Protection of concrete for sewage installations and an accelerated test on protection systems

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Contents

Background

http://www.shieldcrete.com/UniqueApplications5.html

http://www.derm.qld.gov.au/land/ass/impacts.html

Background on concrete corrosion

- Biogenic sulfuric acid (BSA) attack against concrete structures has been reported for many years.
- BSA is believed to be the main degradation source to sewage concrete structures.
- Concrete structures can be damaged to a critical state by BSA attack within 3 years.

Formation of BSA

- Sulfates, SO_4^{2-} from sewage
- In closed environment (Insufficient oxygen) SO_4^{2-} are reduced by sulfate reducing bacteria (SRB).
- H_2S gas is released as a result.
- H_2S gas is metabolized by a sulfur oxidizing bacteria (SOB) and H_2SO_4 is formed finally.

Reactions in concrete

- The side products produced will result in an expansion in volume and damage the concrete structure.
- They also have poor bonding with concrete structure.

<u>Sodium sulfate corrosion:</u>

$Ca(OH)_2 + Na_2SO_4.10H_2O \rightarrow CaSO_4.2H_2O + 2\ NaOH + 8\ H_2O$

$3CaO.Al_2O_3.12H_2O + 3\ (CaSO_4.2H_2O) + 14\ H_2O \rightarrow 3CaO.Al_2O_3.3CaSO_4.32H_2O$

$2\ (3CaO.Al_2O_3.12H_2O) + 3\ (Na_2SO_4.10H_2O) \rightarrow 3CaO.Al_2O_3.3CaSO_4.32H_2O + 2\ Al(OH)_3 + 6\ NaOH + 17\ H_2O$

<u>Magnesium sulfate corrosion:</u>

$Ca(OH)_2 + MgSO_4 \rightarrow CaSO_4 + Mg(OH)_2$

$3CaO.Al_2O_3.6H_2O + 3\ MgSO_4 \rightarrow 3\ CaSO_4 + 2\ Al(OH)_3 + 3\ Mg(OH)_2$

$3CaO.2SiO_2.2H_2O + 3\ MgSO_4.7H_2O \rightarrow 3\ (CaSO_4.2H_2O) + 3\ Mg(OH)_2 + 2\ SiO_2$

<u>Sulfuric acid corrosion:</u>

$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4.2H_2O$

$3CaO.Al_2O_3.12H_2O + 3\ (CaSO_4.2H_2O) + 14\ H_2O \rightarrow 3CaO.Al_2O_3.3CaSO_4.32H_2O$

$CaO.SiO_2.2H_2O + H_2SO_4 \rightarrow CaSO_4 + Si(OH)_4 + H_2O$

Possible solutions

- Physical protections
  - Protective coatings providing physical barriers.
- Biological protections
  - Reduce the rate of bacteria growth.

Objectives

Objectives of this project

- To explore the performance of different types of protective coatings.
- To establish laboratory tests that can accelerate the effect of BSA.
- Carry out field test for real situation simulation.

Laboratory test

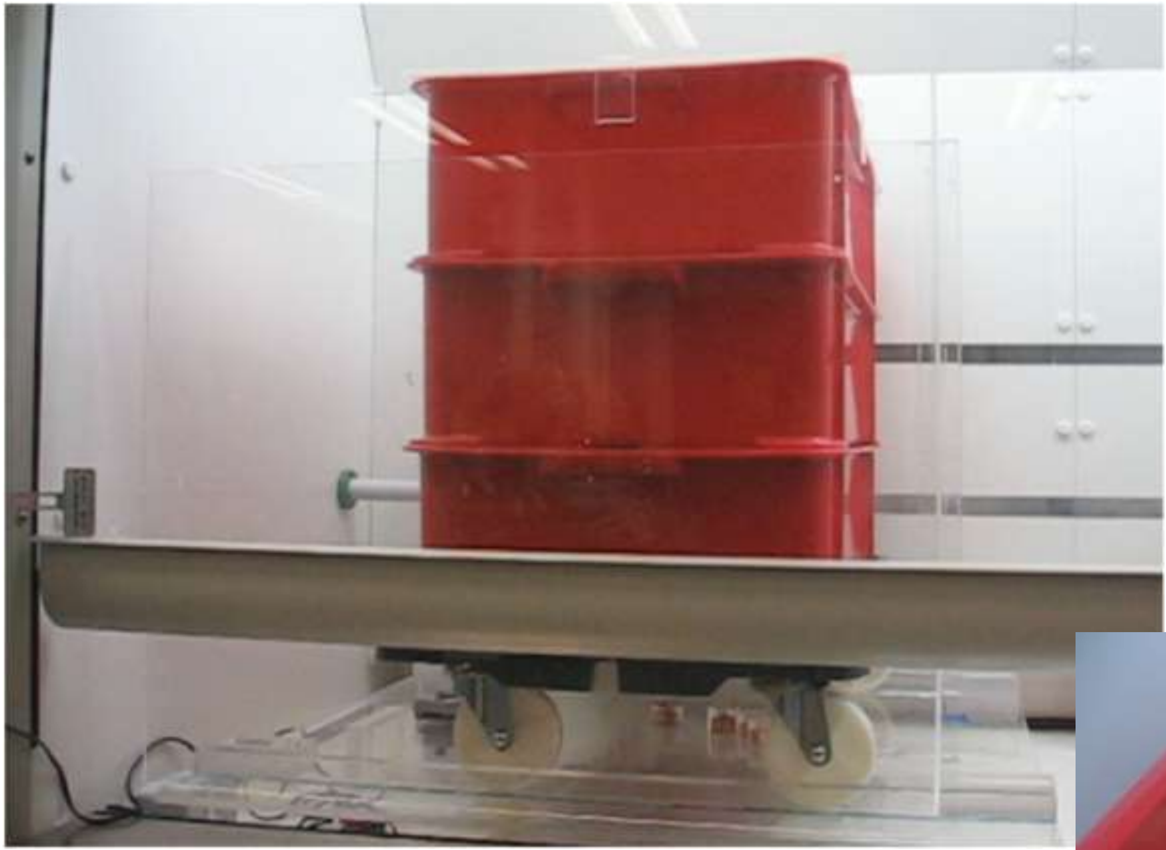
Ideas and concepts of laboratory test

- BSA takes time to take build up and take effect.
- Laboratory test must shorten the time needed for building up of acidity.
- Serve as a screening, reduce the number of samples needed in field test.

Test methods & conditions

- Samples used were 50mm mortar cubes.
- Different coatings were applied on the cubes, e.g. epoxy-based, polyurea etc.
- All samples were immersed in acidic solution for 28 days.
- To speed up the test, solution bath of H_2SO_4 solution (pH~0.5) was used.
- The solution level was about 15mm.
- To simulate the water flow of sewer, the whole solution bath was gently moving forward & aft.

Moving trolley



Test methods & conditions

- Sample cubes with and without coatings were immersed in acidic solution (pH ~ 0.5) for 28 days.
- The solution level was about 15mm.
- Continuous horizontal movement of the acid bath.
- The acidic solutions were refreshed frequently.
- Visual inspection was conducted through the appearance and cross-sections of each coating.

Requirements verified or failed

- Critical failure
  - Visible damage to coatings such as reduction of thickness.
  - Serious delamination of coating from substrates.
- Serious failure
  - Minor and localized delamination of coating from substrates.
  - Acid penetration through pin-holes.

Requirements verified or failed

- Minor failure
  - Color change is experienced.
  - No delamination between substrate and coating even though suffering from acid penetration through pin-holes.
- Pass
  - No acid penetration is found.
  - No substrate suffers from acid attack.
  - No delamination is found.

Lab test results

List of coatings tested

Coating	Material	Application methods and layers applied	Appearances
I	Polyurea	Spraying; multi-layers	Dark Yellow
II	Polyurea	Spraying; multi-layers	Dark green
III	Epoxy-based	By hand; 2 layers	Light grey
IV	Epoxy-based	By hand; 2 layers	Dark grey
V	Epoxy-based	By hand; 2 layers	Dark green
VI	Epoxy-based	By hand; 3 layers	Black
VII	Epoxy-based	By hand; 2 layers	Dark grey
VIII	polyester resin based	By hand; 2 layers	Light grey
IX	Cement-based	By hand; 1 layer	Grey, dull
X	Cement & mineral based	Spraying; multi-layers	Grey, dull

Mortar cubes (Control group)

- Samples without coatings had severe damage after 14 days.
- The dimensions at the bottom of the cubes reduced from 50mm × 50mm to approx. 40mm × 40mm.
- 25% Weight loss.

Polyurea based materials

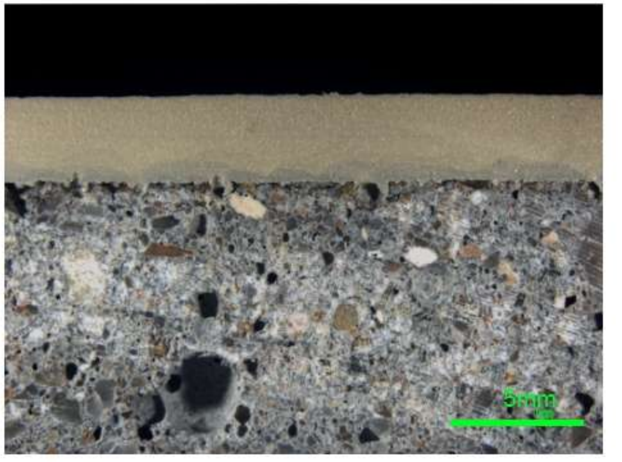
- Coatings I & II passed the lab test.
- No obvious change of appearances.

Coating I

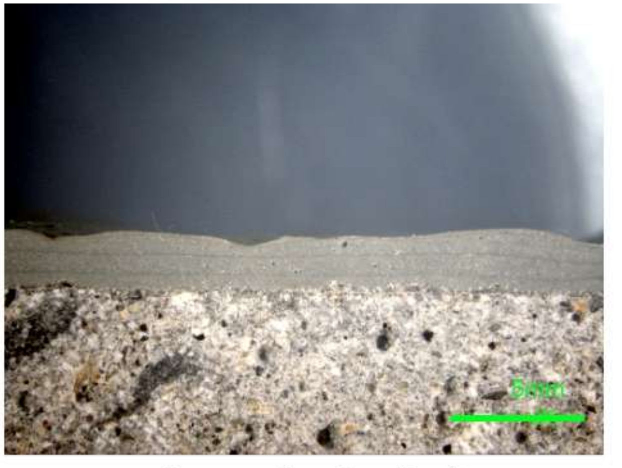
Coating II

Polyurea based materials

- Cross sections of the tested samples.
- No observable failure.



Cross section of coating I



Cross section of coating II

Epoxy based materials

- Coatings III- VIII generally failed in lab tests.
- Change of apperances:
  - Color change;
  - Swelling.

Coating III

Coating VI

Coating Iv

Coating VII

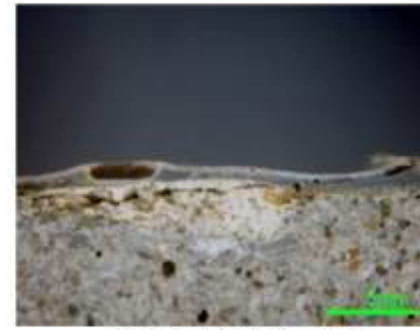
Coating V

Coating VIII

Epoxy based materials

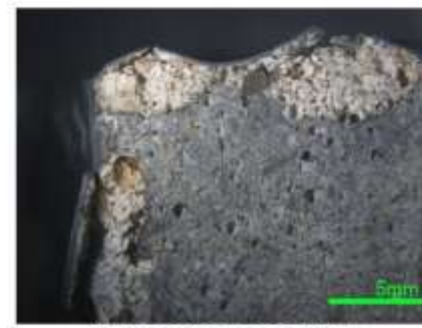
- Cross sections of the failed tested samples.
- Failures:
  - Pin holes;
  - Delaminations.

Cross section of coating III



Cross section of coating VI

Cross section of coating IV



Cross section of coating VII

Cross section of coating V

Cross section of coating VIII

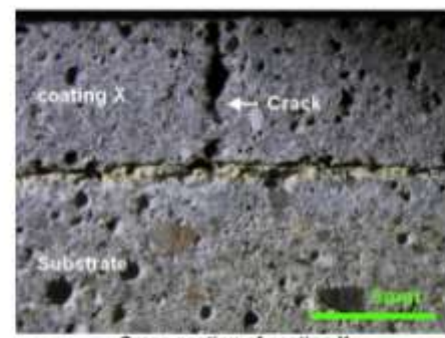
Cement based materials

- Coating IX failed at edges. The coatings peeled off from the substrate.
- Coating X had cracks at surfaces.
- Minor damage to substrate.

Coating IX

Coating X

Coating X



Cross section of coating X

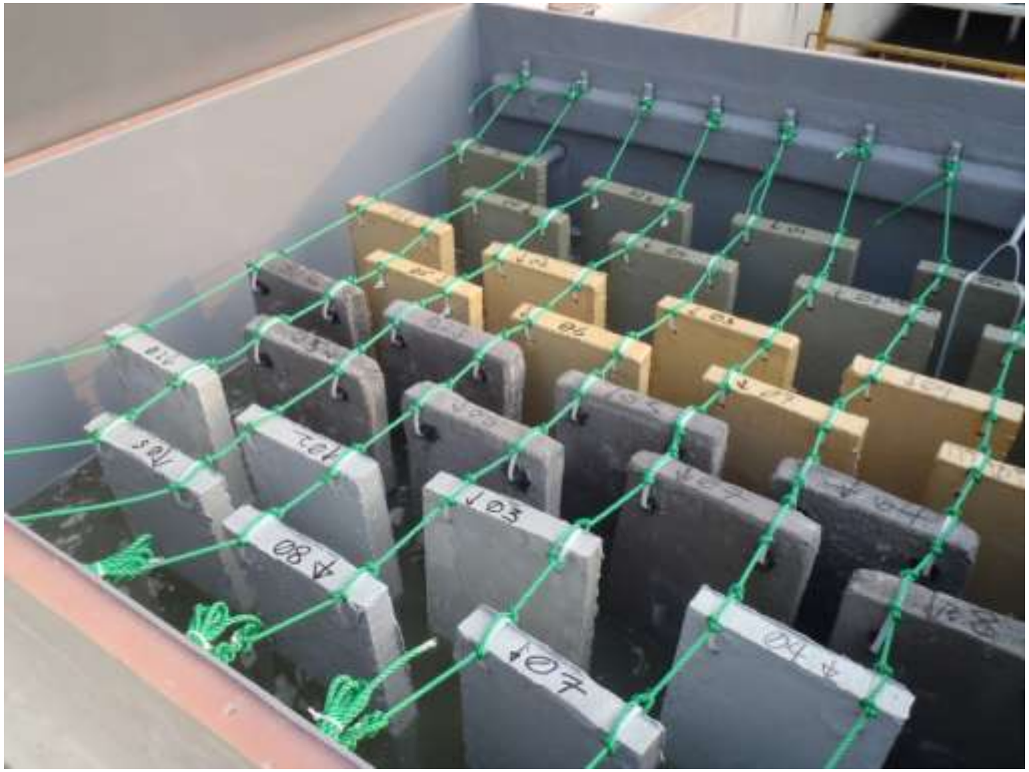
Lab acid test conclusions

- Polyurea based coating has the best performance by far.
- Most epoxy based materials were experiencing failure due to the existence of pin-holes.
- Epoxy coatings maybe considered in field test for comparison.
- Cement based coating. They are brittle in nature but behave very differently.

In-situ tests

In-situ test

- Coated samples (I, II, III and X) were selected for in-situ tests.
- Located in sewage treatment plant, Stonecutter Island, HK
- Target test duration: 24 months – batches 1, 2, 3 & 4



pH on sample surfaces

- Half of the plate above water level.
- Area above the water/ scum stayed acidic (pH 0~2)
- Area covered with scum turned alkaline (pH >8).

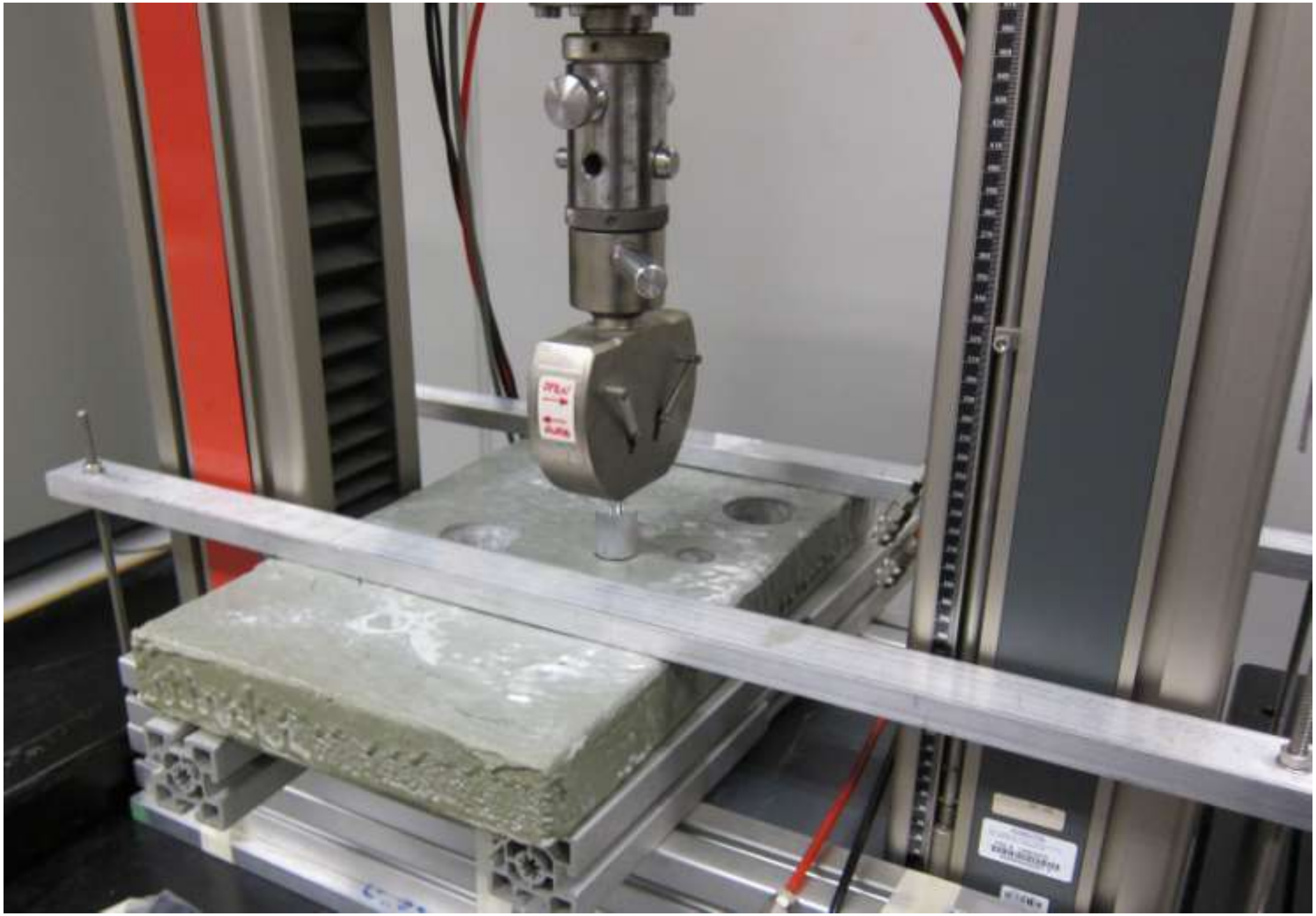
Change in pH & H_2S concentration

- pH 0~2 at samples surfaces above water level.
- Acidity of sewage was generally neutral (pH 6~7).
- Moisture collected from the caps remained at about pH 5~6.
- The concentration of H_2S increased with the water level. The higher the water level (less headspace), the higher the concentration of H_2S inside the water tank.
- The concentration of H_2S recorded did not have direct correlation with the pH recorded on the surfaces of the samples.

Typical pH values

pH at different area					
Time	Sewage at water inlet (pH)	Sewage at water outlet (pH)	Moisture at cap (pH)	Sample surfaces (pH)	Remarks
Week 69	5	6	5	1-2	
Week 71 (Sep)	7	7	5	1-2	
Week 73	7	7	6	0-1	

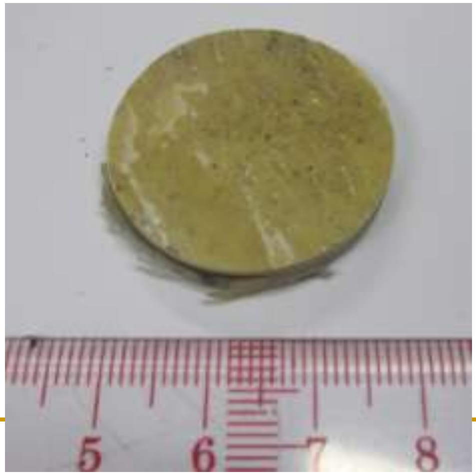
Pull test



Pull test results

- Coating I

Control



Batch 1

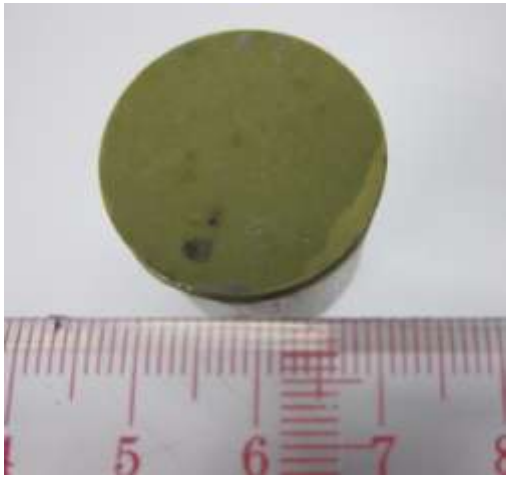
Coating I	MPa	Failure interface
Control #1	1.06	Coating - Adhesive
Control #2	1.04	Primer - Coating
Control #3	0.68	Concrete - Primer

Coating I	MPa	Failure interface
Batch1 #1	1.77	Primer - Coating
Batch1 #2	1.91	Primer - Coating
Batch1 #3	2.37	Concrete - Primer

Coating I	MPa	Failure interface
Batch2 #1	0.79	Concrete - Primer
Batch2 #2	0.78	Concrete - Primer
Batch2 #3	0.72	Primer - Coating

Pull test results

- Coating II



Control

Batch 1

Coating II	MPa	Failure interface
Control #1	0.17	Concrete - Primer
Control #2	0.2	Primer - Coating
Control #3	1.37	Primer - Coating

Coating II	MPa	Failure interface
Batch1 #1	0.43	Concrete - Primer
Batch1 #2	0.78	Concrete - Primer
Batch1 #3	0.29	Concrete - Primer

Coating II	MPa	Failure interface
Batch2 #1	0.46	Concrete - Primer
Batch2 #2	0.54	Concrete - Primer
Batch2 #3	0.20	Concrete - Primer

Pull test results

- Coating III

Coating III	MPa	Failure interface
Control #1	3.21	Coating - Adhesive
Control #2	2.05	Concrete - Primer
Control #3	2.81	Primer - Coating

Coating III	MPa	Failure interface
Batch1 #1	1.53	Primer - Coating
Batch1 #2	1.03	Concrete - Primer
Batch1 #3	0.91	Concrete - Primer

Coating III	MPa	Failure interface
Batch2 #1	1.89	Concrete - Primer
Batch2 #2	1.61	Concrete - Primer
Batch2 #3	1.24	Concrete - Primer

Pull test results

- Coating X
  - Control samples have bond strengths generally > 1MPa.
  - During pull tests, several failures were inside the coating and close to the top surface.

Coating X	MPa	Failure interface
Control #1	1.35	Concrete - Coating
Control #2	0.98	Concrete - Coating
Control #3	1.60	Concrete - Coating

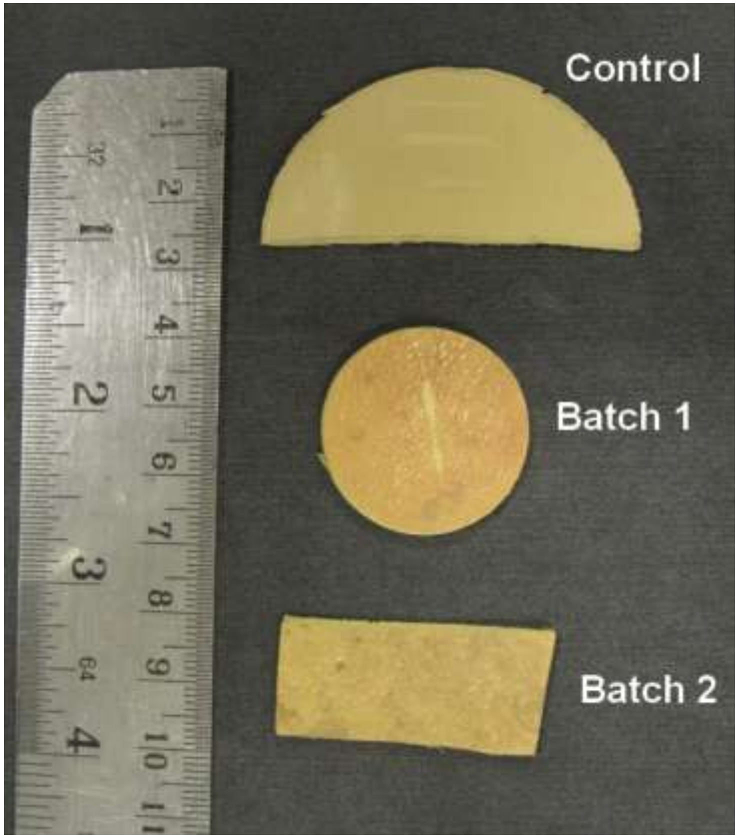
Coating X	MPa	Failure interface
Batch1 #1	0.97	Coating (near top surface)
Batch1 #2	0.75	Coating (near top surface)
Batch1 #3	0.44	Coating (near top surface)

Coating X	MPa	Failure interface
Batch2 #1	0.95	Coating (near top surface)
Batch2 #2	1.33	Concrete - Coating
Batch2 #3	1.42	Concrete - Coating

Wear test results

- Coating I
  - Samples became more wear resistant.

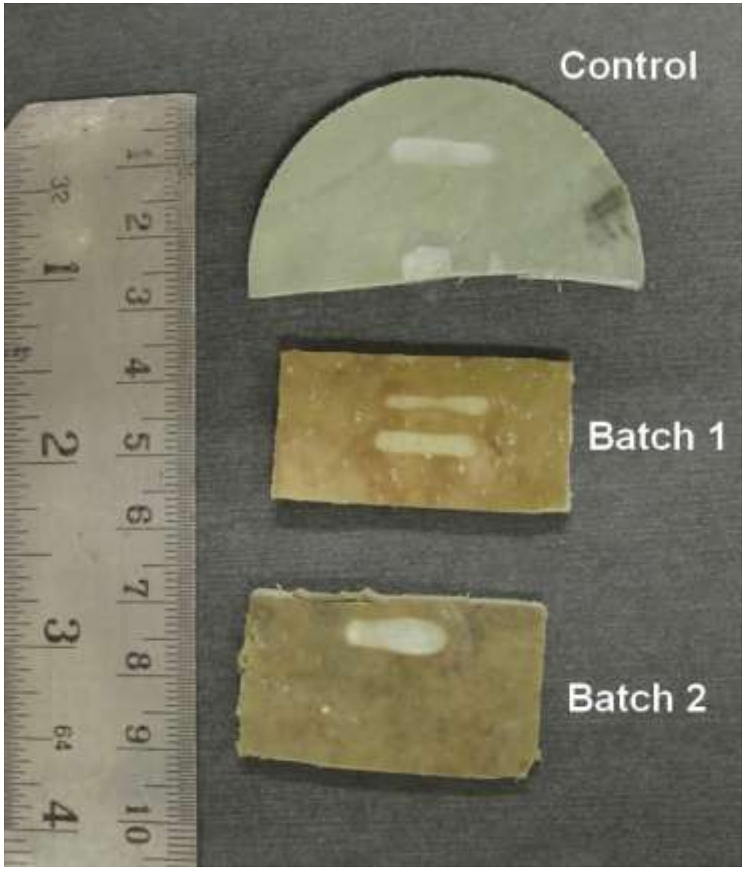
Coating I	Weight loss (gram/day)
Control	0.060
Batch 1	0.036
Batch 2	0.010



Wear test results

- Coating II
  - Samples became less wear resistant.

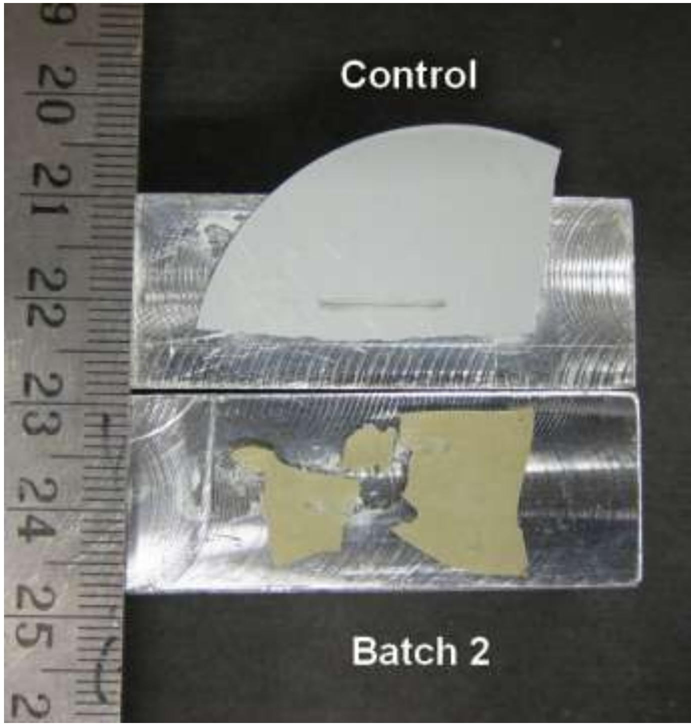
Coating II	Weight loss (gram/day)
Control	0.125
Batch 1	0.106
Batch 2	0.298



Wear test results

- Coating III
  - Batch 1 & 2 samples fractured into pieces during wear test.

Coating III	Weight loss (gram/day)
Control	0.017
Batch 1	n/a
Batch 2	n/a



Further tests

- Selected coatings subjected to more tests such as
  - Chloride penetration test

Summary

- The acid accelerated test successfully screened out coatings that could survive in the long term.
- The set up of in-situ test at Stonecutters Island has been successful; test had been going on well.
- Pull test performance showed that some coatings tested for 1.5 years were still functioning satisfactorily.
- Wear test results showed that some coatings had less wear resistance after 1 year.

Acknowledgement

This research is supported by a R&D grant from

ARUP

The End

Q&A