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Durability performance of concrete structures built with low carbon construction materials

Kirubajiny Pasupathy^{a*}, Marita Berndt^a, Jay Sanjayan^a, Rajeev Pathmanathan^a

^aCentre for Sustainable Infrastructure, FSET, Swinburne University of technology, Hawthorn, Victoria, 3122

Abstract

Here, we demonstrate the feasibility of industrial application of low carbon supplementary cementitious materials (i.e. geopolymer concrete) by investigating the durability performance of eight years aged reinforced geopolymer concrete structure exposed to ambient environment. The corrosion performance of reinforcement bar in concrete and permeability characteristic of cover concrete is investigated by using non-destructive techniques. The results reveal that the reinforcement in geopolymer concrete exhibits higher corrosion risk in atmospheric environment and this attributes to the deterioration of long term durability performance for geopolymer concrete.

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1. Introduction

Concrete industry is a major contributor for the climate change due to carbon dioxide (CO₂) emission from the cement production. Approximately 5 to 7 % of CO₂ produced from the cement production [1, 2]. This will be increased further due to the incremental demand of concrete in future. Geopolymer concrete (GPC) is an alternative for the ordinary Portland cement (OPC) concrete, which is produced from the industrial waste products such as fly ash, slag and meta-kaolin. One ton of GPC production releases only 0.184 tons CO₂ as opposed to the CO₂ emission of OPC concrete, which is about one ton for one ton concrete production [3]. Generally, geopolymer binders could reduce up to 80% of CO₂ emission from OPC concrete production [4]. Therefore GPC could provide the solution for the environmental problems due to the carbon emission by concrete production.

* Corresponding author. Tel.: +61-042-430-9692.
E-mail address: kpasupathy@swin.edu.au.

Although the research studies have been conducted on geopolymer binders for more than three decades, the application of the geopolymer materials in construction industries are very limited. Long term performance of in-situ cast concrete is one of the barriers for the application of GPC in construction industry. The corrosion of reinforcement bar in concrete is the main issue of long term durability of concrete in atmospheric environment, which is due to the penetration of the aggressive agents such as CO₂, chloride ion and other gases/chemical ions. Corrosion behavior of the rebar in concrete can be characterized by half-cell potential (HCP) measurement. Higher potential values indicate that the risk of corrosion in reinforcement is high.

With half-cell potential (HCP) measurement by using Cu/CUSO₄ electrode, low Ca fly ash based GPC showed low level of corrosion risk and high Ca fly ash based GPC displayed severe risk with more negative potential value after 30 days exposure in natural carbonation condition [5].

The electrical resistance of concrete also provides the information about the corrosion risk of concrete. Previous studies showed that the field exposed geopolymer concrete culvert exhibit lower electrical resistance compared to OPC concrete culvert in similar atmospheric environment after three years of exposure [6]. Conversely, Olivia et al. [7] stated that the electrical resistance of the fly ash based geopolymer concrete was higher than OPC concrete by calculating with ohms law. In addition, the penetration of aggressive agents promotes the corrosion activities in concrete, which depend on the porosity of cover concrete. Therefore measuring the permeation properties is an indication for durability performance of concrete structure.

In this study, durability performance of ambient exposed aged reinforced GPC slab structure was investigated by using non-destructive techniques. State of corrosion in aged geopolymer concrete was identified by HCP and electric resistivity measurements. Furthermore, air permeability measurement was carried out to determine the permeable characteristics of GPC concrete structure.

Nomenclature

CO ₂	Carbon dioxide
GPC	Geopolymer concrete
OPC	Ordinary Portland cement
GGBFS	Ground granulated blast furnace slag
NaOH	Sodium hydroxide
KOH	Potassium hydroxide
Na ₂ SiO ₃	Sodium silicate
HCP	Half-cell potential

2. Materials and methods

2.1. Materials and mix compositions

The field investigations were carried out on reinforced geopolymer concrete slab structure exposed to ambient environment for eight years. The dimension of the slab was 7.8 m x 4.07 m size and had a 70 mm thick topping of unreinforced geopolymer concrete. Thickness of the exposed part of the slab was 600 mm. Slab was cast in 2007 by Zeobond PTY Ltd Australia in Campbellfield, Victoria, Australia.

Bayswater type fly ash and ground granulated blast furnace slag (GGBFS) were used to make geopolymer binder with the proportion of 75% and 25% respectively. A combination of 7M (50 mol% Na cations and 50 mol% K cations) of sodium hydroxide (NaOH) and potassium hydroxide (KOH) were used as hydroxide activators and sodium silicate (Na_2SiO_3) is added 2.5% as SiO_2 relative to the binder content. A commercial D grade Na_2SiO_3 solution (29.4% SiO_2 and 14.7% Na_2O by weight) was supplied by PQ Australia.

Water to binder ratio (w/b) used to prepare activator combination was 0.25. However to improve workability, extra water was added and total w/b ratio was maintained as 0.3. Mix detail of the slab is described in Table 1.

Table 1 Mix composition of materials

Materials	Weight(kg/m ³)
Total binder	400
Fine aggregate	630
Coarse aggregate	1150
NaOH pellet	14
KOH pellet	19.6
Na_2SiO_3 solution	34.48
Water used to prepare activator	81.04
Extra water	20

2.2. Experimental methods

The experimental investigations were conducted on the vertical surface of the slab in order to exclude the topping layer. The corrosion activity in the GPC structure was identified with HCP measurement by Corromap non-destructive testing (NDT) equipment. Ag/AgCl electrode was used as reference electrode in CorroMap. Potential readings were taken on the vertical surface of the slab at 250 mm intervals.

Electric Resistance measurements were conducted by Resipod fully integrated, four point Wenner probe resistivity meter. Readings were taken at several places on the slab surface. At a given location, five readings were taken to derive the average value. Gas permeable coefficient at various locations of concrete surface was measured by torrent permeability tester [8].

3. Results and discussion

3.1. In-situ resistivity measurement

The electric resistivity measurements on the geopolymer concrete slab surface was provided in Fig. 1. As shown in Fig. 1, geopolymer concrete exhibits lower electric resistance values and the values are varied with locations due to moisture variation in the slab. According to the information provided by Polder [9], the risk of corrosion in geopolymer concrete structure with the electric resistivity values less than 10 kΩcm is in the highly risk and the values between 10 and 50 kΩcm correlated with moderate corrosion risk regions. The lower electric resistance properties in geopolymer concrete could be attributed by the presents of high alkali content.

The alkali contents, which presents in the pore solution of the concrete mainly influence on electrical resistance values [10]. Geopolymer concrete is produced with high quantity of alkali components as

activators. Therefore, lower resistance values are obtained for geopolymer concrete due to the high alkali species (Na^+ , K^+) in the pore solution of concrete.

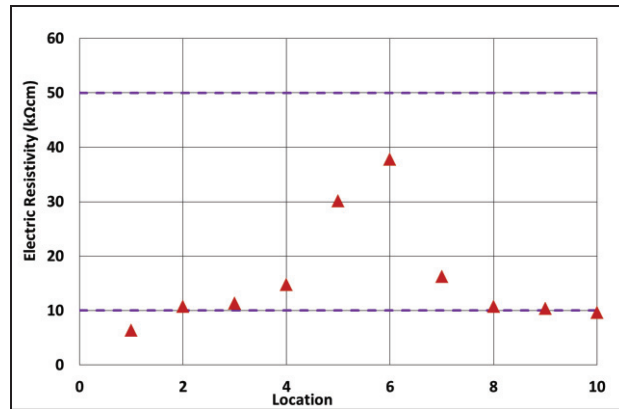


Fig. 1 Electric Resistivity values at various locations

Electric resistance also depends on the pore structure of the concrete surface and dissolved salt content in the pore solution [11]. Carbonation of GPC increases the porosity of concrete [5] and resulted in more alkali salt in the pore solution. This is because of the fact that carbonation reaction in GPC increased the porosity by producing soluble carbonated products such as sodium carbonate and potassium carbonate, which could also be attributed to high alkaline salt components in the pore solutions. Therefore, lower electric resistance of geopolymer concrete was associated with high porosity surface and presence of dissolved salt in the pore solution.

3.2. In-situ half-cell potential measurement

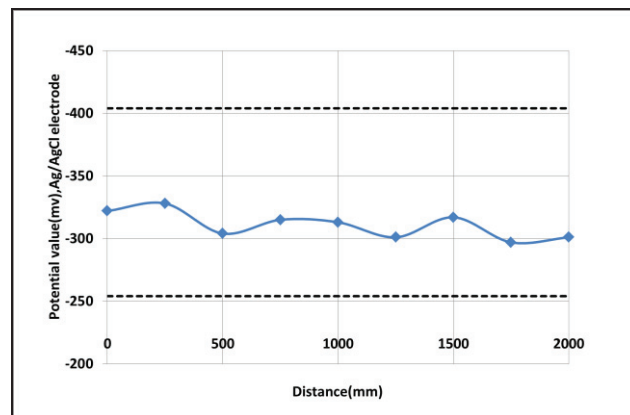


Fig. 2 HCP measurements in different locations

Fig. 2 shows the electric potential measurements of concrete surface at 250mm grid intervals. It was noted that the HCP values are fallen in the range between -254mv to -404mv. According to ASTM C876, chance of corrosion of reinforcement bar in concrete with the potential value between -254 to -404mv is

about 90% [12]. However moisture content of the concrete also influence on the HCP measurement [13]. These readings were taken after the heavy rainy days. Therefore due to the high moisture content in slab, large values of the HCP reading could be obtained during the field investigation. Therefore, the state of corrosion in geopolymer concrete structure was not properly identified by using HCP measurements technique with CorroMap.

3.3. In-situ air permeable coefficient measurement

Air permeability measurement is an indication of the penetration of the CO₂ and other gases into concrete. The coefficient of air permeability values obtained from Torrent permeable tester method was presented in Fig. 3.

According to Fig. 3, it can be seen that most of the permeable coefficient values are in the range between $1 \times 10^{-16} \text{ m}^2$ and $10 \times 10^{-16} \text{ m}^2$. This indicates that field exposed geopolymer concrete contains low quality cover concrete [14] and has high pore content. Thus, the penetration of aggressive gases into concrete cover is high and this attributed to high corrosion activities in geopolymer concrete.

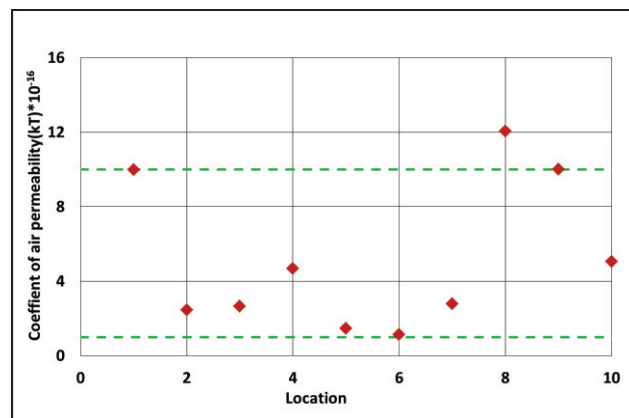


Fig. 3 Coefficient of permeability values

4. Conclusion

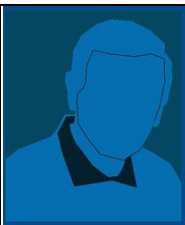
Geopolymer binder is produced with sustainable cementitious materials that ensure the low emission of CO₂ to environment compared to OPC concrete. The investigation of long term durability performance of geopolymer concrete is essential before the commercial application of new supplementary cementitious materials in geopolymer concrete. This study confirmed that the geopolymer concrete contains low electric resistance properties and higher negative corrosion potential values, thus indicating higher chance of corrosion risk when it is exposed in the real field. Moreover, gas permeability coefficient values of geopolymer concrete was significantly high and this indicated that high porous content in concrete structure and the ingress of aggressive species to the concrete surface is high. This can be attributed to the deterioration of concrete and induce corrosion of steel bars in atmospheric environment. Therefore, this preliminary study shows geopolymer concrete contains lower durability performance comparing to OPC concrete. Future studies will investigate the improvement of durability performance of geopolymer concrete.

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Biography

Kirubajiny Pasupathy received the BSc Engineering degree in University of Moratuwa, Sri Lanka. She is currently a full time PhD student in Swinburne University of Technology, Melbourne, Australia. Her main research interests are low-carbon construction materials, sustainable construction practices and supplementary cementitious materials.