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Rational Methods for Evaluating Chloride Penetrability and Corrosion Performance of BCSA Cement Composites

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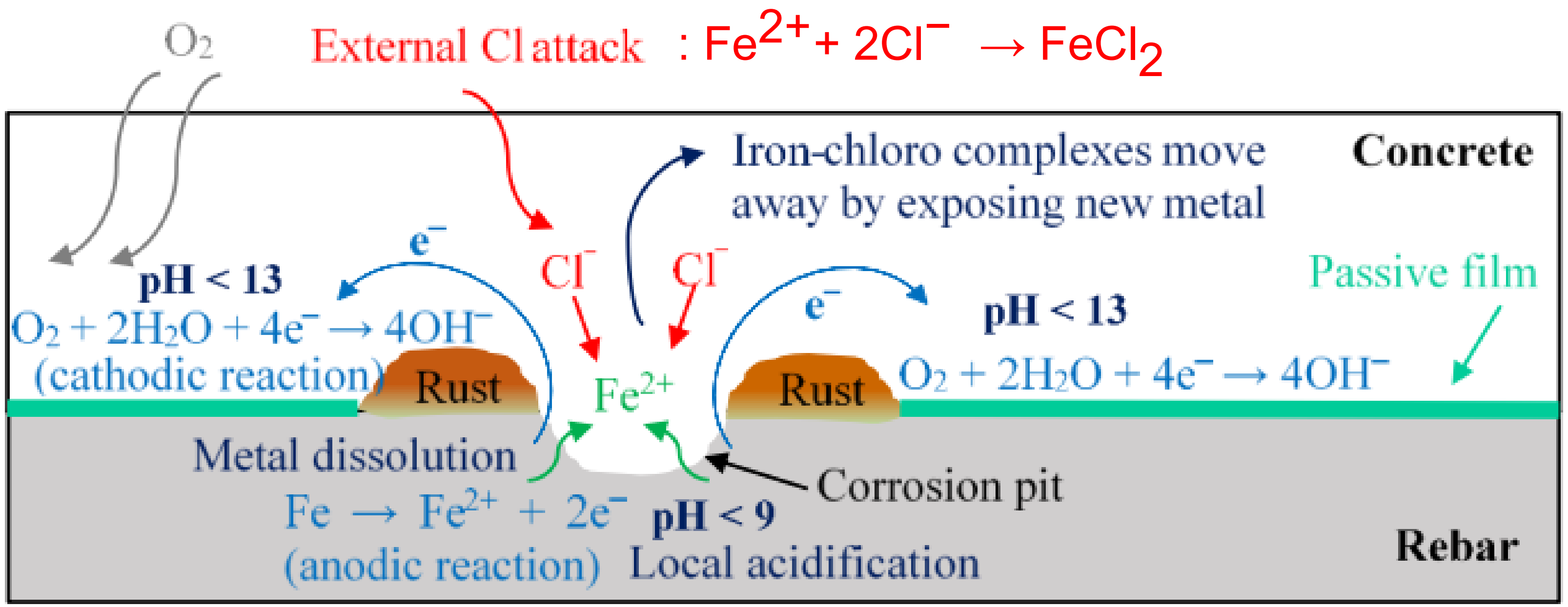
Chloride-induced corrosion of embedded steel



Materials and mixture proportions

Oxide	BCSA	PC
CaO	51	63
SiO_2	14	19
Al_2O_3	14	4.6
Fe_2O_3	0.87	3.3
MgO	0.76	2.0
SO_3	17	4.4
Alkalis	0.61	0.89
LOI	1.6	2.5

Cement type	*w/cm*	Cement *kg/m³*	Water *kg/m³*	Sand *kg/m³*	#67 stone *kg/m³*	Citric acid *% cm*
PC	0.36	360	130	900	1100	1.00
BCSA	0.40	340	136			
	0.45	320	144			
	0.55	280	154			

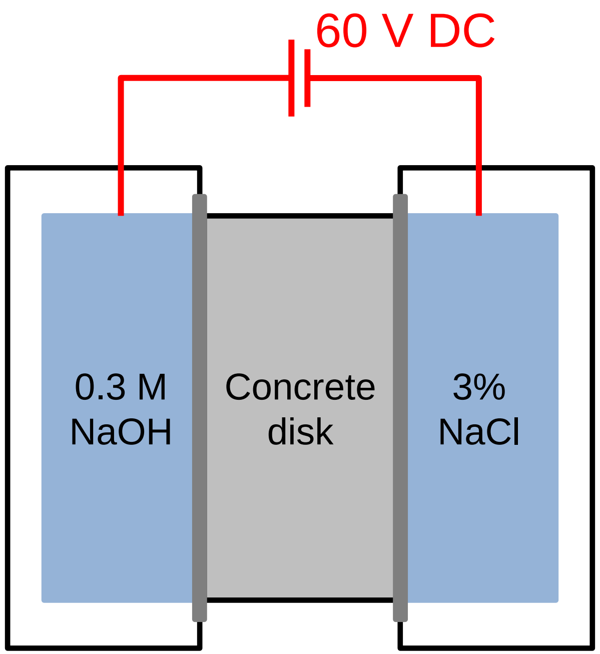
Rough composition of BCSA

Belite	44%
Ye'elimite	27%
Calcium sulfate	24%

Rapid chloride penetrability test – ASTM C1202

Cement	*w/cm*	Charge passed (C)	Penetrability
PC	0.36	337	Very low
BCSA	0.40	175	Very low
	0.45	268	Very low
	0.55	262	Very low

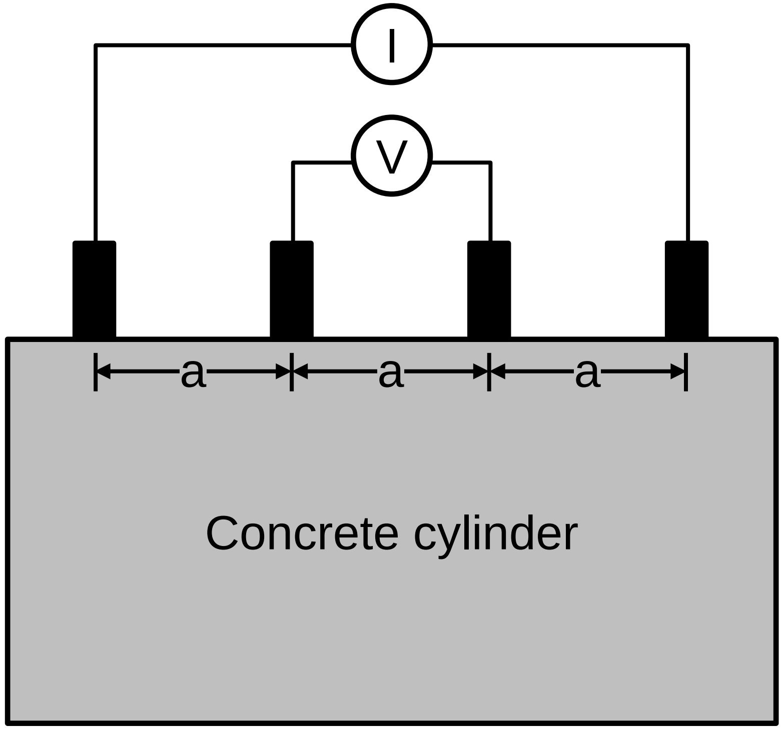
Charge passed (C)	Penetrability
>4,000	High
2,000–4,000	Moderate
1,000–2,000	Low
100–1,000	Very Low
<100	Negligible



Surface resistivity test – AASHTO T 358

Cement	*w/cm*	Resistivity (kΩ-cm)	Penetrability
PC	0.36	10	High
BCSA	0.40	73	Very low
	0.45	48	Very low
	0.55	34	Low

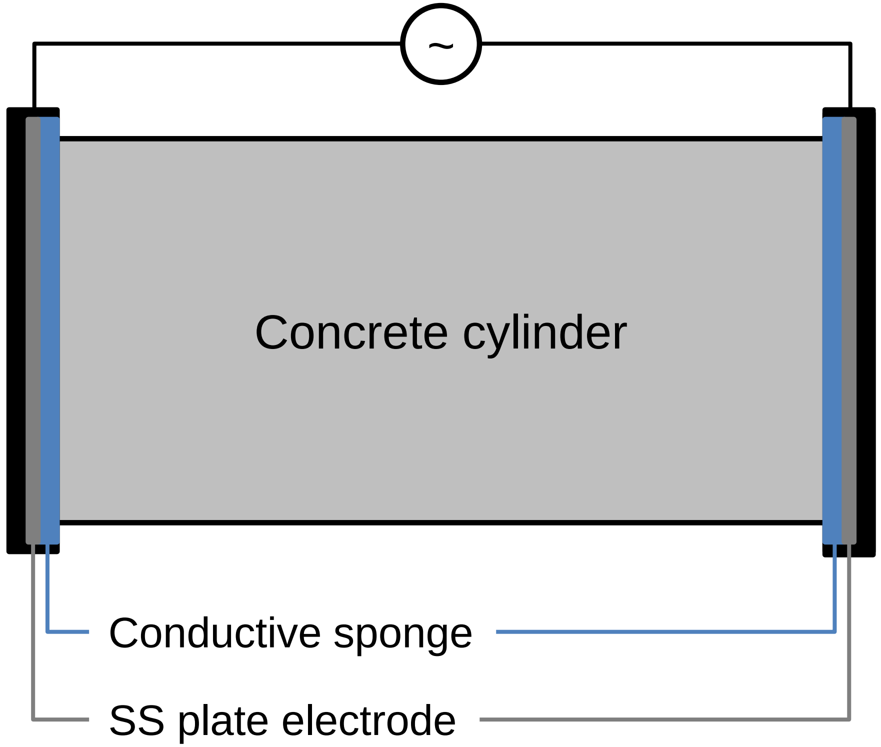
Resistivity (kΩ-cm)	Penetrability
<12	High
12-21	Moderate
21-37	Low
37-254	Very Low
>254	Negligible



Bulk resistivity test – ASTM C1876

Cement	*w/cm*	Resistivity (kΩ-cm)	Penetrability
PC	0.36	3.84	High
BCSA	0.40	6.77	Moderate
	0.45	6.77	Moderate
	0.55	4.63	High

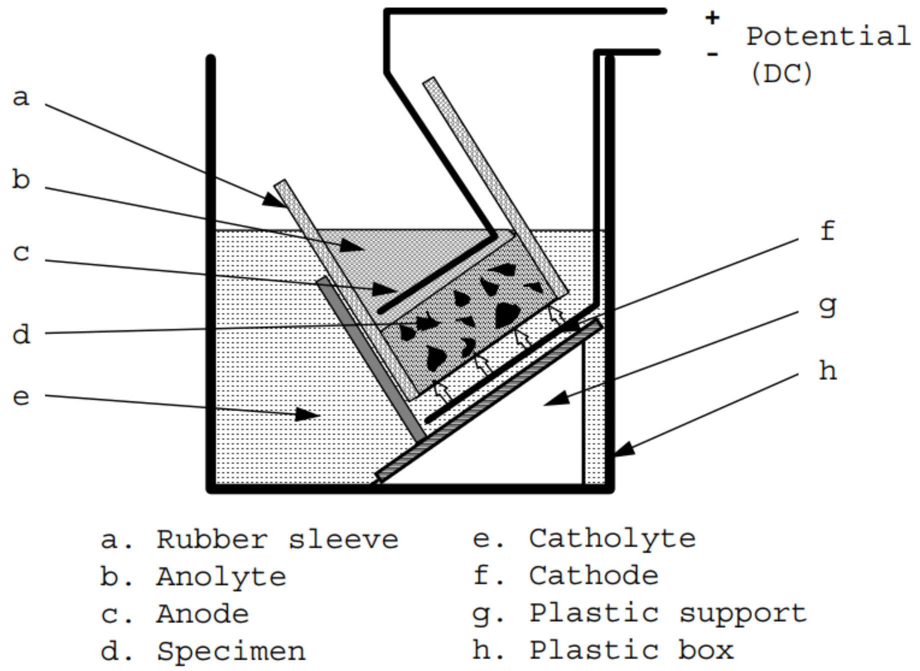
Resistivity (kΩ-cm)	Penetrability
<5	High
5-10	Moderate
10-20	Low
20-200	Very Low
>200	Negligible



Non-steady-state migration test – NT 492

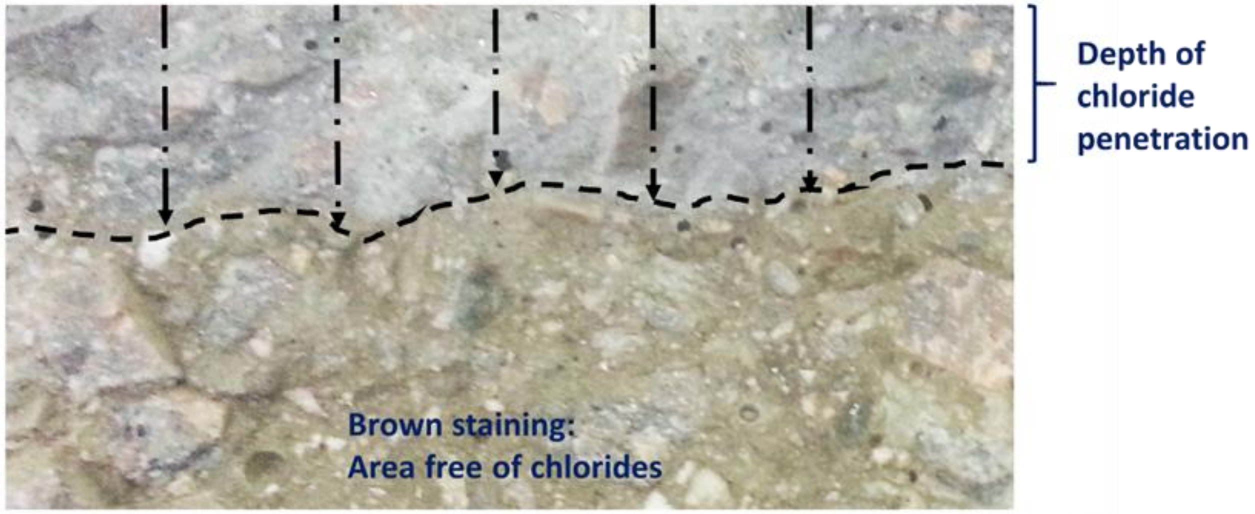
Cement	*w/cm*	Migration coefficient (m^2/s)	Penetrability
PC	0.36	10.78×10^{-12}	Moderate
BCSA	0.40	2.07×10^{-12}	Low
	0.45	10.39×10^{-12}	Moderate
	0.55	17.59×10^{-12}	High

Migration coefficient (10^{-12} m^2/s)	Penetrability
> 16	High
8-16	Moderate
2-8	Low
< 2	Very Low



Non-steady-state migration test – NT 492

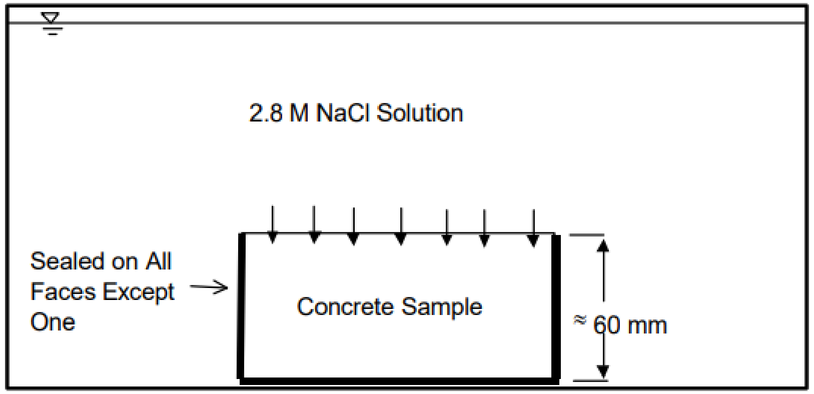
- $D_{NSSM} = \frac{RT}{zFE} \cdot \frac{x_d - \alpha\sqrt{x_d}}{t}$
- $E = 2\sqrt{\frac{U-2}{L}}$
- $\alpha = 2\sqrt{\frac{RT}{zFE}} \cdot \text{erf}^{-1}\left(1 - \frac{2c_d}{c_0}\right)$



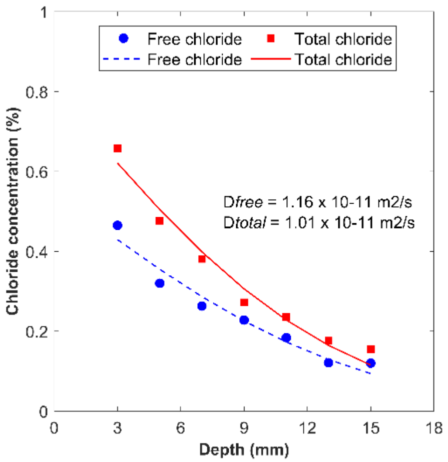
- c_d = chloride concentration threshold for $AgNO_3$ color change
- c_d = 0.07 N for PC concrete
- c_d is unknown for BCSA concrete

Bulk diffusion test (ASTM C1556)

Cement	*w/cm*	Migration coefficient (m^2/s)	Penetrability
PC	0.36	5.80×10^{-12}	Low
BCSA	0.40	28.3×10^{-12}	High
	0.45	23.9×10^{-12}	High
	0.55	15.9×10^{-12}	High



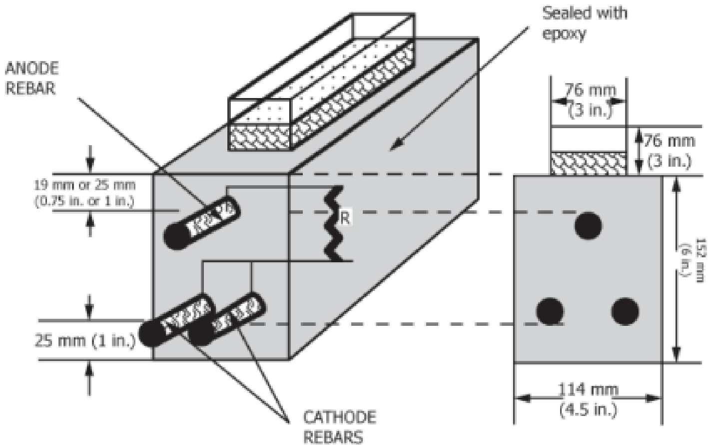
Diffusion coefficient (10^{-12} m^2/s)	Penetrability
> 15	High
10-15	Moderate
5-10	Low
2-5	Very Low
< 2	Negligible

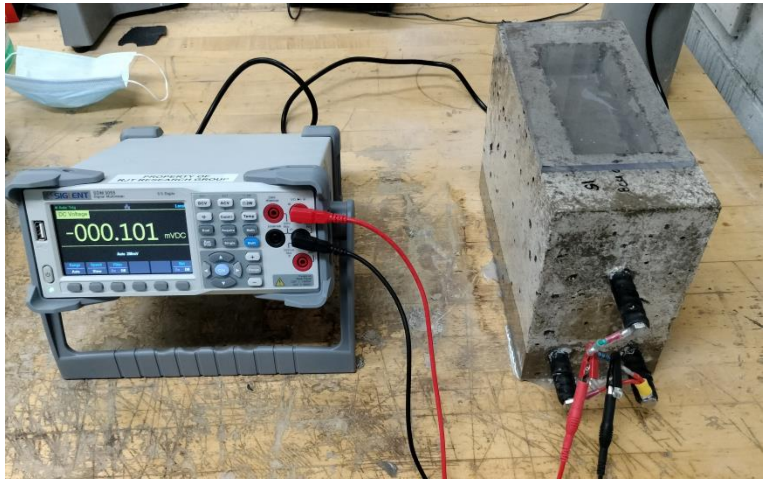


Comparison of penetrability classifications

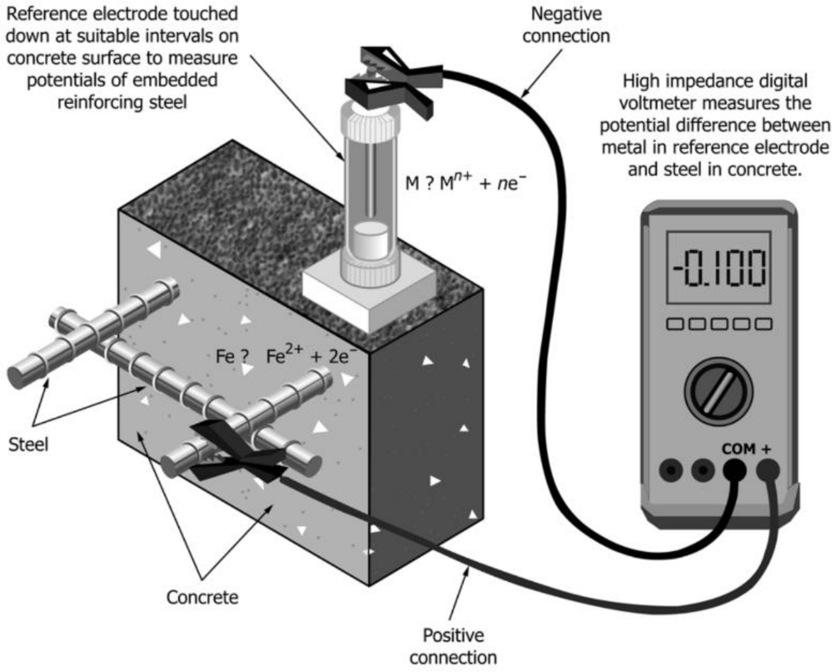
Cement	*w/cm*	RCPT	Surface resistivity	Bulk resistivity	NSSM	Bulk diffusion
PC	0.36	Very low *337 C*	High 10 kΩ-cm	High *4 kΩ-cm*	Moderate $D = 11 \times 10^{-12}$ m²/s	Low $D = 6 \times 10^{-12}$ m²/s
BCSA	0.40	Very low *175 C*	Very low *73 kΩ-cm*	Moderate *7 kΩ-cm*	Low $D = 2 \times 10^{-12}$ m²/s	High $D = 28 \times 10^{-12}$ m²/s
	0.45	Very low *268 C*	Very low *48 kΩ-cm*	Moderate *7 kΩ-cm*	Moderate $D = 10 \times 10^{-12}$ m²/s	High $D = 24 \times 10^{-12}$ m²/s
	0.55	Very low *262 C*	Low 34 kΩ-cm	High *5 kΩ-cm*	High $D = 18 \times 10^{-12}$ m²/s	High $D = 16 \times 10^{-12}$ m²/s

Corrosion performance – ASTM G109

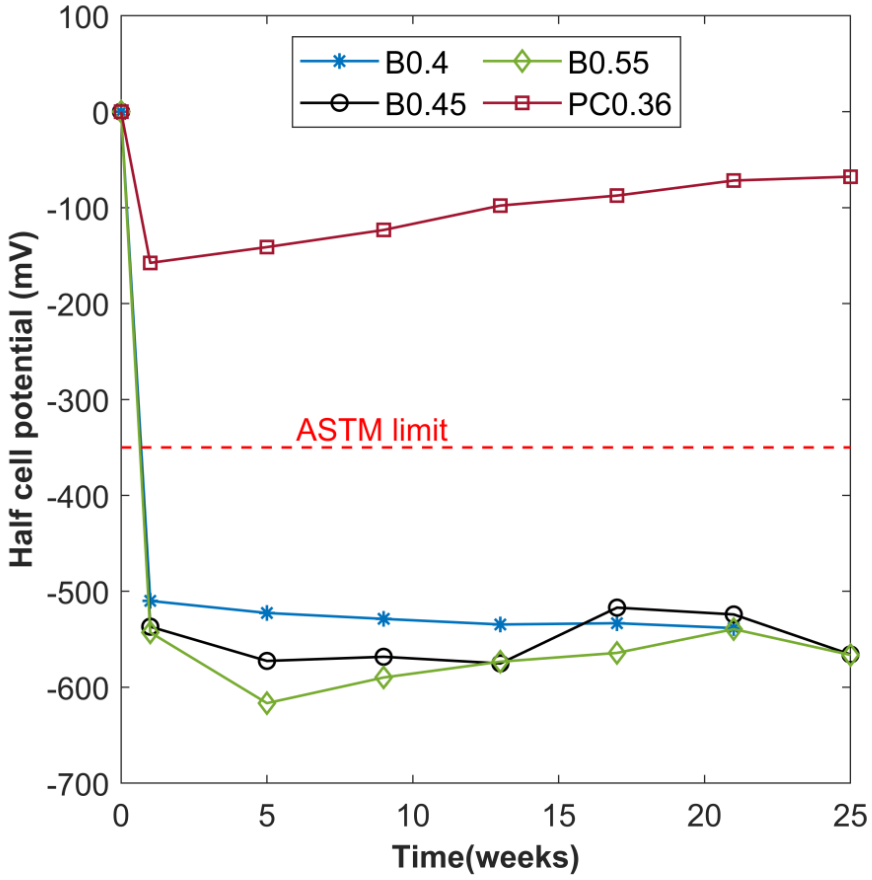




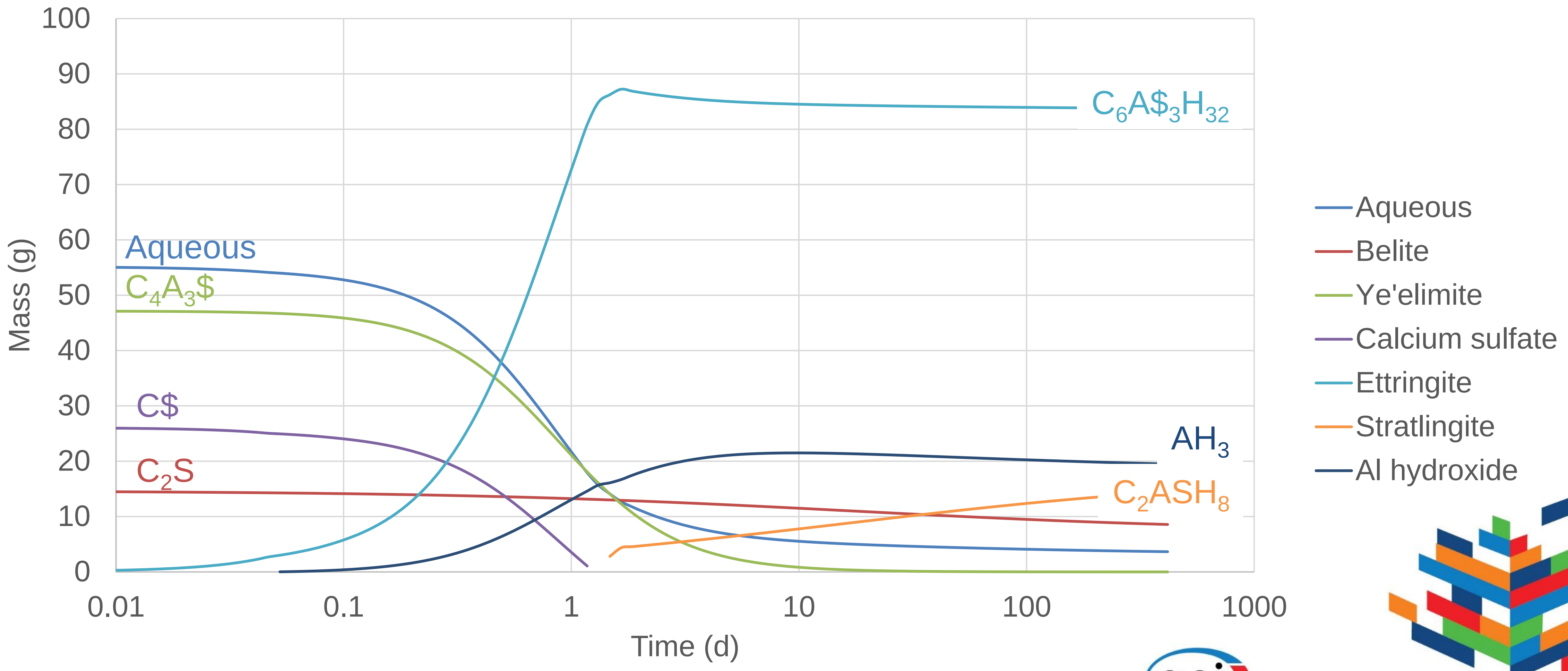
Corrosion performance – ASTM C876



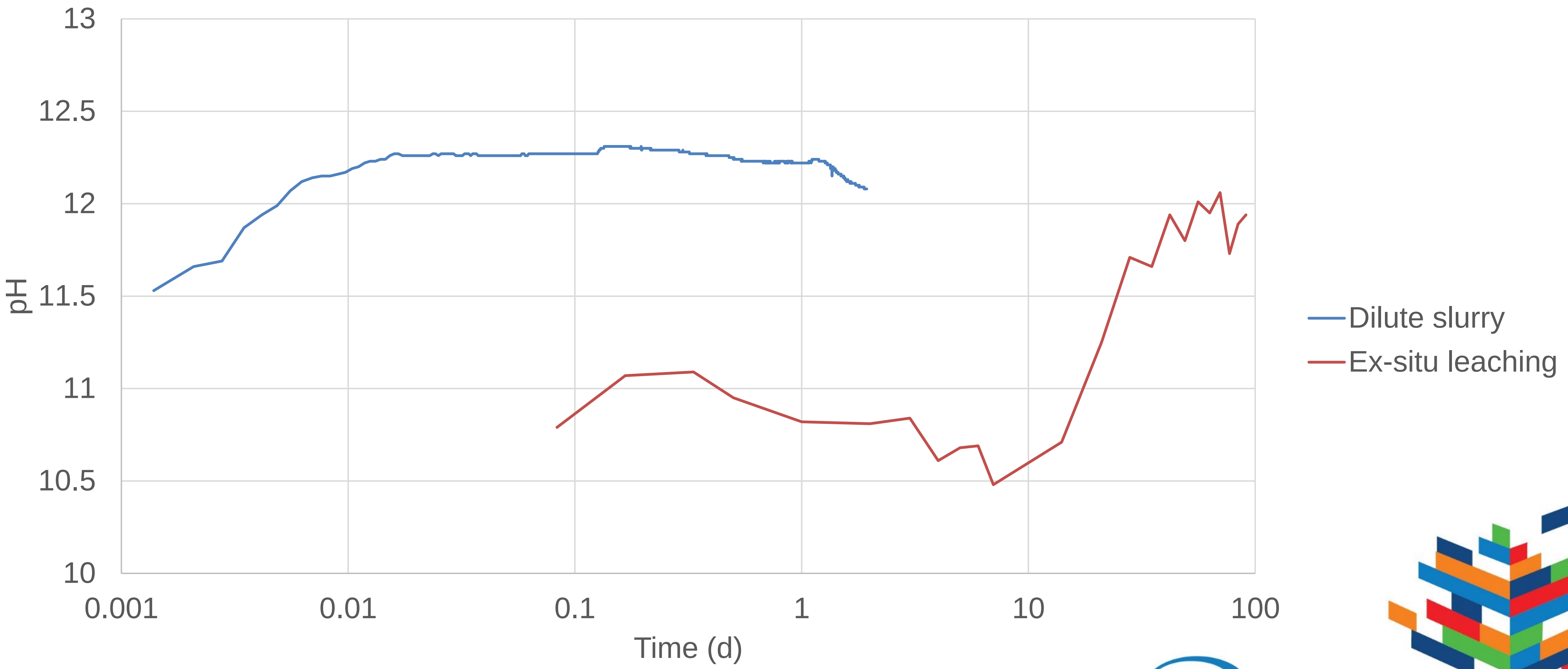
Half cell potential	Corrosion condition
> −200 mV	Unlikely
−200 to −350 mV	Uncertain
< −350 mV	Likely



Hydration modeling - CEMGEMS



Pore solution alkalinity



Remaining questions

1. Does later-age hydration of belite and associated elevation in pH translate to better corrosion resistance under ASTM G109?

2. Do chloride penetrability test results correlate well with later-age corrosion performance?

3. What about formation factor, direct pore solution expression, etc?

Thank you!

Contact information

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