EFC Geopolymer Concrete Aircraft Pavements at Brisbane West Wellcamp Airport

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Abstract: Brisbane West Wellcamp Airport (BWWA) became fully operational with commercial flights operated by Qantas Link in November 2014. BWWA was built with approximately 40,000 m^3 of geopolymer concrete making it the largest application of this new class of concrete in the world. Heavy duty geopolymer concrete was used for the turning node, apron and taxiway pavements using a slip form paving machine. The proprietary geopolymer concrete, known as Earth Friendly Concrete (EFC), was found to be well suited for this construction method due to its high flexural tensile strength, low shrinkage and workability characteristics.

This paper describes the geopolymer concrete pavements delivery from both a materials and construction viewpoint and notes differences to conventional concrete where they occurred. The authors conclude by reviewing earlier projects with this particular geopolymer concrete and discussing how this body of work could help to increase the use of geopolymer concrete in Australia and globally.

Keywords: geopolymer concrete, BWWA, pavement, flexural tensile strength

1. Introduction

Brisbane West Wellcamp Airport (BWWA) is Australia's first greenfield public airport to be built in 48 years. BWWA became fully operational with commercial flights operated by Qantas Link in November 2014. This project marks a very significant milestone in engineering - the world's largest geopolymer concrete project.

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 at the Northern end of the runway, the taxiway on the Western side of the runway and the hangars on the Eastern side of the runway.

In preparation for the project both product testing and 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 and novel solutions.

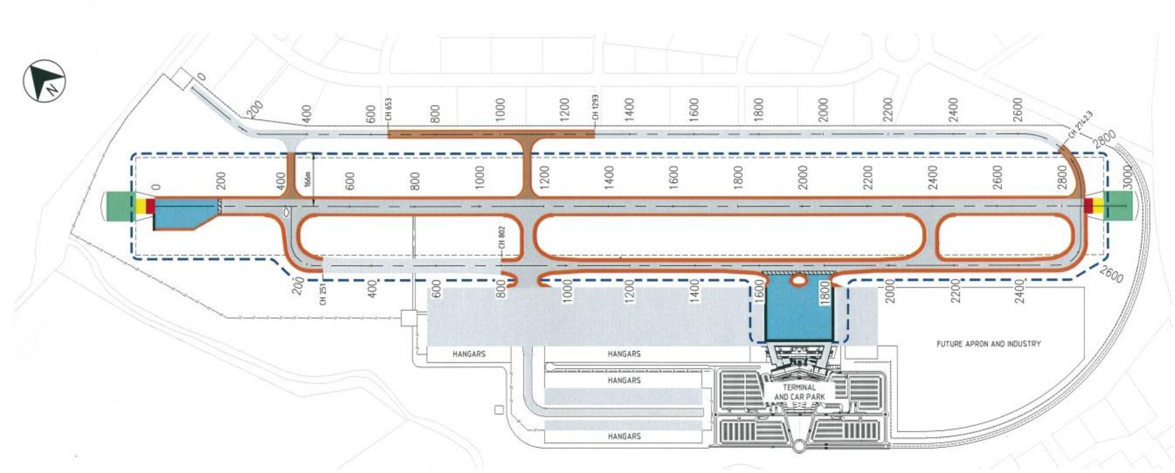
2. Project Outline

Figure 1 shows an overall plan and an aerial photograph of the completed pavement works at the BWWA site. 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. While not shown on the site plan, the private hangar pavement is located outside the boundary of the airport on the Eastern side of the runway which can be seen in the aerial photograph.

The private hangar pavement was constructed in the period May – July 2014 and served as a construction trial area to prove 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 that were placed by the paving contractor using a Gomaco slip form road paver.

In the 6 month period prior to pavement construction, Wagners had developed a geopolymer concrete design mix deemed suitable from laboratory trials and small scale pavement works around the BWWA site. The concrete materials specification written by independently commissioned ACG consulting engineers required:

- 4.8 MPa average flexural strength at 28 days of age, AS 1012.11 (1)
- 450 micro-strain maximum drying shrinkage at 28 days of age, AS 1012.13 (2)

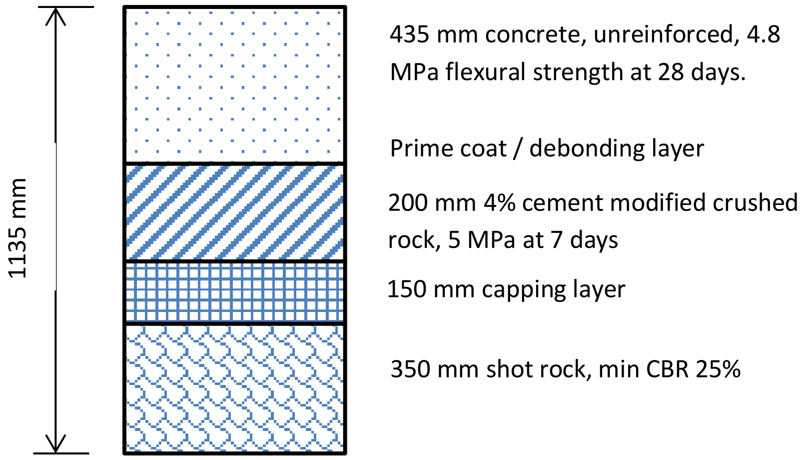


(pavement plan - excerpt from ACG Engineers drawings)

Figure 1. Site plan and aerial photograph – BWWA.

Following a successful trial phase, the geopolymer concrete mix and pavement construction method was approved by the engineers. 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 pavement design was undertaken by ACG Engineers and is shown in Figure 2.



(pavement design by ACG Engineers)

Figure 2. High Strength Concrete Pavement Design Cross Section.

3. Geopolymer Concrete Mix

The proprietary geopolymer concrete mix used in this project follows approximately 10 years of work by Wagners developing a commercial product that is produced and handled in a similar manner to conventional concrete. The project 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, slump and slump retention suitable for transport in tippers and slip form pavement construction.
- Achieve specified flexural strength of 4.8 MPa

The summary mix parameters were:

- Total alumino-silicate binder comprising GGBS + Fly ash, 415 kg/m^3
- Water:binder ratio 0.41
- Nominal 40 mm maximum aggregate size, conforming with 28 mm to AS 2758.1 (3)
- Chemical activator, 37 kg/m^3 solids content
- Proprietary water reducing admixture

Flexural strength testing was conducted by the project site NATA laboratory in accordance with Australian Standards AS 1012.11 at a frequency of 4 different loads taken evenly across the production of one work shift, as per the engineer's specification. The results achieved from making fresh concrete beam specimens across the turning node and apron pavements are shown in Table 1.

Table 1. Flexural tensile strength results (28 days).

No. of Samples	502
Average flexural strength (MPa)	5.8
Standard Deviation	0.6

4. Geopolymer Concrete Production and Supply

The geopolymer concrete was produced in a twin mobile wet mix batch plant established on the BWWA project site as shown in Figure 3. The standard concrete production plants shown have been modified to accommodate the chemical activators which are added to the mix as a solution. An assembly of tanks and pumps are incorporated into the plant that mix, hold and accurately dispense the activators into wet mix bowl using an automated batch system.

A maximum supply capacity of 120 m^3/hr was required to provide a continuous feed of concrete to the slip form paving machine which is shown in Figure 4. This requirement was successfully achieved using the plant configuration and several tipper trucks for delivery. An advantage of wet mix production is that concrete agitator trucks are not required for short transit times. The use of tippers allowed a significantly improved discharge rate at the paver face.

Figure 3. Geopolymer concrete twin batch plant.

Figure 4. Geopolymer concrete delivery to slip form paver.

5. Geopolymer Concrete Pavement Construction

Aircraft pavement construction in Australia is normally undertaken by placing and compacting the concrete into and against steel side forms using a combination of internal mechanical vibration and vibrating beams. This method for the placement of deep lift heavy duty pavements has evolved from construction experience with Portland cement based concrete. The use of slip form paver machines as used in thinner concrete road bases have generally not been used in airport pavement construction due to concerns regarding incomplete compaction for thicker pavement bases.

Using geopolymer concrete in a series of successful trials at the hangar area demonstrated that a very high level of compaction 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 using a vibrating beam. It is estimated that a 30% reduction in the pavement construction program was achieved on this project compared with the traditional process.

The characteristic rheology and internal cohesion of the proprietary geopolymer mix at the specified slump allowed it to extrude considerably better than conventional concrete. This allowed for very efficient placement resulting in the noted speed gains. 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. Winter to Summer (2°C minimum - 40°C Maximum, 5 minutes - 20 minutes transit time).

The proficiency of compaction using the slip form paving machine was validated by comparing in situ density test results with fresh concrete density results, (Table 2). In situ density was undertaken by using both the Nuclear density method (NDM) to AS 1289.5.8.1 (4) and in situ core density testing to AS 1012.14 (5) and AS 1012.12 (6). A density core specimen is shown in Figure 5.

Table 2. Density measurements.

	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
Max	2.540	2.500	2.540	2.510	2.511	2.490	2.490	2.590	2.520
Average	2.400	2.460	2.460	2.470	2.427	2.440	2.460	2.470	2.440
Min	2.280	2.420	2.410	2.410	2.312	2.400	2.430	2.380	2.370
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

In situ density test specimen by coring method. Samples were cut into 3 sections – top, middle and bottom to detect compaction proficiency with depth of pavement, Table 2.

Figure 5. Test core specimen.

The geopolymer concrete required particular attention to curing and pre-curing evaporation control when placing exposed slab surfaces. It displayed very low bleed characteristics and the surface would rapidly dry out without intervening to maintain a moist sheen on the surface. From the supplier's previous development work it was well understood that drying of this geopolymer concrete surface prior to initial set and the application of curing would render the extreme surface prone to wearing with time.

During trials on the hangar pavement area, a novel evaporation control and curing methodology was developed and adopted for the geopolymer concrete that well suited the slip form placement method. 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 products. Curing consisted of applying a water based hydro carbon 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 6.

Figure 6. Curing and side forms with dowels.

Jointing design of the pavements followed conventional rules based on Portland cement 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 temperatures as shown in Figure 7. Dowels were located between paving lanes as shown in Figure 6.

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 56 day drying shrinkage of 350 microstrain, tested to AS 1012.13 (2). 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.

Fine crack in saw cut joint saw suspended on bridge to allow earlier joint formation

Figure 7. Early age saw cutting.

Figure 8. Operational BWWA.

6. Commercialisation of Geopolymer Concrete

The pavements project at BWWA outlined in this paper is believed to be the largest commercial application of modern geopolymer concrete (defined by the authors as post-1970) in the world. Some 25,000 m^3 of aircraft pavement grade concrete was supplied and constructed over a 3.5 month period.

In addition to the pavements, a further 15,000 m^3 of geopolymer concrete was used throughout the BWWA project in a variety of applications including:

- Entry bridge to the airport, (Figure 9).
- Extruded kerb and road barriers, (Figure 9).
- 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 9. Other Geopolymer Concrete Works at BWWA.

While alkali activated slag concrete has a history dating back to the 1930's in Eastern Europe (7), geopolymer concrete is still deemed a relatively new technology in modern concrete construction. 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 within accepted quality control parameters at the commercial scale. However there exist a number of challenges to parties wishing to include geopolymer concrete in projects:

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

The developers of the geopolymer concrete discussed here have made progress in overcoming these barriers as evidenced by the successful delivery of BWWA as well as a wide range of previous geopolymer concrete works, both commercial and internal projects with an R&D focus. This substantial body of work which includes results from independent durability studies by RMIT is reported by Glasby et al (8). A very 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 (9). It is claimed to be a world first application of modern geopolymer concrete suspended floor beams in a multi-storey building.

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 price premium and 3rd party engineering certification of suppliers' data. One very positive step that the author is aware of is the writing of a Handbook on geopolymer concrete under a CRC grant 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 carbon intensive Portland cement (10). By using a figure of 80% reduced CO_2 emission compared to Portland cement, the binder content in this geopolymer concrete compared to a conventional 75% GP / 25% fly ash blended cement in an equivalent normal concrete, saved some 8,640 tonnes of CO_2 emissions in this project alone.

Another strong driver for geopolymer concrete is the performance and durability improvements that are possible due to the different chemistry of the binder. In this project the high flexural tensile strength coupled with low shrinkage of the particular proprietary geopolymer concrete used made it an ideal pavement concrete. In other projects, particular durability properties of acid, sulfate and chloride ingress resistance will offer high value to applications including sewer systems, marine structures and underground works through sulfate soils / ground waters. A cautionary note should be heeded that the term 'geopolymer' can apply to a wide range of alumino-silicate activated materials and their performance will vary depending on a range of factors, including:

- Source of alumino-silicate powder – type, reactivity, quality, etc.
- Alkaline activator chemicals
- Curing regime – ambient vs elevated temperature
- Total water and water:binder ratio for geopolymer concrete

Quality control during production and placement are extremely 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. Conclusion

The successful privately funded BWWA, Australia's first greenfield public airport in 48 years, is built on some 40,000 m^3 of geopolymer concrete making it 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 ideal 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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