THE USE OF ALTERNATIVE CEMENTS TO PROTECT CONCRETE IN AN MICC ENVIRONMENT

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Introduction

- An important limitation of Portland cement based concrete is deterioration when exposed to acidic conditions such as microbially induced corrosion of concrete (MICC). MICC causes significant deterioration of concrete exposed to wastewater and other structures.
- MICC is caused by complex chemical and microbiological processes as a result of putrefaction of organic matter. While MICC is best known in sewage applications, it also occurs in municipal waste facilities as well as oil and gas and estuarine environments.
- This presentation looks at the performance of concrete made with alternative binders exposed to different test procedures and accelerated exposure to assess resistance to MICC.
- Binders to improve resistance to MICC (with an appropriate sacrificial layer) may provide a viable alternative to expensive barrier treatments.

Neutrophilic

Acidophilic – Thiobacillus thiooxidans

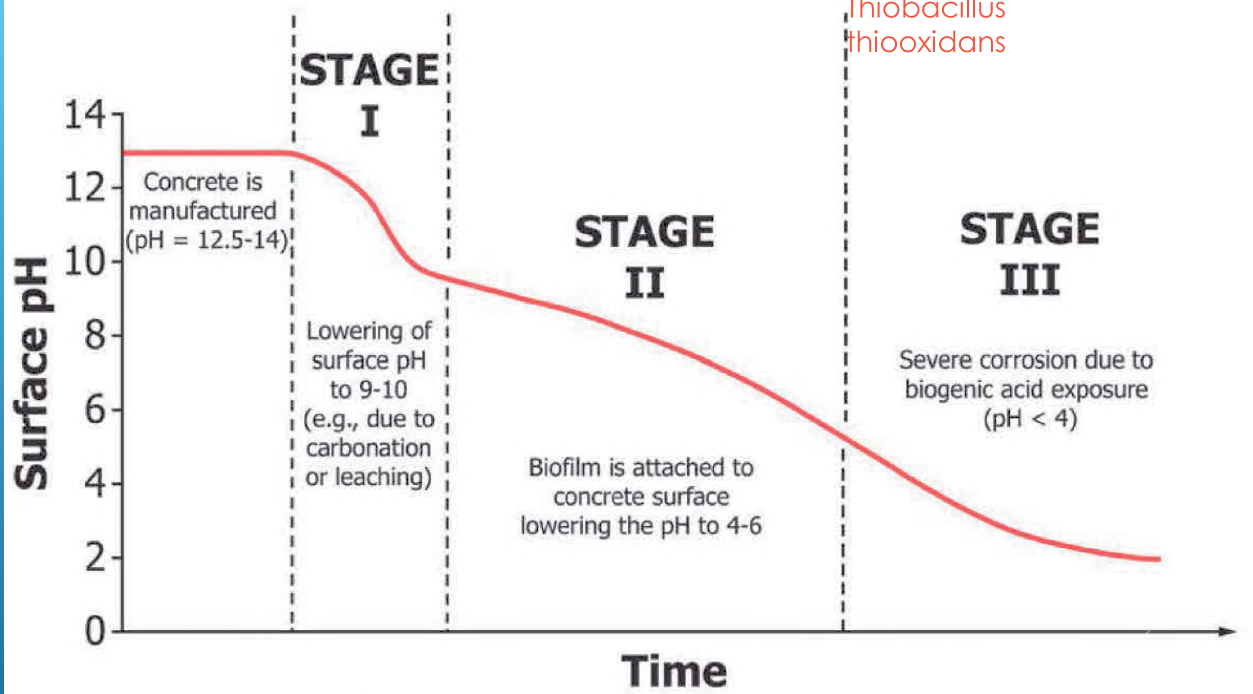
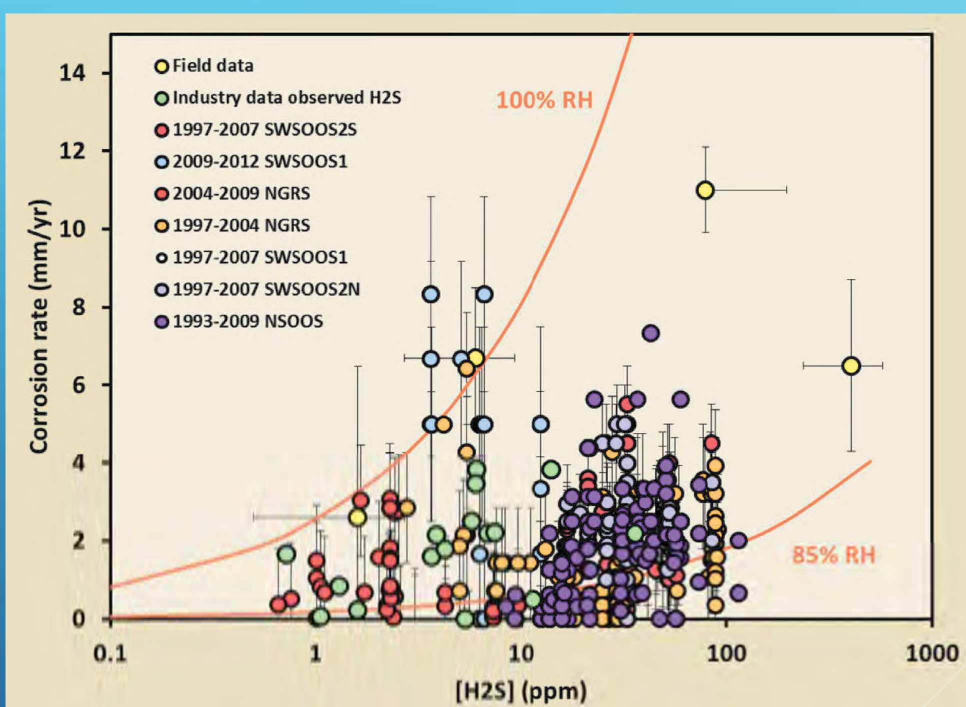
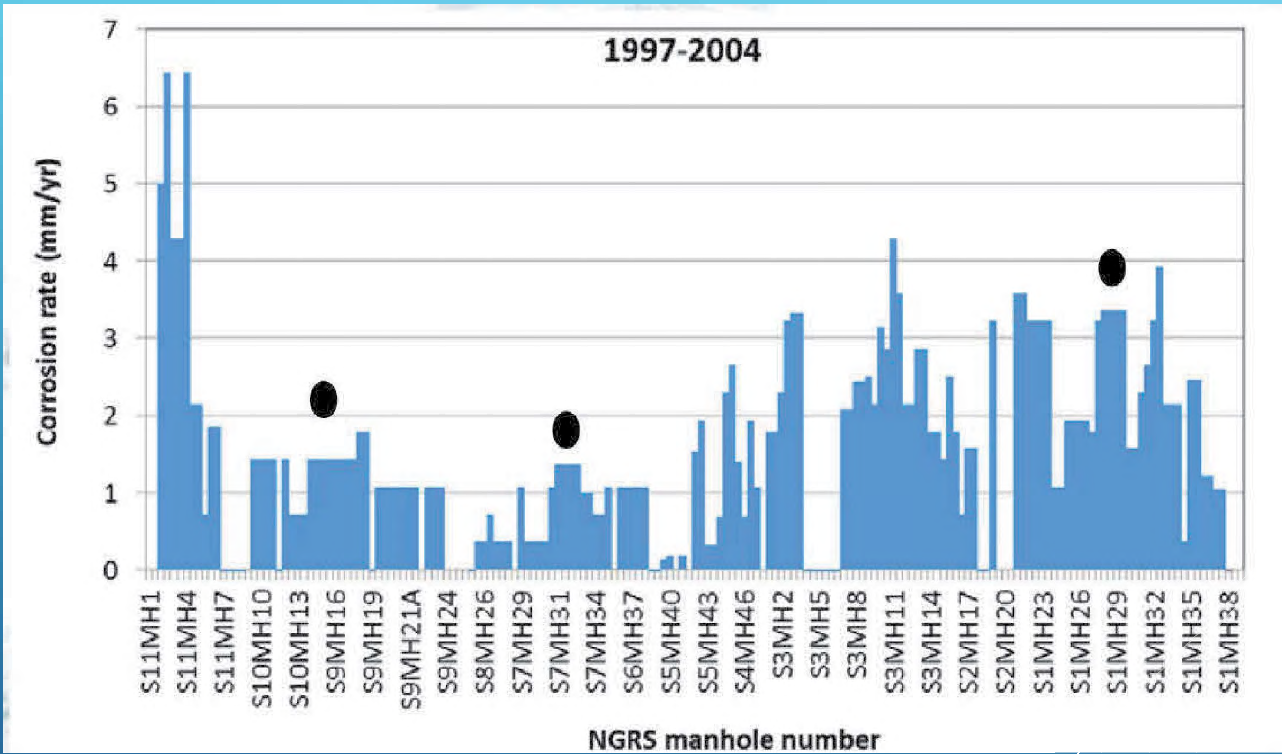


FIG. 1 Three-Stage Process of MIC of Concrete

Source ASTM C1894-19



SCORe 2 – Sewer Corrosion Field Studies (Wells and Melchers 2013)



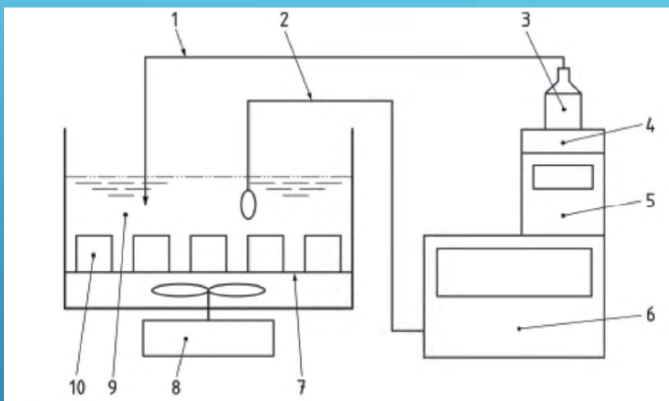
SCORe 2 – Sewer Corrosion Field Studies (Wells and Melchers 2013)

TABLE 2 Overview of the Test Methods Assessing MIC of Concrete

Test	Acidification	Stage	Limitations (L) and Benefits (B)
Accelerated chamber tests	Biogenic	I, II, III	L: Difficult to perform; long (months); expensive; requires large investment in testing infrastructure; involves risks and safety concerns due to presence of H_2S gas; although possible, not easy to use it as a Stage II test due to reduced ability to control the pH of the environment by adjusting the H_2S concentration. B: Realistic
Benchtop biogenic immersion tests	Biogenic	I, II, III	L: Less realistic than accelerated chamber tests in representing field conditions as it does not use H_2S gas; requires the cultivation of bacteria. B: fast (weeks); easier to perform and less expensive than accelerated chamber tests; biosafety Level I when appropriate bacterial strains are grown in the laboratory; can be used to simulate all stages of MIC; Stage II tests can be used to assess antimicrobial presence and performance in concrete.
Acid immersion test	Chemical	III	L: Not a biogenic test; does not reflect field conditions; cannot be used in Stage I or II of MIC; cannot be used to assess the presence and performance of antimicrobial products in concrete. B: Easy to perform; fast (weeks); can be used to assess various concrete mix modifications in Stage III, albeit with some exceptions (for example, CAC).
Tests for screening antimicrobial products	Biogenic	II, III	L: Not specifically developed for concrete.

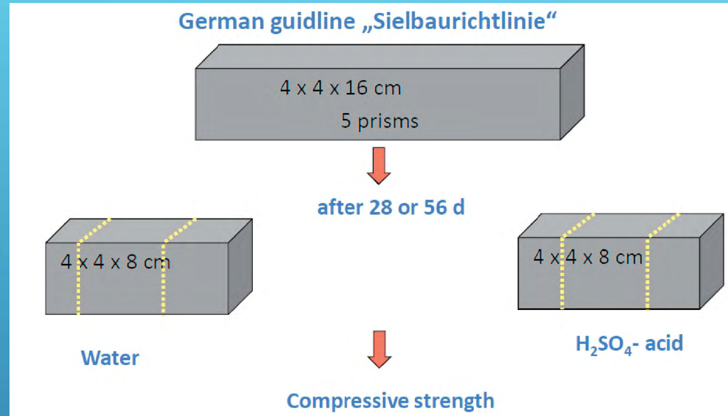
Source ASTM C1894-19

DIN 19573 - Test of the resistance to biogenic sulfuric acid attack



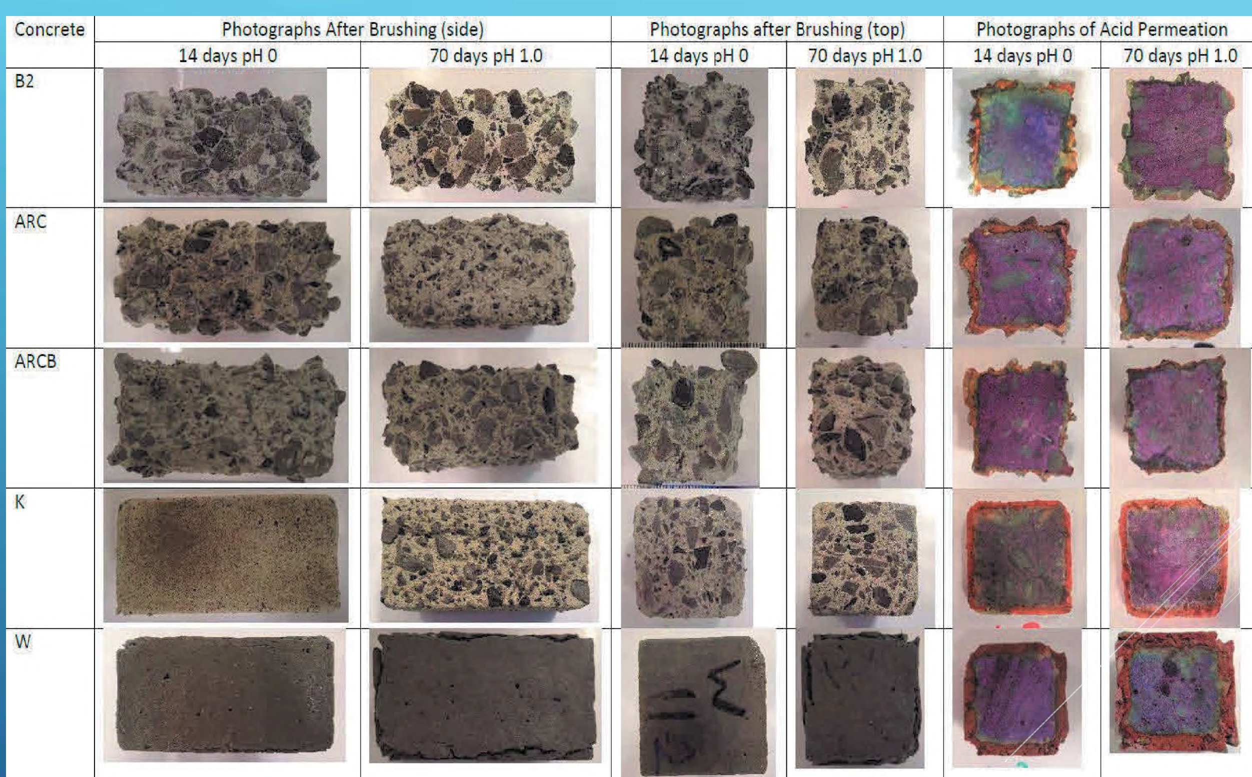
Legend

1. Titration tip
2. pH electrode
3. Reservoir
4. Cap
5. Burette
6. Titration Controller
7. Grid
8. Magnetic stirrer
9. Acid bath
10. Test specimen



Storage conditions	Class 1	Class 2
pH = 0 for 14 d	> 90 %	> 55 %
pH = 1 for 70 d	> 97 %	> 75 %

ASTM C267 - 01(2012) general chemical resistance test. ASTM C1898-20 is a revised acid chemical resistance test based on flexural strength



Source : Watercare Services Ltd – Chemical resistance analysis of ARC according to DIN 19573 – University of Sydney

Fig. 3 Kiwa GmbH, MPA Berlin-Brandenburg, impressions of the "ODOCO-Pilot-Plant"

A: View at the three gravity flow pipes
B: View at the insulated sample chamber
C: Data evaluation in the pilot plant
D: View at the pipes with the incoming sewage and the fermenters (not yet insulated)
E: Main pumps in the pumping station
F: Thermal insulated fermenter
G: Control cabinet with sensors

MPA Performance Test (Kiwa GmbH) is used to determine the comparative MICC resistance or to predict quantitative depth of damage for concrete.

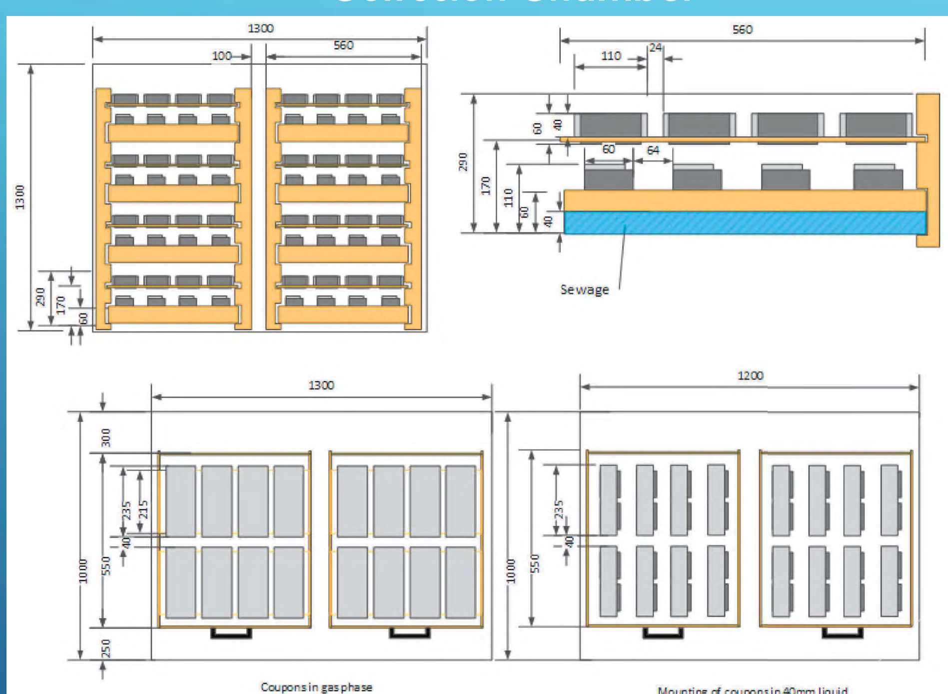
MPA Performance Test also includes;

- Gravimetric determination of mass loss.
- Microscopic determination of damage depth and deposits,
- Freeze-thaw with deicing test to determine the formation of microcracks,
- Determination of chloride migration, residual alkalinity, total porosity and sulfate resistance.

Measured variable	Limit values for concretes with highest resistances	Typical values for 'SRB 85/35'
Acid resistance MPA Berlin-Brandenburg method	max. 10 % greater damage depths than 'SRB 85/35'	Damage depth 1.1 mm bis 1.3 mm (12 weeks H_2SO_4, pH 3.5)
Sulphate resistance SVA method	Longitudinal strain of test specimen < 0.5 mm/m	Longitudinal strain of test specimen < 0.1 mm/m
Total porosity from gross and true density	< 11 % by vol.	9 - 10 % by vol.
Cumulative pore volume r < 0,1 mm, (Hg pressure porosimetry)	< 40 mm^3/g	20 to 30 mm^3/g
Average pore radius r < 0,1 mm, (Hg pressure porosimetry)	< 0.1 µm	0.02 to 0.04 µm
Chloride migration coefficient Method according to Tang & Schiessl	< 1.0 x 10^{-12} mm^2/s	0.4 to 0.6 x 10-12 mm^2/s
Freedom from microcracks, frost/de-icing resistance CDF method with 56 cycles	Decrease in the dyn. modulus of elasticity < 40 % Mass loss < 1,500 g/m^2	Decrease in the dyn. modulus of elasticity 10 to 30 % Mass loss 400 - 1,200 g/m^2
Residual alkalinity $Ca(OH)_2$ content) thermogravimetry	> 2.5 g $Ca(OH)_2$ per 100 g binding agent	7.9 g $Ca(OH)_2$ per 100 g binding agent

Concrete mixes based on a blend of calcium aluminate cement and slag cement complied with the limit values that apply to a *SWB* (acid resistant concrete) according to “ZTV 10.2, Appendix 2: Special requirements acid resistant concrete (SWB)”, Emscher Genossenschaft and “Technical contract conditions for concrete and reinforced concrete work for building structures in the water and waste water sectors, Appendix ZTV 10.1: Special requirements acid resistant concrete”, Emscher Genossenschaft.

Advanced Water Management Centre – University of Queensland Corrosion Chamber



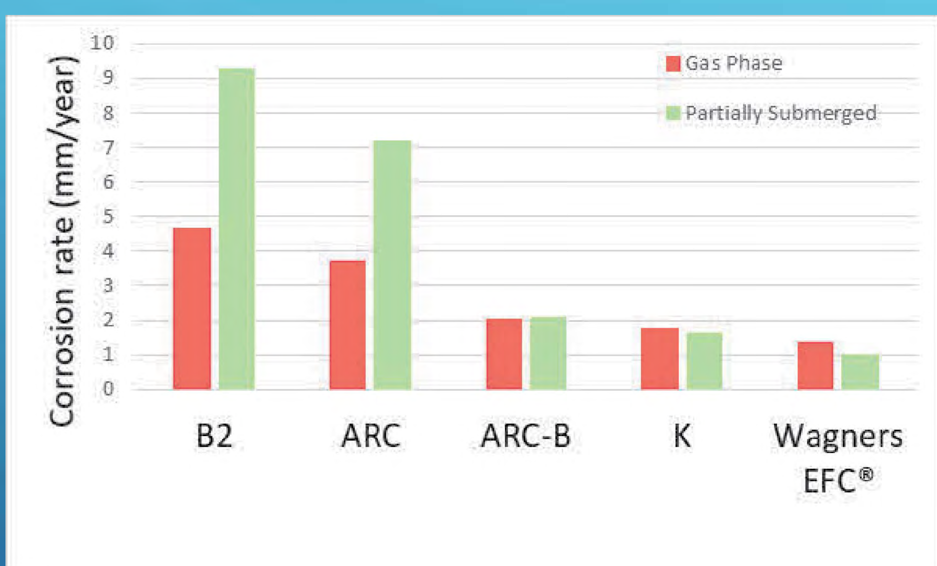
Advanced Water Management Centre – University of Queensland

Concrete corrosion testing - Methodologies

- Concrete properties
  - Surface pH
  - Alkalinity
  - Compressive strength (UQ Concrete Lab)
  - Water absorption/permeability (UQ Concrete Lab)
- Chemical analysis
  - sulphur compounds, metals etc.
- Microbial analysis
  - FISH, DNA extraction and sequencing etc.
- Advanced microanalysis
  - SEM, XRD, EDS, MLA
- Specialised methods
  - Sulphide uptake rate (SUR)
  - Photogrammetry – corrosion rate in mm/year

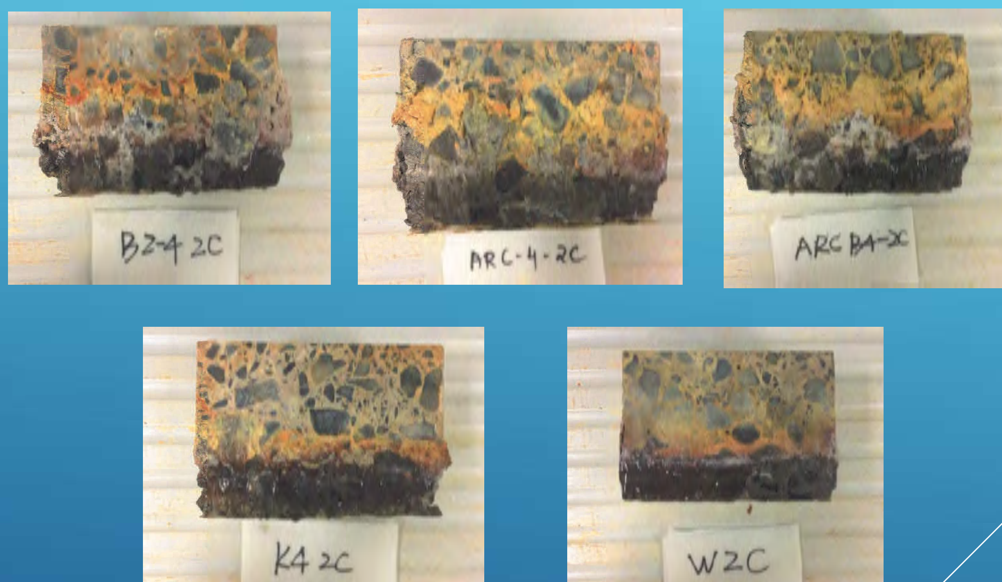
- All the measurements are available for bio-corrosion testing
- Each has specific requirements of samples, time and cost
- Recommended analysis/measurements
  - Mechanical properties
  - Surface pH
  - Chemical analysis
  - SUR
  - Corrosion rate

AWMC biogenic corrosion testing results at 12 months (50 ppm H_2S, 25^{0}C, 100% RH)



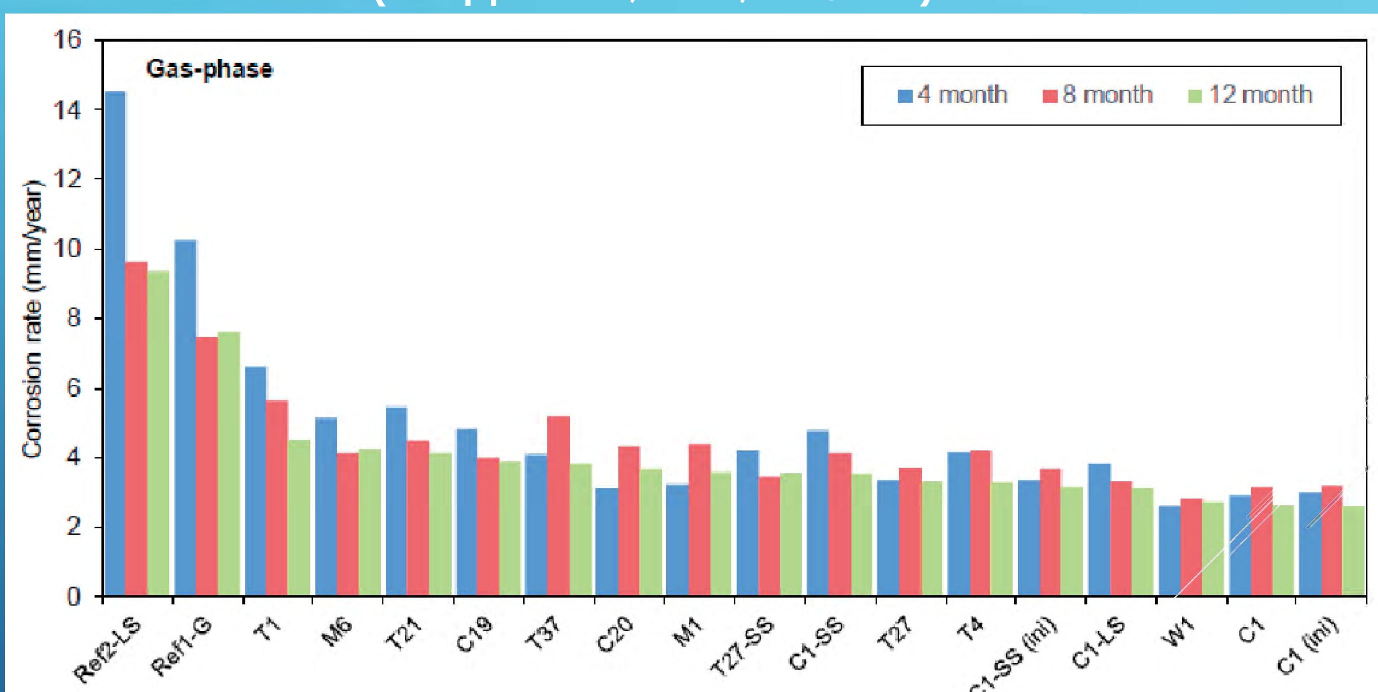
Source : Watercare Services Ltd – Central Interceptor: Pre-tender Concrete Testing AWMC – April 2018

AWMC biogenic corrosion testing at 12 months



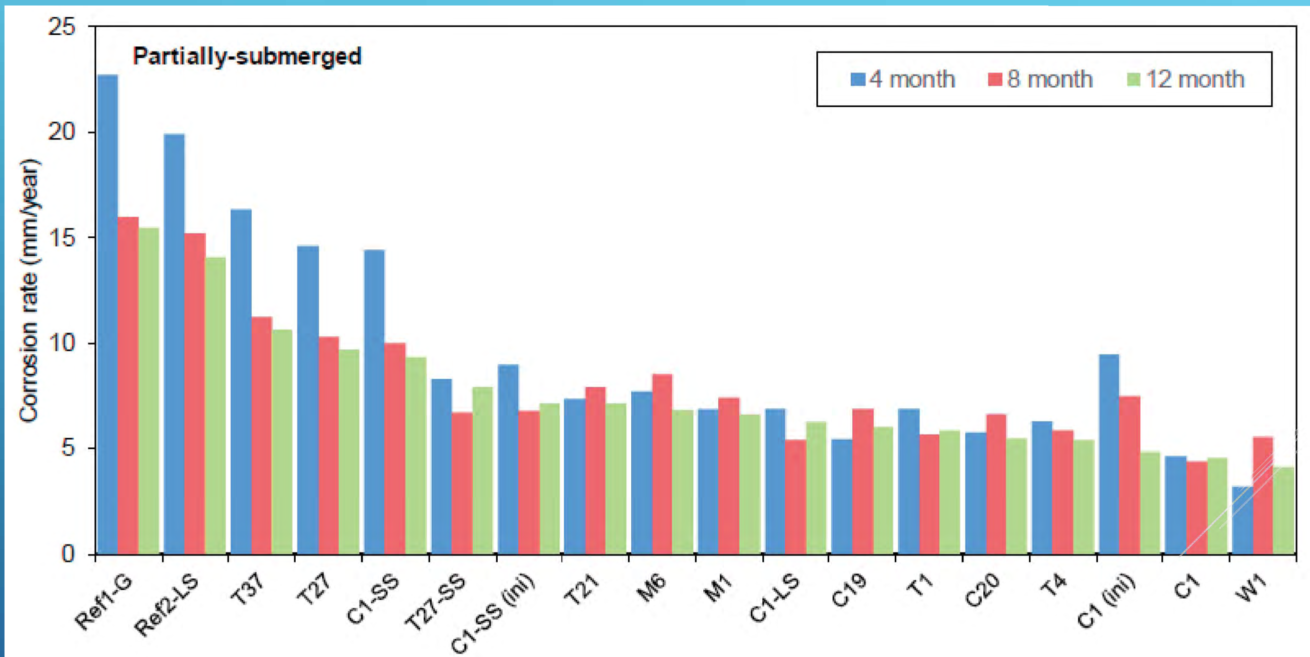
Source : Watercare Services Ltd – Central Interceptor: Pre-tender Concrete Testing AWMC – April 2018

AWMC biogenic corrosion testing results at 12 months (100 ppm H2S, 30⁰C, 100% RH)



Source Charles Allen (OtB Concrete Ltd)

AWMC biogenic corrosion testing results at 12 months (100 ppm H2S, 30⁰C, 100% RH)



Source Charles Allen (OtB Concrete Ltd)

SCC-I Gas-phase

SCC-I Partially-submerged

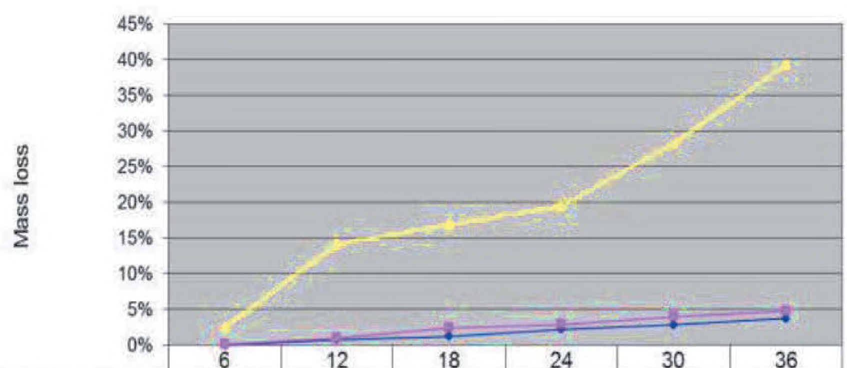
TABLE 15: MEASURED & ESTIMATED CORROSION RATES & MATERIAL FACTORS (11)

Cement/ Aggregate	5 year estimate		12 year estimate		14 year measured		Material factor***
	total	average	total	average	total	average	
PC/SIL	>30	>6,0	>64	>6,0	> 105	> 7.5	1.000
PC/DOL	10 – 15	2 – 3	20 – 30	1,7 – 2,5	43	3.1	0.410
CAC/SIL	5 – 10	1 – 2	10 – 15	0,8 – 1,2	26	1.9	0.250
FC	10 - 12	2 +	20 - 25	1,7 – 2,1			0.270
CAC/DOL *	3,0	0,6	7,2	0,6	8,4	0,6	0.085
CAC/ALM **							0.025

*Values estimated on the basis of other materials and performance of UCT samples in sewer
**Much less than CAC/DOL – no mass loss 17 months in sewer and pH on surface >6,4
***Average of maximum loss at side divided by corresponding value for PC/SIL.

Copy of Table 15 from the Sewer Design Manual (South Africa 2008)

SA Water Results
Mass loss after immersion in sewerage chamber

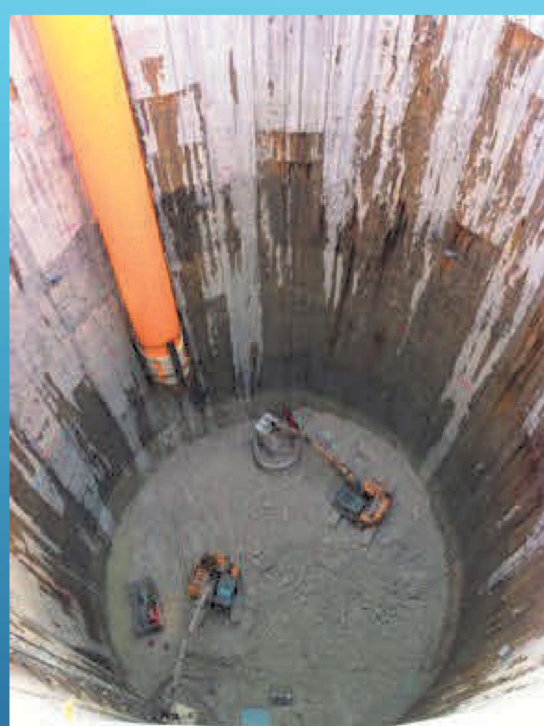


	6	12	18	24	30	36
GPC B-4 pipe #14318	0.00%	0.78%	1.20%	2.22%	2.83%	3.74%
GPC B-3 pipe #13885	0.09%	0.97%	2.46%	2.86%	4.00%	4.79%
OPCC pipe #13884	2.45%	14.22%	16.90%	19.56%	28.29%	39.25%

Months exposure

Mass loss after partial immersion in Sewer Tanks 2007 – SA Water (After G. Johnson – Rocla)

Comparison of Rocla geopolymer and OPC pipe section after 3 years exposure (After G. Johnson – Rocla)



Diaphragm walls for the Thames Tideway project cast with high volume slag concrete (Charles Allen - OtB Concrete Ltd)

MICC Resistance Improved with:

- Calcium aluminate cement based concrete
- Geopolymer concretes
- High volume slag concrete (>80%)

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