The Science Behind PLC – A Thermodynamic perspective

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OPC hydration – a review

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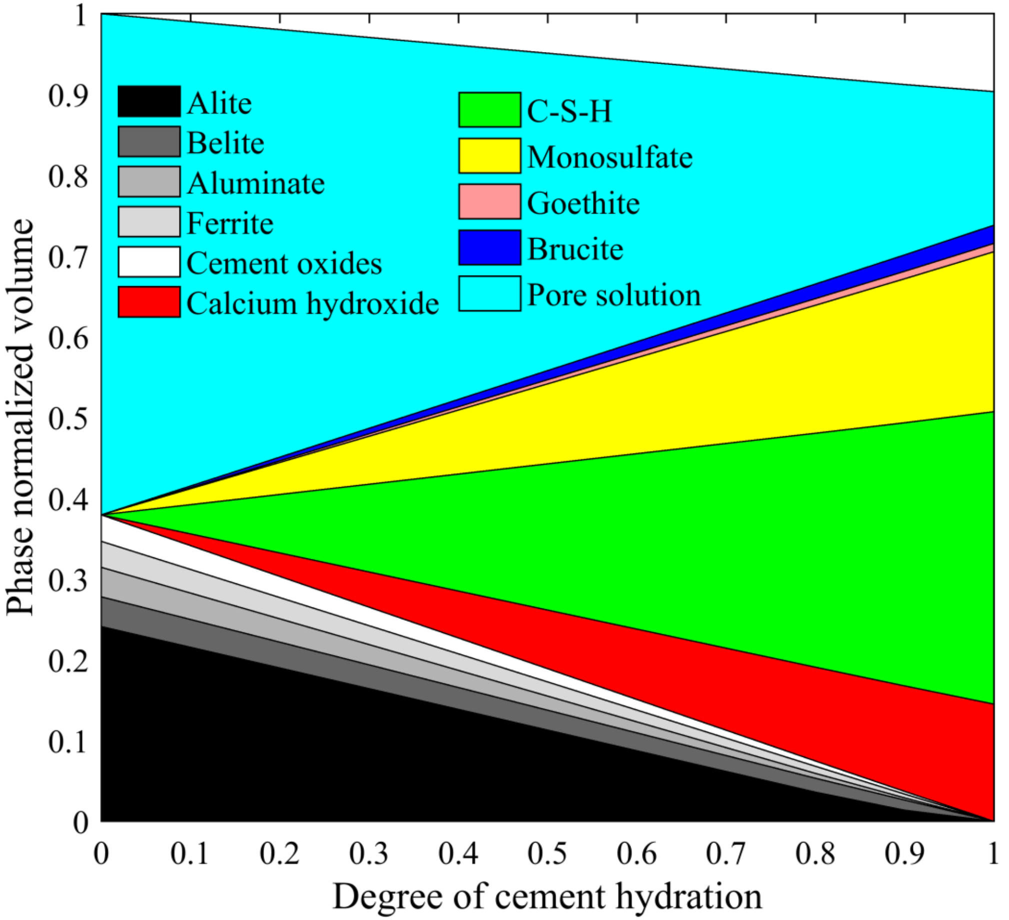
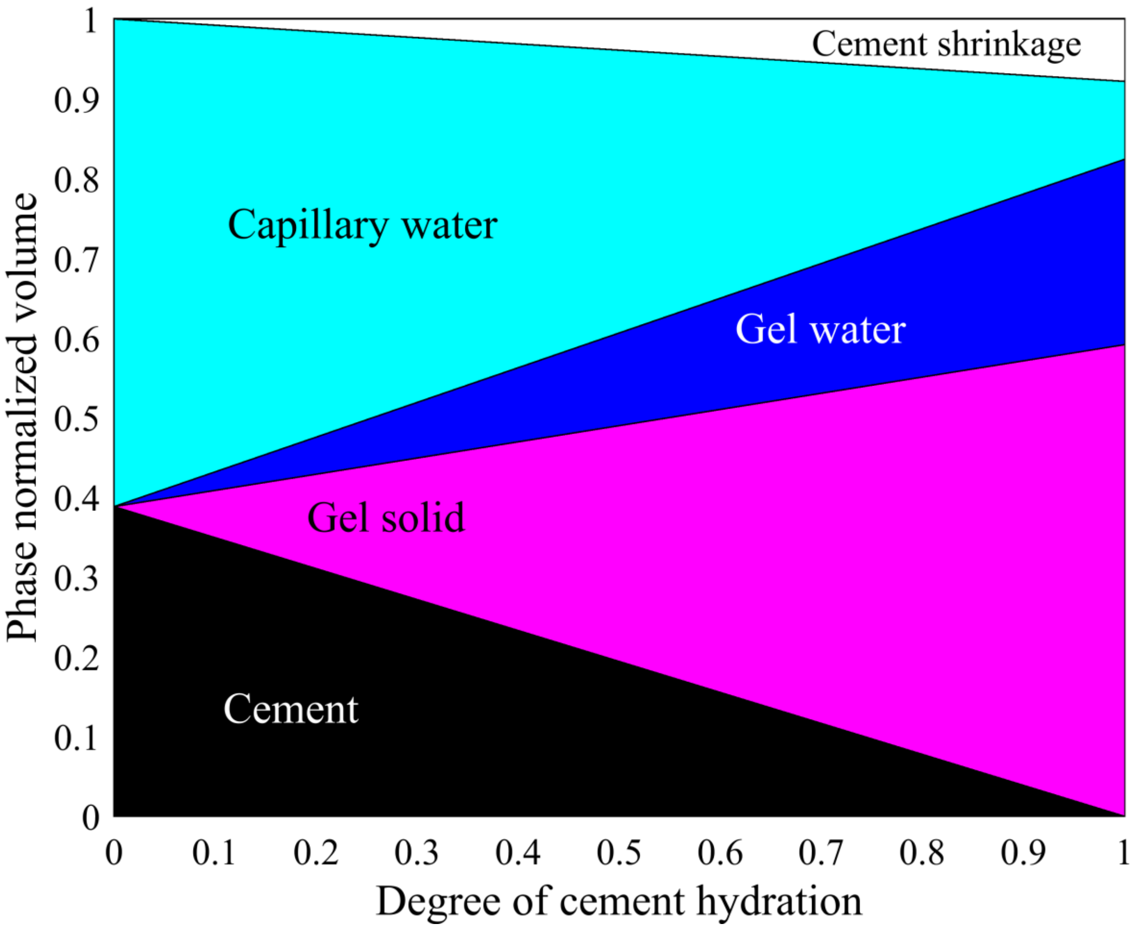
Type I / II OPC





Azad et al. 2017

Type I/II OPC + limestone

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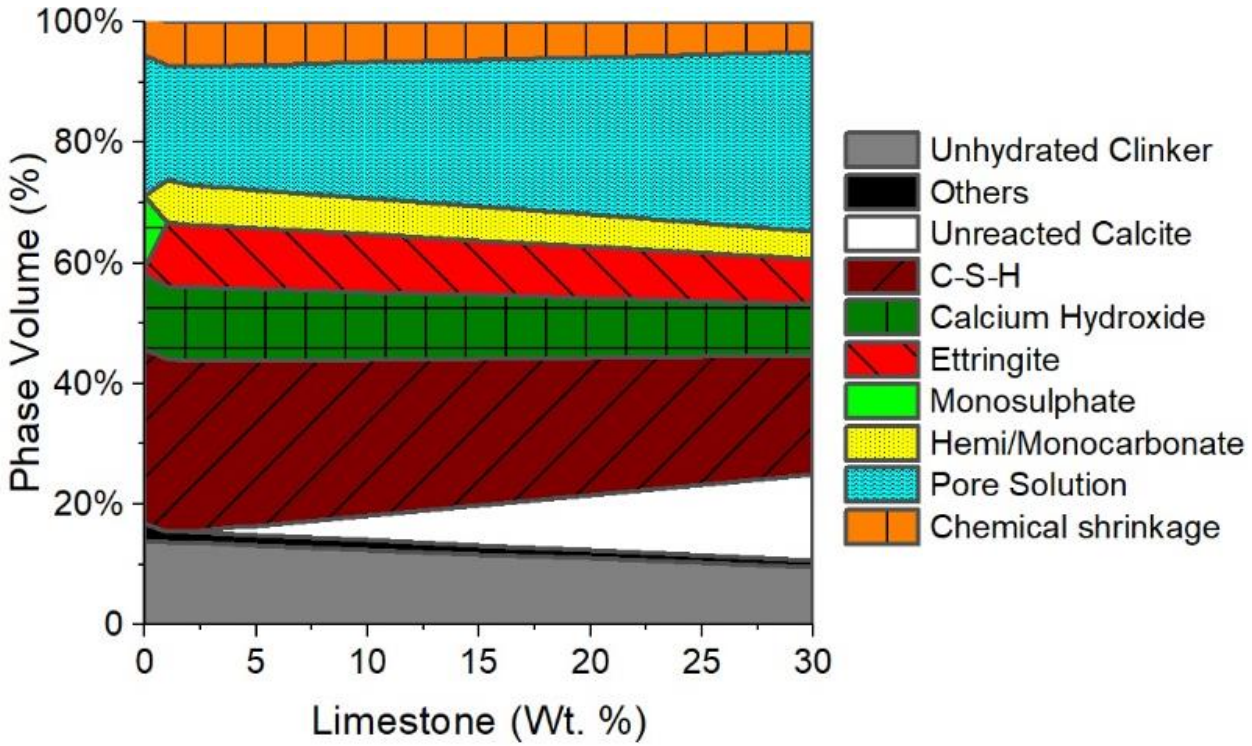
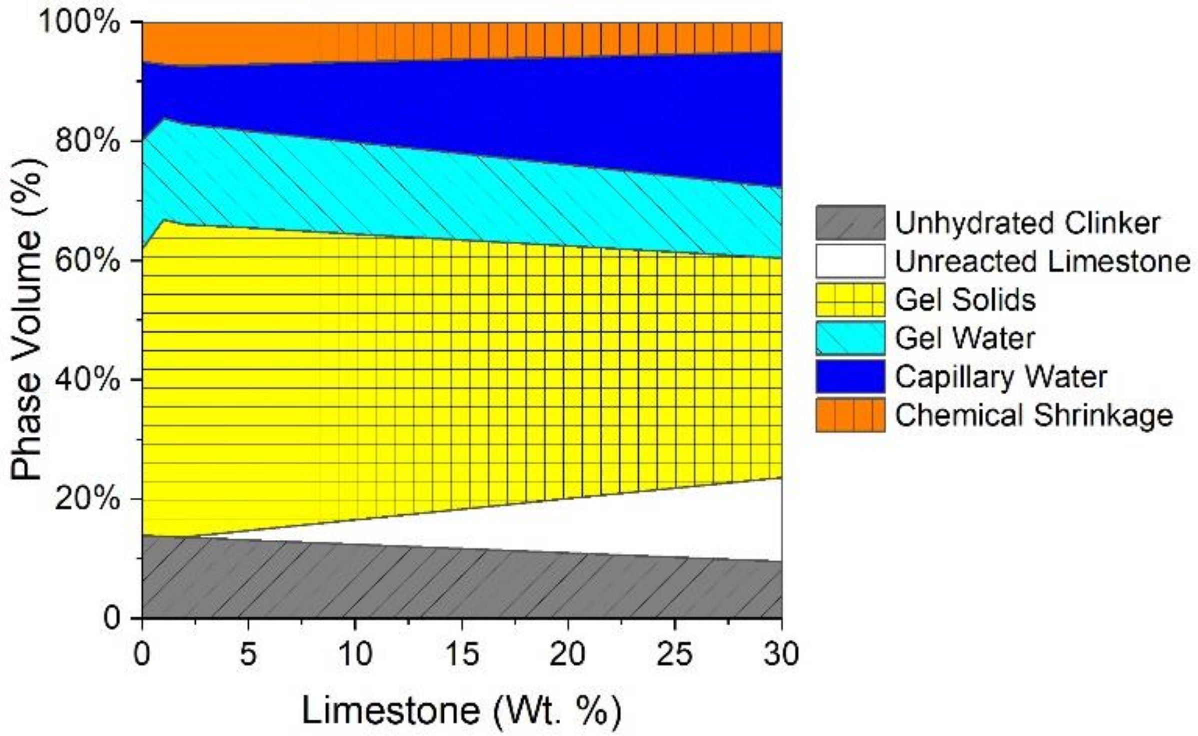
At 90 days of hydration





- Ettringite and hemi/monocarbonate form instead of monosulfate
- Similar C-S-H content; less CH; similar pH

Bharadwaj et al. 2021

Reacted phases vs. limestone %

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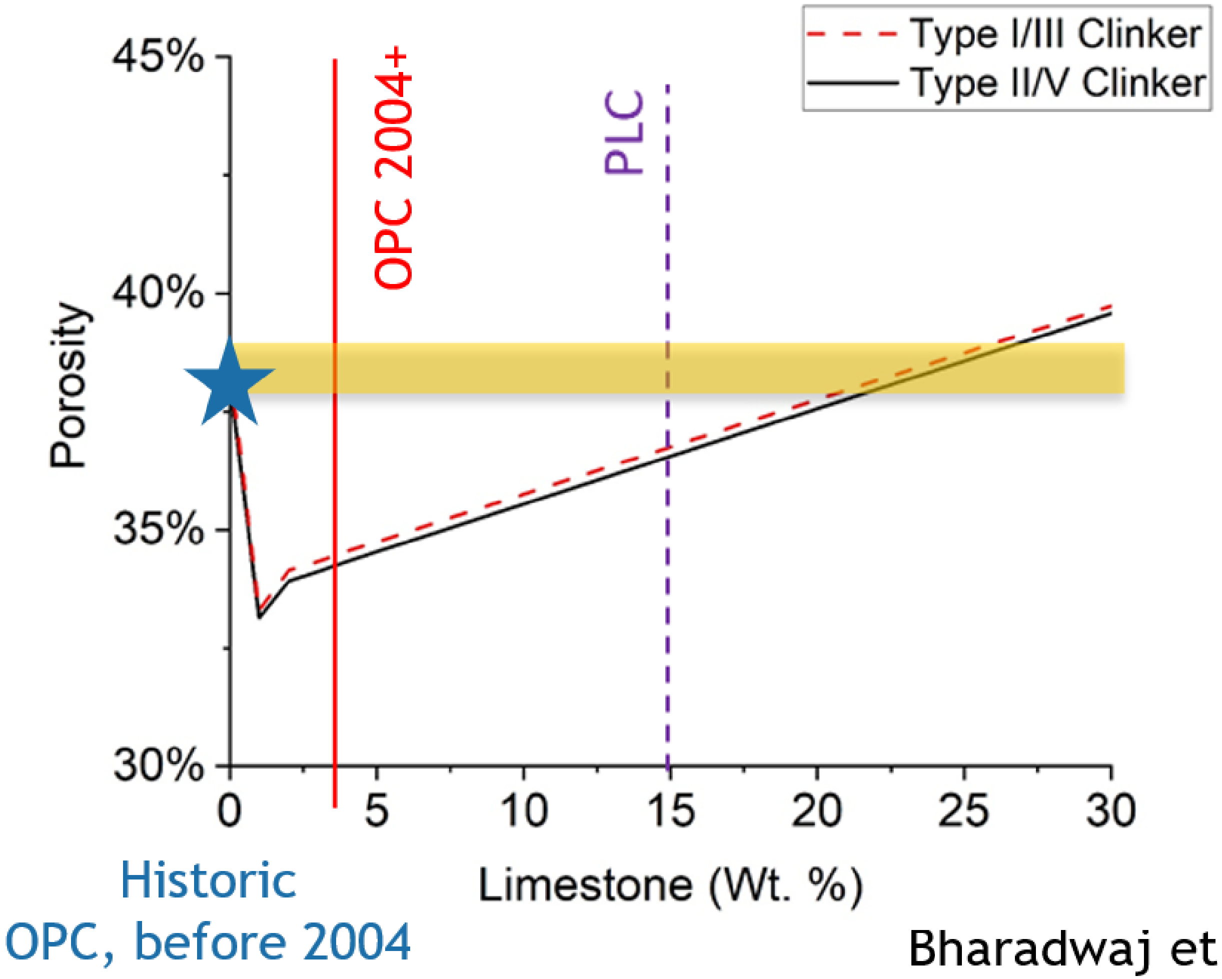
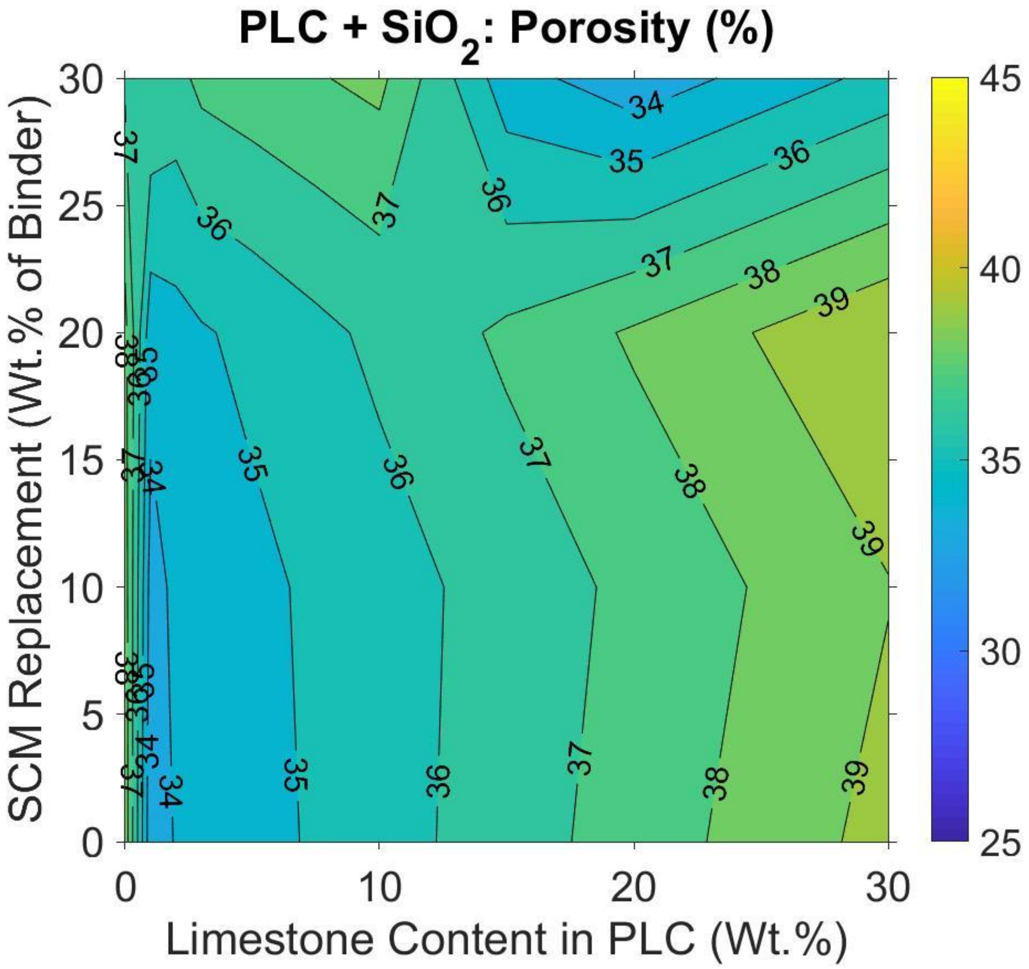
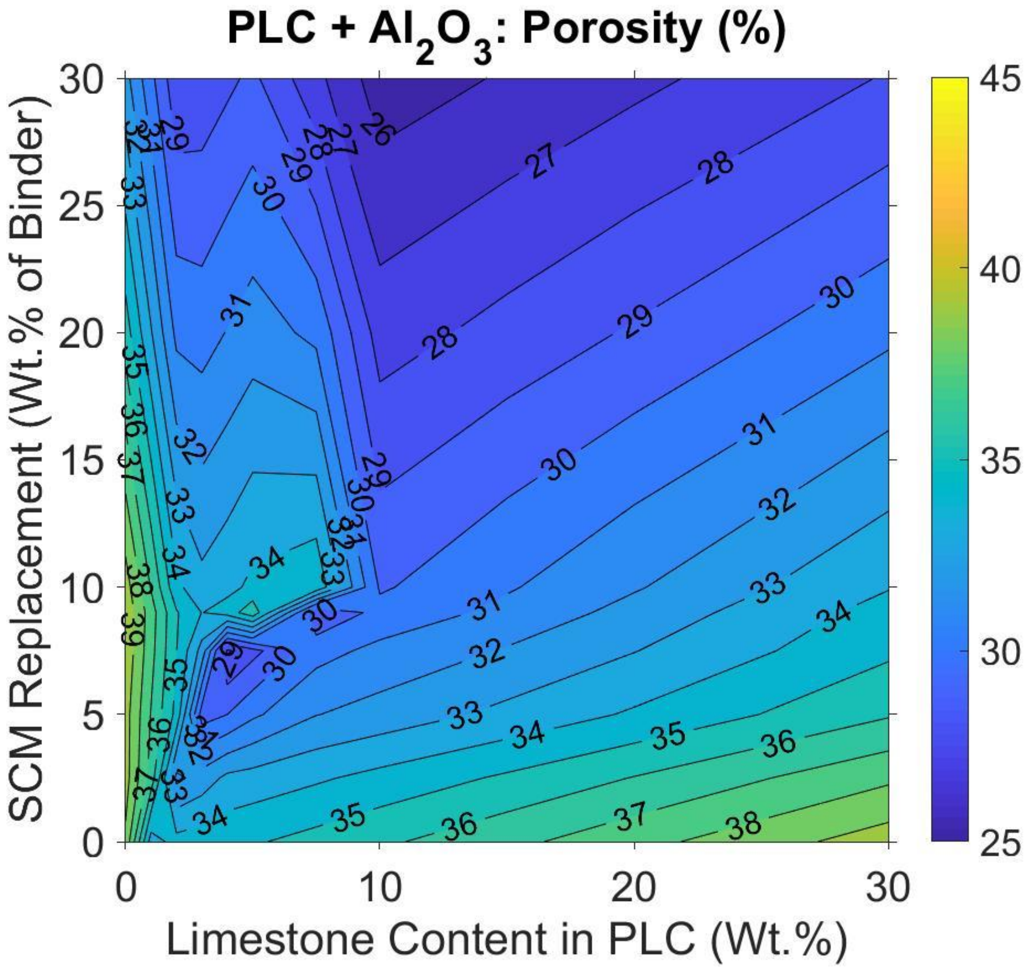


Bharadwaj et al. 2021

- OPC started to include some limestone (2-3%) around 2004
- A lower porosity (higher strength) is observed due to ettringite and hemi/monocarbonate phases
- PLC is typically finer than OPC, which allows comparable strength to OPC

PLC + reactive silica vs. alumina





Bharadwaj et al. 2021

PLC + reactive silica vs. alumina

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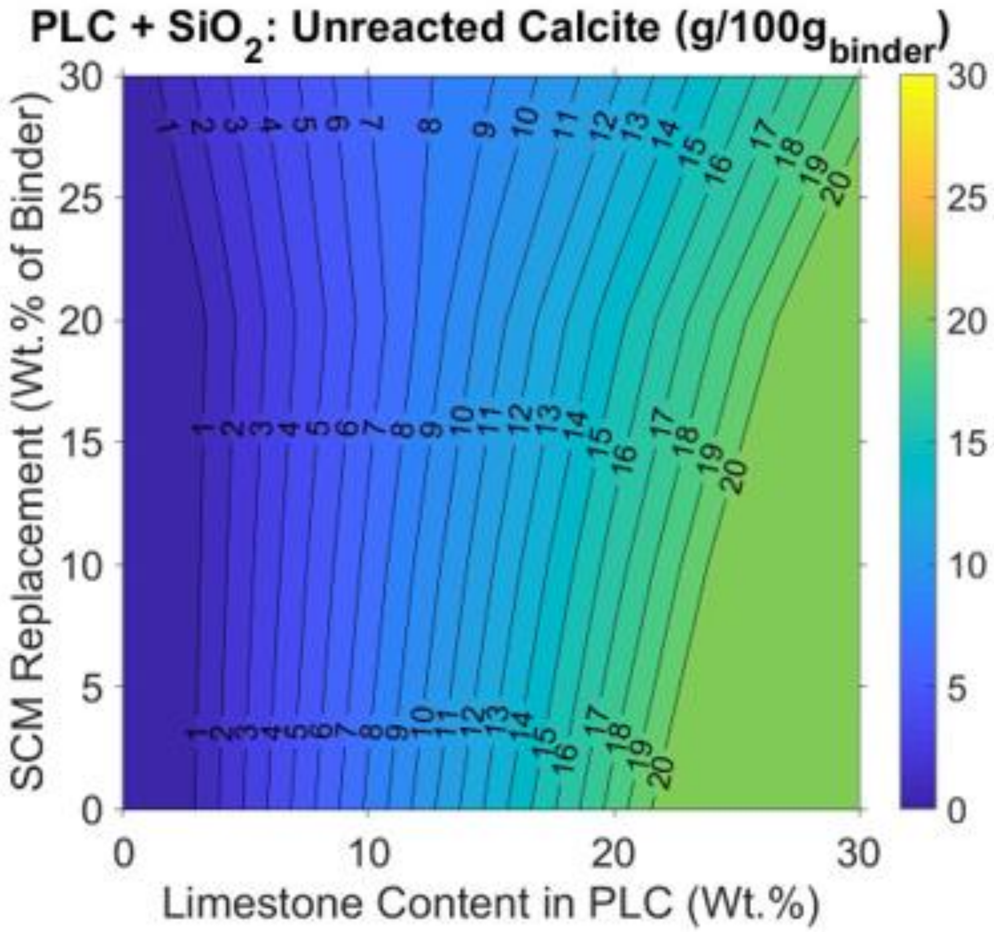
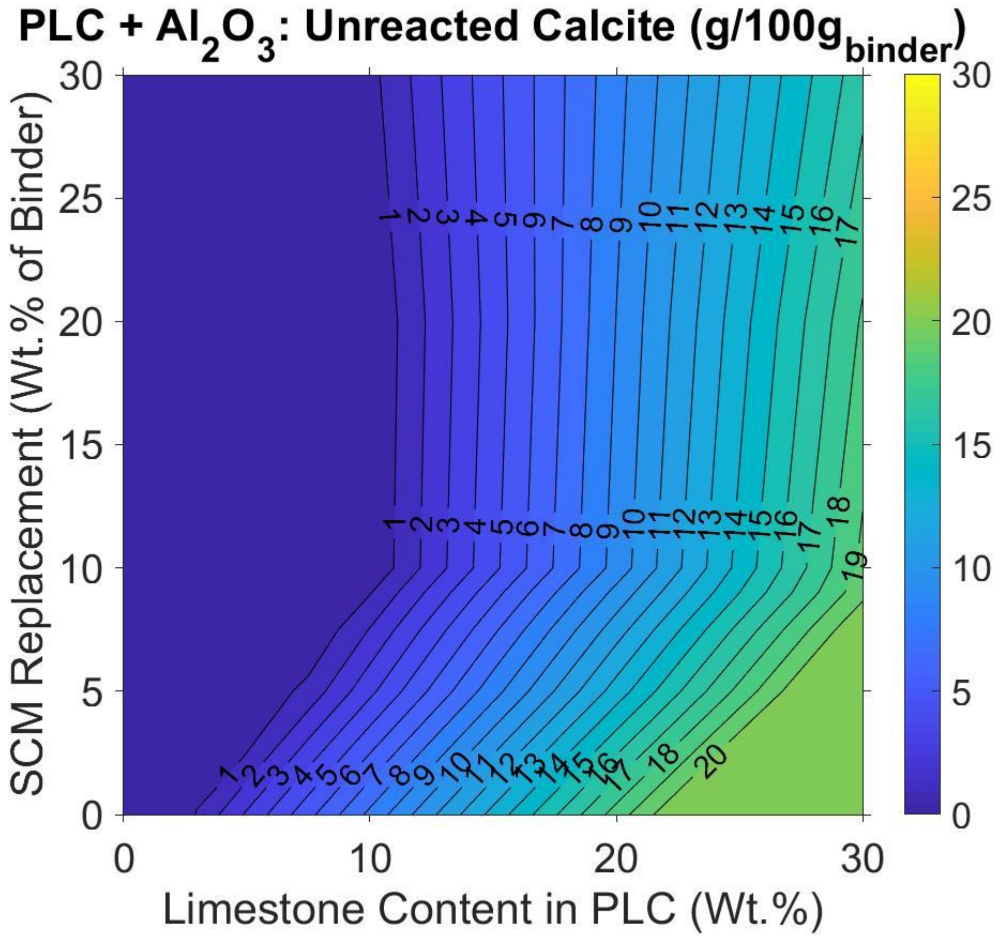
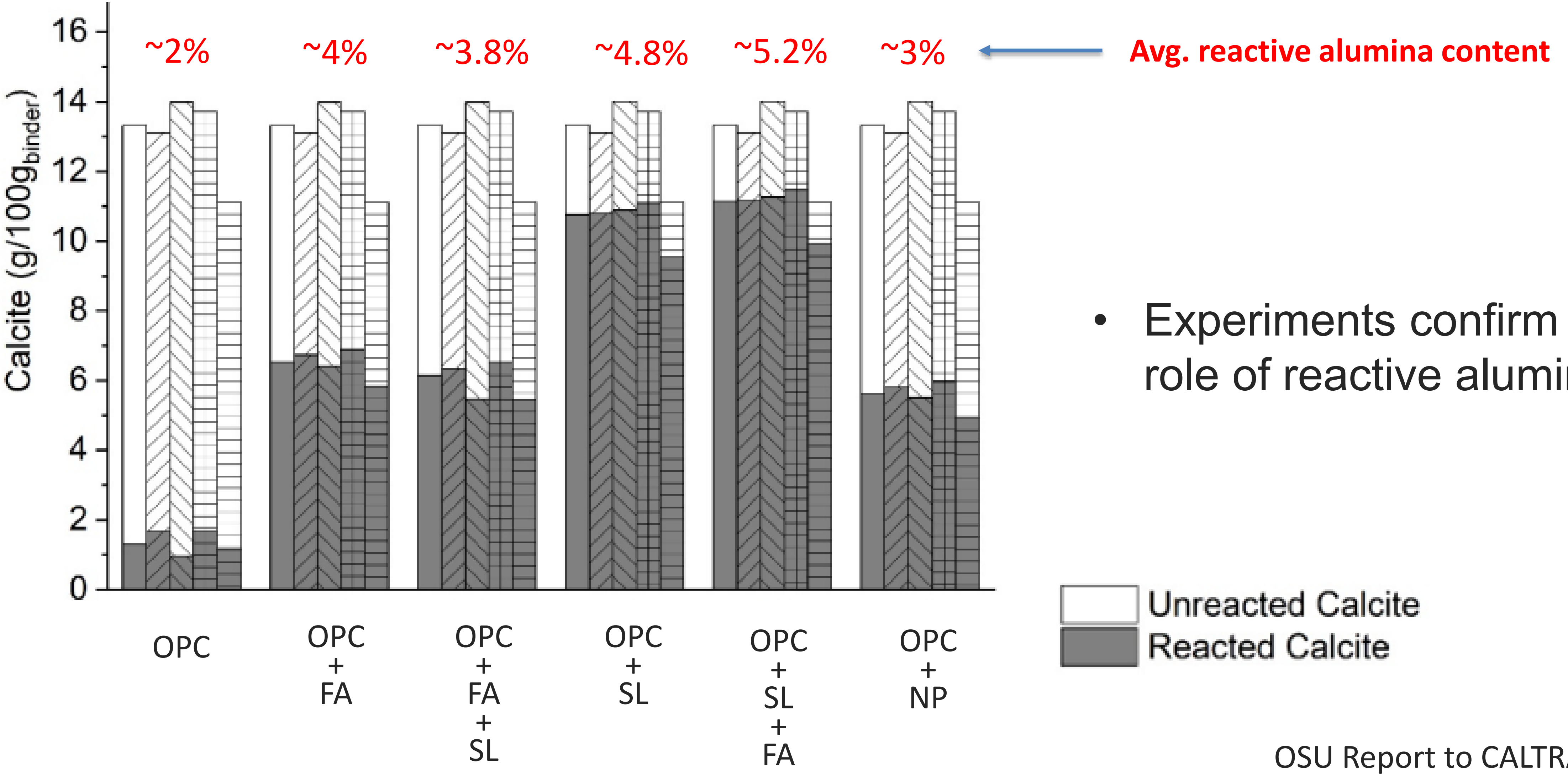




Bharadwaj et al. 2021

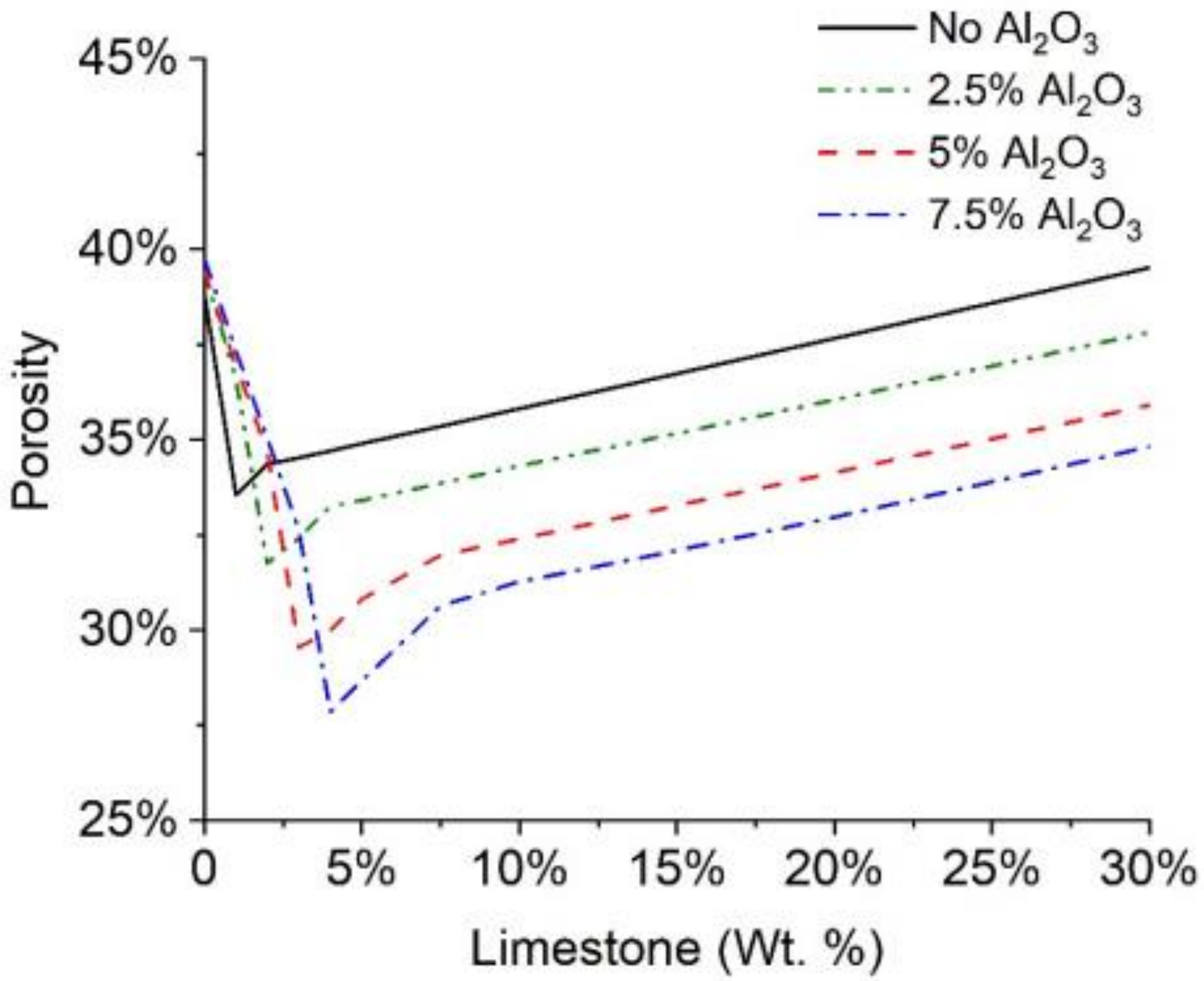
The role of reactive alumina



- Experiments confirm the role of reactive alumina

OSU Report to CALTRANS, 2021

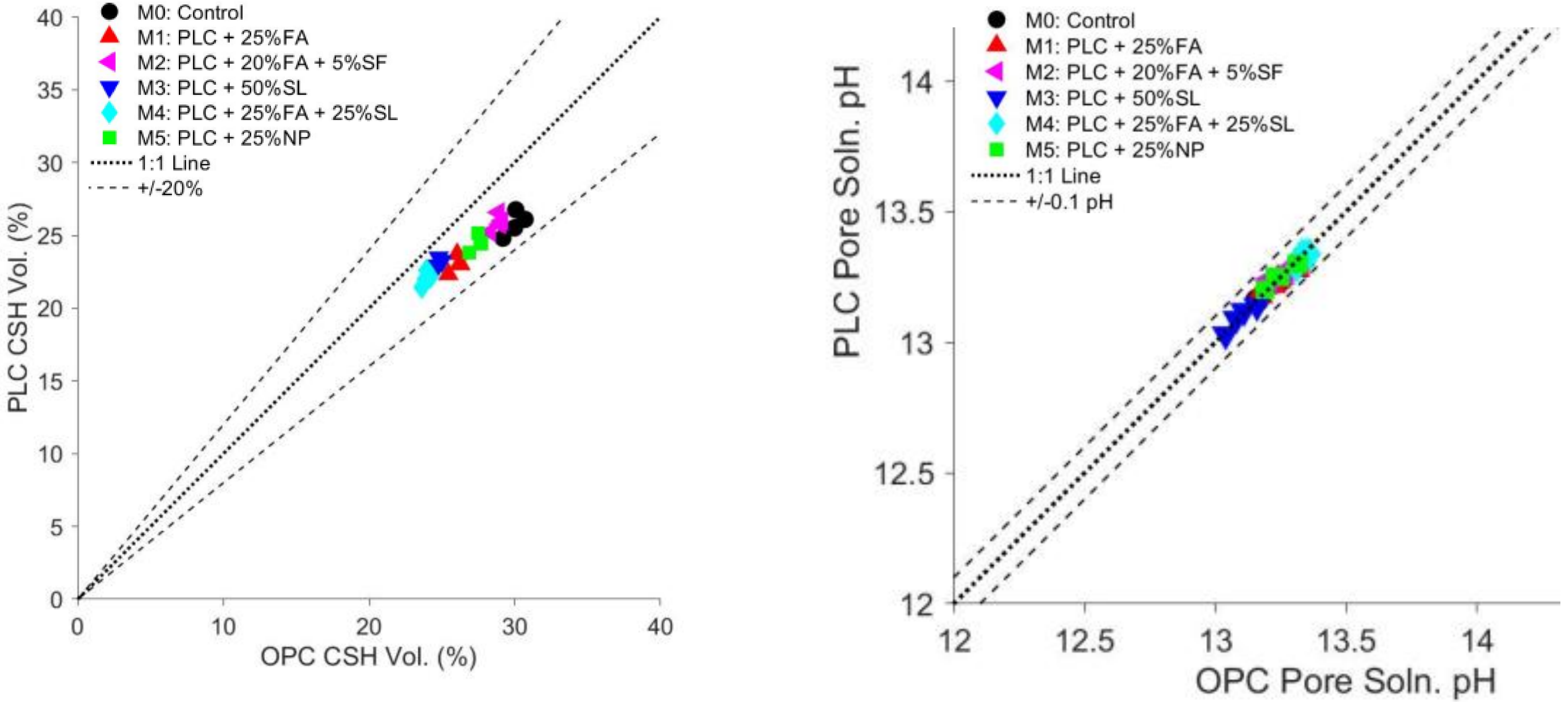
The role of reactive alumina



- Mixtures with limestone contents higher than 15% could give similar properties as PLC when SCMs with highly reactive alumina are used (e.g., some calcined clays, etc.)

Bharadwaj et al. 2021

PLC + SCM



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Optimization of PLC+SCM mixtures

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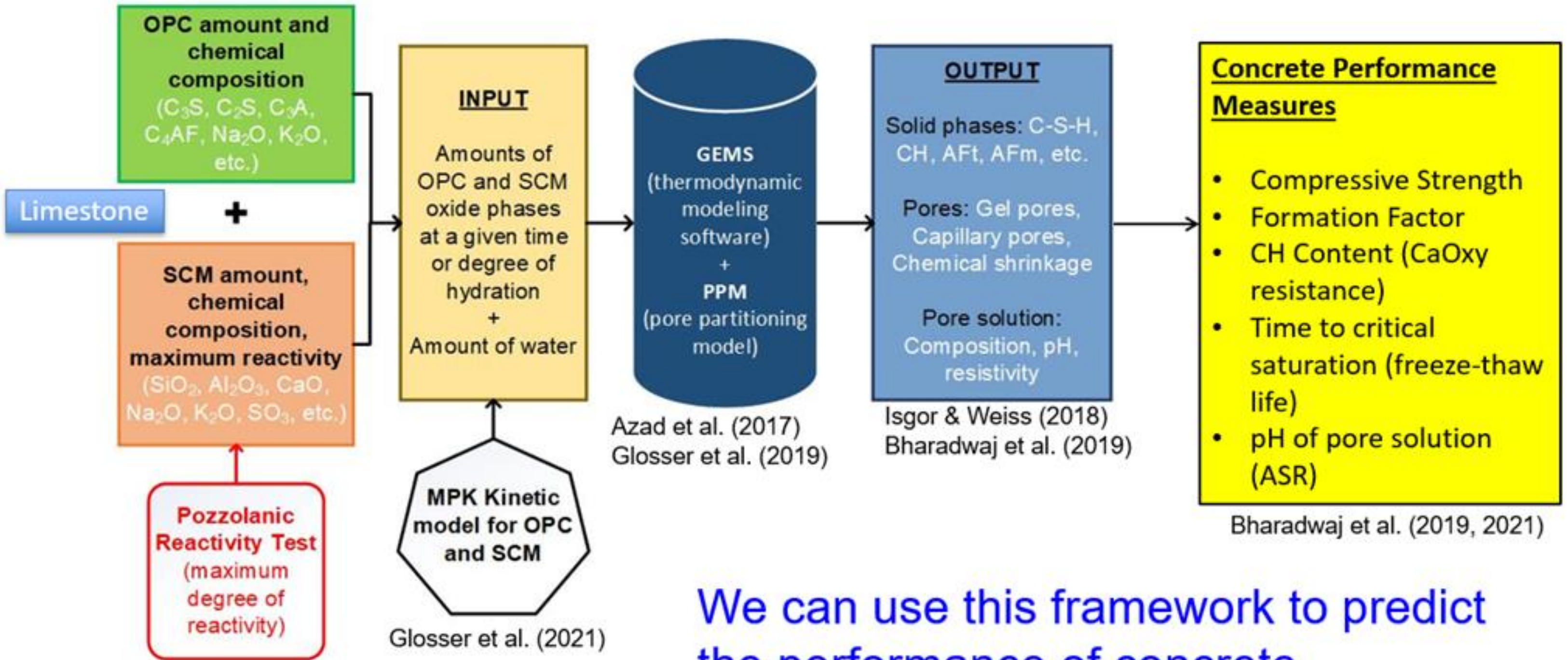
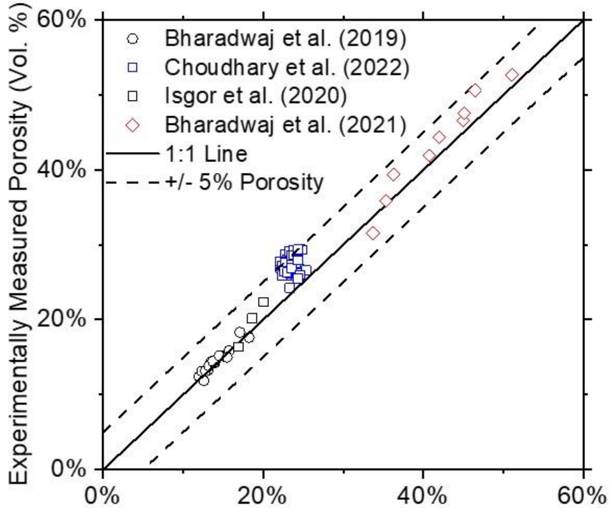
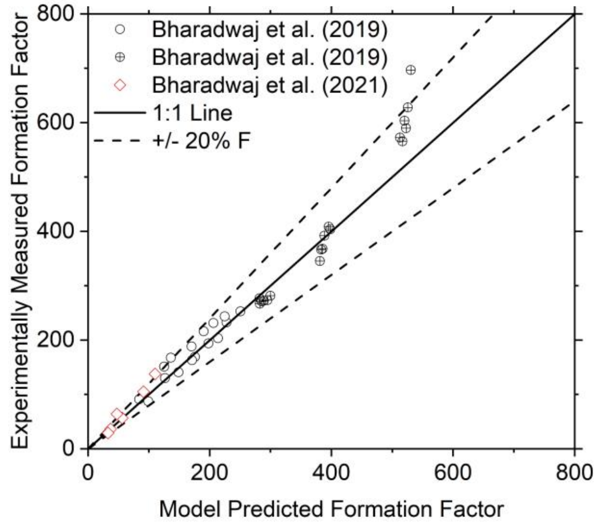
Thermodynamic modeling framework to predict mixture properties



We can use this framework to predict the performance of concrete…





Optimization of PLC+SCM mixtures

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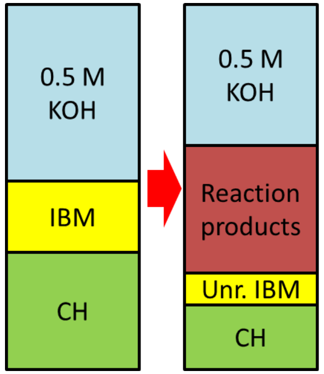
Step 1 - Characterize materials:

Component	PLC	SCM
SiO_2	20.30	48.20
Al_2O_3	4.80	19.10
Fe_2O_3	3.30	5.70
CaO	63.50	14.60
Na_2O_{eq}	0.51	0.78
MgO	0.80	3.80
SO_3	3.10	1.00
$CaCO_3$	13.00	-
Specific Gravity (unitless)	3.09	2.66
Blaine Fineness (m^2/kg)	405	350
DOR*	N/A	43%

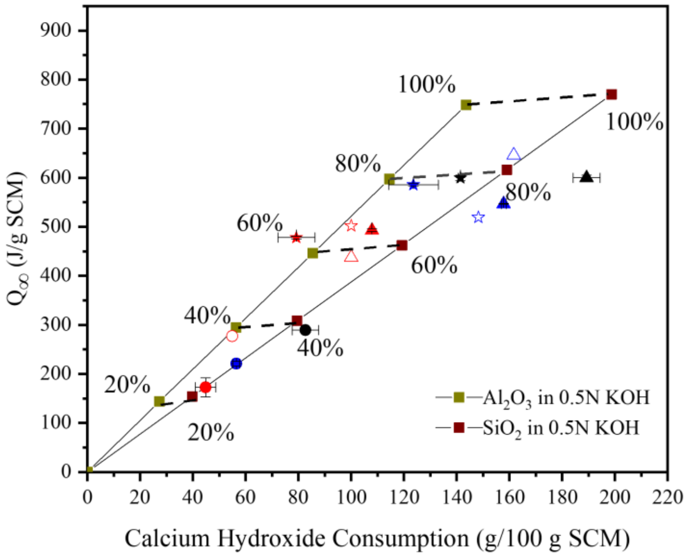
Maximum degree of pozzolanic reactivity (DOR*)



$$SCM + CH + H_2O \rightarrow \text{reaction products} + \Delta$$

Measure CH Consumed

Measure Heat Released



$$DOR^* = \frac{Q_\infty - c_1 \cdot CH_{consumed}}{c_2}$$

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Step 2 - Define the performance criteria:

Concrete Application	Bridge Deck	Midwest Pavement	Foundation
Exposure Class / Durability Requirement	ACI 318: F3, S0, W0, C2 Resistance to chloride ingress, corrosion, and FT	AASHTO PP-84 CaOxy and FT damage specified by SHA	ACI 318: F0, S1, W1, C0 Moderate sulfate and ASR resistance
Strength (56-day)	5000 psi (34 MPa) (min)	4225 psi (29 MPa) (min)	4000 psi (27 MPa) (min)
F Factor (56-day)	375 (min)	270 (min)	200 (min)
CH (56-day)	20g/100g binder (max)	20g/100g binder (max)	N/A
pH (56-day)	12.8 (min)	N/A	13.6 (max)
Time to Critical Sat	30 years (min)	30 years (min)	N/A

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Step 3 – Predict mixture properties satisfying performance:

Concrete Application	Midwest Pavement
Exposure Class / Durability Requirement	AASHTO PP-84 CaOxy and FT damage specified by SHA
Strength (56-day)	4225 psi (29 MPa) (min)
F Factor (56-day)	375 (min)
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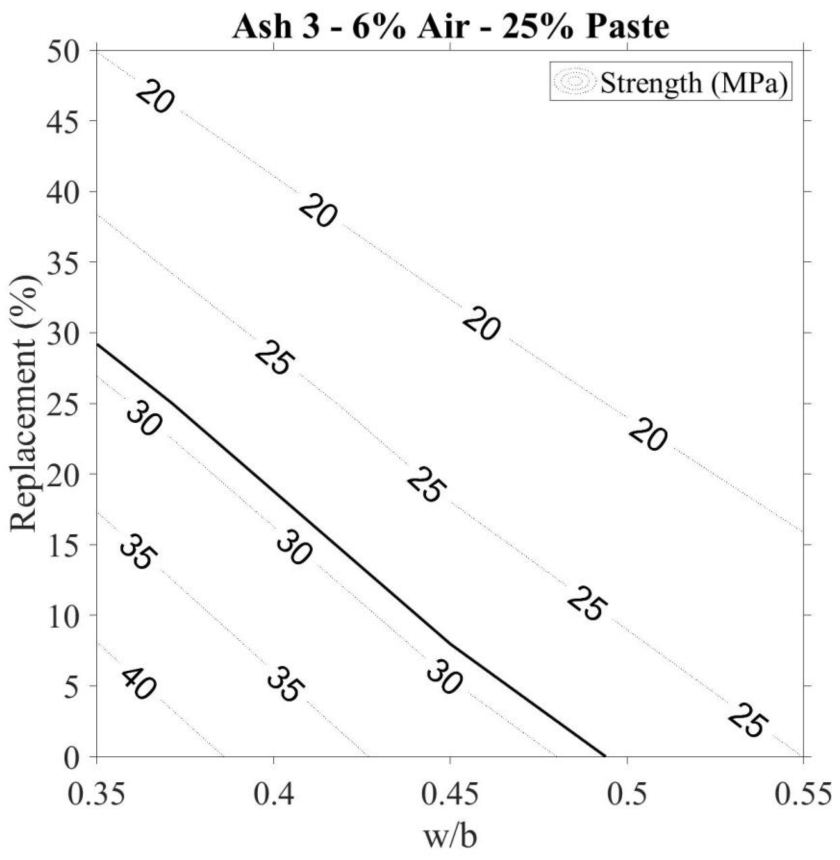
pH (56-day)	N/A
Time to Critical Sat	30 years (min)



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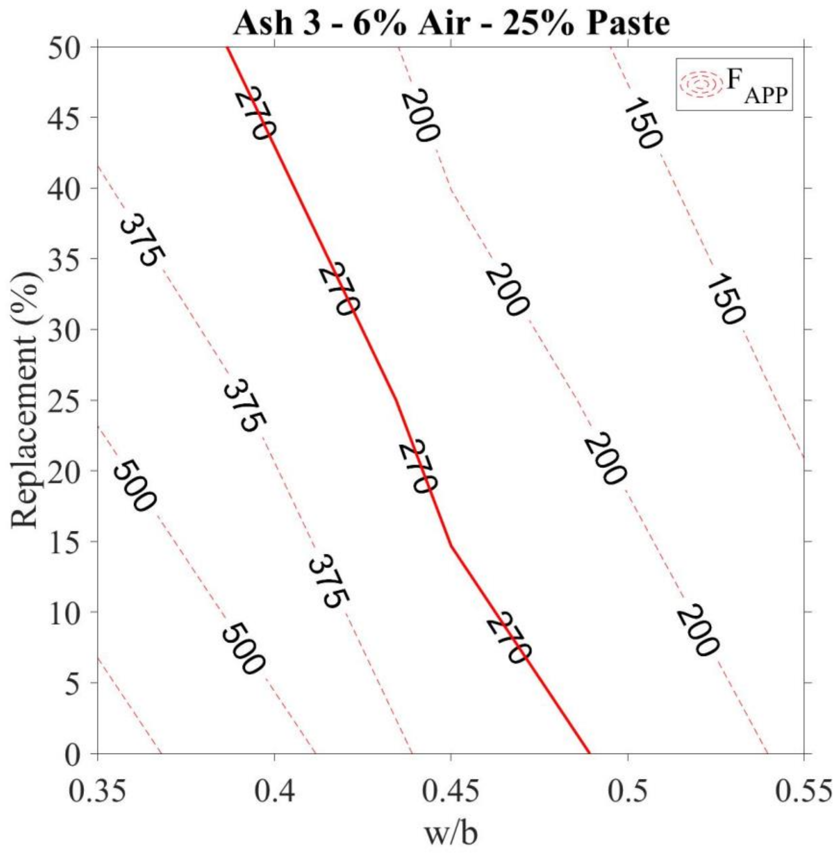

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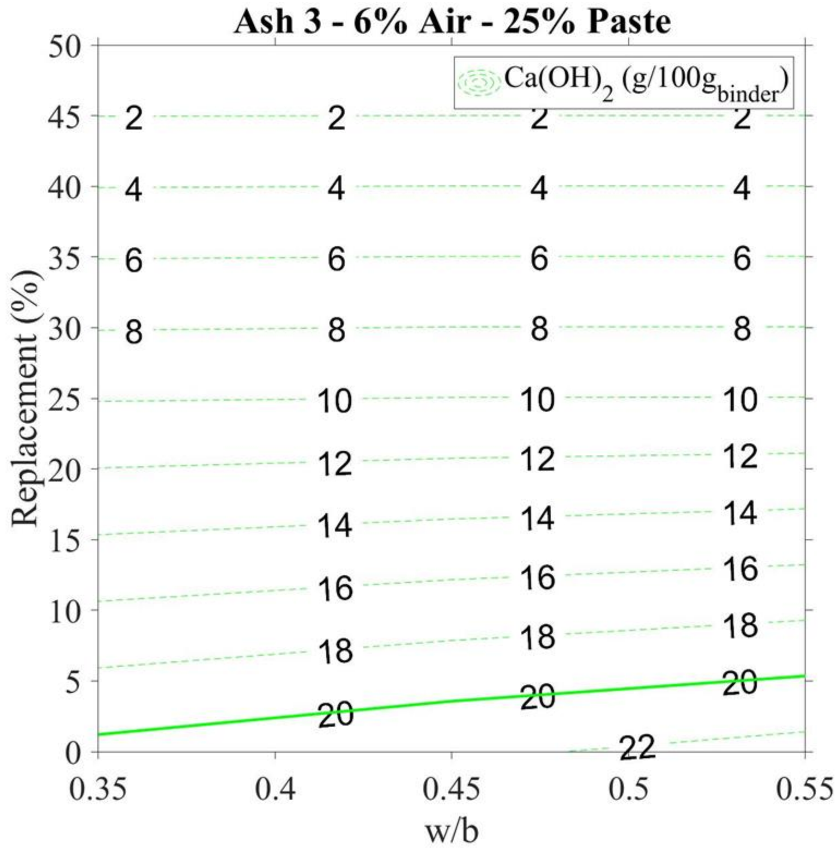
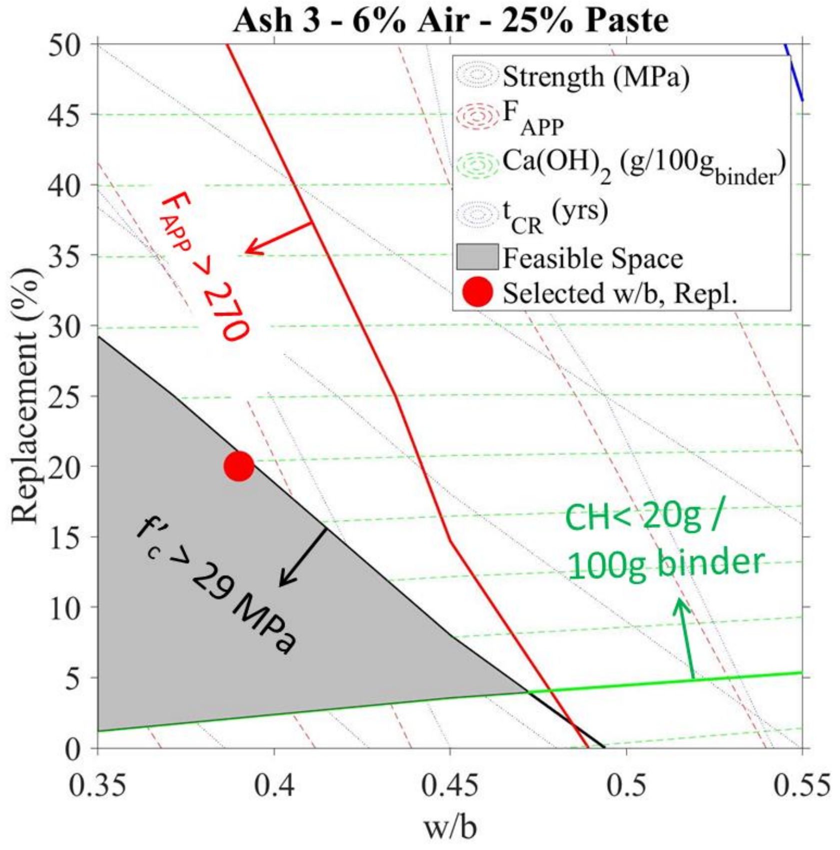


Optimization of PLC+SCM mixtures

Step 4 – Find the feasible space:

Concrete Application	Midwest Pavement
Exposure Class / Durability Requirement	AASHTO PP-84 CaOxy and FT damage specified by SHA
Strength (56-day)	4225 psi (29 MPa) (min)
F Factor (56-day)	270 (min)
CH (56-day)	20g/100g binder (max)
pH (56-day)	N/A
Time to Critical Sat	30 years (min)



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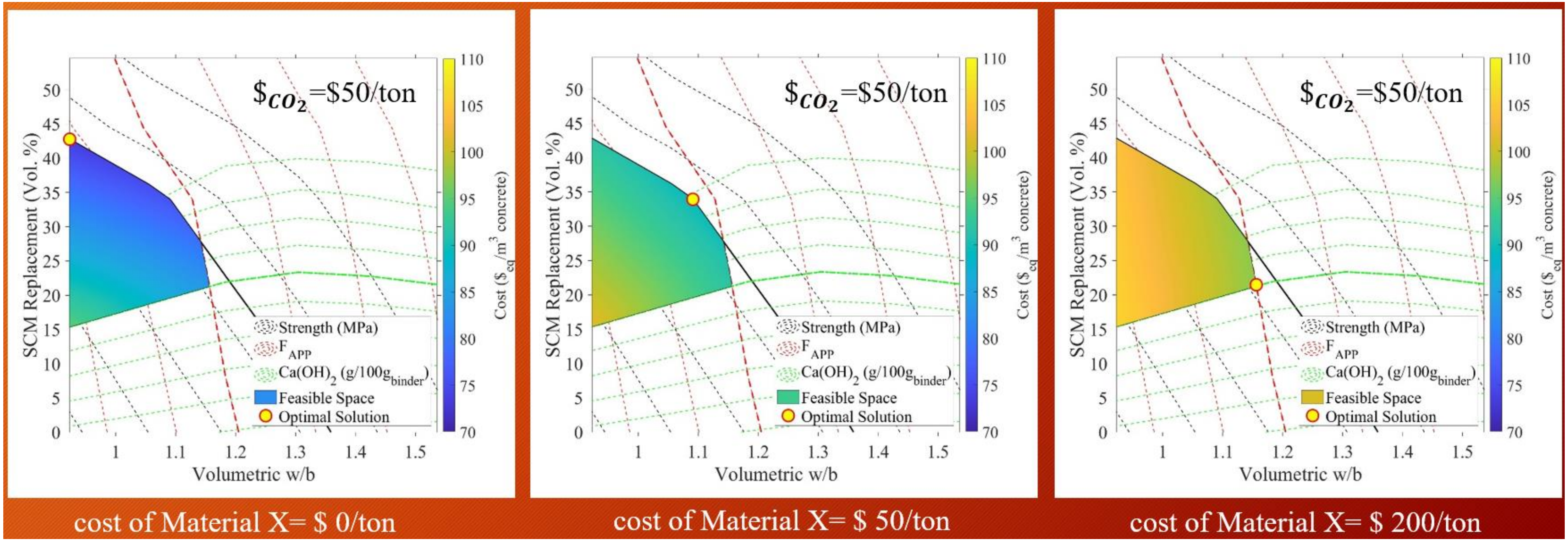
Step 5 – Optimize for CO_2 footprint and/or cost:



Conclusions

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- PLC produces concrete with similar chemical composition to OPC concrete
- Ettringite and hemi/monocarbonate form instead of monosulfate, as a result porosity typically decreases
- PLC is typically finer than OPC, which allows comparable strength to OPC
- Limestone in PLC has synergetic reactions with reactive alumina from SCMs
- Mixtures with limestone contents higher than 15% could give similar properties as PLC when SCMs with highly reactive alumina are used (e.g., some calcined clays, etc.)
- Proportioning PLC+SCM mixtures for a defined performance criteria is possible through the developed framework
- This framework also allows optimization for CO_2 footprint and/or cost

Thank you

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