PURDUE UNIVERSITY

Oregon State University

Forest Products Laboratory

U.S. Endowment for Forestry and Communities

The Improvement of Cementitious Material Properties by Addition of Nanocellulose

Presented by:
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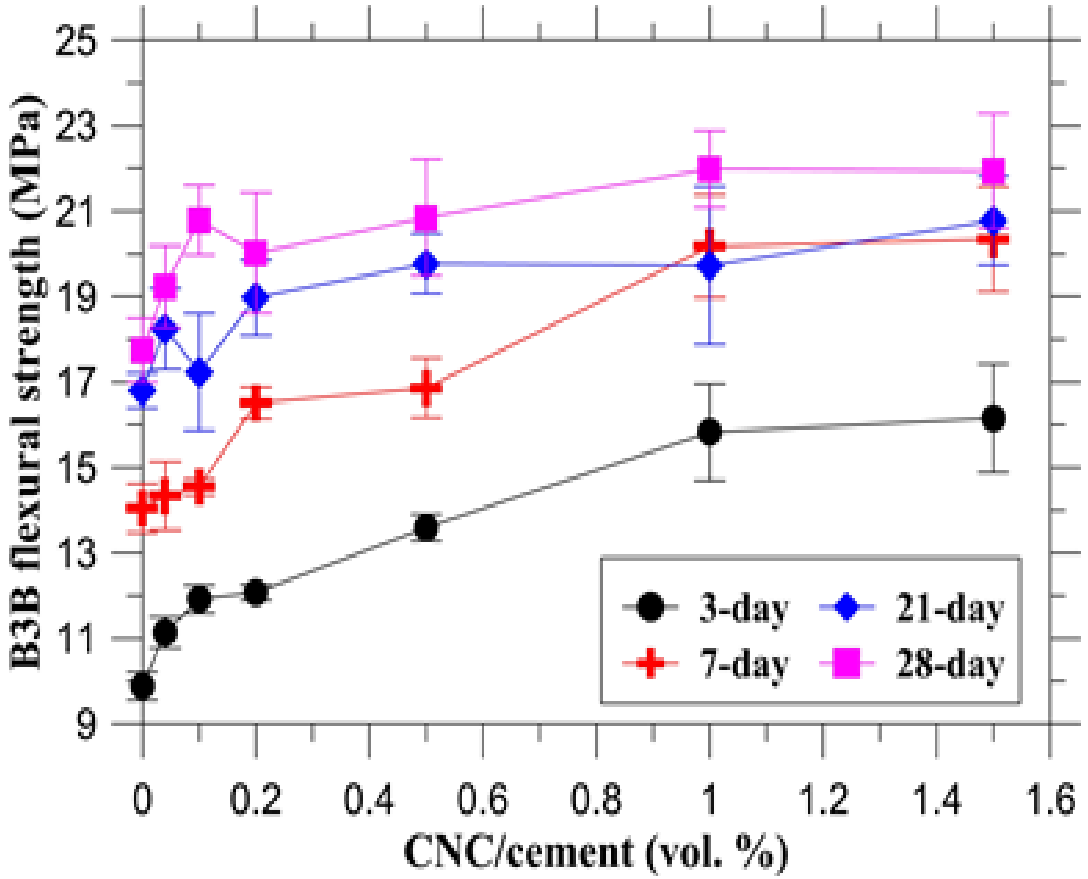
Purdue University

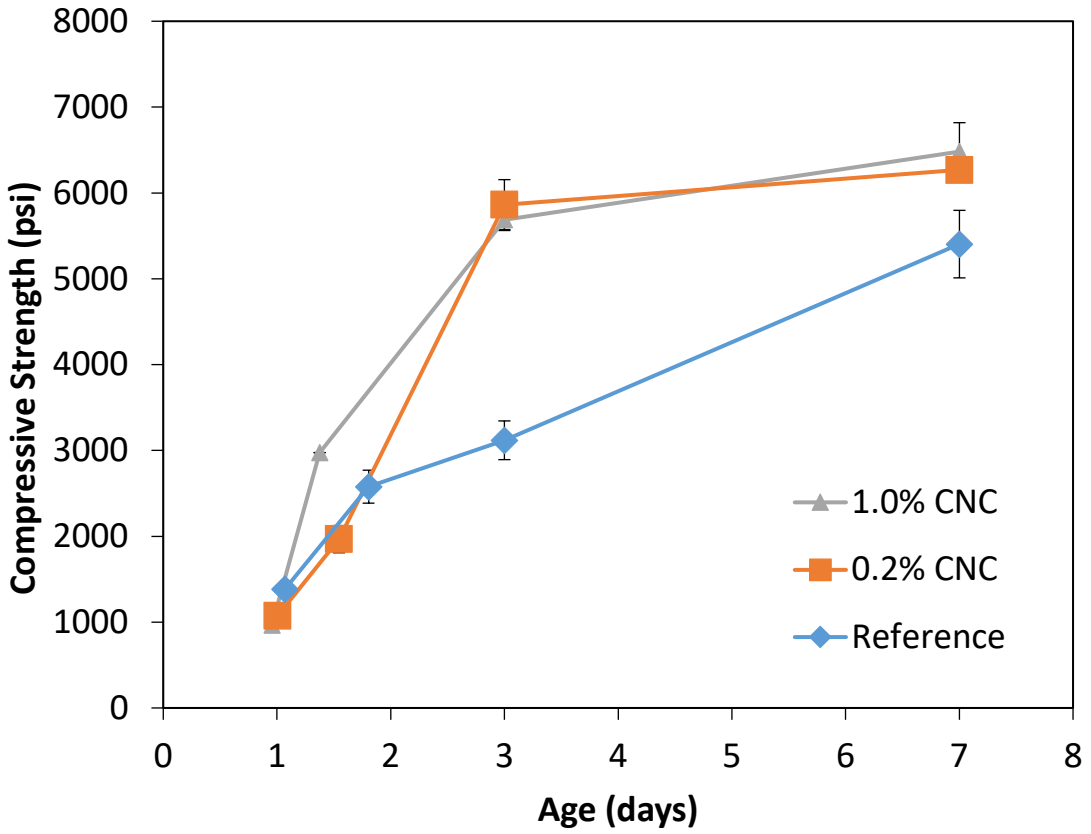
And a host of co-authors at the end

TAPPI NANO DIVISION

CNM in cement and concrete

- ~15 years ago we found that CNC can increase cement strength

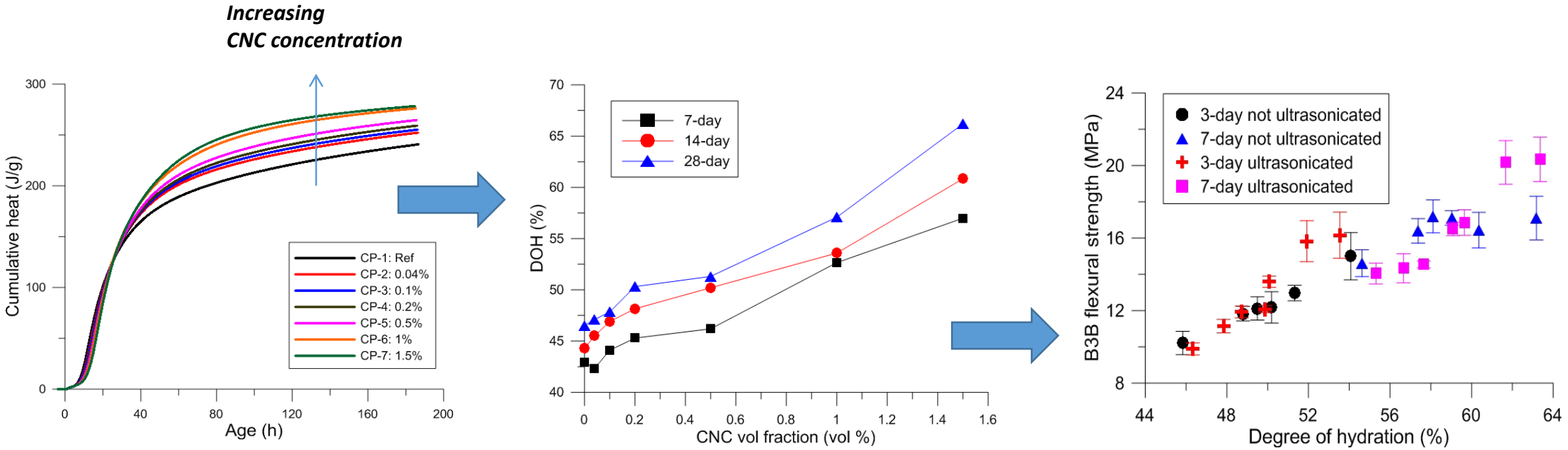




Note: CNC Vol% is relative to initial dry cement powder NOT final material

- Better at early than late strengths

Degree of Hydration (DOH) is increased which leads to higher flexural strength



- Heat release and therefore Degree of Hydration (DOH) is increased with CNC
- CNC induces a delay in onset of cure
- Flexural strength scales with hydration (as expected)
- Plasticization for CNC at low doses, viscosification for CNF and CNC at high doses

How do CNCs help hydration?

What do we know?

- CNCs are too small to bridge microcracks
- No evidence of IC
- CNCs stabilize particles
- CNCs increase DOH more than SP

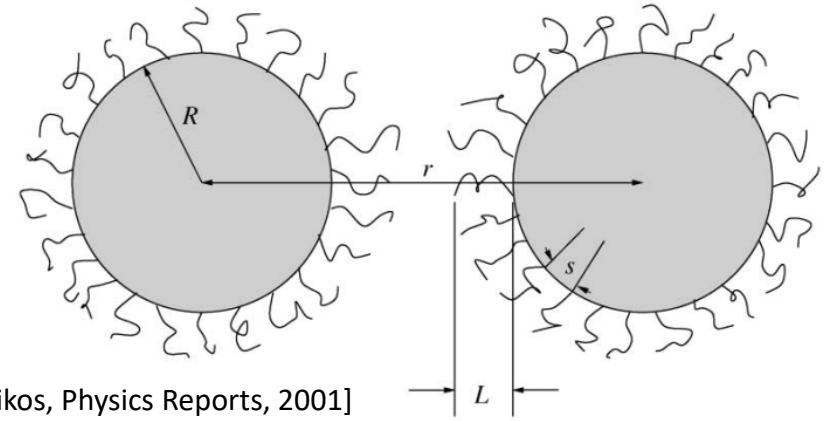
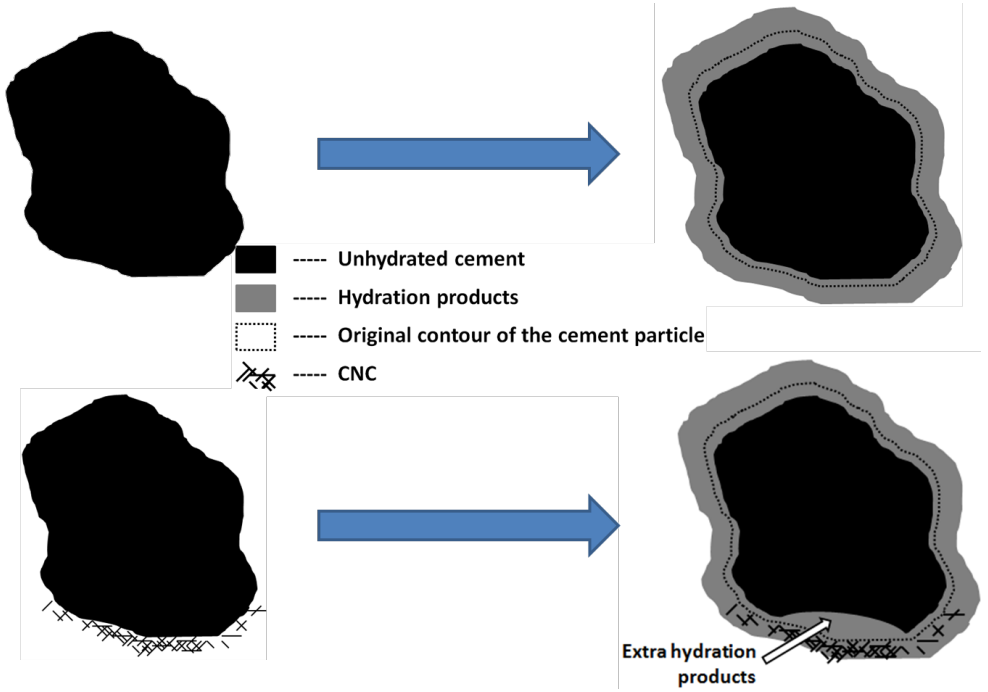


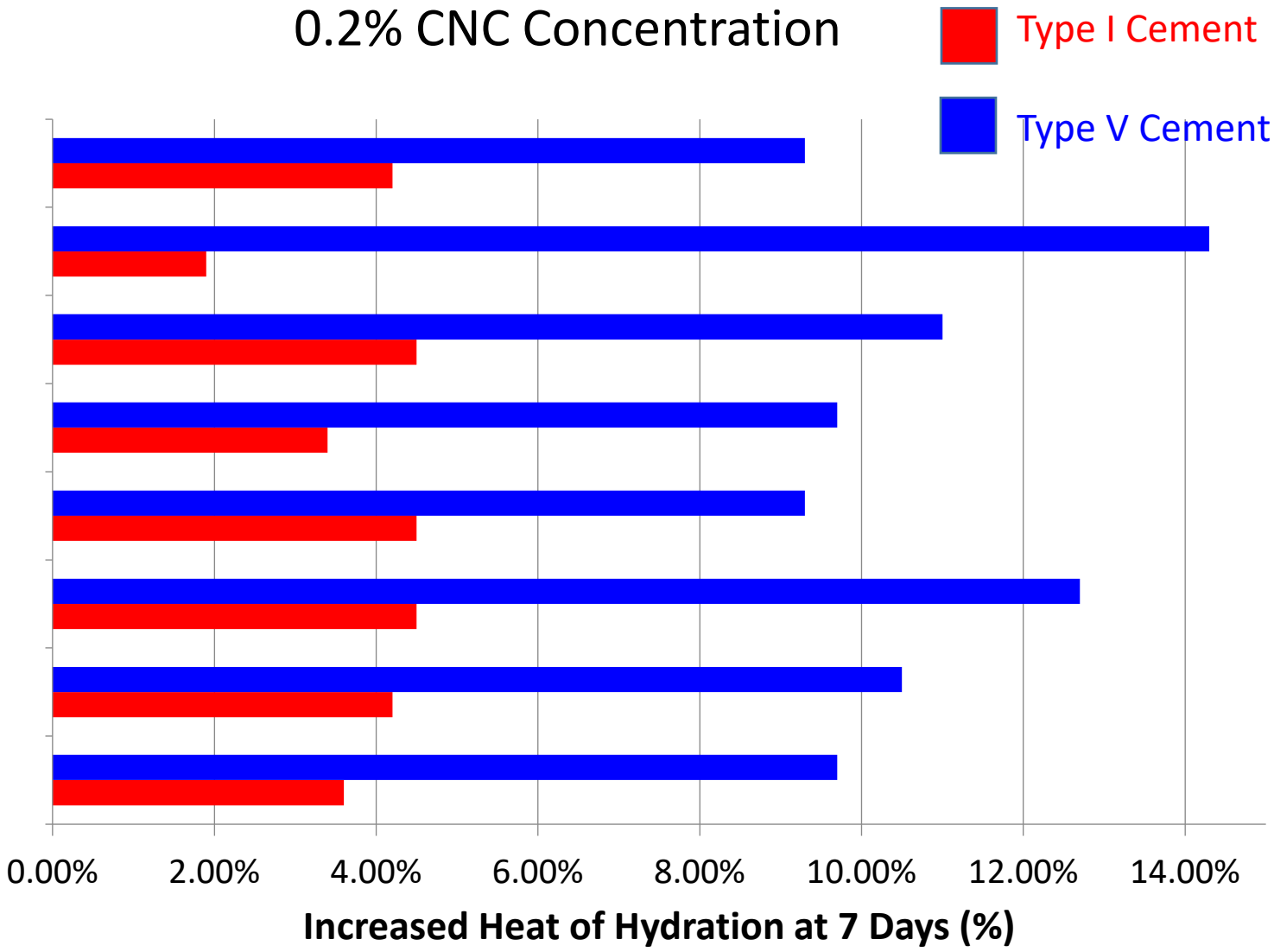
Image from [Likos, Physics Reports, 2001]

Short Circuit Diffusion (SCD)

- Hydration layer around cement particle is dense so diffusion of water is very slow after this layer formed.
- CNCs adhering to cement particles can transport water through the hydration products shell into the unhydrated core, and hence improve DOH.
- The only prerequisite is the attachment of CNCs on to cement and incorporation into hydration layer. No particle separation is needed!

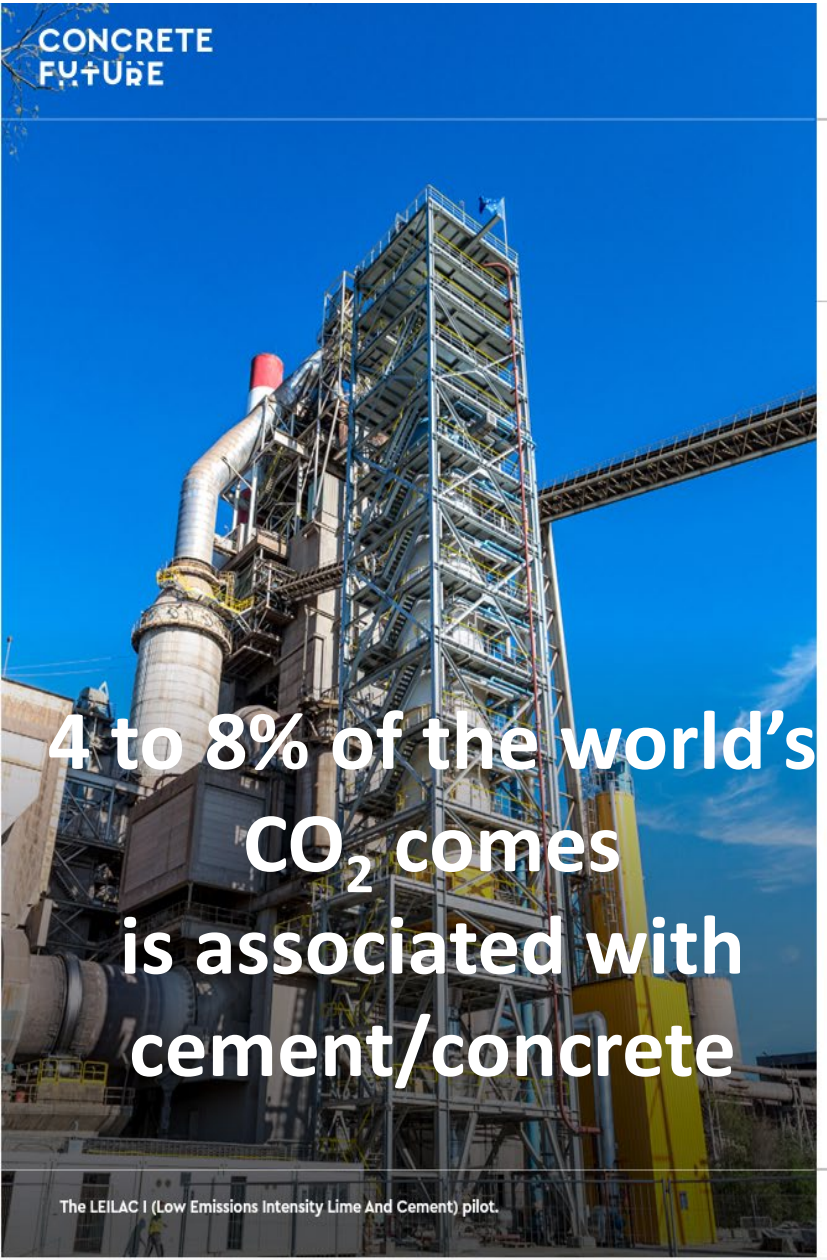


But, unfortunately, CNC AND cement chemistry matters



- A variety of CNCs from multiple sources and companies were utilized
  - 7-day DOH increase was different for each
- Type I/II and Type V used
  - Lower DOH for Type I/II seed for each
- Regional differences observed for mixes of same type
  - SCMs also play large role

CO2 emissions are a pressing need for infrastructure



2020 TO 2030 - THE DECADE TO MAKE IT HAPPEN

In this key decade, we will accelerate our CO_2 reductions through the following actions and initiatives:

- increased clinker substitution – including fly ash, calcined clays, ground granulated blast-furnace slag (ggbs), and ground limestone.
- fossil fuel reductions and increased use of alternative fuels
- improved efficiency in concrete production
- improved efficiency in the design of concrete projects and use of concrete during construction, including recycling
- investment in technology and innovation
- CCUS technology and infrastructure development

In addition, we will strive for and collaborate in establishing a policy framework to achieve net zero concrete.

2030 CO_2 REDUCTION MILESTONES:

(Compared with 2020 Baseline)

Concrete

25%

CO_2 reduction per m^3 of concrete by 2030

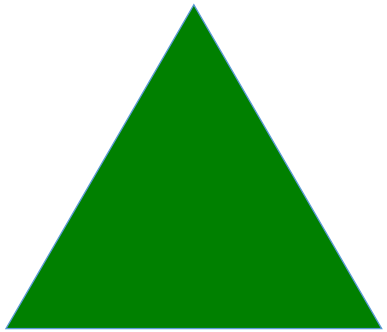
Cement

20%

CO_2 reduction per tonne of cement by 2030

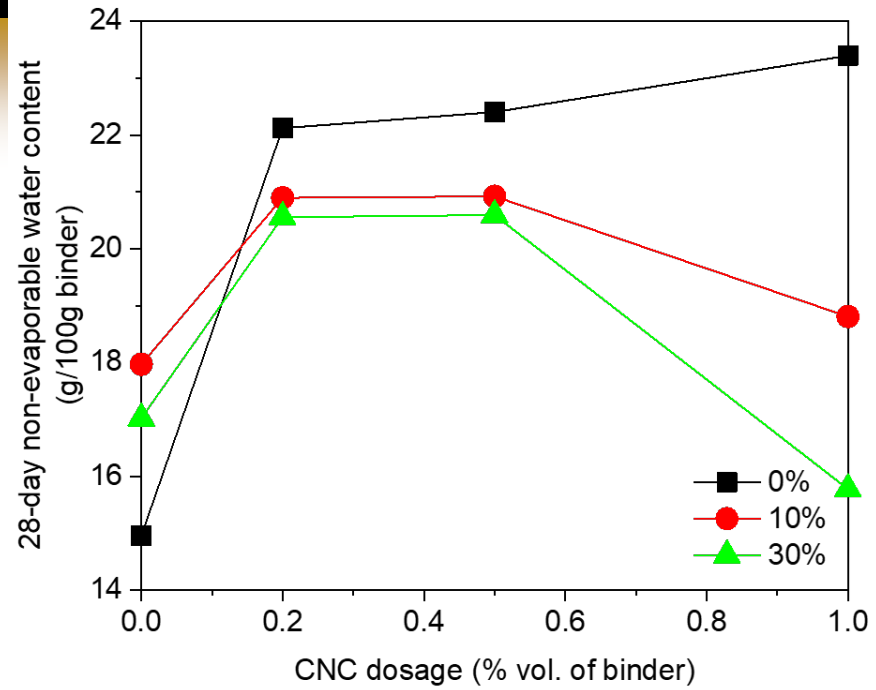
3 ways to solve cement's CO2

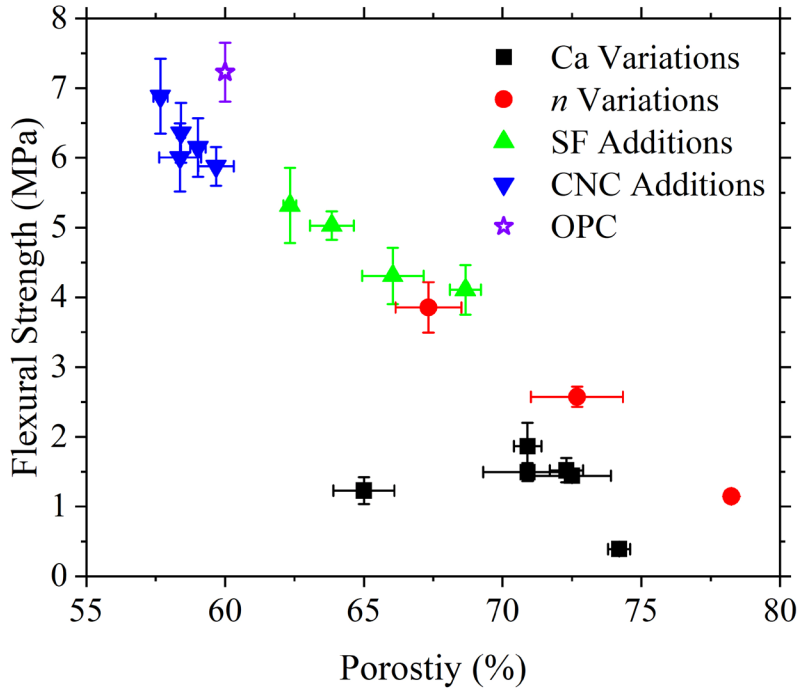
Use Less Clinker



Use Less Cement

Last Longer





CNC increases DOH – can we can use clinker more efficiently?

Yes, yes it does!

- Non-evaporable water is a surrogate for how much cement has reacted.
- We can see that more cement is reacting when we have a moderate CNC dosage level
- This is why the cement is stronger.
- Could allow more water, etc.

However, nobody ever asks for increased DOH

What about using less clinker?

Caltrans Approves Use of Low-Carbon Cement to Help Combat Climate Change

Published: Jan 25, 2022

District: Headquarters
Contact: Tamie McGowen
Phone: (916) 956-0633

Sacramento – Caltrans announced today it is approving the use of low-carbon cement to help reduce the carbon footprint of California's transportation system. By advancing the use of portland limestone cement (PLC), Caltrans' road construction and maintenance projects can generate less carbon dioxide — the primary greenhouse gas contributing to global warming and climate change — with the same high performance standards at a slightly lower cost.

> "Using low-carbon cement can cut Caltrans' concrete-related carbon dioxide emissions annually by up to 10 percent. This is a big step in supporting California's efforts to achieve carbon neutrality by 2045."
>
> — Toks Omishakin, Caltrans Director

Cement is typically produced by mining, grinding, and heating limestone in industrial kilns to temperatures as high as 2,820 degrees Fahrenheit (1,550 degrees Celsius). The process alters the rock's chemistry and creates "clinker" — the basic component in nearly all types of cement — but also generates large quantities of carbon dioxide. PLC contains less clinker.

In 2017 alone, Caltrans used 325,000 tons of cement to upgrade the state highway system. Switching to low-carbon cement has the potential to reduce carbon dioxide emissions by 28,000 tons a year — the equivalent of removing more than 6,000 cars off the road.

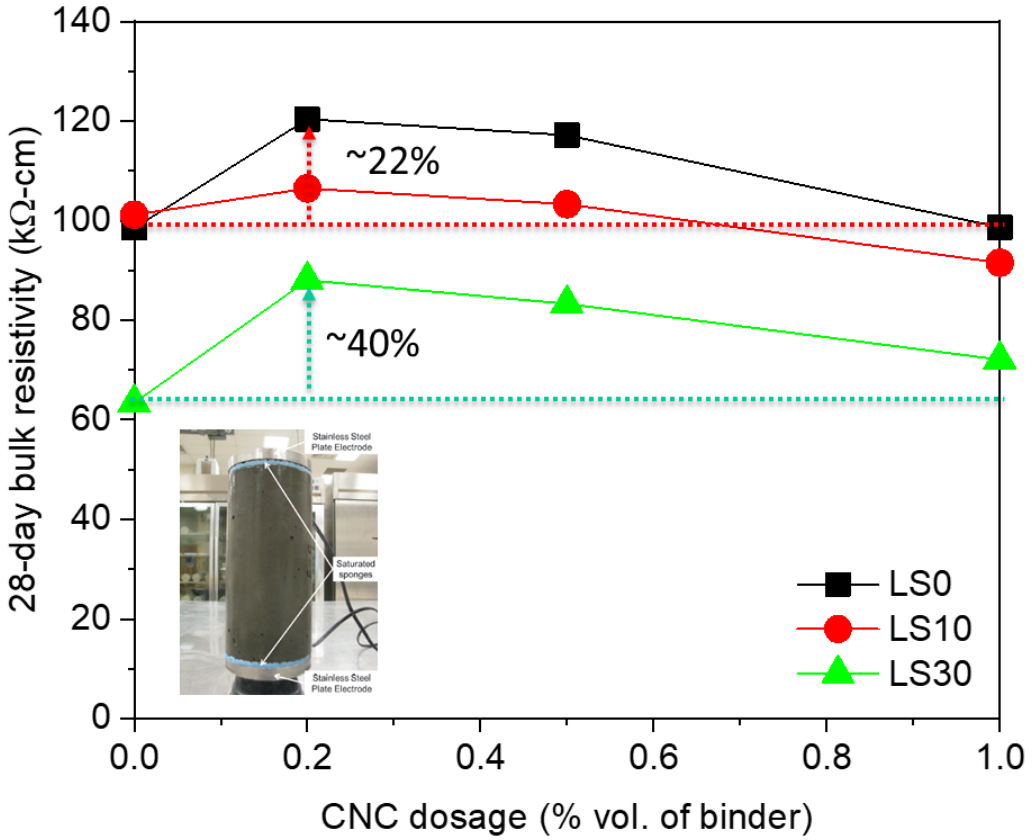
Caltrans expects that the reduced energy needs associated with PLC production will make the cost similar or slightly less when compared to regular cement.

The new low-carbon cement standards are based on Caltrans-funded research conducted at Oregon State University, which concluded that PLC is equally suitable for Caltrans' construction projects as ordinary cement with a reduced carbon footprint. Throughout the review process, Caltrans worked closely with its partners at the California Air Resources Board and industry experts and stakeholders, such as the California Construction and Industrial Materials Association and the California Nevada Cement Association, to draft the new standard specifications.

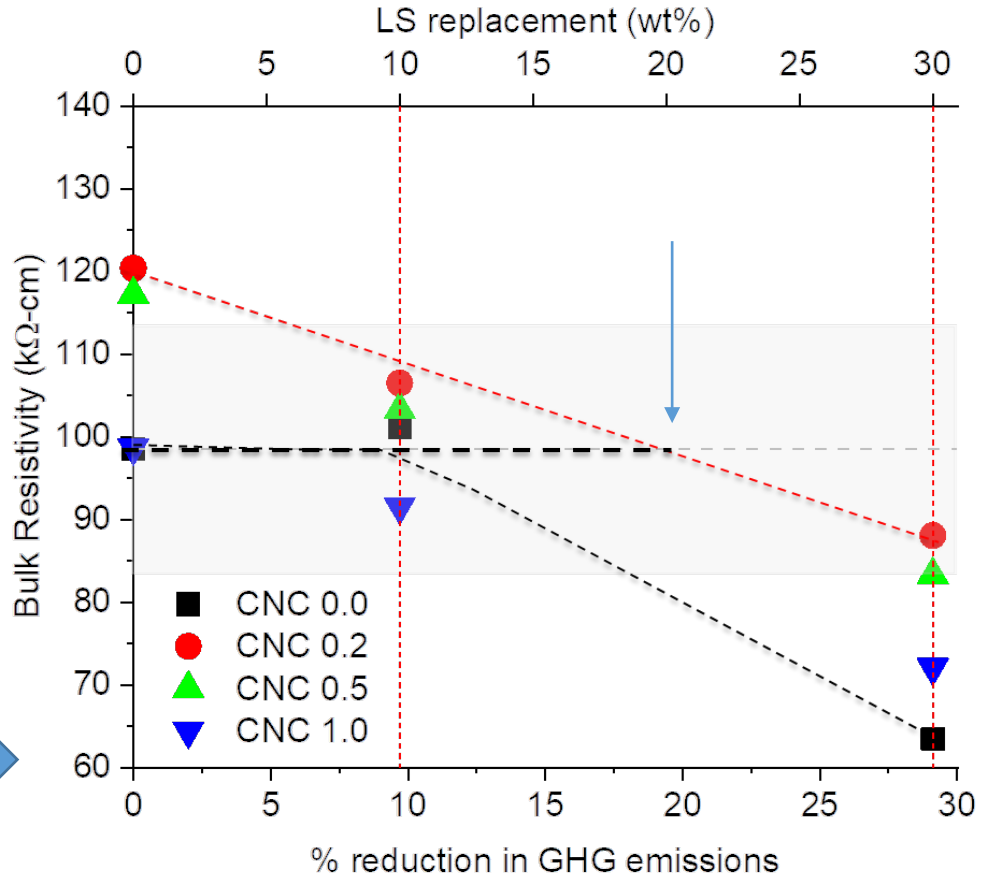
Typically add fillers

- SCMs – fly ash and slag
- Alternative SCM – Natural Pozzolans (Raw and Calcined) generally silica and/or alumina
- Limestone (PLC)

CNC can improve cement with limestone filler

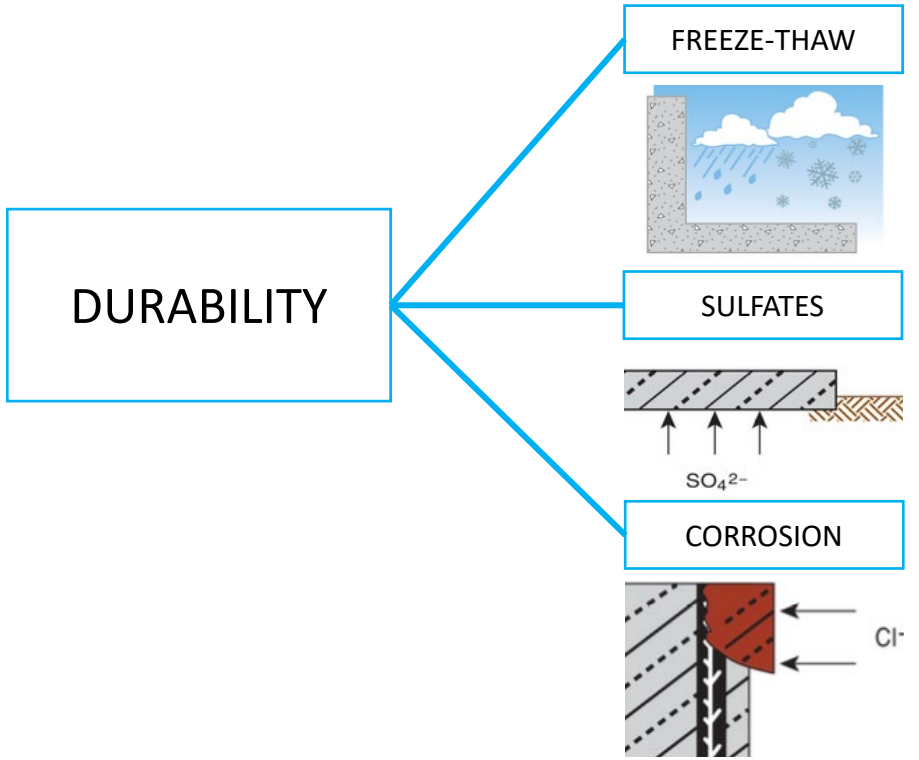


Which can reduce GHG by 20% without loss in properties.



Can CNC make cement last longer, so less concrete is needed?

- Durability = resistance to deterioration processes
- Durability is determined by transport processes at pore level
  - Permeability which is from Diffusivity which is from Porosity



Formation Factor (FF)

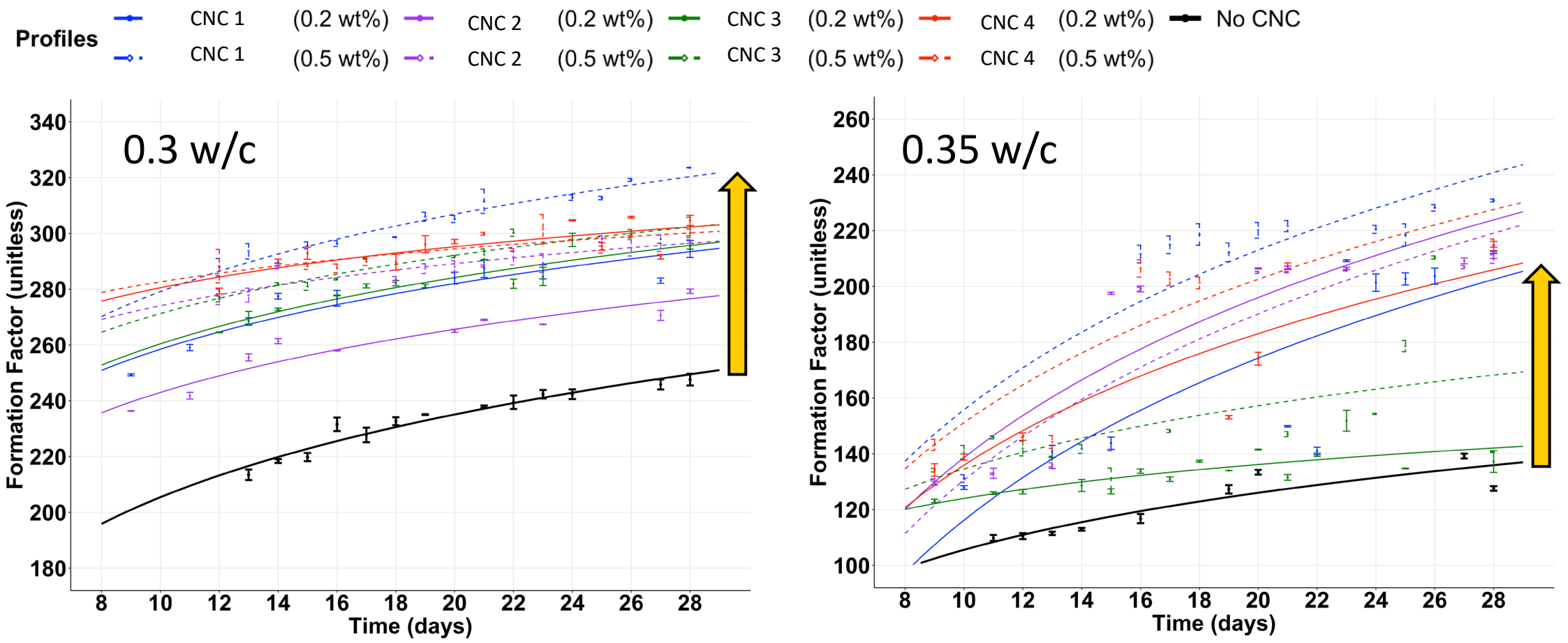
- A property used to describe concrete durability by quantifying transport of porous materials
- A higher formation factor *indicates* slower ions movement, lower porosity and/or porosity tortuosity

- Measured by resistivity

$$FF = \frac{\sigma_0}{\sigma_{eff}} = \frac{\rho_{eff}}{\rho_0} = \frac{1}{\phi\beta}$$

ϕ : system porosity
β : porosity connectivity (tortuosity)

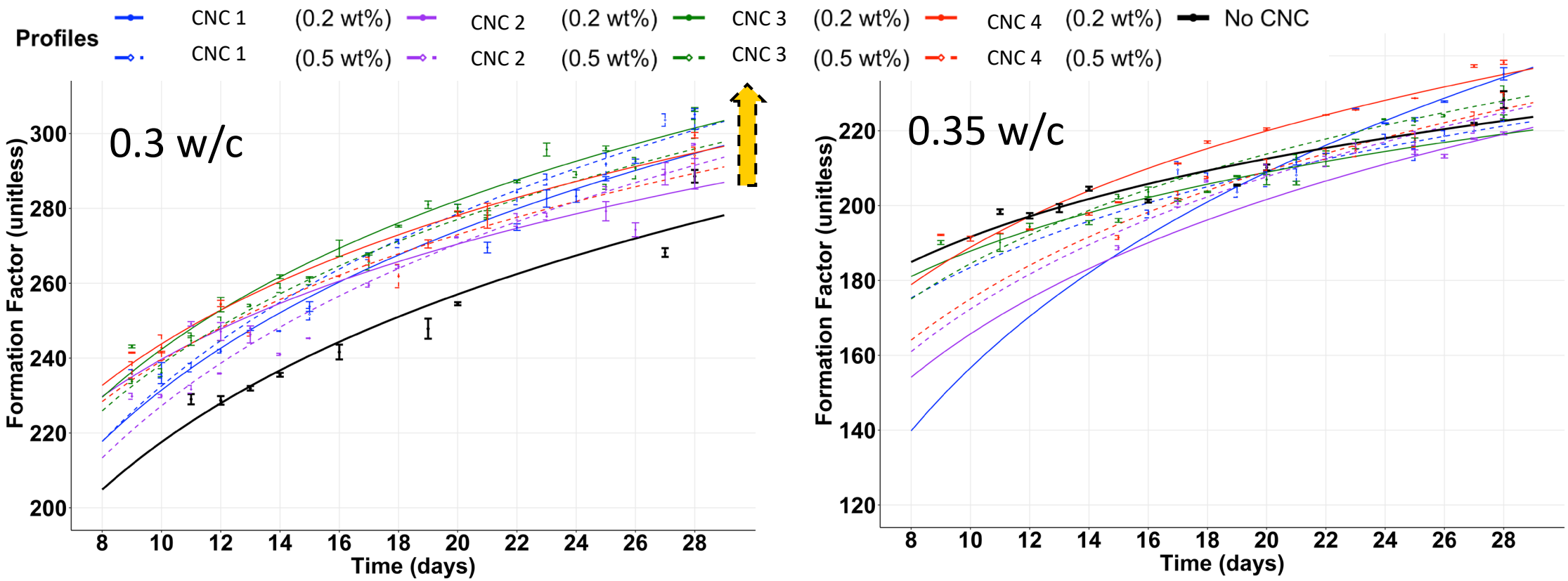
As with DOH and strength FF increases with CNC addition to Type V cement



Increase

Increase

As before improvement reduced in Type I/II



Slight increase

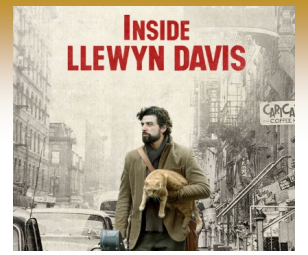
No change

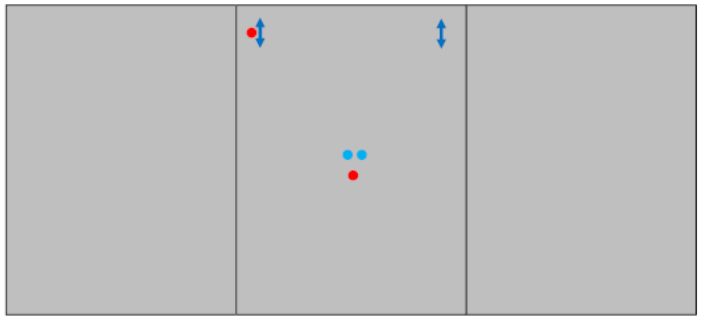
Improvement disappears as w/c increases

CNC Park: Bigger, Longer & Unrut

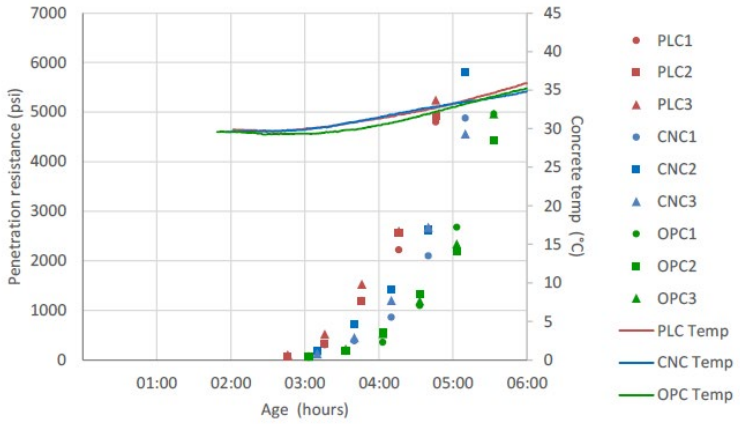
- A CNC-concrete parking lot was poured at the US Endowment in Greenville, South Carolina
- 60 cubic yards of CNC concrete were poured at 0.2% dosage (and 10 yards of standard concrete
- What we learned during the pour:
  - The CNC concrete behaved as well as standard concrete during placement
  - No apparent adverse effects when using heated water for batching CNC concrete
  - No apparent adverse effects on CNC concrete placement due to the cold weather

Sidewalk Inside UC-Davis – but it was sensored

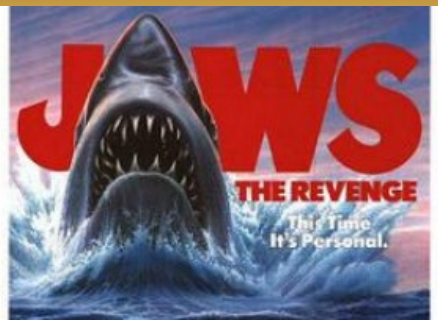




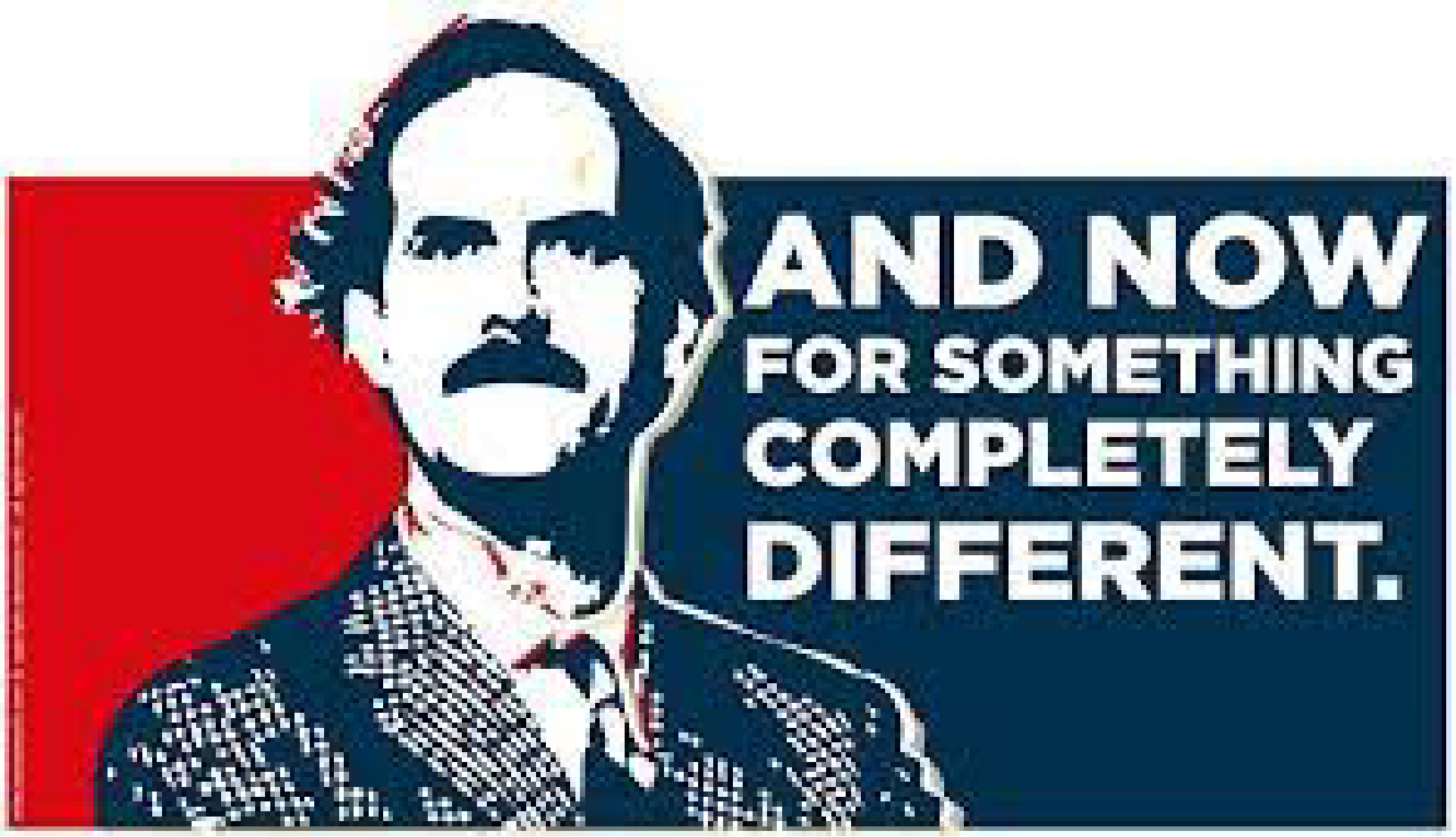
- Thermocouples rod; five depths: 0.2 in. / 0.8 in. / 2 in. / 4 in. (slab bottom) / 6 in. (lean concrete base)
- RH sensor (0.8 in. Depth)
- VWSGs; two depths: 0.8 in. / 3.2 in. (0.8 in. above slab bottom)



Concrete: The Revenge - this time it's structural!



- CNC-cement enabled bridge was precast at Knife River (Oregon) and placed in Siskiyou Co, CA USA
- Driven over every (most?) days


AND NOW
FOR SOMETHING
COMPLETELY
DIFFERENT.

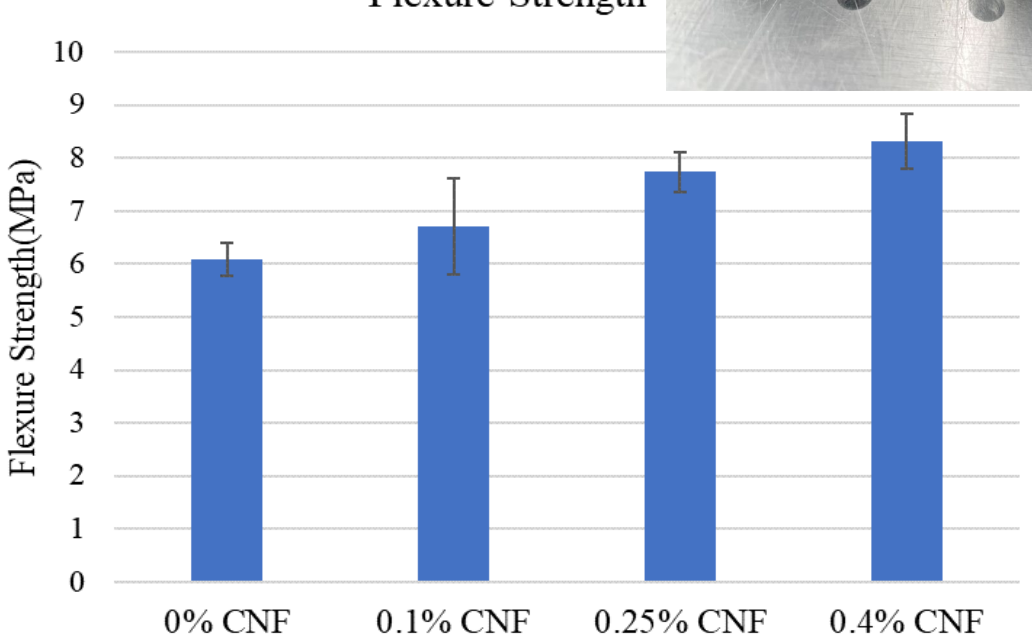
Additive Manufacturing of Cement, Mortar and Concrete.

Purdue Concrete 3D Printing

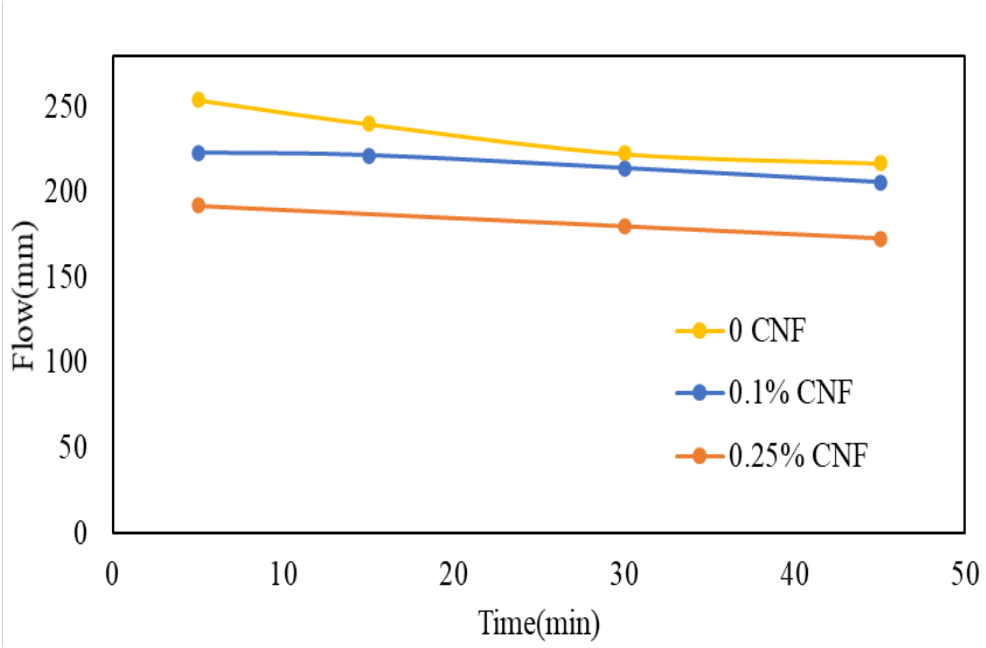
Prof. Jan Olek,
Prof. Pablo Zavattieri,
Prof. Jeffrey Youngblood,
Prof. Christopher S Williams,

Could we combine the two?: CNM and AM of cement? Yes…Yes, we can!

- CNF can enhance the flexure strength by 30% at 7 days



- The results show that increasing CNF content will reduce flow and workability. (like adding VMA)
- Importantly, the material has a more consistent flow by adding CNF.



CNF has promise as alternative VMA for 3DCP

Summary

- CNC has a role to play in cement CO_2 reduction
  - CNC can reduce the clinker needed in OPC, thereby reducing CO_2
  - CNC can improve properties in low CO_2 binder like PLC and allow more clinker replacement to reduce CO_2 further
  - FF increases indicating an improvement in durability, so CNC likely makes cement last longer
- CNF can act as alternative VMA for concrete AM.
  - At same time improving flexural strength.

Funding

US Forest Service – FPL
National Science Foundation
P3Nano

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