normal worth to the nearest 0.6 MPa has proven to be accounted for. Refer Table 2.

- This concrete is poured in the mold in 3 layers and when dried the molds are removed, and test specimens are put in water for curing.
- An apparatus for compressive testing is used to examine these samples.
- Load should be applied gradually at the rate of 0.5 MPa per minute till the Specimens fails.
- The compressive strength of concrete can be calculated by dividing the load at failure by the area of the specimen.

ISSN 2063-5346

- CTM machine of 3000 KN.

Mixture		Label	Compressive Strength (MPa)		
Series	Mix ID		28 days	56 days	90days
A	GPC – 1	A35 S00 R2.5	25.6	28.2	31.2
	GPC – 2	A35 S00 R1.5	27.5	29.7	35.2
B	GPC – 3	A35 S10 R2.5	27.6	30.6	34.2
	GPC – 4	A35 S10 R1.5	26.8	31.9	35.6
OPC	OPC – 1	OPC – 1	28.1	33.3	37.3
	OPC – 2	OPC – 2	26.8	29.5	32.5

Table 2 : Compressive Strength Results

- The compressive strength of the specimens was calculated using the equation (3- 6)

$$fc = \frac{1000 \, X \, P}{A} \quad \text{--} \quad (3\text{-}6)$$

Where,

fc = Compressive strength (MPa)

P = maximum force applied (kN), A = Cross sectional area (mm^2)

ANOVA Result :

Geopolymer Concrete (GPC) without GGBFS Results :

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	*110.02*	*2*	*55.012*	*11.54*	*0.039*	*9.552*
Within Groups	*14.31*	*3*	*4.768*			
Total	*124.33*	*5*				

Geopolymer Concrete (GPC) with GGBFS Results :

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	*282.10*	*2*	*141.052*	*14.752*	*0.028*	*9.552*
Within Groups	*28.69*	*3*	*9.562*			
Total	*310.79*	*5*				

Ordinary Portland Concrete (OPC) Results :

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	*282.10*	*2*	*141.052*	*14.752*	*0.028*	*9.552*
Within Groups	*28.69*	*3*	*9.562*			
Total	*310.79*	*5*				

Testing of Indirect Tensile Strength Test

The parting rigidity of the substantial examples was analytically estimated by AS 1012.10-2000 (Standard Australia, 2000). To get the parting rigidity, a chamber of aspect 300 × 150 millimeter (tallness × width) has been exposed to compressive stacking beside the length and has been verified at period of 28, 56 and 90 days through control MCC8 machine. Refer Table 3.

- The loading strip and the machine's bearing surfaces are both dust-free.
- The specimen should be weighed prior to the test.
- The specimen should now be positioned in the middle of the loading strips with the upper platen parallel to the lower platen.
- Then progressively apply the stress until the specimen breaks, and record the Value.
- The same method has been repeated for other samples.

ISSN 2063-5346

Mixture		Label	Indirect Tensile Strength (MPa)		
Series	Mix ID		28 days	56 days	90days
A	GPC – 1	A35 S00 R2.5	2.1	3.2	3.8
	GPC – 2	A35 S00 R1.5	2.7	3.5	4.2
B	GPC – 3	A35 S10 R2.5	2.2	4.1	4.4
	GPC – 4	A35 S10 R1.5	3.1	4.2	4.8
OPC	OPC – 1	OPC – 1	4.1	5.7	6.8
	OPC – 2	OPC – 2	3.4	4.8	6.2

Table 3 : Indirect Tensile Strength Results

- At each age, two samples were tested, and the average strength was recorded. The splitting tensile strength of the specimens was calculated using the equations (3- 7).

$$f_c = \frac{2000P}{\pi LD} \quad \text{(3-7)}$$

Where,

f_{ct} = Indirect tensile Strength (MPa),

P = Maximum applied force (kN),

L= Length of the specimens (mm),

D= Diameter of the Specimens (mm)

ANOVA Result :

Geopolymer Concrete (GPC) without GGBFS Results :

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.590	2	1.295	12.738	0.034	9.552
Within Groups	0.305	3	0.102			
Total	2.895	5				

Geopolymer Concrete (GPC) with GGBFS Results :

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.17	2	2.085	12.765	0.034	9.552
Within Groups	0.49	3	0.163			
Total	4.66	5				

Ordinary Portland Concrete (OPC) Results :

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7.583	2	3.792	13.705	0.031	9.552
Within Groups	0.83	3	0.277			
Total	8.413	5				

Testing of Flexural Strength Test

The flexural strength has been communicated as factor of burst in Mega Pascal and got as per AS 1012.11-2000 (Standard Australia, 2000). The flexural strength examples for every blend was estimated by stacking 100mm× 100mm cement footer with a 400mm length and tried for 2 examples at 28, 56 and 90 days. Refer Table 4.

- At first, store the test specimens in water at a temperature of 24°C to 30°C for 48 hours before testing.
- As soon as you remove the specimens from the water and while they are still wet, test them.

ISSN 2063-5346

- Note down the dimension of each specimen before testing.
- Cleanly wipe the loading and supporting rollers' bearing surfaces. Also, clean the area of the specimen where the rollers will make contact with it of any loose sand or other debris.
- Put the specimens in the testing apparatus such that the load is delivered along two lines that are 20.0 cm or 13.3 cm apart, along the uppermost surface as cast in the mould.
- Cleanly wipe the loading and supporting rollers' bearing surfaces. Also, clean the area of the specimen where the rollers will make contact with it of any loose sand or other debris.
- Apply the load with thought shock and increase it continuously at a rate such that the extreme fiber stress increases at approximately 7 kg /cm^2/ min.

  During the test, the load should be increased by around (7 kg/cm2)/min, which is at a rate of loading of 400 kg/min for the 15.0 cm specimen and at a rate of 180 kg/min for the 10 cm specimen.

▪ Mixture		Label	Flexural Strength (MPa)		
Series	Mix ID		28 days	56 days	90days
A	GPC – 1	A35 S00 R2.5	4.1	4.5	4.9
	GPC – 2	A35 S00 R1.5	3.8	4.3	4.8
B	GPC – 3	A35 S10 R2.5	3.6	4.3	5.1
	GPC – 4	A35 S10 R1.5	4.1	4.6	5.3
OPC	OPC – 1	OPC – 1	4.1	4.8	5.6
	OPC – 2	OPC – 2	3.4	4.6	5.2

Table 4 : Flexural Strength Results

- The modulus of rupture was determined by applying the equation (3-8).

Where,

$$f_{cf} = \frac{1000\ X\ PL}{BD^2} \quad \text{..........} \quad (3\text{-}8)$$

(when a specimen is > 20.0 cm for 15.0 cm or > 13.0 cm for 10 cm)

Or

$$f_{cf} = \frac{3\ X\ Pa}{BD^2} \quad \text{..........} \quad (3\text{-}9)$$

(When a specimen is 20.0 cm but > 17.0 for a specimen of 15.0 cm or 13.3 cm but > 11.0 for a specimen of 10.0 cm.)

fcf = Modulus of Rupture (MPa),
P is the maximum applied force that the testing device indicates (kN),
L = span length (mm),
B = average width of the specimen at the section of failure (mm),
D is the average depth of the specimen at the failure section (mm)

ANOVA Result :

Geopolymer Concrete (GPC) without GGBFS Results :

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	*0.81*	*2*	*0.405*	*17.357*	*0.022*	*9.552*
Within Groups	*0.07*	*3*	*0.023*			
Total	*0.88*	*5*				

Geopolymer Concrete (GPC) with GGBFS Results :

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	*1.83*	*2*	*0.915*	*14.45*	*0.0289*	*9.552*
Within Groups	*0.19*	*3*	*0.063*			

ISSN 2063-5346

Total	*2.02*	*5*				

Ordinary Portland Concrete (OPC) Results :						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	*2.743*	*2*	*1.371*	*11.928*	*0.037*	*9.552*
Within Groups	*0.345*	*3*	*0.115*			
Total	*3.088*	*5*				

ANOVA results of the flexural strength.

The new composites' noticeably superior plastic performance is supported by the ratio of flexural strength to compressive strength, which has increased by a factor of 2-3.

Durability Properties of Concrete :

Dry Shrinkage Test

Drying shrinkage is depreciation of solidified substantial combination due to the deficiency of slim water. It makes an increment in malleable pressure that might provoke breaking, interior twisting, and outside diversion, prior the substantial is exposed to any type of stacking. Breaking because of drying shrinkage is an ordinary type of break in concrete. Subsequently, diminishing DS will diminish the related breaking and lessen the risk of possessing enormous part in the substantial construction.
The certitude of DS has provisionally done in the center of research. The strategy for AS 1012.13 - 1992 (Standard Australia, 1992) has been traced to quantify the DS all around the review. Examples for DS test has been 76×76×286 mm crystals with check studs as displayed in Table 5.

- Remove the specimen from the mould and keep the mould in water at 25°C to 29°C for 28 days after the concrete has been made remove the water and measure the length of the bar.
- Now keeping the bar at temperature 49°C to 51°C and humidity 17% RH for 44 hour and cooling 4 hour. This process is repeated and constant length is attained.
- below 1000 micro strain which is the limit for normal and special class concrete

▪ **Mixture**		**Label**	**Dry Shrinkage**		
Series	**Mix ID**		**28 days**	**56 days**	**90days**
A	GPC – 1	A35 S00 R2.5	542	662	713
	GPC – 2	A35 S00 R1.5	687	745	764
B	GPC – 3	A35 S10 R2.5	465	593	647
	GPC – 4	A35 S10 R1.5	525	607	632
OPC	OPC – 1	OPC – 1	346	480	512
	OPC – 2	OPC – 2	395	465	561

Table 4 : Dry Shrinkage Test Results

- For each specimen, three measurements were made, and the average value was noted. Finally, the length change was found using the equation 3- 9.

  Lds= (Lt-Li) ×10^6/ L -- (3-9)

  Where,

  Lds = Drying shrinkage in microstrain.
  Lt is the individual specimen's length at any given period. t (mm) (mm)
  Li represents the particular specimen's starting length (mm)
  L= Gauge length (250mm)

ISSN 2063-5346

ANOVA Result :

Geopolymer Concrete (GPC) without GGBFS Results :

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	16348	2	8174	1.61	0.035	9.552
Within Groups	15258	3	5085.8			
Total	31606	5				

Geopolymer Concrete (GPC) with GGBFS Results :

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	22310	2	11155	16.645	0.024	9.552
Within Groups	2010.5	3	670.17			
Total	24321	5				

Ordinary Portland Concrete (OPC) Results :

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.743	2	1.371	11.928	0.037	9.552
Within Groups	0.345	3	0.115			
Total	3.088	5				

ANOVA results of the Dry Shrinkage Test.

As for the results of water resistance, an increase in frost resistance is noted with an increase in the content, as the storage capacity is up to 30%, after which a decrease occurs.

Sorptivity Test

- The specimen used in the testing was consisted of 100 mm diameter and 50 mm thick discs cut (wet). All the samples were cut at 50mm length by ignoring the first 50mm from the top of the cylinder. Three specimens were retrieved from three different cylinders for each mixture.
- After cutting from the cylinder, the specimens were put in the oven for 24 hours at a temperature of 105 °C and checked for constant mass at every 24 hours. The procedure was continued until the difference between two successive weights was not greater than 1gm. The samples were put in the desiccator for 24hr to a temperature of 23 ±2°C for cooling.
- The average diameter of the test specimen was determined from the four consecutive values.
- The side and top of each specimen’s surface were sealed with epoxy coating material. The weight of the sealed specimens was recorded as initial mass to the nearest 0.01gm.
- Pins were placed at the bottom of the pan to hold the specimens and the pan was filled with tap water to allow free access of water to the inflow surface. The water level was maintained not more than 3 mm from the bottom face of the specimen during the test.
- Time was recorded immediately after placing the specimens on the support device (initial contact with water).

ISSN 2063-5346

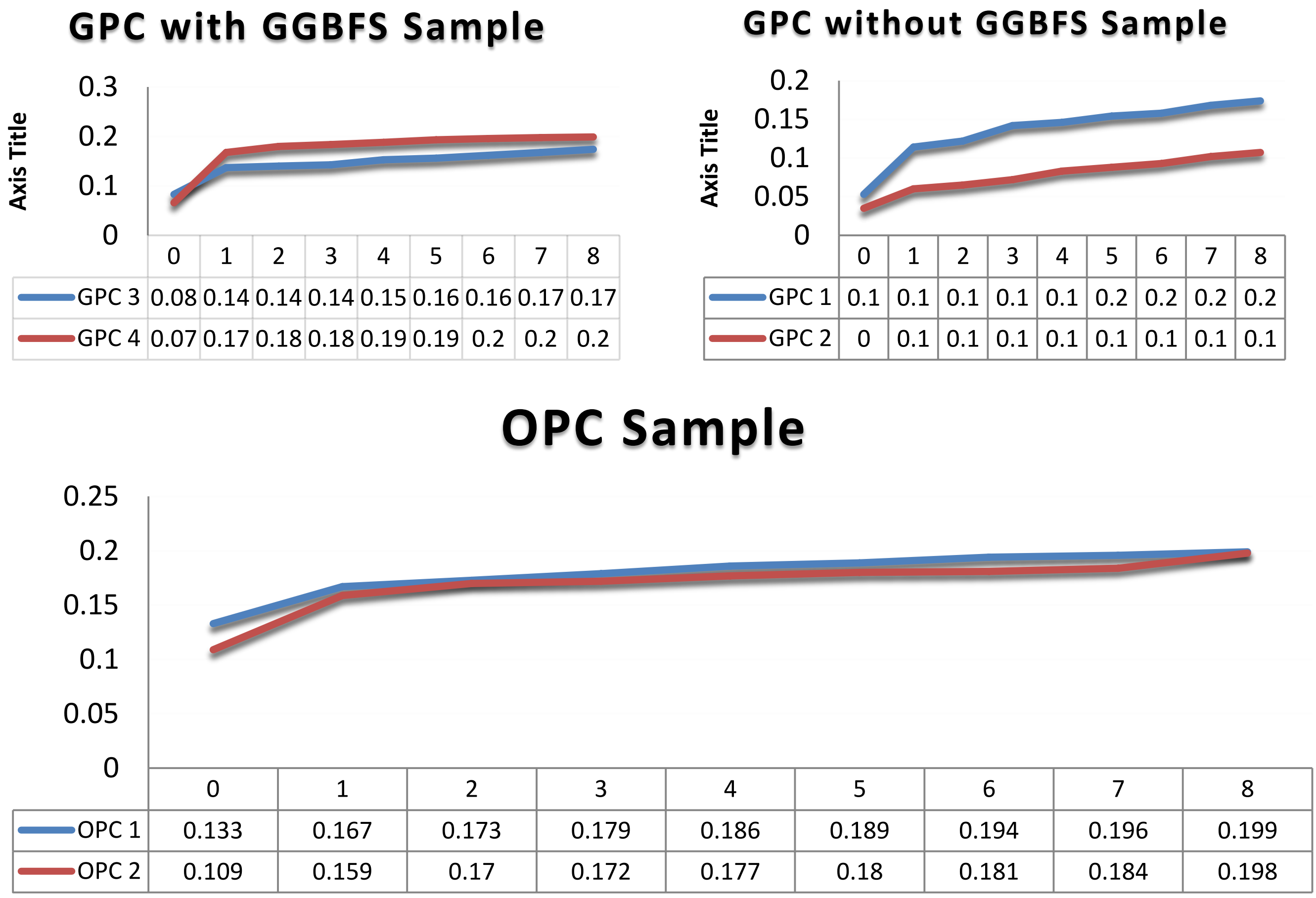


Figure 1 : Dry Shrinkage Test Results

- As per Concrete performance classification (Papworth and Grace)

Test Methods	Performance Limits		
	Poor	Acceptable	Very Good
Sorptivity Test. (mm/mm$^{1/2}$)	>0.2	0.1 to 0.2	<0.1

Table 5 : Sorptivity Test Results

ISSN 2063-5346

Sulphate Resistance Test

Visual Resistance

- Visual inspections of the Geopolymer and OPC concrete specimens were done after 90 days of exposure in sulphate solution.

(a) Geopolymer concrete sample cured in ambient condition

(b) Geopolymer concrete sample soaked in 5% sodium sulphate solution

(c) OPC concrete sample soaked in 5% sodium sulphate solution.

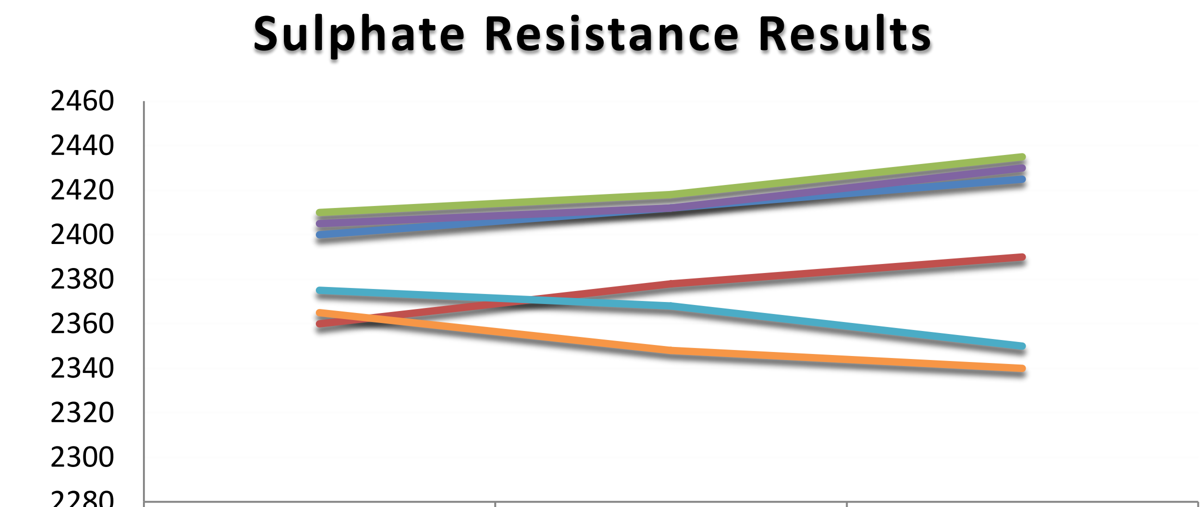
Figure 2 : Visual Resistance Test Results

Mass Change

Change in unit weight of Geopolymer and OPC concrete specimens soaked in 5% sodium sulphate solution as follows:

1. Unit weight of Geopolymer concrete without GGBFS increased from 2375 to 2400, 2412 and 2425 kg/m^3 after 28, 56 and 90 days respectively.
2. Unit weight of Geopolymer concrete without GGBFS increased from 2345 to 2360, 2378 and 2390 kg/m^3 after 28, 56 and 90 days respectively.
3. Unit Weight of Geopolymer concrete with GGBFS increased from 2395 to 2410, 2418 and 2435 kg/m^3 after 28, 56 and 90 days respectively.
4. Unit Weight of Geopolymer concrete with GGBFS increased from 2385 to 2405, 2412 and 2430 kg/m^3 after 28, 56 and 90 days respectively.
5. Unit weight of Ordinary Portland concrete marginally decreased from 2380 to 2375, 2368 and 2350 kg/m^3 after 28, 56 and 90 days respectively.
6. Unit weight of Ordinary Portland Concrete marginally decreased from 2370 to 2365, 2348 and 2340 kg/m^3 after 28, 56 and 90 days respectively.

ISSN 2063-5346



	28 days	56 days	90 days
GPC 1	2400	2412	2425
GPC 2	2360	2378	2390
GPC 3	2410	2418	2435
GPC 4	2405	2412	2430
OPC 1	2375	2368	2350
OPC 2	2365	2348	2340

Figure 3 : Sulphate Resistance Test Results

Change in Compressive Strength (MPa)

To decide adjustment of Geopolymer's compressive strength and OPC concrete, the compressive strength for chose tests has been tried at 28, 56, and 90 days of age as per the AS1012.9-1999 (Standard Australia, 1999). The examples has been eliminated through the sulfate arrangement later chose times of openness and left for 24 hour for drying. Sulfur covering has been utilized to give constant burden dissemination and the example has been tried with a consistent pace of 0.334 Mega Pascal/sec (identical to 20 ± 3 Mega Pascal compressive pressures each moment) till disappointment. Refer Table 6.

Mixture		Change in Compressive Strength (MPa)						
Series	MIX ID	28 Days	56 Days			90 Days		
		Ambient Curing	Ambient Curing	Sodium Sulphate Solution	% of Change in Compressive Strength	Ambient Curing	Sodium Sulphate Solution	% of Change in Compressive Strength
A	A35 S00 R2.5	25.6	28.2	31.8	11.32 %	31.2	34.6	9.83 %
	A35 S00 R1.5	27.5	29.7	31.9	6.89 %	35.2	37.9	7.12 %
B	A35 S10 R2.5	27.6	30.6	33.0	7.28 %	34.2	36.3	5.79 %
	A35 S10 R1.5	27.8	31.9	36.1	11.63 %	35.6	38.1	6.56 %
OPC	OPC – 1	24.1	33.3	31.8	- 4.71 %	37.3	34.7	- 7.49 %
	OPC – 2	26.8	29.5	27.8	- 6.12 %	32.5	30.5	- 6.58 %

Table 6 : Change in Compressive Strength (MPa) Results

ISSN 2063-5346

RCPT Test

- A cell where concrete would be placed connected to Brass Cell for potential supply 100mm dia. and 50 mm thickness.
- Sample placed in air tight with screws
- 3 percent NACL on one side and 0.3 molar NAOH
- NAOH to positive and NACL to negative measurement in mill amperes
- Measurement at every 30 mins for about 6 hours
- ASTM C 1202
- Charge passed less than 4000, the concrete is good and less than 2000.

Sr No.	GPC – 1	GPC – 2	GPC – 3	GPC – 4	OPC – 1	OPC – 2
	A35 S00 R2.5	A35 S00 R1.5	A35 S10 R2.5	A35 S10 R1.5	OPC – 1	OPC – 2
1	28.2	27.2	29.8	30.5	37.9	37.3
2	29.7	29.4	30.2	31.6	38.6	39.4
3	30.5	31.4	32.1	33.3	40.9	41.2
4	31.8	33.3	33.6	34.8	42.9	43.2
5	32.9	35.5	34.2	33.5	45.6	44.6
6	33.7	36.8	36.4	35.9	47.8	45.7
7	34.9	37.1	39.1	37.3	49.7	46.9
8	36.3	38.2	40.8	39.4	50.6	48.6
9	37.4	39.7	41.2	40.1	51.7	50.8
10	38.6	40.1	41.9	40.9	52.8	51.8
11	39.7	41.5	42.5	42.6	53.6	53.4
12	40.2	41.9	43.6	44.1	54.5	54.9
13	41.2	42.6	44.3	45.6	56.8	55.7
Average Current (Q)	**756.72**	**791.64**	**814.77**	**812.79**	**1036.89**	**1020.6**
	774.18		**813.78**		**1028.75**	
Results	**Very Low**		**Very Low**		**Low**	

Table 7 : RCPT Test Results

Change Passed	Charge Passing Coulombs	Typical Concrete Type
High	>4000	High w-c ratio(>0.6) conventional PC Concrete
Moderate	2000 to 4000	Moderate w-c ratio(0.40 to 0.50) conventional PC Concrete
Low	1000 to 2000	Low w-c ratio (<0.40) conventional PC Concrete
Very Low	100 to 1000	Latex – modified concrete, internally sealed concrete
Negligible	<100	Polymer – impregnated concrete, polymer concrete

Table 8 : Chloride Penetrability Based on Charge Passed

Cost Indexing of Geopolymer Concrete (GPC) Vs Ordinary Portland Concrete (OPC)

Mixtures	Price Per Unit	Weight						Price					
		GPC 1	GPC 2	GPC 3	GPC 4	OPC 1	OPC 2	GPC 1	GPC 2	GPC 3	GPC 4	OPC 1	OPC 2
Label	-	A35 | S00 | R2.5	A35 | S00 | R1.5	A 35 | S 10 | R 2.5	A 35 | S 10 | R 1.5	-	-	A35 | S00 | R2.5	A35 | S00 | R1.5	A 35 | S 10 | R 2.5	A 35 | S 10 | R 1.5	-	-
CA[a]	1.7	1222	1222	1216	1216	1054	1054	2077.4	2077.4	2067.2	2067.2	1791.8	1791.8
Sand	2.2	658	658	655	655	768	740	1447.6	1447.6	1441	1441	1689.6	1628
Fly Ash	2.5	400	400	360	360	-	-	1000	1000	900	900	-	-
GGBFS	2	-	-	40	40	-	-	-	-	80	80	-	-
Cement	7	-	-	-	-	446	376	-	-	-	-	3122	2632
SH[b]	25	40	56	40	56	-	-	1000	1400	1000	1400	-	-
SS[c]	12	100	84	100	84	-	-	1200	1008	1200	1008	-	-
Water	1	-	-	8	8	165	151	-	-	8	8	165	151
SP[d]	40	6	6	6	6		4.2	240	240	240	240	-	168
Total Amount :-								**6965**	**7173**	**6936.2**	**7144.2**	**6768.4**	**6370.8**

ISSN 2063-5346

Conclusion

These conclusions are made in reference of the test results:

- Geopolymer concrete cured in the laboratory ambient condition gained compressive strength with age. The inclusion of slag improved the early-age strength as compared to control fly ash geopolymer concrete. Significant strength development occurred during the period between 28 days and 56 days. The addition of extra water and a naphthalene-based superplasticizer improves the workability of the fresh geopolymer concrete. However, the addition of extra water in geopolymer concrete mixtures decreased the compressive strength. The 28-day compressive strength of slag blended fly ash-based geopolymer concrete reached 54 MPa using 20% GGBFS with a SS/SH ratio of 1.5 which further increased to 70 MPa at 180 days.
- The incorporation of slag in the fly ash-based geopolymer concrete increased flexure and tensile strengths. Strength at 28 days increased for the 20% replacement of fly ash by GGBFS along with a reduced SS/SH ratio. The test results for both flexure and tensile strength values are higher than the values calculated by the equations given in the relevant Australian Standard for OPC concrete.
- The drying shrinkage of ambient-cured geopolymer concrete decreased with the increase of slag content up to 20% as a replacement of fly ash. The incorporation of GGBFS in the binder of fly ash based geopolymer concrete showed less drying shrinkage than the concrete without GGBFS (series B). Moreover, the values of drying shrinkage for all geopolymer concrete at 56 days were well below than 1000×10^{-6} as specified by AS 1379-2007 (Standard Australia, 2007). On the other hand, the geopolymer concrete mixture achieved less drying shrinkage than the OPC concrete of similar strength.
- The incorporation of slag in the binder of geopolymer concrete reduced the sorption at 28 days. A significant reduction of sorption was observed for the inclusion of 20% GGBFS with a reduced SS/SH ratio (series A). Effect of additional water on sorption rate indicated similar trend as that of compressive strength (Series B). Moreover, rate of sorption further decreased for all geopolymer concrete after 180 days. When compared with OPC concrete of similar compressive strength, geopolymer concrete has shown less sorptivity.
- The slag blended fly ash-based geopolymer concrete has good resistance to sulphate attack. The resistance to sulphate attack increased with the increase of slag content in the mixtures. There was no sign of crack or any other damage on the surface of the geopolymer concrete samples after exposure to 5% sodium sulphate solution up to 180 days. There are no significant changes in the mass and the compressive strength of test specimens after 180 days of exposure. The geopolymer concrete showed low expansion property in sulphate solution. Moreover, the results show that the expansion of the geopolymer concrete was much less than the OPC concrete specimens.
- Geopolymer concrete subjected to repetitive cycles of wetting in sodium chloride solution and drying at different temperature conditions showed higher compressive strength increment than the OPC concrete. The rate of strength increment is higher for the oven-dry specimens than the ambient-dry specimens. In addition, the weight of the geopolymer concrete specimens remained the same over the alternate wet and drying cycles whereas some weight loss was observed in the OPC concrete specimens during the exposure periods.

ISSN 2063-5346

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