The Use of a Proprietary Geopolymer Concrete in Sewer Infrastructure Applications

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Abstract: The design, construction and maintenance of sewer infrastructure is a major undertaking for all industrialised countries. The major challenge is to provide a concrete material that has the necessary resistance to the immensely corrosive effects of sewage effluent. Wastewater facilities and pipe lines have aggressive environments characterised by:

* Effluent with low pH in liquid and gas phases.
* Aerobic and anaerobic conditions with oxidising & reducing environments.
* Sulphates & chlorides which may enter through industrial wastewater or external ground water.

Recent trends in new trunk line sewers of large diameter have seen Tunnel Boring Machine (TBM) construction with precast concrete lining segments. Two projects with this method in the Pacific Rim include Singapore Deep Tunnel Sewerage System (DTSS) Phase 2 and Central Interceptor, Auckland. While the two projects differ in their overall design approach to providing a 100 year design life for the pipeline, both projects have incorporated a performance based testing procedure for acid resistant concrete (ARC). A proprietary geopolymer concrete, EFC®, developed by Wagners has been included along with other ARC mixes in the test program for the Central Interceptor project. This paper will present and discuss the results of this testing and the potential application extension to sewer infrastructure in Australia and internationally.

Keywords: ARC, EFC®, geopolymer, MIC, sewer

1.0 Introduction

The design, construction and maintenance of sewer infrastructure is a major undertaking for all industrialised countries whether it be replacing existing systems at the end of their serviceable life or new sewer pipe lines and associated works. Globally, the losses due to sewer pipe corrosion is estimated to be in the order of billions of dollars per year (1).

Reinforced concrete has been the material of choice for these structures on the criteria of availability, economy and constructability. The major engineering design challenge is to provide a concrete material that has the necessary resistance to the immensely corrosive effects of sewage effluent or otherwise protect the concrete with acid resistant coatings. Corrosion in sewers involves a combination of physical, chemical and biological processes, and is commonly termed microbially induced corrosion (MIC). The aggressive environment created in sewers is due to:

* Effluent with low pH in liquid and gas phases.
* Humidity and temperature effects.
* Aerobic and anaerobic conditions with oxidising & reducing environments.
* Sulfates & chlorides which may enter through industrial wastewater or external ground water. (2)

Recent trends in new trunk line sewers of large diameter have seen Tunnel Boring Machine (TBM) construction with precast concrete lining segments. Two projects with this method in the Pacific Rim include Singapore Deep Tunnel Sewerage System (DTSS) Phase 2 and The Central Interceptor, Auckland. While the two projects differ in their overall design approach to providing a 100 year design life for the pipeline and shafts, both projects have incorporated a performance based testing procedure for acid resistant concrete (ARC). A proprietary geopolymer concrete, EFC®, developed by Wagners has been included along with other ARC concrete mixes in the test program for both of these projects.

The Central Interceptor project's MIC testing has been completed and the results show this geopolymer to have extremely high resistance, outperforming the other four technologies included in the test program. MIC testing was carried out by the Advanced Water Management Centre at University of Queensland (UQ) which revealed EFC® geopolymer concrete as having a very high level of resistance after 12 months exposure to sewer and acid corrosion. The results of this work indicate geopolymer concrete as an ideal choice where acid sewer resistance is a key performance requirement. This has obvious applicability to pipes, tunnels and other elements involved in sewer networks.

2.0 MIC tests on five concrete mixes

Watercare Services Limited, New Zealand commissioned specialist MIC exposure testing on five different concrete mixes to investigate their potential corrosion resistance for a new sewer pipe line project in Auckland named The Central Interceptor. This is a 13 km long, 4.5 m diameter TBM bored underground tunnel that runs between 15 and 110 metres below the surface. It will have 16 permanent shafts for operational use and future access.

While the durability design of the precast concrete tunnel segments incorporates a lining for protection against MIC corrosion, the shafts rely on acid resistant concrete (ARC) with enough sacrificial thickness to meet the 100 year design life. In order to determine a suitable concrete mix(s) for the ARC specification MIC testing was carried out at the Advanced Water Management Centre using laboratory scale corrosion chambers simulating sewer conditions. The MIC test method is outlined by Jiang (4).

2.1 Concrete mix details

The test specimens for all five concrete mixes were cast by Opus laboratory in Wellington, New Zealand prior to being cured and sent to the Advanced Water Management Centre in Brisbane, Australia for the specialist MIC testing.

Table 1 below shows the mix design parameters along with slump, 28 day compressive strength and chloride resistance test results that were also carried out by Opus laboratory.

The B2 concrete mix is a reference concrete with 100% Portland cement as the binder for comparison purposes. The other four mixes were chosen by Watercare as those with acid resistant properties following a formal RFI process to invite companies to propose binder technologies and supporting acid resistance data.

Table 1. Concrete mixes in MIC test program.

Material	Unit	Concrete binder description				
		GP cement (B2)	GP ; Flyash ; Silica Fume (ARC)	GP ; Flyash ; Silica Fume + Biocide (ARC-B)	Calcium Aluminate cement (K)	EFC® geopolymer (W)
Binder powder	kg/m^3	450	450	454	450	450
Course aggregate	kg/m^3	1025	1025	1035	1035	1045
Fine aggregate	kg/m^3	730	730	735	768	790
w/b ratio		0.36	0.36	0.35	0.42	0.39 *
Slump	mm	230	220	220	220	140
28d Compressive strength	MPa	87.5	78	77.5	74.5	53
Chloride ion migration coefficient	$10^{-12} m^2/s$	5.4	1.7	1.5	0.7	0.84
Chloride ion diffusion coefficient	$10^{-12} m^2/s$	4.6	1.4	1.2	1.6	0.48

* For geopolymer concrete the w/b ratio is calculated with b = combined binder mass of GGBFS + Fly ash + activator chemical solids

2.2 MIC test procedure

All the concrete specimens for MIC tests were pre-treated to temporarily reduce surface pH to acidic (2-4) to facilitate the growth of acidophilic microorganisms. The MIC specimens were then placed in two corrosion chambers – gaseous phase and partially submerged phase. For the first 3 months, the MIC specimens were inoculated (spraying sewage to concrete surface) with real wastewater weekly to induce active microbial corrosion.

The corrosion chambers were constructed to achieve a controlled environment simulating that of real sewers, i.e. the gas-phase temperatures at 25 °C, relative humidity of 100% and H_2S gas concentration of 50 ppm.

The corrosion development and activity was monitored using five different measures - surface pH, sulfide uptake rate (SUR), photogrammetry, weight change and sulfur compounds. The monitoring period lasted for a full 12 months. A full description of the methodology and results is provided by Jiang and Hogan (5).

2.3 MIC test results

The test results of sulfide uptake rate (SUR), photogrammetry and weight change are the most relevant to corrosion loss rate and are presented in this section.

2.3.1 Sulphide uptake rate (SUR)

It is generally accepted that the concrete corrosion rate has a positive correlation with the uptake of H_2S onto the concrete surface therefore the lower the SUR the lower the corrosion rate. SUR measurements on the five types of concrete were conducted at 2, 4, 5, 8, 10 and 12 months after being exposed to the H_2S containing corrosion chambers. Test results are graphically displayed in figure 1. The proprietary geopolymer has the lowest and hence the best performance on this measure.

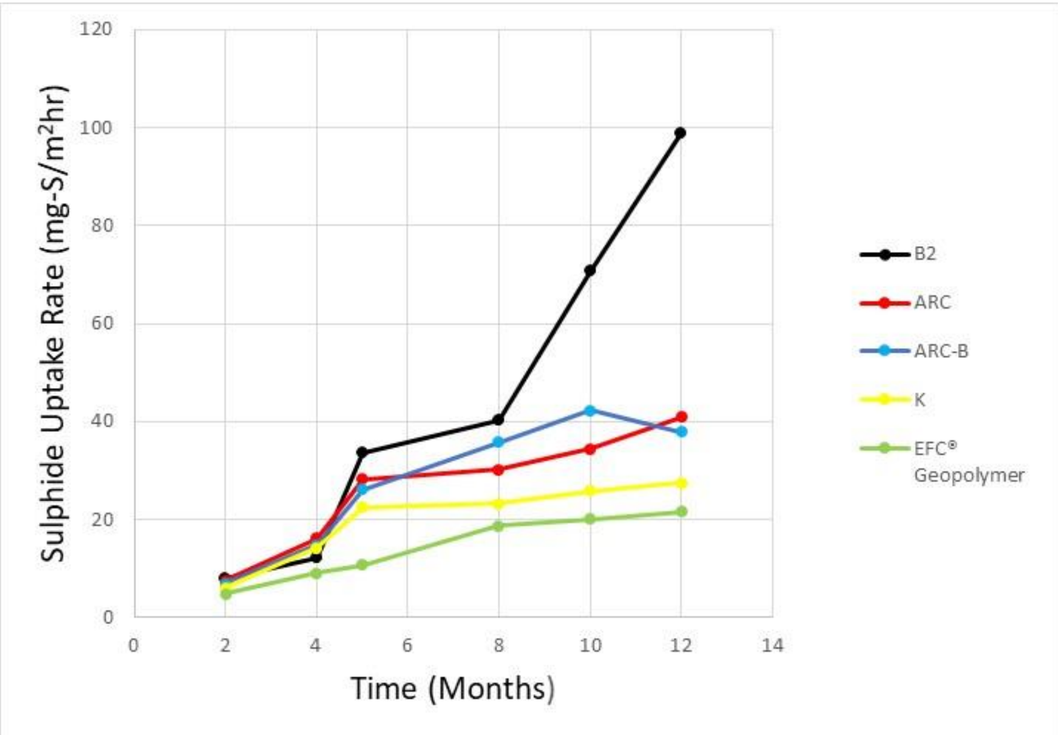

Figure 1. Sulphide Uptake Rate

2.3.2 Corrosion rate by photogrammetry

Photogrammetry was used to get an accurate measure of the average loss of concrete surface due to corrosion. Five photos for each MIC test specimen were taken to measure the thickness after washing and then a 3D image of the exposed surface was generated. The decrease in thickness at the different exposure time was then calculated.

Photogrammetry measurements on the five types of concrete were conducted at 5 and 12 months after being exposed to the H_2S containing corrosion chambers. The averaged test results are graphically displayed in figure 2. The proprietary geopolymer has the lowest corrosion rate and hence the best performance on this measure. Corrosion rate is a key parameter used in deterioration modelling to size the concrete element for the desired design life.

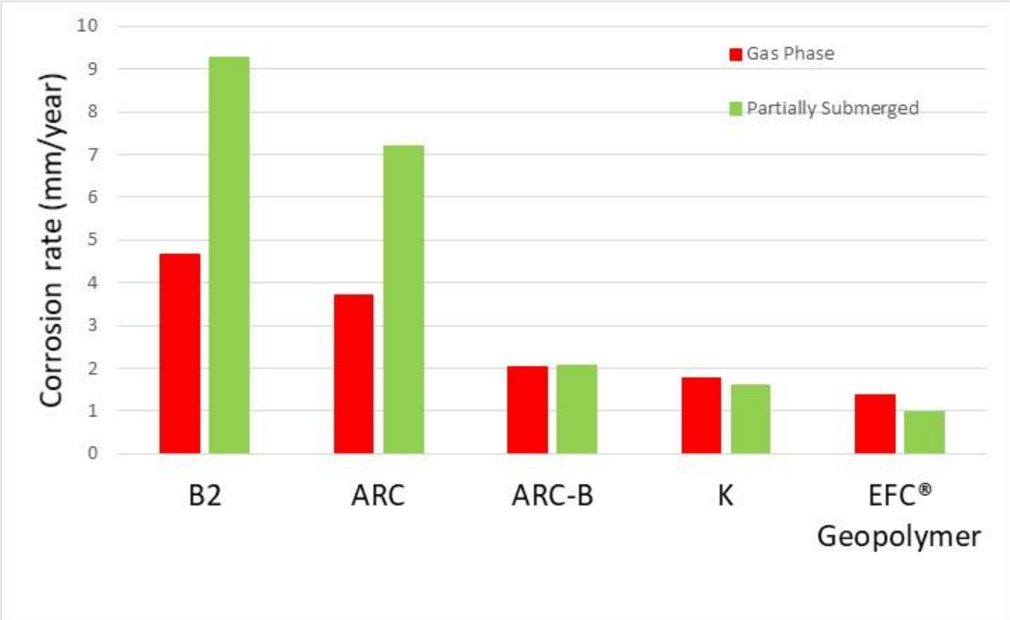

Figure 2. Corrosion rate by photogrammetry

2.3.3 Weight loss

The weight of each concrete specimen was measured at the start, 5 months and 12 months. The change of weight recorded at 5 and 12 months is thus the mass loss due to corrosion from exposure to the H_2S containing corrosion chambers. The results are graphically displayed in figure 3. The proprietary geopolymer has the lowest weight loss and hence the best performance on this measure.

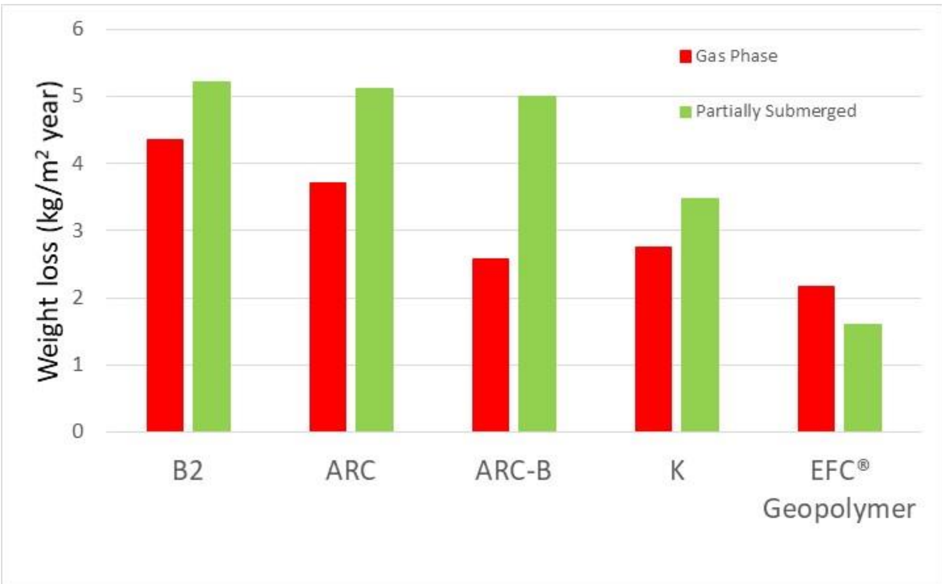

Figure 3. Weight loss

2.4 MIC test summary

Overall, EFC® geopolymer concrete showed the best corrosion performance in the MIC test measures. It had the lowest corrosion rate being 1.36 mm/year for the gas phase chamber and 0.98 mm/year for the partially submerged chamber.

Theses corrosion rates measured by photogrammetry are consistent to the other corrosion measures undertaken in the study which all produced the same rankings of B2 being the worst performer, then ARC, then ARC-B, then K and the proprietary geopolymer the best performer.

3.0 Implications for geopolymer concrete and sewer applications

Under an extremely robust and completely independent MIC study conducted over 12 months a commercially available geopolymer concrete has been shown to have the highest level of biogenic acid corrosion resistance when compared to the best available conventional binder concrete technologies. This geopolymer concrete has a binder comprised of ground granulated blast furnace slag (GGBFS) and low calcium flyash that is reacted by a proprietary alkaline solution. Its development and commercial project history has been outlined by Glasby (6). Importantly this is a commercial ready concrete that is produced in standard production facilities and can be supplied under the typical conditions of the premixed (in situ) concrete supply industry. It is not 'labcrete'! (7). It is also well suited to precast manufacture which is relevant to sewer pipes.

The results of this study conform with previous researchers' findings (8,9) that show certain forms of geopolymer concrete display a resistance to acid which is an order of magnitude better than ARC based on conventional binders.

The results from the Advanced Water Management Centre in association with previous research make a clear case for incorporating geopolymer concrete into sewer infrastructure projects to improve the performance of concrete elements in these applications. Corrosion due to biogenic acid development in sewer environments is a major problem globally and performance improvements would save billions of dollars annually (1).

A further advantage of sulfate resistance for the case of sulfate rich groundwater would also be available if the geopolymer concrete was the main structural element in the case of precast TBM linings, precast sewer pipes, manholes and wastewater treatment plant structures. Geopolymer concrete has very high resistance to chemical attack for both acids and sulfates (6).

4.0 Validation by performance testing

Watercare New Zealand have undertaken a rigorous performance testing regime in order to investigate the MIC resistance of different ARC technologies prior to building a major piece of new sewer infrastructure. The MIC test method chosen has been developed over many years by a number of collaborators and with the involvement of many water authorities that operate sewer networks in Australia (4). The methodology has therefore been validated with real long term data and provides a comprehensive analysis on biogenic corrosion rate across several data measures.

Apart from the Auckland Interceptor project which is the focus of this paper the author is aware of another major sewer project that is also undertaking performance testing to assist in the decision of appropriate ARC. Singapore's DTSS Phase 2 is a massive project that includes 50 km of TBM constructed tunnel with a diameter varying between 3 and 6 m. The internal MIC protection to the precast concrete tunnel lining segments is twofold – an outer HDPE acid resistant liner in addition to an inside MIC resistant concrete layer. The principal for DTSS is the Singapore Public Utilities Board (PUB) who are following a similar performance testing approach to quantify the corrosion rate of different ARC technologies offered by tenderers for the MIC layer. This project is also testing the MIC resistance at the Advanced Water management Centre in UQ, Brisbane using their MIC methodology and biogenic corrosion chamber test facility.

The public developers and operators of these two high investment sewer infrastructure projects have set an instructive example by opting for the most realistic performance testing to direct the selection of MIC corrosion resistant concrete technologies.

5.0 Conclusion

MIC testing of five different concrete mixes for the Auckland Interceptor project commissioned by Watercare, New Zealand has shown a proprietary geopolymer concrete as having the highest level of resistance after 12 months exposure to biogenic sewer acid corrosion. This concrete was an order of magnitude better than conventional ARC concrete mixes and also distinctly ahead of the next best performing concrete which had a calcium aluminate cement binder.

Geopolymer concrete has long been researched and discussed at academic level as a high potential sewer resistant technology but has not had a high adoption rate into commercial projects due to a range of factors including availability, standards and cost. The application of geopolymer into the sewer construction area would seem to be an ideal fit for this technology due to its naturally high level of resistance to MIC corrosion and the billions of dollars currently being spent globally to maintain existing sewer works for this degradation area.

The technical leadership shown by two different public sewer authorities in carrying out comprehensive performance testing for MIC is an instructive example for verifying the fit for purpose nature of innovative concrete technologies that may not fit into existing codes of practise.

6.0 Acknowledgement

The authors thank the following organisations and associated people for their diligent and professional work as well as their helpful engagement throughout the MIC performance testing program and reporting - Watercare New Zealand, Mr Stephen Grace ; Advanced Water Management Centre, Dr Guangming Jiang ; Concrete Future, Dr James Aldred.

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