Carbon sequestration of Type I (OPC) and IL (PLC) cement paste with the addition of nano silica

04/05/2023

Presenter: Rui He (he566@purdue.edu)

Advisor: Dr. Luna Lu (luna@purdue.edu)

The LUNA Group

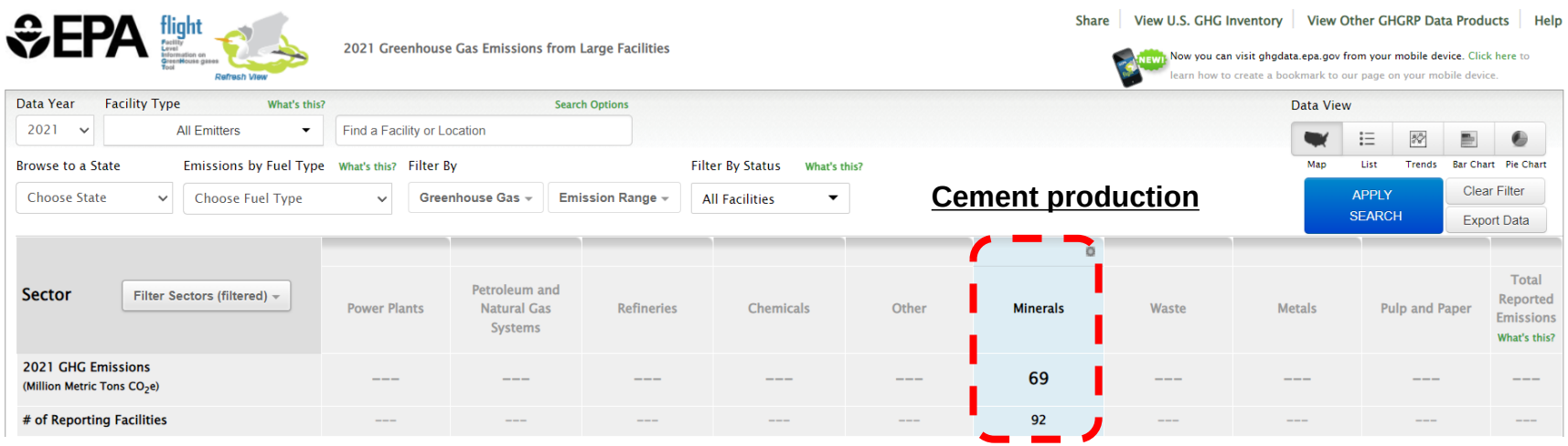
Lyles School of Civil Engineering

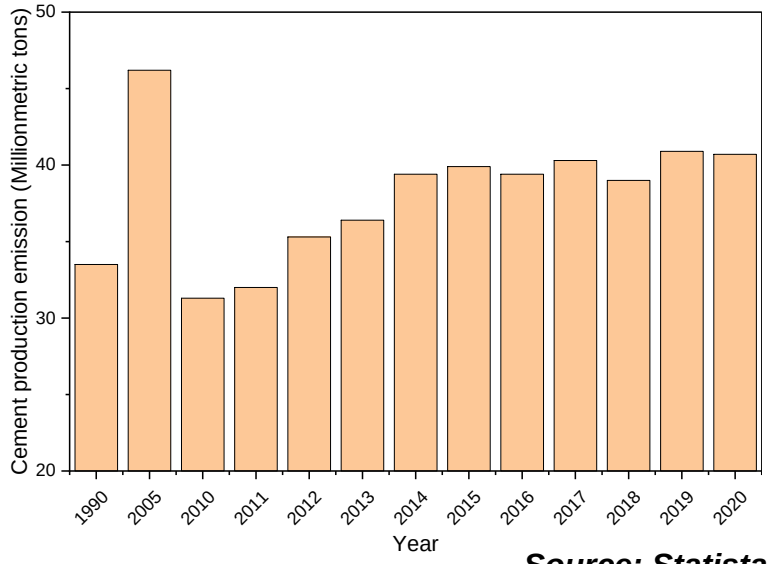
PURDUE UNIVERSITY

Contents

- Research background and motivation
- Characterization results of Type I and IL cements and nano silica
- Experimental program
- Results and discussion
- Conclusions

Research background and motivation



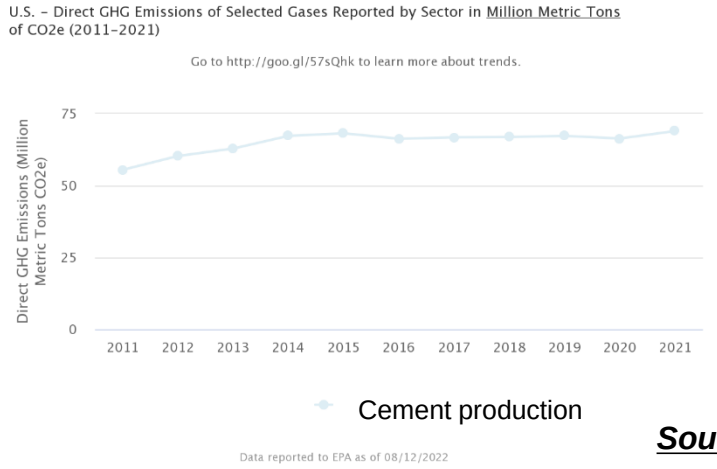


Source: Statista

Why Type IL (Portland limestone cement, PLC) cement?

- Same durability
- Same resilience
- Up to 10% carbon footprint reduction

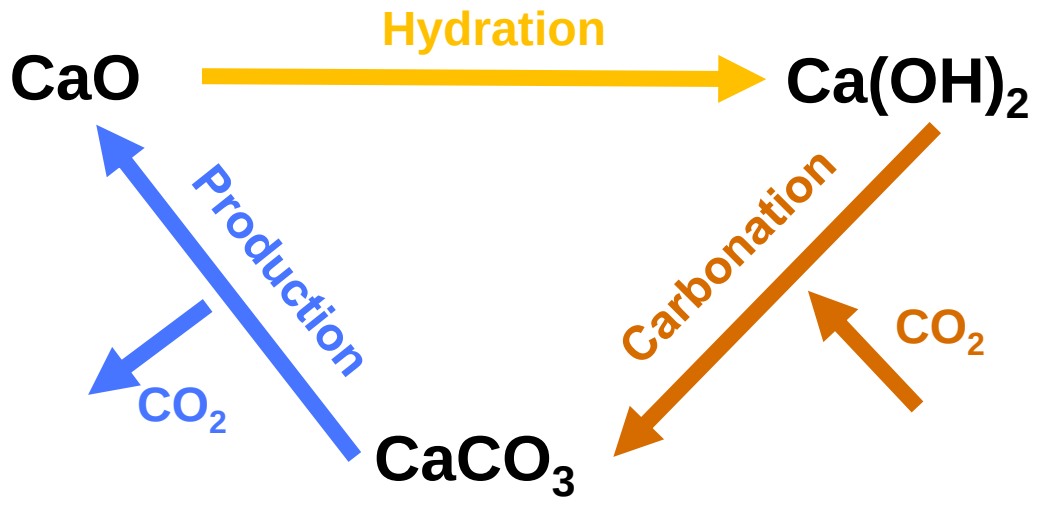
https://www.greenercement.com/



Source: EPA

Research background and motivation

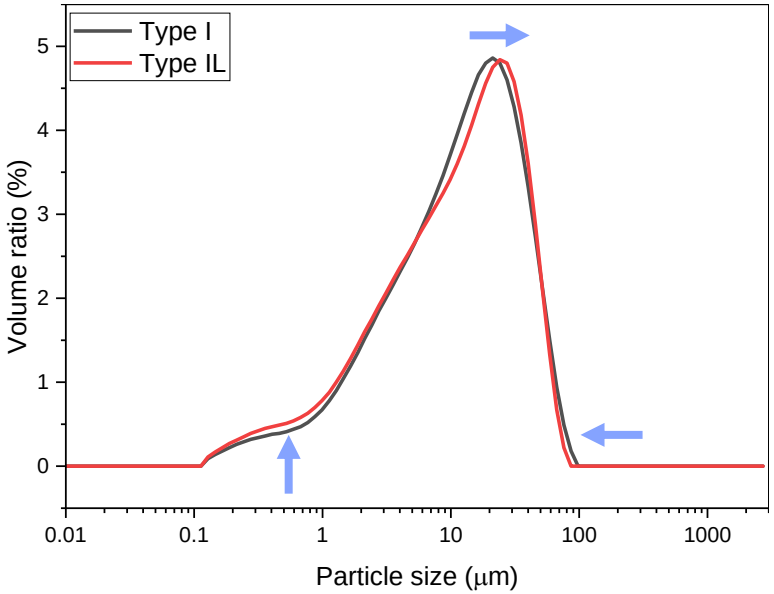
Carbonation: **the sponge effect**

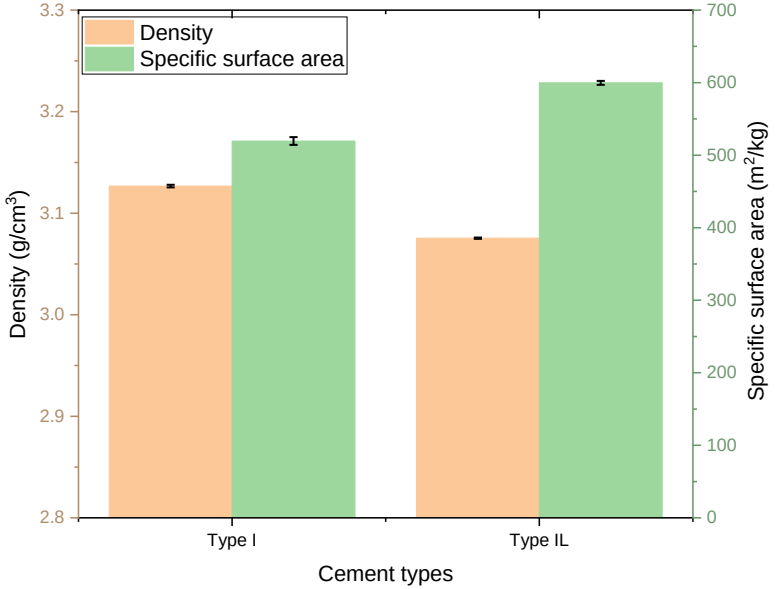


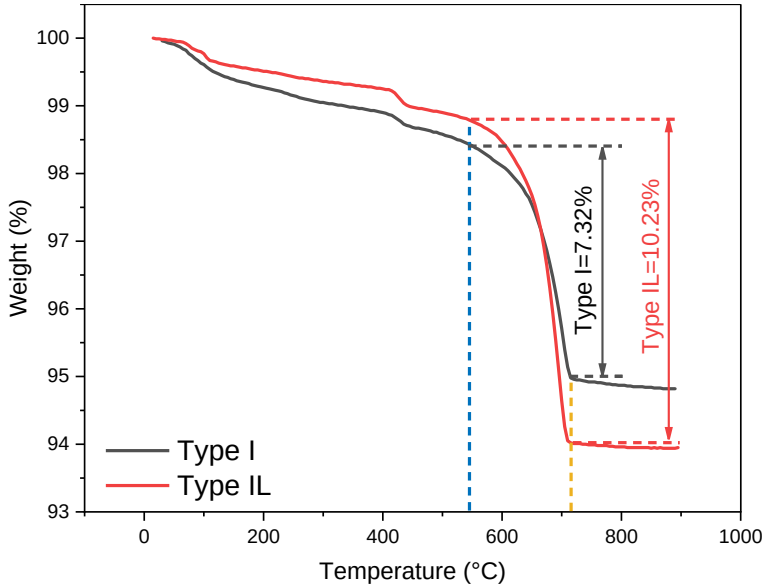
- Future reabsorption of CO_2 will be significant (~30% of cumulative CO_2 emissions from 2015 to 2100).
- Climate goal compliant net CO_2 emissions reduction along the global cement cycle will require both radical technology advancements (e.g., carbon capture and storage) and widespread deployment of **material efficiency measures**.

[1] Z. Cao, R.J. Myers, R.C. Lupton, H. Duan, R. Sacchi, N. Zhou, T. Reed Miller, J.M. Cullen, Q. Ge, G. Liu, The sponge effect and carbon emission mitigation potentials of the global cement cycle, Nat. Commun. 11 (2020) 1–9. doi:10.1038/s41467-020-17583-w.

Cement characterization







- The density of Type IL cement is lower than that of Type I cement, while the specific surface area of Type IL cement is higher than that of Type I cement.
- Thermogravimetric analysis (TGA) results indicate the Type I cement has 7.32% weight loss in the range of 550 °C – 725 °C, while Type IL cement lost 10.23% of weight.

Both Type I and Type IL cement came from Buzzi Unicem USA, Greencastle Plant in Indiana

Cement characterization

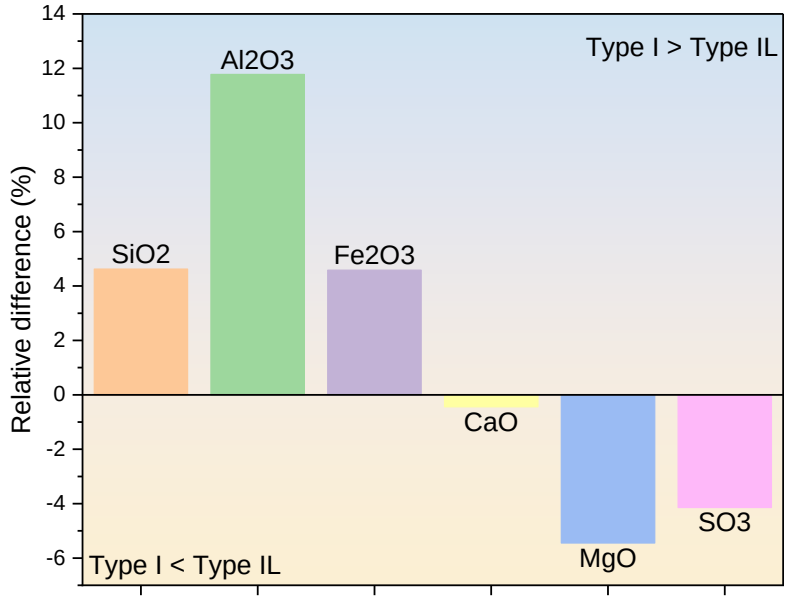
- **Mill certificate:**

Chemical compositions (%, cm^2/g)

Cement	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LoI	Limestone	Blaine
Type I	**19.46**	**5.03**	2.51	**63.31**	2.43	3.24	**2.86**	**4.32**	**3911**
Type IL	**18.60**	**4.50**	2.40	**63.59**	2.57	3.38	**5.30**	**11.00**	**4420**

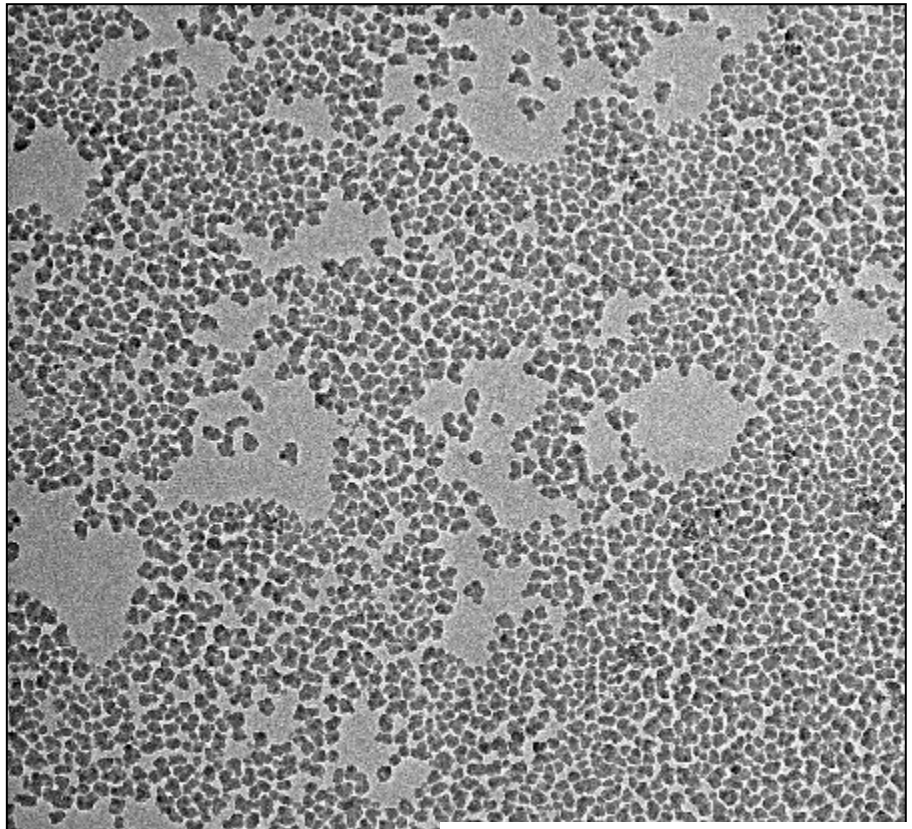
$CaCO_3$ in limestone: 93.0%

- The blaine fineness results indicate that Type IL cement is finer than that of Type I cement. Which is consistent with specific surface area characterization results.
- The largest difference in chemical composition is aluminum content.



Nano silica

- Nano silica (E5):
  - ❖ Liquid content: 70%
  - ❖ Solid content: 30%
    - ➢ SiO_2: 98.29%
    - ➢ Na_2O: 1.57%
    - ➢ Others: 0.14%
  - ❖ Density = 1.2 g/cm^3



Scale bar =50 nm

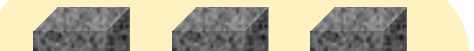
We would like to express our gratitude to Specification Products for providing E5™ products used in this research.

- Under the TEM image, the nano-sized particles with average particle size around 10-20 nm were observed.

https://www.specificationproducts.com/rcsproducts/rcs-internalcure/

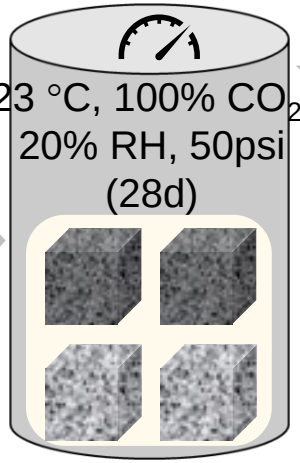
Experimental program

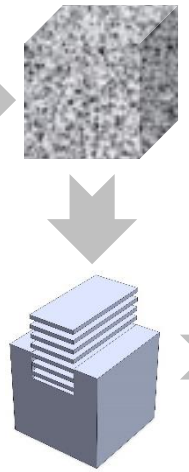
Saturated lime water curing
w/c=0.45, T=23 °C
(28d)



OPC OPC3 OPC6

PLC PLC3 PLC6

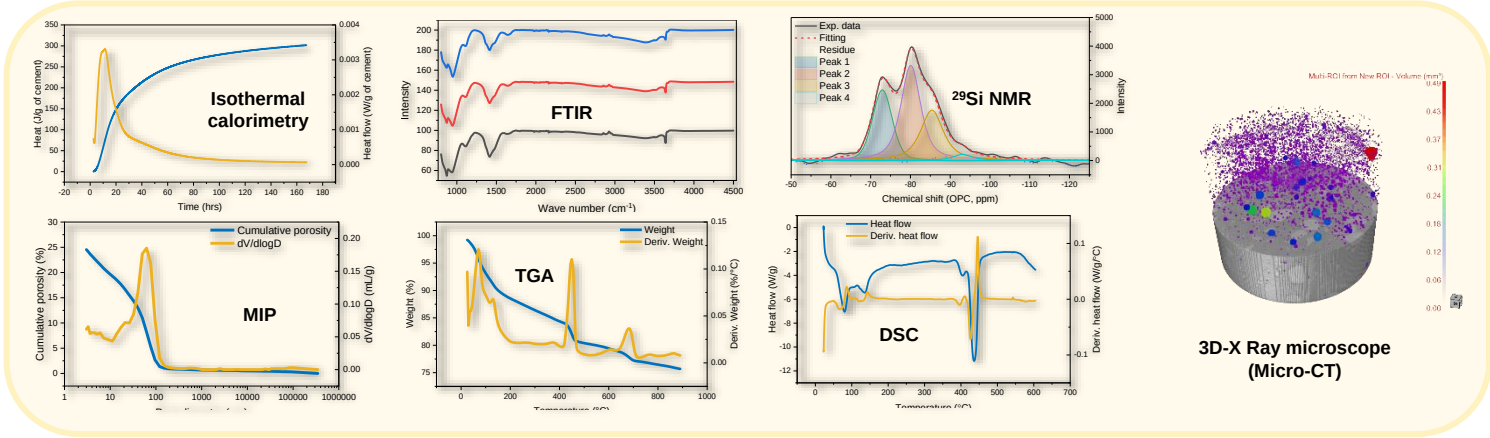


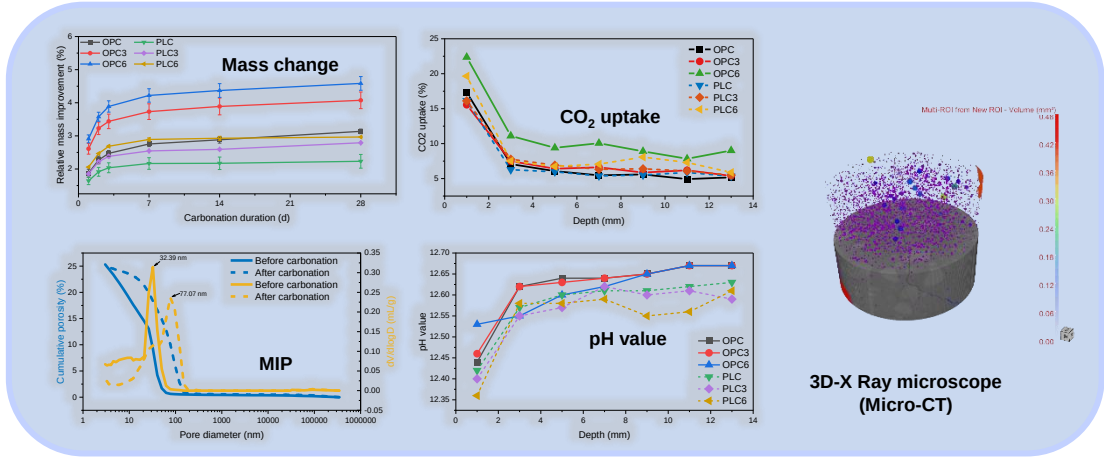


Grind to 7 layers
(2mm per layer)

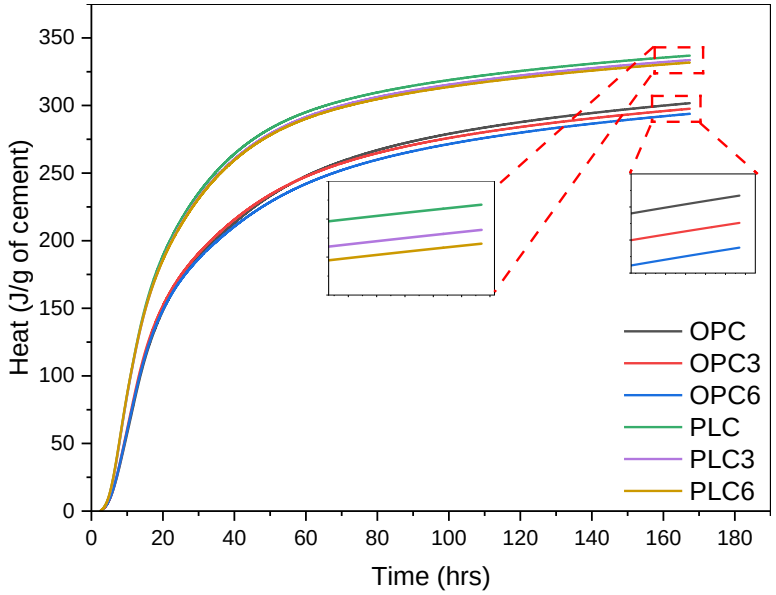
OPC3

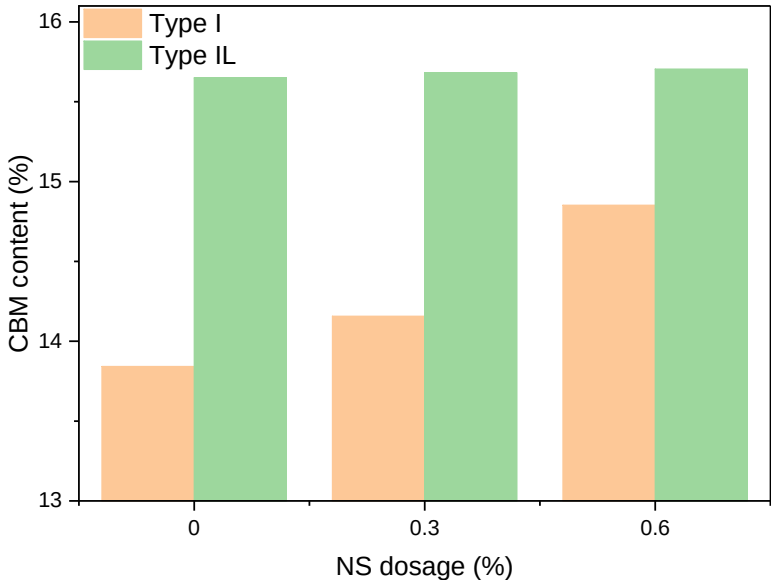
0.3% mass ratio of cement

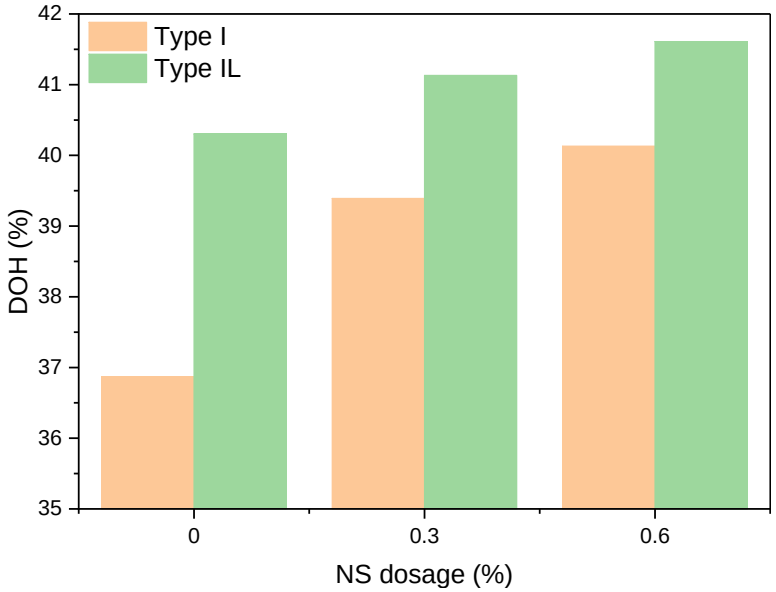




Hydration property



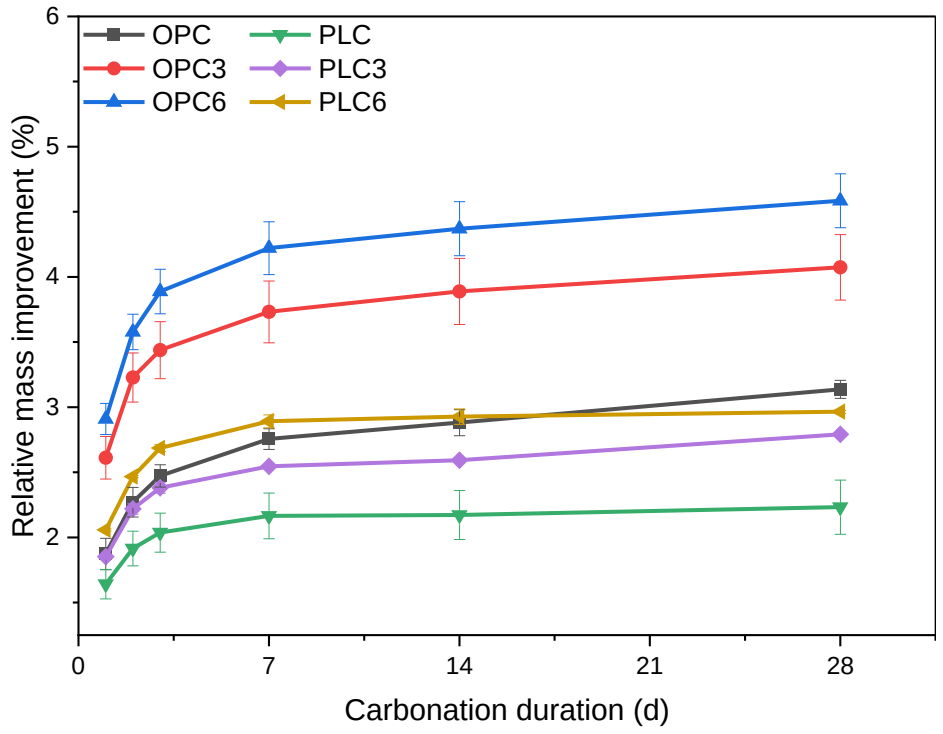


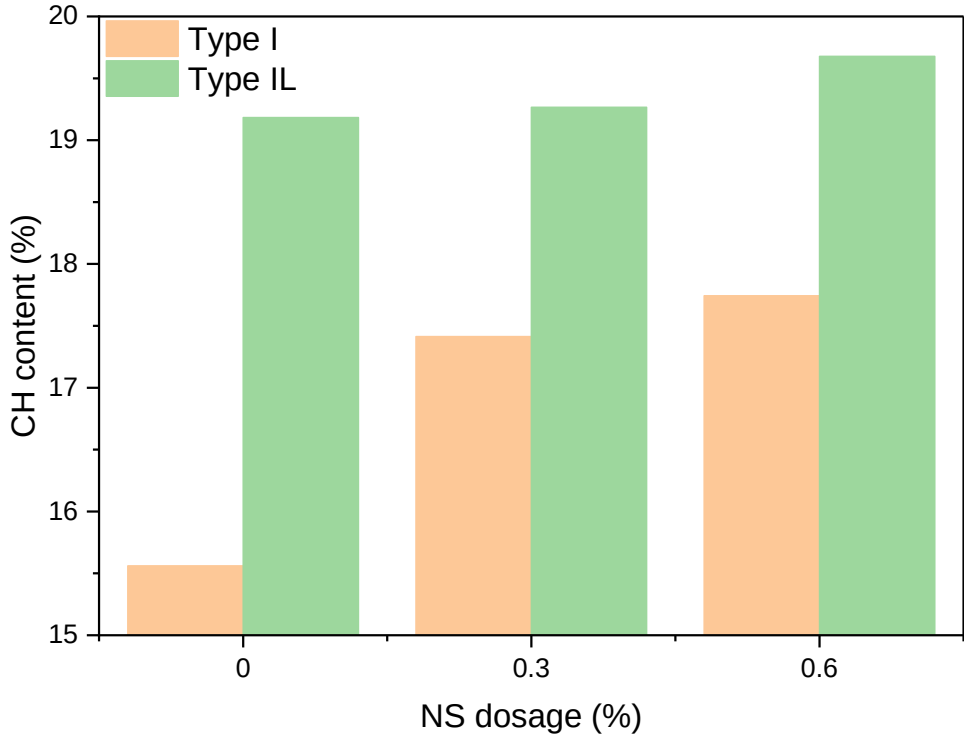


- The hydration heat of Type IL paste is higher than that of Type I cement paste. With the addition of NS, the hydration heat reduced in first 7d age.
- Chemically bound water and hydration degree results from TGA analysis on 28d age samples indicate the hydration promotion effect of NS.

CBM: Chemically bound water
DOH: Degree of hydration

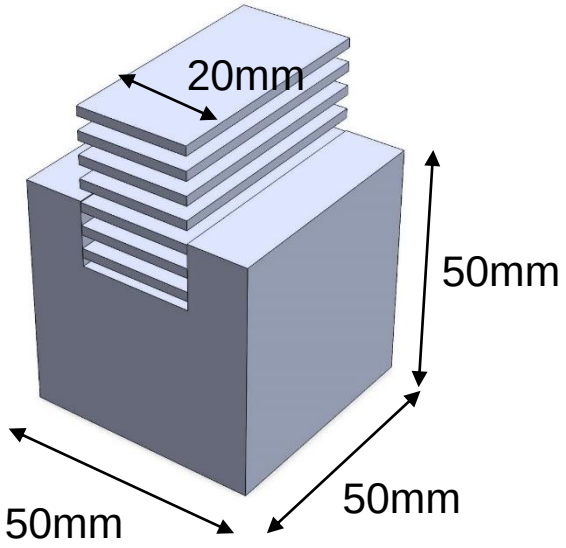
CO_2 uptake – overall mass change

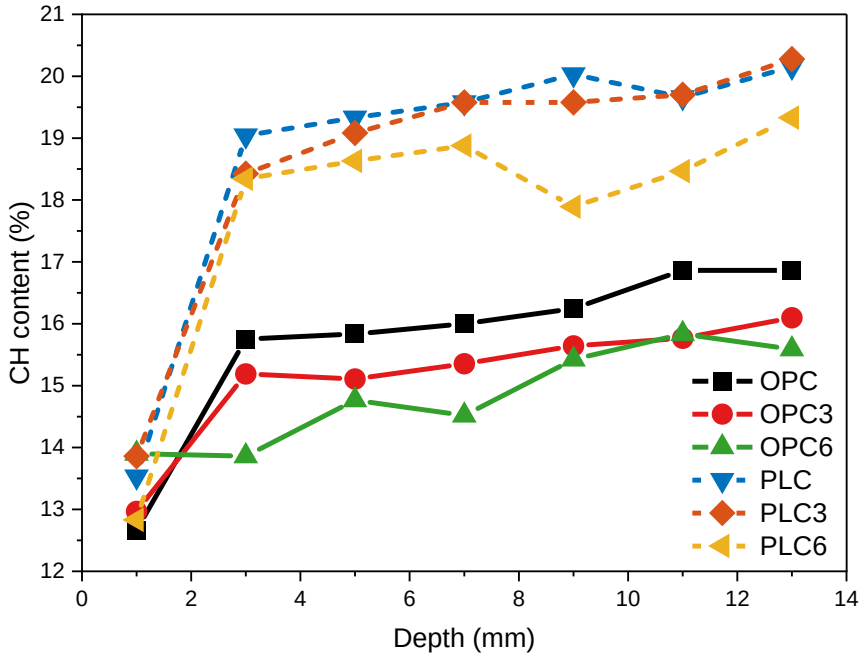


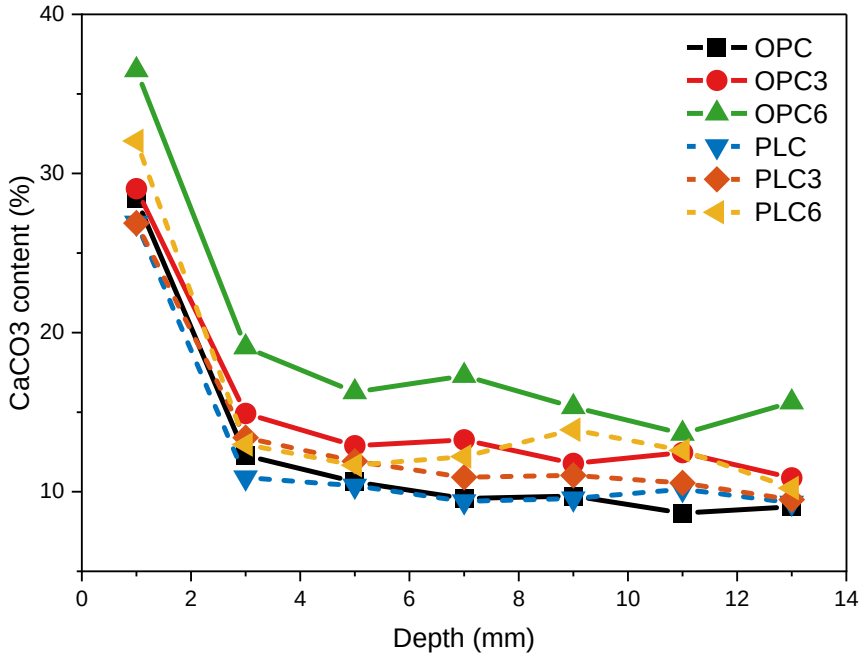


- The mass change results indicates the addition of NS improves the carbon sequestration ability of cement paste.
- The carbon sequestration ability of Type IL cement is inferior to that of Type I cement.

CO_2 uptake – TGA results



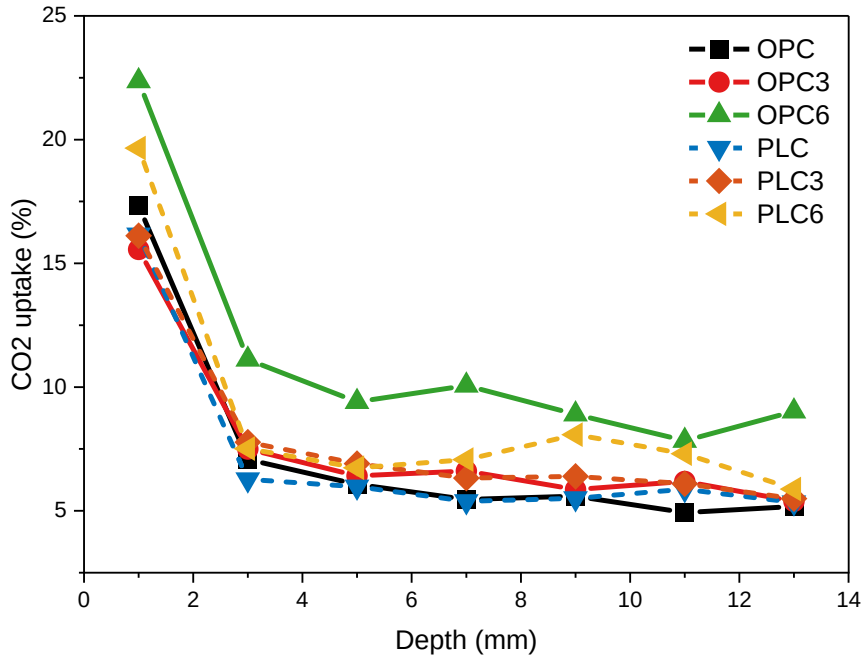


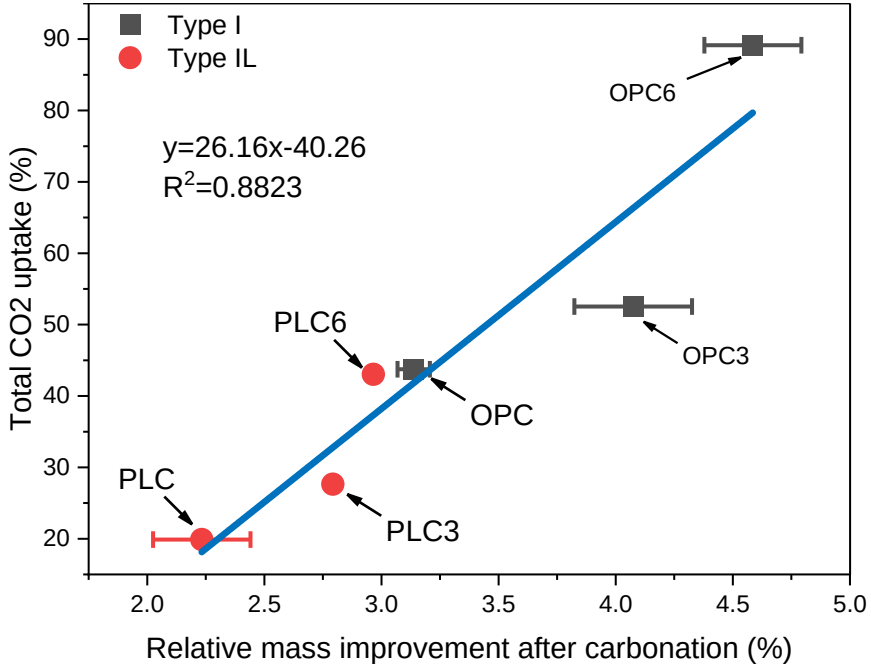


- Average depth of each layer is taken here.
- For example, 1st layer is 0-2mm, and the depth value is 1mm

- After carbonation, cubes were ground in the middle part to 7 layers, with 2mm thickness of each layer, powder samples were collected.
- TGA and pH value tests were performed on each layer's powder sample.

CO_2 uptake – TGA results

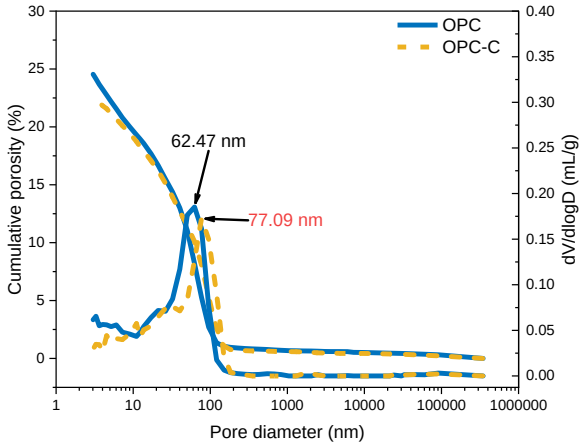


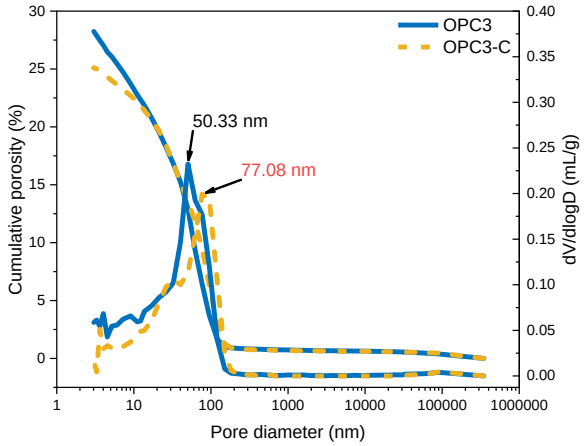


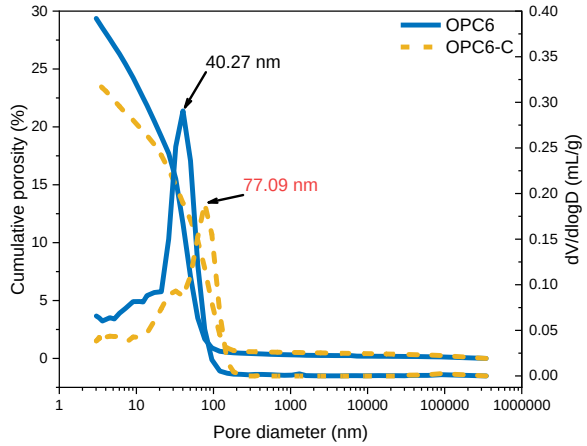
- TGA results substantiate the incorporation of NS enhances the carbon sequestration capability of cement paste.

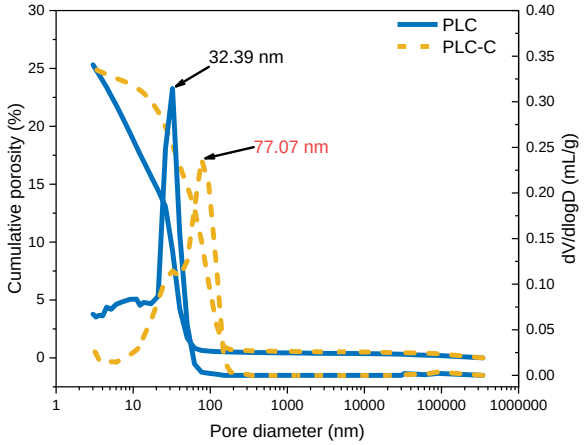
he566@purdue.edu

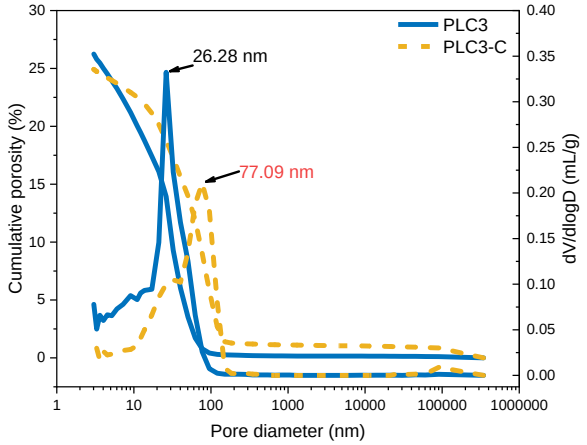
CO_2 uptake – microstructure evolution

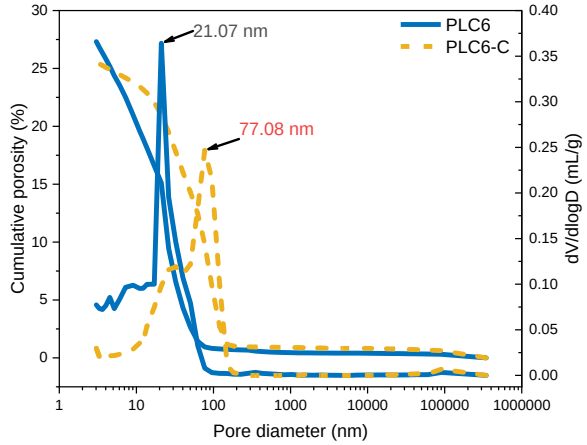






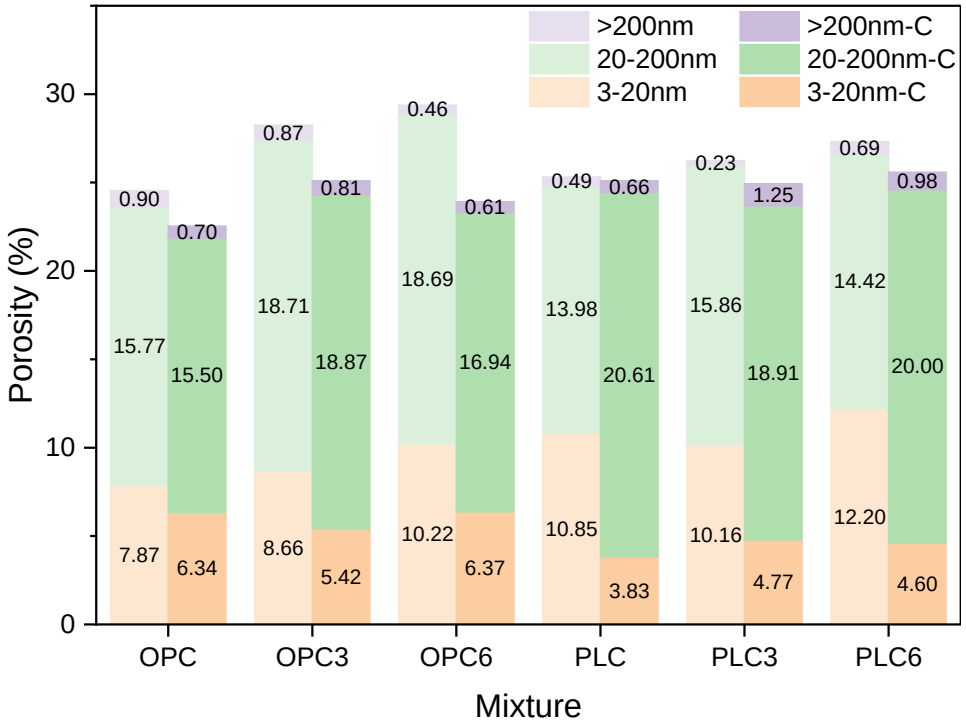


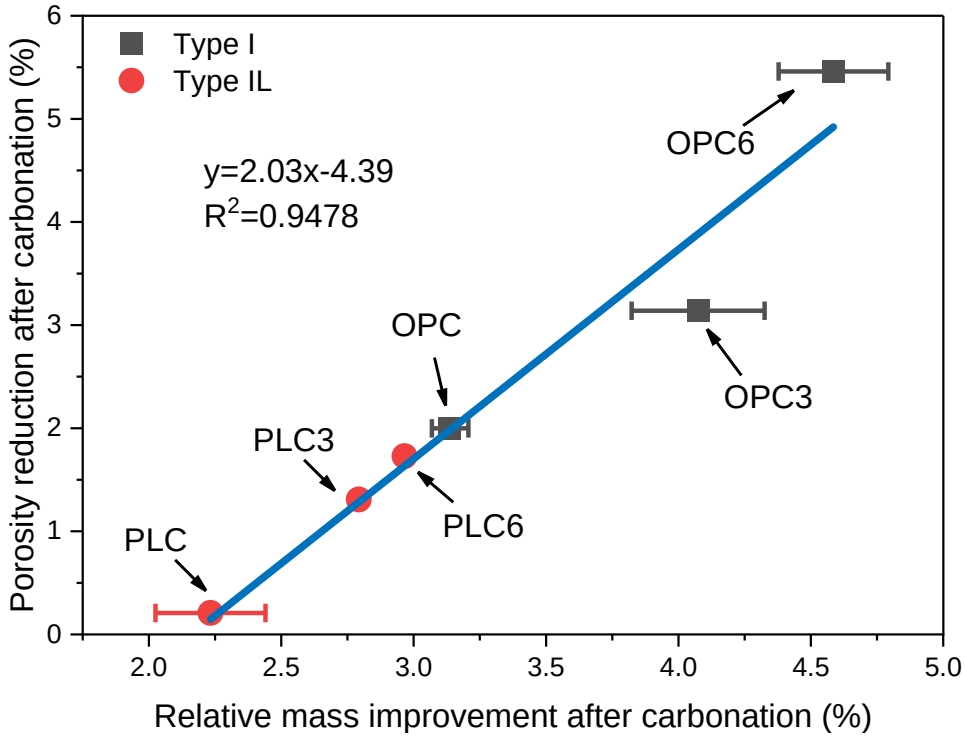




- Before carbonation, the size of most probable pore reduced with the addition of NS.
- Pore size of Type IL cement paste is finer than that of Type I cement.
- The carbonation process significantly altered the pore size distribution of cement paste.

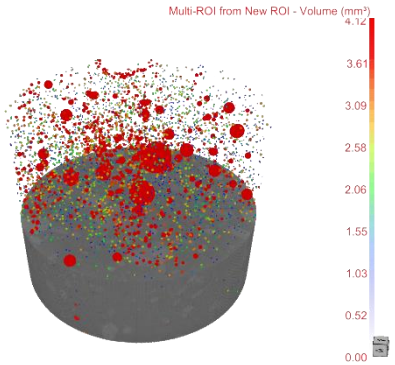
CO_2 uptake – microstructure evolution



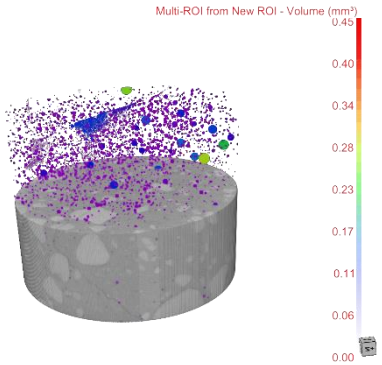


- Porosity reduction correlates well with mass change.
- The major porosity reduction is contributed by these of pores less than 20nm.

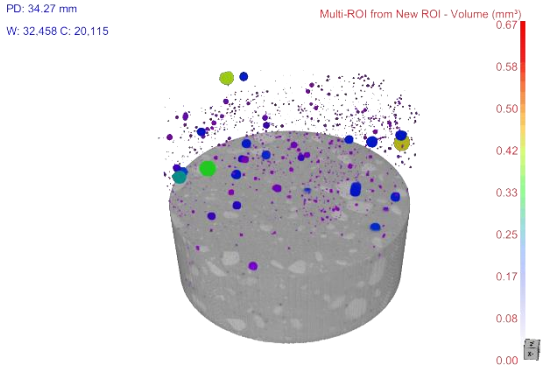
CO_2 uptake – microstructure evolution



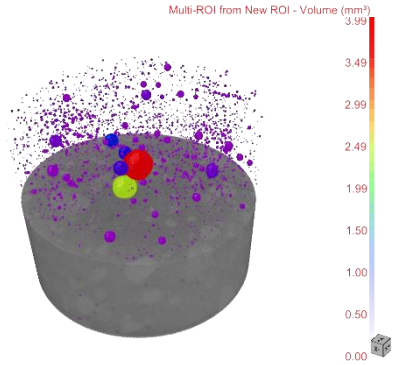
OPC



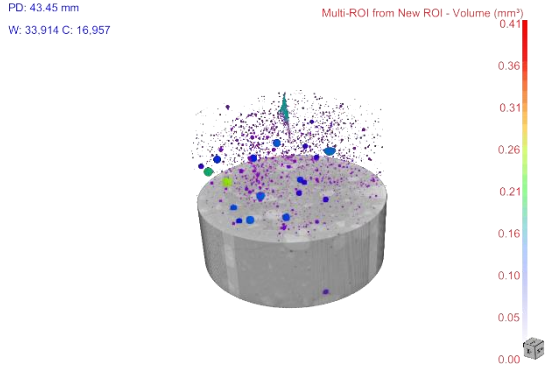
OPC3



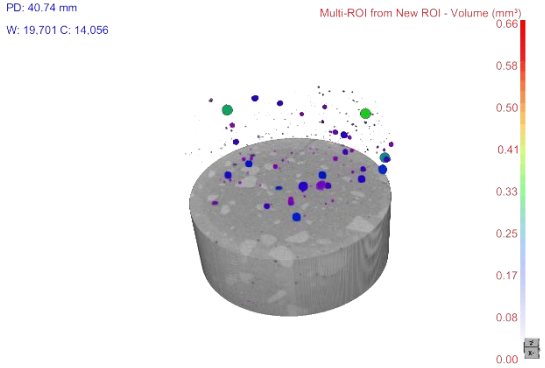
OPC6



OPC-C



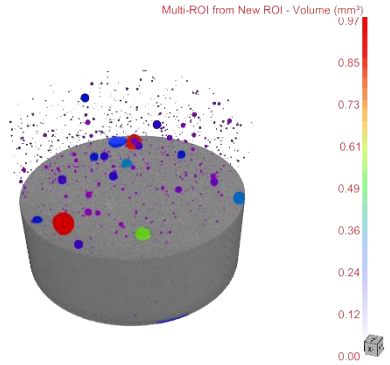
OPC3-C



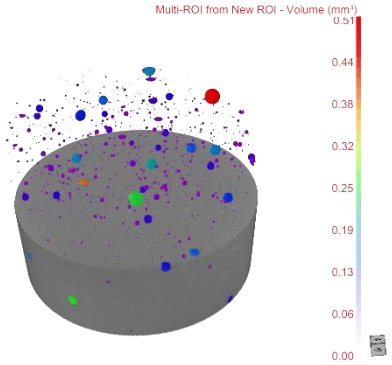
OPC6-C

- 3D-XRM results also verify the reduction in large pores (>18 μm) with the addition of NS.
- The results also indicate less pores and finer pore size after carbonation.

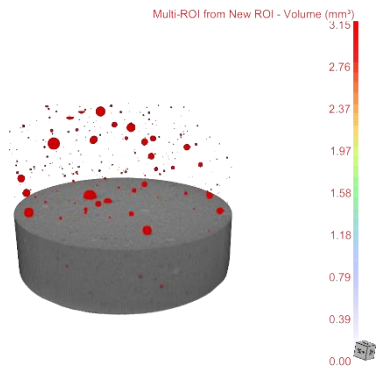
CO_2 uptake – microstructure evolution



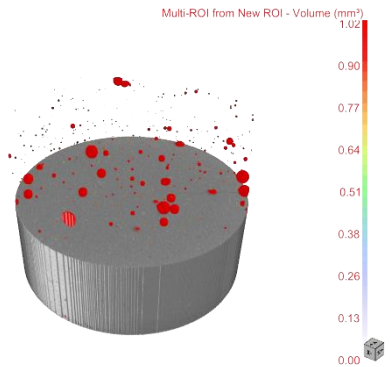
PLC



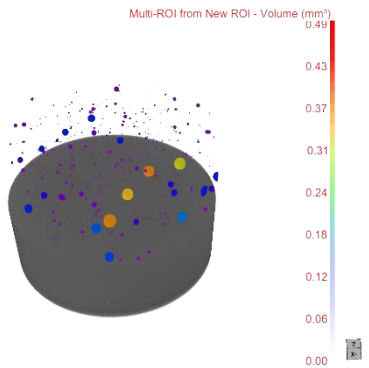
PLC3



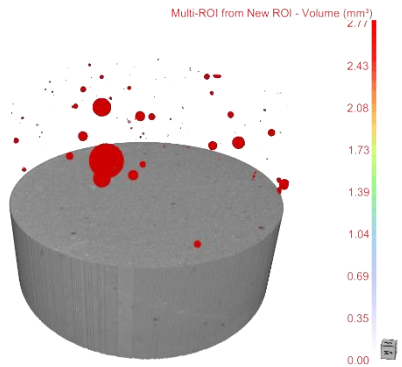
PLC6



PLC-C



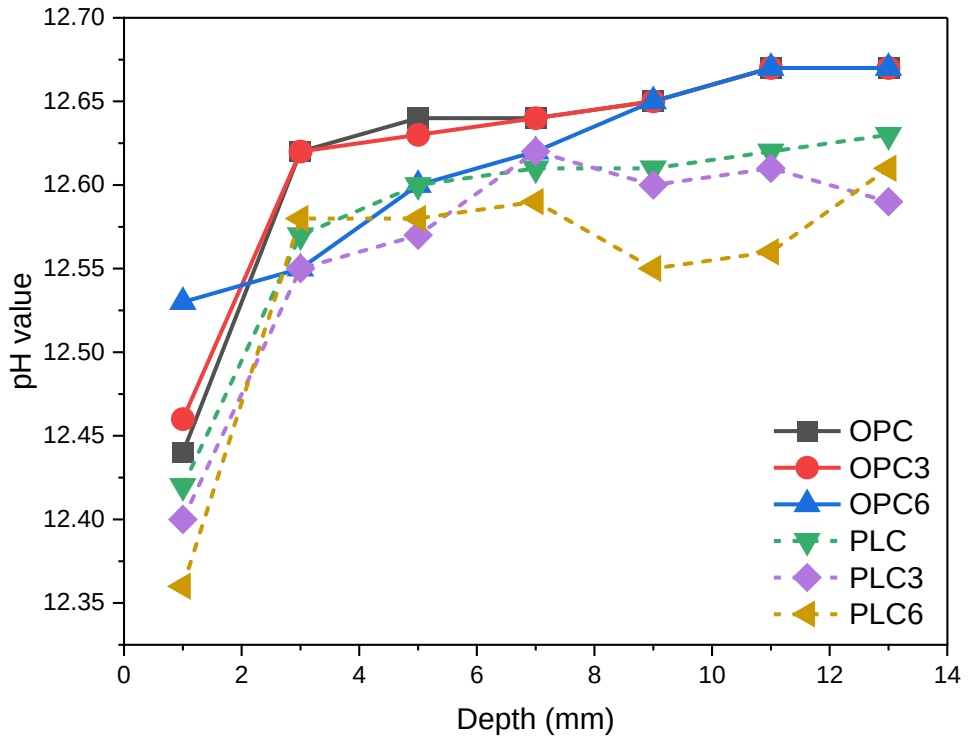
PLC3-C

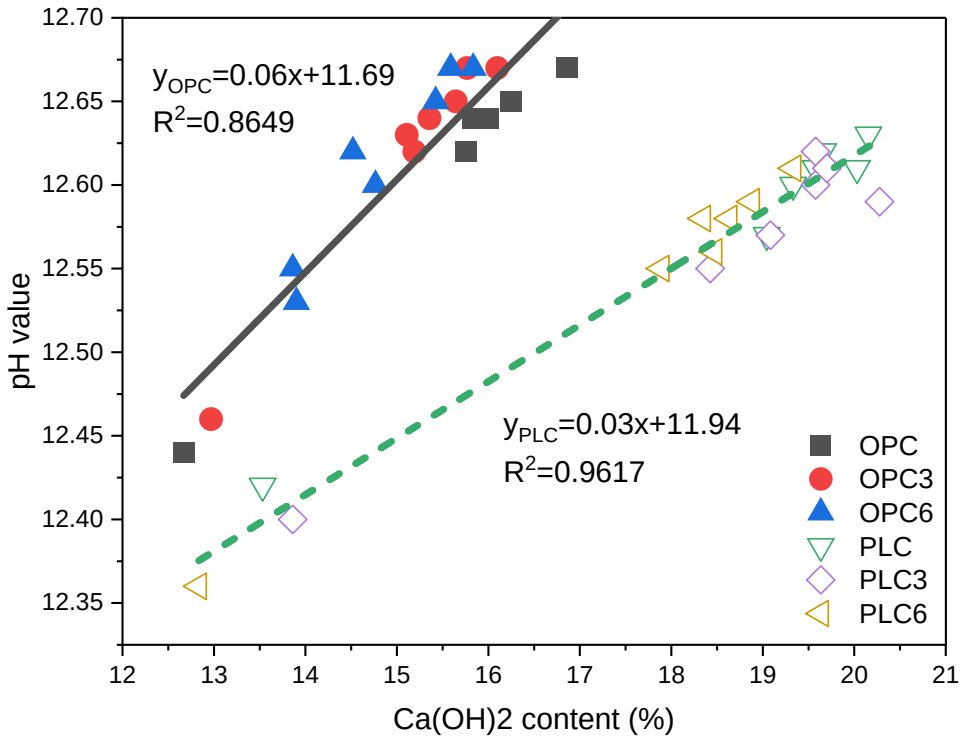


PLC6-C

- 3D-XRM results also verify the reduction in large pores (>18 μm) with the addition of NS.
- The results also indicate less pores and finer pore size after carbonation.

CO_2 uptake – pH value





- Although Type I cement paste absorbed more CO_2, but it still showed higher pH value than that of Type IL cement paste.
- The alkalinity of cement paste is mainly contributed by $Ca(OH)_2$, which shows good correlation with pH value.

Conclusions

- Adding nano silica (E5) may result in reduced hydration heat releasing at first 7 days age, but the TGA results indicate the improved hydration degree at 28 days age.
- Due to the reduced clinker amount, the CO_2 uptake efficiency of in Type IL (PLC) cement paste is lower than that of Type I (OPC) cement paste.
- In this testing scenario, adding nano silica (E5) improves the CO_2 uptake efficiency of cement paste. The reason could be the improved $Ca(OH)_2$ content and more transportation channels.
- The modification of C-S-H with the incorporation of nano silica and its effect on carbon sequestration will be explored in future study.

Thanks!