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GEOPOLYMER CONCRETE – NO LONGER LABCRETE!

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Abstract. *Recent publications on concrete technology include a vast number of papers on geopolymer concrete. The impression given is that geopolymer technology has potential as a binder for concrete but requires significant additional research to become a viable alternative to Portland cement. A proprietary geopolymer concrete, marketed as "Earth Friendly Concrete" or EFC, has made the transition to practical application in construction. The Brisbane West Wellcamp Airport (BWWA) and associated developments in Southern Queensland recently became fully operational with commercial flights. The concrete elements including aprons and bridges as well as the terminal and business park structures used geopolymer concrete. Approximately 40,000 cubic metres of geopolymer concrete was used making it the largest application of this type of concrete in the world.*

This paper describes the use of geopolymer concrete for the project from both a materials and construction perspective and highlights differences with conventional concrete where they occurred. The project demonstrates that appropriate geopolymer concrete is becoming a viable alternative to Portland cement based concrete.

1 INTRODUCTION

Geopolymer concrete, often called inorganic polymer concrete, is the result of the reaction of materials containing aluminosilicate with concentrated alkali hydroxide and/or silicate solution to produce an inorganic polymer binder. The term “geopolymer” was first coined by Davidovits [1].The concept of alkali activated binders has a history starting in the 1940’s [2] and has attracted significant academic research over the years. Recently, the considerable sustainability benefits of using a binder system composed almost entirely of recycled materials has resulted in an acceleration of research in this area. Concrete conferences and journals contain a bewildering number of papers on geopolymer technology. The impression often given is that geopolymer concrete is an interesting idea with an array of attributes which would require substantial further research to become a viable alternative to Portland cement based concrete. However, alkali activated concrete was used in structures in Ukraine in 1960’s. Xu et al. [3] reported the performance of samples cast between 1964 and 1982, and subjected to service conditions since that time. They state that; “All samples demonstrate high compressive strengths—significantly higher than when initially cast—and excellent durability over a service life of up to 35 years in aggressive conditions”. There are numerous examples of the use of geopolymer concrete in different applications in Australia (for example Aldred and Day [4], Bligh and Glasby [5] as well as niche applications of geopolymers in various applications [6].

Brisbane West Wellcamp Airport (BWWA) became fully operational with commercial flights operated by Qantas Link in November 2014. Geopolymer concrete (EFC) was supplied by Wagners for the construction of the 435 mm thick heavy duty pavements in the aircraft turning areas. There were three distinct areas of geopolymer pavement including the turning node, the taxiway and the hangars. Construction trials were undertaken to ensure that this geopolymer concrete could meet the performance criteria of the contract specification as well as be placed in the intended method using a slip form paving machine. The construction trials highlighted a number of challenges which were overcome by some innovative solutions.

2 THE PAVEMENT MIX

The pavement design was undertaken by ACG Engineers. The concrete materials specification required:

- Average flexural strength 4.8 MPa at 28 days of age (AS 1012.11) with each sample greater than 4.45 MPa,
- 450 micro-strain maximum drying shrinkage after 21 days drying (AS 1012.13)

Following extensive development, the proprietary geopolymer concrete can be produced and handled in a similar manner to conventional concrete. In the 6 month period prior to pavement construction, Wagners adjusted the geopolymer concrete design mix to achieve the specific requirements of the project through laboratory trials and small scale pavement works around the BWWA site.

The project mix was developed for the BWWA heavy duty pavements to suit placement with a slip form paving machine. The private hangar pavement located outside the boundary of the airport, east of the runway, was constructed from May to July 2014. This provided a field testing area to confirm the intended geopolymer design mix and the pavement placement method. The pavement construction trials consisted of 10 individual pours of 5 m wide x 50 metres long using a Gomaco slip form road paver. Following the successful trial phase, the geopolymer concrete mix and pavement construction method was approved. Construction of the turning node pavements was undertaken during August and September 2014 and the apron pavements were constructed during October and early November 2014. BWWA was opened for its first commercial flight on 17 November 2014.

The overall plan of the geopolymer concrete pavement works at the BWWA site is shown in Figure 1. The turning node is located at the Northern end of the runway and the apron is located on the Western side of the runway in front of the terminal and carpark.

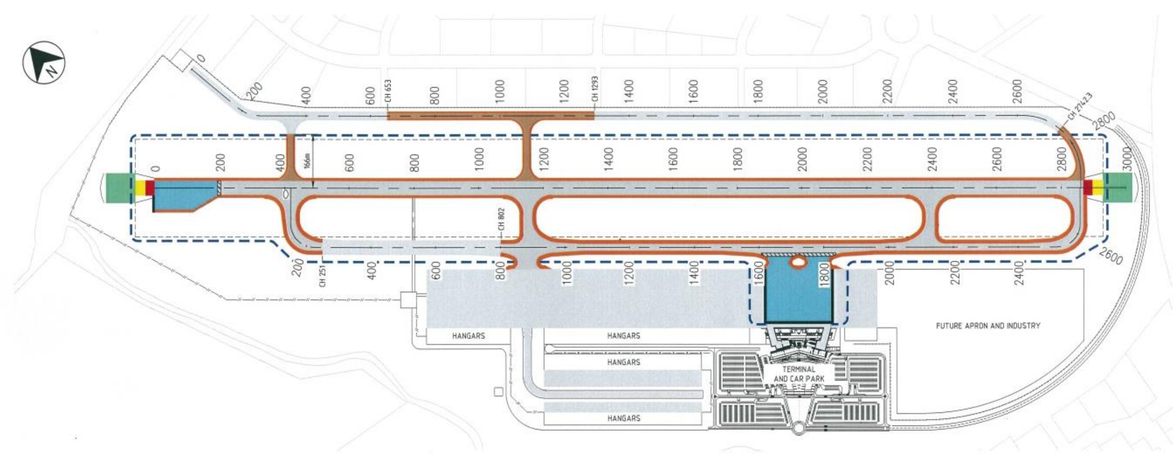


Figure 1: Site plan of BWWA.

3 GEOPOLYMER CONCRETE PROPERTIES

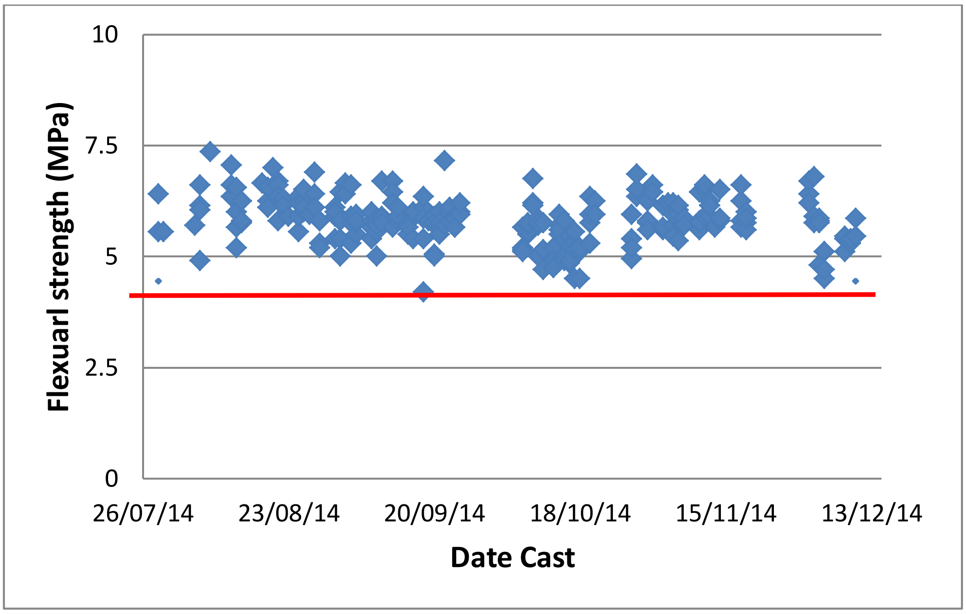
The geopolymer concrete mix was developed for the BWWA heavy duty pavements to suit placement with a slip form paving machine. Key criteria of the mix included workability and workability retention suitable for transport in tippers and slip form pavement construction as well as achieving the specified flexural strength parameters.

The summary mix parameters were:

- Total alumino-silicate binder comprising ground granulated blast-furnace slag (GGBS) + Fly ash (415 kg/m^3)
- Water:binder ratio 0.41
- Nominal 28 mm aggregate size
- Chemical activator, 37 kg/m^3 solids content
- Proprietary water reducing admixture

Compliance testing was based on flexural strength testing in accordance with Australian Standard AS 1012.11. The results from 502 samples for the turning node and apron pavements showed an average of 5.8 MPa with a standard deviation of 0.5 MPa. These data are shown in Figure 2 and confirmed compliance with the specification requirement and variability comparable to flexural strength testing on Portland cement based concrete. There was only one result that fell nominally below the minimum specified limit of 4.45 MPa.

This proprietary geopolymer concrete has low drying shrinkage [4] and the shrinkage was approximately one third of the specified limit at 21 days. This suggests that the standard joint spacing adopted may be able to be increased.



4 GEOPOLYMER CONCRETE PRODUCTION, SUPPLY AND CONSTRUCTION

The geopolymer concrete was produced in standard twin mobile wet mix batch plants at the project site. These had been modified to facilitate accurate and safe dispensing of the chemical activators to the mix as a solution. A maximum plant capacity of 120m^3/hr was able to provide a continuous supply of concrete to the paving machine using tipper trucks for delivery. The use of tippers significantly improved the discharge rate at the paver face. They also significantly reduced the cost of equipment necessary to undertake the construction.

In Australia concrete for aircraft pavement construction is normally placed and compacted against steel side forms using a combination of internal mechanical vibration and vibrating beams. This method has evolved from construction experience with Portland cement based concrete for thicker heavy duty pavements. The use of slip form paver machines which is common for thinner concrete road bases has generally not been used in airport pavement construction due to concerns regarding incomplete compaction for thicker pavement bases.

The trials conducted at the hangar area demonstrated that a high level of compaction of the geopolymer concrete could be achieved with a slip form paver machine. Steel side forms were chosen over the option of unformed extrusion to ensure the 435 mm thick pavements could be fully compacted at the sides without any loss in surface flatness. Slip form construction was adopted at BWWA due to its efficiency and increased production rate compared to a vibrating beam. It is estimated that a 30% reduction in the pavement construction programme was achieved on this project compared with the traditional process.

The contractor reported that the rheology and internal cohesion of the proprietary geopolymer mix at the specified workability enabled better extrusion than conventional concrete. This resulted in more efficient placement. The level of admixtures and activators in the mix were able to be customised for the differing weather conditions and length of transit time across the project site. The temperatures ranged from a minimum of 2°C in Winter to a maximum of 40°C in Summer. The transit time ranged from 5 to 20 minutes.

The effectiveness of the compaction procedure using the slip form paving machine was validated by comparing in-situ density test results with fresh concrete density results (Table 1). In situ density was measured by nuclear density method (NDM) to AS 1289.5.8.1 (5) and in situ core density testing to AS 1012.14 (6) and AS 1012.12 (7).

The geopolymer concrete required particular attention to pre-curing evaporation control and curing when placing exposed slab surfaces. It displayed very low bleed characteristics and the surface would rapidly dry out if measures were not taken to maintain a moist sheen on the surface. From the supplier's previous experience, drying of this geopolymer concrete surface prior to initial set and the application of curing would make the extreme surface prone to wearing with time.

	All areas	**Turning node area – In situ testing**				**Apron area – In situ testing**			
	Cast beams and cylinders	Core method middle	Core method top	Core method bottom	NDM method	Core method middle	Core method top	Core method bottom	NDM method
Min	2.280	2.420	2.410	2.410	2.310	2.400	2.430	2.380	2.370
Max	2.540	2.500	2.540	2.510	2.510	2.490	2.490	2.590	2.520
Average	2.400	2.460	2.460	2.470	2.430	2.440	2.460	2.470	2.440
No. Samples	1038	57	57	55	764	72	22	22	364
Standard Deviation	0.040	0.016	0.022	0.022	0.029	0.018	0.015	0.038	0.023

Table 1: Density measurements

During trials on the hangar pavement area, an innovative evaporation control and curing methodology was developed and adopted that well suited the slip form placement method of the geopolymer concrete. A new type of alkaline anti-evaporation spray was developed that reduced the evaporation rate while maintaining the alkalinity of the fresh geopolymer concrete surface that can be depleted through the application of traditional water based evaporation retarders. Curing consisted of applying a water based hydrocarbon resin curing compound, followed by covering with a geotextile to limit any thermal shock brought about by the difference of daytime and night time temperatures, Figure 3. Geopolymer concrete appeared more sensitive thermal shock from cooling as the concrete has a very low heat of reaction. Initially the thermal shock during particularly cold nights caused some cracking.

Figure 3: Curing and side forms with dowels.

The jointing design of the pavements was based on the guidelines developed for Portland cement based concrete. In the direction of paving, joints were saw cut at 5 metres centres with isolation joints provided every 70 metres. Early age saw cutting was carried out as soon as possible, generally 1 to 5 hours after placement depending on the ambient temperature. Dowels were located between paving lanes, Figure 3.

The geopolymer concrete's lower shrinkage properties compared with conventional concrete would indicate that joint spacing could be increased compared with conventional concrete.

However, this option was not pursued in order to maintain a low risk for this application of an innovative material. The supplier's test data on this geopolymer concrete indicated an average 21 day drying shrinkage of approximately 150 microstrain, tested to AS 1012.13 [8]. A significant benefit and cost saving on future work would be to increase the joint spacing based on the higher flexural strength and lower shrinkage properties of this geopolymer concrete.

5 APPLICATION OF GEOPOLYMER CONCRETE

The BWWA pavements project is believed to be the largest commercial application of modern geopolymer concrete in the world. Some 25,000 m3 of aircraft pavement grade concrete was supplied and constructed over a 3.5 month period.

In addition to the pavements, a further 15,000 m3 of geopolymer concrete was used throughout the BWWA project in a variety of applications including:

- Entry bridge to the airport, (Figure 4).
- Extruded kerb and road barriers, (Figure 4).
- Precast culverts.
- Site cast tilt panels for the terminal building.
- Footings, piles, pads and the tunnel slab for the terminal building.
- Footings, pads and site cast tilt panels for establishment of quarrying and concrete plants.
- Pavements for median strips and associated road works (some coloured).
- Sewer tanks.

Figure 4. Other geopolymer concrete works at BWWA.

The entry bridge incorporated vibrating wire strain gauges in the geopolymer concrete to monitor performance over time. The behaviour due to diurnal temperature fluctuations is shown in Figure 5. UNSW will be monitoring the bridge as part of a Low Carbon Living Cooperative Research Centre project which will provide data on structural behaviour of the geopolymer.

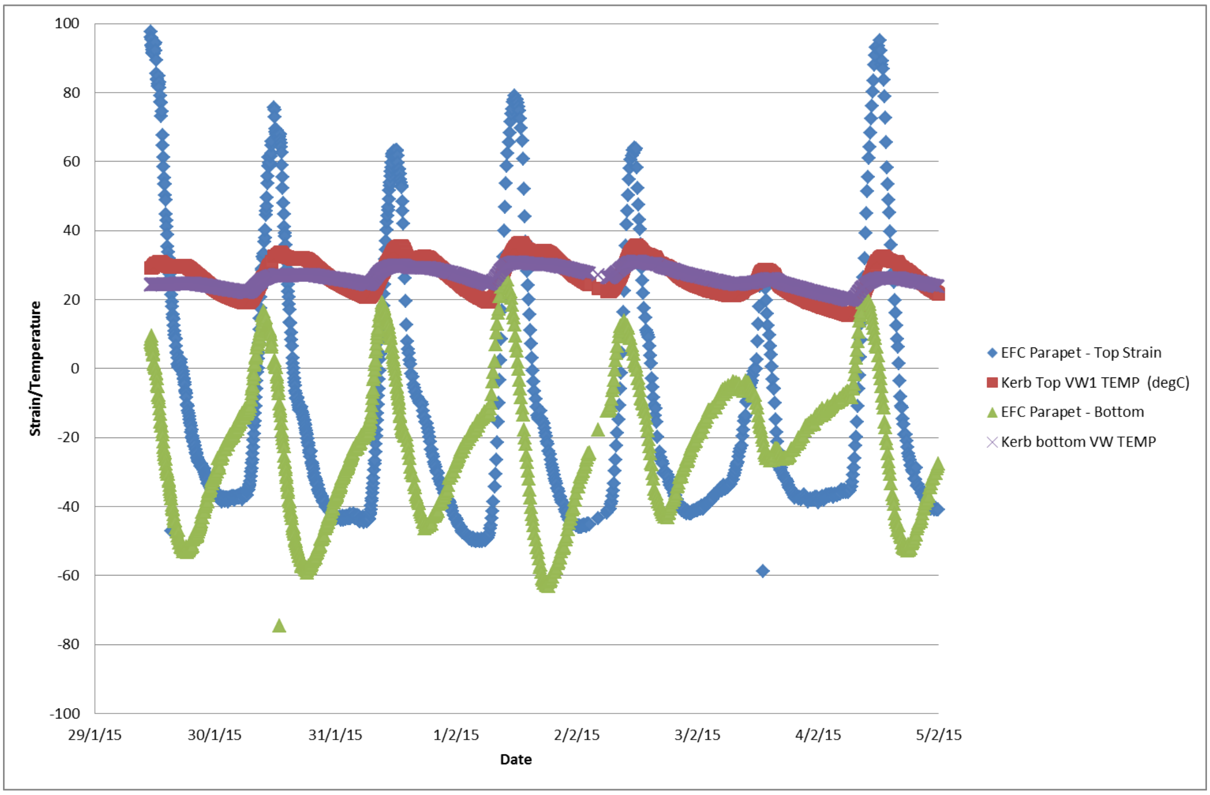


Figure 5. Monitoring of temperature and strain in the geopolymer concrete bridge at BWWA.

6 DISCUSSION

While alkali activated concrete has a history dating back to the 1930's in Eastern Europe [2], geopolymer concrete is still considered a relatively new technology. The successful and rapid construction of the BWWA project serves as an excellent demonstration that geopolymer concrete is a viable alternative to Portland cement based concrete. Contractors, developers, specifiers and approval authorities can be confident that geopolymer concrete can be designed, produced and constructed at a commercial scale within the same quality control parameters as Portland cement concrete. There are a number of challenges to the more widespread use of geopolymer concrete in projects:

- No international standard for either manufacture or design
- Cost disadvantages due to lack of economies of scale
- Availability from suppliers
- Lack of older geopolymer structures locally to confirm long-term durability.

Some adjustments to construction procedures enabled this proprietary geopolymer concrete to overcome these barriers as evidenced by the successful delivery of BWWA as well as a range of previous geopolymer concrete works project. This substantial body of work which includes results from independent durability studies by RMIT is reported by Glasby et al. [12]. A significant previous project is the Global Change Institute (GCI) building in Brisbane on the University of Queensland campus that is reported by Bligh and Glasby (10). It is claimed to be a world first application of modern geopolymer concrete suspended floor beams in a multi-storey building (ref).

It remains the case however that until significantly more progress is made on removing the barriers, new geopolymer concrete projects at the commercial scale will remain the domain of highly motivated parties that are willing to accept a nominal price premium and 3rd party engineering certification of suppliers' data. A Handbook on geopolymer concrete being developed as part of the Low Carbon Living Cooperative Research Centre is a positive step that may lead to an Australian standard.

A key driver for the use of geopolymer concrete in Australia and elsewhere has been the environmental benefits of a concrete that utilises a large component of recycled material (slag and / or flyash) which completely replaces Portland cement which has a high embodied energy and carbon footprint. By using a figure of 80% reduction in CO_2 emission from the binder content in this geopolymer concrete compared to a conventional 75% GP / 25% fly ash blended cement in an equivalent normal concrete, some 13000 tonnes of CO2 emissions were saved in this project alone.

Another reason geopolymer concrete is the performance and durability improvements that are possible due to the different chemistry of the binder. In the BWWA pavement project the good flexural tensile strength coupled with low shrinkage of the geopolymer concrete used made it a good option. In other projects, particular durability properties may provide advantages to applications such as sewer systems, marine structures and underground works through sulfate soils / ground waters.

One concern is that the term ‘geopolymer’ can apply to a wide range of alumino-silicate activated materials and their performance can vary widely depending on a range of factors. The properties will be influenced by the source of alumino-silicate powder as well as the type, reactivity, quality, etc., the alkaline activators used and the dosage, the curing regime and the water/binder ratio. Until appropriate screening tests are developed to discriminate between effective and ineffective products, it would be recommended that products with a proven track record should be used.

Quality control during production and placement are important in producing high quality geopolymer concrete, even more so than is the case for conventional concrete. Purpose made water reducing admixtures were a vital component in this proprietary geoplymer concrete having the necessary workability and slump retention at low water contents.

7 CONCLUSIONS

The rapid and successful construction of the BWWA using some 40,000 m3 of geopolymer concrete is the largest application of this new class of concrete in the world. This paper has reported on the heavy duty geopolymer concrete pavements that comprise the turning node, apron and taxiways. Production was undertaken using commercial scale concrete batch plants that delivered a continuous supply to a slip form paving machine and returned an excellent production rate. The proprietary geopolymer concrete proved an suitable material for the construction method due to its high flexural tensile strength, low shrinkage and workability characteristics.

A comprehensive trial program leading up to the works ensured a suitable mix was developed that could be placed with a slip form paving machine. A new alkali anti-evaporation spray was developed that protected the geopolymer concrete surface from drying out prior to curing.

This successful application of geopolymer concrete at the full commercial scale should support future uptake of a truly novel and environmentally responsible technology.

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