



Carbonation of a blended slag-fly ash geopolymer concrete in field conditions after 8 years



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HIGHLIGHTS

- Carbonation of geopolymer concrete exposed to atmospheric environment was investigated.
- The mix compositions of geopolymer concrete was influenced on the carbonation rate in atmosphere.
- The presence of carbonation reaction components was identified by TGA and FTIR analysis.
- MIP analysis test results was providing a good correlation with carbonation depth values.

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ABSTRACT

In this study, the carbonation resistance of two geopolymer concretes exposed to outdoor field conditions for eight years was investigated. Core specimens were used to determine the in-situ carbonation depth, concrete porosity was assessed and the carbonation reaction products of aged concrete were identified by TGA and FT-IR analysis. Carbonation of the geopolymer concretes was compared to OPC and fly ash concretes exposed to similar conditions. The results indicated that the carbonation rate of geopolymer concrete is highly dependent on the activator components of geopolymer concrete. Type 1 geopolymer concrete, with 75% fly ash/25% GGBFS and additional Na_2SiO_3 activator, showed a poor resistance against carbonation compared to OPC concrete. However, the performance of Type 2 geopolymer with 70% fly ash/30% GGBFS and no additional Na_2SiO_3 activator, was similar to OPC concrete. In addition, water absorption, sorptivity, total porosity and differential pore size distribution analysis correlated well with the carbonation resistance. Investigation of long term durability performance of geopolymer concrete is critical for the development of standard specifications for commercial application. This study reveals that two geopolymer concretes, with a similar mix design and compressive strength, have different carbonation behaviour. Therefore, a performance based approach is an appropriate strategy to develop standard specifications for geopolymer concrete.

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1. Introduction

Approximately 5% to 7% of global CO_2 emissions are produced from Portland cement production [1,2]. These emissions are likely to further increase due to a rising demand for concrete. Geopolymer concrete (GPC) is produced with supplementary cementitious materials and has potential to reduce the environmental issues associated with CO_2 emission from cement production. One tonne of GPC production releases only 0.184 tonnes CO_2 and this amount is much lower compared with Ordinary Portland Cement (OPC) concrete production [3]. While, previous studies have shown that

the geopolymer is a suitable alternative material to Portland cement, the implementation of the GPC into the commercial applications has been very limited. Durability is the key limiting factor for the adoption of geopolymer technology in the construction industry [4]. The, durability of geopolymer concrete structures must therefore be demonstrated to enhance the usage of geopolymer concrete in construction.

Carbonation is an important phenomenon for the durability of concrete structures in an atmospheric environment. Carbonation of OPC concrete occurs when the CO_2 from the atmosphere penetrates in to the concrete and reacts with calcium hydroxide. It has been reported that the carbonation resistance of alkali activated slag concrete is lower than OPC concrete based on accelerated carbonation tests [5,6]. However, Bernal et al. [7] observed

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that the carbonation product from natural carbonation process and accelerated carbonation testing can be dissimilar. That is, unlike natural carbonation, sodium bicarbonate products are mostly formed during accelerated carbonation testing at high CO₂ concentration level (i.e. 3% CO₂). This induces a pH reduction of the pore solution higher compared to natural carbonation. Therefore, measuring the carbonation depth of geopolymer concrete exposed in ambient conditions is the appropriate way to determine the durability performance in realistic atmospheric CO₂ environments.

The permeation properties and the pore structure of the concrete are key indicators of penetration by aggressive agents such as CO₂, chloride ion and other species that promote the deterioration of the concrete and corrosion of embedded steel. In OPC concrete, carbonation reaction reduces the porosity due to formation of a dense CaCO₃ layer. In contrast, according to Badar et al. [8], porosity of fly ash based geopolymer concrete increases when exposed to an accelerated carbonation environment. However, this study used 5% of CO₂ for their accelerated carbonation tests. As previously mentioned, sodium bicarbonate products (nahcolite) form at high CO₂ concentration levels. The molar volume of nahcolite is five times smaller than that of natron which is the sodium carbonate forming in natural conditions. Thus nahcolite does not provide the same degree of pore blockage as natron. As a result, the outcomes of the studies conducted by Badar et al. [8] are not representative of field conditions.

Here, the carbonation resistance of two eight-year-old ambient exposed geopolymer concretes was determined by measuring the loss of alkalinity and the formation of carbonation products through thermogravimetric analysis (TGA/DTG) and Fourier transforms infrared (FT-IR) analysis. Since the pore structure is important for the durability of concrete, porosity and the pore size distribution of aged geopolymer concrete was determined using mercury intrusion porosimetry (MIP) measurements. In addition, the transport properties of aged concrete were evaluated by measuring the apparent volume of permeable voids (AVPV) and the sorptivity to correlate with the carbonation data.

2. Materials and methods

2.1. Sampling locations in the slabs

Experimental investigation was conducted on core specimens extracted from two different reinforced geopolymer concrete slabs exposed to an outdoor environment. The slabs were cast in 2007 by Zeobond Pty Ltd Australia in Campbellfield, Victoria, Australia. Two

different geopolymer mixes were used for Type 1 and Type 2 slabs as detailed in the next paragraph. The first slab (Type 1) was 7.8 m × 4.07 m size and had a 50–70 mm thick topping of unreinforced geopolymer concrete. The thickness of the exposed part of the slab was 600 mm. The next slab, which was located adjacent to the Type 1 slab, was classified as Type 2. Only the top surface of the Type 2 slab was exposed to the atmosphere and the thickness of the slab that was submerged into soil was 150 mm. The core specimens were extracted from the vertical surfaces of the Type 1 slab, to avoid the influence of the topping, and from the top surface of the Type 2 slab. Fig. 1 shows the schematic diagram of the core locations. The diameter of the extracted core samples was 94 mm and the lengths were 165 to 275 mm.

2.2. Mix composition of concrete

The geopolymer binder in the slabs was prepared with a combination of Bayswater type fly ash and ground granulated blast furnace slag (GGBFS). Table 1 presents the chemical composition of fly ash and GGBFS determined by X-ray Fluorescence (XRF) analysis. A combination of 75% of fly ash and 25% of GGBFS was used to produce the binder in Type 1 concrete, whereas 70% of fly ash and 30% GGBFS was used for the binder in Type 2 concrete. A combination of 7 M (50 mol% Na cations and 50 mol% K cations) of sodium hydroxide (NaOH) and potassium hydroxide (KOH) were used as hydroxide activator for both slabs. In addition, sodium silicate (Na₂SiO₃) was added to activator combinations for the Type 1 slab, which consisted in of 2.5% SiO₂ relative to the binder content. A commercial D grade Na₂SiO₃ solution (29.4% SiO₂ and 14.7% Na₂O by weight) was supplied by PQ Australia.

The water to binder ratio used to prepare activator combination was 0.25. However, to achieve sufficient workability, extra water was added to maintain total water to binder ratio at 0.3. Mix compositions of the slabs are described in Table 2.

2.3. Experimental methods

2.3.1. Compressive strength and elastic modulus properties of aged concrete

The compressive strength and elastic modulus of core specimens were measured in compliance with ASTM C39 and ASTM C 469 standards, respectively, using a UTM with a capacity of 2 MN.

2.3.2. Carbonation depth and pH profile measurement

Carbonation testing was conducted on core specimens immediately after sampling the cores from the slabs. A 1% solution of phe-

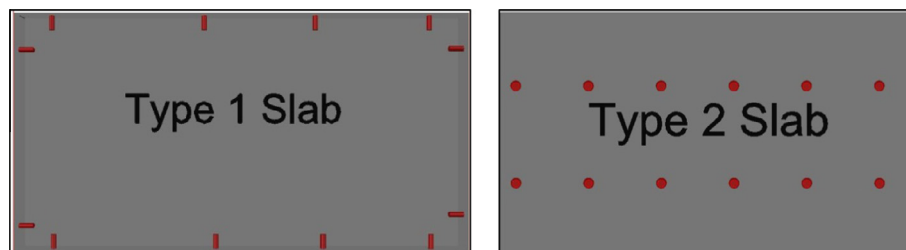


Fig. 1. Schematic diagram of core locations.

Table 1
Chemical composition of fly ash and GGBFS determined by XRF.

Series	SiO ₂	Al ₂ O ₃	CaO	MgO	Fe ₂ O ₃	Na ₂ O	P ₂ O ₅	K ₂ O	MnO	SO ₃	TiO ₂	LOI
Bayswater fly ash (mass%)	80.4	14.0	0.04	0.31	3.57	0.10	0.09	0.85	0.04	0.08	0.49	0.54
GGBFS (mass%)	34.2	13.8	43.1	5.4	0.4	0.1	–	0.4	–	0.8	–	1.8

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