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PROPERTIES OF FLY ASH AND SLAG BLENDED GEOPOLYMER CONCRETE CURED AT AMBIENT TEMPERATURE

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The properties of concrete using fly ash based geopolymer as the binder were shown in recent studies. However, most of the previous studies focused on the properties of geopolymer concrete samples cured at high temperature. In this study, fly ash based geopolymer concrete suitable for curing at ambient temperature was designed and some durability properties were investigated. Geopolymer mixtures were prepared with fly ash as the primary binder which was activated by a mixture of sodium silicate and sodium hydroxide solutions. Ground granulated blast furnace slag (GGBFS) was added as 0%, 10% and 20 % of the total binder. Samples were also cast from an ordinary Portland cement (OPC) concrete mixture in order to compare with the properties of geopolymer and OPC concretes. All the concrete samples were ambient-cured (15-20^{o}C) after casting until tested. The tests conducted include compressive strength, drying shrinkage, sorptivity and volume of permeable voids (VPV) test. The strength of the geopolymer concretes enhanced from the early age and continued to develop in similar trend as OPC concrete. Strength increased with the increase of slag in the mixture. The geopolymer concretes showed drying shrinkage, sorptivity and VPV values comparable to those of the control OPC concrete. In general, the results show that it is possible to design fly ash and slag blended geopolymer concrete suitable for ambient curing with similar or better durability properties of conventional OPC concrete.

Keywords: Ambient curing, geopolymer, fly ash, slag, sorptivity.

1 Introduction

Geopolymer is a rising field of research for utilizing by-products. It has paved the way for finding new alternative for the replacement of cement in concrete. Geopolymers are members of the family of inorganic alumino-silicate polymer synthesized from alkaline activation of various aluminosilicate materials or other by-product materials like fly ash, metakaoline, blast furnace slag etc. (Davidovits, 2008). The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The final products of geopolymerisation are influenced by several factors regarding chemical composition of the source materials and alkaline activators (Diaz et al. 2010; Yip et al. 2008). The polymerisation process is generally accelerated at higher temperature than ambient. Fly ash based geopolymer produced in ambient temperature achieve lower strength in early days as compared to heat cured specimens (Vijai et al. 2010).

Durability of concrete primarily depends on its permeability characteristics. Lower permeability gives higher resistance to the ingress of aggressive ions into the concrete and thereby reduces the extent of deterioration of concrete. Heat-cured fly ash based geopolymer concrete has high compressive strength and tensile strengths, and low effective porosity, which are all beneficial for concrete in an aggressive environment (Olivia and Nikraz, 2011).

Most of the previous studies were conducted on heat-cured geopolymer concrete that is considered to be ideal for precast concrete members. However, geopolymer concrete produced without using elevated heat for curing will widen its application to the areas beyond precast members. Hence this study aimed to produce geopolymer concrete suitable for ambient curing condition. GGBFS was mixed with low calcium fly ash in order to accelerate the curing of geopolymer concrete in ambient temperature. Durability properties such as drying shrinkage, sorptivity and VPV of geopolymer concrete were tested.

2 Experimental programs

2.1 *Materials*

Low calcium Class F (ASTM C 618) fly ash was used for making geopolymer concrete. GGBFS was added to fly ash to study its effect on the durability properties of concrete. Table 1 shows the chemical compositions of the fly ash and slag. The alkaline activator used was a combination of sodium hydroxide and sodium silicate solution. Sodium hydroxide solution of 14M concentration was prepared by mixing 97-98% pure pallets with tap water. Sodium silicate solution with SiO_2 to Na_2O ratio by mass of 2.61 (SiO_2=30.0%, Na_2O= 11.5% and water=58.5%) was used. Fine aggregates having a specific gravity of 2.62, unit weight of 1687 kg/m^3 and fineness modulus of 1.97, was used. Coarse aggregate were crushed granite with nominal maximum size of 7, 10 and 20 mm that met the Australian Standard (AS 2758.1-1998) specifications. The fineness modulus of combined coarse aggregates was 6.12.

Table 1: Chemical composition of fly ash and GGBFS

Sample	Fly ash (%)	GGBFS (%)
SiO_2	53.71	29.96
Al_2O_3	27.20	12.25
Fe_2O_3	11.17	0.52
CaO	1.90	45.45
Na_2O	0.36	0.31
K_2O	0.54	0.38
SO_3	0.30	3.62
P_2O_5	0.71	0.04
TiO_2	1.62	0.46
LOI[a]	0.68	2.39

[a]Loss on ignition

Table 2: Mixture proportions (kg/m^3) and slump of the concrete mixtures

Mixtures	GPC1	GPC2	GPC3	OPC
Label	A35 S0	A35 S10	A35 S20	-
CA[a]	1222	1216	1216	1054
Sand	658	655	655	740
Fly ash	400	360	340	-
GGBFS	-	40	80	-
Cement	-	-	-	366
SH[b]	40	40	40	-
SS[c]	100	100	100	-
Water	-	8	8	201
SP[d]	6	6	6	-
Na_2O/SiO_2	0.107	0.11	0.113	-
H_2O/Na_2O	11.69	12.79	12.81	-
Si/Al	1.73	1.76	1.8	-
w/s[e]	0.18	0.197	0.197	0.55
Slump(mm)	230	210	200	150

[a]Coarse aggregate, [b]Sodium hydroxide, [c]Sodium silicate, [d]Superplasticiser, [e]Water to solid ratio

2.2 *Manufacture of geopolymer concrete*

2.2.1 *Mixture proportions*

The concrete mixtures were proportioned based on the previous works on fly ash based geopolymer concrete (Nath and Sarker 2012).

Fly ash was replaced by GGBFS in the range of 10 to 20%. Water and superplasticizer was added to increase the workability of the mixtures. The ordinary Portland cement concrete was designed based on ACI 211.1 (ACI Committee 211).

The mixture proportions of four mixtures studied are shown in Table 2. Mixture GPC1, GPC2 and GPC3 were designed with Constant sodium silicate to sodium hydroxide ratio (SS/SH) of 2.5 and the fly ash replacing with slag as 0%, 10% and 20% of the total binder respectively. In each mixture, 35% alkaline activator was used.

2.2.2 Mixing, curing and casting of geopolymer concrete

The alkaline activator was prepared in the laboratory by mixing the sodium hydroxide solution with sodium silicate solution about 30 minutes before the actual mixing. The fly ash and the aggregates were first mixed together in the pan mixer. This was followed by the addition of the activator solutions to the dry materials and the mixing continued for further about 3-5 minutes to produce fresh geopolymer concrete.

2.3 *Experiments*

The workability of fresh concrete mixtures was measured by slump test in accordance with the ASTM C 143 method. Cylinder specimens of 100 mm in diameter and 200 mm in height were cast and put in ambient curing at 15-20 ^{0}C and 70±10% relative humidity. These specimens were used for compressive strength, sorptivity and volume of permeable voids tests. Compressive strength was tested at 7, 28 and 56 days. Specimens for drying shrinkage test were prepared in accordance with AS 1012.13-1992 and tested up to 56 days. In addition, the sorptivity (ASTM C 1585) test was conducted for three specimens (100 mm dia × 50 mm height). The side and top of the specimens were coated with epoxy to allow free water movement only through the bottom face (unidirectional flow). The results were plotted against the square root of the time to obtain a slope of the best fit straight line (sorptivity coefficient). For VPV (AS 1012.21-1999) test, the 100 mm diameter × 200 mm high concrete cylinder were cut into four equal parts and tested at 28 days.

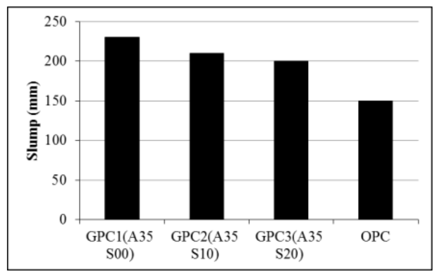

Figure 1. Slump of OPC and geopolymer concrete.

3 Results and discussions

3.1 *Workability of fresh concrete*

Slump test was conducted immediately after mixing of each geopolymer and OPC concrete. Slump values are shown in Table 2 and Figure 1. Generally geopolymer concrete mixtures had ‘collapse’ slump due to its sticky and viscous nature in fresh state. Slump value decreased with the increase of slag content in the mixture. Geopolymer concrete with 20% slag and SS/SH ratio 2.5 (GPC3) exhibited the lowest slump value among all the geopolymer mixtures. The addition of water and super plasticizer in the slag blended mixtures helped to improve the workability of GPC2 and GPC3.However, when compared to the OPC mixture, geopolymer concrete mixtures exhibited more cohesiveness than the OPC concrete mixture.

3.2 *Compressive strength*

Figure 2 shows the development of compressive strength for different geopolymer and OPC concrete mixtures.

Table 3: Compressive strength of geopolymer and OPC concrete

Mix	Compressive strength, f'_c (MPa)		
	7days	28days	56 days
GPC1	11.4	25.0	29.5
GPC2	14.5	27.0	34.9
GPC3	22.1	34.7	39.6
OPC	22.0	33.0	37.0

When different percentage of GGBFS was incorporated in the mixture with constant alkaline activator (35%) and SS/SH ratio of 2.5, the strength increased from the early age of 7 days and continued up to 56 days. At 28 days, mixture GPC2 and GPC3 having 10% and 20% slag achieved 10% and 40% higher strength, respectively, than the geopolymer concrete without slag (GPC1). The improvement of strength of fly ash and slag blended geopolymer concrete is due to the increase of calcium bearing compound in the dissoluted binder which produced reaction product from both slag and fly ash. The strength increase of GPC2 and GPC3 as compared to GPC1 is relatively small because of the extra water added in these two mixtures which eventually increased the molar ratio of H_2O-to-Na_2O. As reported in a previous study by Nath and Sarker (2012), similar mixtures without extra water exhibited higher compressive strength than the mixtures of this study.

Geopolymer concrete with 20% slag (GPC3) gained similar strength of the OPC mixture at 28 days. However, the rate of strength development was slightly higher for GPC3 than OPC mixture which continued up to 56 days (Figure 2).

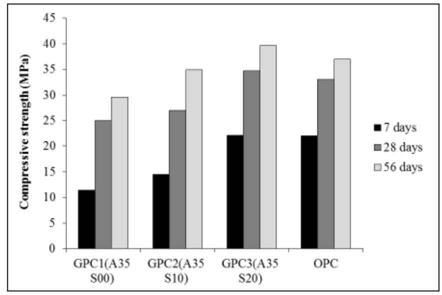

Figure 2. Development of compressive strength of the geopolymer and OPC concretes.

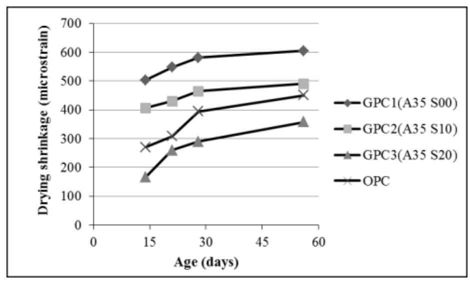

Figure 3. Drying Shrinkage of OPC and Ambient-cured geopolymer concrete.

3.3 *Drying shrinkage*

The drying shrinkage measurements commenced on the seventh day after casting. The effect of incorporation of slag in geopolymer concrete on drying shrinkage is shown in Figure 3. It can be seen from the figure that shrinkage continued to occur until 56 days of age in all the concrete samples. The values of shrinkage in all the specimens at 56 days were well below 1000 microstrain as specified by the AS1379-2007 standards (Standard Australia, 2007) for normal and special class concrete.

The drying shrinkage values of geopolymer concrete are found to be significantly reduced by the amount of slag content in the mixtures. From Figure 3 it can be seen that the rate of shrinkage decreased with the increase of slag content in geopolymer mixtures. Mixture GPC2 (10%

slag) and GPC3 (20% slag) achieved 20% and 50% less shrinkage, respectively, than that of GPC1 (no slag). Moreover, the geopolymer concrete mixture GPC3 that achieved similar strength of OPC at 28 days, exhibited a considerably lower value of drying shrinkage than the OPC concrete.

3.4 *Sorptivity*

Figure 4 shows the comparison of sorptivity of different geopolymer and OPC concrete mixtures. Comparing the results of geopolymer concrete mixtures GPC1, GPC2 and GPC3, it can be seen that sorptivity values decreased with the increase of compressive strength of geopolymer mixtures. It also indicates that resistance to permeation increased with the increase of slag content in the mixture. Geopolymer mixture GPC3 having the most (20%) amount of slag exhibited the lowest sorptivity value than the geopolymer concrete mixtures GPC1 and GPC2 at 28 days.

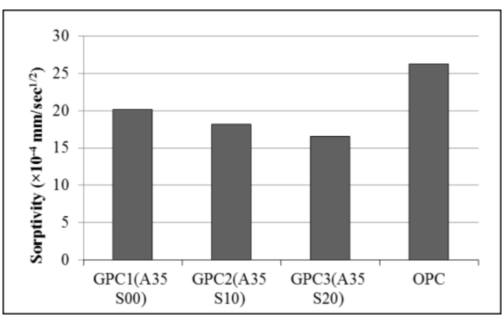

Figure 4. Sorptivity of OPC and ambient-cured geopolymer concrete at 28-days.

Recommended values of sorptivity provided by Papworth and Grace (1985) were used in this study to rate the quality of the concretes. According to this study, the geopolymer concrete mixtures can be classified as “very good”, as the sorptivity values are less than 129.1×10^{-4} mm/sec$^{1/2}$. Geopolymer concrete mixture GPC3 that achieved similar strength of mixture OPC at 28 days, have shown significantly lower sorption than OPC mixture. The lower values of sorptivity for geopolymer concrete shows a reduced moisture intake as compared to the corresponding OPC concrete.

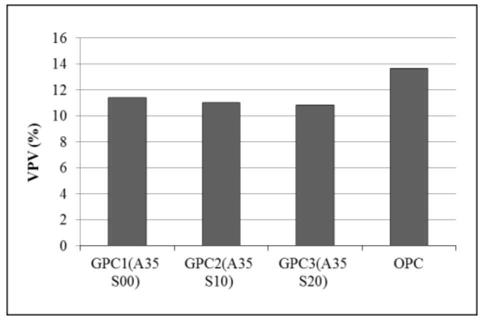

Figure 5. VPV of OPC and ambient-cured geopolymer concrete at 28-days.

3.5 *Volume of permeable voids (VPV)*

Volume of permeable voids was determined at 28 days for both the geopolymer and OPC concrete specimens. The VPV of all the geopolymer and OPC concrete are shown in Figure 5. It is observed that the VPV values of the geopolymer concrete specimens showed the same trend as the sorptivity values with the variation of slag. The VPV values of the geopolymer concrete mixtures decreased with the increase of slag content. Moreover, it can be seen that the geopolymer concrete mixture GPC3 that achieved similar strength of OPC at 28 days, exhibited a considerably lower value of VPV. The VPV value of GPC3 is less than 11% which is classified as “excellent” concrete according to Vicroads classification (Concrete Institute of Australia 2001) for concrete durability based on the VPV of vibrated cylinders. Mixture GPC1 and GPC2 are just at the margin of 11- 13% which can be classified as a “good” concrete.

4 Conclusion

Three geopolymer concrete mixtures were designed with fly ash and slag as the binder source materials. Compressive strength, drying shrinkage, sorptivity and VPV of ambient cured geopolymer concrete were compared with variation of slag content. The results of the study are summarized below.

- Geopolymer concrete cured in the laboratory ambient condition gained compressive strength with age. Inclusion of slag improved the early strength as compared to control fly ash geopolymer concrete. Slag content of up to 20% of the total binder showed reasonable workability and increased compressive strength.
- The drying shrinkage of ambient-cured geopolymer concrete decreased with the increase of slag up to 20% as replacement of fly ash. Geopolymer 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 and VPV in comparison to control geopolymer concrete mixture. When compared with OPC concrete of similar compressive strength, geopolymer concrete has shown less sorptivity and permeable void at 28 days.

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