Testing acid resistance of fly ash based geopolymer concrete for sewer environments

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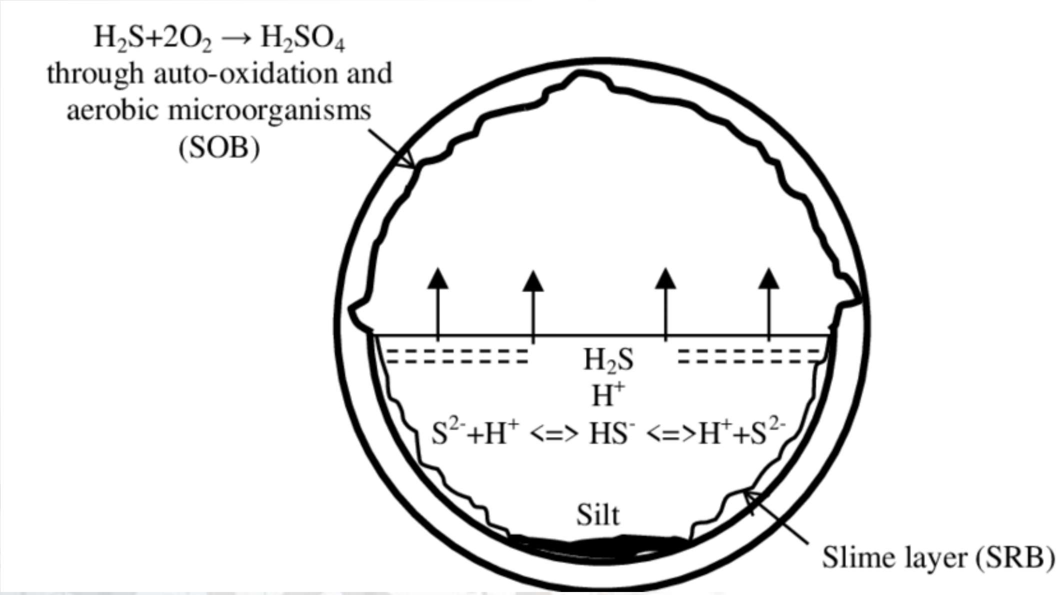
Presentation outline

1. Introduction and Background
   i. Virginia Experimental Sewer- South Africa and microbial induced corrosion.
2. Research methodology
   i. Material characterisation
   ii. Concrete mixes
   iii. Static and dynamic acid test conditions
3. Results and analysis
4. Conclusions

1. Introduction and background

In 1988 (34 years ago) a 65 m experimental sewer section was commissioned in Virginia, Free State. It comprised three sets of 900 mm diameter concrete pipe, each of which contained nine different types of cementitious materials.

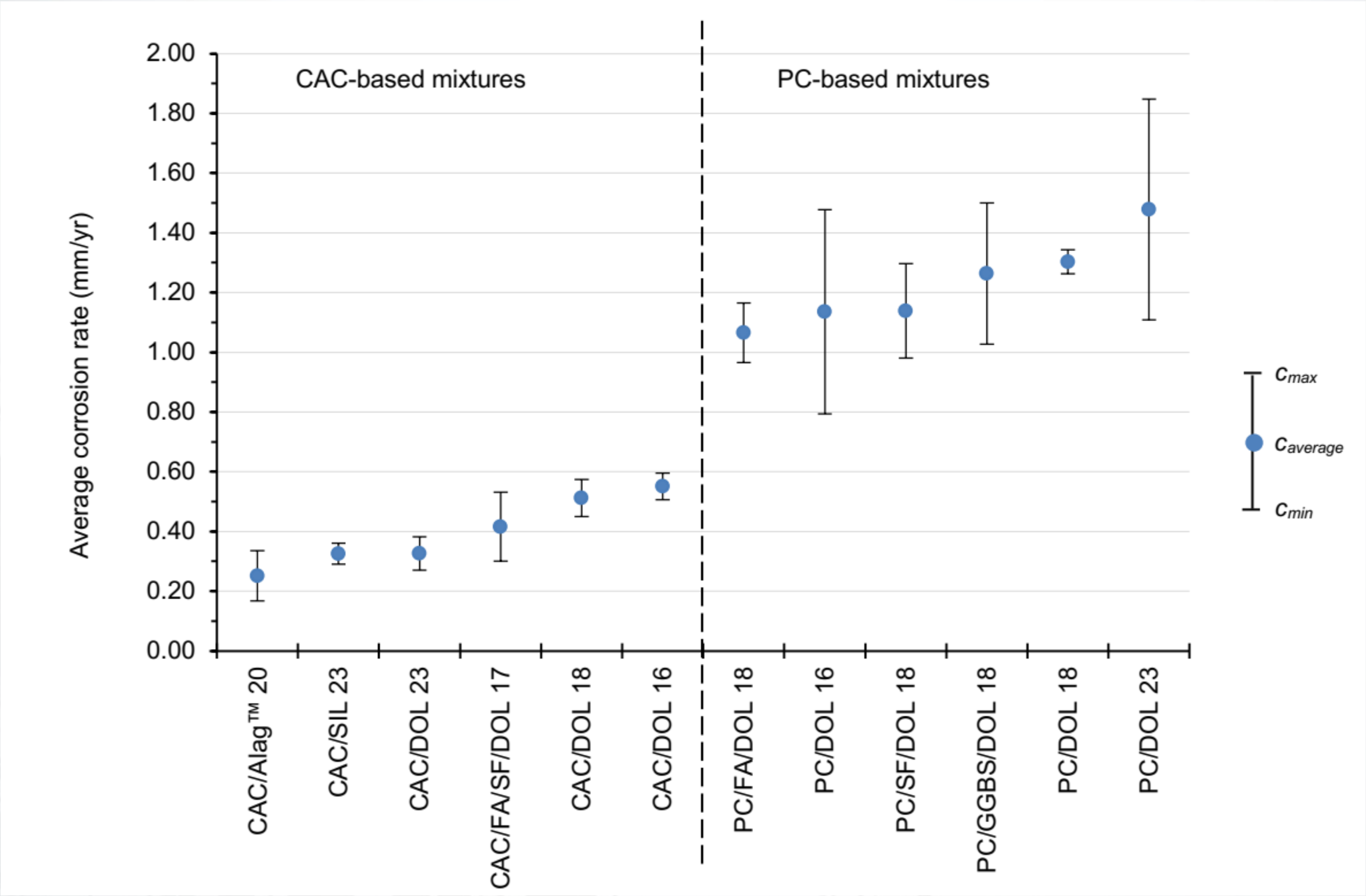
Microbial induced corrosion



Impacts of MIC: Need for repairs to sewers

- 456 million Euro P/A German sewers (Kaempfer and Berdnt 1999)
- United Kingdom: 84.8 million Pounds P/A (Gutierrez et al. 2010)
- USA: 3.3 billion dollars P/A in 2009 (Herrison and Saucier 2013)

The Virginia Live Sewer Experiment Results



Fly ash precursor in South Africa

Fly ash

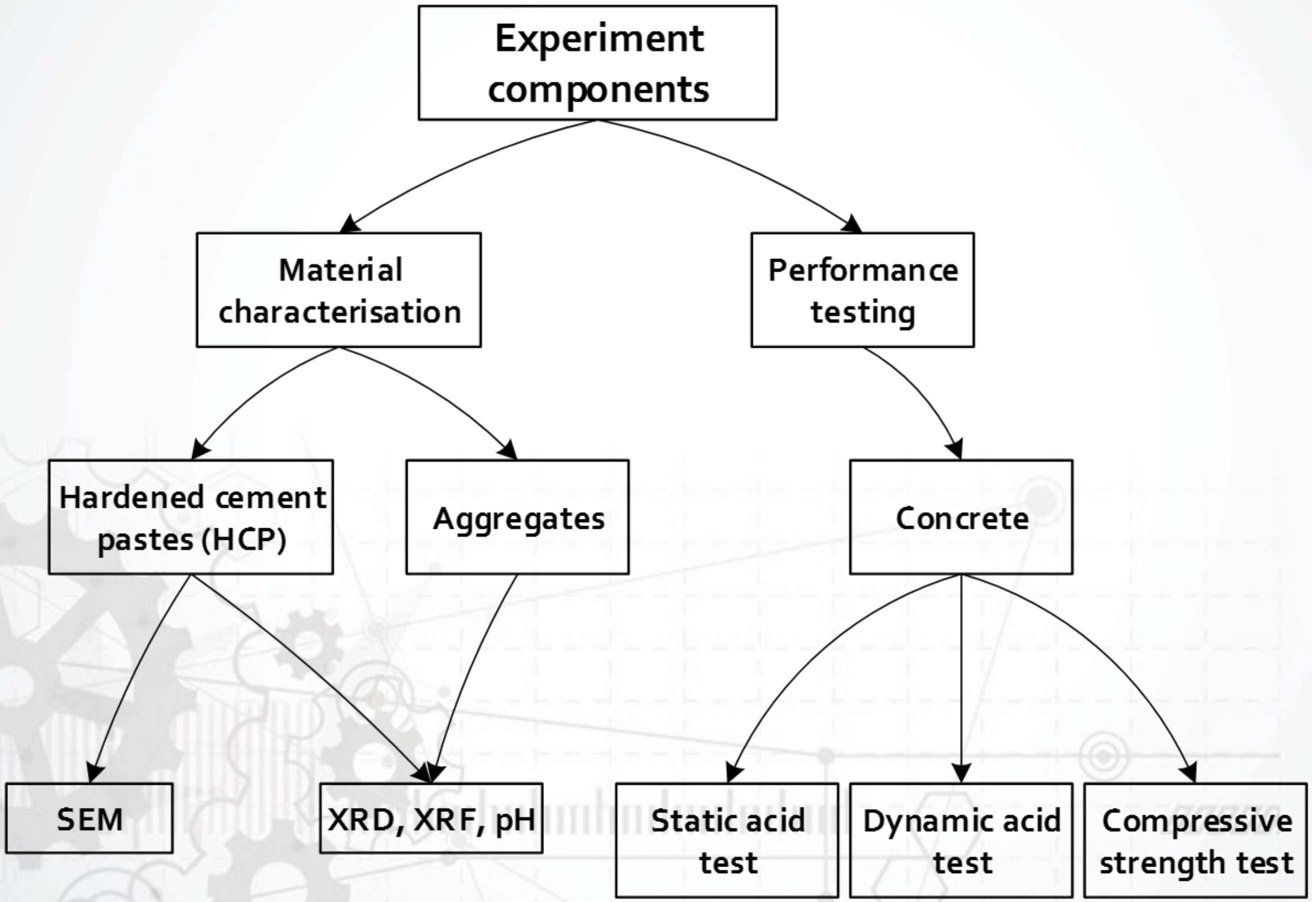
- 36 million tonnes per annum happens to be available*
- South Africa is largely Class F (Low CaO)
- Less than 7% is currently recycled, largely as SCM's in Portland cement
- Alumino-silicate rich material
- Amenable to geopolymer technology*

Ash dam: Mpumalanga, South Africa

Ash disposal problems: Lethabo Powerstation

2. Research Methodology

Experimental program



Materials

Binders

- Fly Ash Based Geopolymer Cement (GP)
- Portland Cement (PC) – Cem 1 (Control #1)
- Calcium Aluminate Cement- Imerys (Control #2)

Aggregate

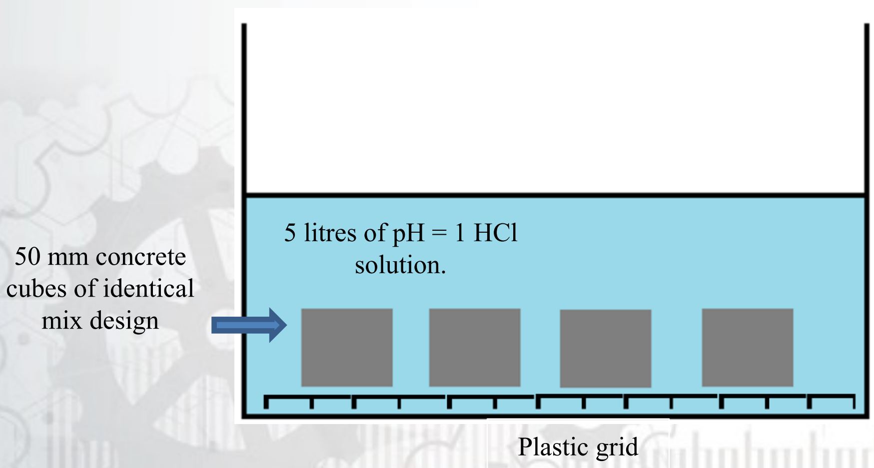
- Dolomite
- Quartzite
- Andesite
- Dolerite
- Granite

Materials preparation

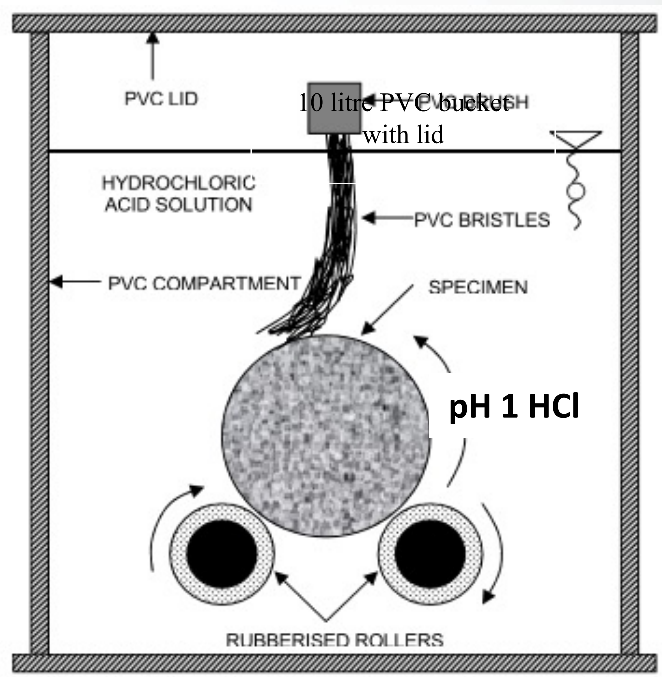
Test method	Sample preparation method
Dynamic Acid Test	Heavy mechanical compaction, curing @ 60° C for 4 hours, coring @ 28 days
Static Acid Test	Hand compaction- 50 mm cube mould, curing @ 60° C, 23 ° C there-after for 28 days.
XRD, XRF, pH	Milling HCP or Aggregate down to 75 micron

Acid (HCl) performance tests

Static HCl test



Dynamic HCl test



3.Results

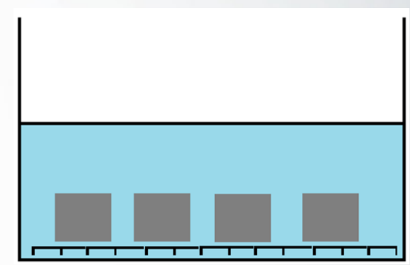
Corrosion rates

Static HCl test corrosion rates

Rank in resistance	Concrete mix	Corrosion rate ($mg/cm^2/hr$)	Abrasion factor
1	GP-ferro-quartz	0.056	3.3
2	GP-granite	0.059	7.5
3	GP-andesite	0.086	5.4
4	GP-dolerite	0.14	32.9
5	CAC-dolomite	0.27	196
6	GP-dolomite	0.54	39
7	PC-dolomite	3.85	8.8

GP-Siliceous aggregate (ranks 1–4)

Dolomite Aggregate (ranks 5–7)



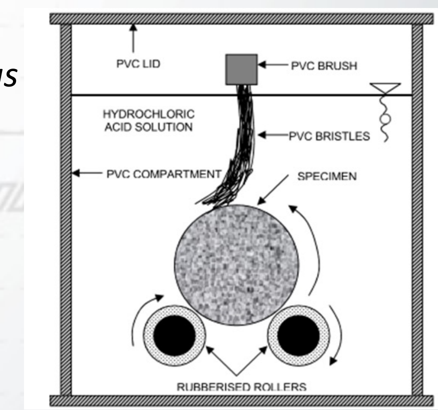
Dynamic HCl test corrosion rates

$$\text{*Abrasion factor} = \frac{\text{Dynamic corrosion rate}}{\text{Static corrosion rate}}$$

Rank in resistance	Concrete mix	Corrosion rate ($mg/cm^2/hr$)
1	GP-ferro-quartz	0.19
2	GP-granite	0.44
3	GP-andesite	0.46
4	GP-dolerite	4.43
5	GP-dolomite	21.1
6	PC-dolomite	34.12
7	CAC-dolomite	52.1

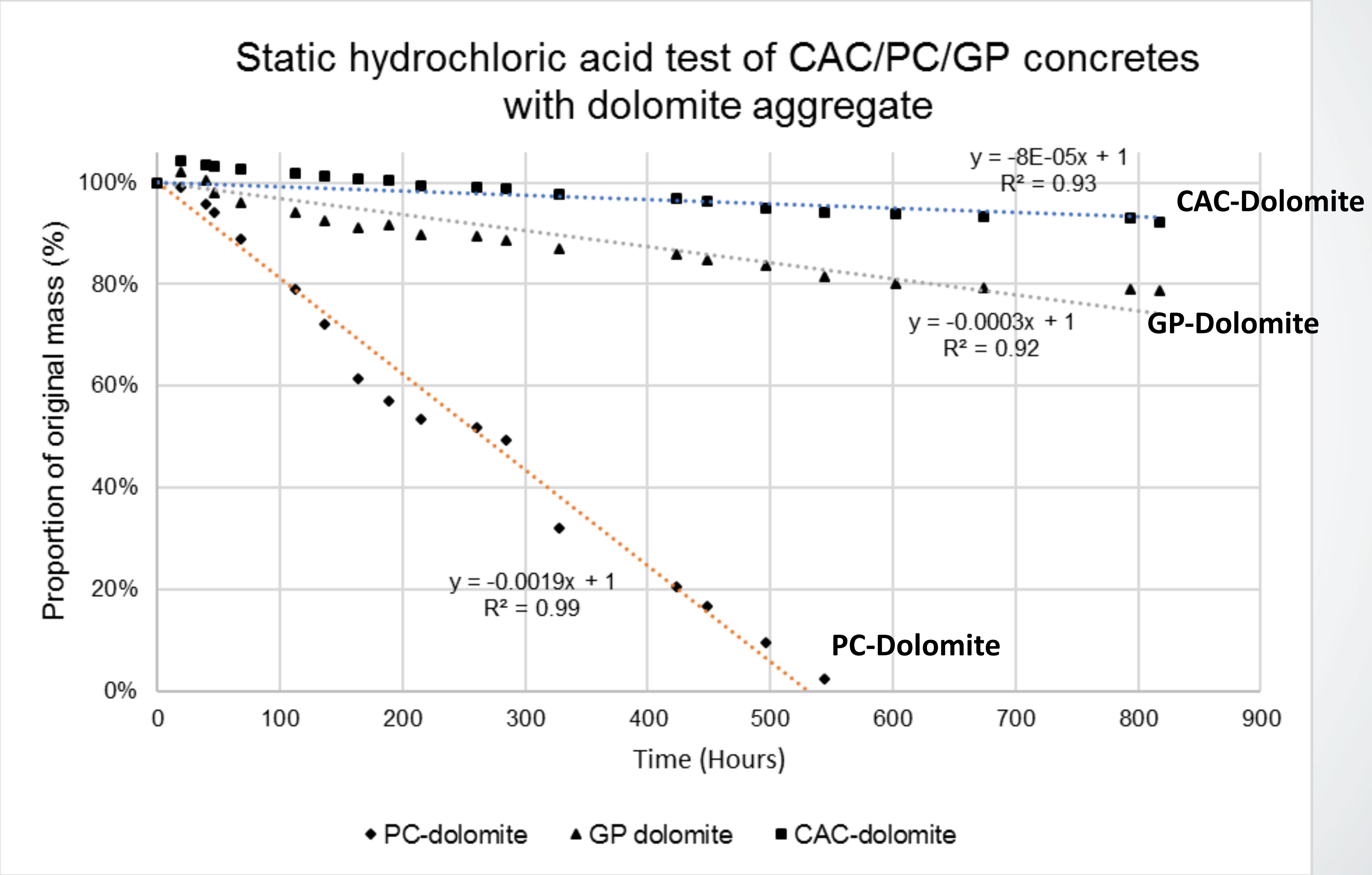
GP-Siliceous aggregate (ranks 1–4)

Dolomite Aggregate (ranks 5–7)



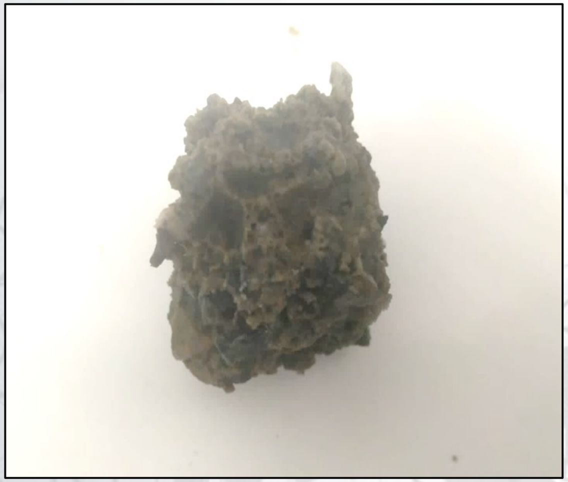
3.1 Dolomite aggregate corrosion rates

Static Corrosion rates



Visual assessment: Static HCl test

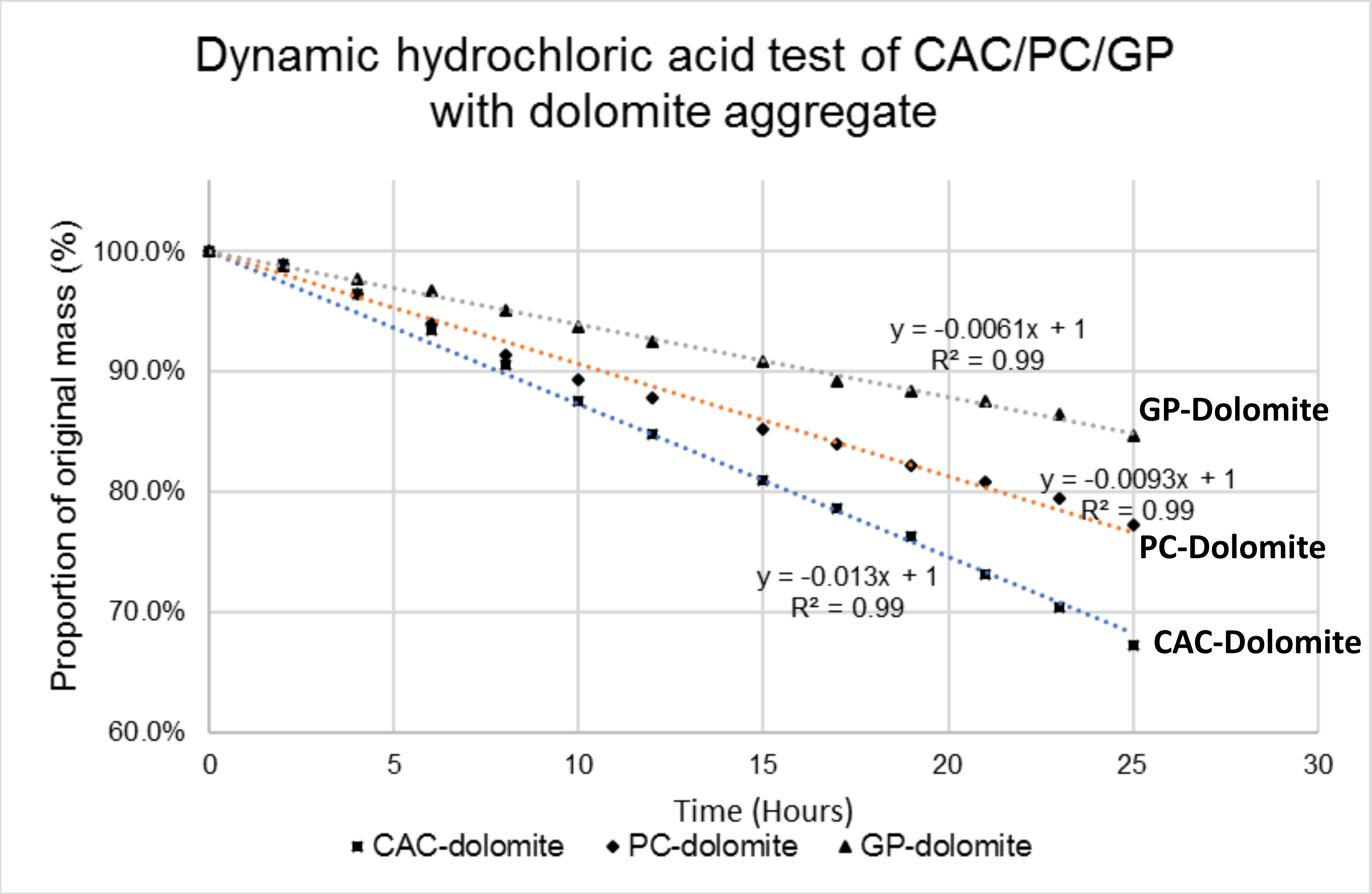
PC-Dolomite
(3.85 g/cm²/hr)
After 350 hours



CAC –Dolomite
(0.27 g/cm²/hr)
After 350 hours

GP –Dolomite
(0.54 g/cm²/hr)
After 350 hours

Corrosion rates



Visual assessment: Dynamic HCl test

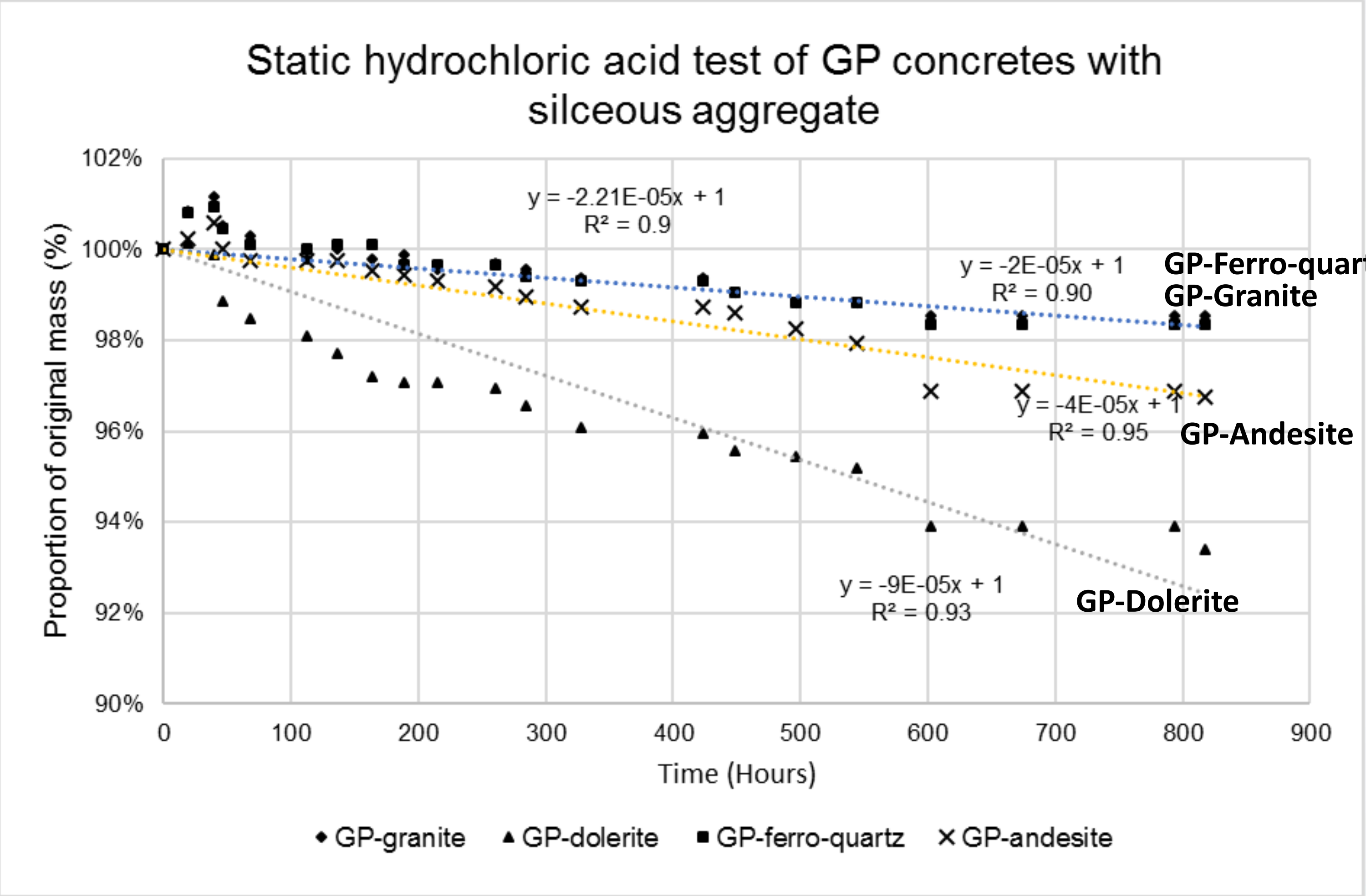
PC-Dolomite
34.1 g/cm²/hr)

CAC –Dolomite
(52.1 g/cm²/hr)

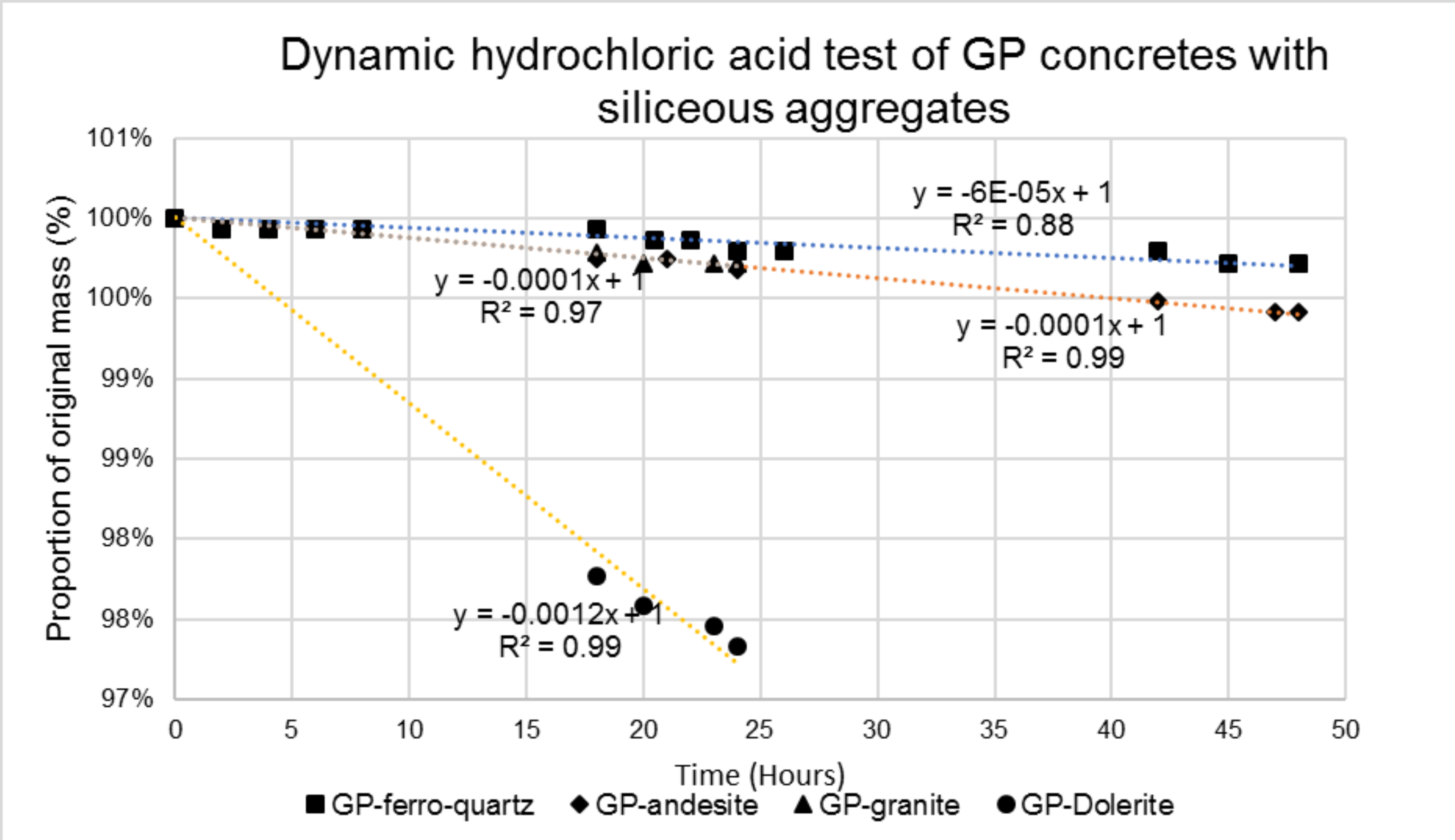
GP –Dolomite
(21.1 g/cm²/hr)

3.2 Geopolymer/siliceous aggregate corrosion rates

Static acid corrosion: Geopolymer/Siliceous aggregates



Corrosion rates: GP/PC/CAC Calcareous aggregates



Visual assessment: Dynamic HCl test

GP-Ferro-quarts

After 48 hours

0.19 g/cm²/hr

GP-Granite

After 48 hours

0.44 g/cm²/hr

GP-Andesite

After 48 hours

0.46 g/cm²/hr

GP-Dolerite

After 48 hours

4.43 g/cm²/hr

3. Analysis
(Effect of chemical properties on corrosion rates)

Effect of basic and acidic oxides in HCP and aggregates on HCl corrosion

- Using quantitative XRD, the oxides in aggregates and pastes and their percentages were determined.
- Basicity formula is the same as that found in SANS 50197-1 and BS EN 197-1:2011

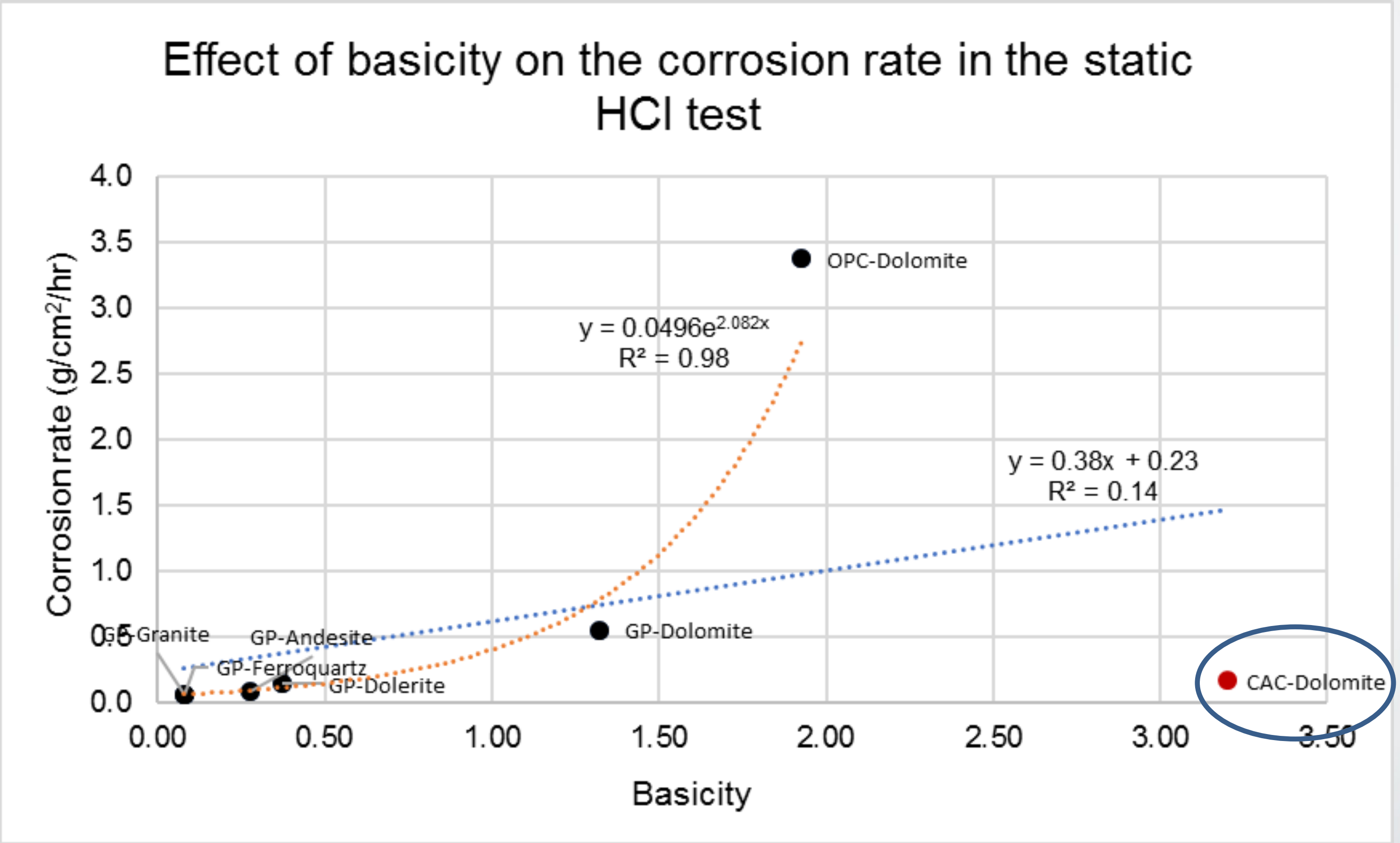
Li	Be	B	C	N	O	F
Na	Mg	Al	Si	P	S	Cl
K	Ca	Ga	Ge	As	Se	Br
Rb	Sr	In	Sn	Sb	Te	I
Cs	Ba	Tl	Pb	Bi	Po	At
Basic Oxides			Amphoteric Oxides		Acidic Oxides	

$$\textbf{Basicity} = \frac{CaO(\%) + MgO(\%)}{SiO_2(\%)}$$ (SANS 50197-1 and BS EN 197-1:2011)

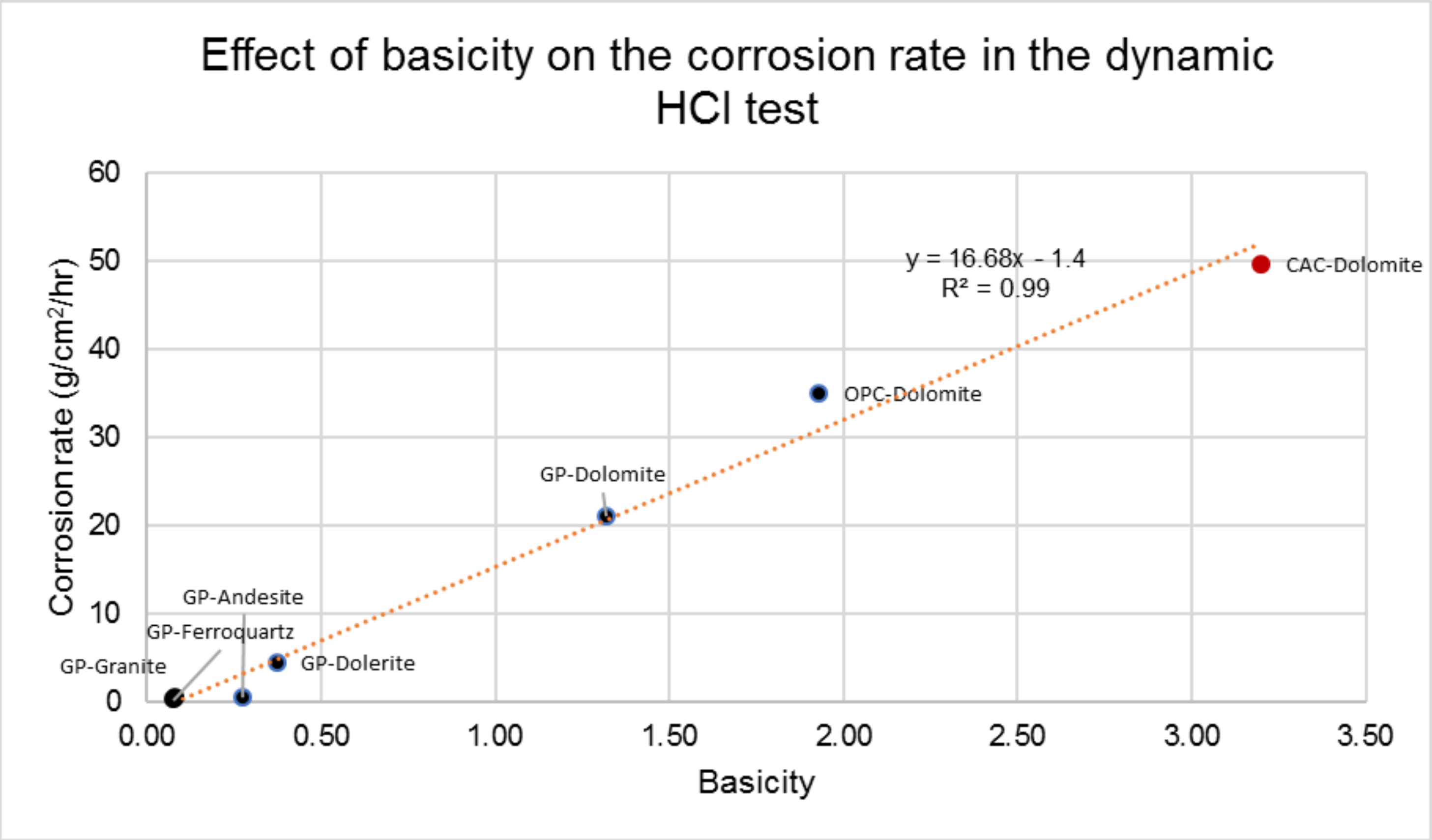
Basicity concrete specimen = (Basicity HCP × binder %) + (Basicity Aggregate × aggregate %

Basicity differential = (Basicity HCP - Basicity Aggregate)

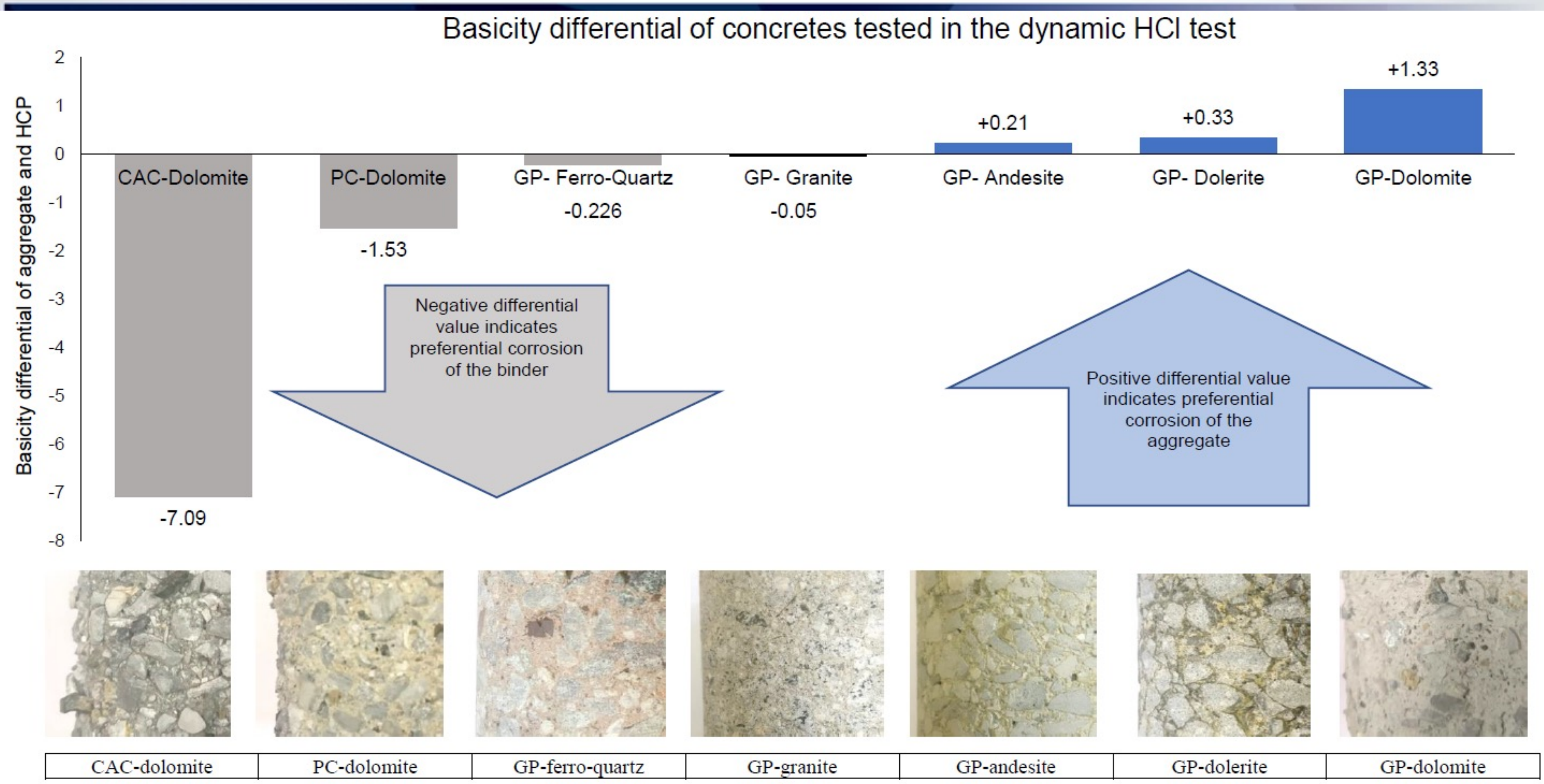
Effect of basicity on the rate of corrosion in the static HCl test



Effect of basicity on the rate of corrosion in the dynamic HCl test



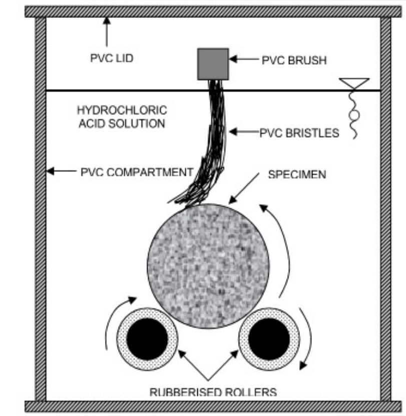
Relative basicity: HCP vs Aggregate



4.Conclusions

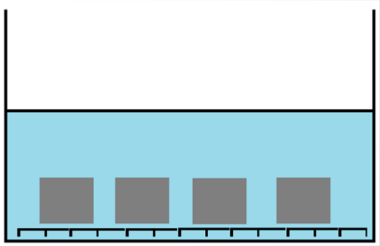
Conclusions: Geopolymer concrete performance

Dynamic Acid HCl Test



Concrete Type	Control Mix	Fold improvement
GP-ferro-quartz	PC-dolomite	180
GP-ferro-quartz	CAC-dolomite	275

Static HCl Test



Concrete Type	Control Mix	Fold improvement
GP-ferro-quartz	PC-dolomite	69
GP-ferro-quartz	CAC-dolomite	4.82

The most resistant geopolymer concrete mixtures made use of siliceous (low basicity) aggregates.

Conclusions: Control Mixes

2. Calcium-aluminate cement concrete

CAC-dolomite concrete was found to have the highest difference in performance between the dynamic HCl test and the Static HCl test (quantified using the abrasion factor).

The higher performance in the static HCl test of CAC is attributed to the formation of alumina gel (Ah_x) on the corroding surface. Protective effects of AH_x are observed at pH 1- 2.

3. Portland cement concretes

Exhibit poor resistance to static or dynamic dynamic HCl conditions.

General Conclusions

1. Geopolymer concretes have significantly higher resistance compared to calcium based hydraulic binder concretes. This performance is attributed to higher chemical stability of the material.
2. Pairing your Cement-aggregate combinations is important for acid corrosion.
3. Exposure conditions can have a significant effect on acid durability (static vs dynamic conditions)
4. Chemical characterisation by analytical methods has a key role to understanding acid corrosion of concrete.
5. Secondary acid resistance mechanisms can be significant (precipitates/gels).

Thank you.

Questions?

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