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# UHPC Fresh Chloride Limit Testing

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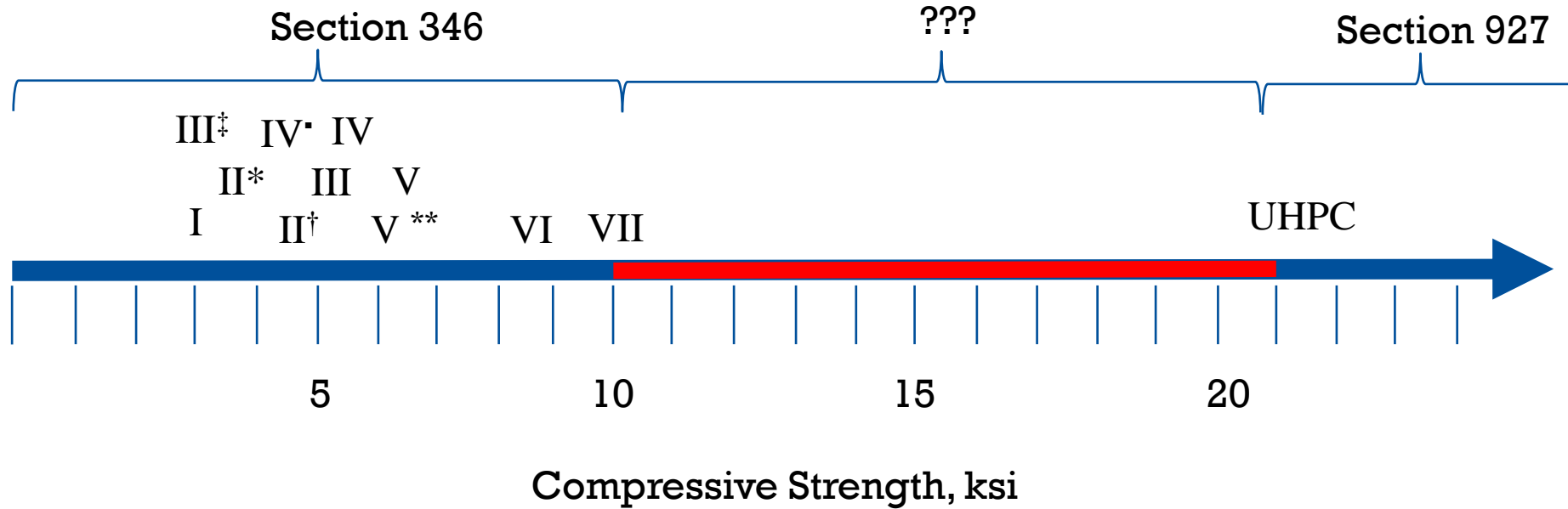
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# 2 Outline

- Background
- Mix design proportions
- Test methodology
- Test results
- Acid and water-soluble tests
- Conclusion

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# FDOT Concrete Classes



Only tensile strength limits are for section 927: 1200 psi

- \*pavement
- <sup>†</sup>bridge deck
- <sup>‡</sup>Seal
- <sup>•</sup>Drilled Shaft
- \*\*Special

**Do We Need Different Strength & Durability Classes?**

## 4 Background

- Mixes with higher cementitious values are more prone to exceeding the chloride threshold value
  - Compared to normal concrete, UHPC uses too much admixtures

### Fresh Chloride Limits:

- ACI 318 limit

Exposure Class	Maximum water-soluble chloride ion (Cl-) content in concrete, % by mass of cementitious materials	
	Nonprestressed Concrete	Prestressed Concrete
C0: Concrete dry or protected from moisture	1.00	0.06
C1: Concrete exposed to moisture but not to an external source of chlorides	0.30	0.06
C2: Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	0.15	0.06

- FDOT limit is 0.4 lb/yd<sup>3</sup> (acid soluble)
  - The 0.4 lb/yd<sup>3</sup> limit for FDOT is based on a 667 lb/yd<sup>3</sup> mix with 0.06% by mass chloride limit

# UHPC Mix Proportions

Mix (ksi)	Weight (lb/yd <sup>3</sup> )				Admixtures (lb/yd <sup>3</sup> )			Calculated Values	
	Sand	Type IL	Slag	Silica fume	HRWR	WRWR	SE	w/cm	cm/s
12-15	1852	1583	0	83	10.9	10.9	2.1	0.25	0.9
15-18	1811	1404	272	136	16.4	16.4	3.4	0.20	1.0
18-21	1585	1597	309	155	30.9	30.9	5.1	0.1625	1.30

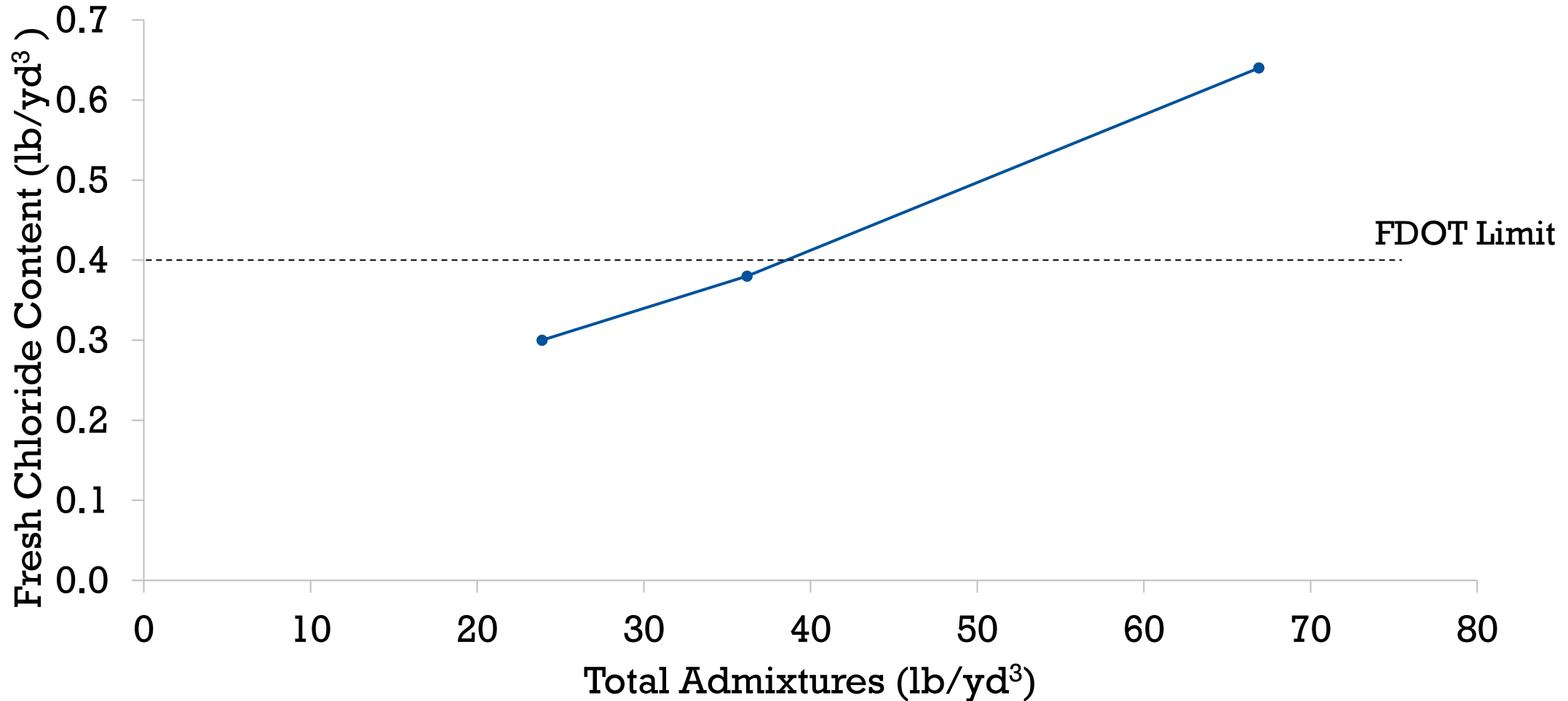
Mix (ksi)	Weight (lb/yd <sup>3</sup> )				Admixtures (lb/yd <sup>3</sup> )				
	Sand	Type III	Silica Flour	White Silica fume	HRWR	Accelerator	RHRWR	w/cm*	cm/s*
21+	1359	1477	369	369	46.1	23.1	40.3	0.13	1.63

\*includes silica flour

Mix	Weight (lb/yd <sup>3</sup> )			
	Sand	coarse aggregate	Cement IL	w/cm
0.44	955	1781	700	0.44

No admixtures were used

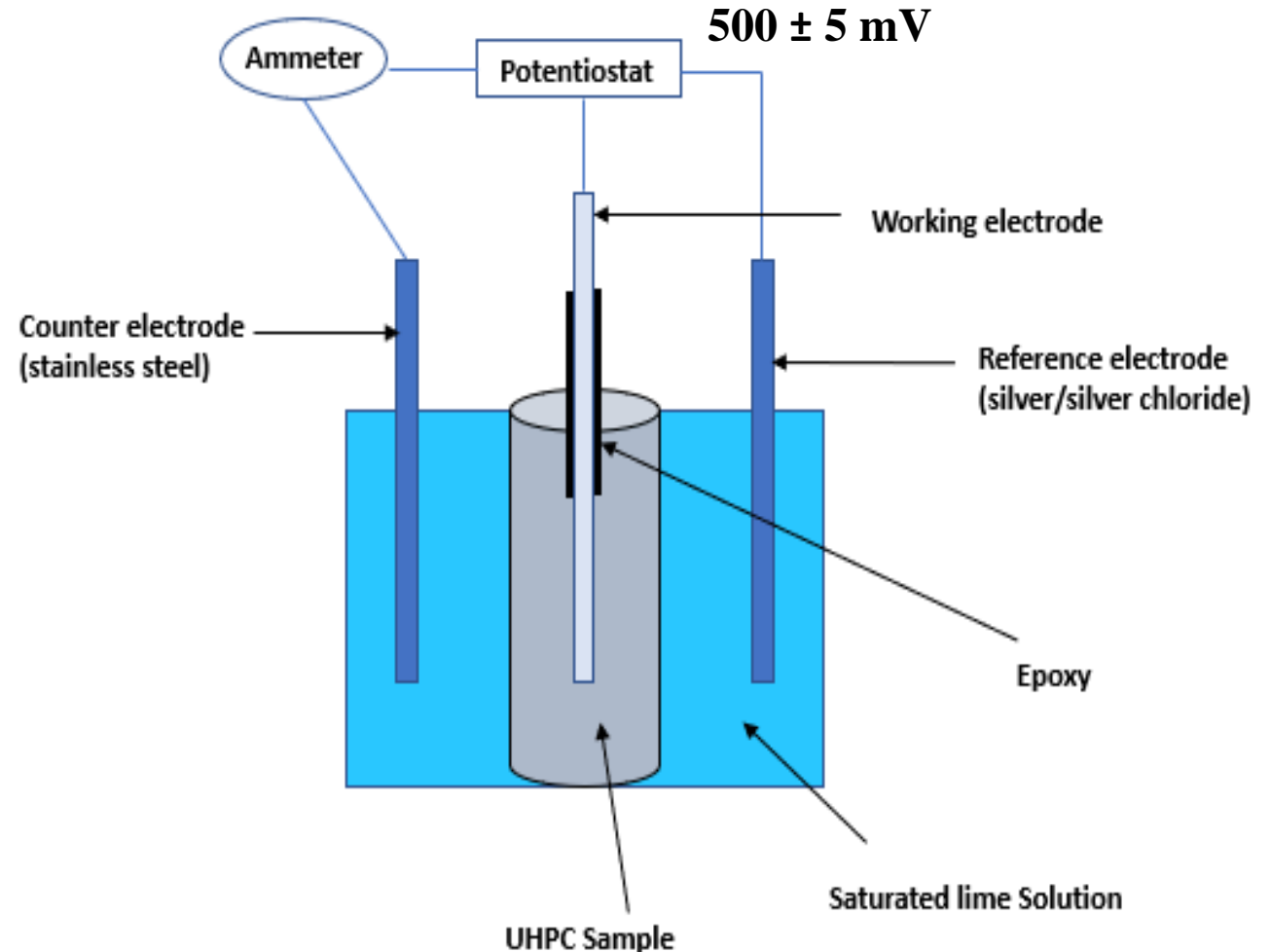
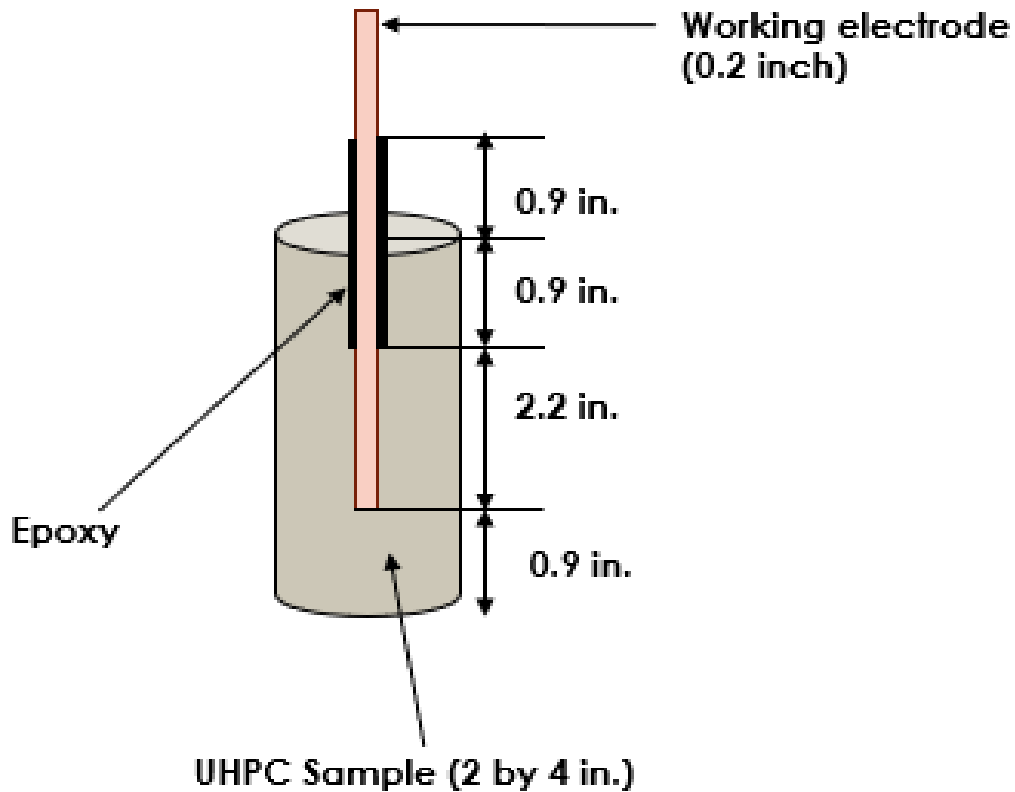
# Fresh Chloride Content

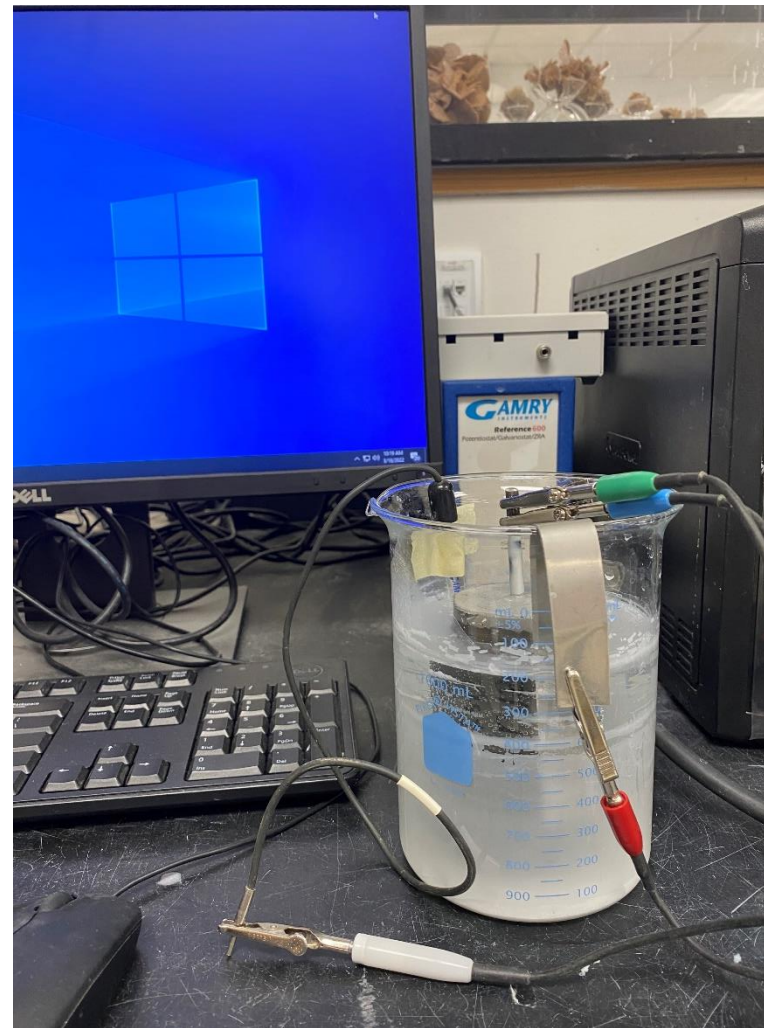


# Methodology: Modified EN 480-14

Determination of the Effect on Corrosion Susceptibility of Reinforcing Steel by Potentiostatic Electro-Chemical Test

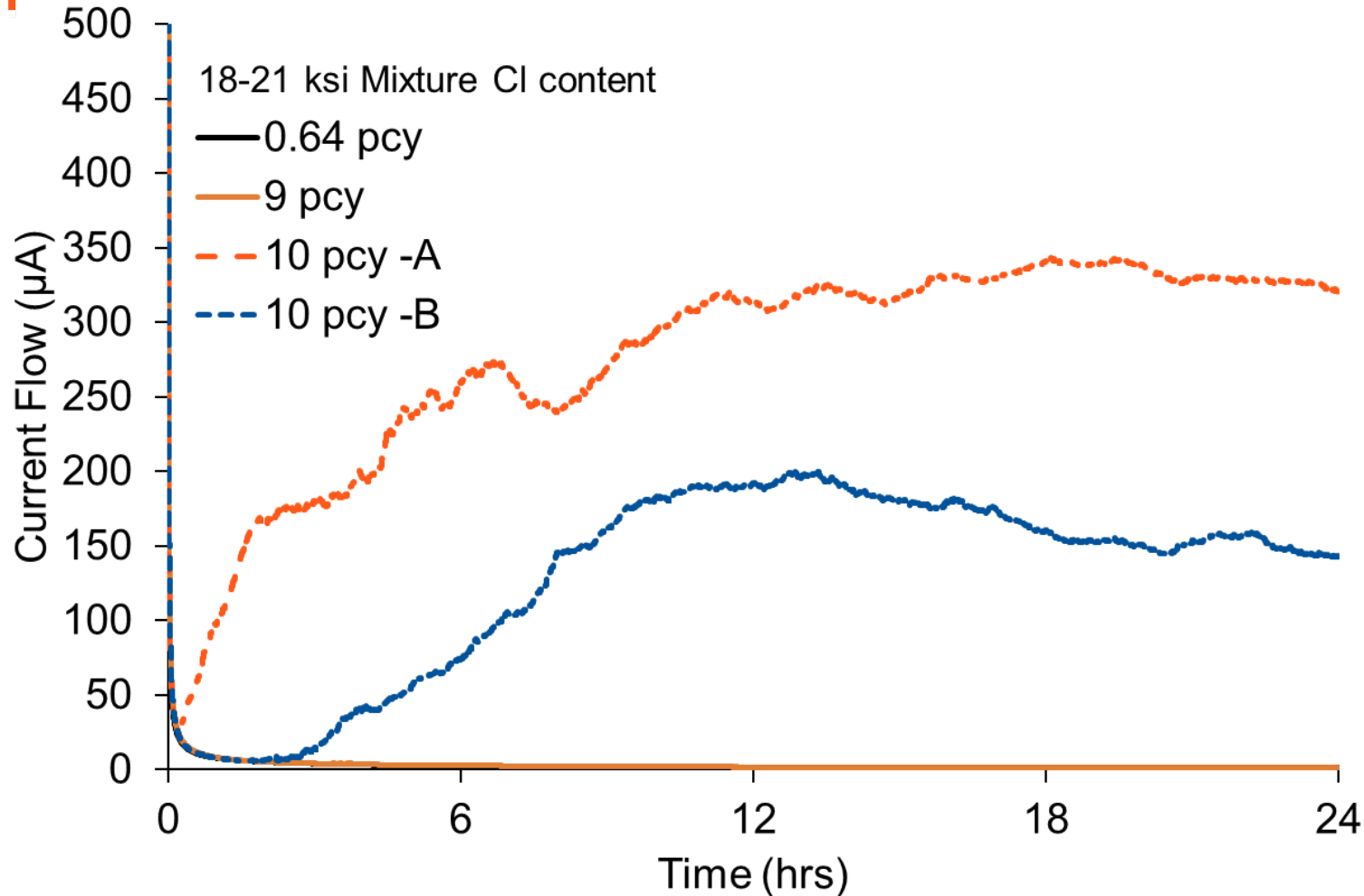
Demolded at 1 day, samples placed in lime solution for 1 day, then tested







# 18-12 ksi Mixture Cl Content



## 18 ksi UHPC

Mix	Total Cl content (lb/yd <sup>3</sup> )	Max current (µA)	Max Current density (µA/cm <sup>2</sup> )
0-A	0.64	7.8	0.82
0-B	0.64	8.3	0.87
5-A	5.0	7.8	0.82
5-B	5.0	7.8	0.82
8-A	8.0	4.6	0.48
8-B	8.0	4.6	0.48
9-A	9.0	8.1	0.85
9-B	9.0	4.4	0.47
10-A	10.0	200	21.0
10-B	10.0	343	36.0

<10 pcy: No corrosion



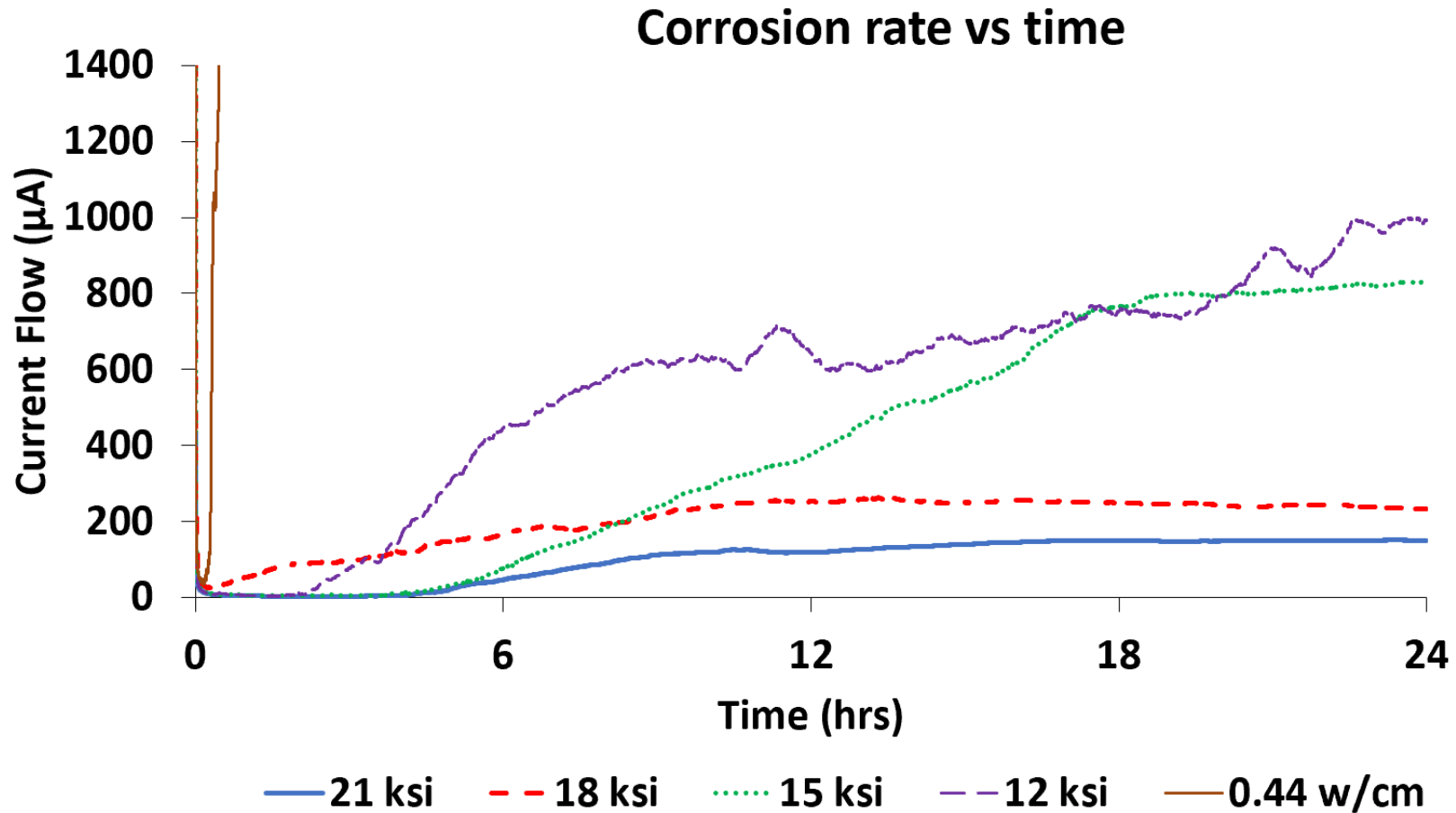
10 pcy -A



10 pcy -B



# Corrosion Rate vs Time





# 14 Safe Amount of Chlorides Added to Mix- Or Are They?

<b>Mix (ksi)</b>	<b>Highest Cl Level w/o Corrosion (lb/yd<sup>3</sup>)</b>	<b>Highest Chloride Level w/o Corrosion (% by Mass Cement)</b>
<b>0.44 w/cm</b>	<b>11</b>	<b>1.57</b>
<b>12-15</b>	<b>10</b>	<b>0.60</b>
<b>15-18</b>	<b>13</b>	<b>0.72</b>
<b>18-21</b>	<b>9</b>	<b>0.44</b>
<b>21+</b>	<b>12</b>	<b>0.54</b>

# Acid and Water-soluble Tests

Mixes	Cementitious lb/yd <sup>3</sup>	Measured Total chlorides (acid soluble) lb/yd <sup>3</sup>	Water soluble chlorides lb/yd <sup>3</sup>	Leached chlorides after testing lb/yd <sup>3</sup>	Bound chlorides lb/yd <sup>3</sup>
0.44 w/cm	704	11.79	5.64	3.87	2.28
12-15	1666	13.21	5.13	0.94	7.14
15-18	1802	16.37	6.34	1.27	8.75
18-21	2060	10.45	3.73	0.66	6.06
21+	2295	13.67	4.95	0.85	7.88

Normal concrete leaches chlorides at ~ 4 times higher than the UHPC in test  
 Need to look at chlorides in concrete during testing rather than what went into mixture

# Fresh Chloride Threshold After Accounting for Leaching

Mixes	Acid soluble Cl- for corrosion % cementitious	Water soluble Cl- for corrosion % cementitious	Bound chlorides % cementitious
0.44 w/cm	1.13	0.81	0.33
12-15	0.74	0.31	0.43
15-18	0.83	0.35	0.48
18-21	0.47	0.18	0.29
21+	0.63	0.22	0.41

Maximum water-soluble chloride ion (Cl-) content in concrete, % by mass of cementitious materials

Exposure Class	Nonprestressed Concrete	Prestressed Concrete
C0	1.00	0.06
C1	0.30	0.06
C2	0.15	0.06

Lower allowable Cl- limit for UHPC than normal strength concrete when normalized by % cementitious material

# 17 Conclusions

- Chloride binding of fresh chlorides in UHPC is similar to normal strength by % cementitious
- ACI chloride limits as a % cementitious material are non-conservative for nonprestressed UHPC
- FDOT specification of 0.4 lb/yd<sup>3</sup> could be increased by 25% to 0.5 lb/yd<sup>3</sup> while maintaining same level of safety factor



# Acknowledgement

- FDOT for funding this work.