U.S. Department of Transportation
Federal Highway Administration

Turner-Fairbank Highway Research Center

The Influence of Accelerating Admixtures on the Electrical Resistivity of Cement Pastes

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Luca Montanari
Luca.montanari@arup.com
Graduate Student at University of Texas at Austin

Maria Juenger
mjuenger@mail.utexas.edu

Michelle Cooper
Michelle.Cooper@dot.gov

Photo Source: FHWA

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Authors

Luca Montanari
lucopr@gmail.com
Graduate Student
The University of Texas at Austin

Dr. Maria Juenger
mjuenger@mail.utexas.edu
Professor
The University of Texas at Austin

Michelle Cooper
Michelle.Cooper@dot.gov
Concrete Materials Research Engineer
Federal Highway Administration

Acronyms

Acc	Accelerator
BR	**Bulk Resistivity**
Cl	Chlorides
DOH	**Degree of Hydration**
FF	**Formation Factor**
FHWA	Federal Highway Administration
HES	High Early Strength
N	Nitrate
OPC	Ordinary Portland Cement
PSR	**Pore Solution Resistivity**
SCM	Supplementary cementitious materials
SR	Surface resistivity
TFHRC	Turner-Fairbank Highway Research Center
TGA	Thermogravimetric Analysis
W/CM	Water-to-cementitious materials ratio

Outline

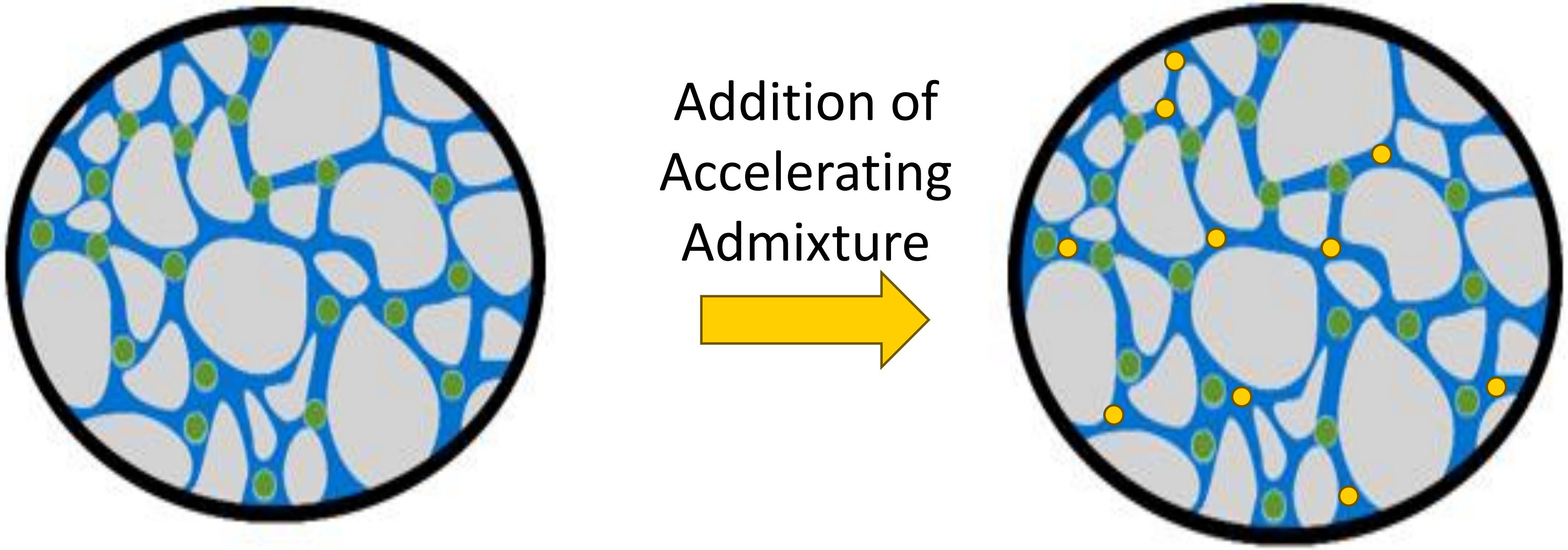
- Background
- Research Objectives
- Materials and Experimental Methods
- Results
- Summary
- Major Takeaways

Background

- Repair of concrete infrastructures relies on High Early Strength (HES) Concrete Mixtures
- HES concrete mixtures characterized by:
  - High cement content
  - Low W/CM
  - Low-to-zero SCM content
  - High dosage of accelerators and water-reducing admixtures

Background

- High dosage of accelerators and water-reducing admixtures

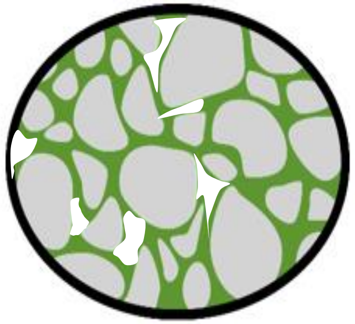


Pore Solution Composition in Typical Concrete:
Na^{+}, K^{+}, $SO4^{2-}$, Ca^{2+}, OH^{-}

Pore Solution Composition in Concrete with Accelerators:
Na^{+}, K^{+}, SO_4^{2-}, Ca^{2+}, OH^{-} + (Cl^{-}, NO_2^{-}, NO_3^{-}, SCN^{-} , …)

Background

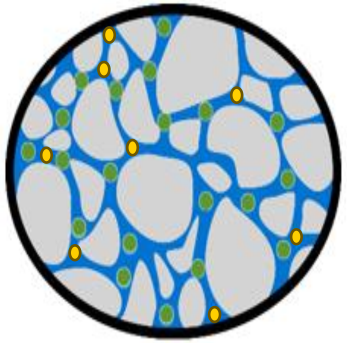
Temperature



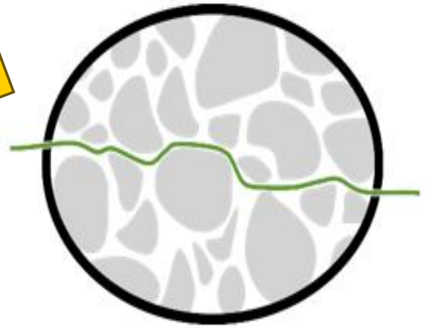
Degree of saturation

Moisture filled porosity

Variables affecting electrical resistivity in concrete



Pore solution resistivity



Pore connectivity

Research Objectives

- Study how accelerating admixtures affect the pore solution resistivity, bulk resistivity, degree of hydration, and porosity of an OPC system
- Verify whether electrical resistivity correlates with microstructural features when accelerating admixtures are included
  - Relevant to establish whether electrical tests can be extended to mixtures which incorporate accelerating admixtures

Materials and Experimental Methods

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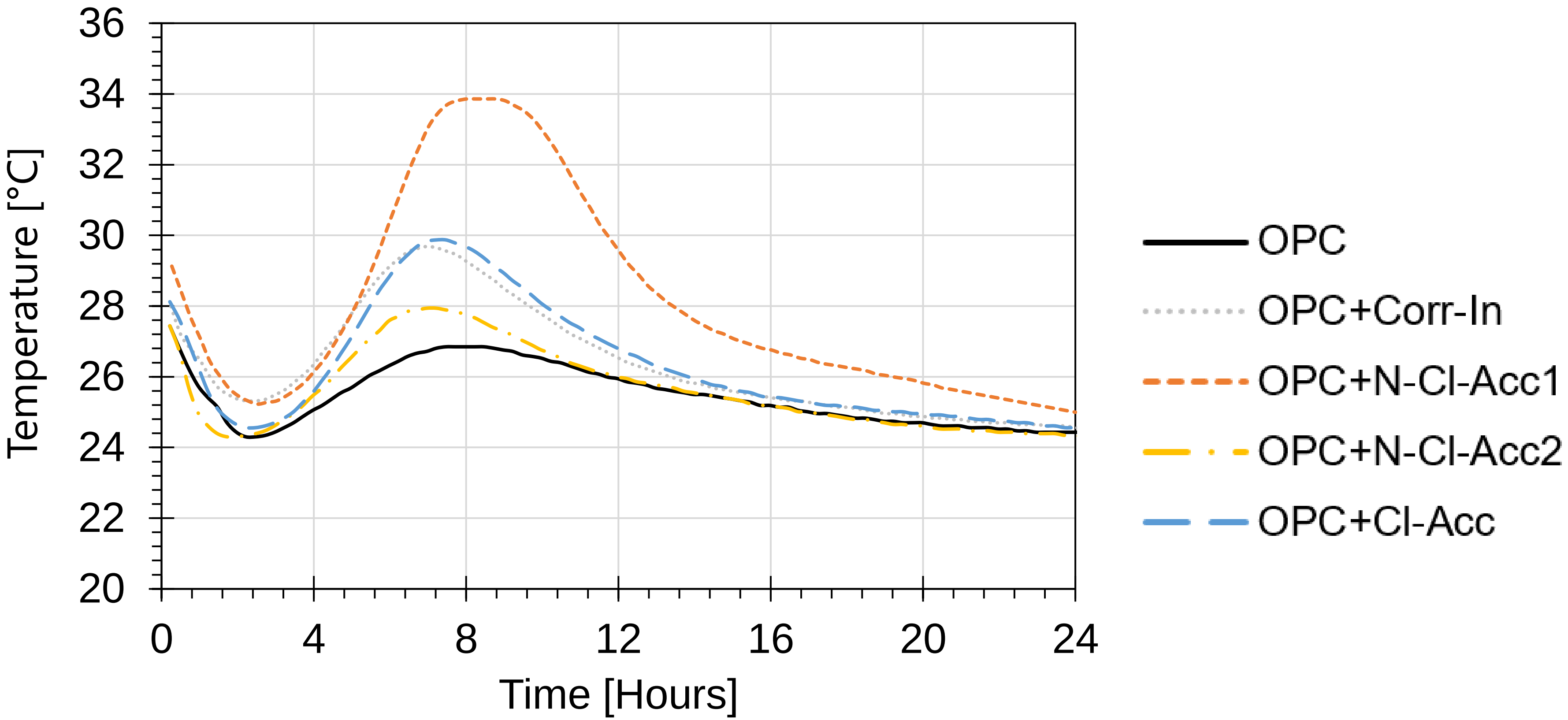
Materials

- OPC paste, w/cm 0.42, combined with different accelerating admixtures:

Admixture Type	ASTM Compliance	ID	Main Chemical Components	Chemical Components Concentrations Ranges (%)*	Dosage (ml/ 100 kg cement)	Dosage (oz/cwt)
Corrosion Inhibitor	ASTM C494 - Type C	Corr-In	Calcium Nitrite; Calcium Nitrate;	30 - 50; 1 - 5;	4235	65
Accelerator	ASTM C494 - Type C	N-Cl-Acc1	Sodium Nitrate; Sodium Thiocyanate; (methylimino)diethanol;	10-20; 5-10; 1-5;	1820	28
Accelerator + Water Reducer	ASTM C494 - Type C and E	N-Cl-Acc2	Calcium nitrate Tetrahydrate; Sodium Thiocyanate;	50 - 70; 1 - 5;	1590	24
Accelerator	ASTM C494 - Type C and E	Cl-Acc	Calcium Chloride;	20 - 30	2275	35

Curing



- Paste specimens were cured in sealed conditions at 23 ± 0.5 ^{o}C, up to 28 days

Experimental Methods – Degree of Hydration

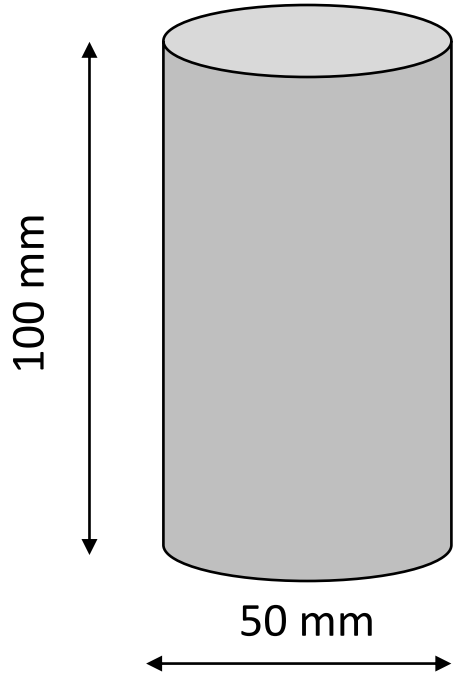
- Degree of Hydration (DOH) was tested with 2 different methods:
  - Isothermal Calorimetry (IC) - between 0 and 7 days:
    - $H(t)$ = Cumulative heat at time 't' from mixing (J/g_{cement})
    - H_u = Ultimate heat from cement phase composition (J/g_{cement})

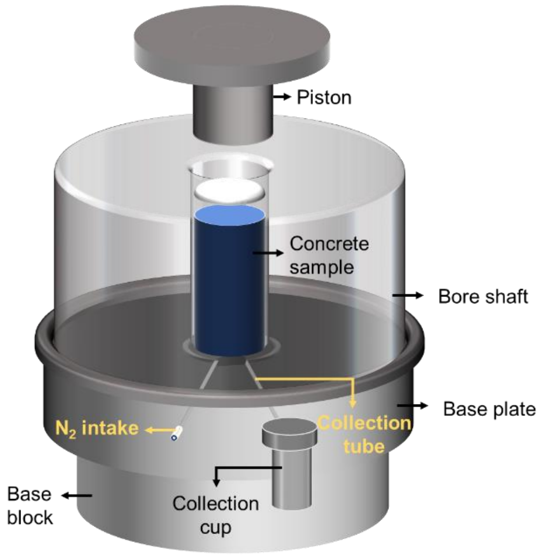
$$DOH = \frac{H(t)}{H_u}$$

  - Thermogravimetric analysis (TGA) - between 24 hours and 28 days:
    - $w_b(t)$ = bound water from TGA at time 't' from mixing (g_{water} / g_{cement})
    - $w_{b,u}$ = ultimate bound water from thermogravimetric analysis (g_{water} / g_{cement})

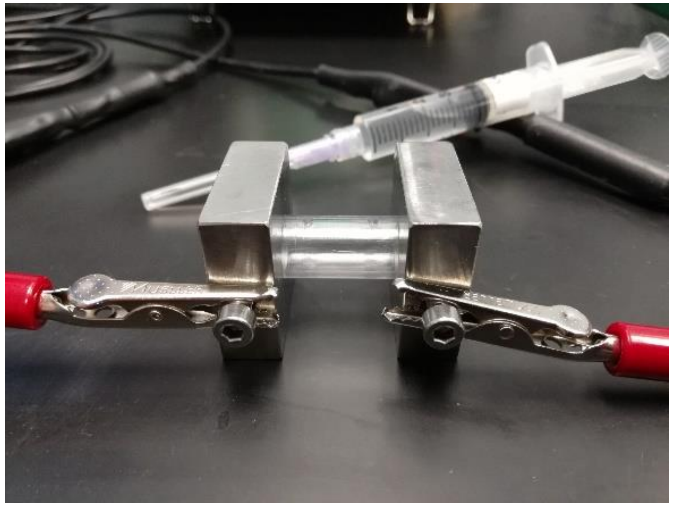
$$DOH = \frac{w_b(t)}{w_{b,u}}$$

Experimental Methods – Pore Solution Resistivity (PSR)





Pore Solution Expression
(Max Pressure: 250 MPa)

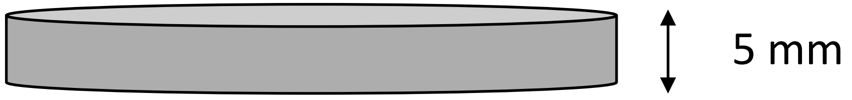


Measurement of PSR with cylindrical cell

All Figures Source: FHWA

Experimental Methods – Porosity

- 5 mm disks cut from 2” x 4” paste cylinder
- Age of testing: 1, 7, and 28 days
- Vacuum saturation using limewater



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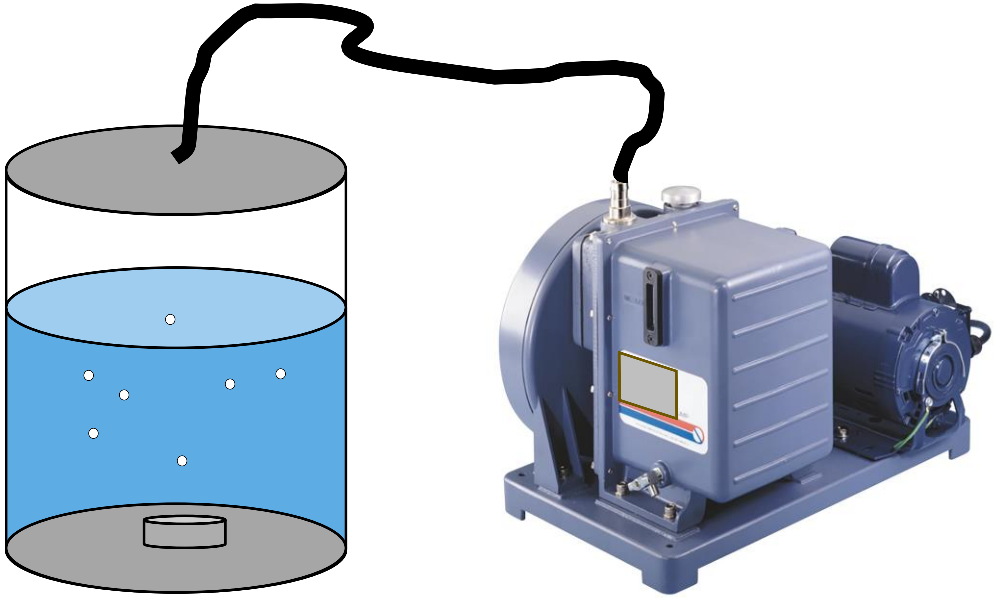

Source: FHWA

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$$\text{Porosity (\%)} = \frac{M_{SSD} - M_{OD}}{M_{SSD} - M_B} \cdot 100$$

Experimental Methods – Bulk Resistivity (BR) and Formation Factor (FF)

- Age of testing: 1, 7, and 28 days
- Resistivity was tested on 2” x 4” paste cylindrical specimens
- FF was calculated by normalizing the BR by the measured PSR

$$\text{Formation Factor} = \frac{\text{Bulk Resistivity}}{\text{Pore Solution Resistivity}}$$

Results

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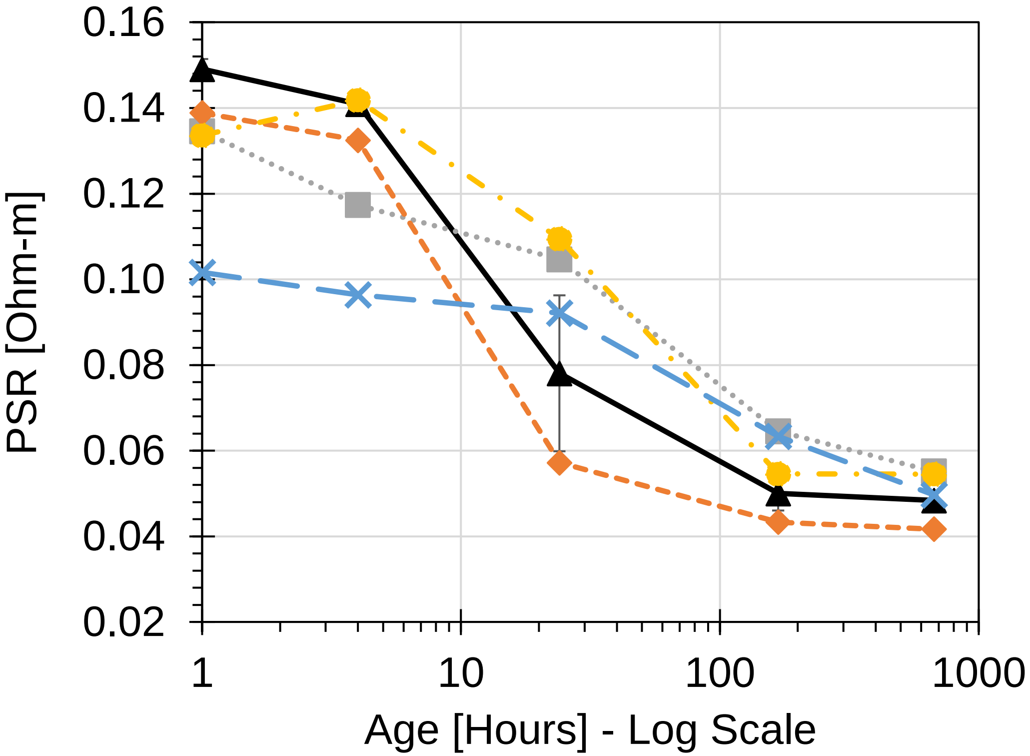
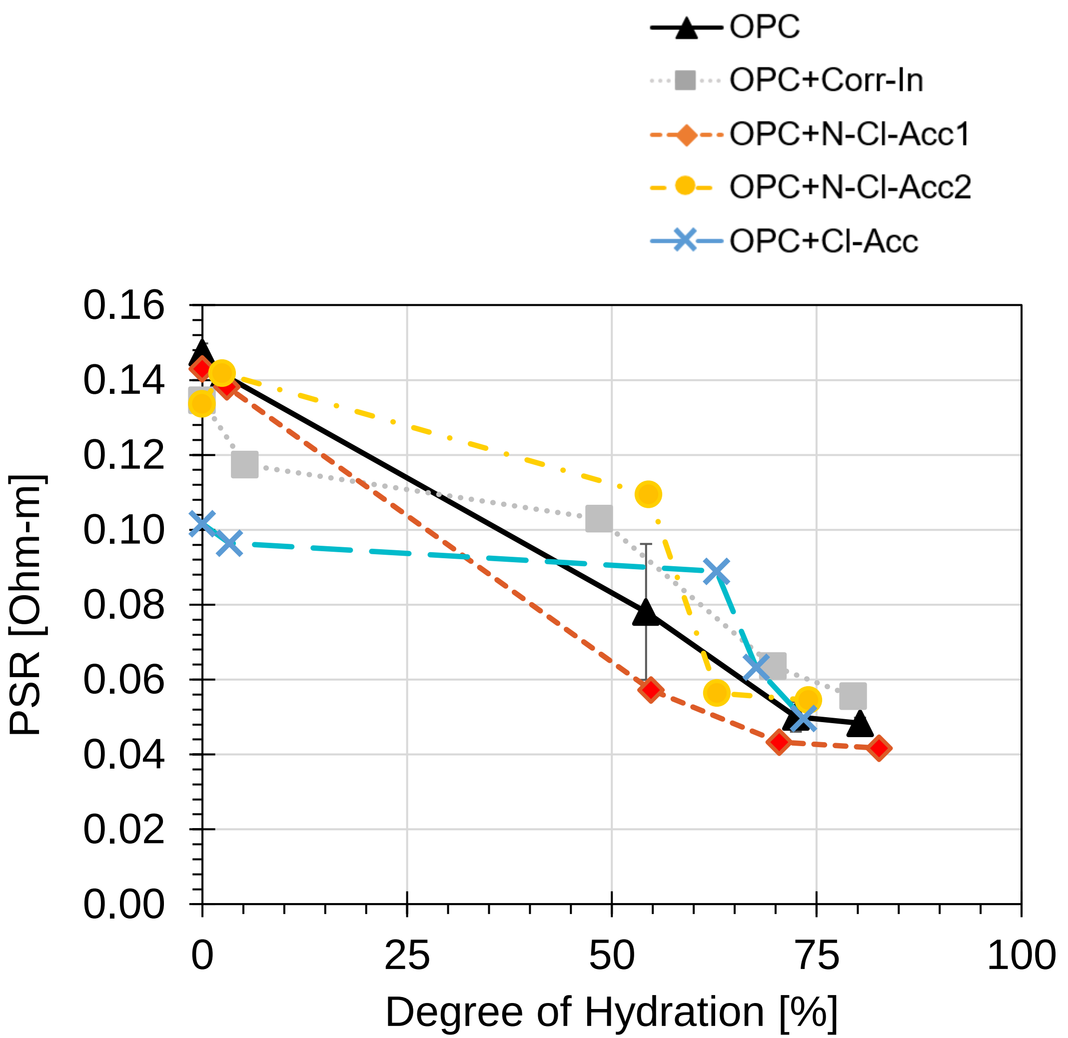
Degree of Hydration

Age (Days)	Technique	Degree of Hydration (%)				
		OPC	OPC + Corr-In	OPC + N-Cl-Acc1	OPC + N-Cl-Acc2	OPC + Cl-Acc
0.04	IC	0	0	0	0	0
0.2	IC	3	5	3	3	2
1	TGA / IC	54 / 45	49 / 42	55 / 47	63 / 46	55 / 45
7	TGA / IC	72 / 71	70 / 69	70 / 69	68 / 70	63 / 68
28	TGA	80	80	83	73	74

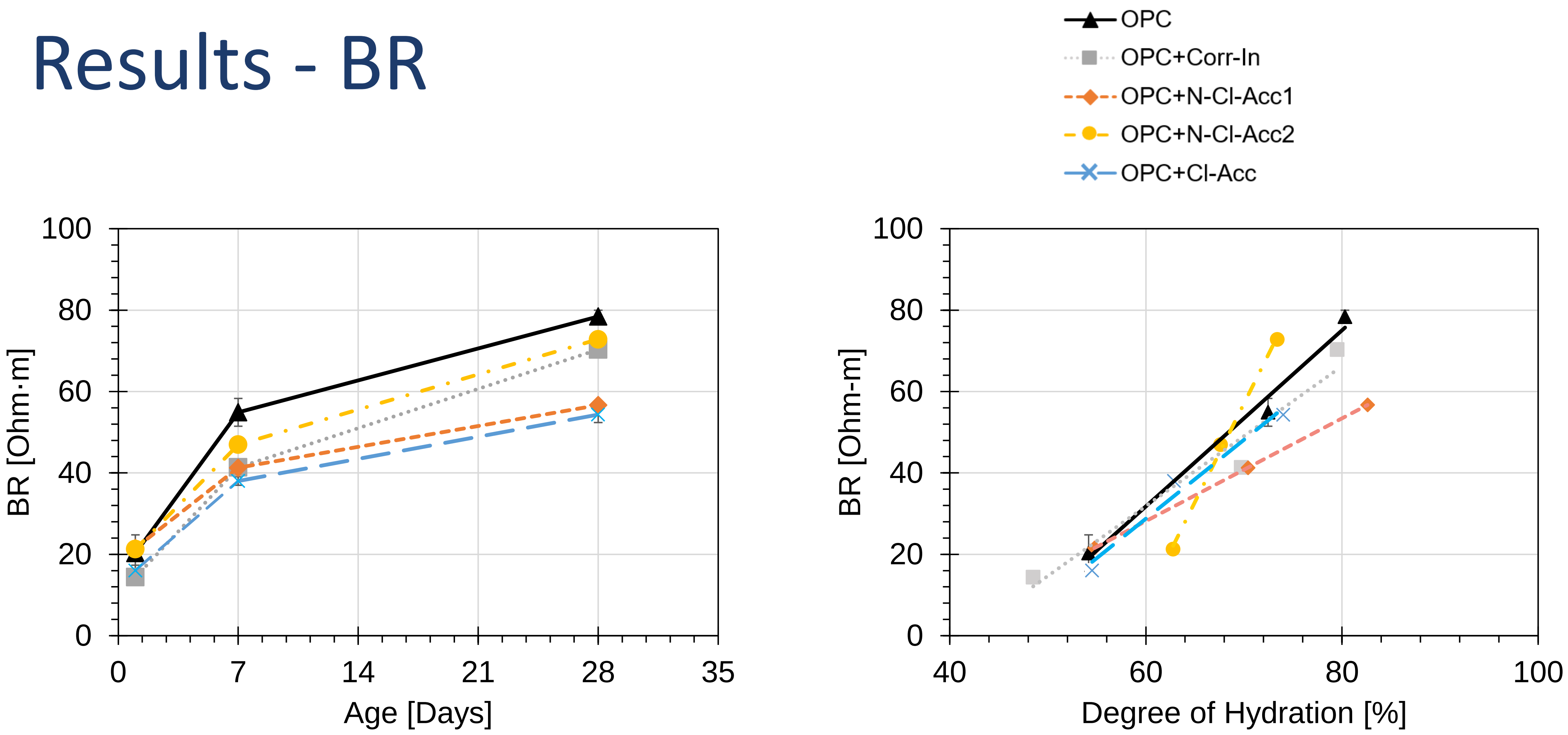
Results - PSR





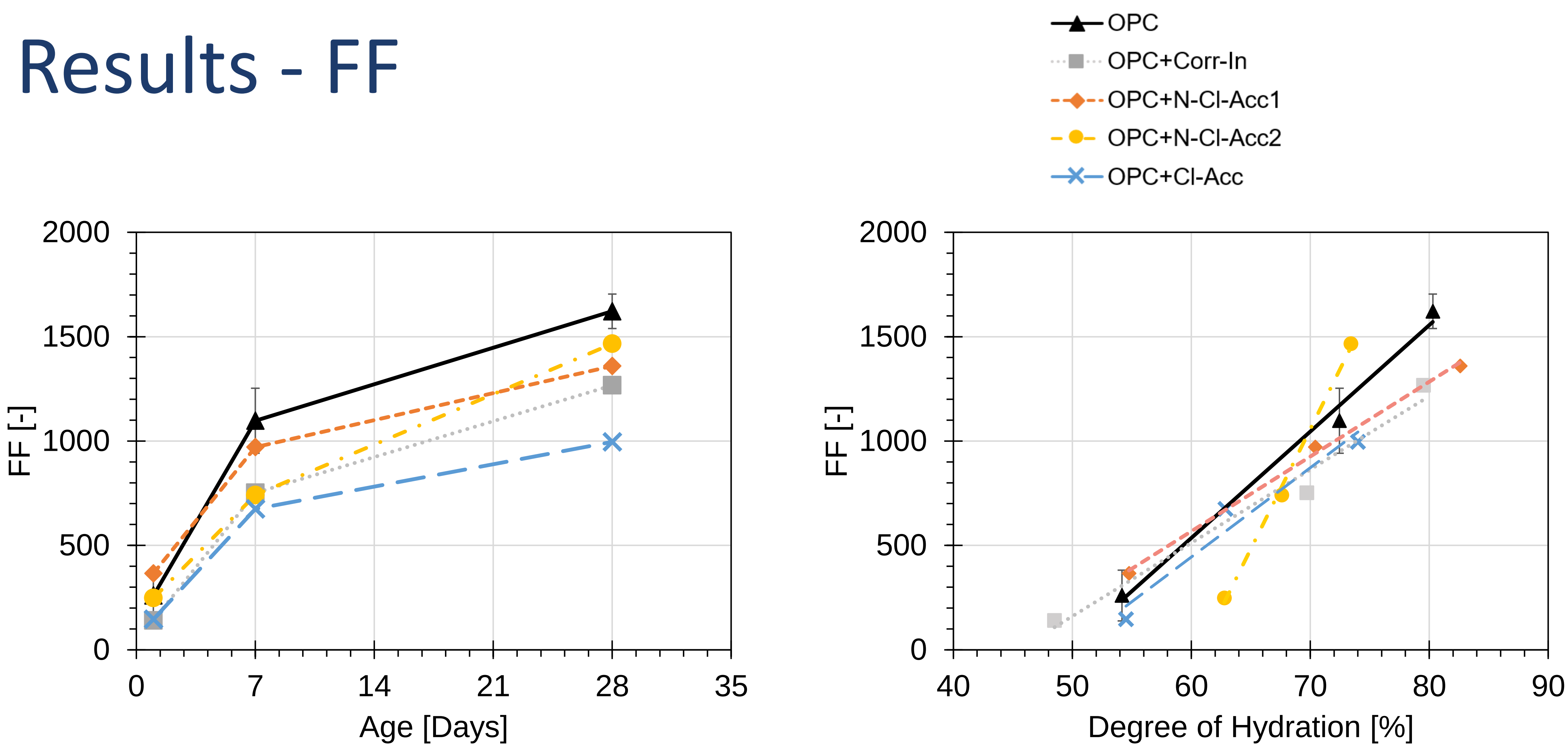
- Impact of accelerating admixtures on the pore solution resistivity is reduced over time

Results - BR



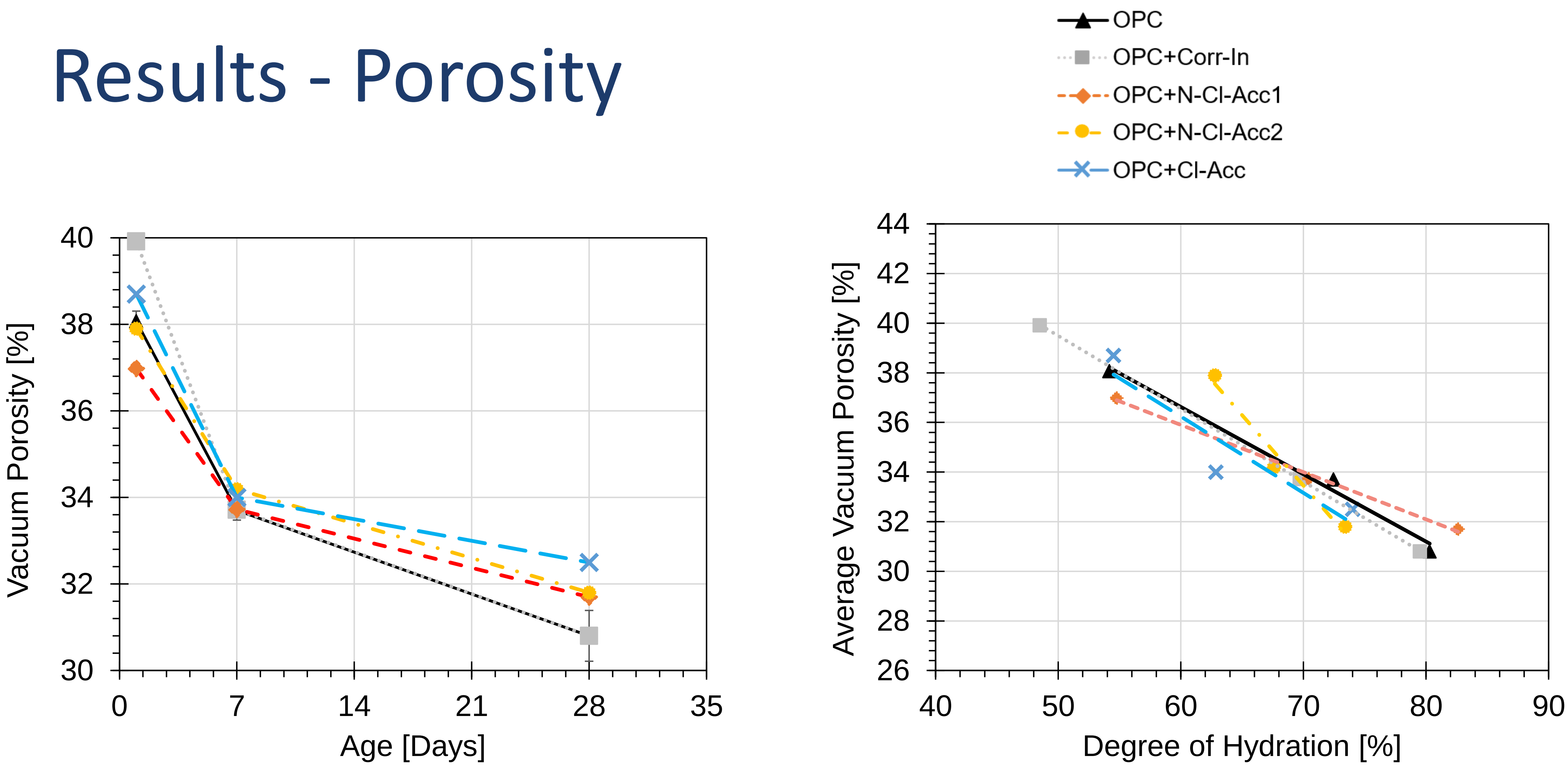
- Control mixture exhibits higher BR when plotted vs time
- When plotted vs DOH, some admixtures seem to affect the resistivity evolution

Results - FF



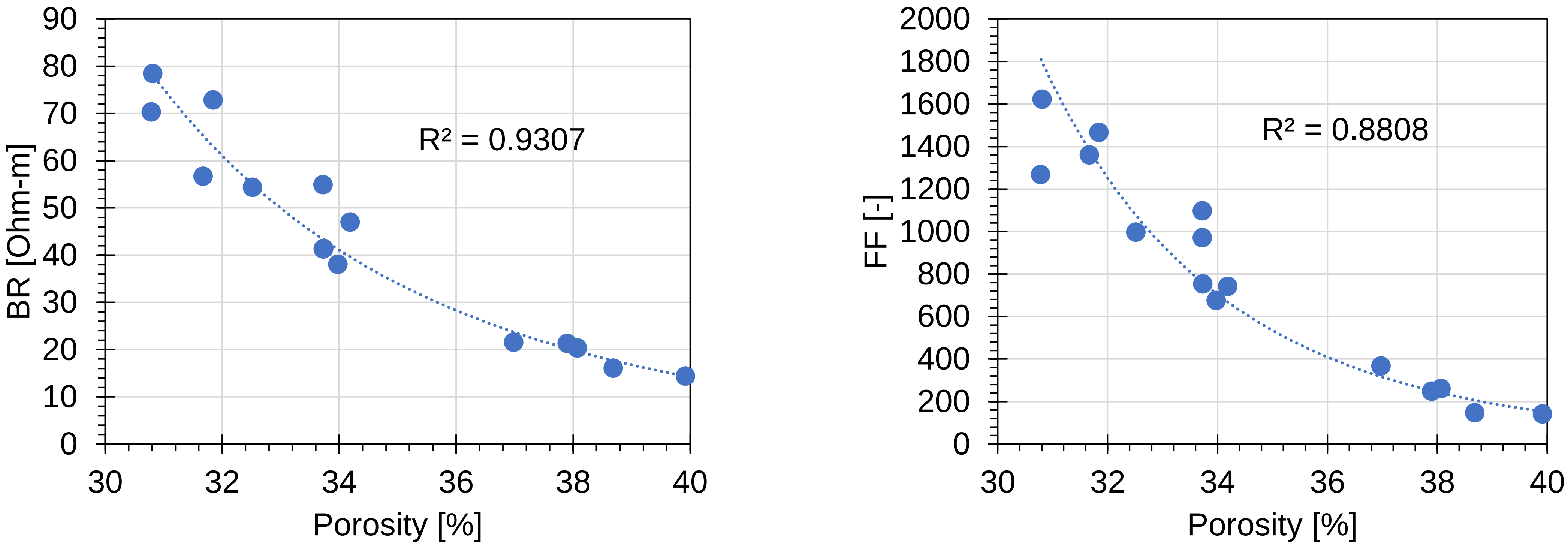
- FF shows similar trends to resistivity

Results - Porosity



- Porosity shows inverse development when compared to BR and FF

Porosity vs BR and FF



- Both BR and FF show inverse relationship with the porosity of the system
- FF shows greater scatter than BR at lower porosity

Summary

1 DOH

- At early ages, accelerating admixtures increase the cement DOH
- At later ages, the presence of admixtures can decrease the measured DOH (up to 9% compared to the OPC control system)

2 PORE SOLUTION

Accelerating admixtures affected the pore solution resistivity:

- At early ages up to 35% measured reduction
- At 28 days under 20% measured reduction compared to control

3 BULK RESISTIVITY

Concretes with accelerating admixtures had lower BR measurements than the control at the same age

- Not purely attributable to pore solution resistivity (based on FF results)

Summary

4 BR / FF vs DOH

- BR, FF, and the porosity showed linear correlation to the measured DOH.

5 CHANGE IN PROPERTIES

- When accounting for DOH, the accelerating admixture can increase, decrease, or have negligible impacts on the BR or FF of the paste.

6 BR / FF vs POROSITY

- Both BR and FF showed good correlation with the saturated porosity (goodness-of-fit of 0.96 and 0.88, respectively).

Conclusions

- Effect of accelerating admixtures inclusion on the pore solution resistivity seems to lessen over time
- BR and FF are closely related to the vacuum porosity of the systems
- Sealed BR and FF can successfully characterize microstructure / transport properties in HES concrete mixtures that incorporate accelerators

References

- Luca Montanari, Michelle Helsel, Igor de la Varga, Robert Spragg, Maria Juenger (2022). *Impact of accelerating admixtures on the electrical properties of ordinary portland cement pastes.* Cement and Concrete Composites, Vol. 133, 104651.

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