Experimental Investigation on the Effect of Colloidal Nanosilica on Concrete Carbonation

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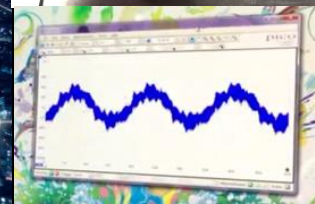


Content

- Background and motivation
- Literature review and research objective
- Experimental result
- Conclusion

Background

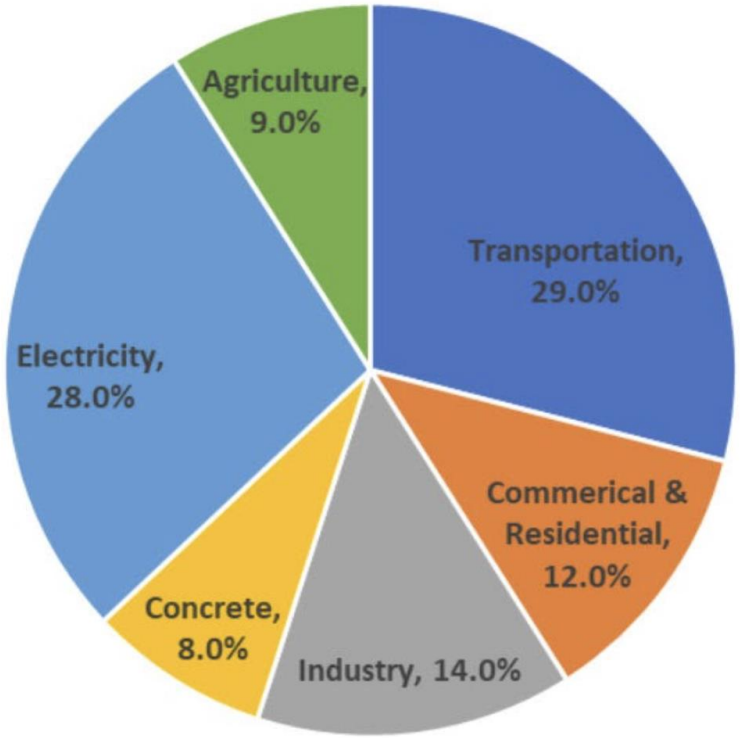


Table 4-3: CO_2 Emissions from Cement Production

Year	1990	2005	2017	2018
MMT CO_2 Eq.	33.5	46.2	40.3	39.0
kt	33,484	46,194	40,324	38,971

- Cement industry is responsible for about 8% of carbon dioxide emissions
- Carbon dioxide emissions from cement production increased by 23.4 percent from 1990 through 2021.

https://www.epa.gov/system/files/documents/2023-02/US-GHG-Inventory-2023-Main-Text.pdf

Background

Carbonation process

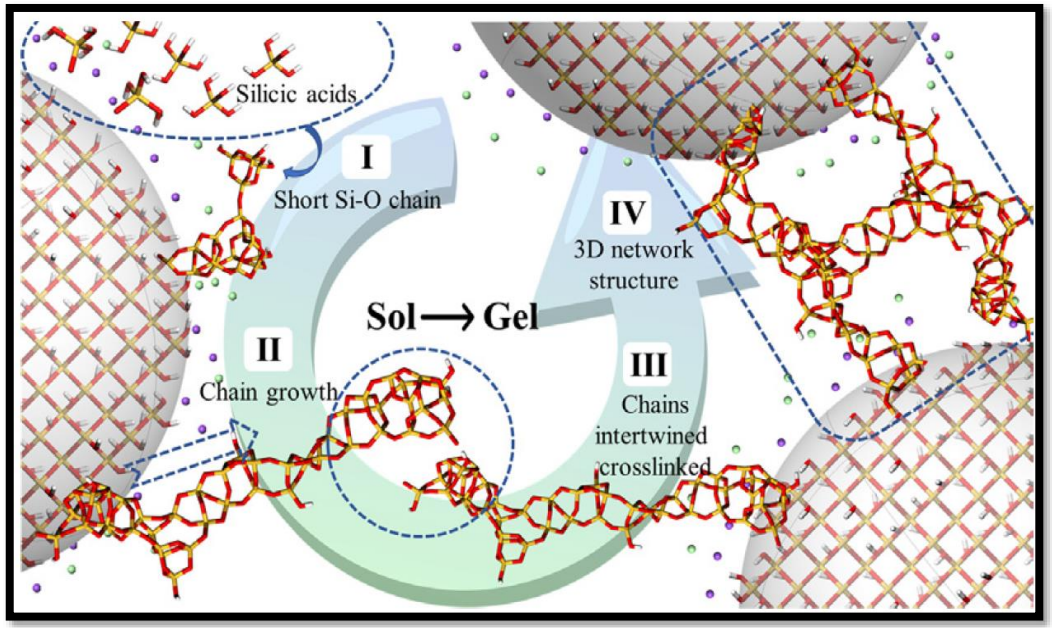
1. **$Ca(OH)_2$** + $CO_2 \rightarrow CaCO_3 + H_2O$
2. **$(CaO)_x(SiO_2)(H_2O)$** + $xCO_2 \rightarrow xCaCO_3 + SiO_2(H_2O)t + (z\text{-}t)H_2O$
3. Others: AFt, AFm, C_3S, C_2S…

https://www.linkedin.com/pulse/concrete-faq-carbonation-tom-kline

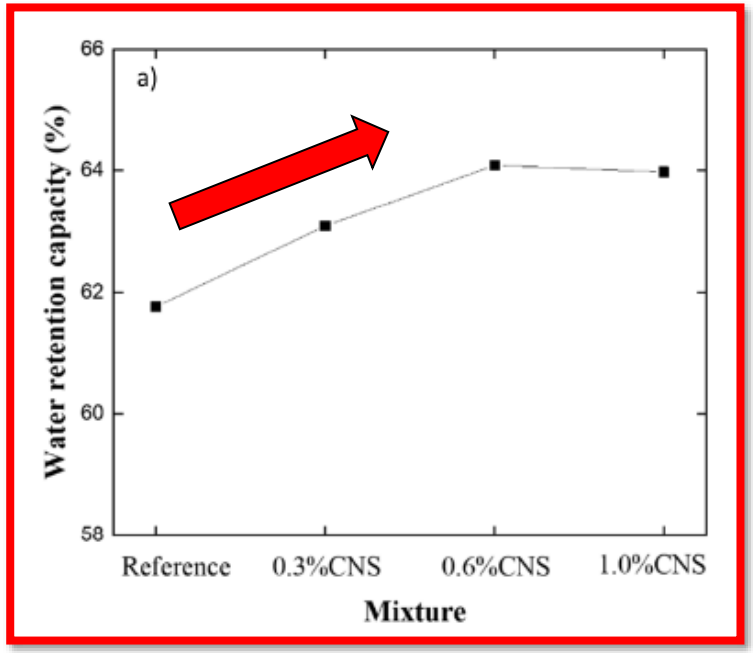
Chang, Cheng-Feng, and Jing-Wen Chen. "The experimental investigation of concrete carbonation depth." *Cement and Concrete research* 36.9 (2006): 1760-1767.

Colloidal Nanosilica (CNS)

- CNS will gel immediately and form flocculation, generating a three-dimensional network, under an alkaline environment such as cement pore solution.
- The network could slow down the diffusion of the water and ions within the concrete system.



Wen L, Xu J, Yang Q, et al. Chemical Engineering Science, 2020, 216: 115538.



Rubin B. AIChE Journal, 1969, 15(2): 206-208.

Colloidal Nanosilica (CNS)

Previous research: Nanosilica & Carbonation

Year	Carbonation resistance	Nanosilica type	Ref
2023	Increase	Powder	Zhang, et al. "Carbonation Resistance of Marine Concrete Containing Nano-SiO2 under the Action of Bending Load." Journal of Marine Science and Engineering 11.3 (2023): 637.
2021	Increase	Powder	Li, Leo Gu, et al. "Synergistic cementing efficiencies of nano-silica and micro-silica in carbonation resistance and sorptivity of concrete." Journal of Building Engineering 33 (2021): 101862.
2019	Increase	Powder	Singh, L. P., et al. "Durability studies of nano-engineered fly ash concrete." Construction and Building Materials 194 (2019): 205-215.
2017	Increase	Powder	Li, L. G., et al. "Combined effects of micro-silica and nano-silica on durability of mortar." Construction and Building Materials 157 (2017): 337-347.
2016	Decrease *	Suspension	Torabian Isfahani, Forood, et al. "Effects of nanosilica on compressive strength and durability properties of concrete with different water to binder ratios." Advances in Materials Science and Engineering 2016 (2016).
2015	Decrease *	Colloidal nanosilica	Rao, S., P. Silva, and Jorge De Brito. "Experimental study of the mechanical properties and durability of self-compacting mortars with nano materials (SiO2 and TiO2)." Construction and Building Materials 96 (2015): 508-517.
2015	Increase	Powder	Lim, Seungmin, and Paramita Mondal. "Effects of incorporating nanosilica on carbonation of cement paste." Journal of Materials Science 50 (2015): 3531-3540.

Limited research has been done for the carbonation of concrete with CNS

Factors for Carbonation

Factors

- Transport properties
- Degree of saturation
- Volume of cement
- Degree of hydration
- …

→

Quality of interface

Internal humidity

Hydration performance

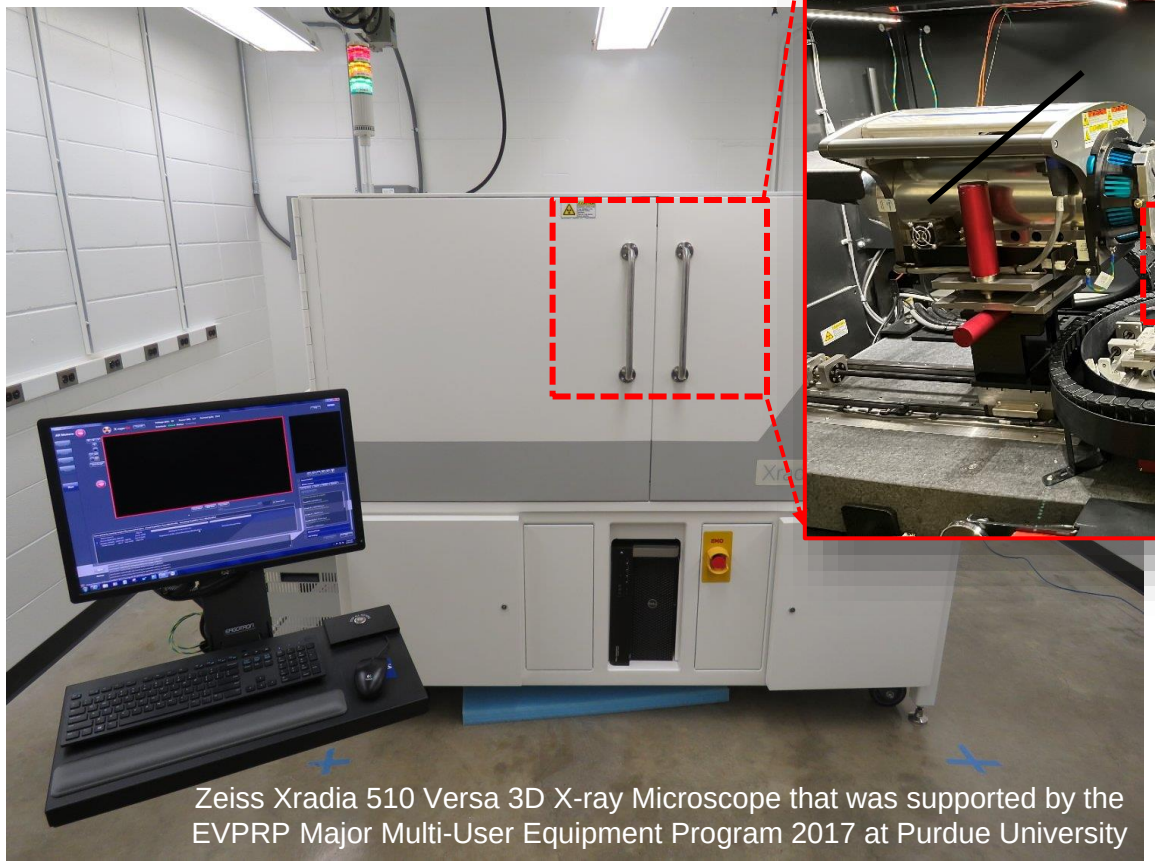
Mechanical strength

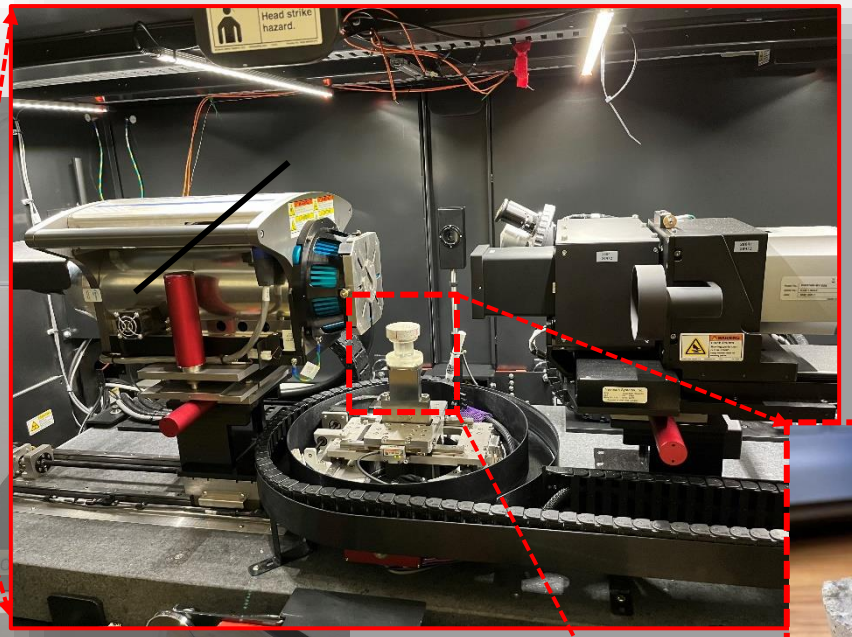
Porosity

Carbonation degree

❑ Based on the mechanism of carbonation, series of experiment are designed to evaluate the influence of CNS on the carbonation of concrete materials.

Study of Interface with CNS

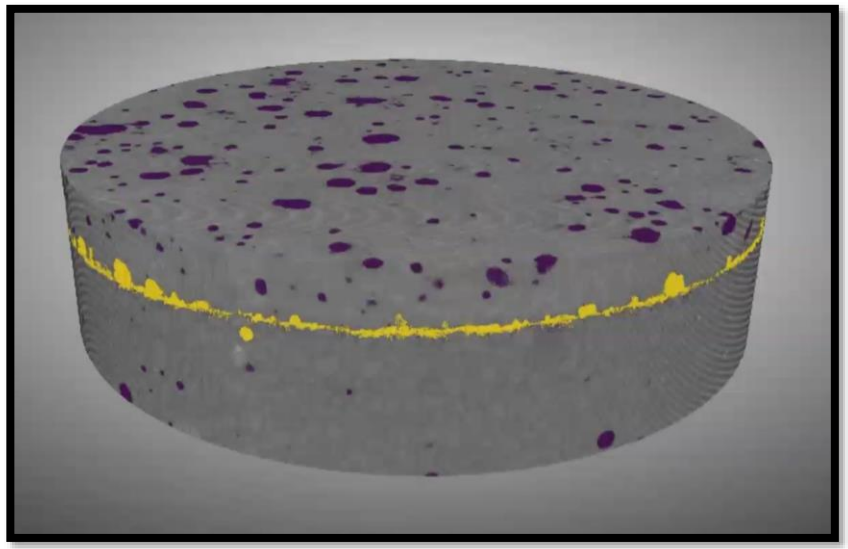




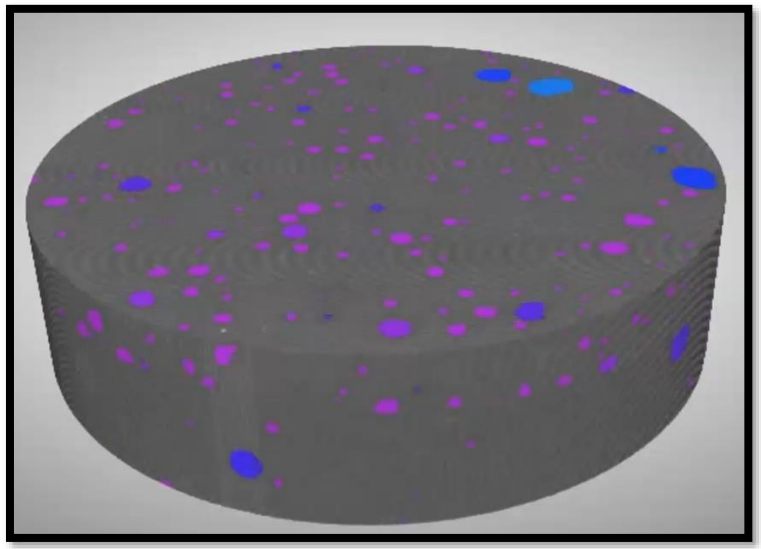
Mortar- w/c = 0.47

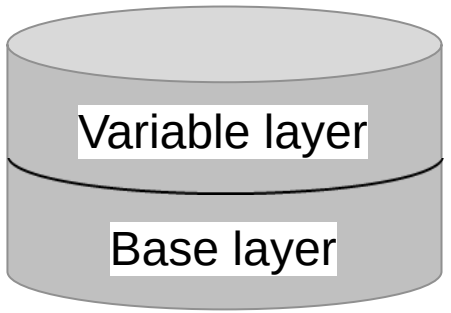
Influence of CNS on Interface

Ref



0.3%

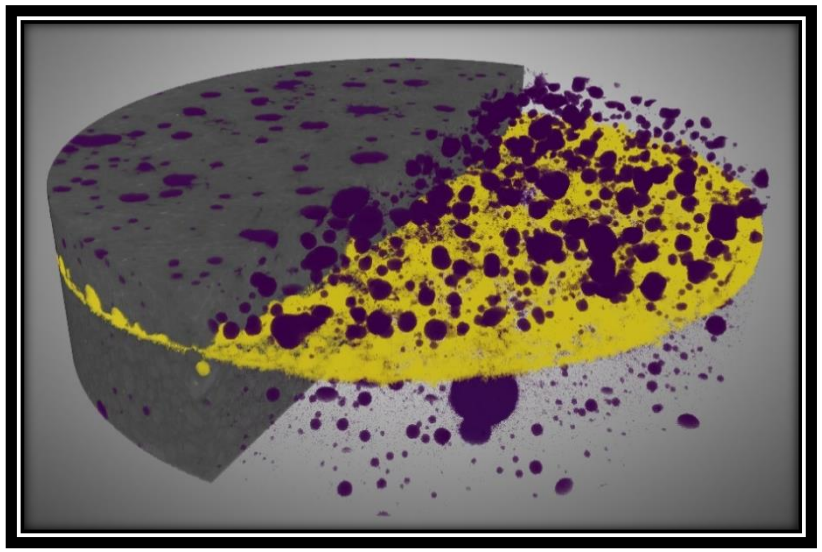




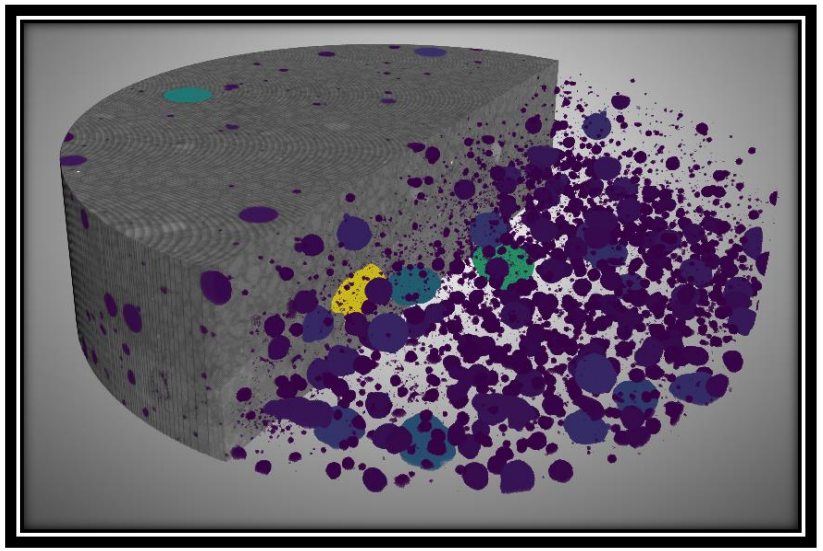
- A wide interface can be observed in the reference sample.
- The interface was unable to find in the 0.3%CNS sample.

Influence of CNS on Interface

Ref



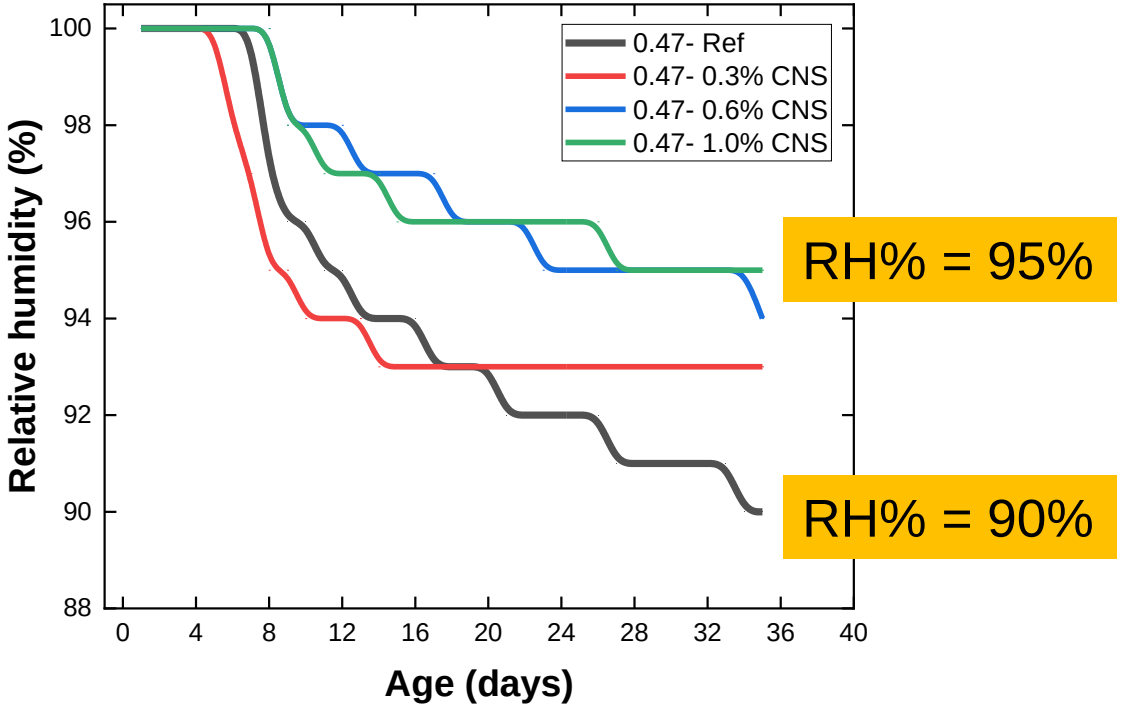
0.3%



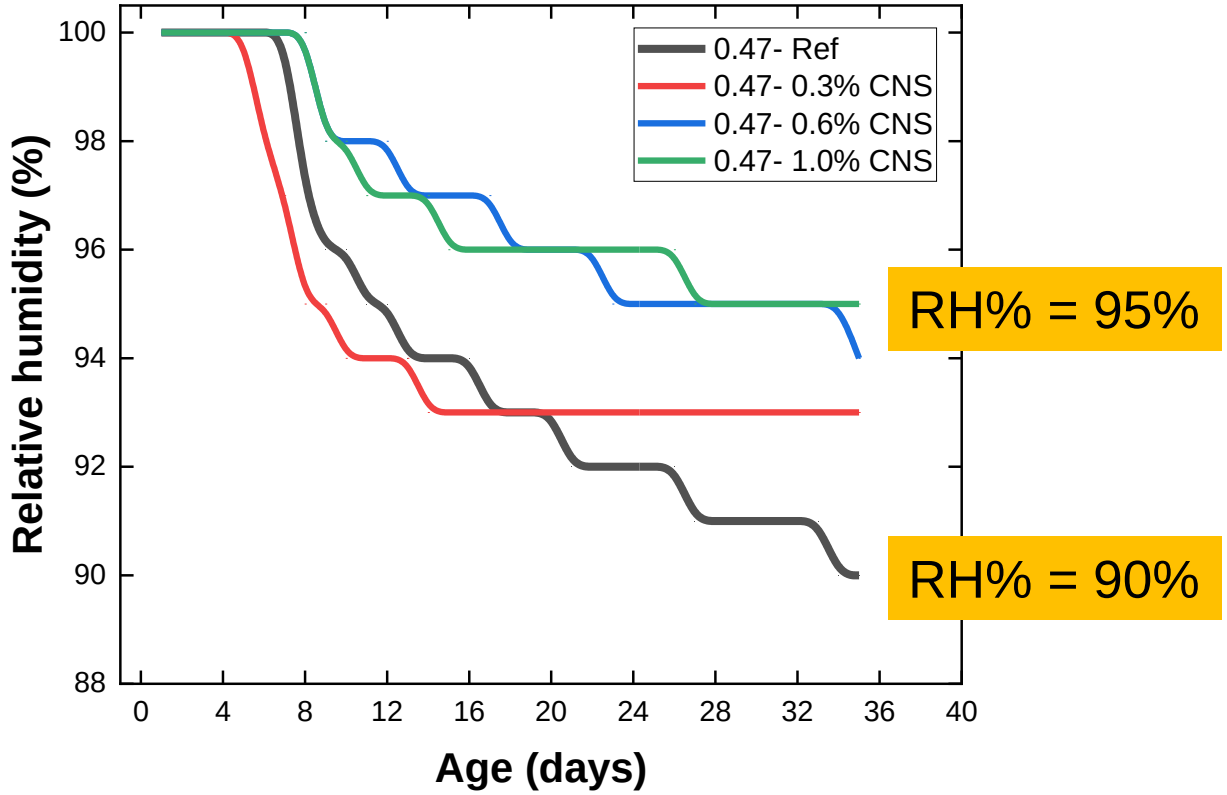
- Quality of interface ✓
- Internal humidity
- Hydration performance
- Mechanical strength
- Porosity
- Carbonation degree

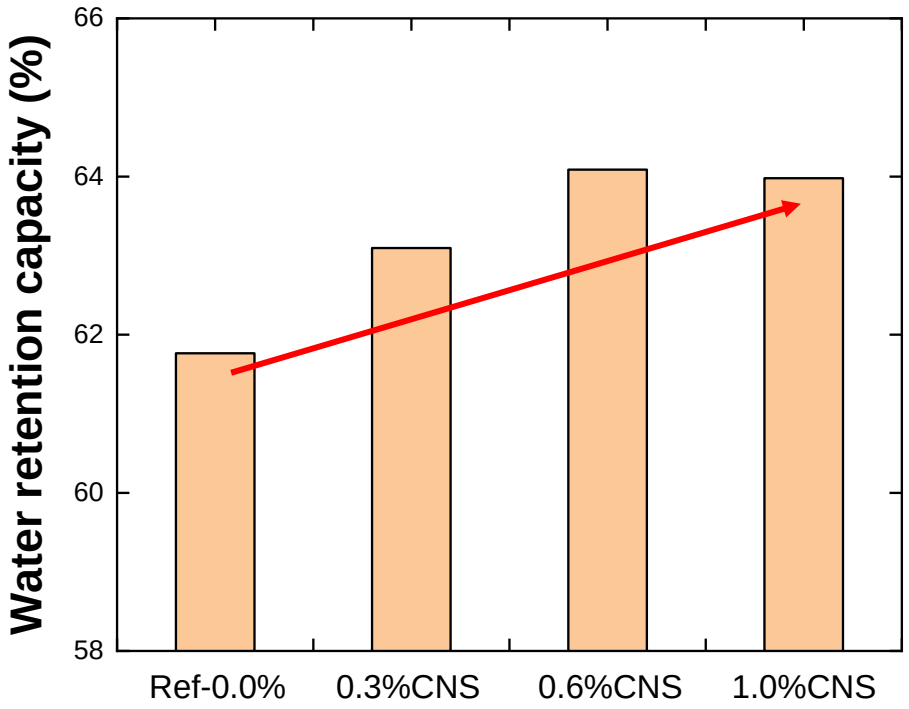
- The improvement is due to pore refinement and improved particle packing.

Influence of CNS on Internal Humidity



Influence of CNS on Internal Humidity





- CNS slowed down the water evaporation rate due to a high water retention capacity;
- Sol-gel effect of CNS → Floc network → Higher internal humidity

Factors for Carbonation

Factors

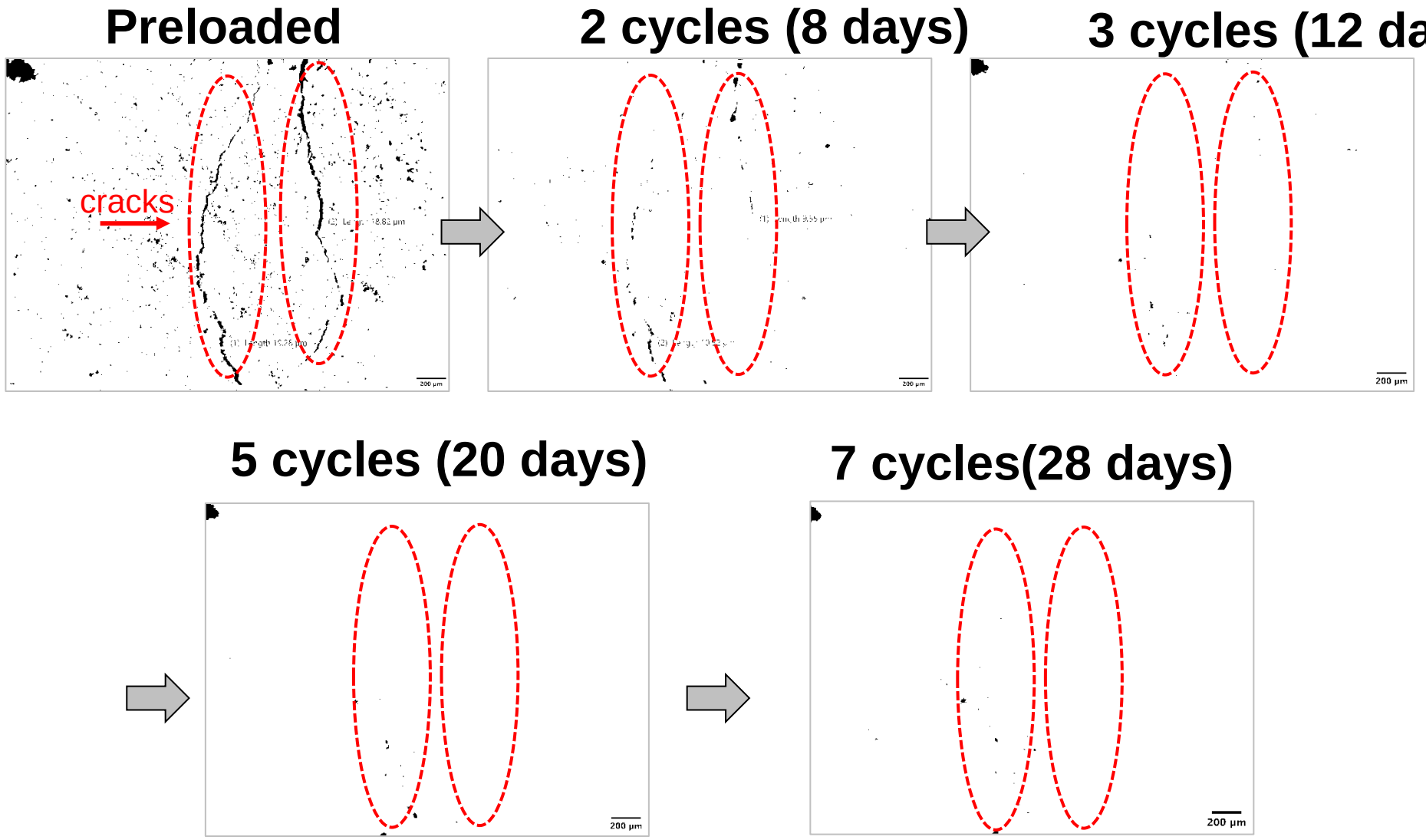
- Transport properties
- Degree of saturation
- Volume of cement
- Degree of hydration
- …

→

- Quality of interface ✓
- Internal humidity ✓
- Hydration performance
- Mechanical strength
- Porosity
- Carbonation degree

❑ Based on the mechanism of carbonation, series of experiment are designed to evaluate the influence of CNS on the carbonation of concrete materials.

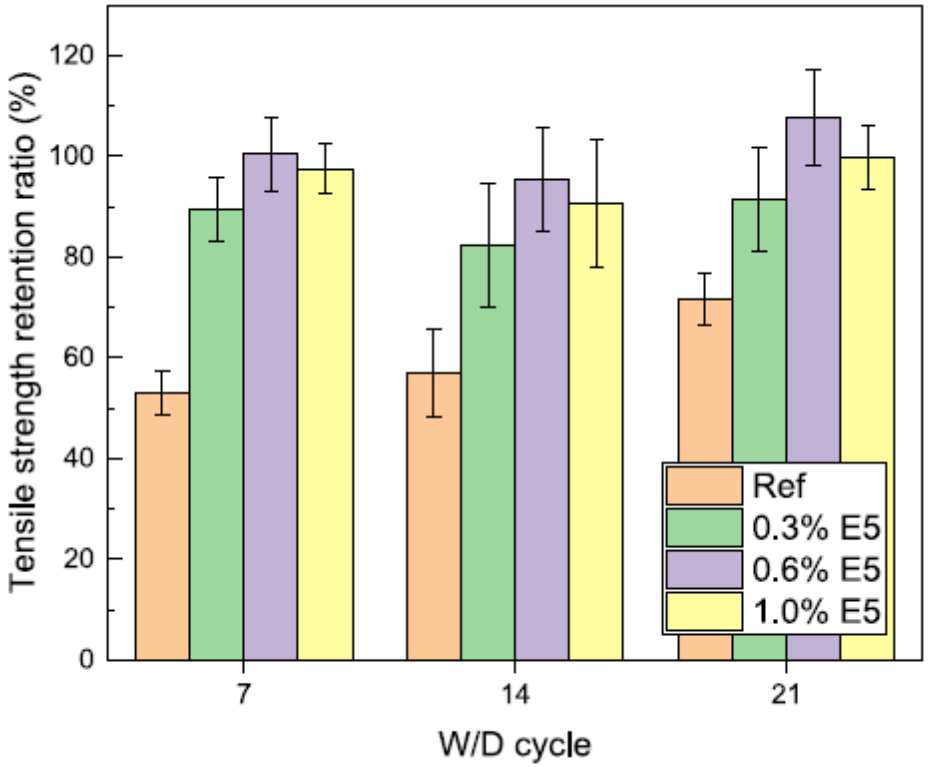
Hydration and Self-healing



Huang C, Su Y F, Baah P, et al. Construction and Building Materials, 2022, 348: 128687.

Hydration and Self-healing

In addition…



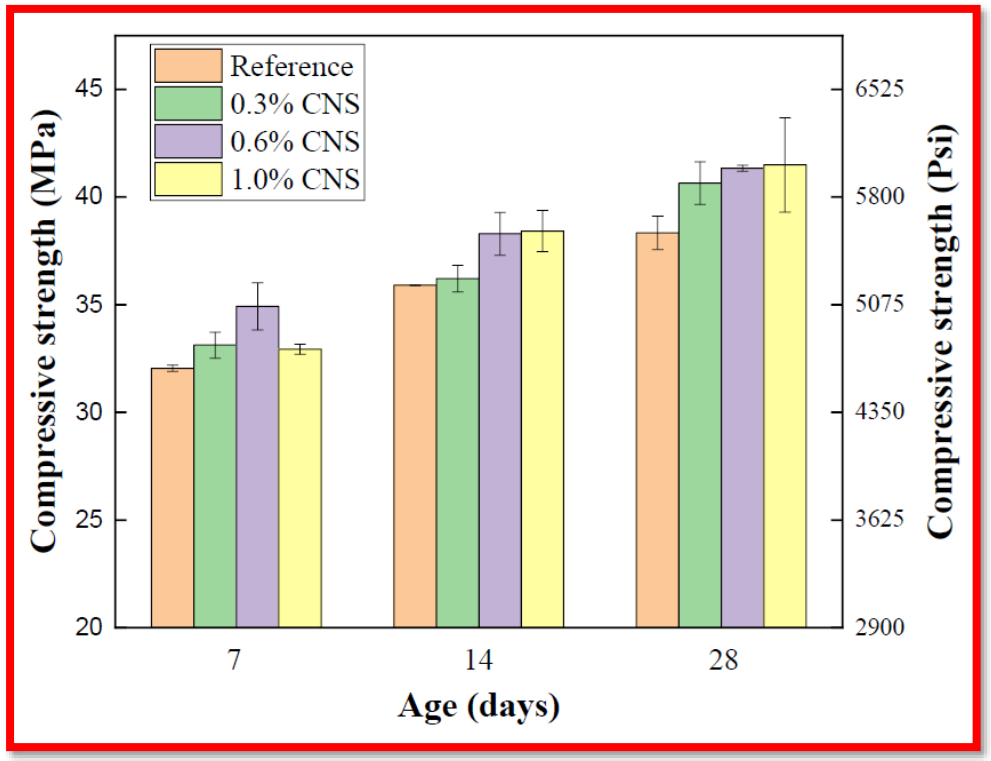
Tensile strength retention ratio

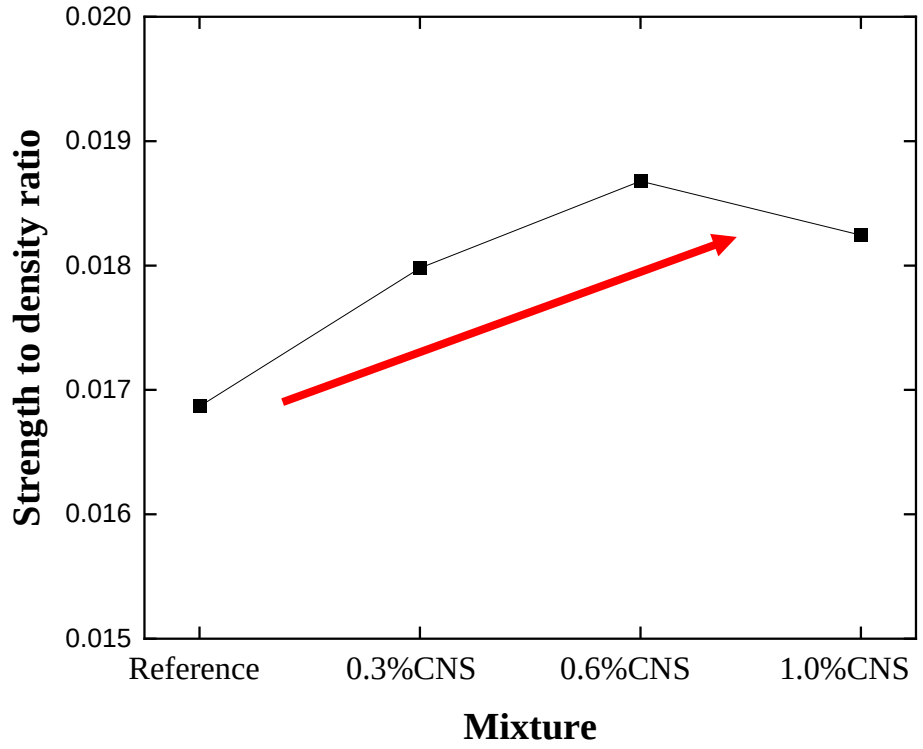
The self-healing was not only based on observation, but also reflected on the mechanical performance

Huang C, Su Y F, Baah P, et al. Construction and Building Materials, 2022, 348: 128687.

Mechanical Performance

Compressive strength and strength to density ratio



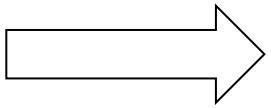


- A higher mechanical strength can be observed as the content of CNS increased;
- Strength to density ratio is also found to be increased.

Factors for Carbonation

Factors

- Transport properties
- Degree of saturation
- Volume of cement
- Degree of hydration
- …



Quality of interface ✓

Internal humidity ✓

Hydration performance ✓

Mechanical strength ✓

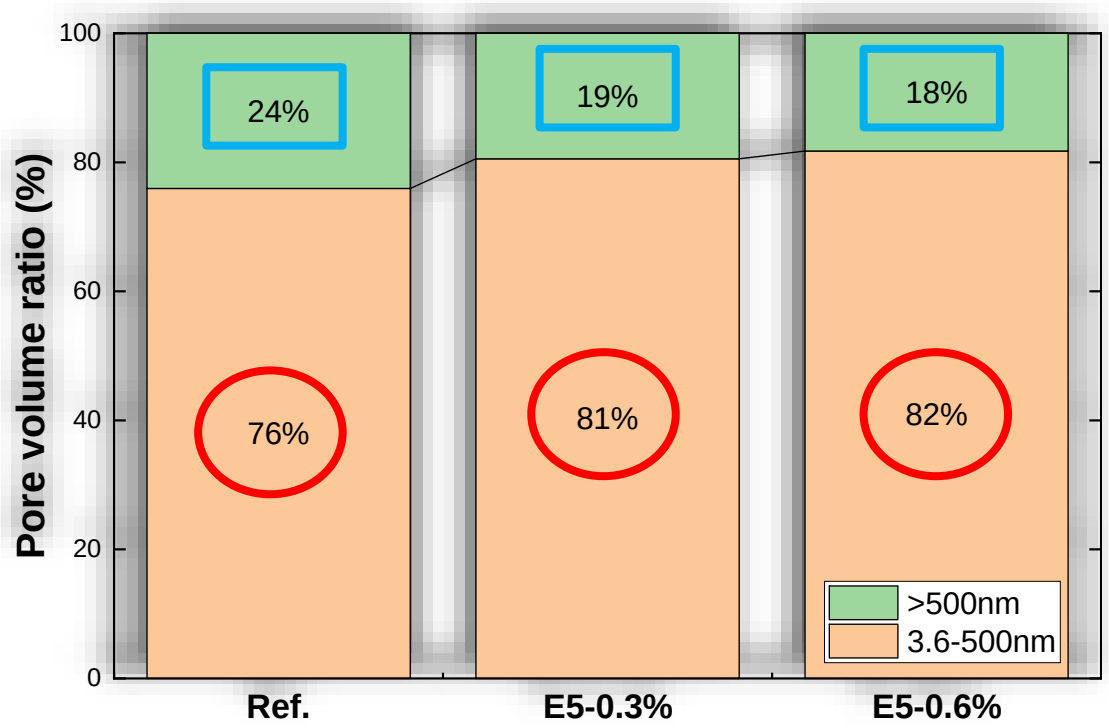
Porosity

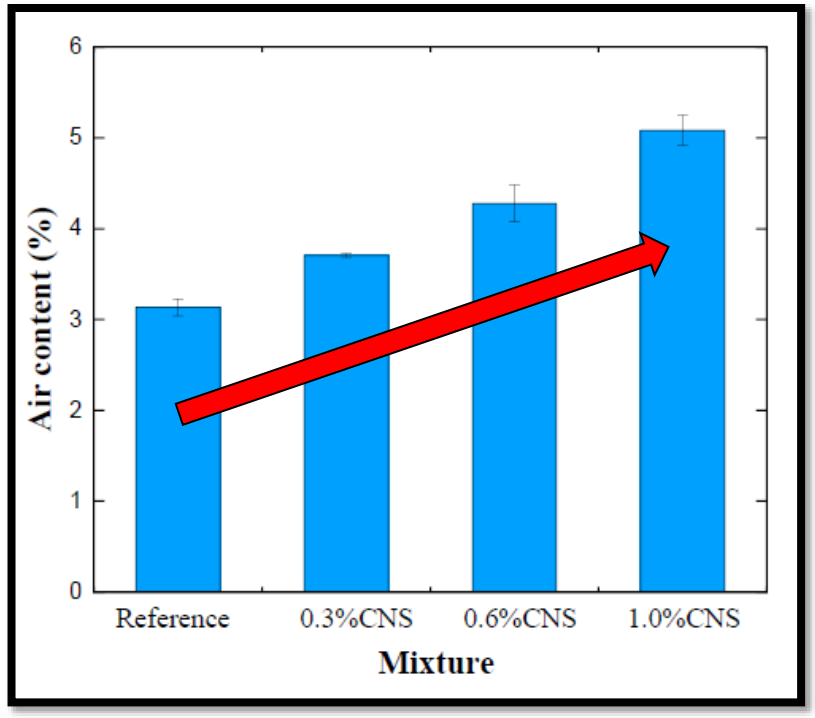
Carbonation degree

❑ Based on the mechanism of carbonation, series of experiment are designed to evaluate the influence of CNS on the carbonation of concrete materials.

Change in Pore Structure

MIP and Rapid Air

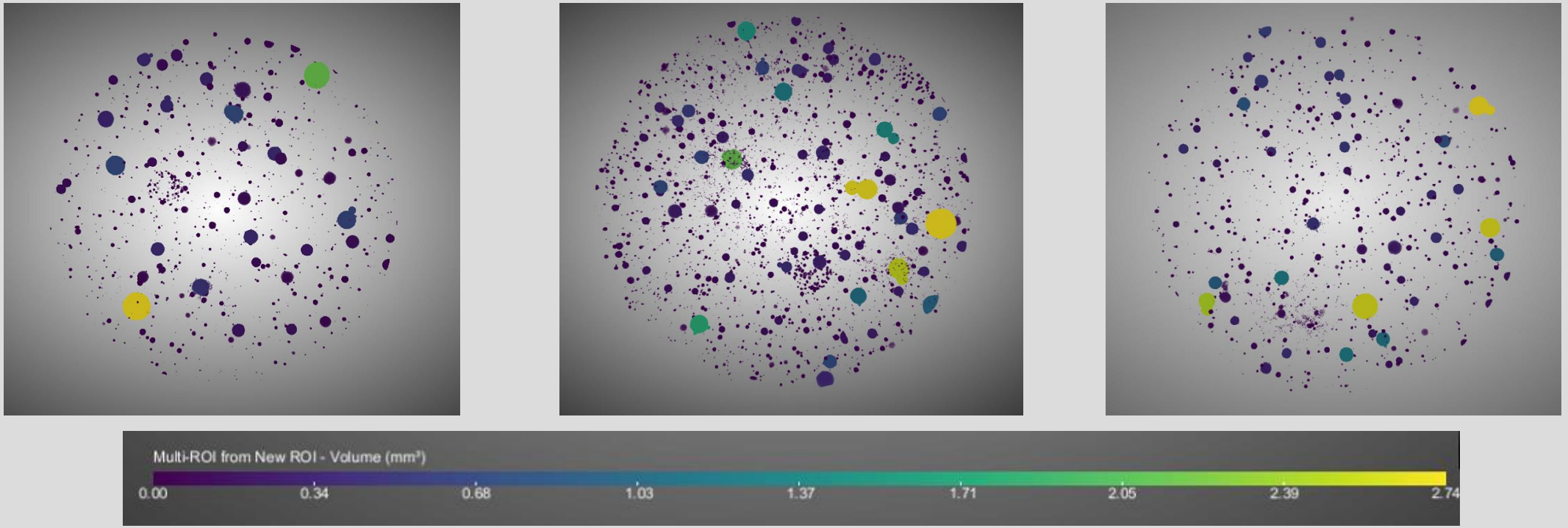




- MIP and image analysis (Rapid air analysis) indicate an increase in the porosity and a decrease in the large voids.

Change in Pore Structure

Reference | **0.3%CNS** | **0.6%CNS**

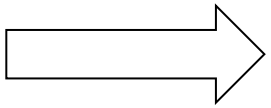


- The micro-CT images suggest an increase in the overall porosity, while a decrease in the volume of large pores can also be found.

Factors for Carbonation

Factors

- Transport properties
- Degree of saturation
- Volume of cement
- Degree of hydration
- …



Quality of interface ✓

Internal humidity ✓

Hydration performance ✓

Mechanical strength ✓

Porosity ✓

Carbonation degree

❑ Based on the mechanism of carbonation, series of experiment are designed to evaluate the influence of CNS on the carbonation of concrete materials.

Carbonation of Paste Powder

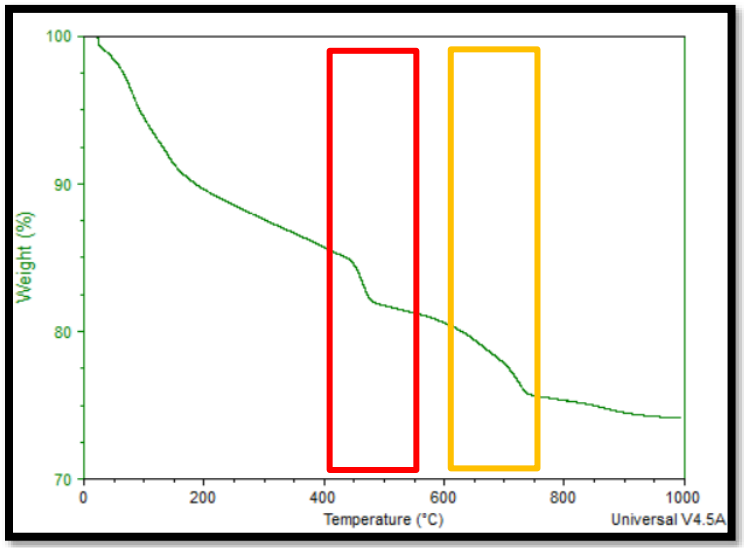
Pure cement paste

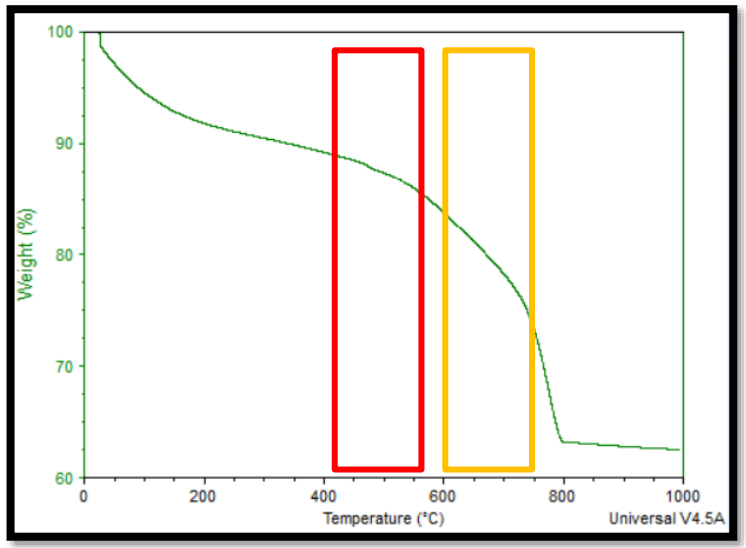
- w/c = 0.45;
- CNS dosages of 0.3;
- Curing condition: limewater cure for 28 days and 7 days cure in 50% RH chamber;
- Ground to powder and proceed to carbonation;
- The evaluation of the powder samples only chemically considers the effect of CNS on carbonation intensity.

100% CO_2 with a pressure of 50 psi for 24 hours

Carbonation of Paste Powder

$Ca(OH)_2$ & $CaCO_3$





- After carbonation, $Ca(OH)_2$ content was reduced while the content of $CaCO_3$ was significantly increased.

Carbonation of Paste Powder

$Ca(OH)_2$ & $CaCO_3$

$CaCO_3$ content

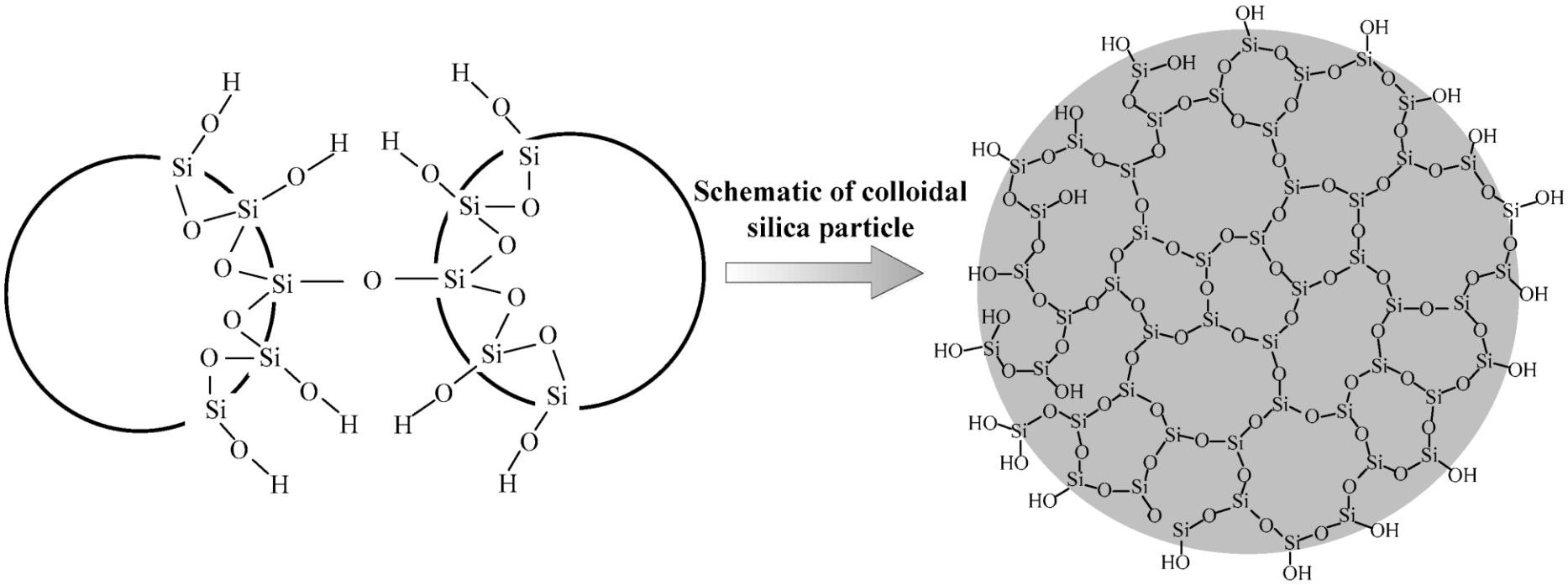
- Reference: 11.7 wt% → 39.2 wt% (**12.1% increase**)
- 0.3% CNS: 12.3 wt% → 43.4 wt% (**13.7% increase**)

$Ca(OH)_2$ content

- Reference: 17.6 wt% → 15.3 wt% (**12.8% reduction**)
- 0.3% CNS: 18.2 wt% → 16.6 wt% (**8.9% reduction**)

- A **higher** **$CaCO_3$** increase ratio can be found in the sample with CNS, while its **$Ca(OH)_2$** reduction is **lower** than the reference sample;
  - ➢ Carbonation of CH + CSH gel

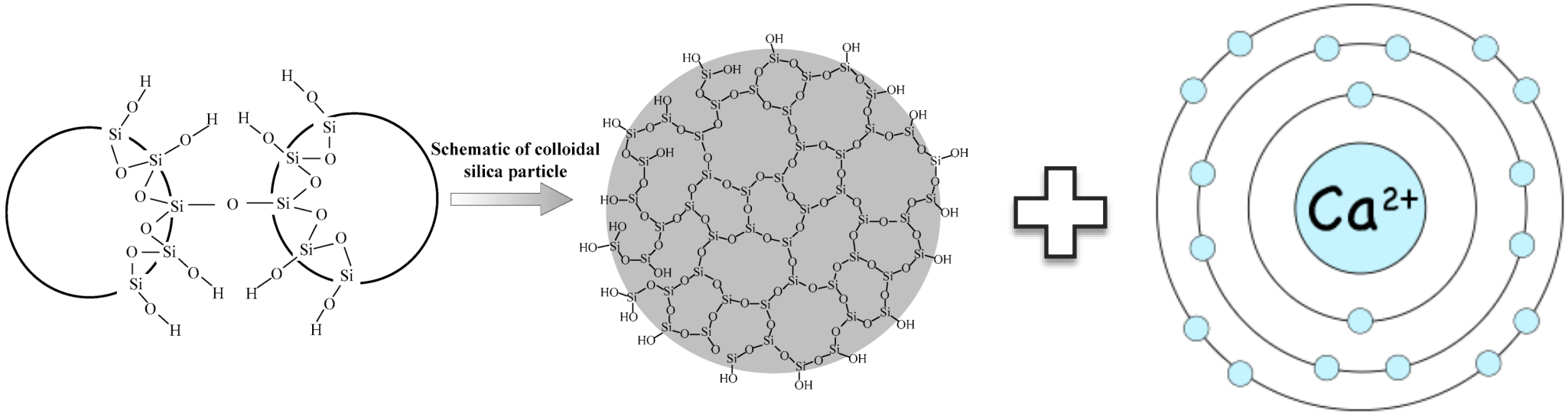
Formation of physical 3D network



- CNS particles have hydroxylated surfaces (-OH) and achieve stability by possessing a net negative charge on the surface.
- A positively charged ion (such as Ca^{2+}) can neutralize a site on the silica surface.

Zhao M, Liu G, Zhang C, et al. State-of-the-art of colloidal silica-based soil liquefaction mitigation: An emerging technique for ground improvement[J]. Applied Sciences, 2019, 10(1): 15.

CNS in Carbonation



- Colloidal nano silica has strong negative charge on the surface, which could potentially react with the Ca^{2+} in C-S-H gel and the extraction of Ca^{2+} increase the possibility of carbonation process.

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Carbonation of Paste Powder

pH value

pH value

- Reference: 12.56 → 9.73 (**22.5% decrease**)
- 0.3% CNS: 12.59 → 8.67 (**31.1% decrease**)

- Due to a higher level of carbonation, sample with CNS exhibits more pH reduction after carbonation process.
  - ❑ Further research is needed for the evaluation of the influence of CNS dosages and pore structure.

Summary

- A higher degree of hydration and better quality of the cement matrix can be found in the sample with CNS
  - improved hydration and particle packing;
- The incorporation of CNS has the potential to increase the carbonation level of concrete materials and contribute to the carbon neutralization
  - negative charge on the surface of CNS;
  - higher porosity achieved by CNS;
- Research about CNS & carbonation is limited, more studies are needed…

Acknowledgements

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Prof. Na (Luna)Lu

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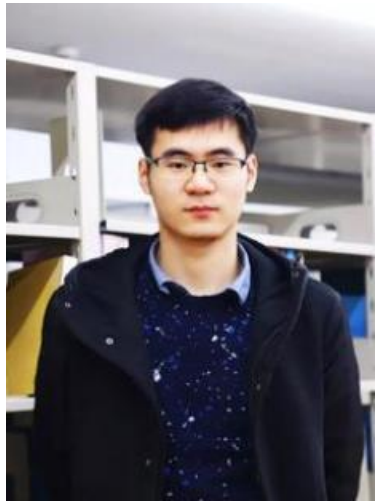

Rui He

Qingchen Yu

Thank you!