CHLORIDE INGRESS AND CHLORIDE-INDUCED CORROSION IN CONCRETE PRODUCED WITH CALCIUM SULFOALUMINATE CEMENT

Presented by:

Tijani Mohammed (Ph.D. Candidate)

Contributors:

Ikechukwu K. Okechi (Ph.D. Candidate) Texas State University

Dr. Anthony Torres, Texas State University

Dr. Federico Aguayo, University of Washington

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- Research Objectives/ Significance
- Research Methodology
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  - Testing
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- Conclusion
- Future work

Background

CSA Benefits

- Rapid setting and hardening (33 MPa in 1st 3 hours of hydration)
- Lower CO_2 emissions during production
- Self-stressing and shrinkage compensation
- High resistance to sulfates

Carbonation in CSA concrete

- Lower initial alkali content (lower buffer capacity)
- Potentially more rapid rate of carbonation
- Potential breakdown of ettringite due to carbonation
- Alteration in hydrates may potentially lead to increased porosity and reduced strength

Chloride-ion ingress in CSA concrete

- Potentially lower chloride binding capacity
- Lower Friedel's salt formation
- High penetrability of chlorides worsened by carbonation and increased porosity
- Can be exacerbated by the presence of cracks

Research Problem

- Use limited to rapid repair applications
- Limited long term durability data of use in reinforced concrete

Research Objective/Significance

Objective

- To assess the corrosion rate due to chloride-ion ingress on cracked, pre-carbonated, and normal (control) reinforced concrete produced with CSA cements using Type I/II as control.

Significance

- Gain understating of chloride-ion corrosion resistance of reinforced concrete produced with CSA cements.
- Generate data that will provide guidance for safe and effective use of CSA cement in reinforced concrete

Methodology

Materials

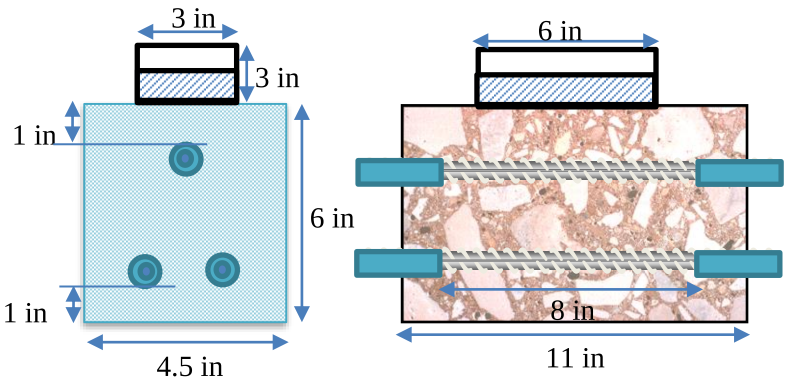
- 4 CSA cements and Type I/II cement (OPC2)
- A liquid polycarboxylate-ether-based superplasticizer
- Set retarders (Citric acid)
- Well-graded coarse aggregate and river sand

Cement mix proportion and compressive strength

Cement Type	W/CM	Total Binder Kg/m^3(lb/yd^3)	Strength (MPa)		
			1-Day	7-Day	28-Day
OPC2	0.35	446 (752)	41.4	60.3	69.0
CSA1	0.35	446 (752)	51.1	59.9	65.2
CSA2	0.38	390 (658)	36.5	41.6	43.9
CSA3	0.38	390 (658)	55.7	58.7	57.9
CSA4	0.38	390 (658)	35.6	39.7	45.2

Sample preparation

- Samples prepared per ASTM G109 with three series of beam preconditioning:
- **Series 1 – Control:** Standard G109 reinforced beams (no carbonation or crack)
- **Series 2 – Cracked:** Reinforced beams cast with thin 1.0 mm plastic shim at a depth of 10mm at the center of the sample (removed prior to final set)
- **Series 3 – Carbonated:** Reinforced beams placed into accelerated carbonation chamber @ 4%CO_2 and 57% RH for 28 days



Schematic representation of ASTM G109 samples

Series 3: Carbonation depth

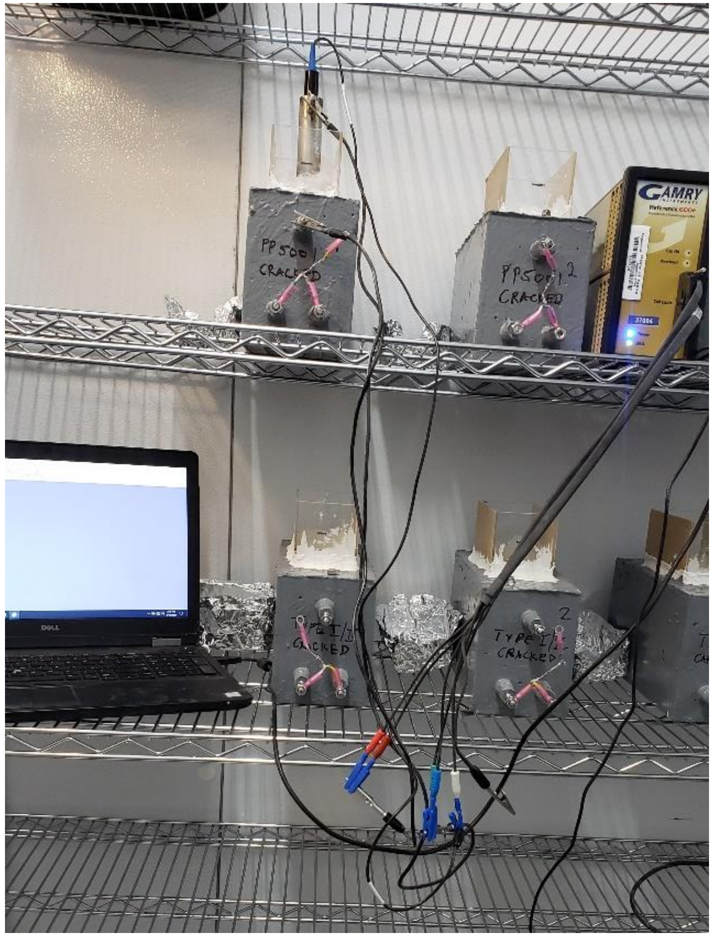
Cement Type	Depth (mm)	Deviation (mm)
OPC2	0	± 0
CSA1	6.9	± 0.86
CSA2	8.8	± 1.30
CSA3	9.2	± 1.04
CSA4	10.3	± 1.50

Series 2: Crack introduction

Series 3: Carbonation chamber

Testing

- Samples were ponded with 3% NaCl for 2 weeks and left dry for another 2 weeks repeatedly
- Microcell corrosion measurement with Gamry equipment (LPR technique)
  - ✓Half-cell potential (Vs Ag/AgCl)
  - ✓Current density

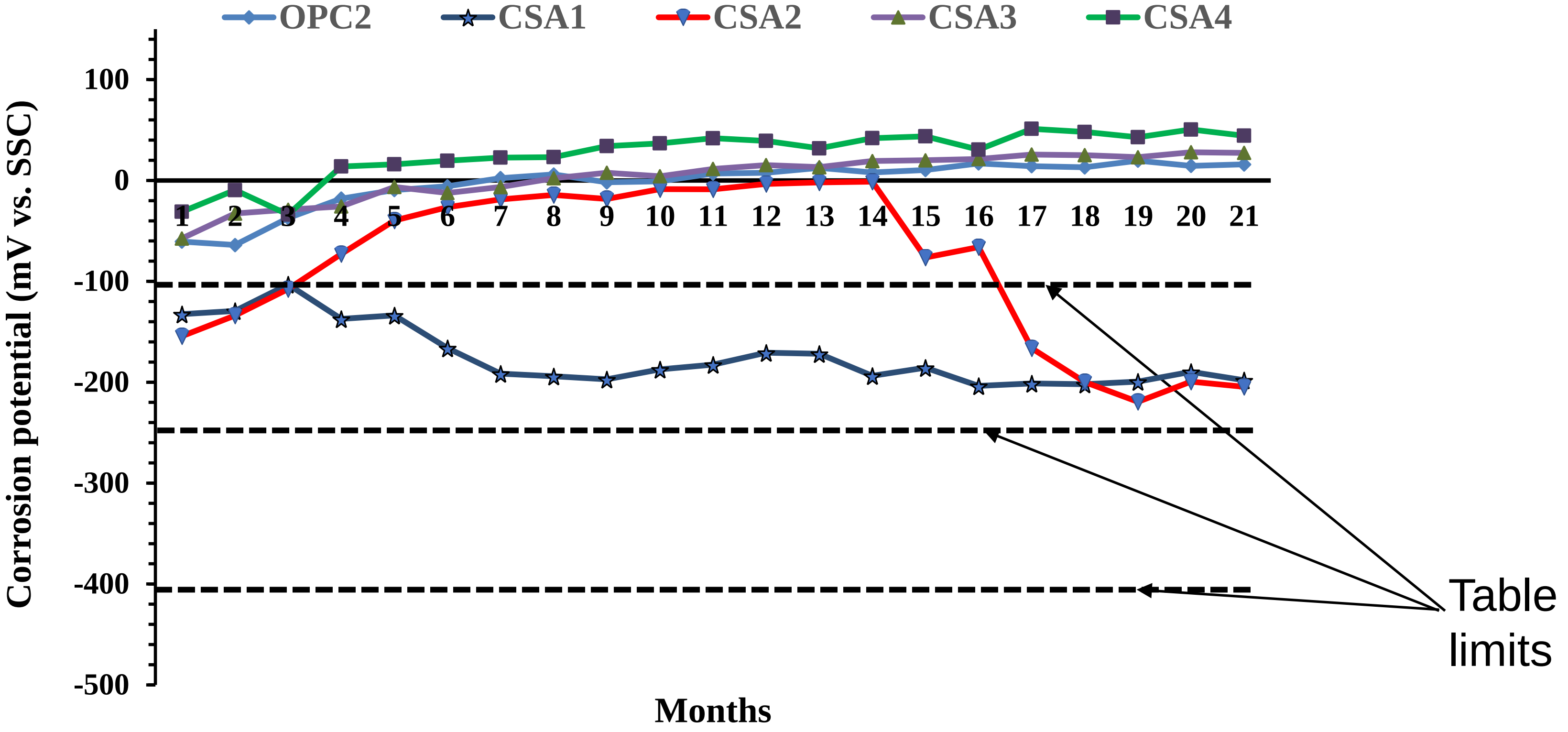


Microcell corrosion measurement

Results and Discussion

Control (half-cell)

- OPC2, CSA3, and CSA4 indicate a low risk of corrosion due to high binding
- CSA1 (high ye'elmite) intermediate risk throughout due to lower binding. CSA2 (high belite) low risk of corrosion until 14 months where it showed intermediate corrosion rate



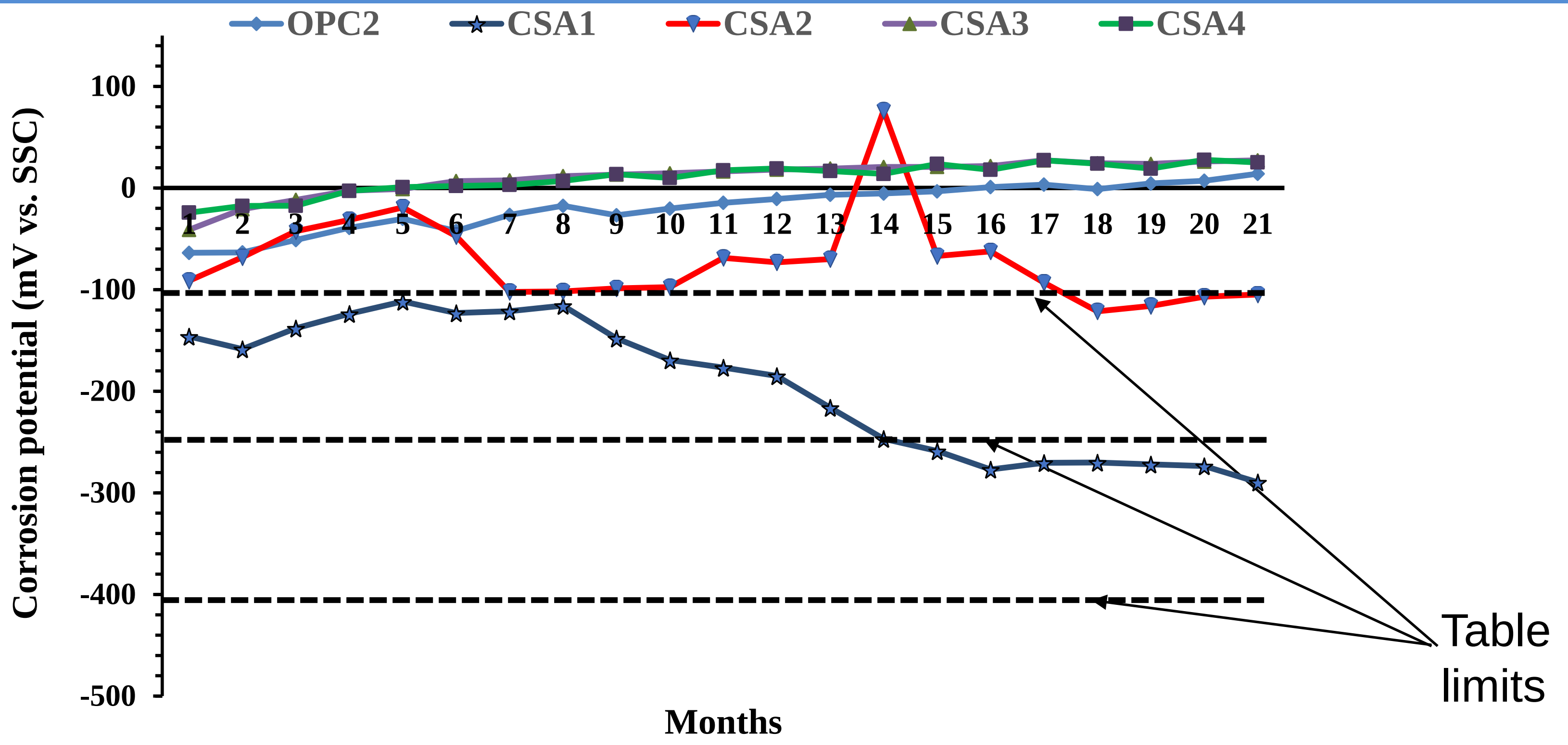
Equivalent Ag/AgCl potentials for classifying corrosion activity based on ASTM C876

Corrosion potential (mV vs Ag/AgCl)	Condition
> -106	Low (< 10% risk of corrosion)
-106 to -256	Intermediate (50% risk of corrosion)
-256 to -406	High (> 90% risk of corrosion)
< -406	Severe corrosion

Results and Discussion

Carbonated (half-cell)

- OPC2, CSA3, and CSA4 indicate a low risk of corrosion due to high binding.
- CSA1 (high ye'elmite) high risk of corrosion from AFt phases breakdown due to carbonation. CSA2 (high belite) showed low risk of corrosion not affected much by carbonation



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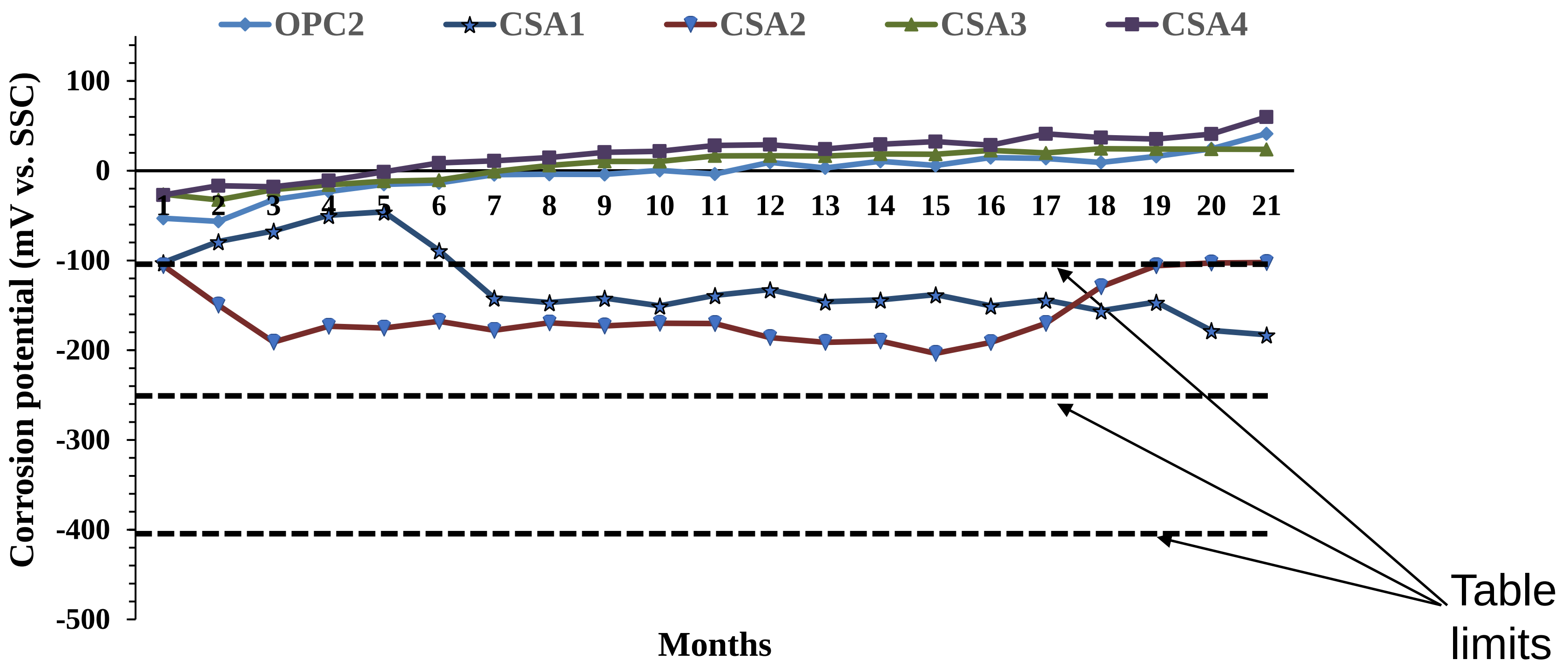
< -406	Severe corrosion

Results and Discussion

Cracked (half-cell)

- OPC2, CSA2, and CSA3 indicate a low risk of corrosion due to high chloride binding due to the presence of Friedel's salt (OPC2) and permeability-reducing admixtures (CSA3 & CSA4)
- CSA1 (high ye'elmite) and CSA2 (high belite) intermediate risk of corrosion due to low binding and no Friedel's salt and perhaps cracks



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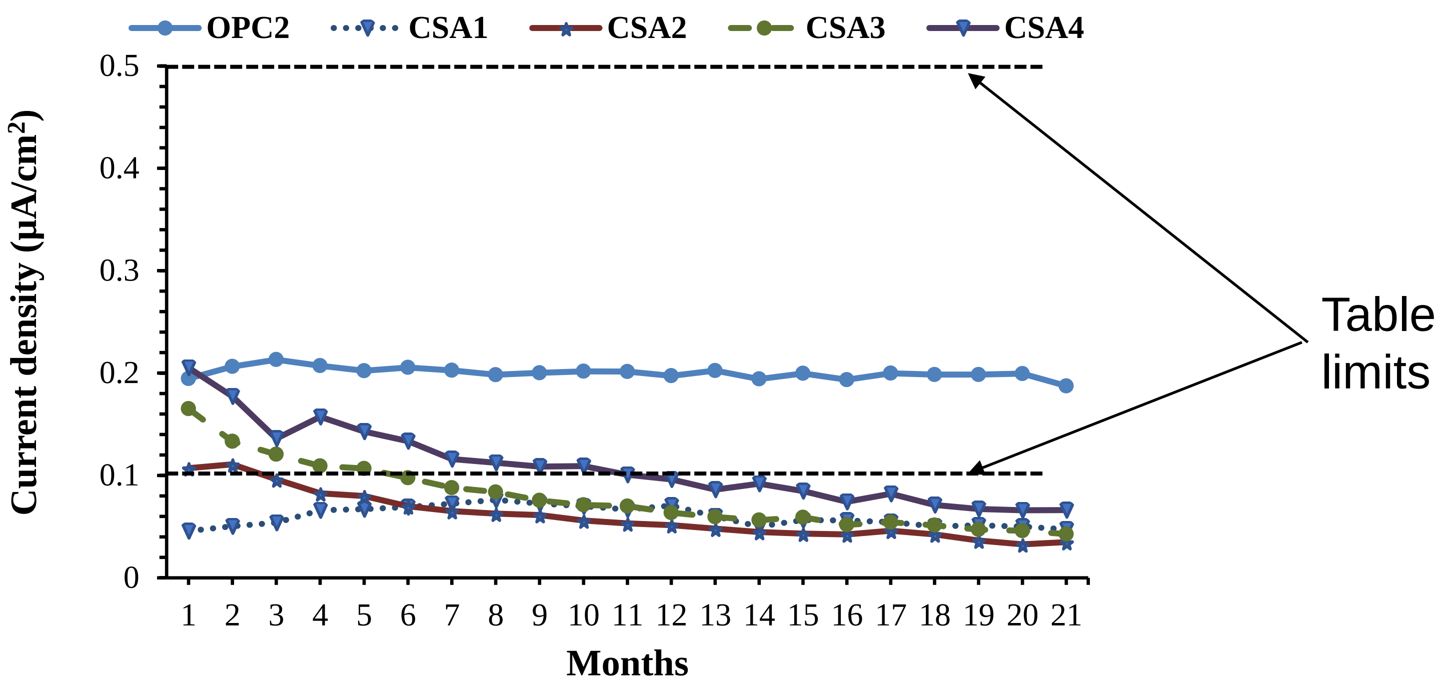
Results and Discussion

Current density Normal

- Samples exhibiting passive to moderate corrosion rate



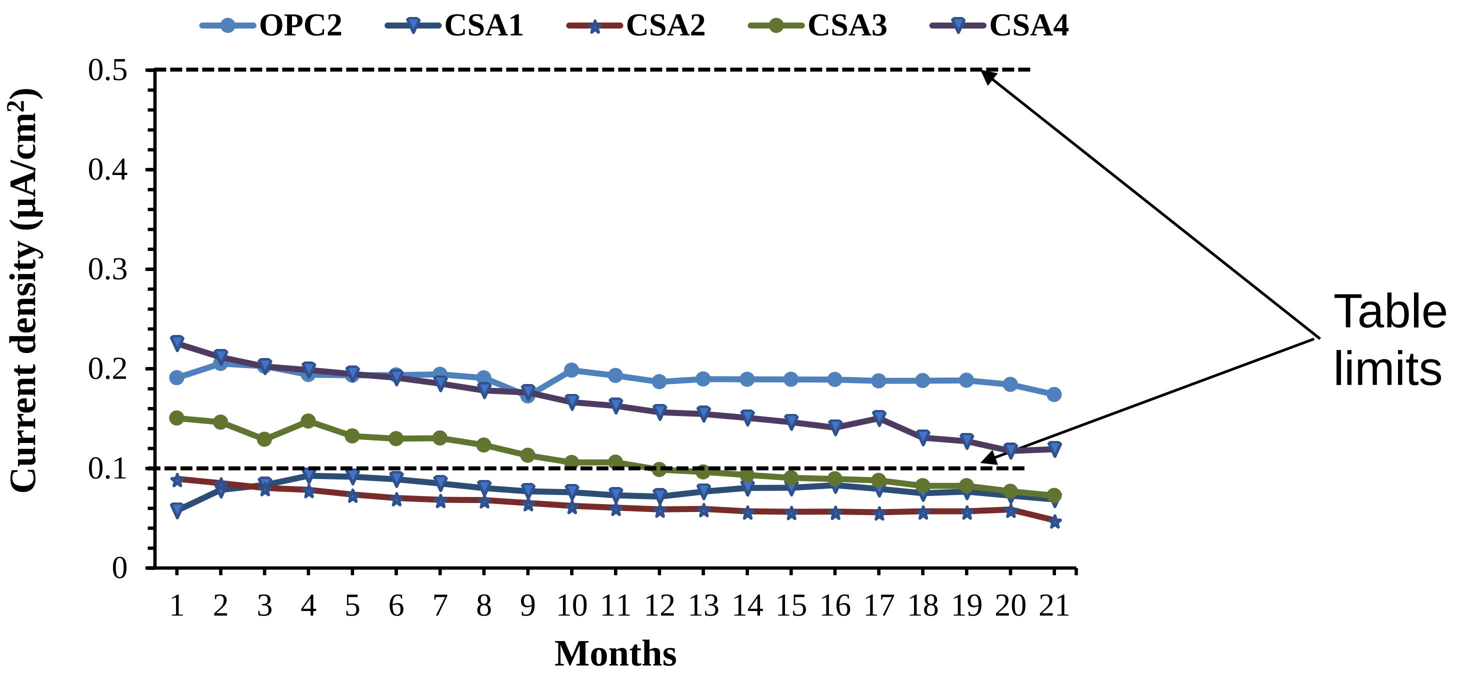
Classifying risk of corrosion using corrosion current density

Corrosion current density (μA/cm^2)	Corrosion classification
Up to 0.1	Passive condition
0.1 – 0.5	Low to moderate corrosion
0.5 – 1	Moderate to high corrosion
More than 1	High corrosion rate

Results and Discussion

Current density Carbonated

- Samples exhibiting passive to moderate corrosion rate



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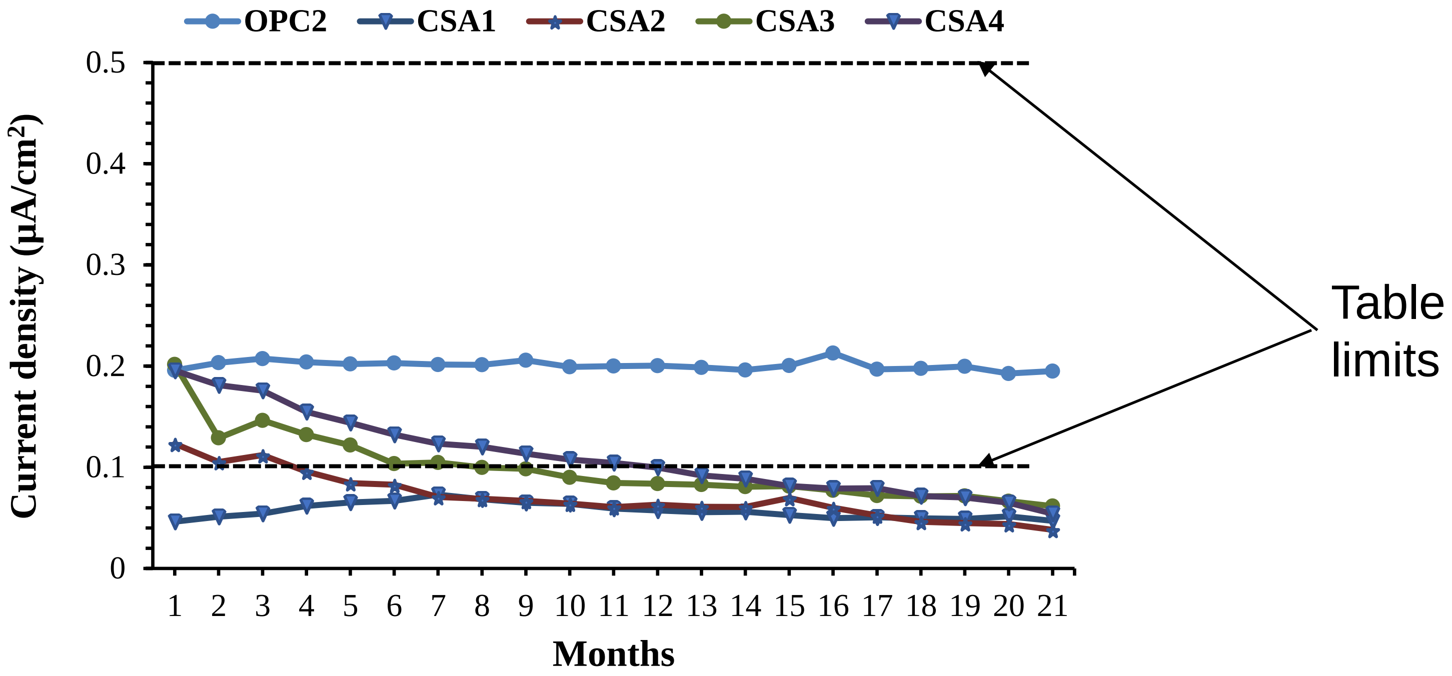
More than 1	High corrosion rate

Results and Discussion

Current density Cracked

- Samples are considered as exhibiting passive to moderate corrosion rate



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More than 1	High corrosion rate

Conclusion

- Based on half-cell potential:
  - Carbonated CSA1(high ye’elmite) showed a high corrosion rate and could be associated with the breakdown AFt phases and their low binding capacity.
  - CSA1 and CSA2 had a higher rate of corrosion among the cracked samples
  - OPC2 demonstrated a low corrosion rate due to a high binding capacity and the presence of Friedel's salt.
  - CSA3 and CSA4 (Both Belite cements) showed low corrosion rate due to addition of permeability reducing admixtures.

- Based current density:
  - Cracked, Carbonated, and Normal samples demonstrated a passive and a low to moderate corrosion rate.

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Contact

Name	Institution	Email
Tijani Mohammed	Texas State University	t_m382@txstate.edu
Okechi Kingsley	Texas State University	iko4@txstate.edu
Dr. Anthony Torres	Texas State University	anthony.torres@txstate.edu
Dr. Fred Aguayo	University of Washington	aguayo12@uw.edu

Thank you for Listening

Q/A

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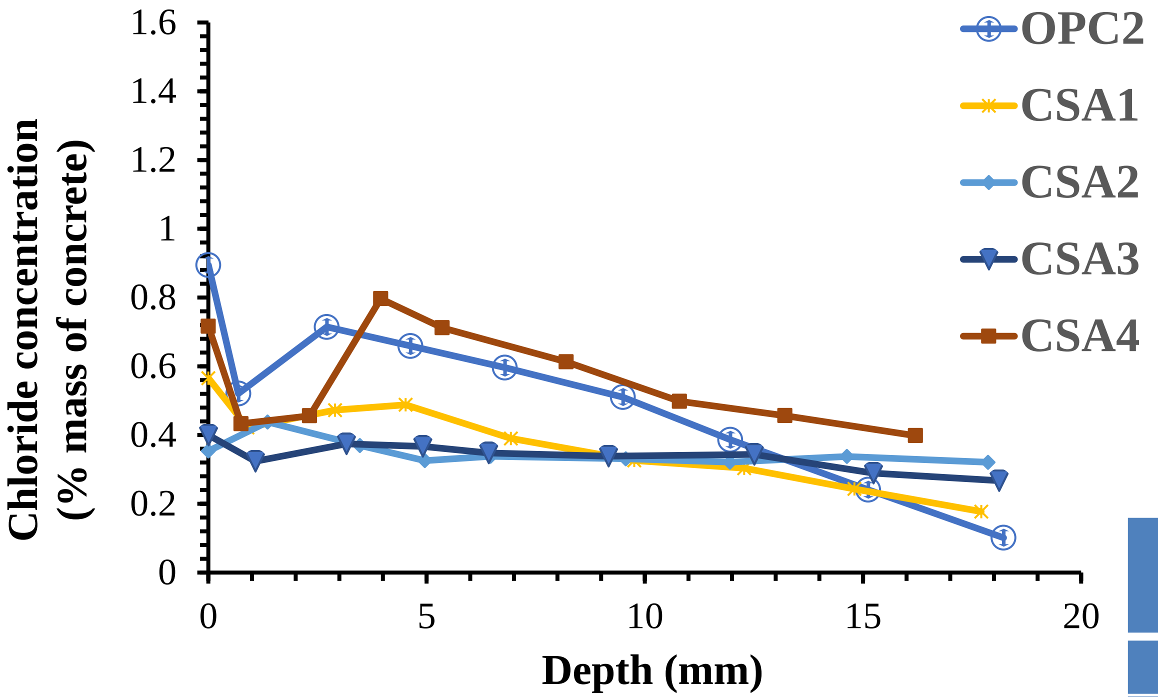
Diffusion coefficient and surface concentration



Cement Type	Surface concentration, C_S (%)	Diffusion coefficient, D_C (m^2/s)
OPC2	0.89	6.25E-12
CSA1	0.57	1.04E-11
CSA2	0.35	6.75E-10
CSA3	0.40	6.41E-11
CSA4	0.72	2.94E-11

Chemical composition

Cement ID	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Na_2O_e	LOI
OPC2	21.06	4.02	3.19	63.91	1.08	2.89	0.14	0.61	0.53	2.29
CSA1	9.07	21.61	2.26	45.26	0.94	20.26	0.07	0.30	0.27	1.05
CSA2	20.56	16.14	1.35	45.31	1.23	14.73	0.77	0.72	1.24	4.74
CSA3	13.63	15.82	0.75	51.28	1.14	16.62	0.29	0.62	0.69	3.06
CSA4	14.72	14.37	1.22	53.85	1.23	14.40	0.10	0.59	0.49	3.39

Cement Type	Description
OPC2	OPC Type I/II
CSA1	High Ye’elmite CSA (40% Ye’elmite)
CSA2	High belite CSA (58% belite)
CSA3	Belite cement (39% belite) + permeability reducing admixtures
CSA4	CSA belite cement (42% belite) + permeability reducing admixtures

Phases	CSA1	CSA2	CSA3	CSA4	PCSA1	PCSA2
C_4A_3S (Ye'elmite)	40.2	30.5	30.6	27.1	18.3	26.9
C_2S (Belite)	26.0	58.9	39.1	42.2	49.8	57.7
CS	25.5	18.2	21.4	18.4	14.1	15.9
C_4AF	6.9	4.1	2.3	3.7	9.1	10.7