3D Graphene-Enhanced Limestone Calcined Clay Cements (LC3): A Pathway to Improved Performance

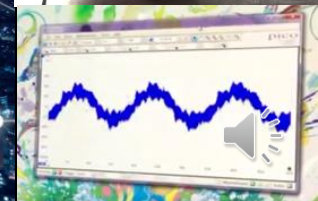
Advisor: Luna Lu & Yining Feng

RA: Cihang Huang Renee Rios Rui He

Joe and Lisa Shetterley Innovation Lab

Lyles School of Civil Engineering

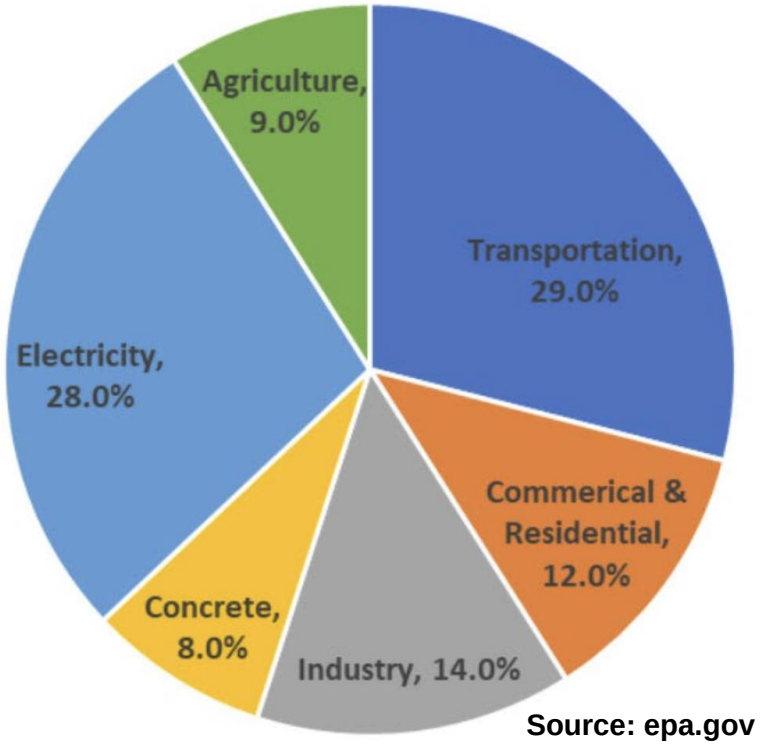
PURDUE UNIVERSITY



Content

- Background and Motivation
- Objective
- Experimental result
- Summary
- Acknowledgement

Background and Motivation



Source: epa.gov

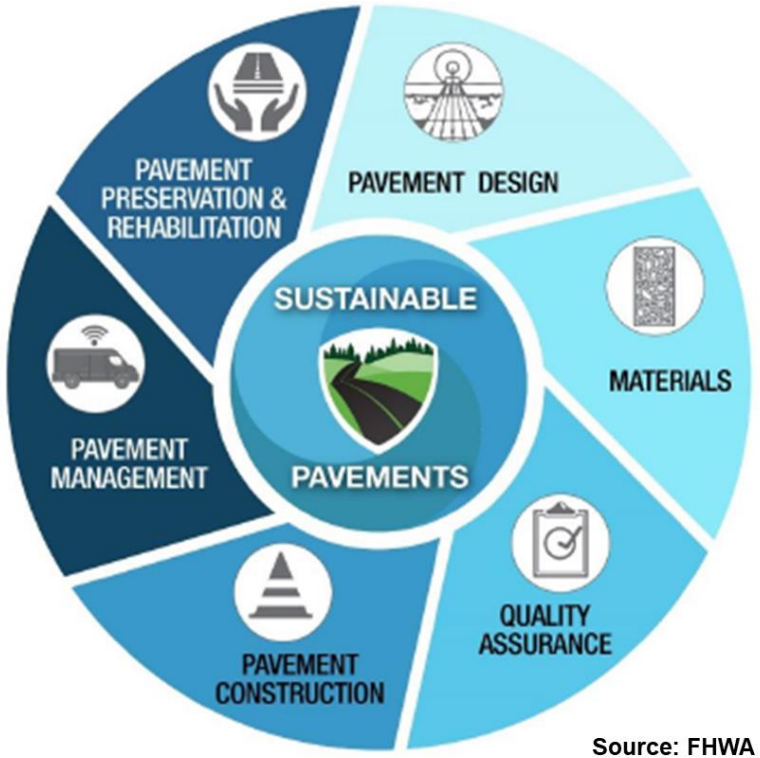
Table 4-3: CO_2 Emissions from Cement Production (MMT CO_2 Eq. and kt)

Year	1990	2005	2017	2018	2019	2020	2021
MMT CO_2 Eq.	33.5	46.2	40.3	39.0	40.9	40.7	41.3
kt	33,484	46,194	40,324	38,971	40,896	40,688	41,312

- 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 and Motivation



Source: FHWA

Table 4-3: CO_2 Emissions from Cement Production (MMT CO_2 Eq. and kt)

Year	1990	2005	2017	2018	2019	2020	2021
MMT CO_2 Eq.	33.5	46.2	40.3	39.0	40.9	40.7	41.3
kt	33,484	46,194	40,324	38,971	40,896	40,688	41,312

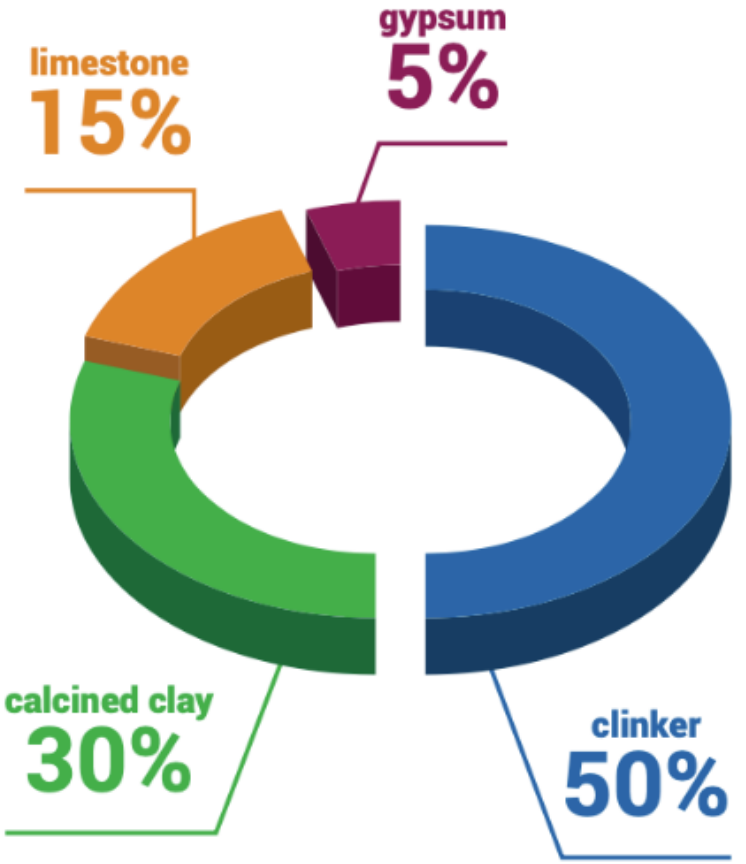
- The impact on economic, environment and society should be considered for the concrete materials, especially the long-term influence.

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

Background and Motivation

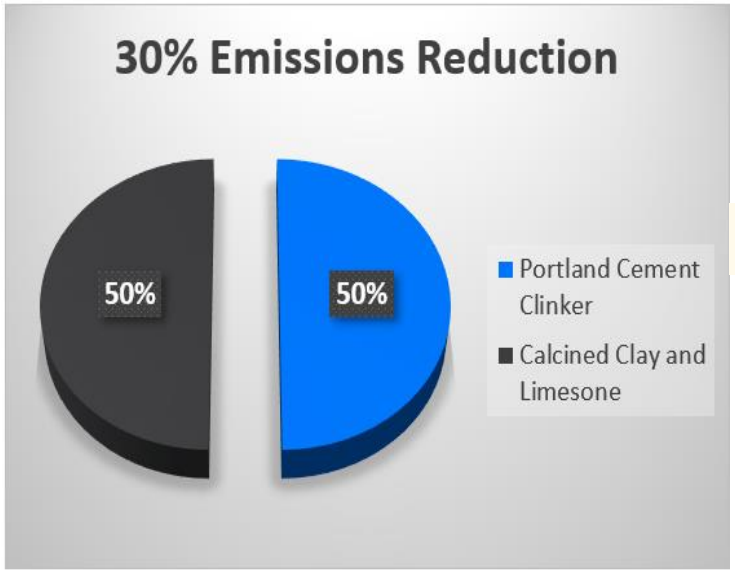
Limestone Calcined Clay Cement (LC3): A new type of cement blend based on limestone and calcined clay.

- **Environmental Impact**: Can reduce CO_2 emissions by up to 40%.
- **Material Availability**: Uses abundant, low-grade limestone and clays.
- **Cost Efficiency**: Consume less energy, requires no major capital-intensive modifications to existing cement plants, keeping production costs low.

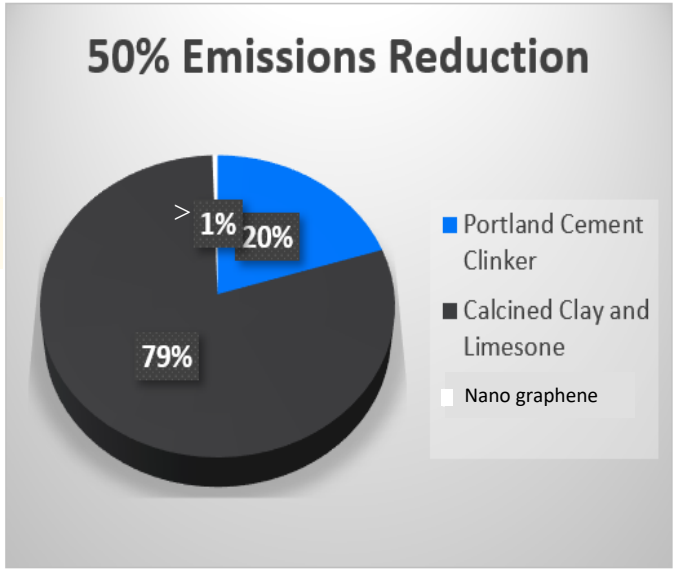


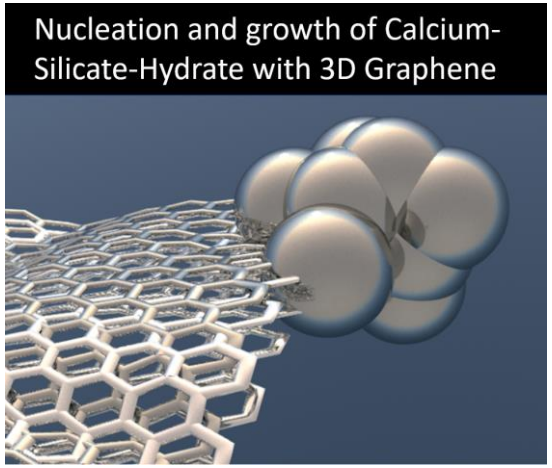
Background and Motivation

- Blends of supplementary cementitious materials have been demonstrated up to 50% clinker replacement.
- Extending further Portland clinker replacement beyond 50% leads to concerns regarding the strength and durability.



additives

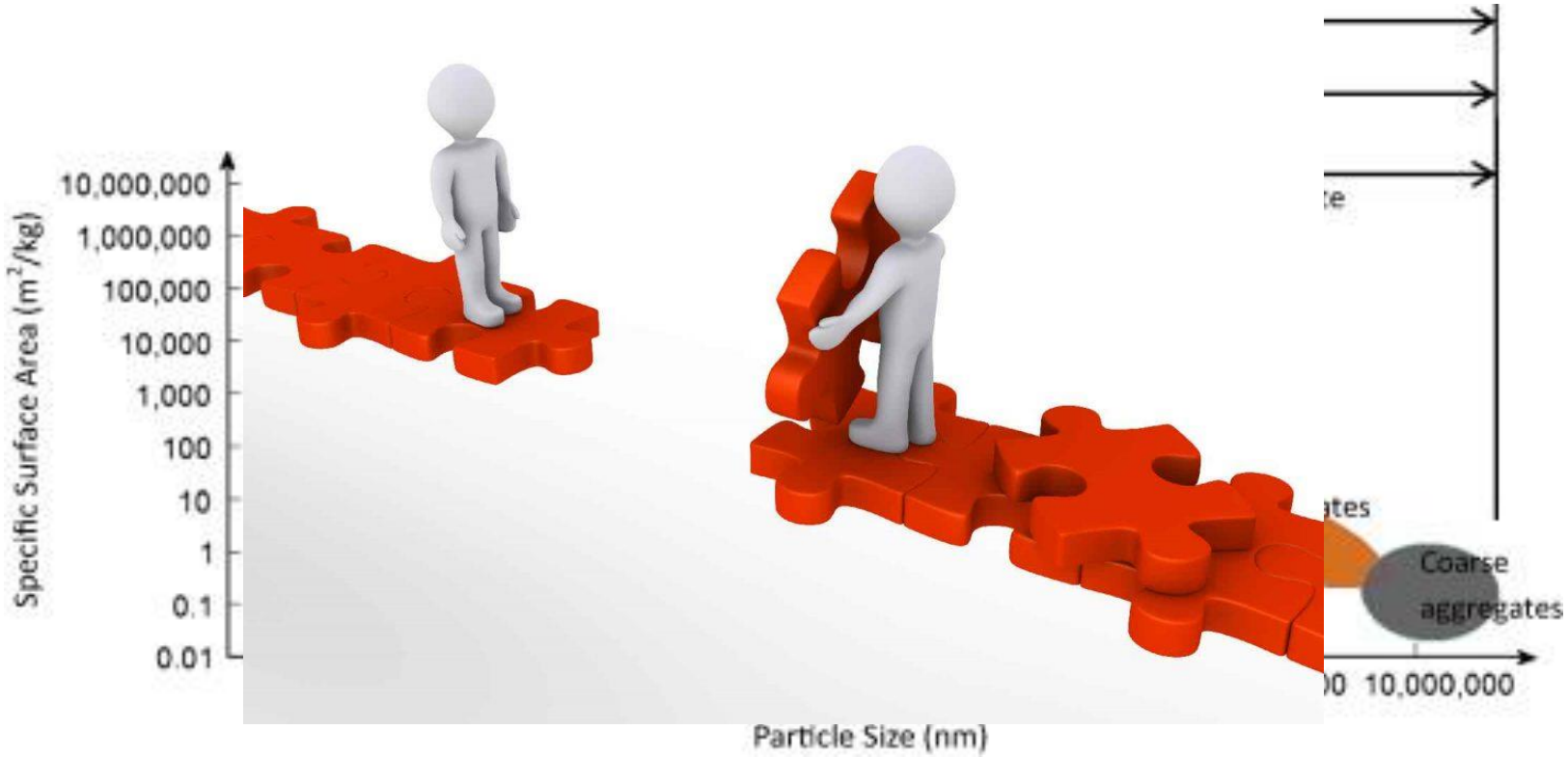




Stretch goal → more emissions reductions

Background and Motivation

- 3D graphene has been demonstrated as an additive which can accelerate the C-S-H gel formation and densify the cement matrix. This is required for increasing the proportion of supplementary materials for clinker replacement.



"How Nanotechnology Can Change the Concrete World." *American Ceramic Society Bulletin* 84.11 (2005): 17.

Content

- Background and Motivation
- Objective
- Experimental result
- Summary
- Acknowledgement

Objective

- Methodology exploration for mixing LC3 with 3D graphene.
- Evaluate the impact of 3D graphene on strength performance of LC3.
- Conduct durability assessment to understand the long-term behavior.
- Study and discover the underlying mechanism.

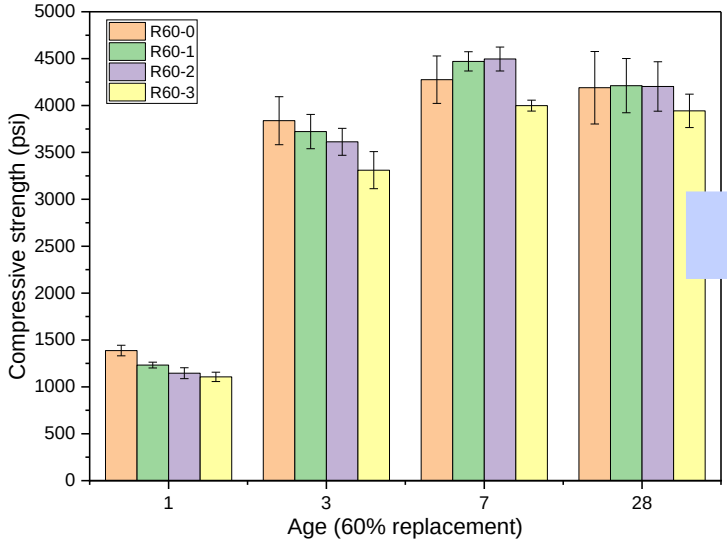
Content

- Background and Motivation
- Objective
- Experimental result
- Summary
- Acknowledgement

LC3 Mixture Design

Mix ID	PLC	LS	MK	Gypsum	Sand/b	w/b
R0-0	100%	0%	0%	3%	2.75	0.485
R60-0	40%	20%	40%	3%	2.75	0.485
R60-3	40%	20%	40%	3%	2.75	0.485

In order to prevent fresh setting of the LC3, extra gypsum is added.



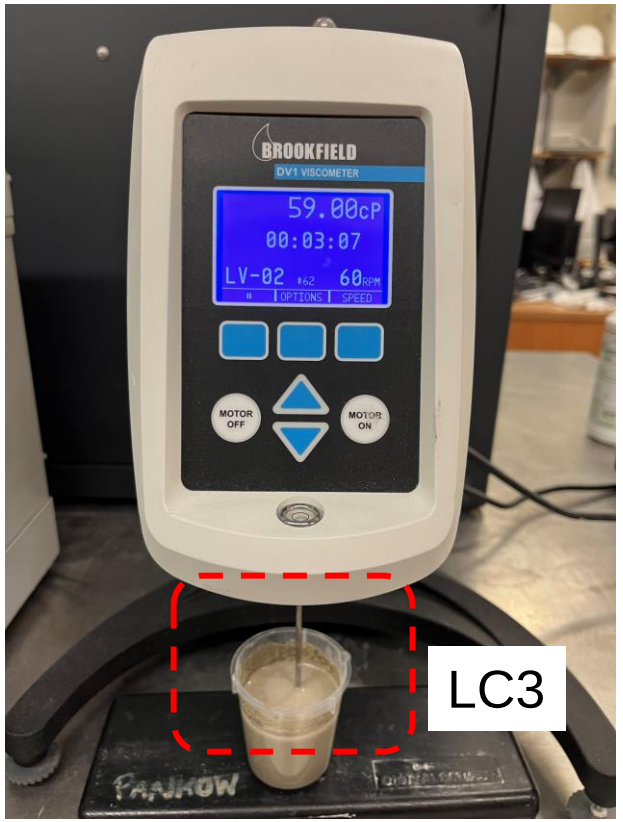
- The initial trial of the LC3 suggests that the strength performance of mortar cubic was negatively impacted by 3D graphene.
- It is suspected it was due to the dispersion of graphene particles that was not ideal.

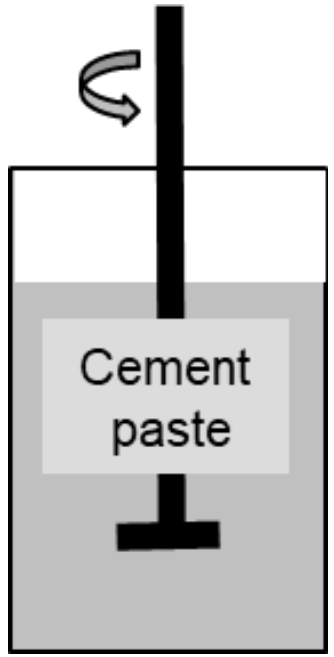
Superplasticizer

Sonication

Viscosity measurement

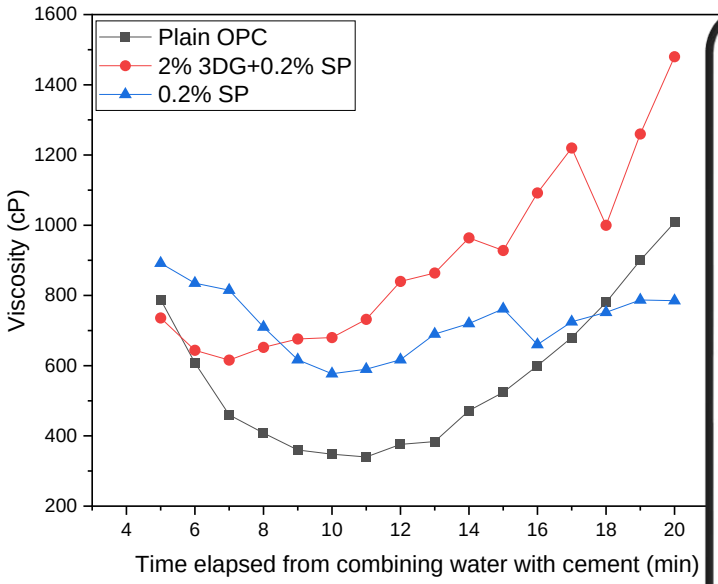
Evaluation of dosage

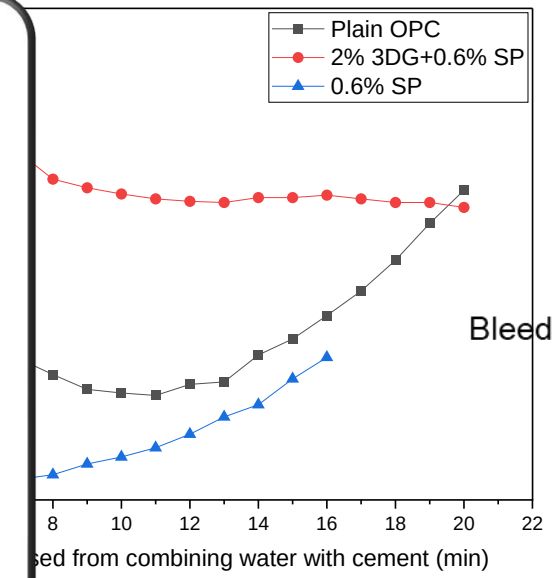


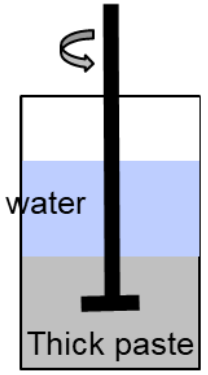


Viscometer can determine the viscosity of fluid by rotating the spindle

Viscosity results

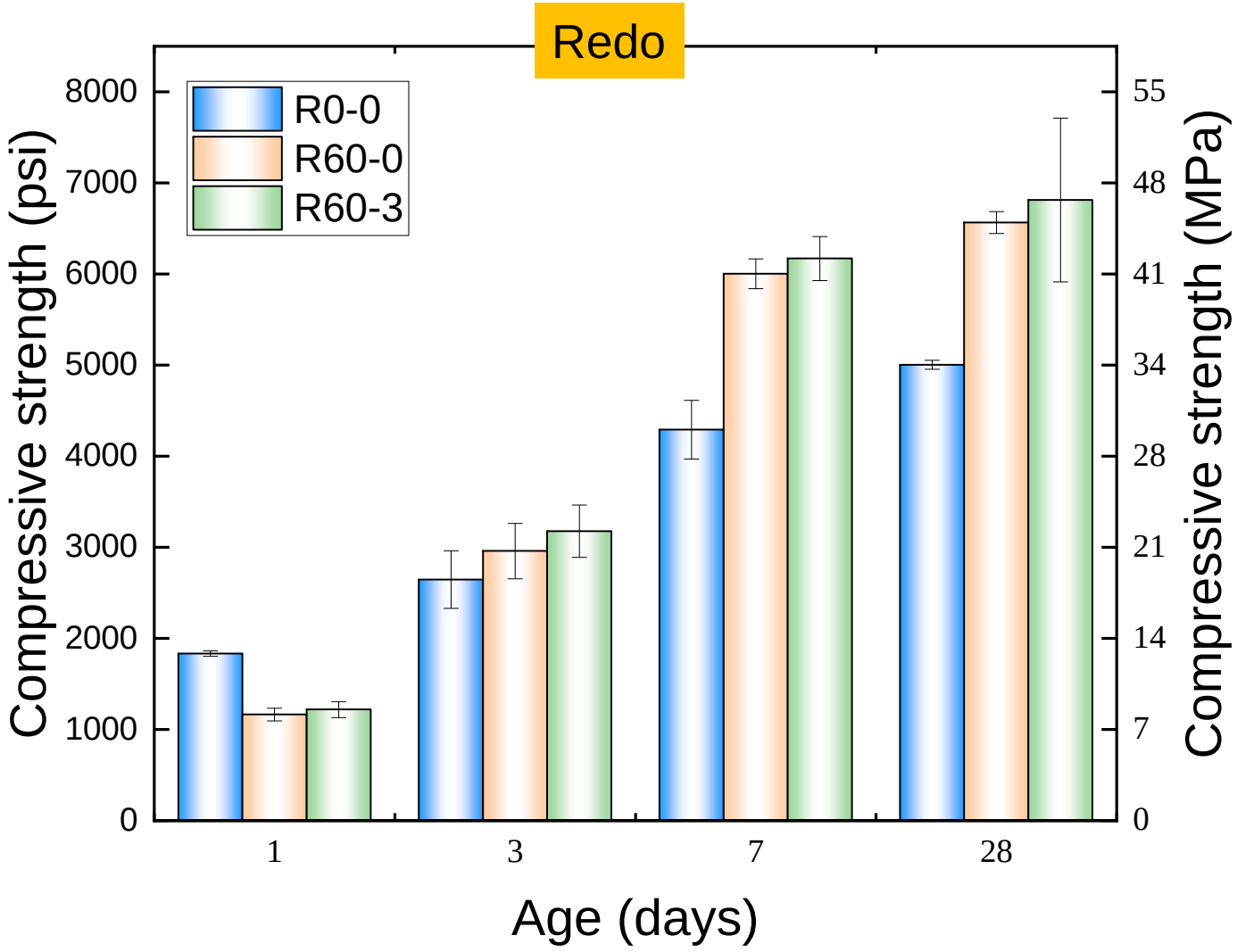






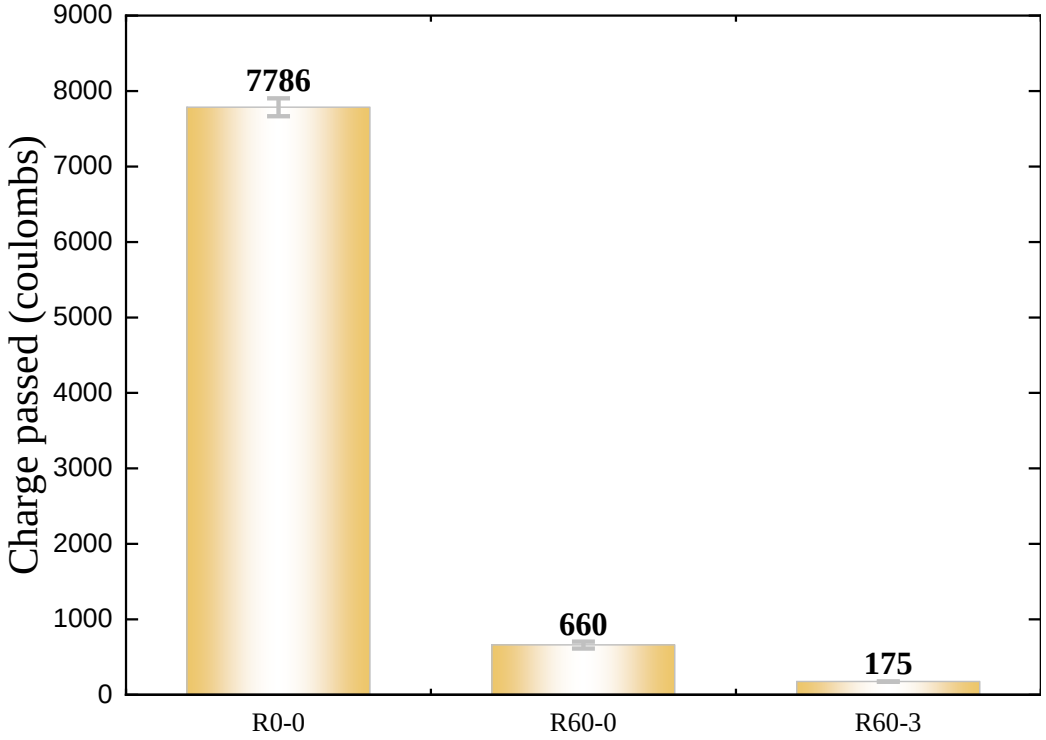
- Bleeding was observed in superplasticizer.
- The high viscosity values blained by the poor consistency (severe bleeding). The spi and hard to rotate.
- It is suggested to use 0.2% ments.

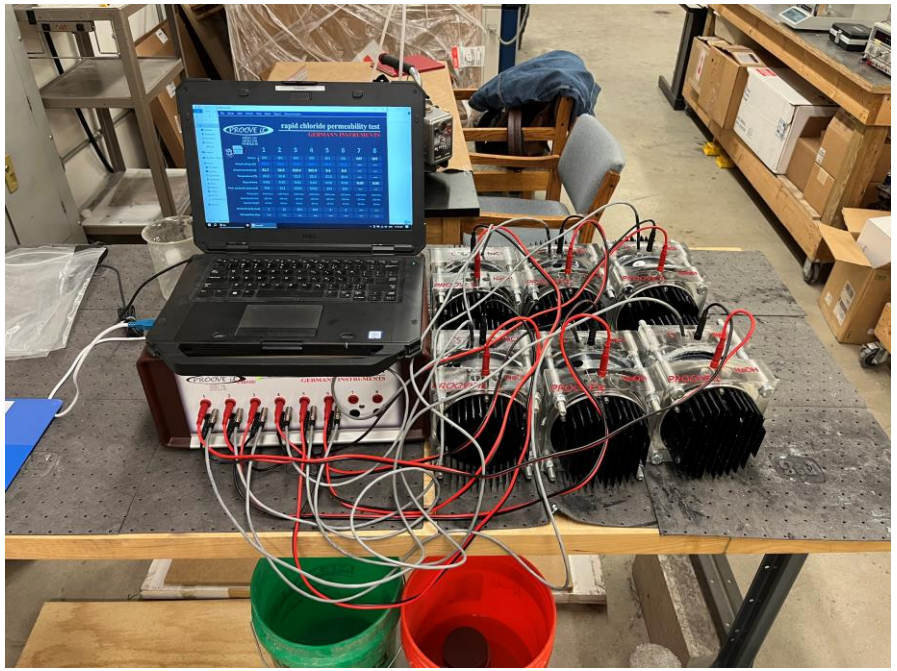
Test Result-Strength



With proper mixing protocol adjustment and design modification, 60% cement replacement ratio with 3D graphene led to strength improvement.

Test Result-RCPT

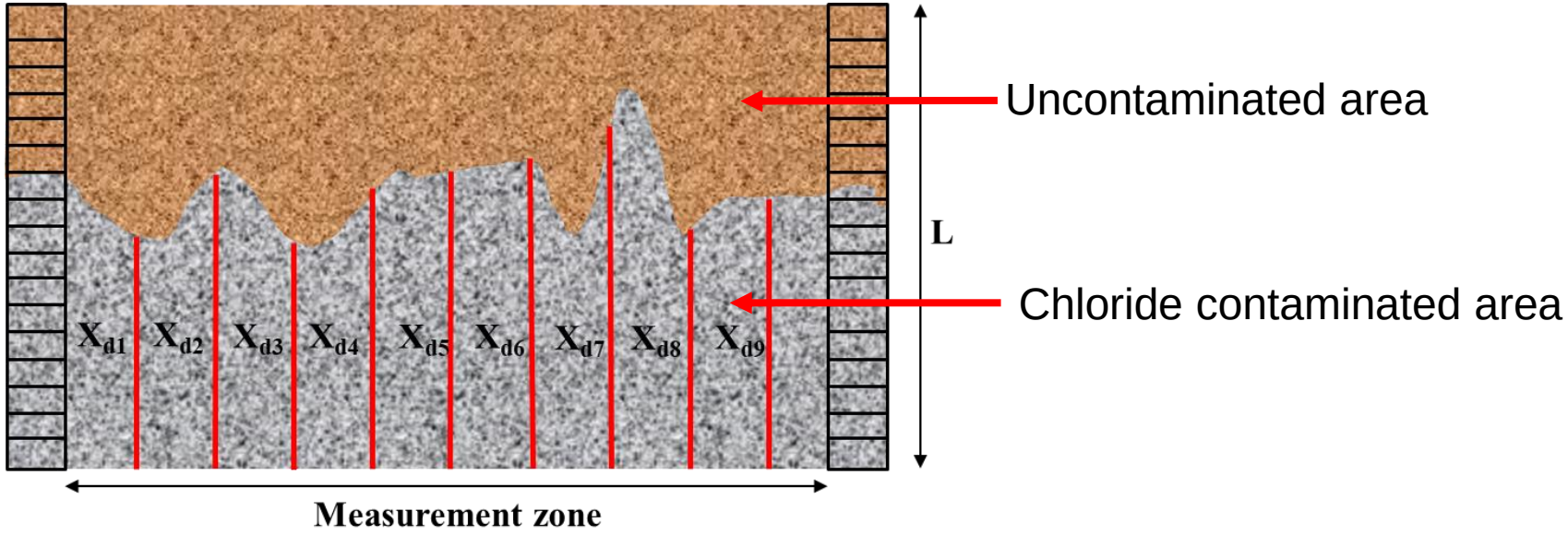




Test setup

- Reference sample (OPC) showed the highest passed charge value (~7800). LC3 sample without 3D graphene showed moderate charged passed value (~660). With 0.3% 3D graphene addition, 60% cement replacement sample showed the lowest passed charge value (~175).

Test result-RCM

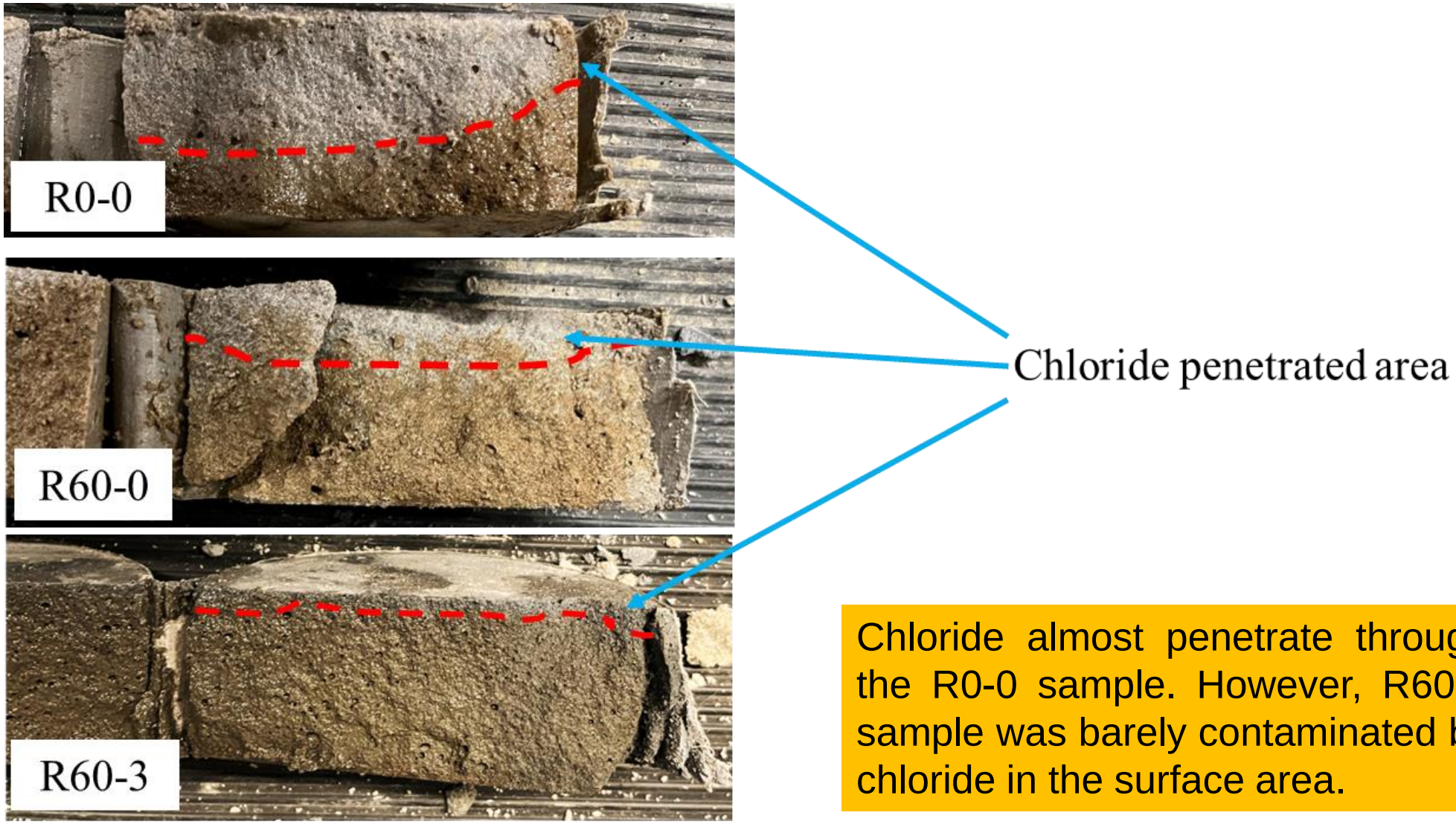


- After RCM test, samples were axially split into 2 halves and sprayed with 0.1 M $AgNO_3$. Area contaminated by chloride would appear white.
- The non-steady state chloride migration coefficient can be calculated from RCM penetration depth:

$$D = \frac{0.0239(273+T)L}{(U-2)t}\left(x_d - 0.0238\sqrt{\frac{(273+T)Lx_d}{U-2}}\right)$$

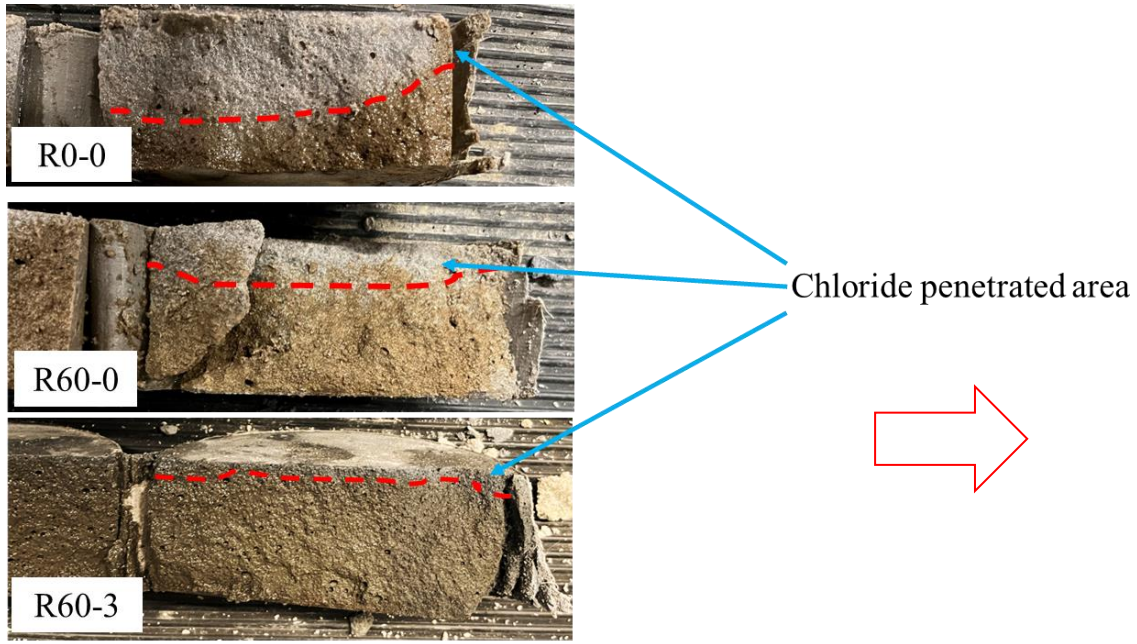
[1] NT Build 492, Concrete, mortar and cement-based repair materials: Chloride migration coefficient from non-steady-state migration experiments, Nordtest, Espoo, Finland, 1999.

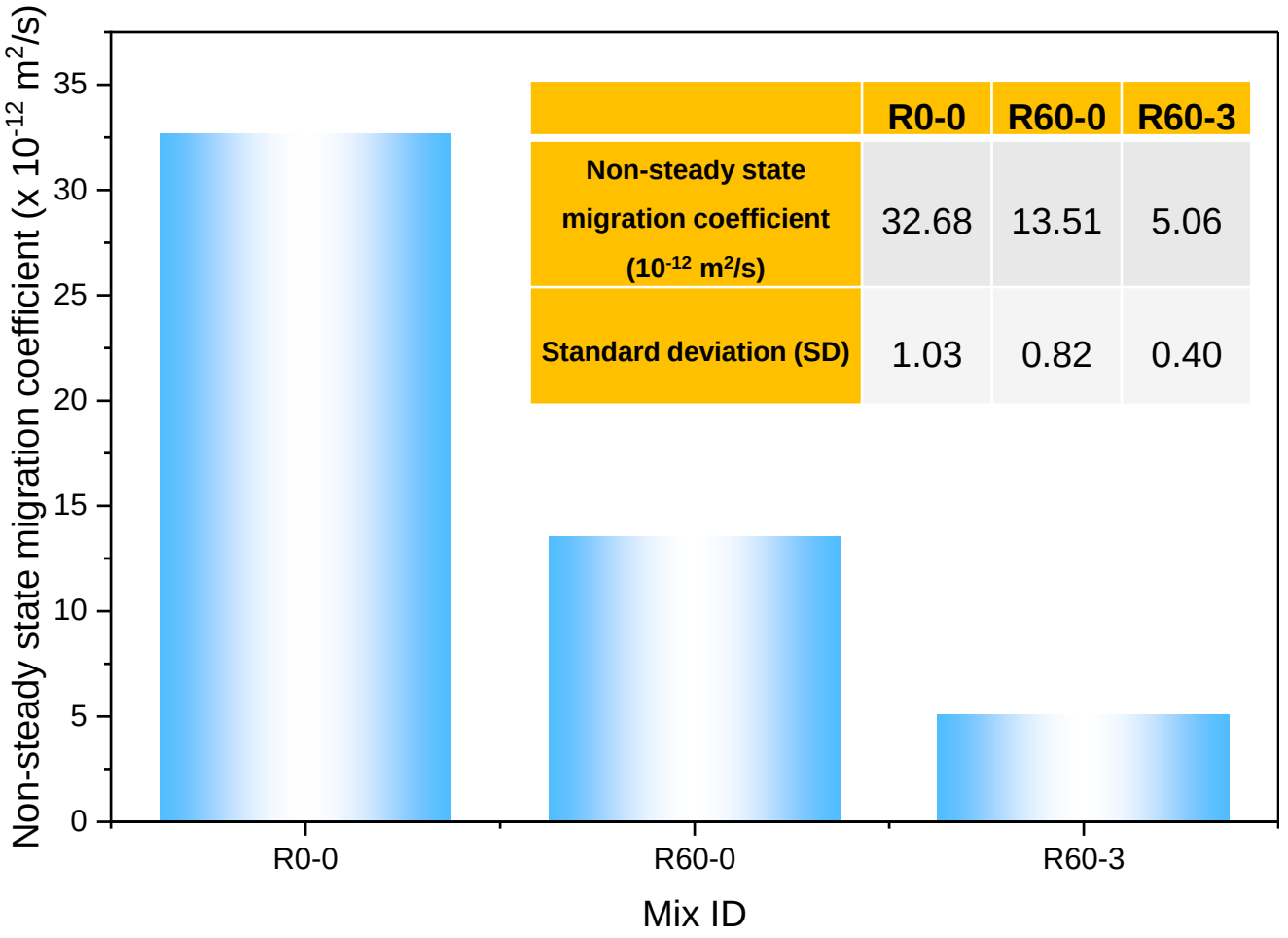
Test results - RCM



Chloride almost penetrate through the R0-0 sample. However, R60-3 sample was barely contaminated by chloride in the surface area.

Test results - RCM

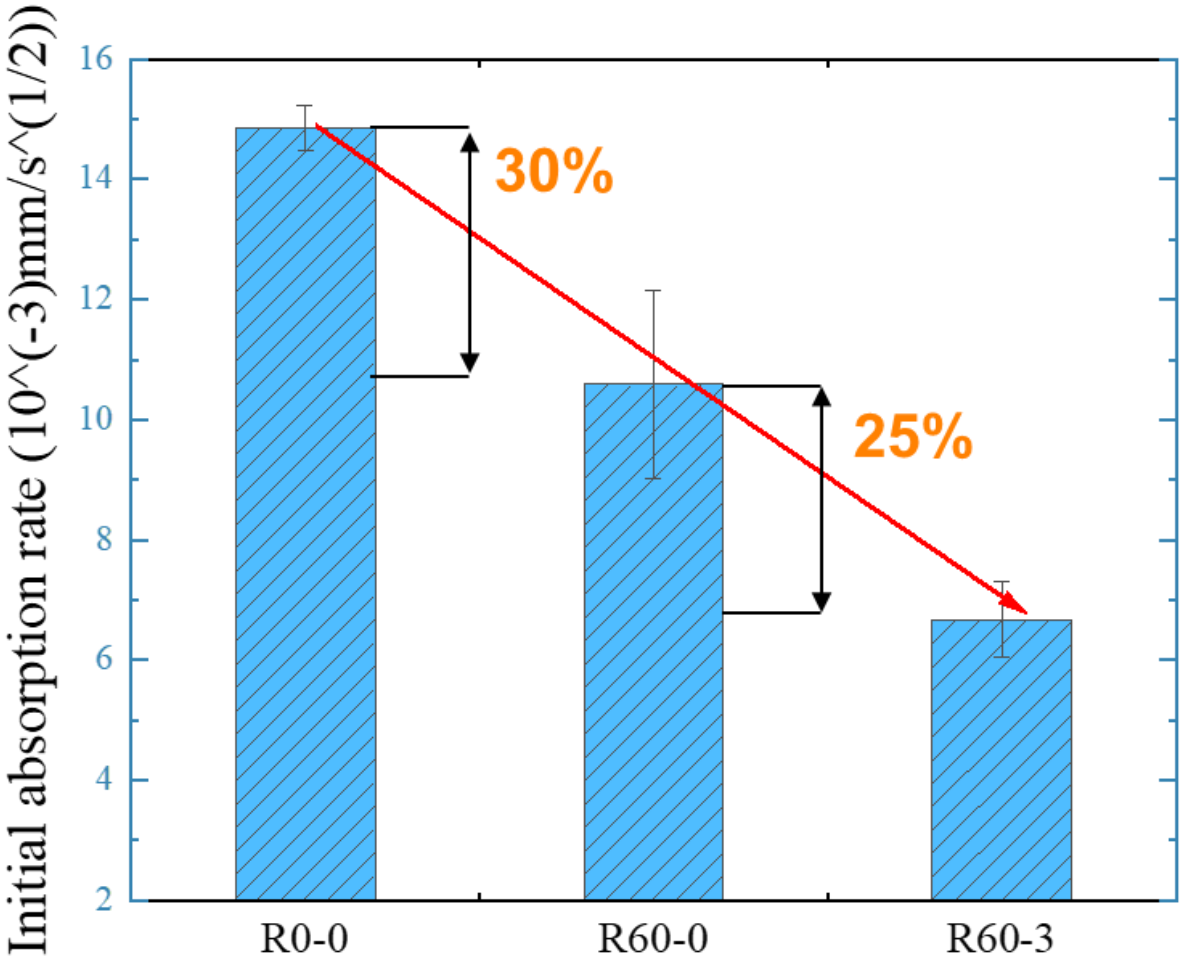




	R0-0	R60-0	R60-3
Non-steady state migration coefficient (10^{-12} m^2/s)	32.68	13.51	5.06
Standard deviation (SD)	1.03	0.82	0.40

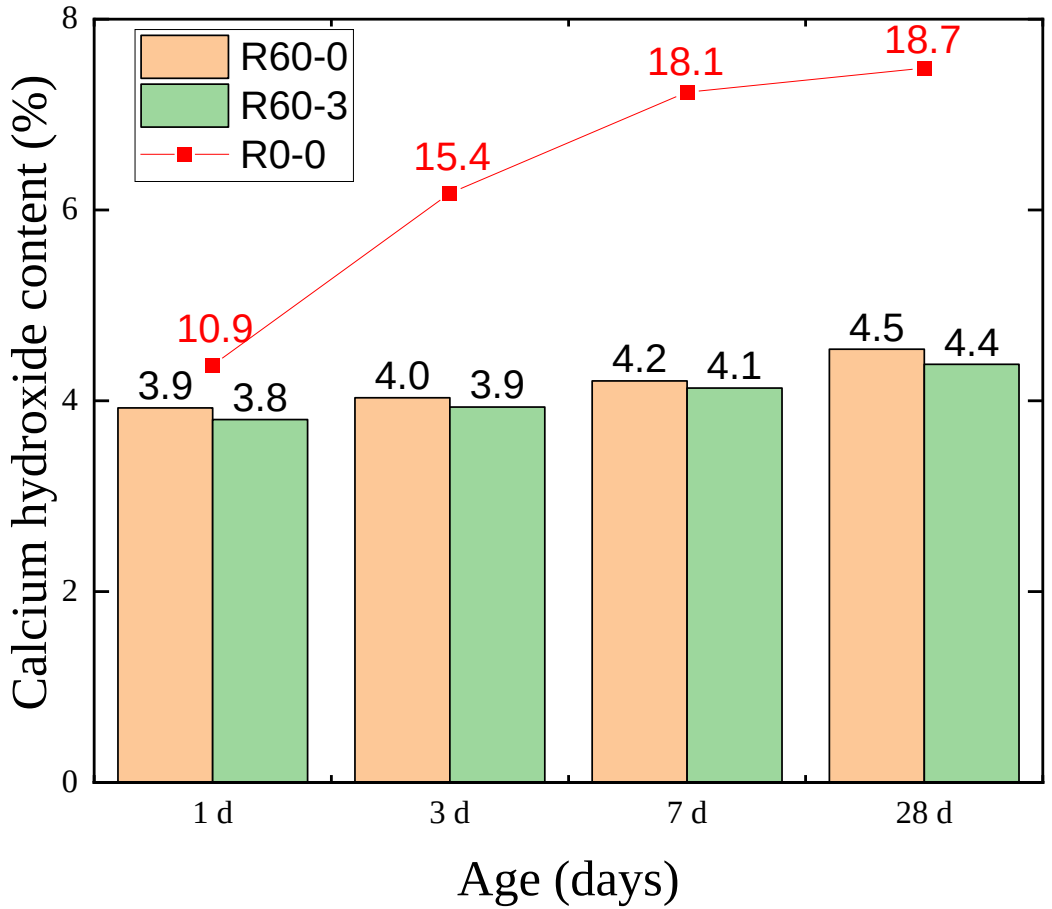
The results indicate that adding 3D graphene could significantly improve the chloride resistance of sample.

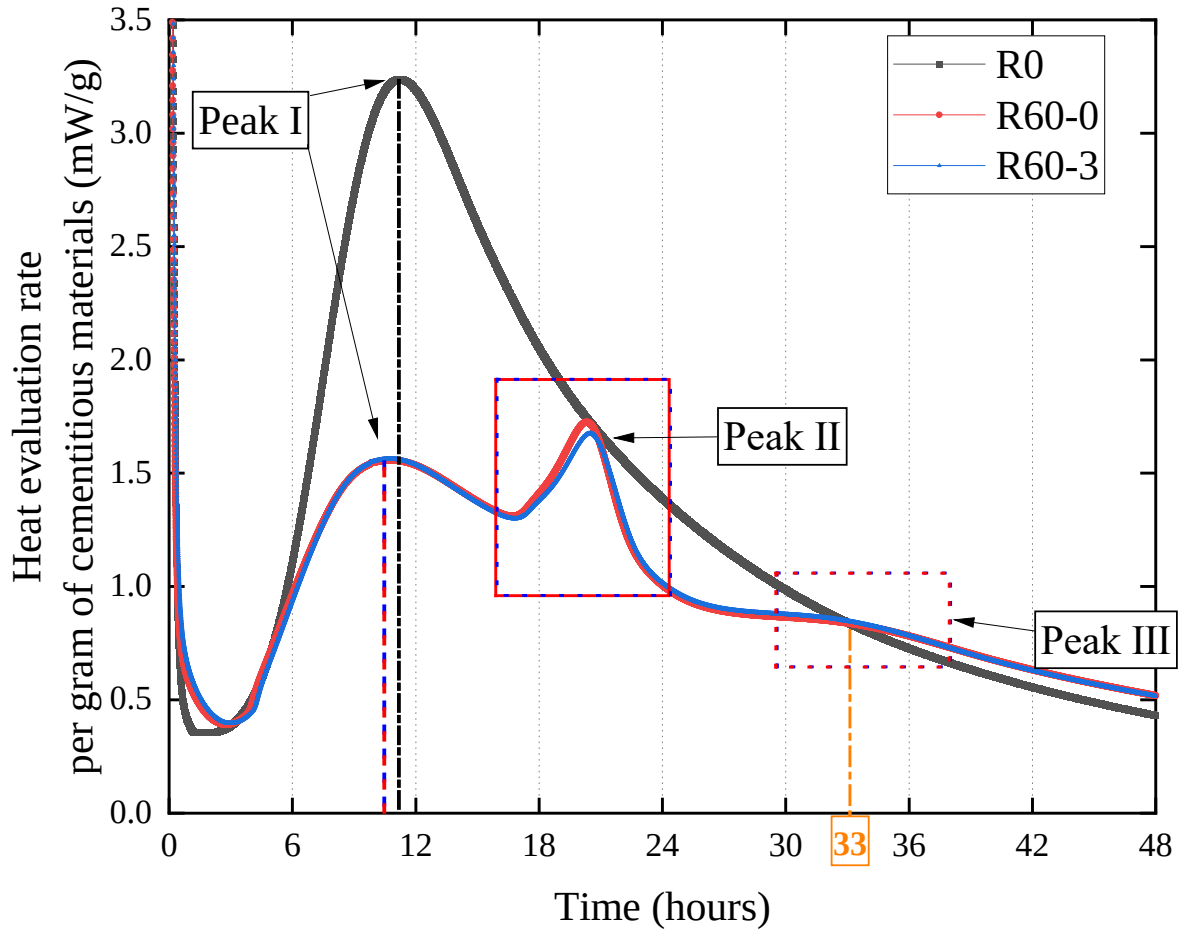
Test Result-Water Sorptivity



- With the addition of 0.3% addition of 3D graphene, the water absorption rate of the sample is only half to the sample without 3D graphene addition.
- The results indicate that adding 3D graphene could significantly improve the impermeability of sample.

Hydration Assessment





In current study, the addition of 3D graphene did not alter the hydration profile of cementitious materials.

Content

- Background and Motivation
- Objective
- Experimental result
- Summary
- Acknowledgement

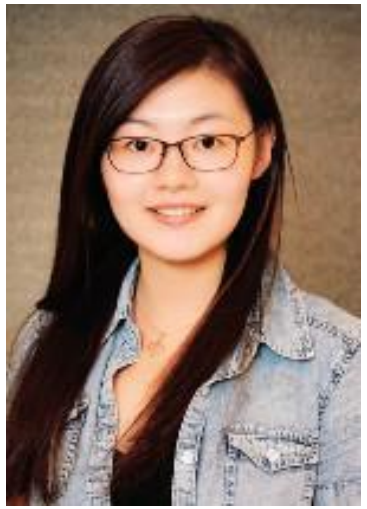
Summary

- The mixing procedure and the dispersion of 3D graphene play a significant role in the performance of LC3.
- Better compressive strength performance was obtained by the incorporation of 3D graphene.
- The incorporation of 3D graphene significantly improved the impermeability of the LC3, leading to lower water absorption rate and higher chloride resistance.
- The addition of 3D graphene did not significantly affect the hydration profile of LC3 system at early ages. It is therefore believed that the improvement of LC3 performance by 3D graphene is mainly due to the nano filling effect.
- Cement replacement ratio might be further increased beyond 60% with the use of 3D graphene.

Acknowledgements

Faculty Advisor:

Prof. Na (Luna)Lu



Prof. Yining Feng

Lab Colleagues:

LYTEN

PURDUE UNIVERSITY | Joe and Lisa Shetterley Innovation Lab

Niko Abercrombie, Ariful Hasnat, Salik Kahn, Anne Ruminski, John Baldwin and Peter Boul

Thanks!