Admixtures and Cements: Efficiency and Changes

National Concrete Consortium

April 2024

Agenda

- Performance Differences between Cements
  - Water demand
  - Bleeding
  - Temperature sensitivity
- Water demand control
  - Water Reducers: choice and efficiency
- Set time control
  - Accelerators and retarders efficiency
- Other admixtures
- Conclusions

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Introduction and Motivation

- Cement and cementitious materials producer → Produce SCMs and blended cements
- Concrete producer → Purchase and use SCMs and blended cements
- Concrete admixture and grinding aid producer → Solve challenges with SCMs and blended cements

We have the most ambitious goals in the industry.

2030 Goals

- To be below 475kg of CO_2 per ton of cementitious material, equivalent to a **40% reduction.***
- To reduce the carbon content per cubic meter of concrete by 165kg, equivalent to a **35% reduction.***
- To reach 55% in clean energy consumption for a 43% reduction of indirect emissions.**

*According to our 1990 baseline.
**According to our 2020 baseline.

Global Alignment and Validation

- Our 2023 goals are aligned with the Science Based Targets Initiative (SBTi) commitments made by Cemex under the Well Below 2°C Scenario.
- Our 2050 goal aligns with the Business Ambition for 1.5°C.
- We have joined the Race to Zero campaign from the United Nations.

SCIENCE BASED TARGETS
DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

BUSINESS AMBITION FOR 1.5°C

RACE TO ZERO

New(ish) Admixture Technologies

- **Colloidal silicas and nanoparticles**
  - **Benefit**: Decrease permeability
  - **Materials**: Integral and surface applied
  - ASTM subcommittees developing standards for integral and surface applied applications
- **Alkali activated cementitious materials**
  - **Materials**: Highly alkaline activators / admixtures (1 to 4%) with ash, other pozzolans, and/or slag cement: little to no portland cement clinker : ASTM C1948
    - » These are systems: specific alkali activators and dosages with specific cementitious material combination
  - **How**: Reaction product is forming between the Al-Si and the alkalis
- **Carbon sequestration technologies**
  - **Benefit**: encapsulate carbon, big differences
  - **Materials**: Carbonating cements (ASTM C1905), biochar, CO2 rich SCMs, liquid CO2 injection, …

New(ish) Admixture Technologies

Integral cracking mitigation

- **Plastic shrinkage reduction**
  - **Material type:** Manufactured polymers and gums
  - **Benefits**: Integral evaporation retarders to prevent evaporation
- **Internal curing agents**
  - **Material types**: Super absorbent polymers (SAP) and lightweight aggregate
  - **Primarily benefit**: Autogenous / chemical shrinkage for lower w/cm mixtures
  - **Secondarily benefit**: drying shrinkage reduction and some SAPs can also mitigate plastic shrinkage
  - **Mechanism**: Provide a reservoir of water released at the right time
- **Drying shrinkage reduction**
  - **Shrinkage reducing admixtures**: reduce surface tension of water in the concrete reducing internal stresses when water leaves, up to 50% reduction, ASTM standard in development
  - **Shrinkage compensating additives**: form expansive compounds that offset shrinkage, 100% shrinkage reduction

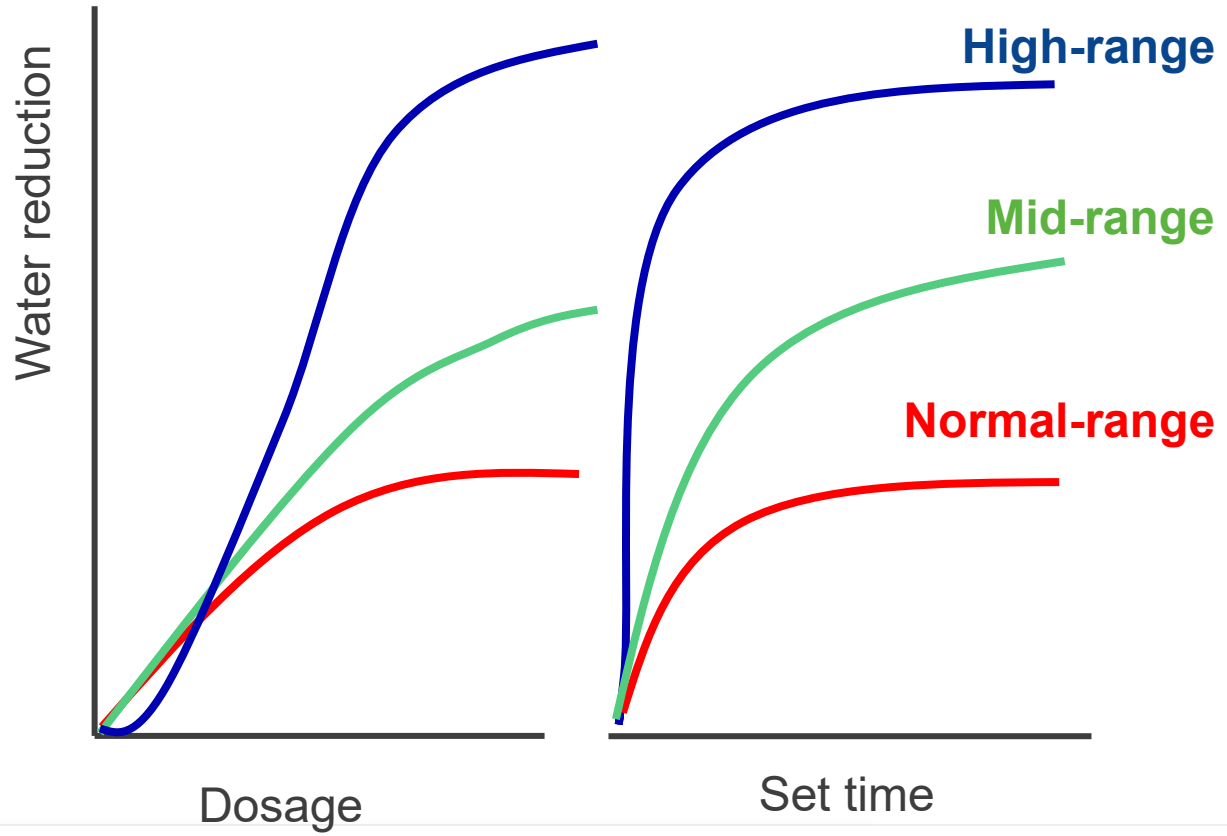
New(ish) Admixture Technologies

- **Rheology modifying admixtures**
  - **Benefit**: Improve pumpability or extrusion without increasing slump
  - **Materials**: Polymers and gums,
    - » many viscosity modifying admixtures (VMAs) fall into this category, but not as high of dose as in SCC
- **Strength enhancing admixtures**
  - **Benefit**: Increase strength without changing other parameters of mixture design or maintain strength with cementitious reduction
  - **Materials:** Amines, nucleation particles, and others that increase reactivity of cement phases,
    - » Effectiveness and age of strength increase are dependent on product and cement
- **Water reducers**
  - **Benefits:** Increased water reduction / retardation ratio
    - » Normal-range to mid-range to high-range
  - **Materials**: Customized for new cementitious and aggregates sources
    - » Blended cements (Type IL, IP, IS, IT), natural pozzolans, calcined clays, dirty aggregate, …

New(ish) Admixture Technologies

Water Reducers

- **Most popular admixture in terms of volume, $$$, and frequency**
- **Most variations available**
  - 100's of different water reducers available,
    - » 260 unique products NTPEP Datamine today
  - 10's of choices from each supplier
  - More added all the time
- **Differences between products**
  - Water reduction / workability
  - Setting time impact
  - Performance with specific or types of materials (cementitious, aggregates)
  - Robustness
  - Slump life
  - Early strength
  - Air content
  - Cost
  - Mixture design
  - Rheology (stickiness / finishability / pumpability)



New(ish) Admixture Technologies

Water Reducers

- Performance with specific or types of materials (cementitious, aggregates)
  - Higher water demand with some blended cements
  - Fly ash general has 3 to 5% water reduction vs portland cement
  - Natural pozzolans neutral to higher water demand vs. portland cement
  - New SCMs types: neutral, higher or lower water demand?
- More SCM use →

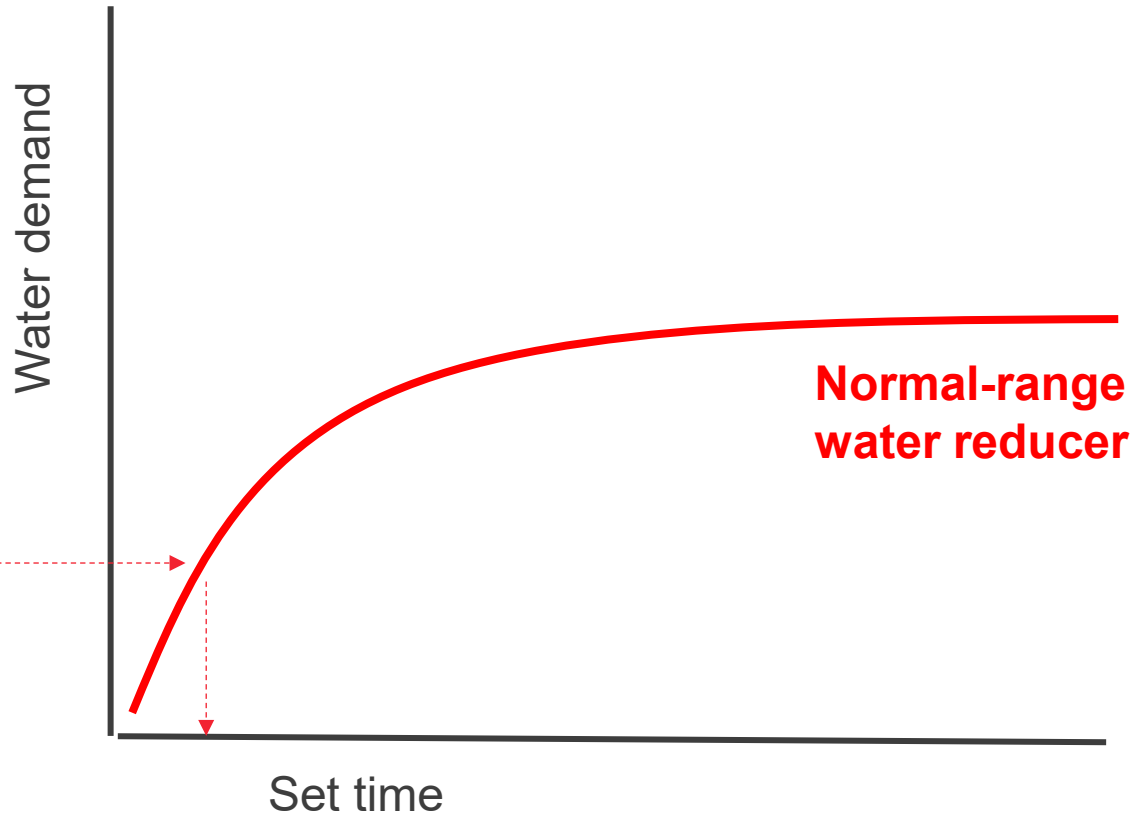
  Lower earlier strength →

  Lower water content in concrete →

  Lower workability and maintain strength →

  Use more water reducer or more efficient water reducer

Example: increase in water demand



New(ish) Admixture Technologies

Water Reducers

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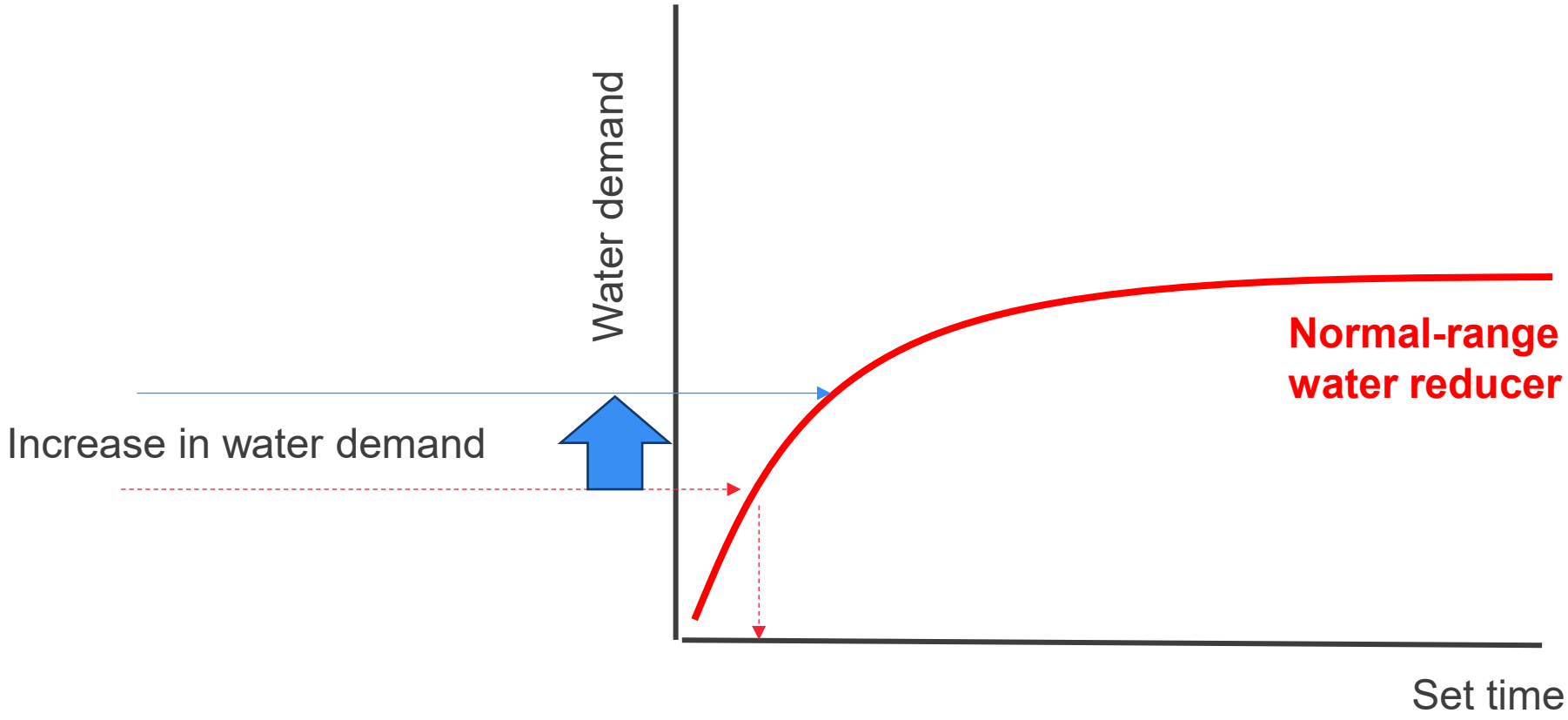

New(ish) Admixture Technologies

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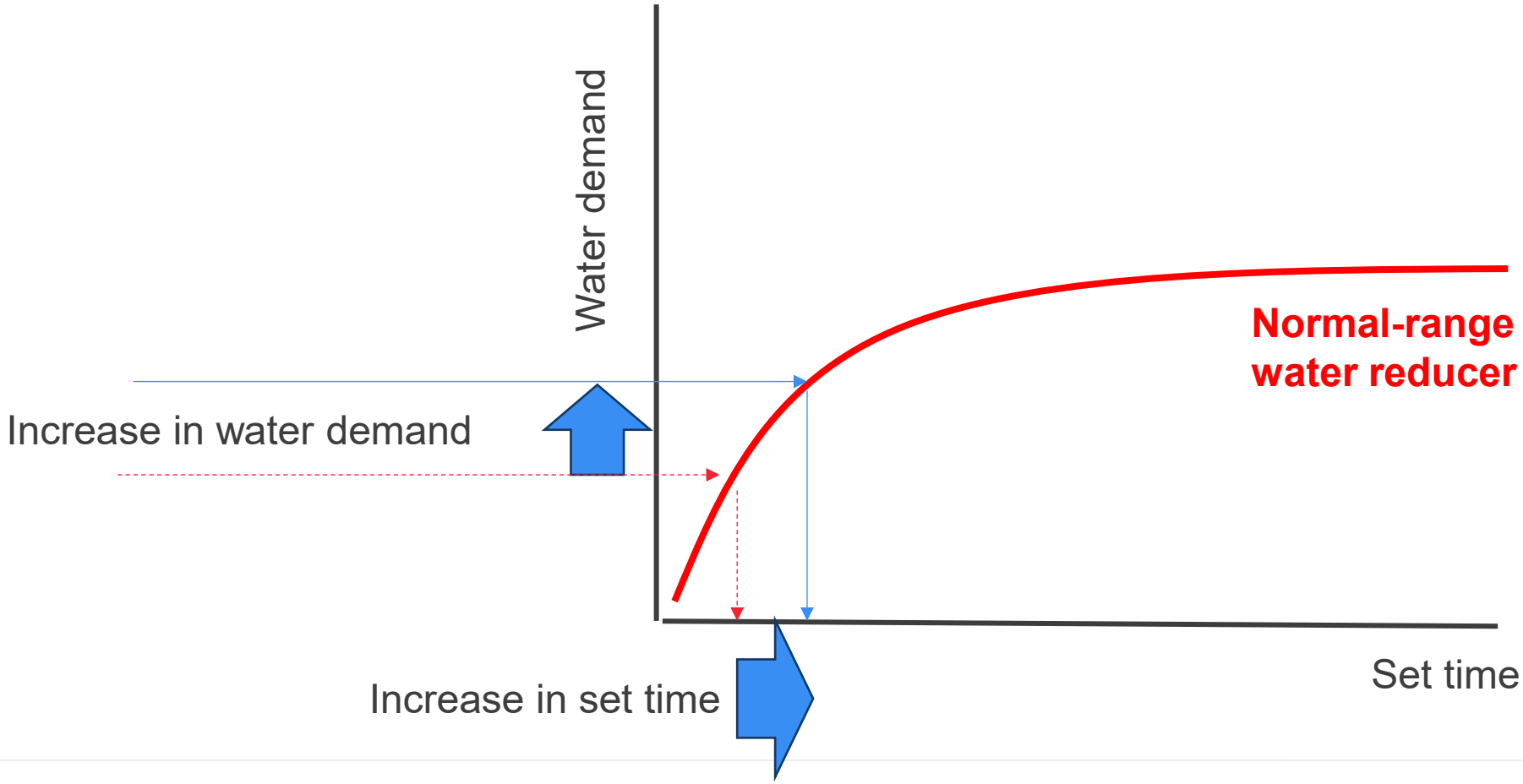

New(ish) Admixture Technologies

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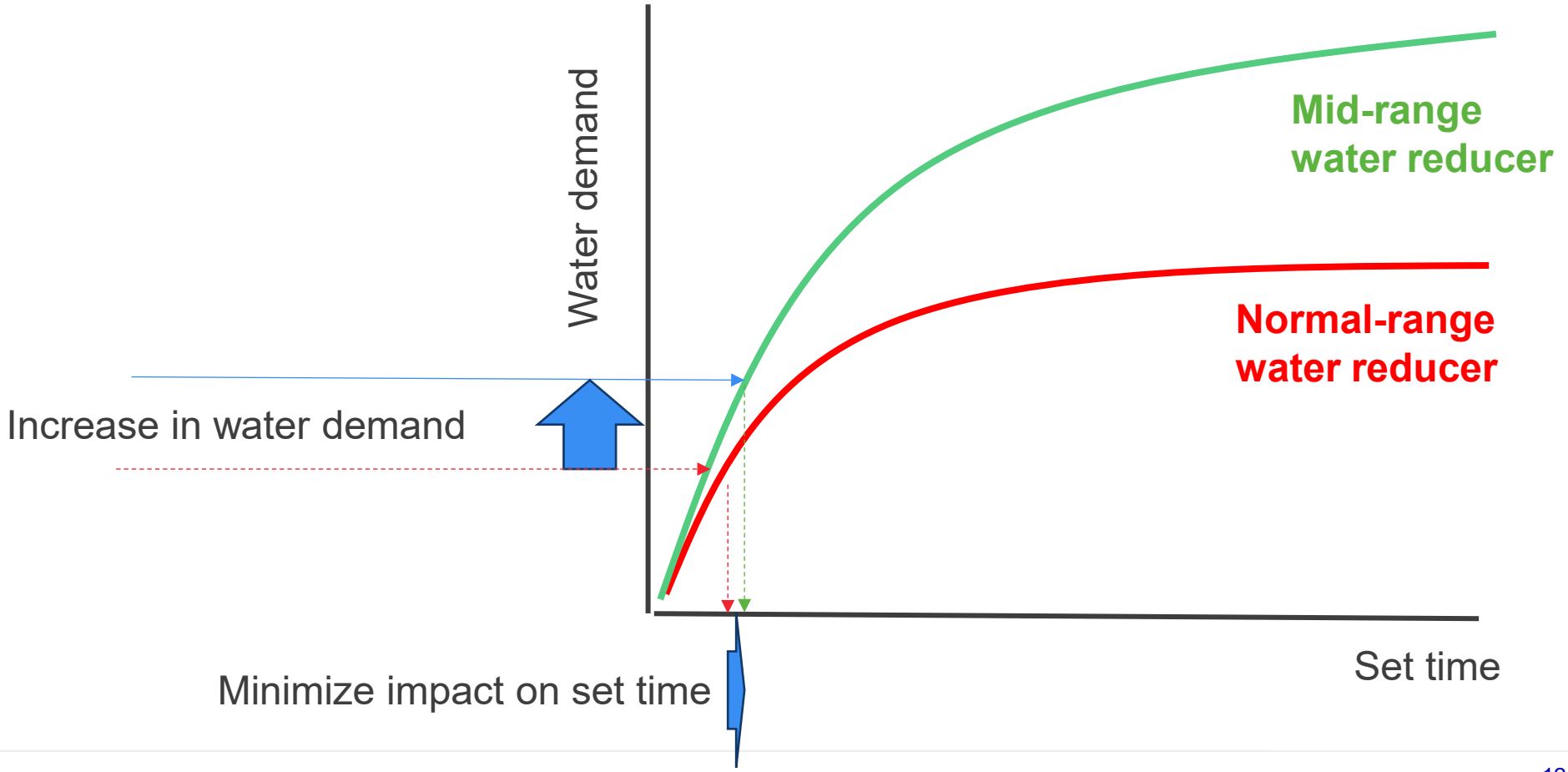


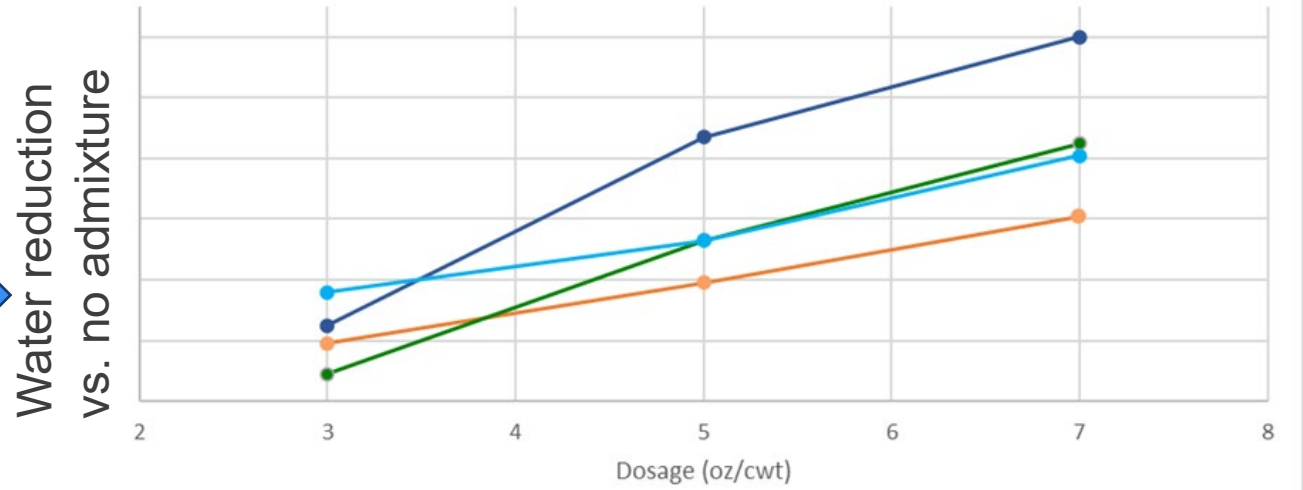
New(ish) Admixture Technologies

Water reducers

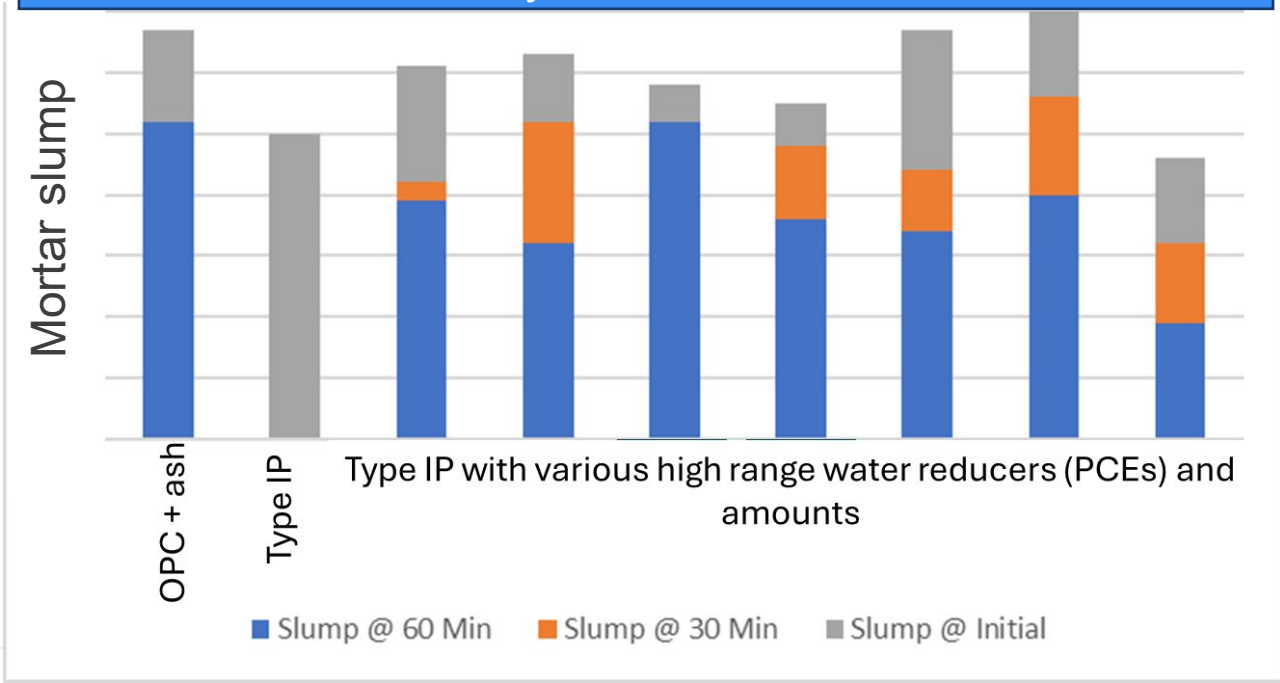
Not just single dosage

Not just initial slump

Various cementitious systems with same water reducer

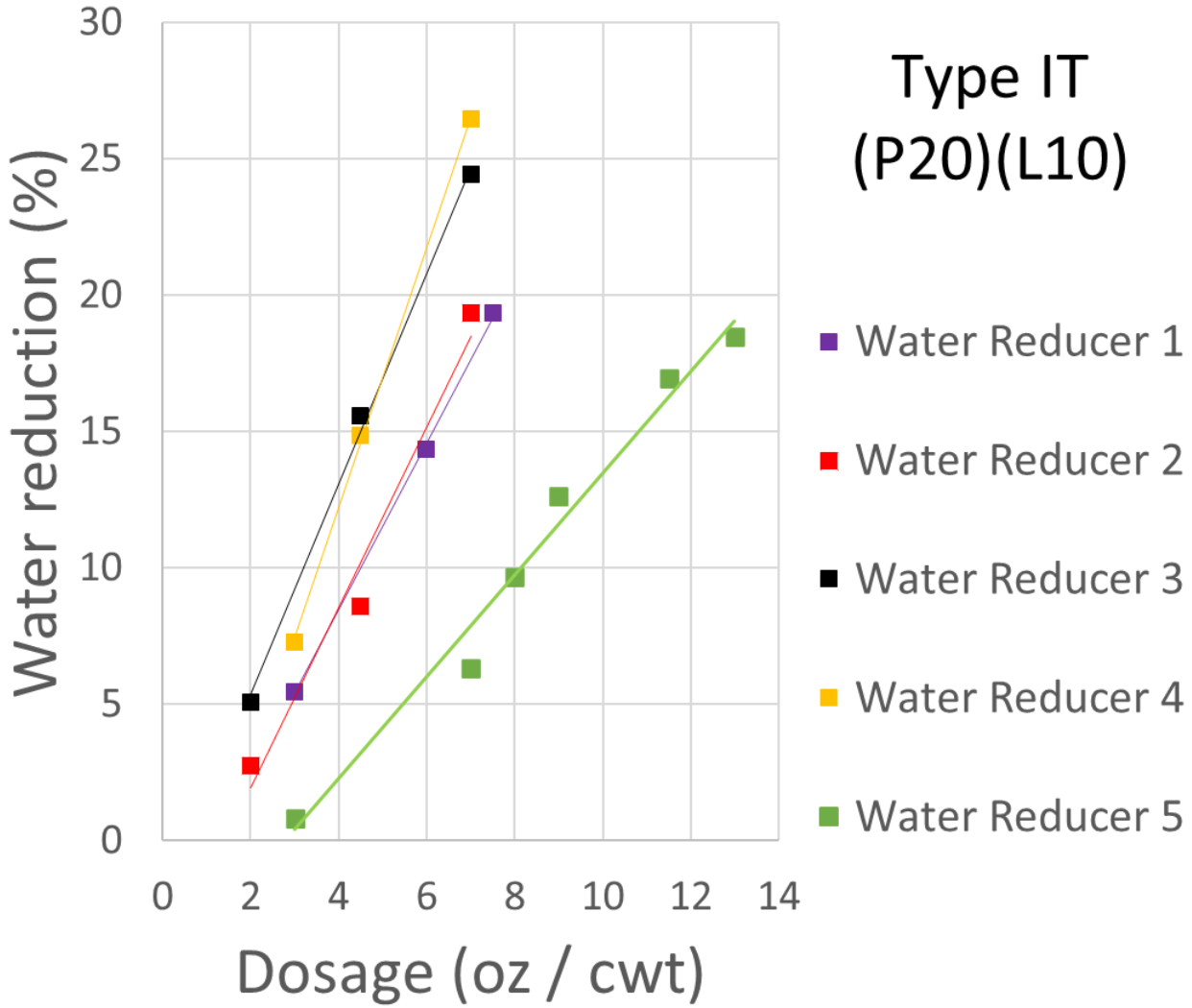


Various admixture systems with same cementitious



New(ish) Admixture Technologies

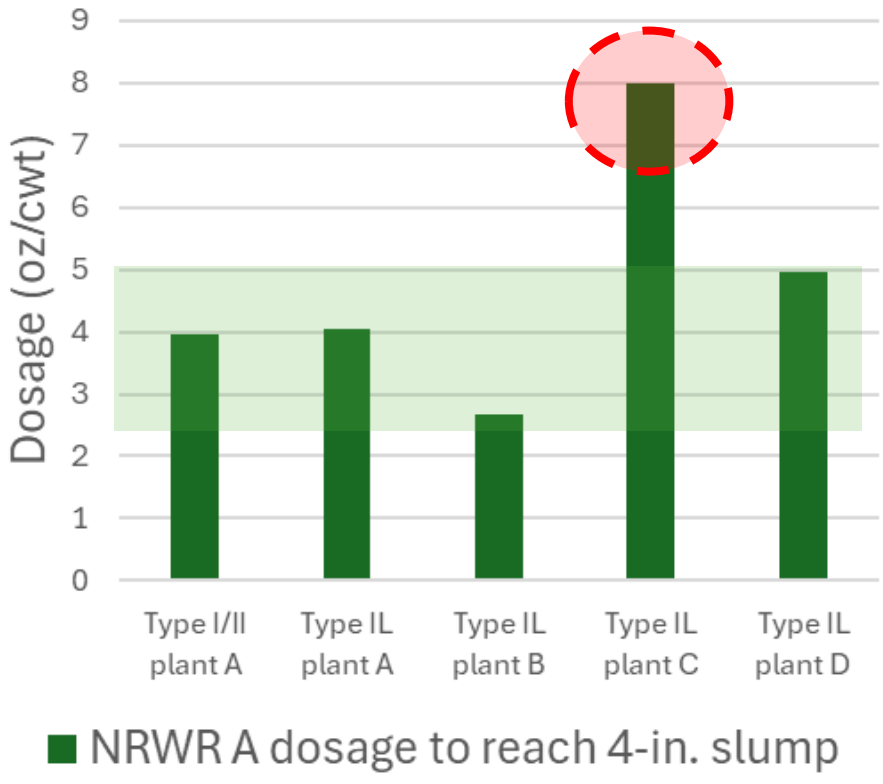
Water reducers

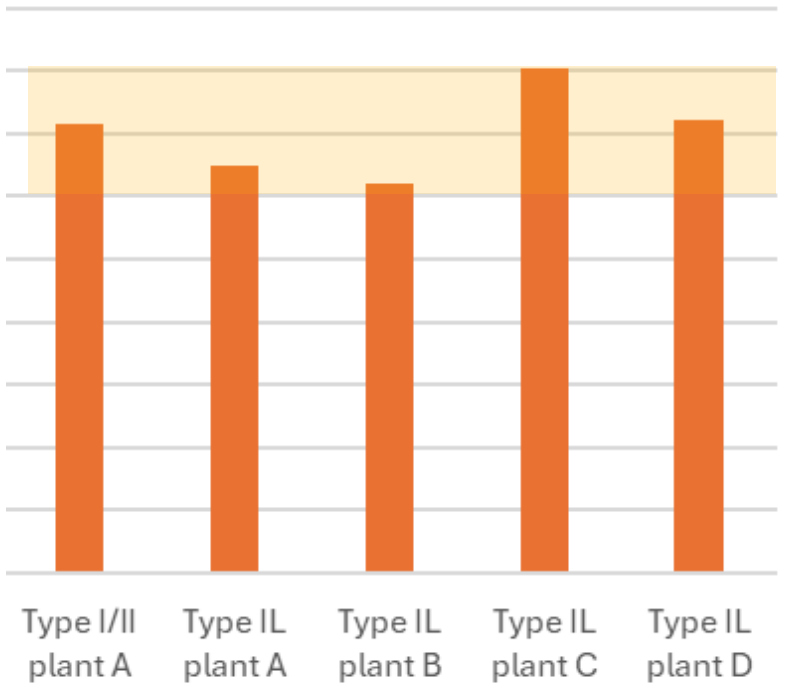


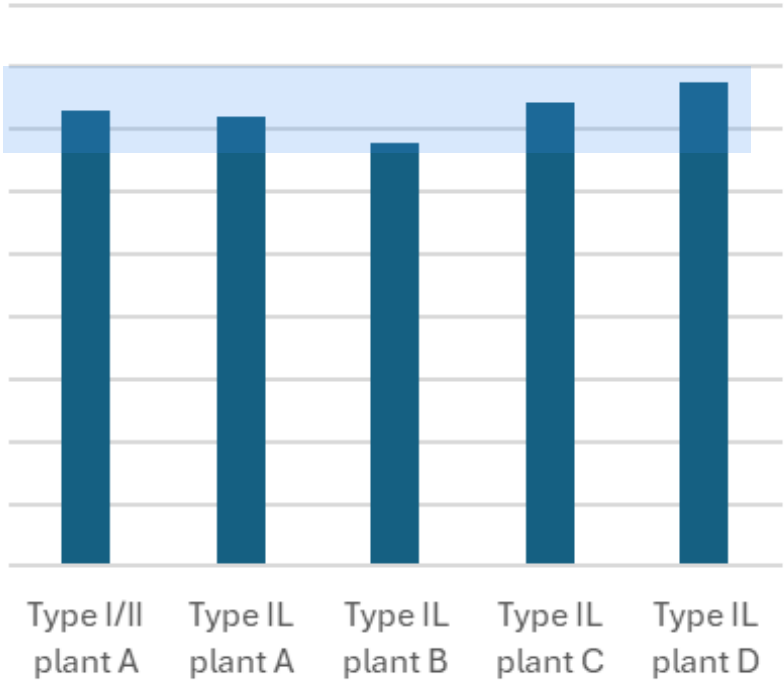
New(ish) Admixture Technologies

Water reducers

- Demand for water or water reducers can change when changing cement sources
  - Applies to portland cements and Type IL/PLC
- Example data notes: Same NRWR, MRWR, and HRWR used with all cements, 25% C ash by mass, slump is at 30 minutes, 73 °F lab temperature, fixed water contents during testing,







Admixture – Cement Interaction Impact on Setting Time

Challenge

- Rule of thumb are helpful but limiting…
  - More accelerator faster setting and more hydration stabilizer slow setting
- Exact level of impact on setting time is dependent on many things besides just accelerator and hydration stabilizer
  - Cement, admixture-cement interaction, other admixtures, concrete and environment temperature, mixture design (water content in concrete, cement content, admixture dosages, …), …
- I don’t have an infinite amount of time and resources to develop the data

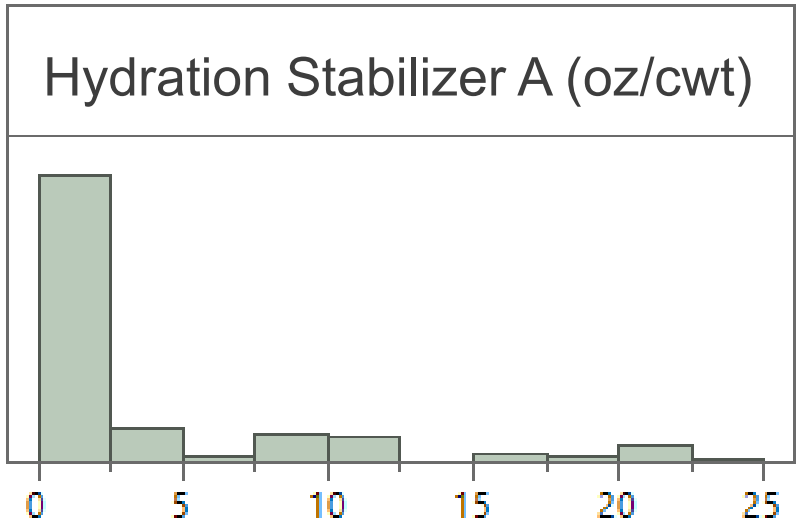
Solution

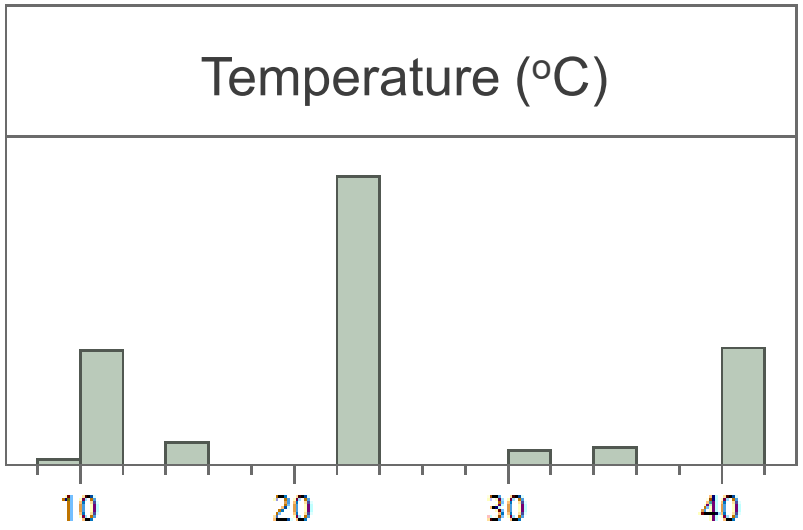
- To quantify impact of:
  - Interaction of cement x accelerator
  - Interaction of cement x hydration stabilizer
- Must also quantify impacts of:
  - Different cement
  - Interaction of accelerator, hydration stabilizer, and cement x temperature Accelerator dosage
  - Accelerator and hydration stabilizer dosage
  - Non-linear dosage response of admixtures
  - Water reducers (dosage, product/brand)
  - Normal temperature ranges
- While assuming constant water content, aggregate, and cement content
- Use isothermal calorimetry (reproducible, low effort per test, temperature control) + statistical analysis

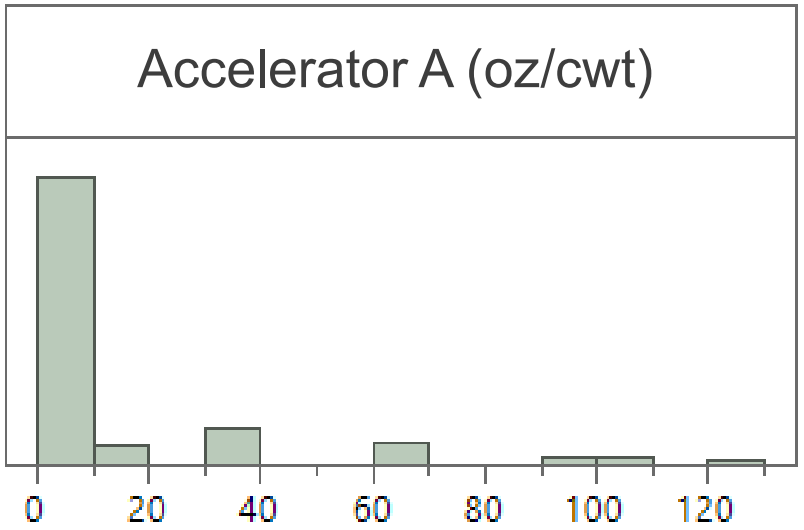
Admixture – Cement Interaction Impact on Setting Time

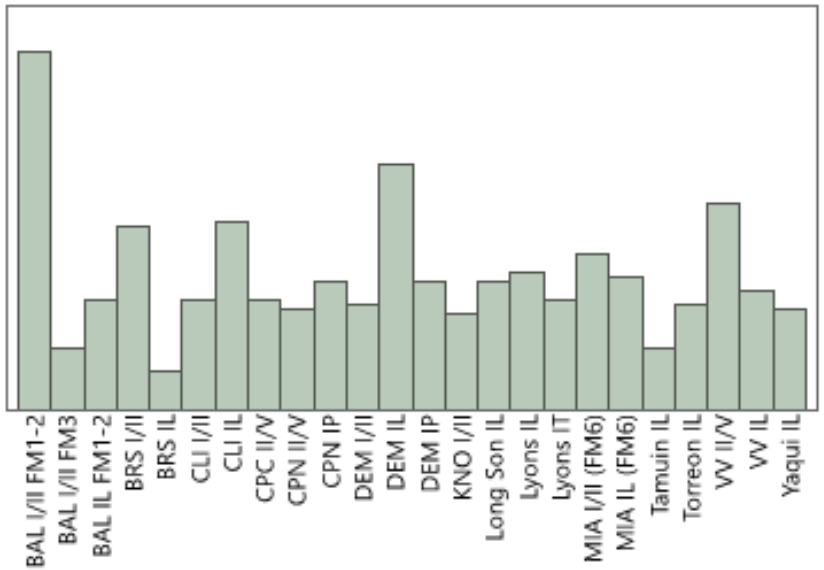
Variables

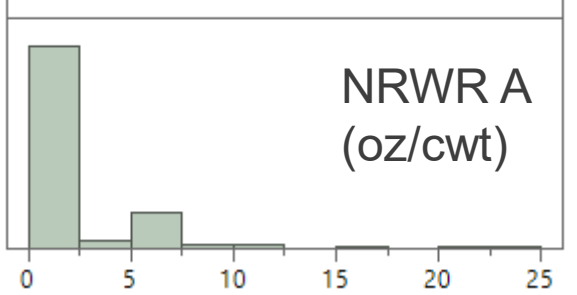
>650 test results

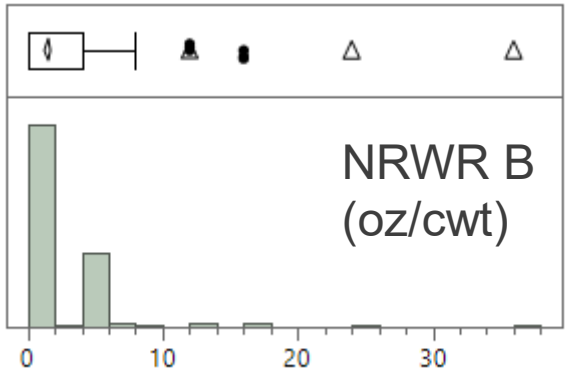


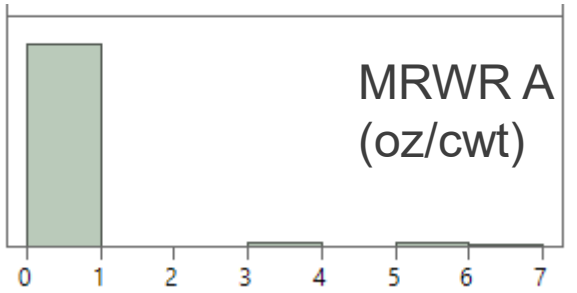


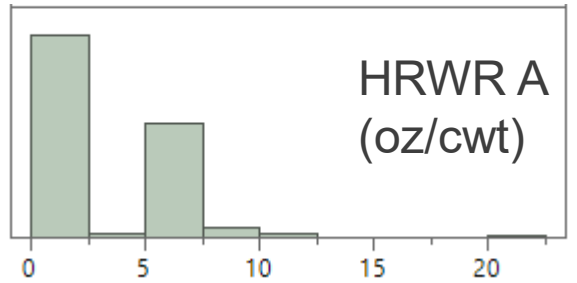








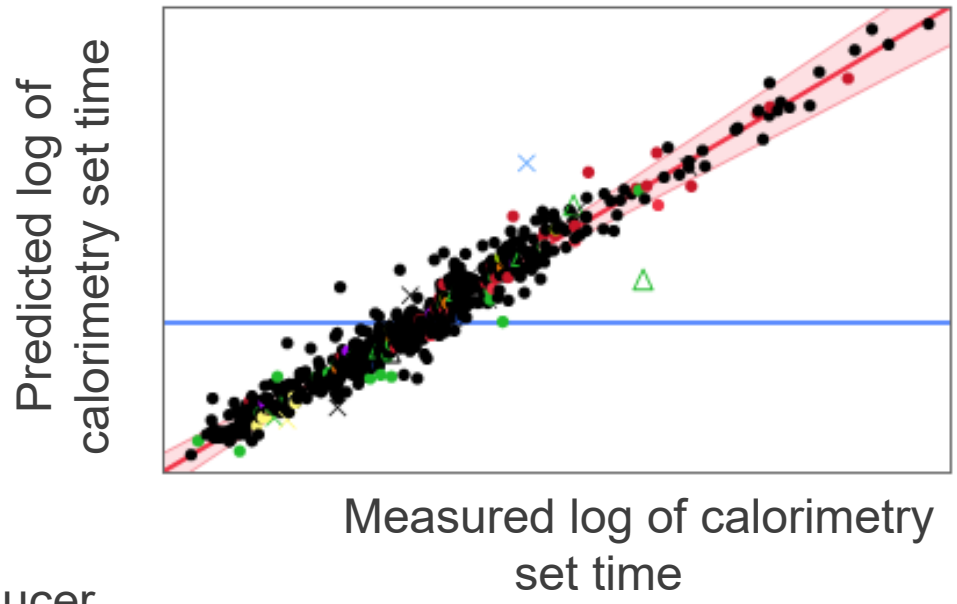




Admixture – Cement Interaction Impact on Setting Time

Model parameters

- Hydration stabilizer
  - Dosage x Interaction with cement → efficiency with CM
  - Dosage ^2 → over-dosing response
  - Interaction with temperature → efficiency at different temperatures
- Accelerator
  - Dosage x Interaction with cement → efficiency with CM
  - Dosage ^2 → max dosage
  - Interaction with temperature → efficiency at different temperatures
- Cement
  - Source and type → direct impact
  - Interaction with temperature → temperature sensitivity



- Water reducer
  - Brand → chemistry impact
  - Dosage → dosage efficiency
  - Dosage^2 → over-dosing response
- Limitations / constraints
  - Constant w/cm,
  - No SCMs built into model
    - Majority of setting is driven by hydraulic cement
    - Limitations of testing

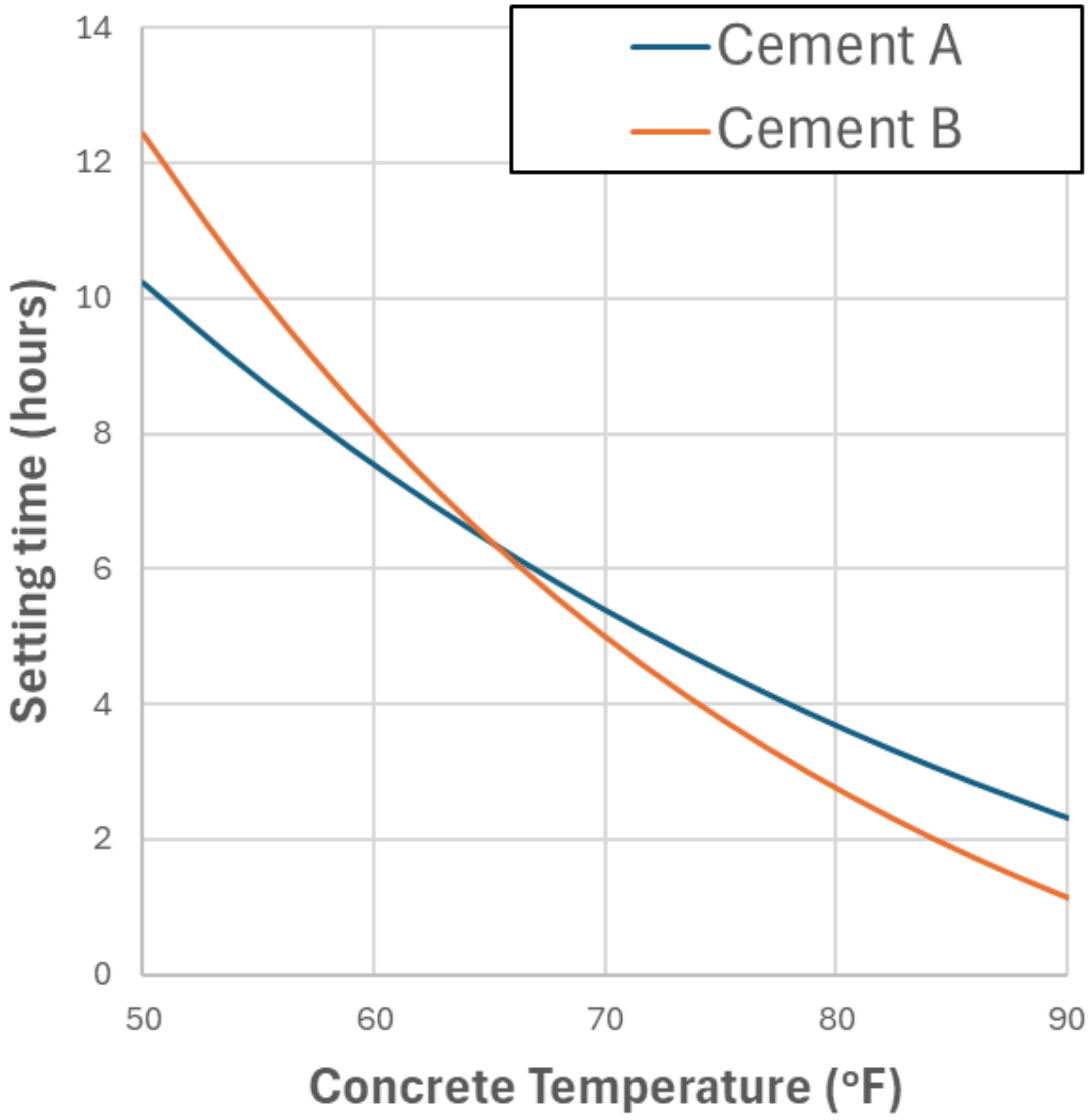
Admixture – Cement Interaction Impact on Setting Time

What is the primary factor impacting setting time on a day-to-day basis?

Admixture – Cement Interaction Impact on Setting Time

Temperature Sensitivity

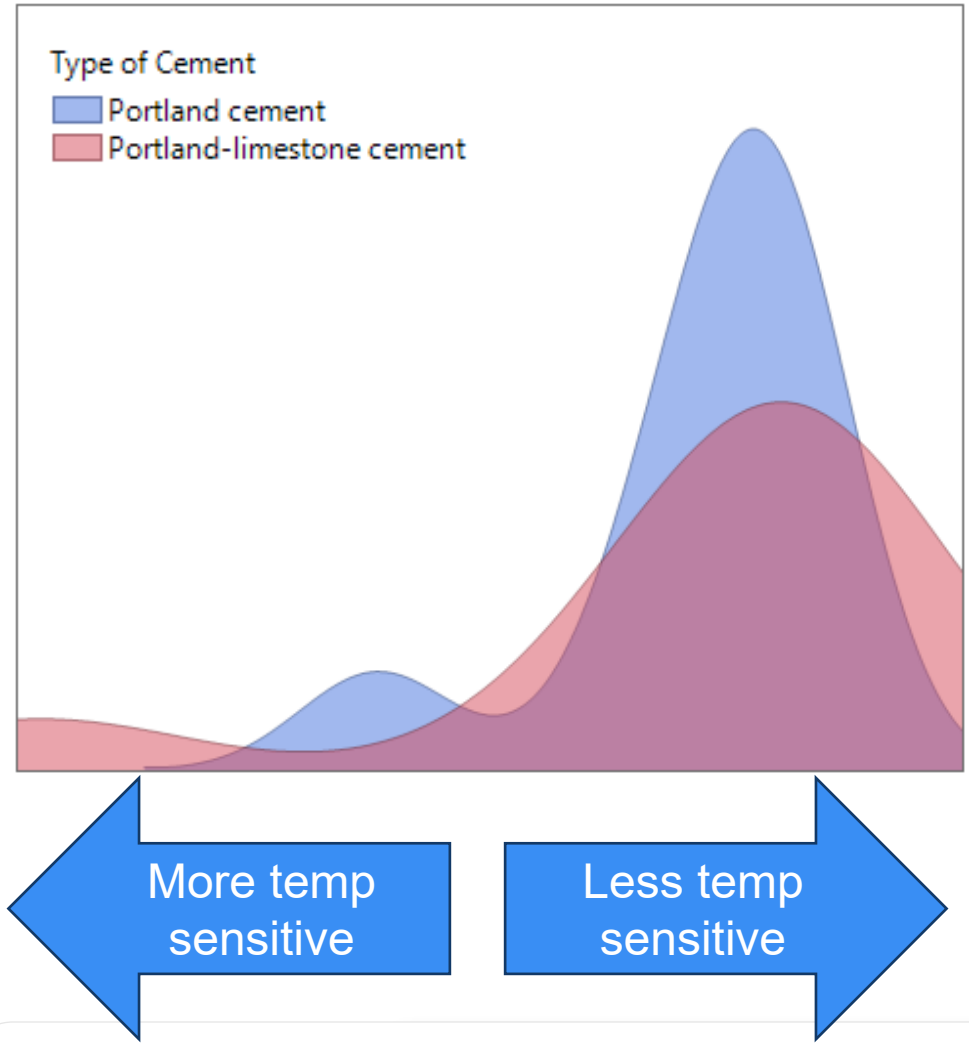
i.e. Cement B is more temperature sensitive than Cement A



Admixture – Cement Interaction Impact on Setting Time

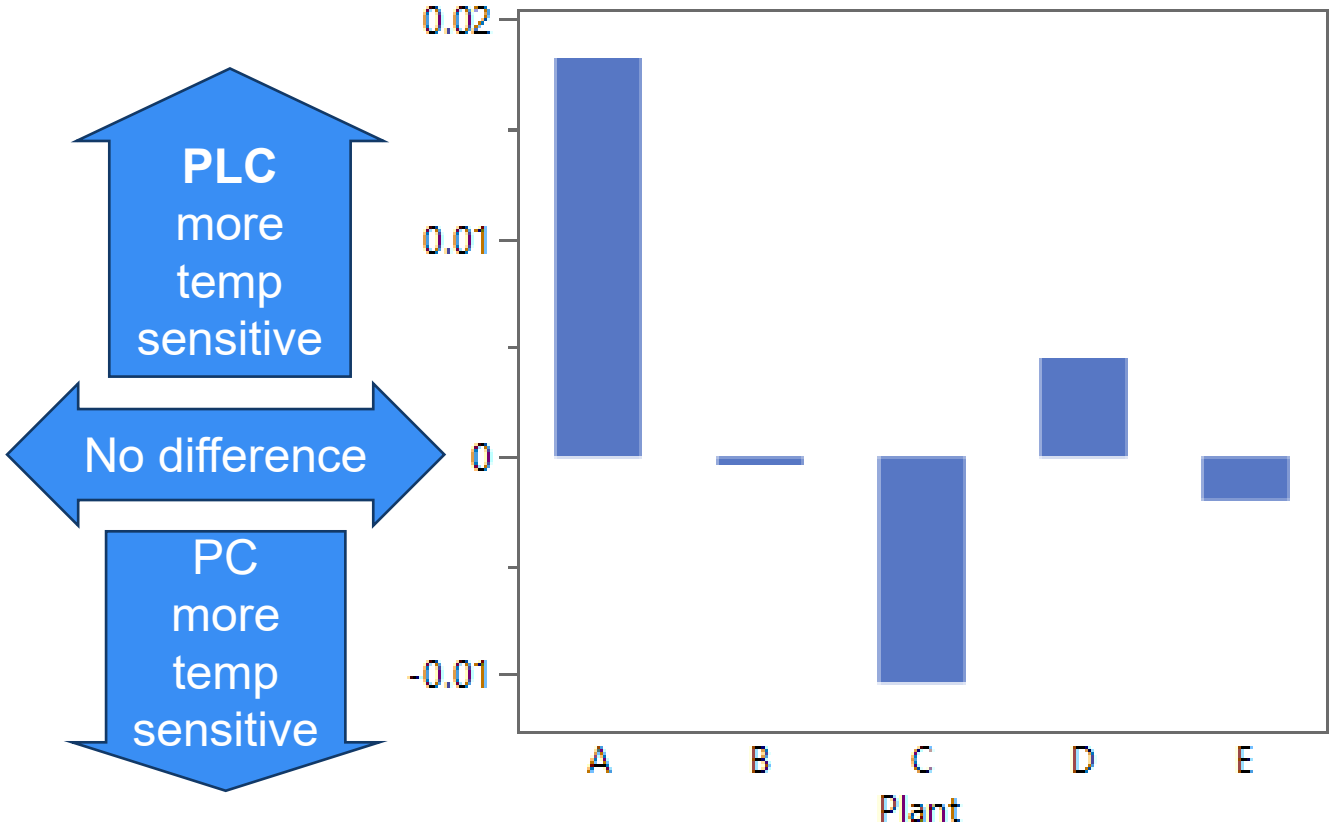
Temperature Sensitivity: Portland cement (PC) vs Portland Limestone Cement (PLC)

9 different PLCs and 9 different OPCs



5 cement plants with both PC and PLC production

- Matched pair analysis: No statistically significant differences between PLCs and PCs
- Sometimes they are the same, sometimes PLC is more sensitive

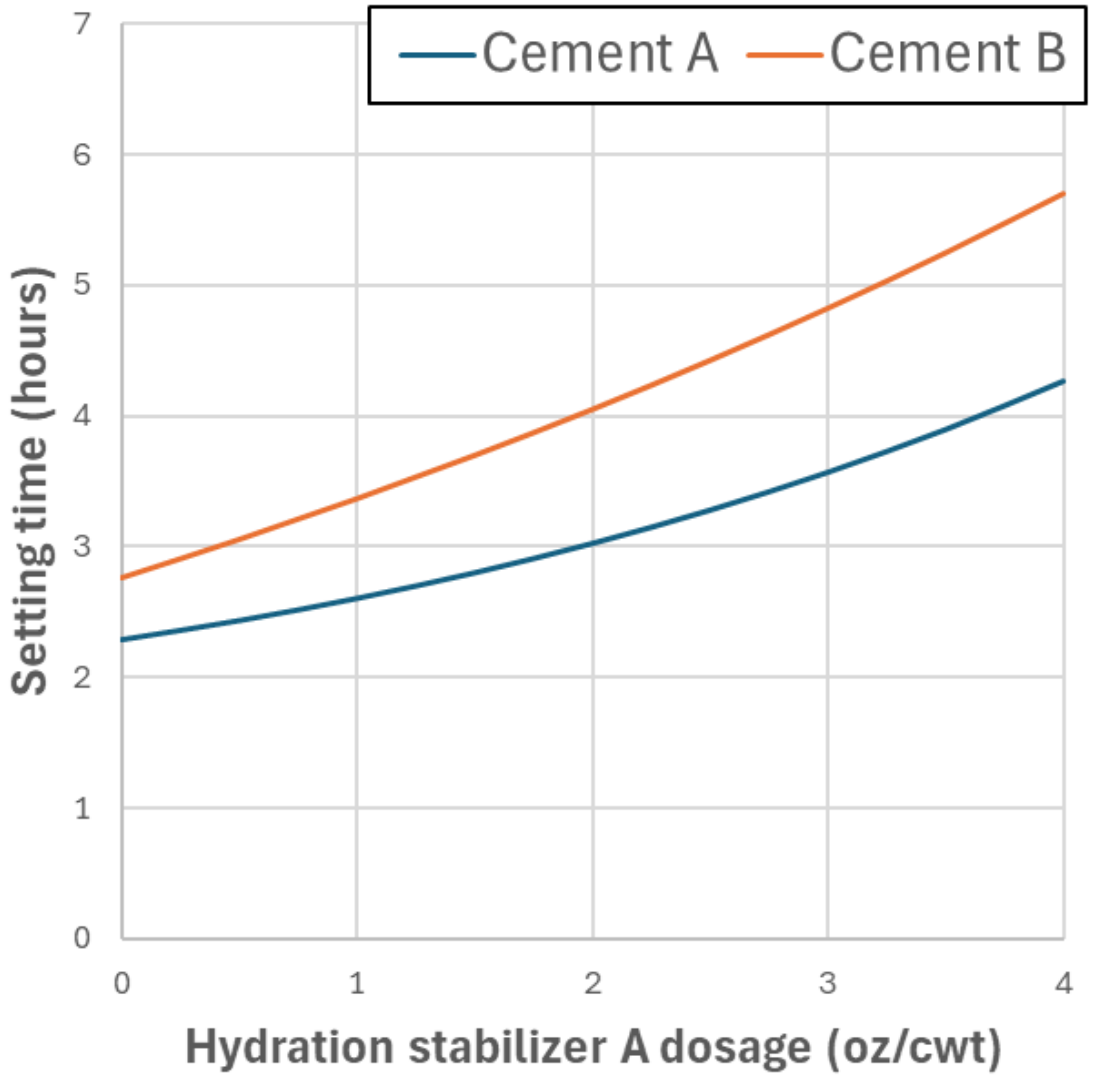


Admixture – Cement Interaction Impact on Setting Time

Hydration stabilzier effectiveness

- Cement A is slower setting (i.e. offset of lines)
- Cement A is less responsive to the hydration stabilizer (i.e. slope of the line)

- For example: When switching from Cement B to Cement A
  - Cement A is slow setting → hydration stabilizer may not be needed
  - The dosage of hydration stabilizer to get longer setting time will be different
    - » Cement A: 1 hr more of setting time needs about 1.5 oz/cwt
    - » Cement B: 1 hr more of seting time needs about 2.5 oz/cwt



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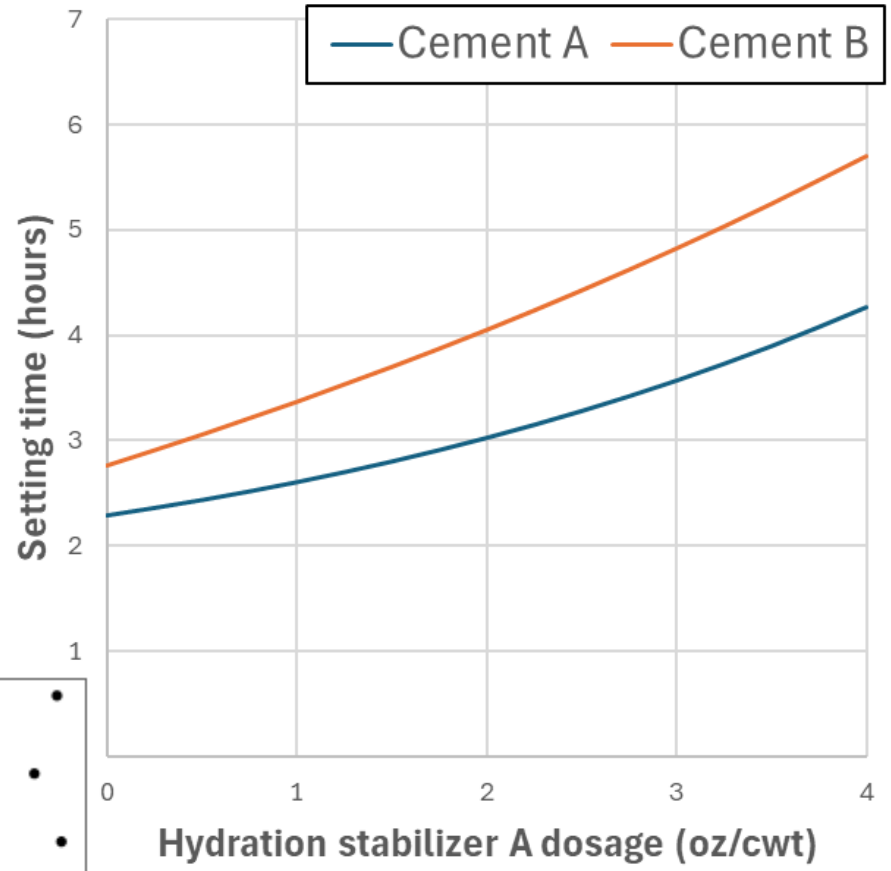

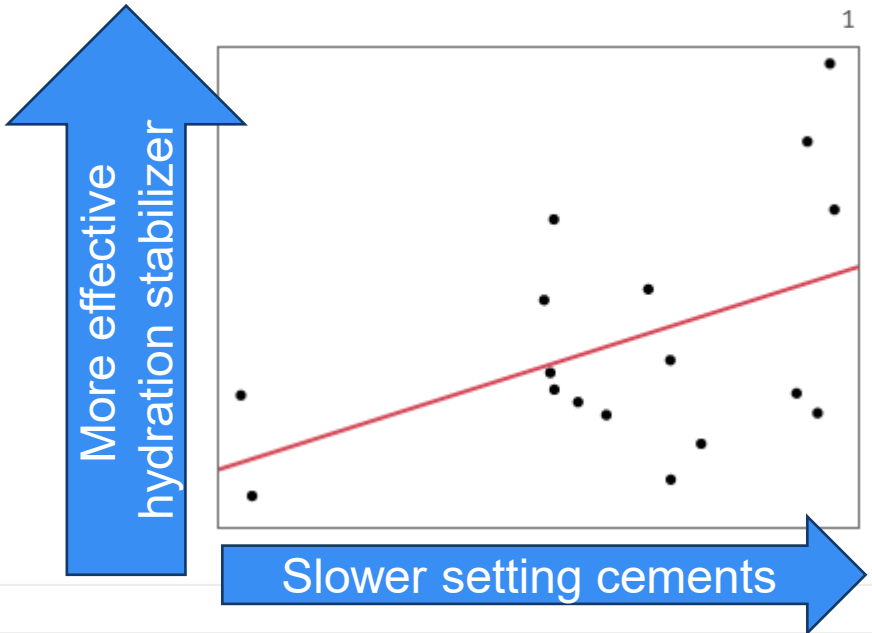

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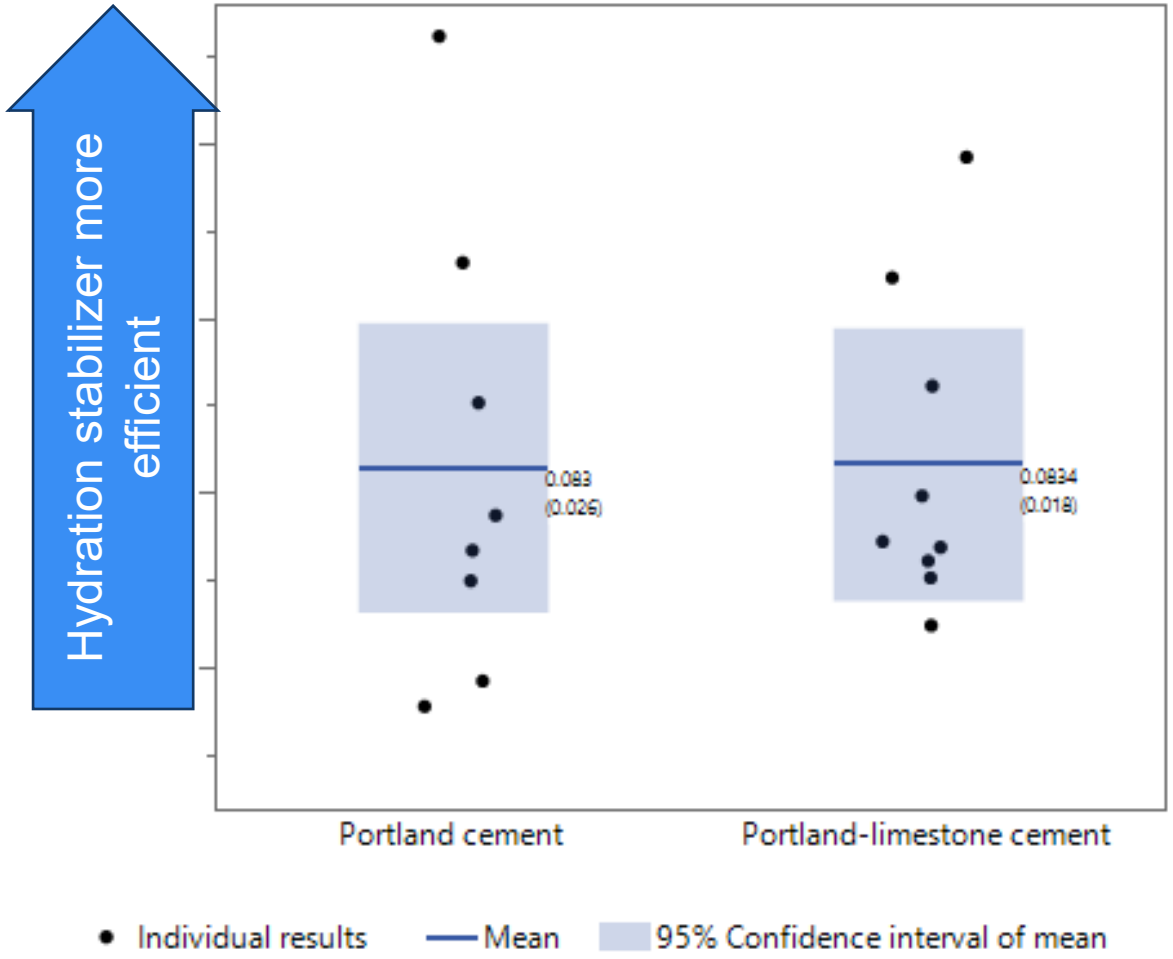

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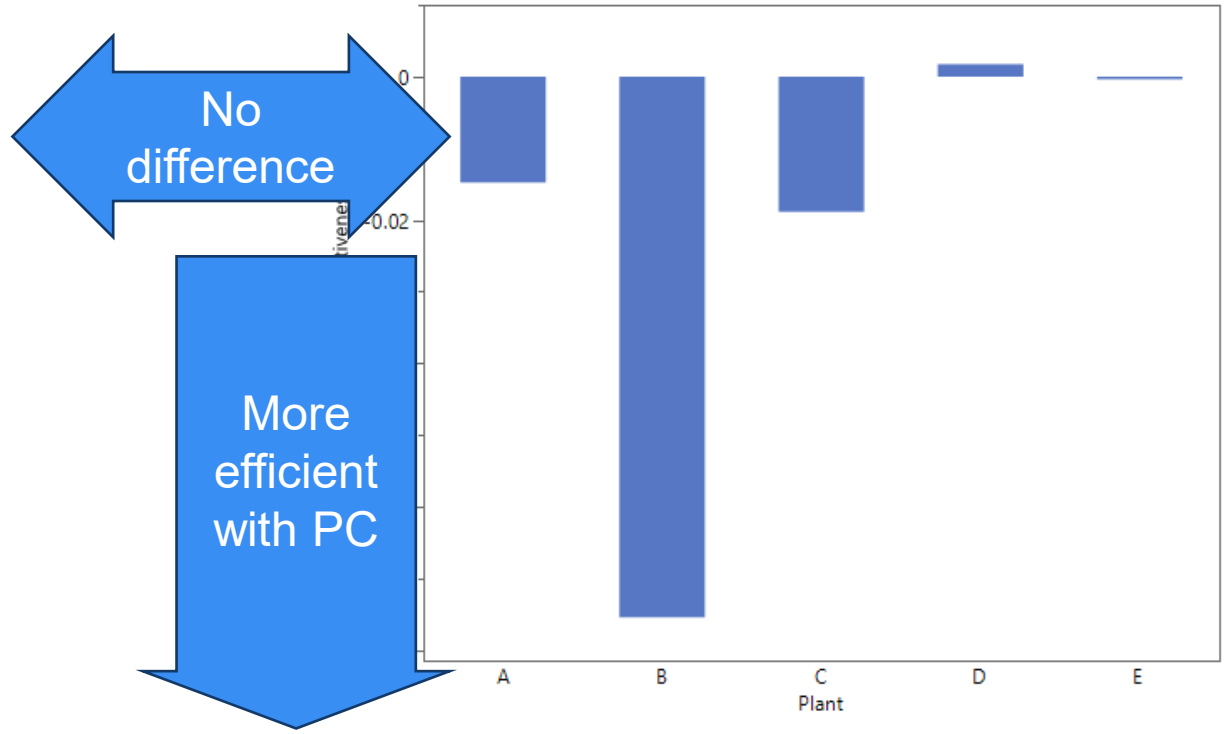

Admixture – Cement Interaction Impact on Setting Time

Accelerator effectiveness

- Cement A is slower setting (i.e. offset of lines)
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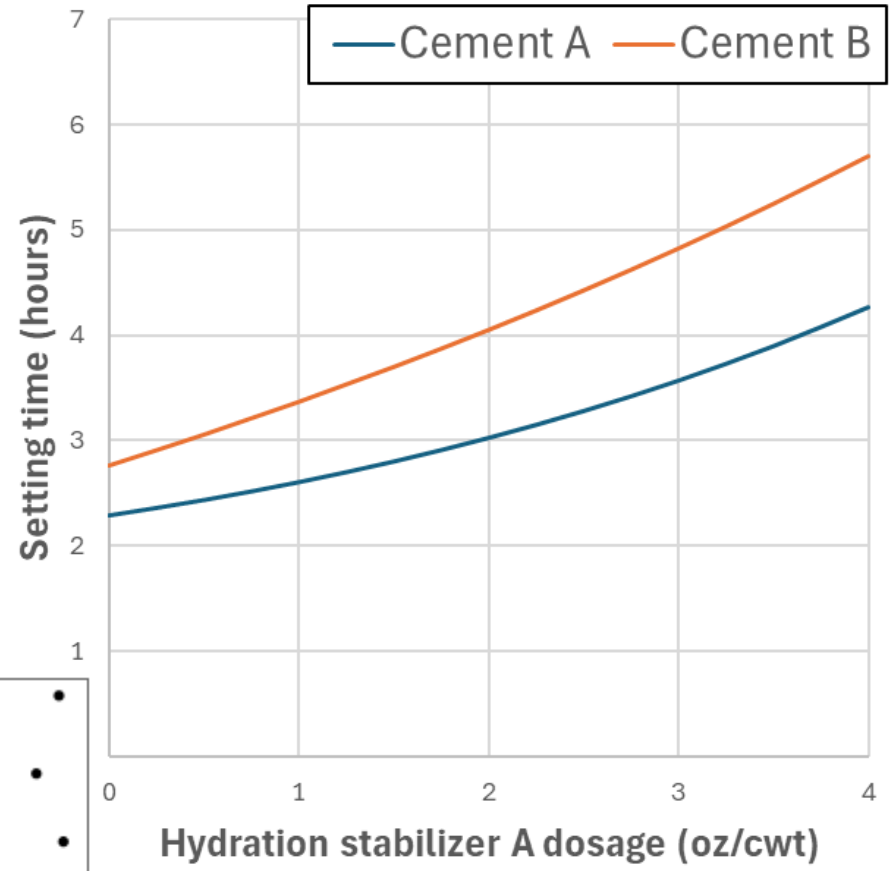

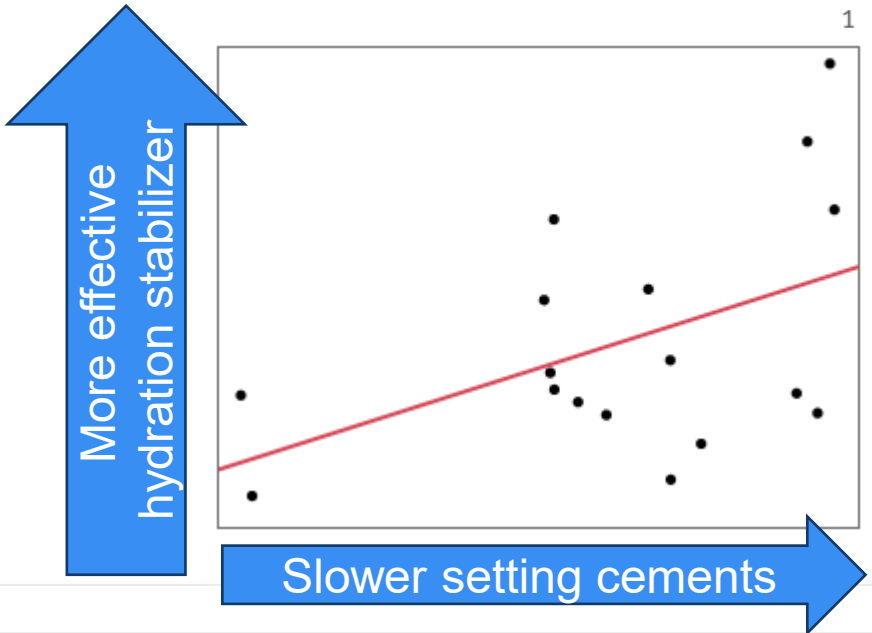

Accelerator stabilizer effectiveness: Portland cement (PC) vs Portland Limestone Cement (PLC)

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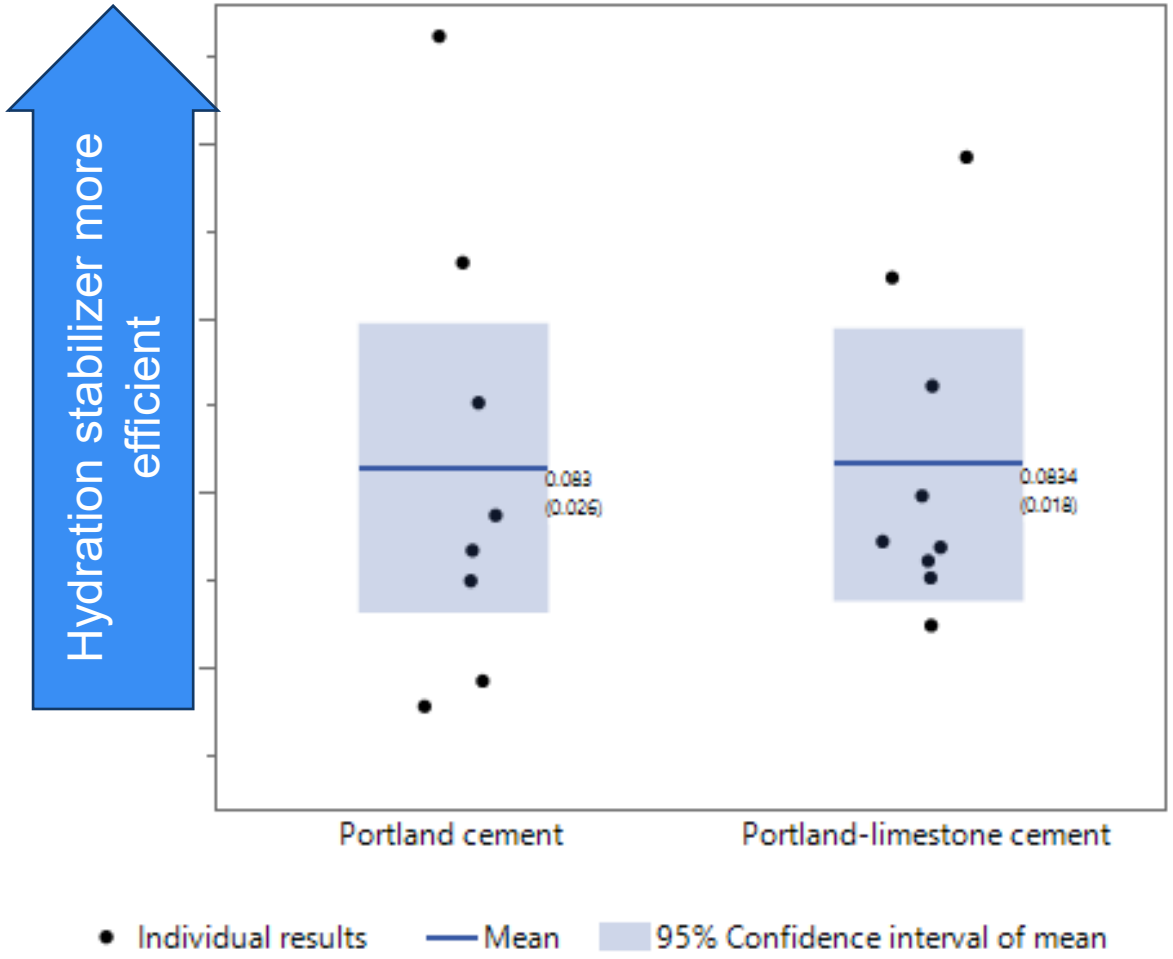

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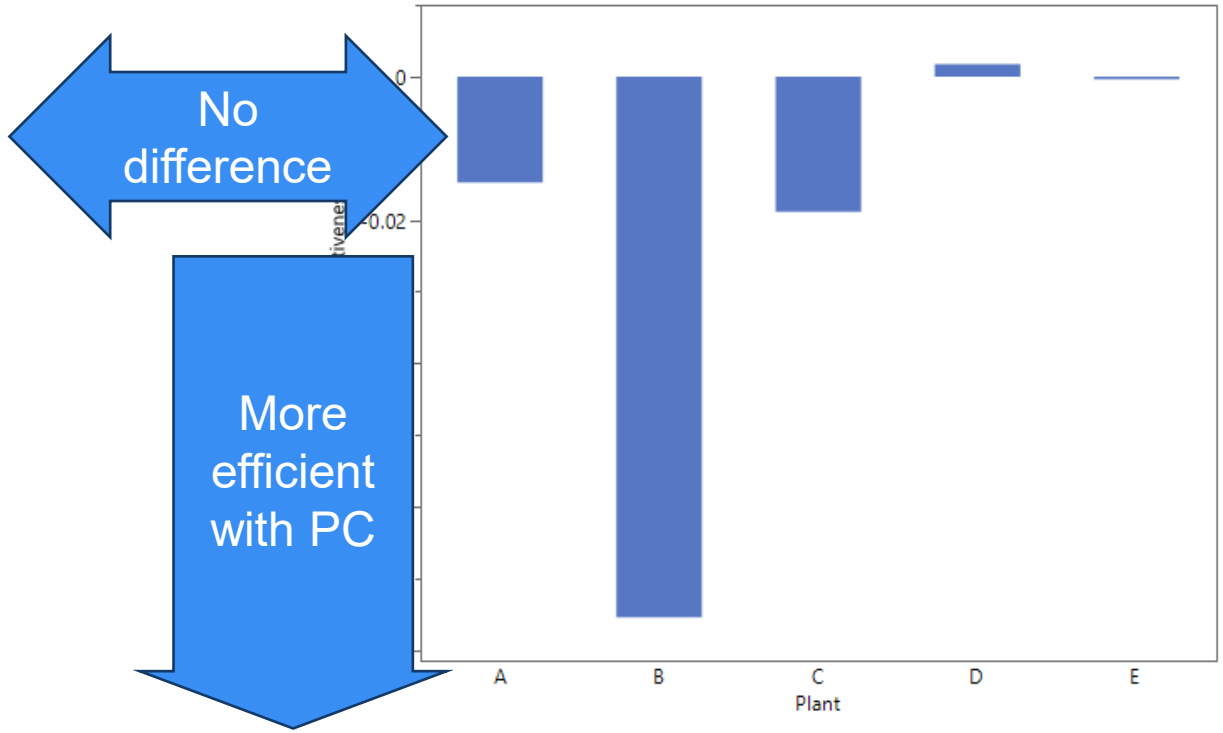

Conclusions

- There are interactions between cementitious materials and admixtures that impact performance
- Performance predictions are limited from just knowledge of the:
  - Type of cement (Type IL vs I/II vs II/V) or
  - Type of admixture (NRWR / Type A/D vs MRWR Type A/F vs HRWR Type F)
- Better performance predictions require specific knowledge of the:
  - Source / brand of cement
  - Brand and dosage of the admixtures
  - Expected temperature

Requires testing or experience

What is the “performance” attribute that matters → What is the right test to measure “performance”

Thank You

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