CORROSION OF STEEL IN SYNTHETIC FLY ASH PORE SOLUTION

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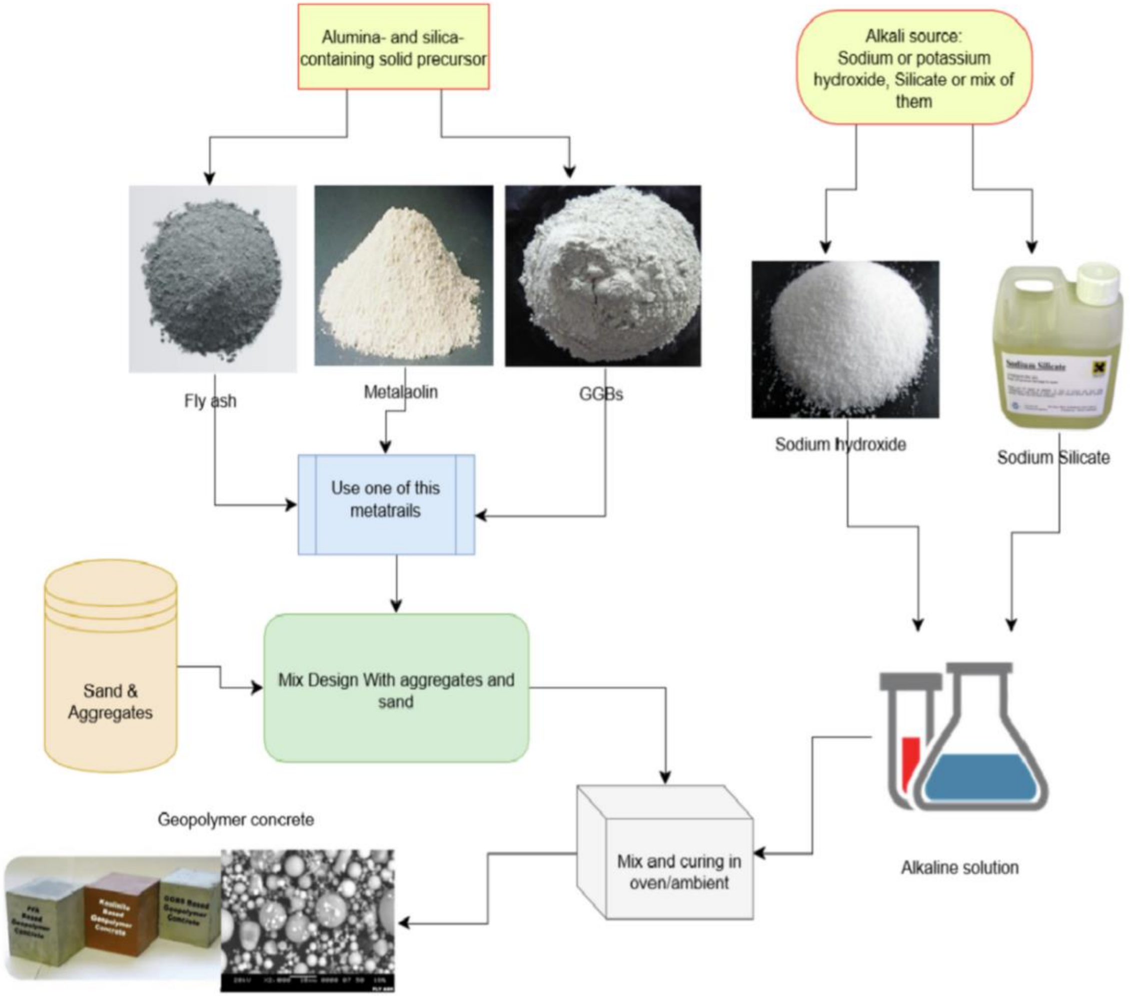
CONTENT

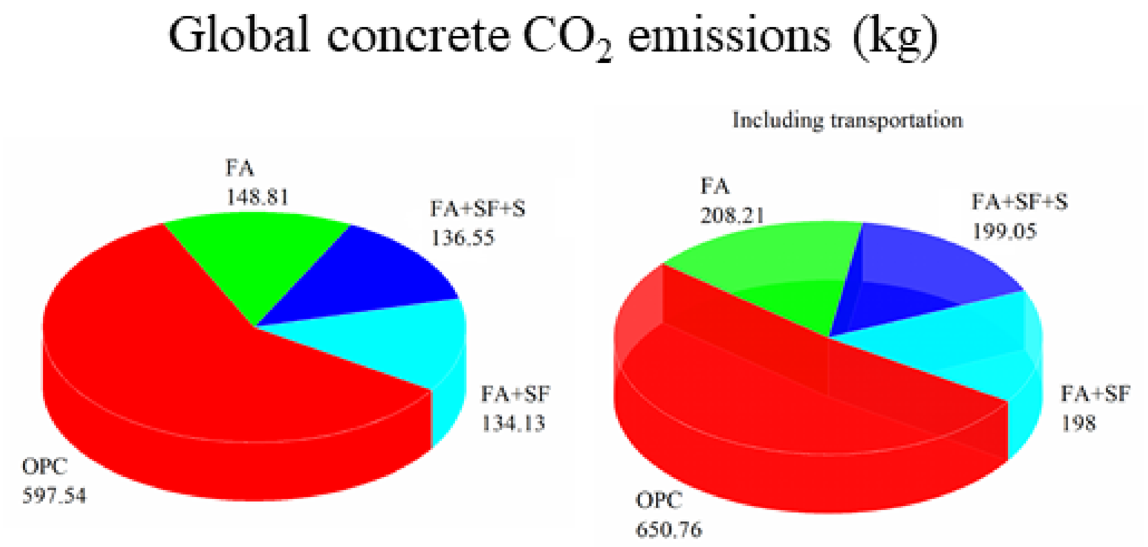
- What is Fly Ash concrete
- Why do we use reinforcement material
- Corrosion of steel in concrete
- Corrosion of steel in simulated pore solution
- Motivation and objectives
- Experimental techniques
- Results
- Conclusions

WHAT IS FLY ASH CONCRETE



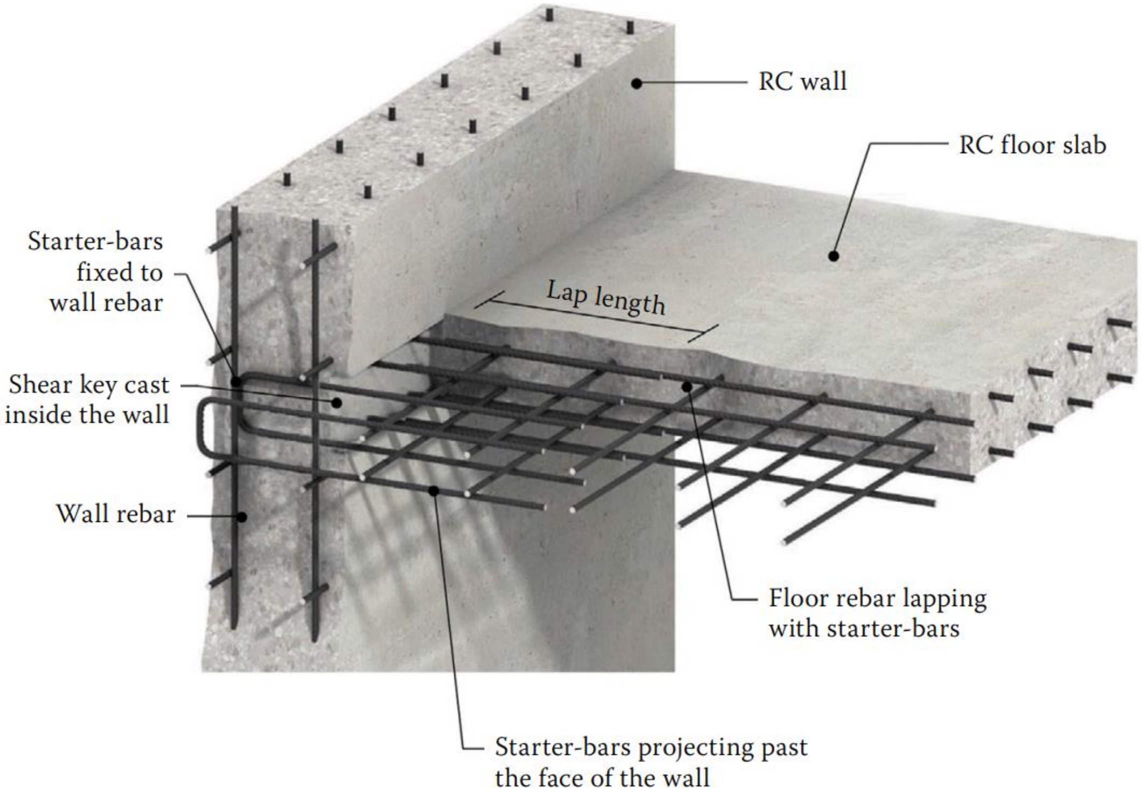
Ordinary Portland cement (OPC) manufacturing industry is responsible of the 5% of total global CO_2 emissions.

- Coal power generation by-product.
- Generates up to 80% less CO_2 than OPC.



WHY REINFORCING STEEL

High strength requirements make it necessary to use metal reinforcements in structural applications.



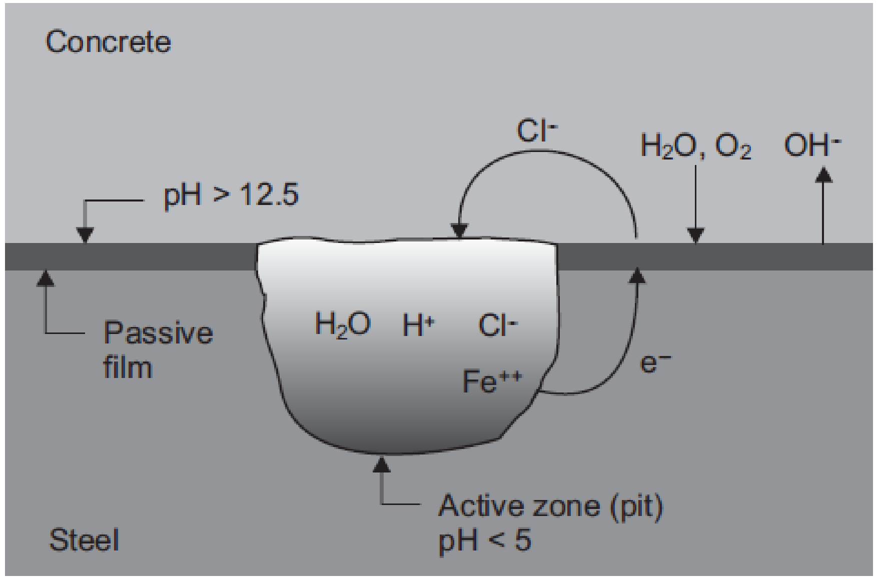
Major concern in reinforced structures is chloride induced corrosion. Repair costs are estimated to be 4% of GDP for industrialized countries.

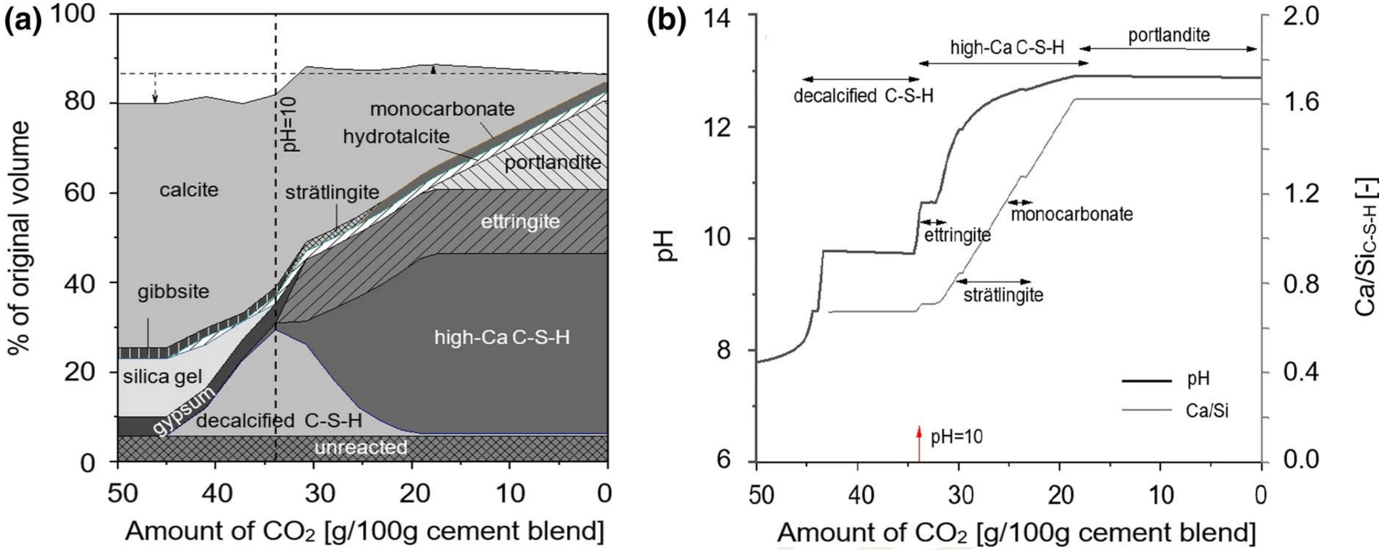
Gerber, J D, & van Zijl, G P A G. (2017). Alternative wall-to-slab connection systems in reinforced concrete structures. *Journal of the South African Institution of Civil Engineering*, *59*(3), 36-47. https://dx.doi.org/10.17159/2309-8775/2017/v59n3a5

CORROSION OF STEEL IN CONCRETE

Chloride induced corrosion

Carbonation induced corrosion





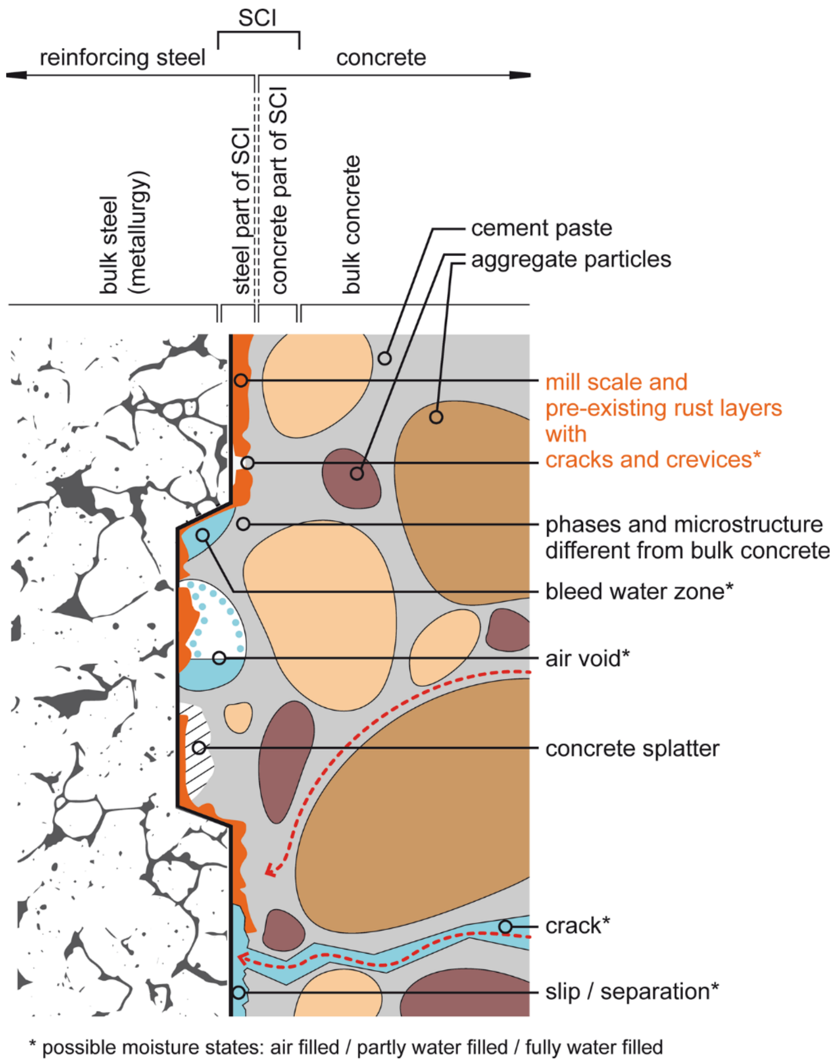
Pitting corrosion

Uniform corrosion

von Greve-Dierfeld S, Lothenbach B, Vollpracht A, et al. Understanding the carbonation of concrete with supplementary cementitious materials: a critical review by RILEM TC 281-CCC. *Mater. Struct. Constr.* **2020**, *53*, 1–34. doi: 10.1617/s11527-020-01558-w.

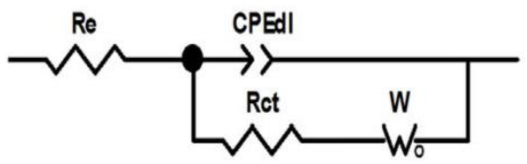
CORROSION OF STEEL IN SIMULATED PORE SOLUTION

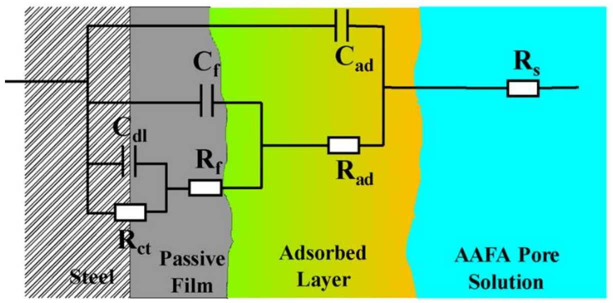
Why pore solution?



Limited and scattered results

- Mundra et al. showed higher [Cl]/[OH] ratio to promote pitting corrosion compared to OPC. But others reported lower values





- Corrosion model is not clear

S. Mundra, M. Criado, S.A. Bernal, J.L. Provis, Chloride-induced corrosion of steel rebars in simulated pore solutions of alkali-activated concretes, Cem. Concr. Res. 100 (2017) 385–397. https://doi.org/10.1016/j.cemconres.2017.08.006.
R. Chen, J. Hu, Y. Ma, W. Guo, H. Huang, J. Wei, S. Yin, Q. Yu, Characterization of the passive film formed on the reinforcement surface in alkali activated fly ash: Surface analysis and electrochemical evaluation, Corros. Sci. 165 (2020) 108393.

(Angst et al., 2017)

MOTIVATION AND OBJECTIVES

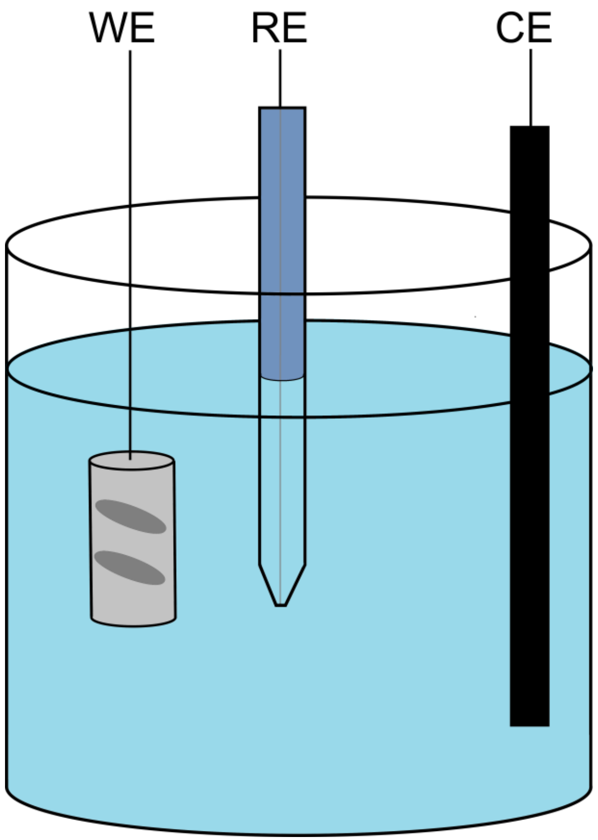
- Limited studies about corrosion of steel in carbonated fly ash geopolymer concrete
- Lack of agreement on carbonation and chloride induced corrosion mechanisms of fly ash geopolymer concrete.
- Lack of agreement on the products formed during the carbonation process on low Ca fly ash

❑ Disentangle the corrosion mechanisms behind carbonation and chloride induced corrosion of steel in fly ash pore solution

❑ Study of the passive film formation of steel in fly ash pore solution.

❑ Study the corrosion products formed during the corrosion process

EXPERIMENTAL TECHNIQUES



Material and Solution

Carbon steel (AISI 1018) rebar

Fly ash pore solution (0.612 M NaOH and 2.7 mM KOH)

Chloride contamination 0, 0.1 M and 0.6 M NaCl

Carbonation induced via CO_2 bubbling

Electrochemical setting

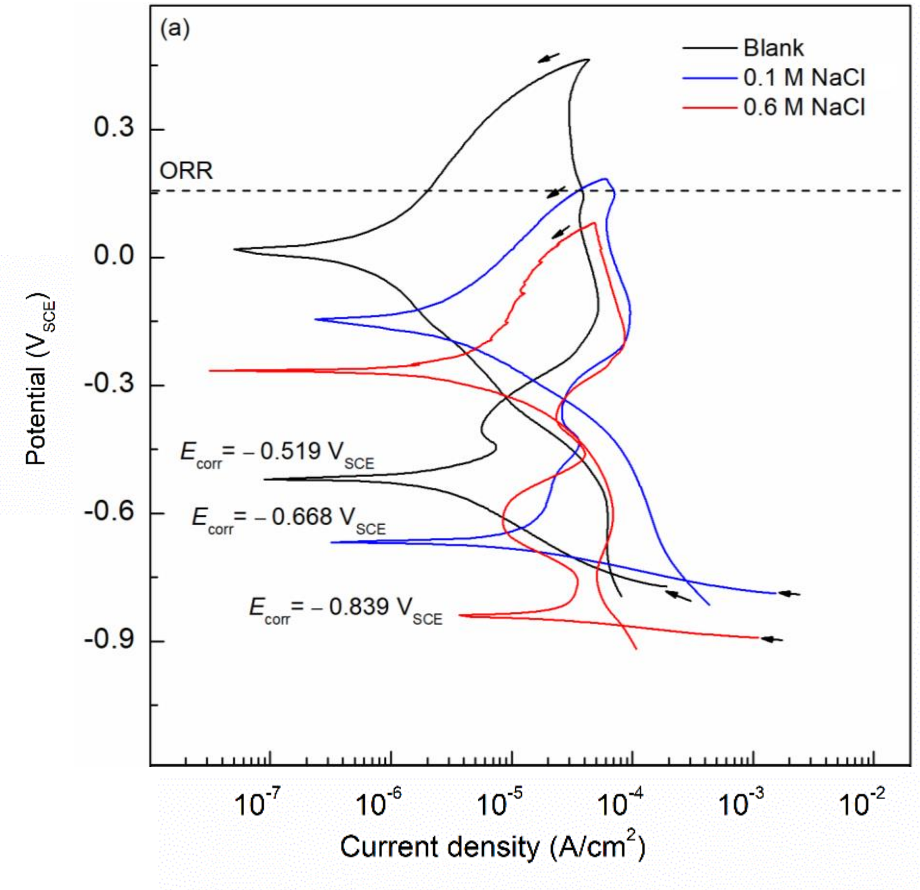
EIS and CPP.

Equipment: Potentiostat/galvanostat Gamry Reference 600. Three-electrode configuration cell setup. Saturated calomel reference electrode (SCE). SEM OM, IFM

Electrochemical standards: ASTM G1-03, ASTM G61-86 and ASTM G3-14
Characterization: ASTM E986-04

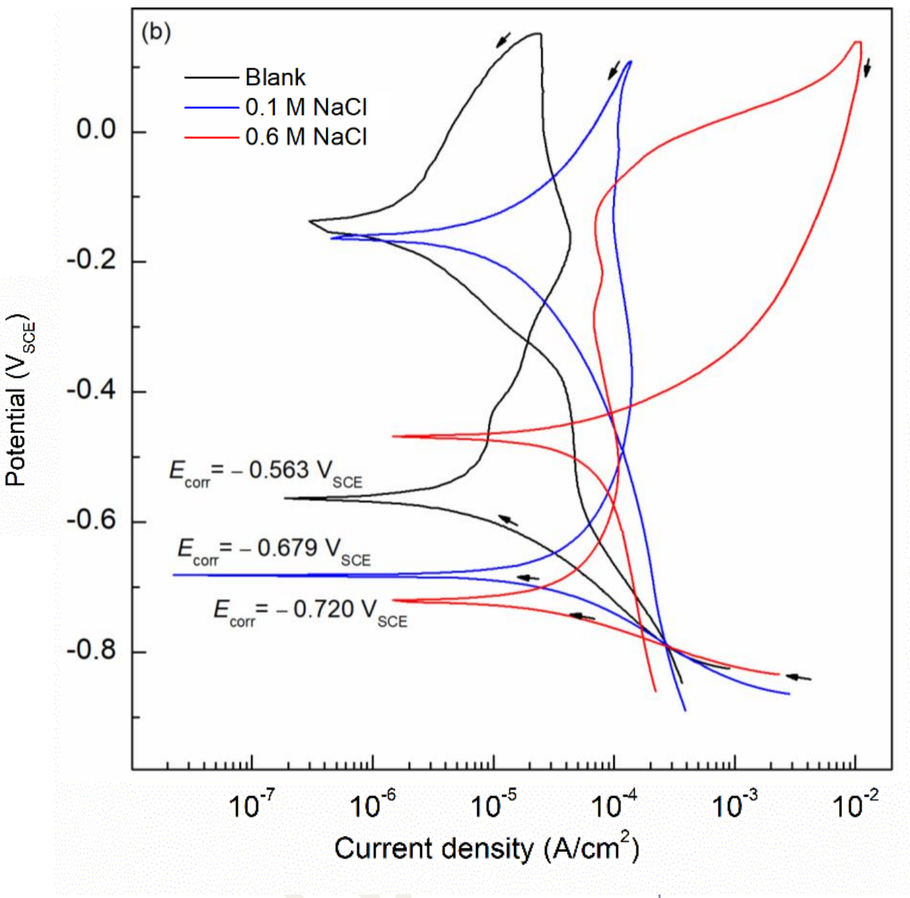
CPP RESULTS

FA pore solution (pH 13.6)



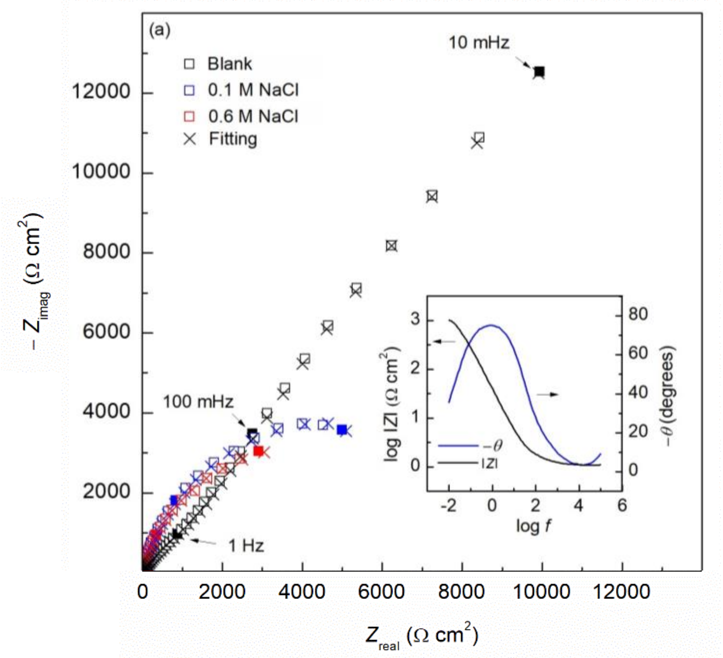
[NaCl] M	i_{corr} (μA/cm²)	E_{corr} (V_{SCE})	$i_{corr,back}$ (μA/cm²)	$E_{corr,back}$ (V_{SCE})
Synthetic FA pore solution (pH 13.6)				
0	1.670	−0.519	0.399	0.016
0.1	8.230	−0.668	1.875	−0.148
0.6	27.23	−0.839	3.159	−0.265
Carbonated synthetic FA pore solution (pH 8.4)				
0	3.217	−0.563	1.439	−0.139
0.1	16.17	−0.679	6.518	−0.163
0.6	35.47	−0.720	32.7	−0.469

Carbonated FA pore solution (pH 8.4)

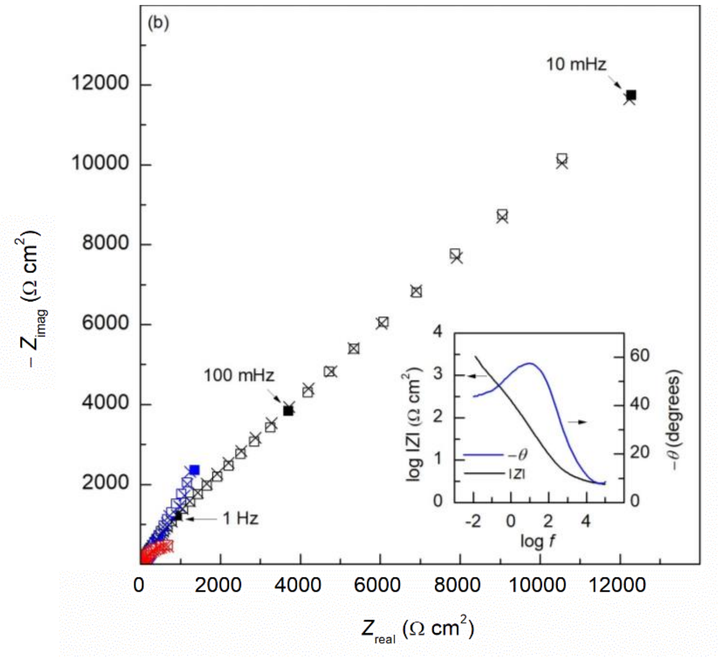


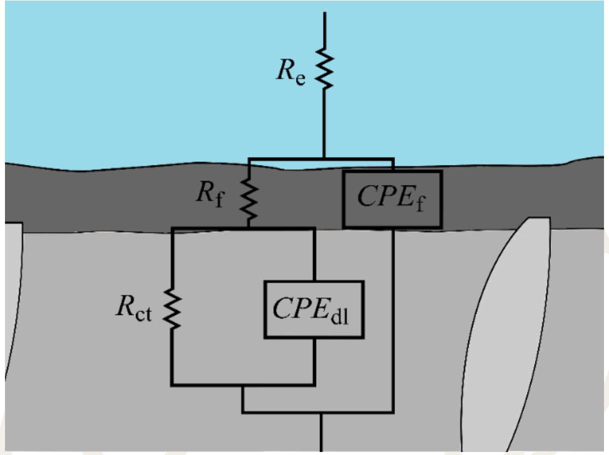
EIS RESULTS

FA pore solution (pH 13.6)



Carbonated FA pore solution (pH 8.4)



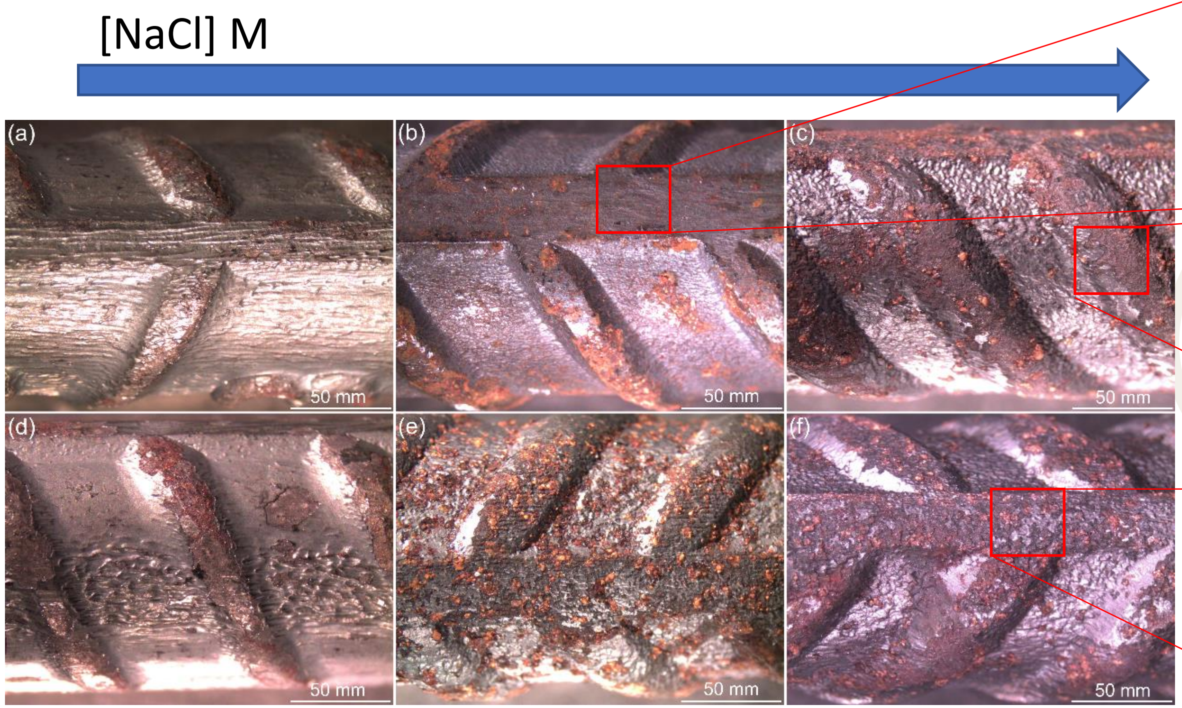


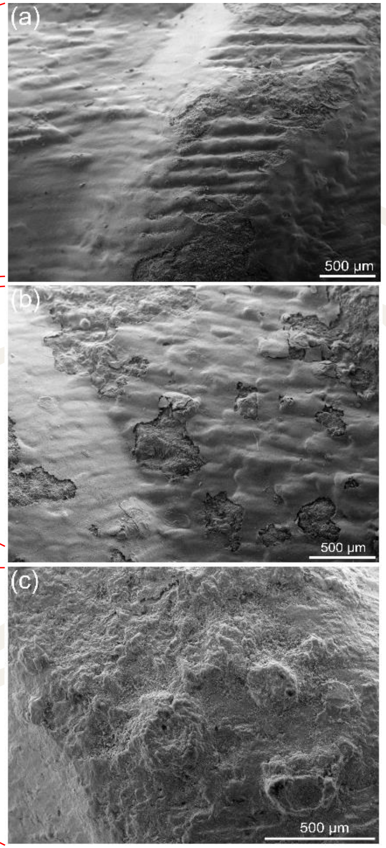
[NaCl] M	R_s (Ω cm²)	R_{film} (Ω cm²)	Y_{film} (S/cm² $s^{n,film}$)	n_{film}	R_{ct} (Ω cm²)	Y_{dl} (S/cm² $s^{n,dl}$)	n_{dl}	$C_{eff,dl}$ (μF/cm²)	X² [adim]
pH 13.6									
0	8.76	2790.01	1.91×10^{-4}	0.671	1.10×10^{5}	2.03×10^{-4}	0.681	10.42	3.24×10^{-3}
0.1	6.56	8.71	5.07×10^{-4}	0.812	9.33×10^{3}	3.59×10^{-4}	0.916	207.34	5.67×10^{-3}
0.6	5.01	1.99	7.11×10^{-4}	0.796	7.56×10^{3}	1.05×10^{-4}	0.911	633.12	3.08×10^{-3}
pH 8.4									
0	19.23	68.97	1.75×10^{-4}	0.478	1.09×10^{5}	9.27×10^{-5}	0.753	9.39	2.02×10^{-3}
0.1	17.39	13.13	1.02×10^{-3}	0.607	4.01×10^{3}	1.12×10^{-3}	0.661	151.65	4.68×10^{-3}
0.6	16.82	1.18	3.12×10^{-3}	0.634	1.77×10^{3}	2.16×10^{-3}	0.701	438.37	1.31×10^{-3}

OPTICAL AND SEM MICROGRAPHS

FA pore solution (pH 13.6)

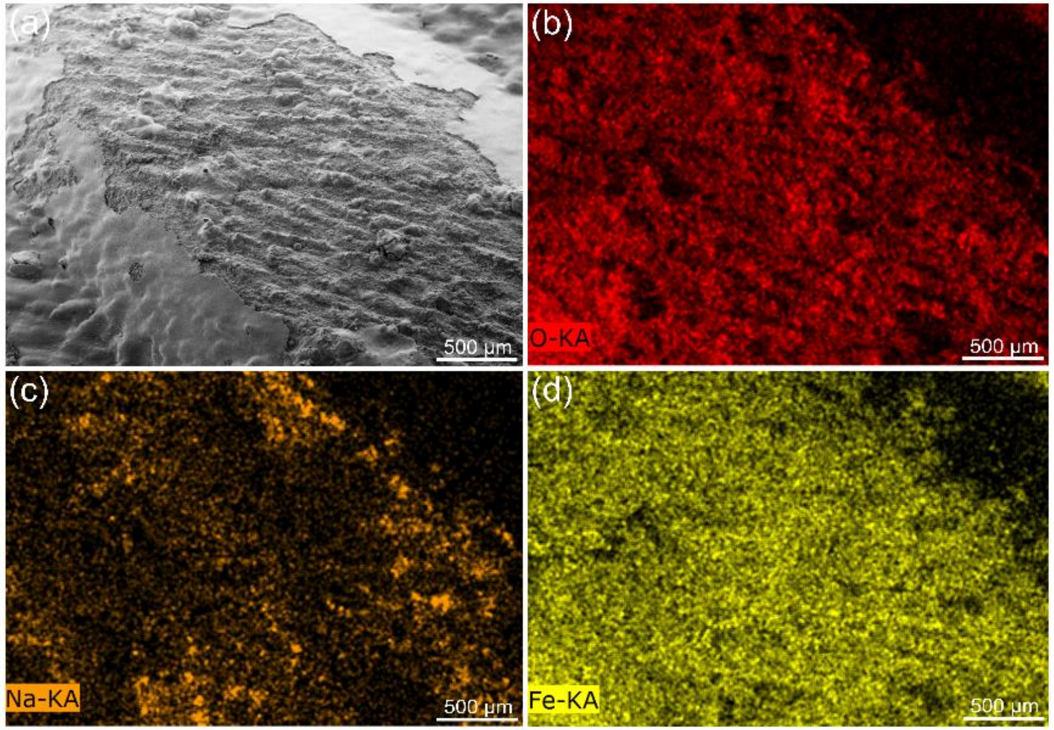
Carbonated FA pore solution (pH 8.4)



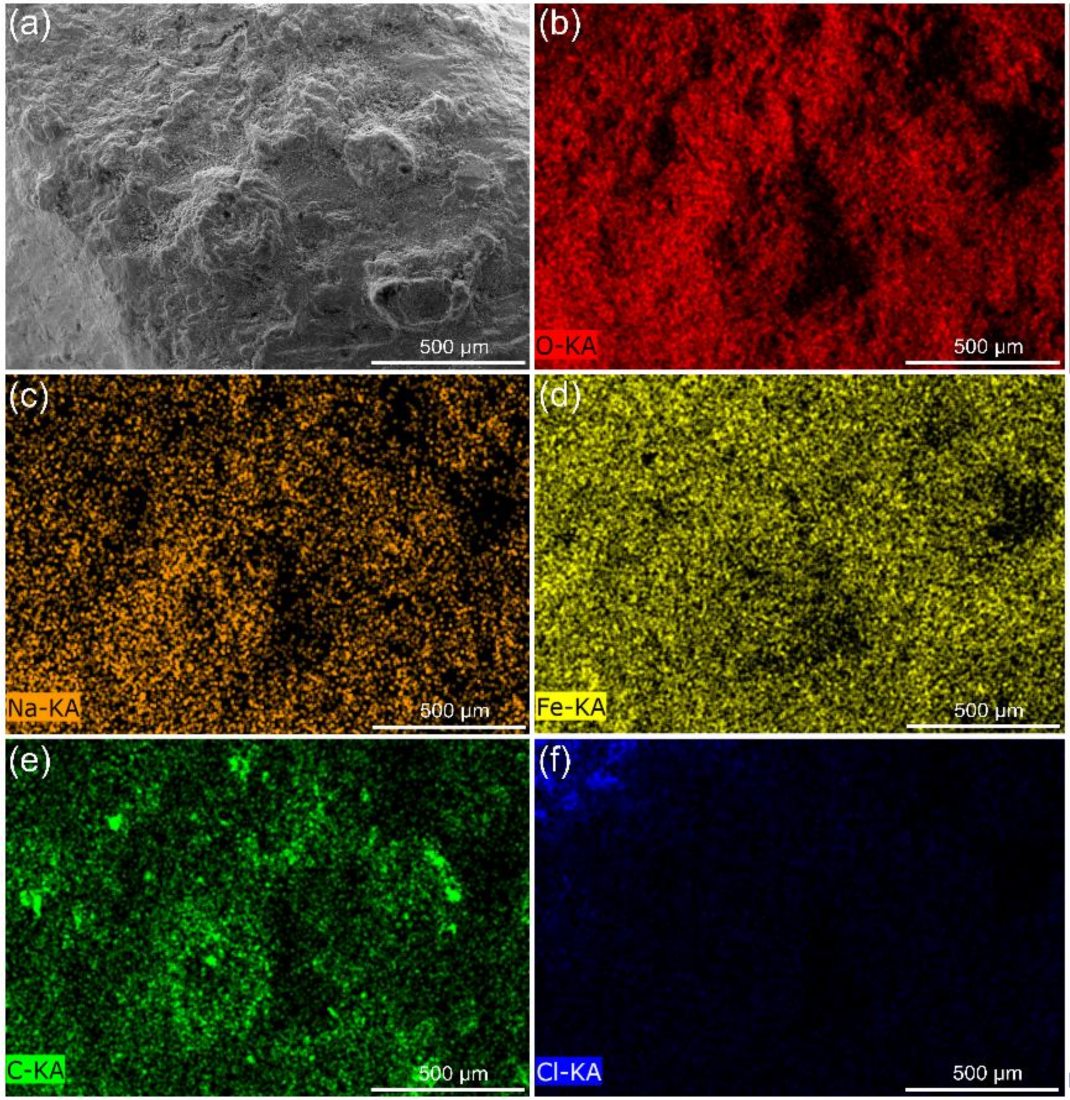


EDX ANALYSIS

FA pore solution (pH 13.6) 0.6M NaCl



Carbonated FA pore solution (pH 8.4) containing 0.6M NaCl



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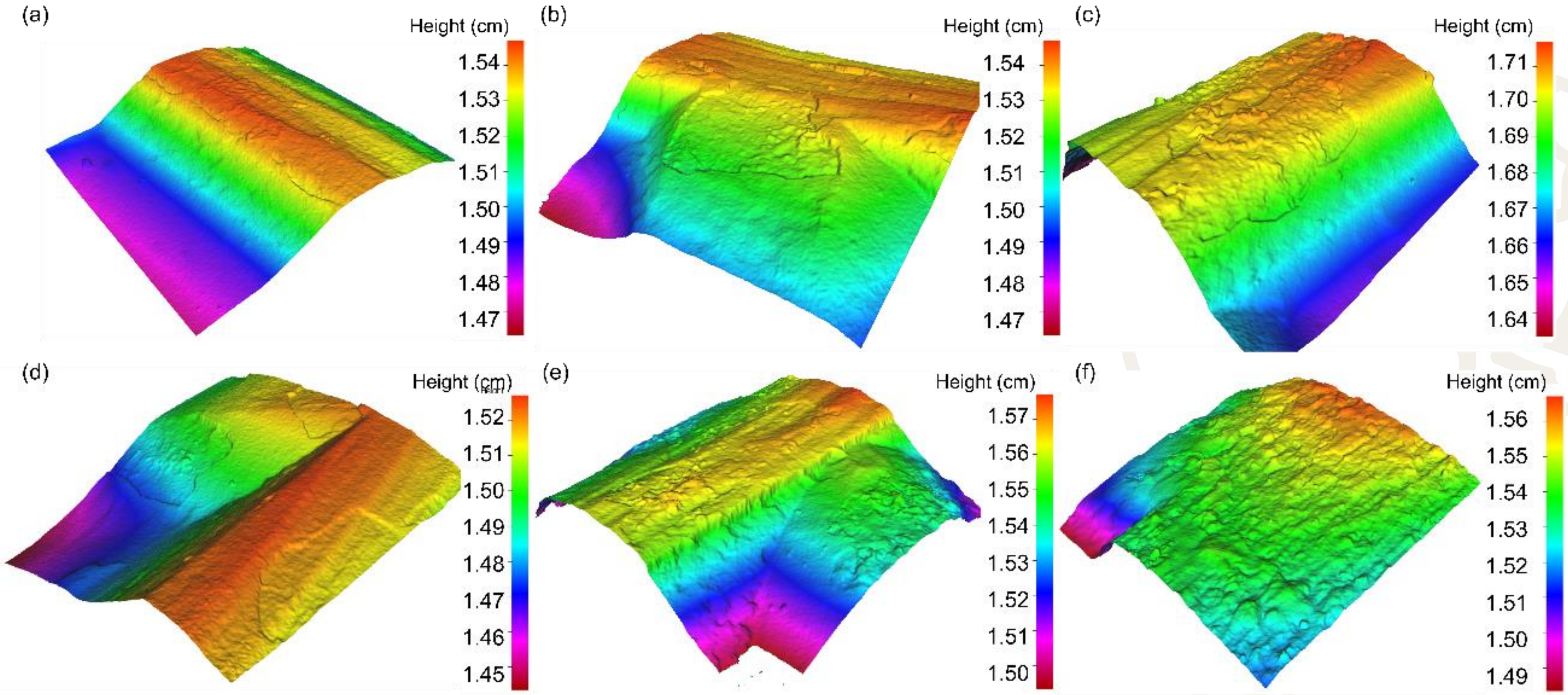
IFM CHARACTERIZATION

[NaCl] M

FA pore solution (pH 13.6)

Carbonated FA pore solution (pH 8.4)



CONCLUSIONS

- The synthetic FA pore solution promotes the formation of a passive layer. Showing an enhanced corrosion behavior compared to OPC.
- The reduction of the pH lowers the corrosion protection displaying a more unstable passive film *CPE* elements.
- $C_{eff,dl}$ shows the thinning of the passive film as the chloride addition increased.
- Higher localized corrosion is found in the riveted section of the rebars.
- Pit density and size is in accordance with the higher current densities found on the CPP curves.
- EDX analysis of the carbonated samples with 0.6 M NaCl evidenced the presence of sodium carbonates in the surface of the corroded CS rebar.

THANKS FOR YOUR TIME