SCMs, Admixtures, and Other Concrete Additives

Iowa Concrete Pavement Lunch & Learn
Spring 2025

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Institute for Transportation

National Concrete Pavement Technology Center
Tech Center

Evaluation Survey

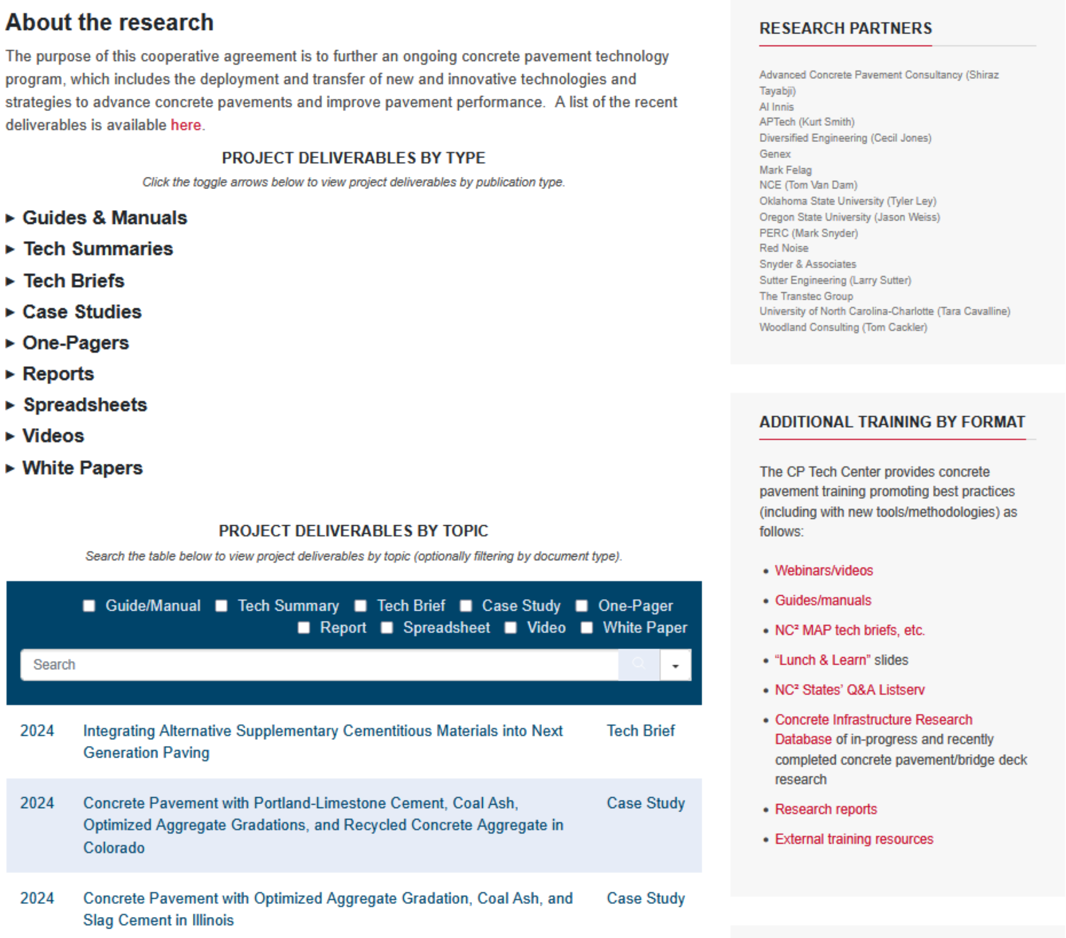
- We'd like to hear from you!
  - Interest in future topics
  - Thoughts on the lunch & learn series

Acknowledgments & Additional Resources

- Thanks to Iowa DOT & ICPA for supporting this program
- Check out **cptechcenter.org** to view our latest resources on concrete pavements and materials
  - Lots of new items have been published this spring!

Acknowledgments & Additional Resources

- Go to “Resources” > “FHWA Cooperative Agreement Resources”



About the research

The purpose of this cooperative agreement is to further an ongoing concrete pavement technology program, which includes the deployment and transfer of new and innovative technologies and strategies to advance concrete pavements and improve pavement performance. A list of the recent deliverables is available here.

PROJECT DELIVERABLES BY TYPE

Click the toggle arrows below to view project deliverables by publication type.

- Guides & Manuals
- Tech Summaries
- Tech Briefs
- Case Studies
- One-Pagers
- Reports
- Spreadsheets
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PROJECT DELIVERABLES BY TOPIC

Search the table below to view project deliverables by topic (optionally filtering by document type).

Guide/Manual Tech Summary Tech Brief Case Study One-Pager Report Spreadsheet Video White Paper

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2024	Integrating Alternative Supplementary Cementitious Materials into Next Generation Paving	Tech Brief
2024	Concrete Pavement with Portland-Limestone Cement, Coal Ash, Optimized Aggregate Gradations, and Recycled Concrete Aggregate in Colorado	Case Study
2024	Concrete Pavement with Optimized Aggregate Gradation, Coal Ash, and Slag Cement in Illinois	Case Study

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Woodland Consulting (Tom Cackler)

ADDITIONAL TRAINING BY FORMAT

The CP Tech Center provides concrete pavement training promoting best practices (including with new tools/methodologies) as follows:

- Webinars/videos
- Guides/manuals
- NC² MAP tech briefs, etc.
- “Lunch & Learn” slides
- NC² States’ Q&A Listserv
- Concrete Infrastructure Research Database of in-progress and recently completed concrete pavement/bridge deck research
- Research reports
- External training resources

Today’s Presentation

- Review of Concrete Materials & Hydration
- Supplementary Cementitious Materials (SCMs)
- Chemical Admixtures
- Other Concrete Additives

Review of Concrete Materials & Hydration

Concrete Materials

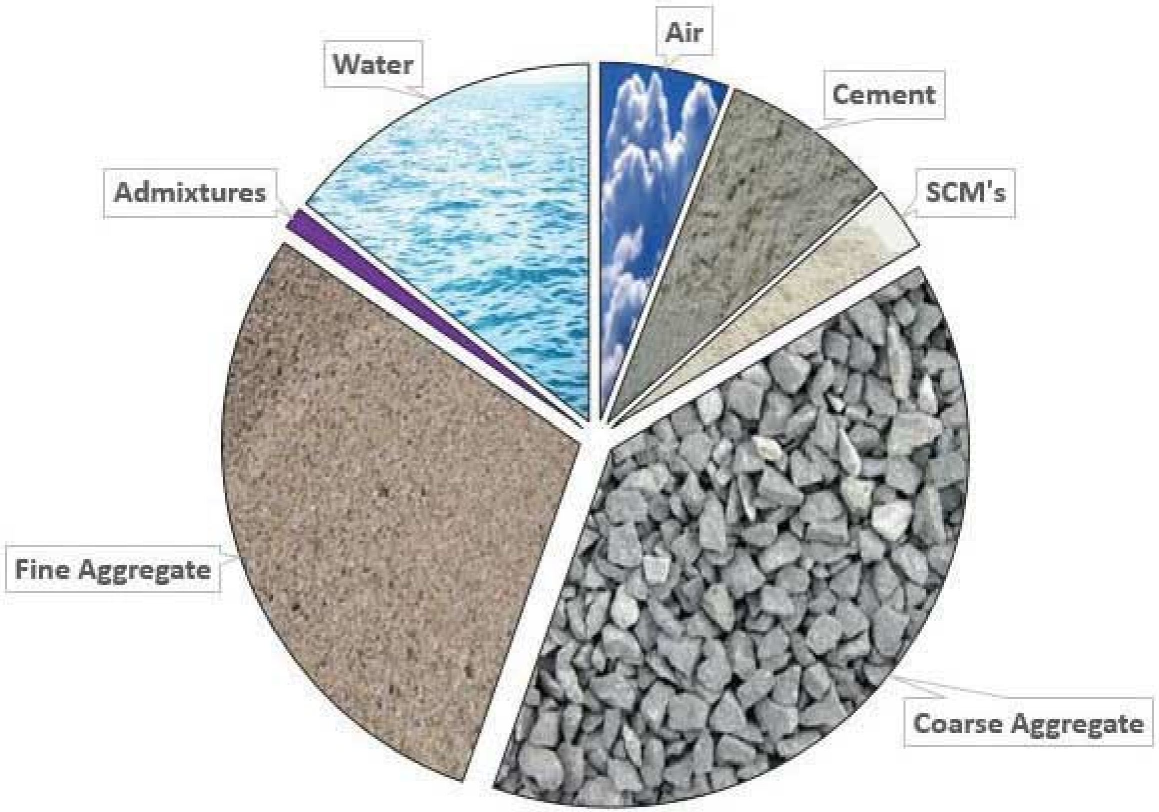
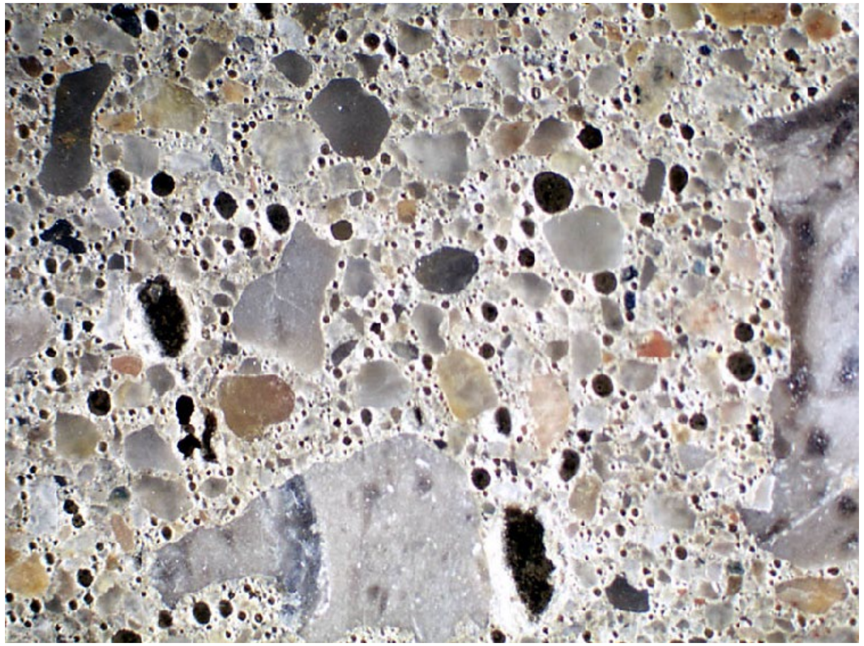


Image: Construction Specifications Institute

Aggregates

- **Aggregates** provide concrete with most of its volume
  - About 55% to 80%, depending on the type of mix
  - Include crushed stone, natural sands, and gravels
  - Consist of coarse and fine fractions (distinguished at #4 sieve)

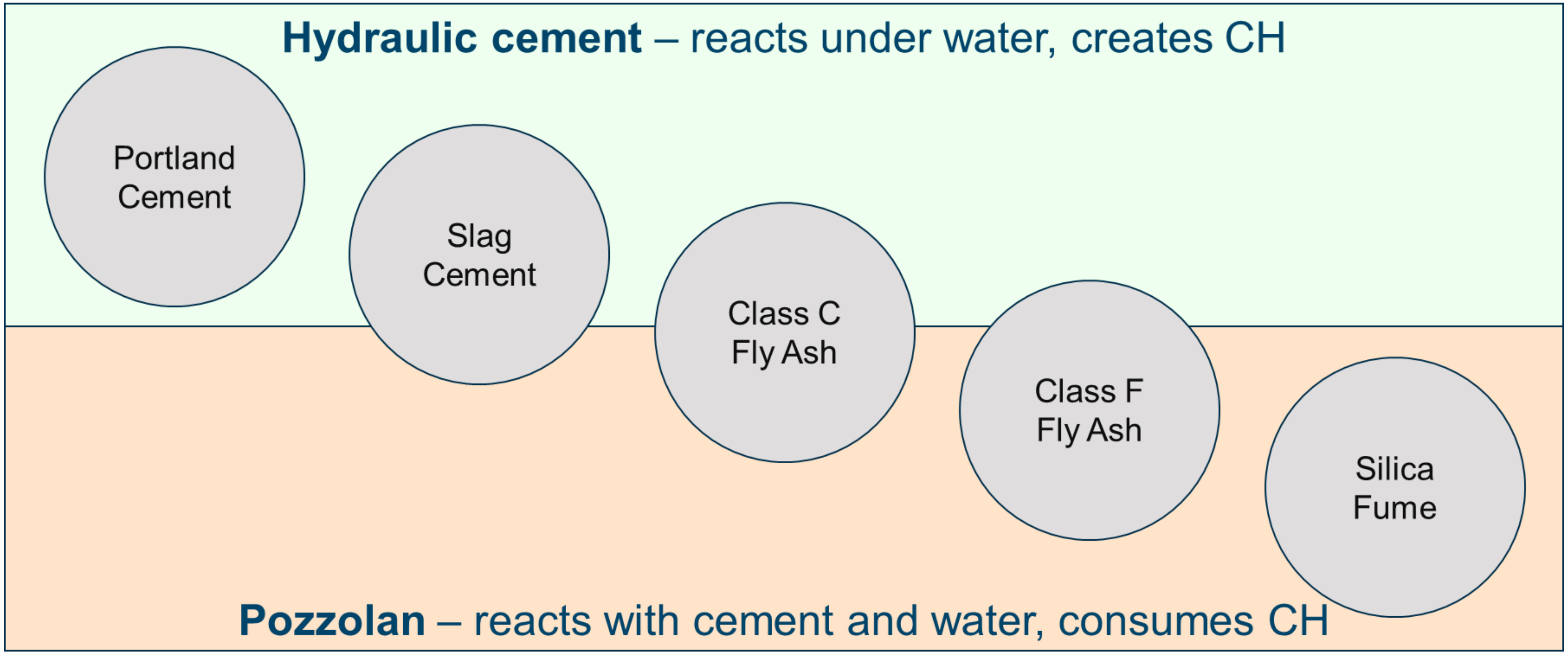


Reactive Materials

- **Reactive materials** govern concrete properties and behavior
  - Cementitious materials
    - Hydraulic cements
    - SCMs
  - Water
  - Chemical admixtures

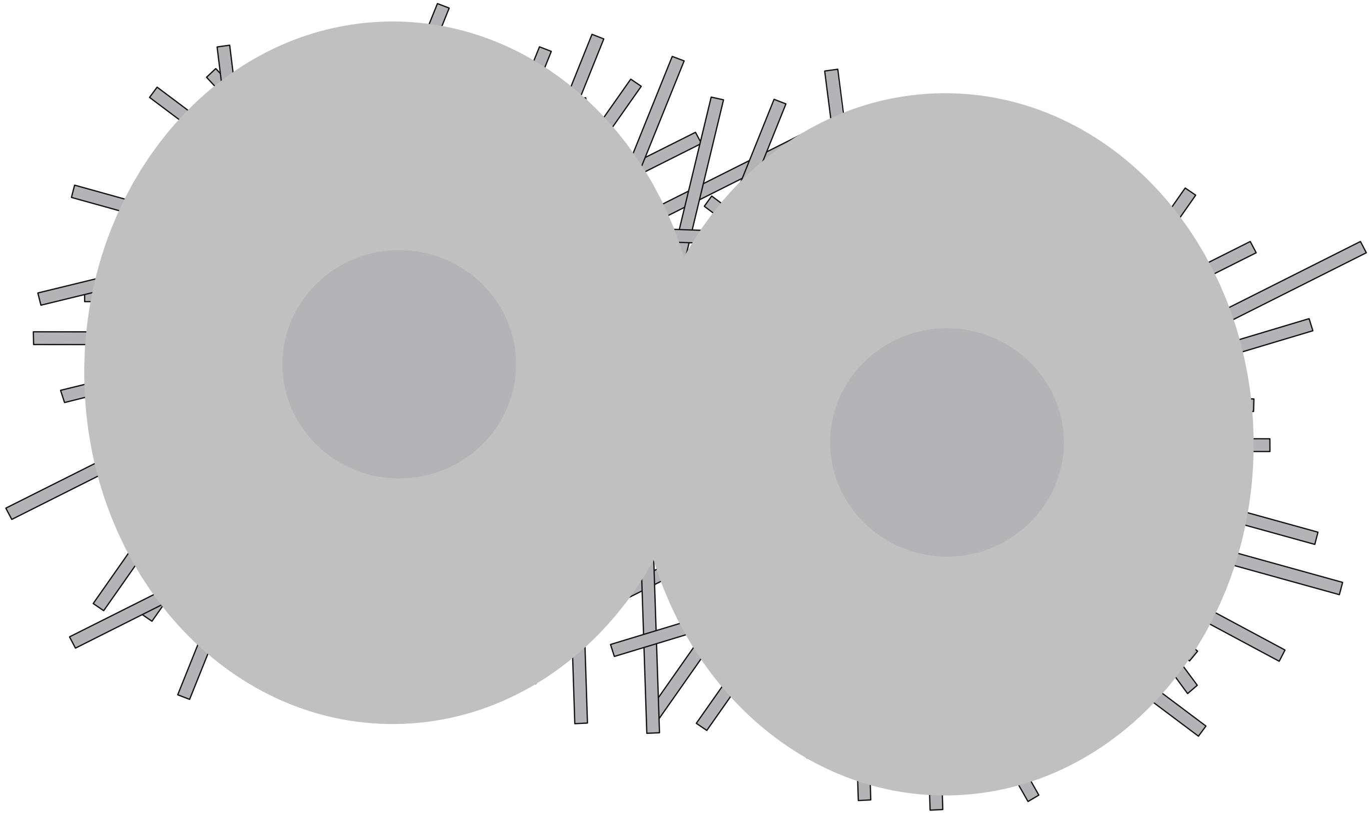
Cementitious Materials

- **Cementitious materials** are the key components of the binder that holds concrete together

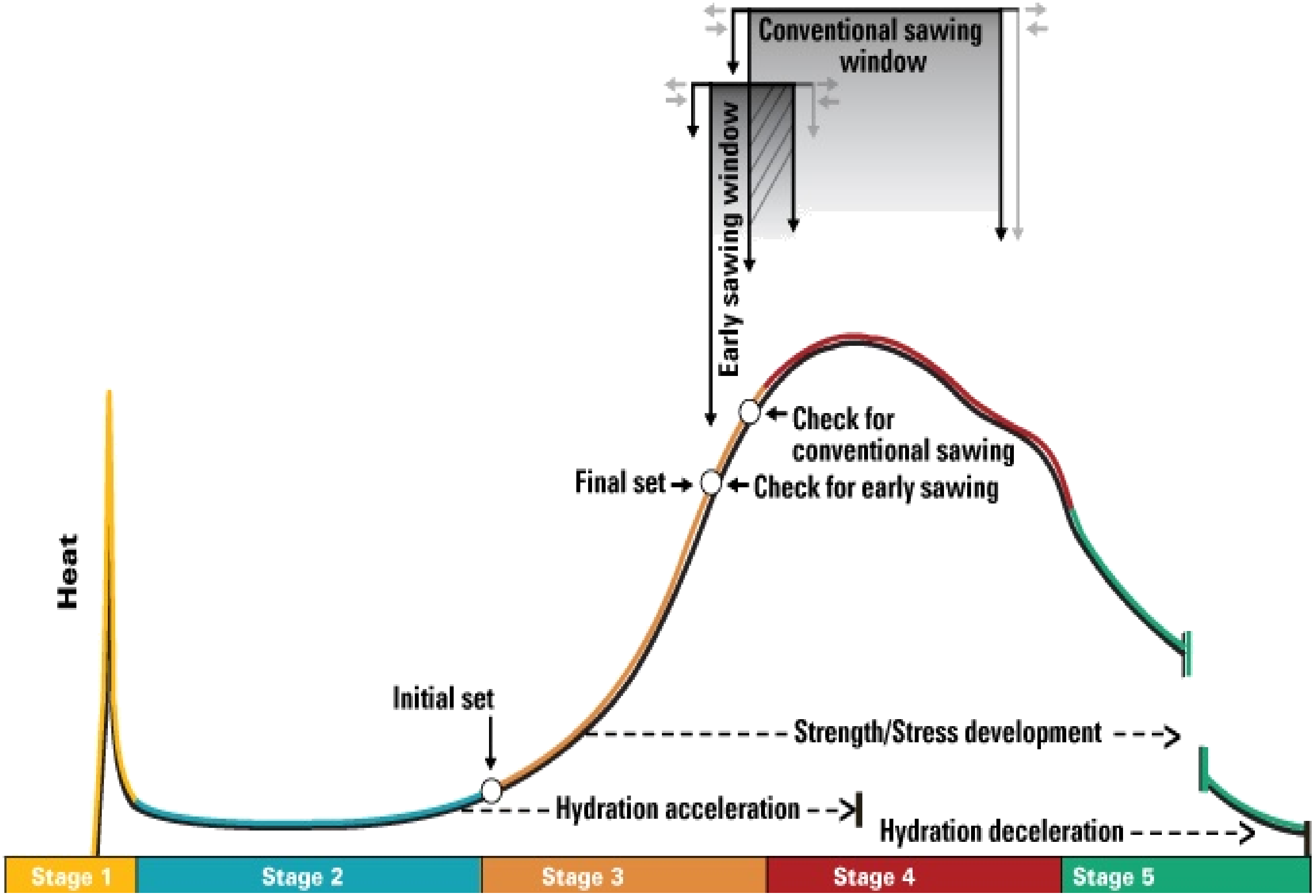


Hydration

- Hydraulic cements (traditionally **portland cement**) react with water in a series of irreversible **hydration** reactions



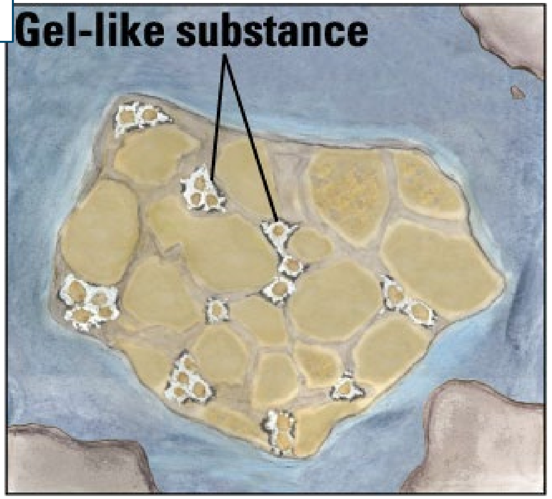
Five Stages of Hydration



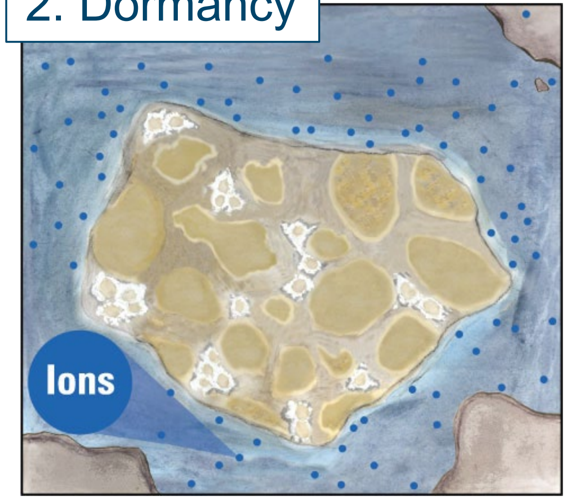
Mixing Dormancy Hardening Cooling Densification

Five Stages of Hydration

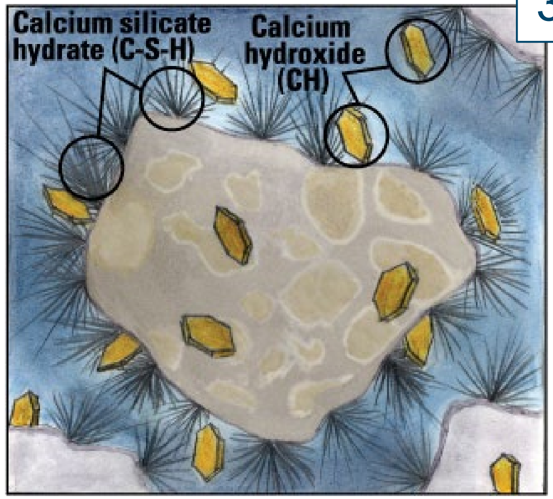
1. Mixing

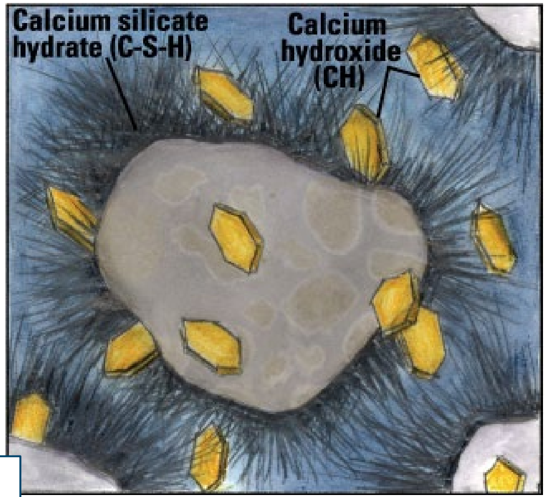


2. Dormancy

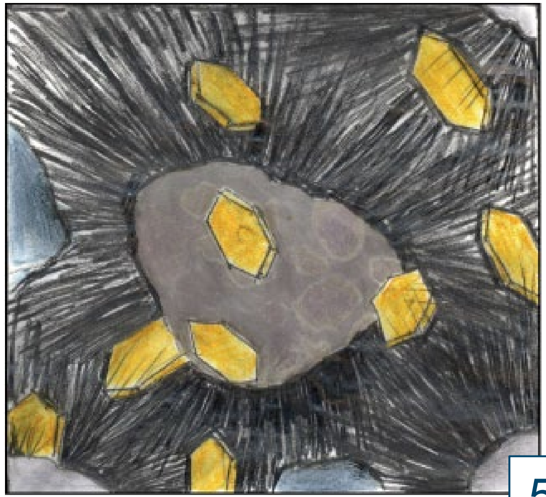


3. Hardening



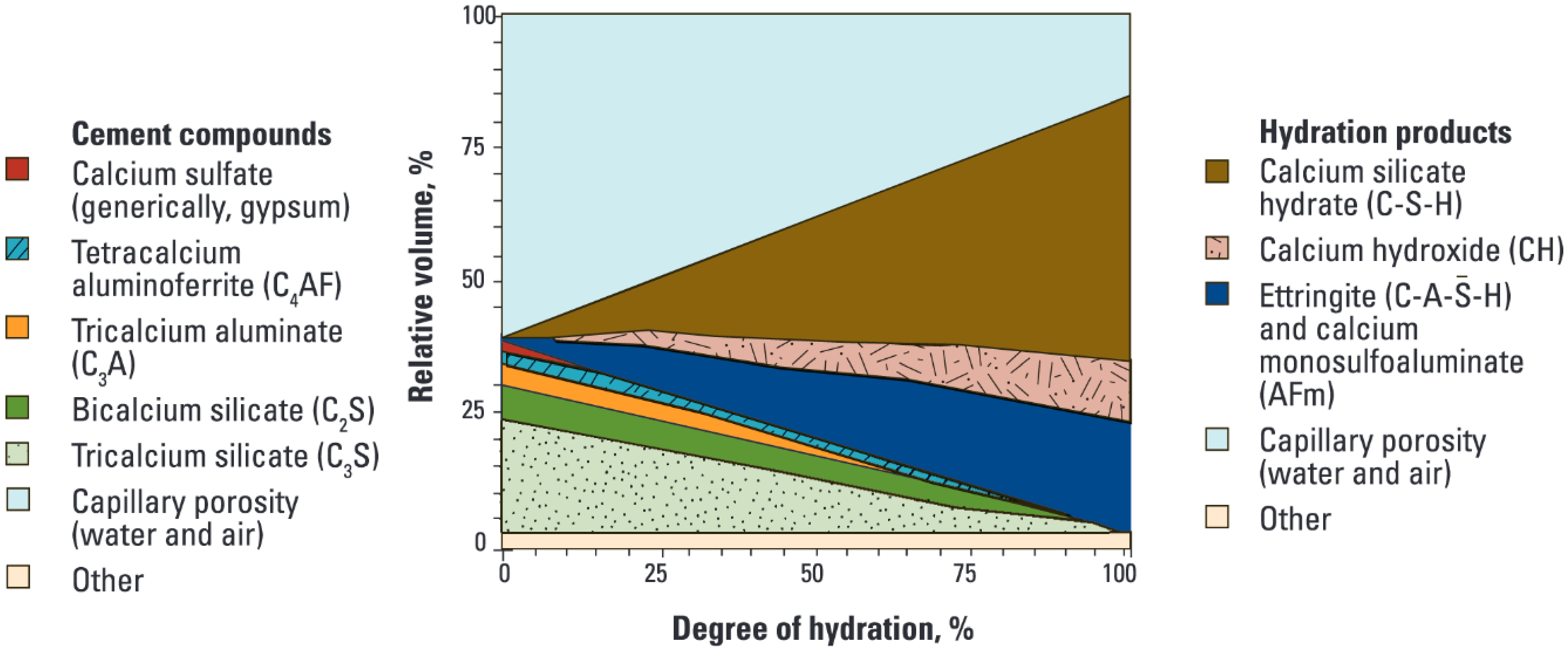


4. Cooling



5. Densification

Hydration Products

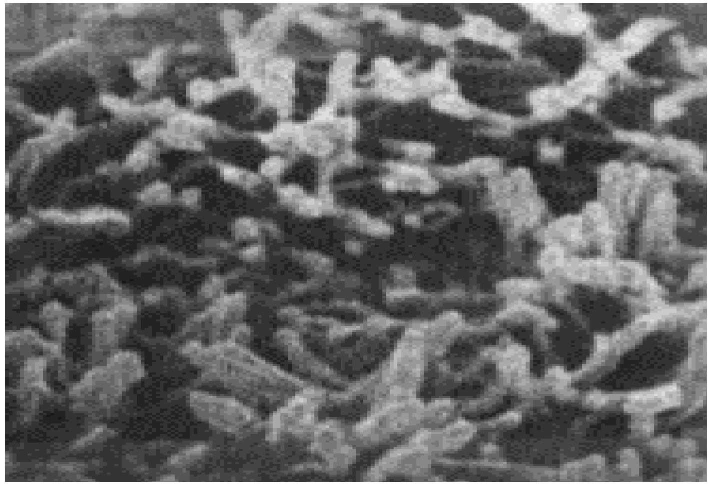


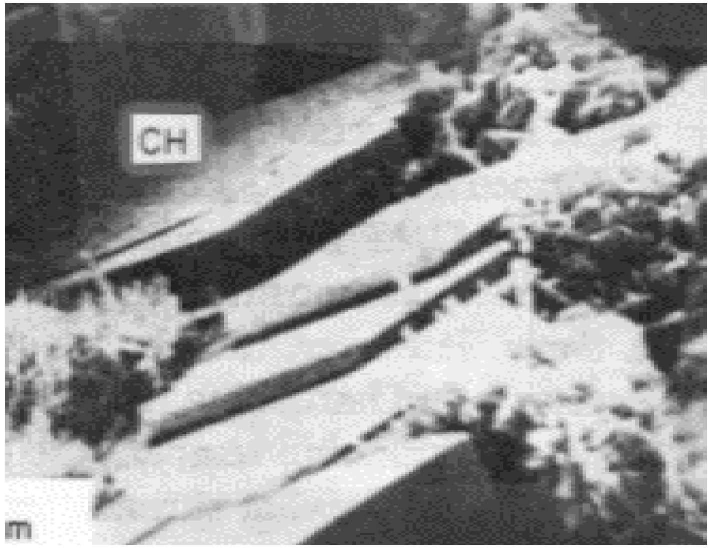
Note: These estimates are for a 0.50 water/cementitious materials ratio; decreasing the ratio will decrease the capillary porosity.

Adapted from Tennis and Jennings 2000

Hydration Products

- C-S-H: calcium silicate hydrate
  - Primary desirable hydration product
  - Major contributor to concrete strength and low permeability
  - Binds other particles together
- CH: calcium hydroxide, or $Ca(OH)_2$
  - Gives concrete its high pH
  - Stabilizes C-S-H
  - Dissolves easily and can contribute to carbonation and durability problems





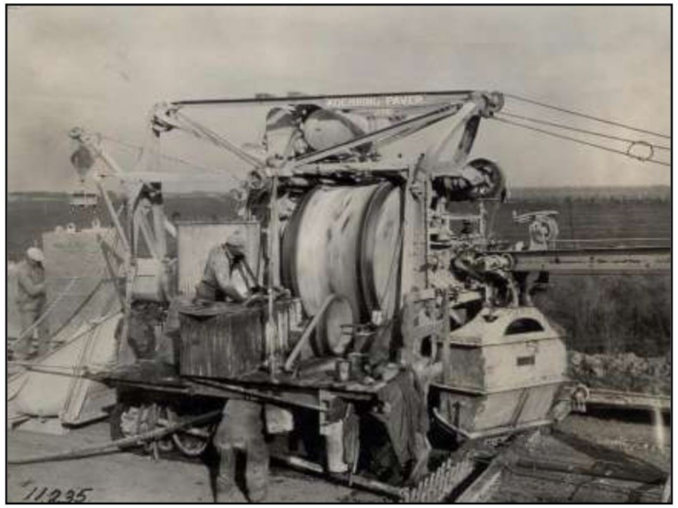
Materials Selection and Proportioning

- We choose and proportion materials to achieve desired concrete properties and to meet design goals:
  - Workability
  - Setting time
  - Strength
  - Durability

L Image: Baker Concrete

Materials Selection and Proportioning

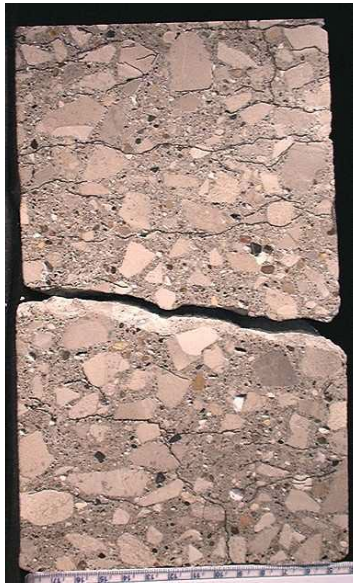
- 100 years ago, most concrete consisted of four core ingredients:
  - Coarse Aggregate
  - Fine aggregate
  - Portland cement
  - Water



Images: Todd Hanson, Iowa DOT

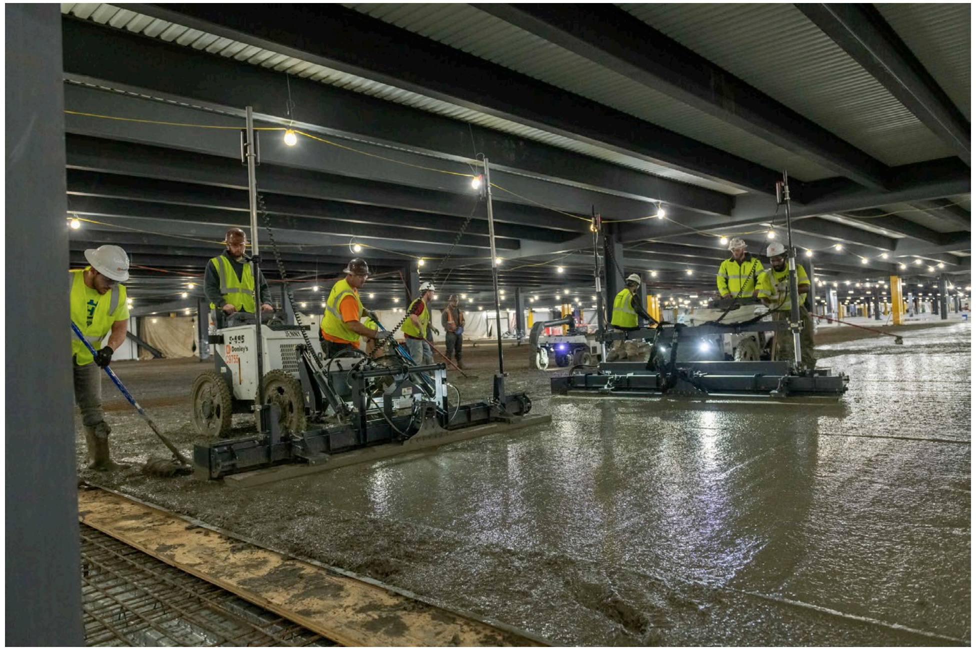
Materials Selection and Proportioning

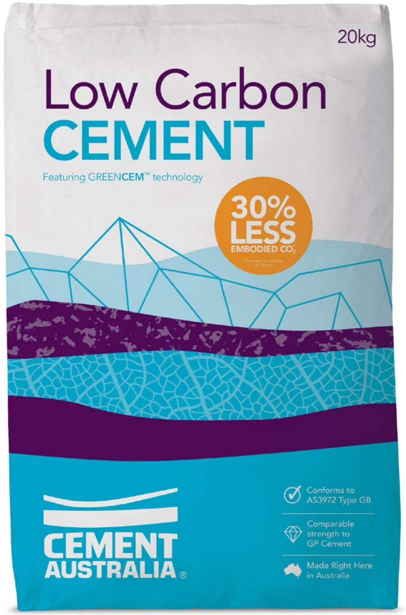
- In the following decades, new materials were introduced for use with concrete to address problems, improve performance, and enable new types of construction:
  - Air-entraining admixtures
  - Water reducing admixtures
  - Fly ash
  - And many more



Materials Selection and Proportioning

- Today, we're adapting to many changes to materials and in the market, and we demand more from our concrete than ever
- We also have a significantly greater variety of additional materials we can use to meet these demands and our design goals

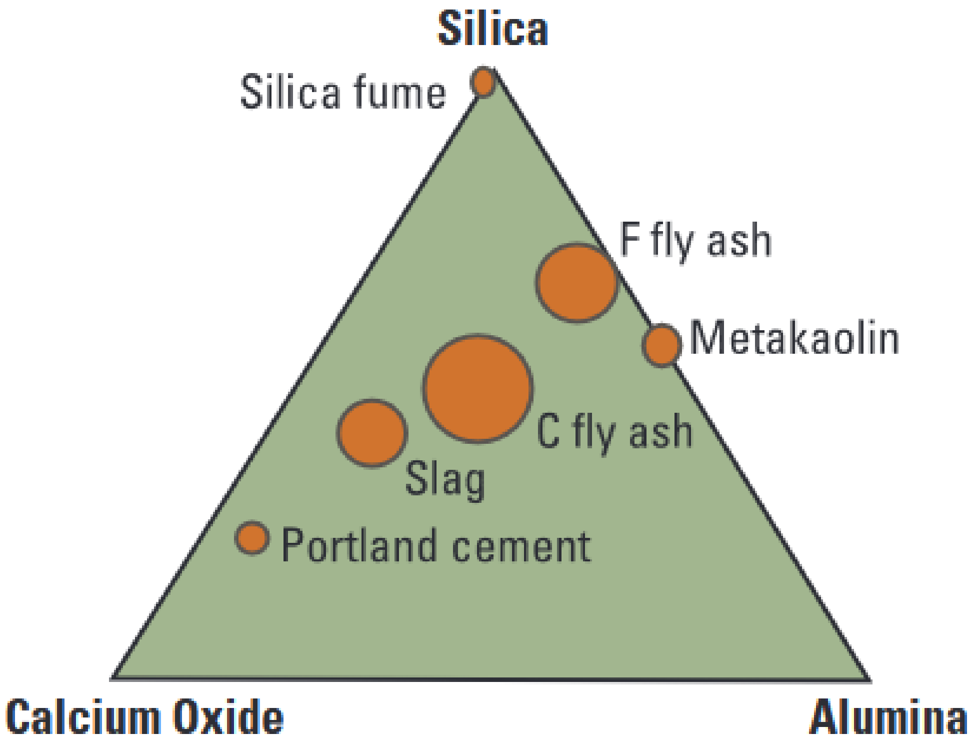




Supplementary Cementitious Materials (SCMs)

What are SCMs?

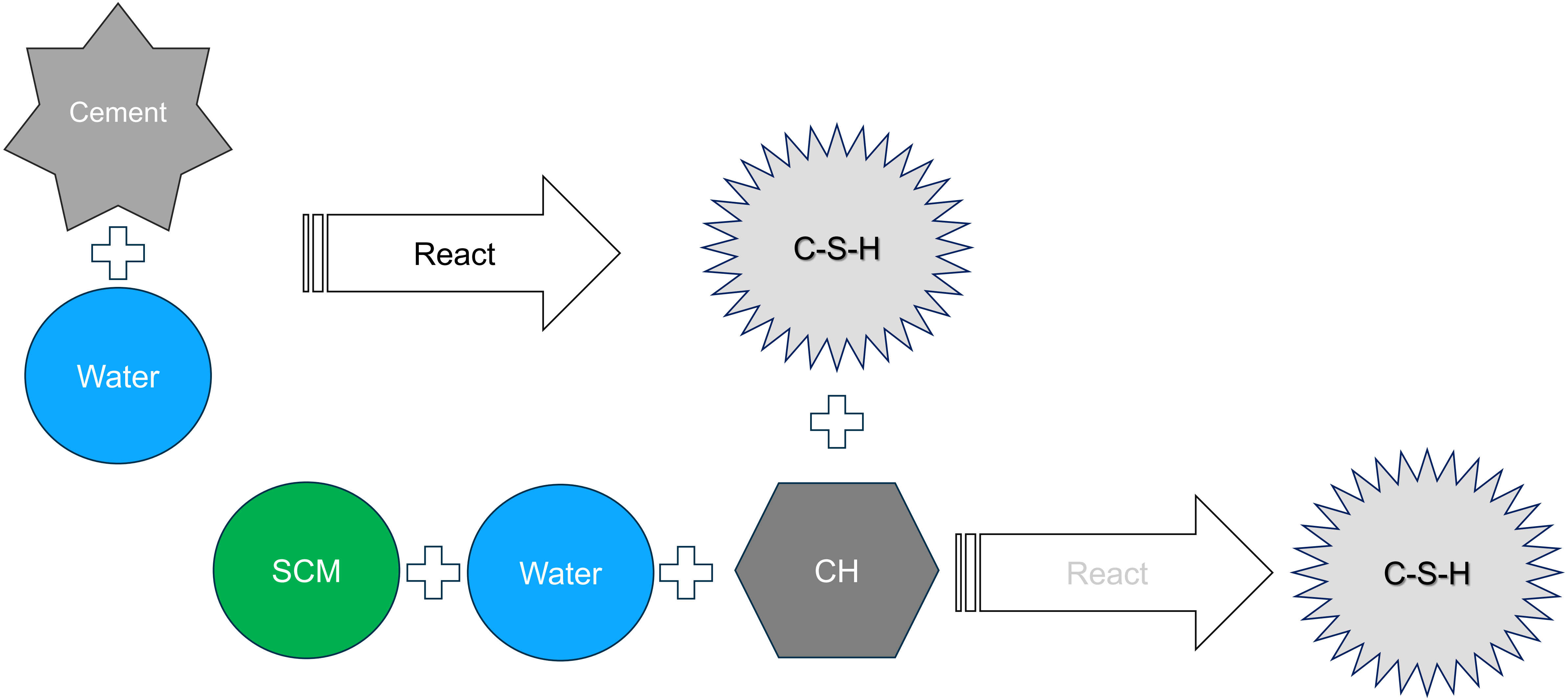
- Materials that contribute to the properties of cementitious materials through hydraulic or pozzolanic activity
- Consist of many of the same chemical compounds as portland cement
- Can be naturally-occurring minerals, industrial byproducts, or processed from raw or recycled materials



Why Do We Use SCMs in Concrete?

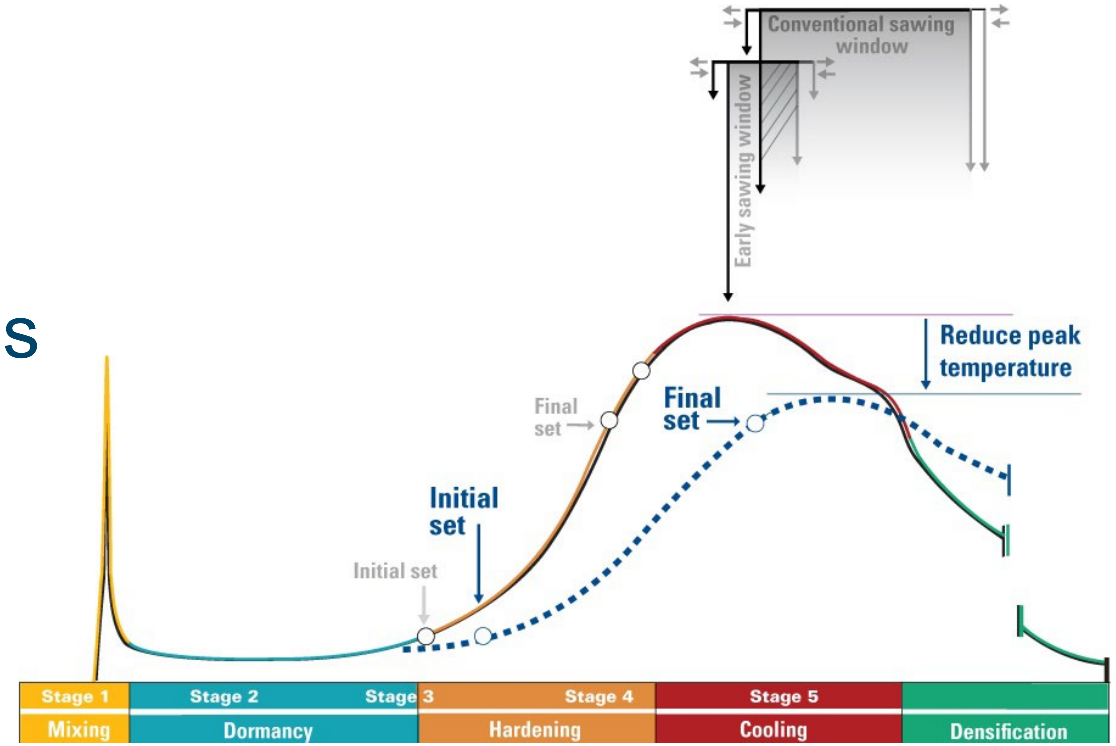
- SCMs are included in concrete to complement hydration of hydraulic cement hydration (portland cement)
- When used properly, SCMs can enhance many desired concrete properties:
  - Workability
  - Long-term strength
  - Long-term durability
- They achieve these goals by spurring **pozzolanic** reactions to convert CH into additional C-S-H

How SCMs Work



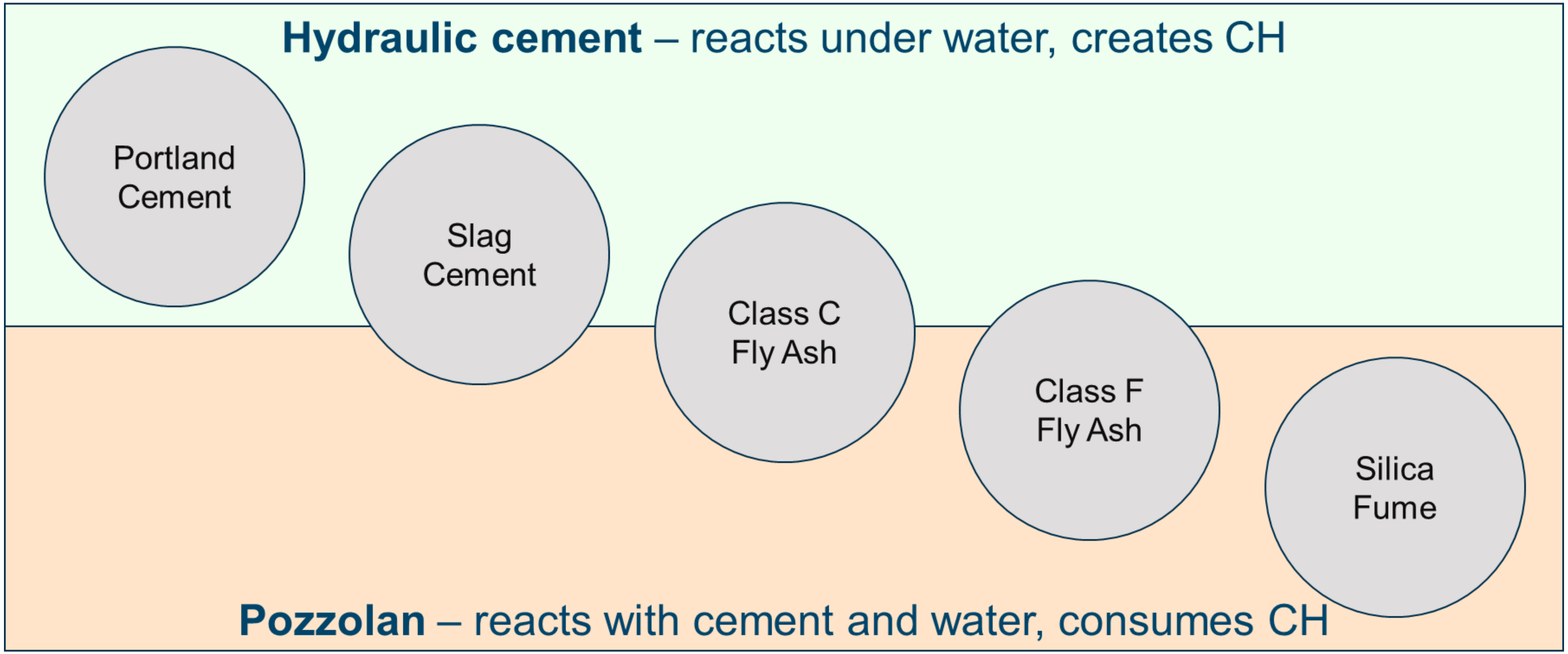
Effects of SCMs on Concrete

- Slowing of the hydration reaction
  - Delayed final set
  - Reduced heat peak
  - Extended heat generation
- Increased long-term strength
- Reduced permeability
- Mitigation of specific durability issues
  - Alkali-silica reaction (ASR)
  - Sulfate attack
  - Damage from de-icing salts



Types of SCMs

- Many SCMs have both hydraulic and pozzolanic characteristics



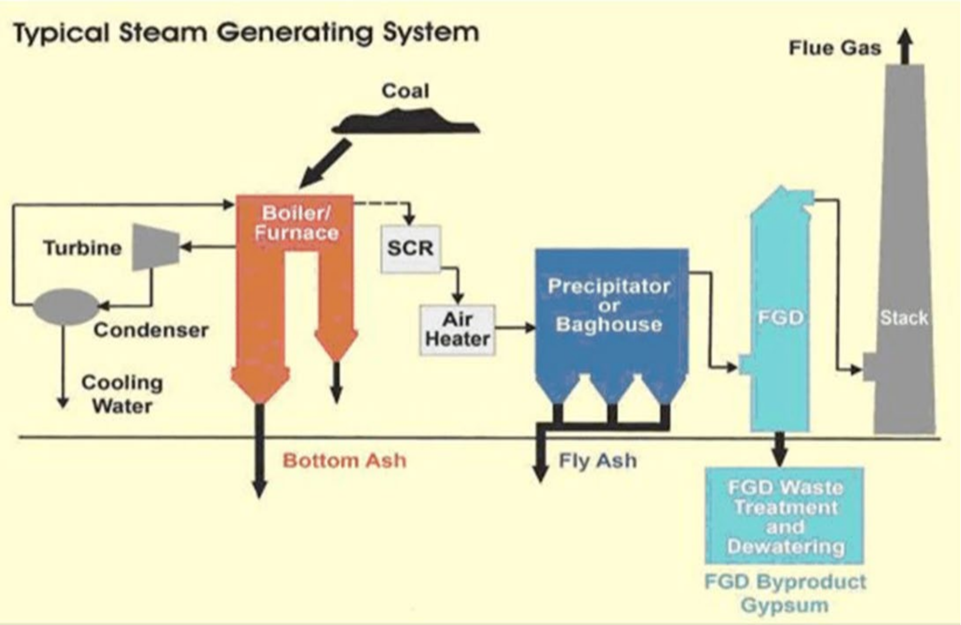
Typical SCM Replacement Rates

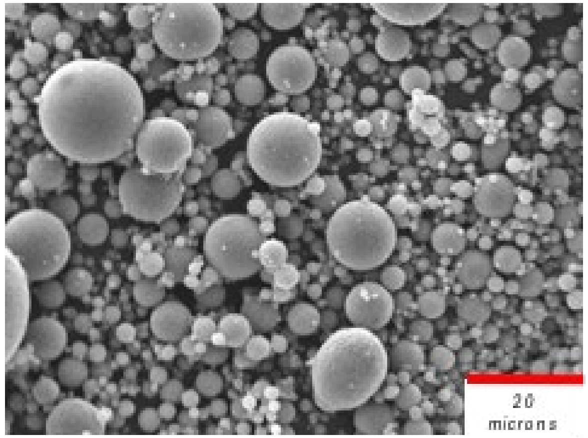
- SCMs may be blended at the concrete batch plant, or blended or interground at the cement plant (**blended cement**)
- The SCM content of a concrete mix is usually expressed as a rate of replacement of portland cement

Product	Typical Replacement Rate
Class F fly ash	15% to 25%
Class C fly ash	15% to 40%
Slag cement	25% to 50%
Silica fume	5% to 15%

Coal Fly Ash

- Byproduct of coal combustion at power plants
  - VOCs and carbon burned off
  - Mineral impurities remain in flue gas
  - Fused materials cool into glass spheres



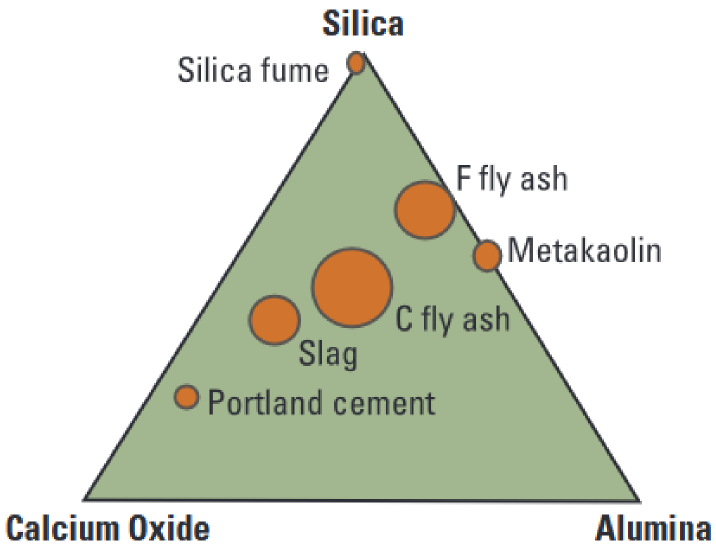


L Image: Sani et al. (2010)

Coal Fly Ash

- One of the most widely-used SCMs in many types of concrete applications for more than 70 years
- Consists primarily of silica, iron, aluminum, and calcium
- Classified according to chemistry, which varies based on the source of coal & the burning and collection processes:
  - Class F: 0 to 15% CaO
  - Class C: 15% to 30% CaO

  - See ASTM C618 for full details



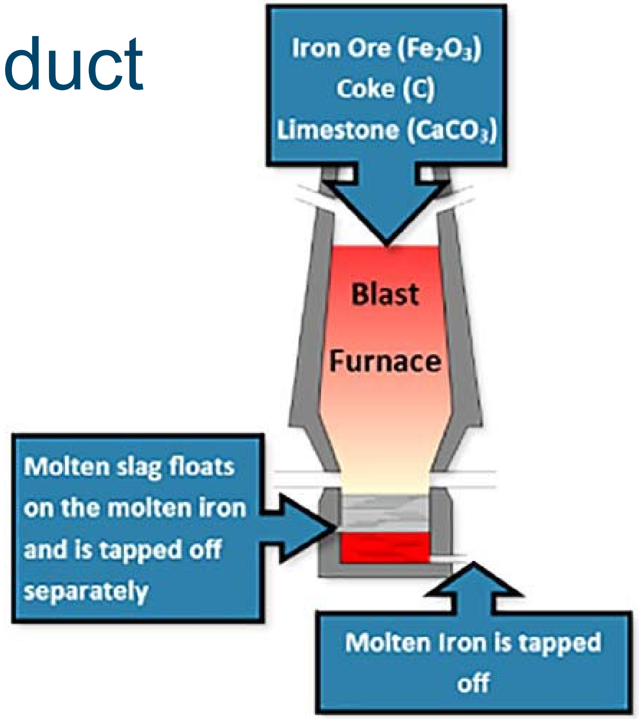
Coal Fly Ash

- Class F fly ash is more **pozzolanic** than Class C fly ash
- At the same fly ash replacement rate:
  - F ash slows set time and initial strength gain more than C ash
  - F ash improves strength and permeability more than C ash
- Both F and C ash improve workability and reduce bleeding

- Unburnt carbon content (LOI) of both F and C ash must be limited to 6% to avoid adsorption of air bubbles
- Class C ash may not mitigate ASR or sulfate attack
  - These are not concerns in Iowa

Slag Cement

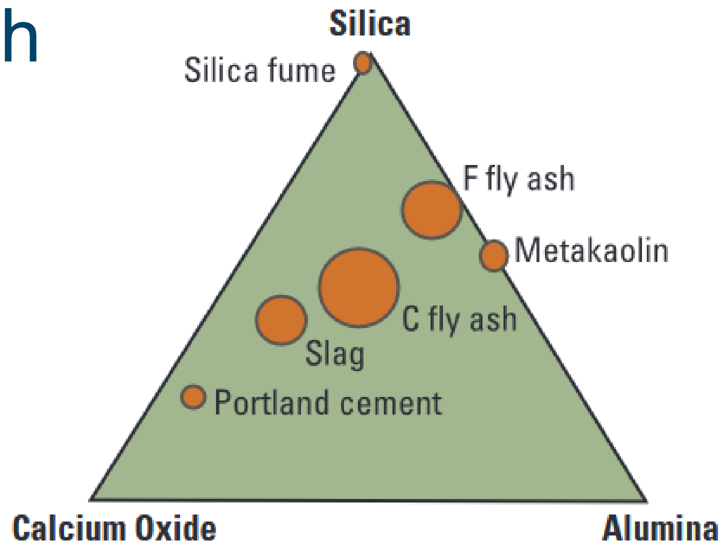
- Byproduct of iron manufacturing
  - Molten slag forms inside the blast furnace
  - Slag is tapped off, quenched, and dewatered, producing glassy, granulated slag
  - Ground to produce final product



Images: Skyway Cement, SCA

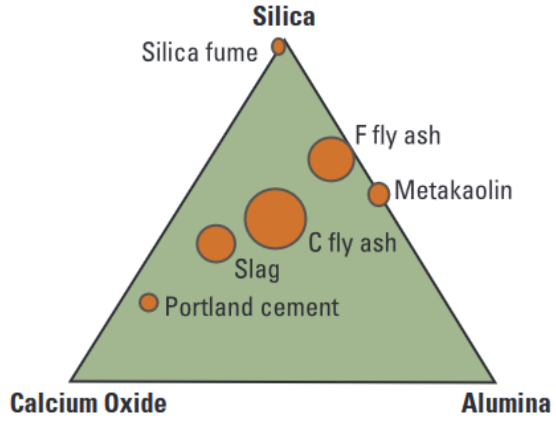
Slag Cement

- Used in all types of concrete applications
- Effects are very similar to fly ash (and other SCMs):
  - Slower set time and initial strength gain
  - Improved workability
  - Improved long-term strength and permeability
- Grades of slag (80, 100, 120) indicate strength development



Silica Fume

- Byproduct of production of silicon alloys in electric arc furnaces
- Highly pozzolanic due to high SiO_2 content (85%) and fineness
- Significantly improves strength and permeability
- Increases rate of hydration
- Used primarily in high strength concrete applications



Future of SCMs

- While demand is rising, supplies of conventional SCMs are becoming less abundant and more uncertain
  - The production of **fly ash** in particular is in long-term decline:

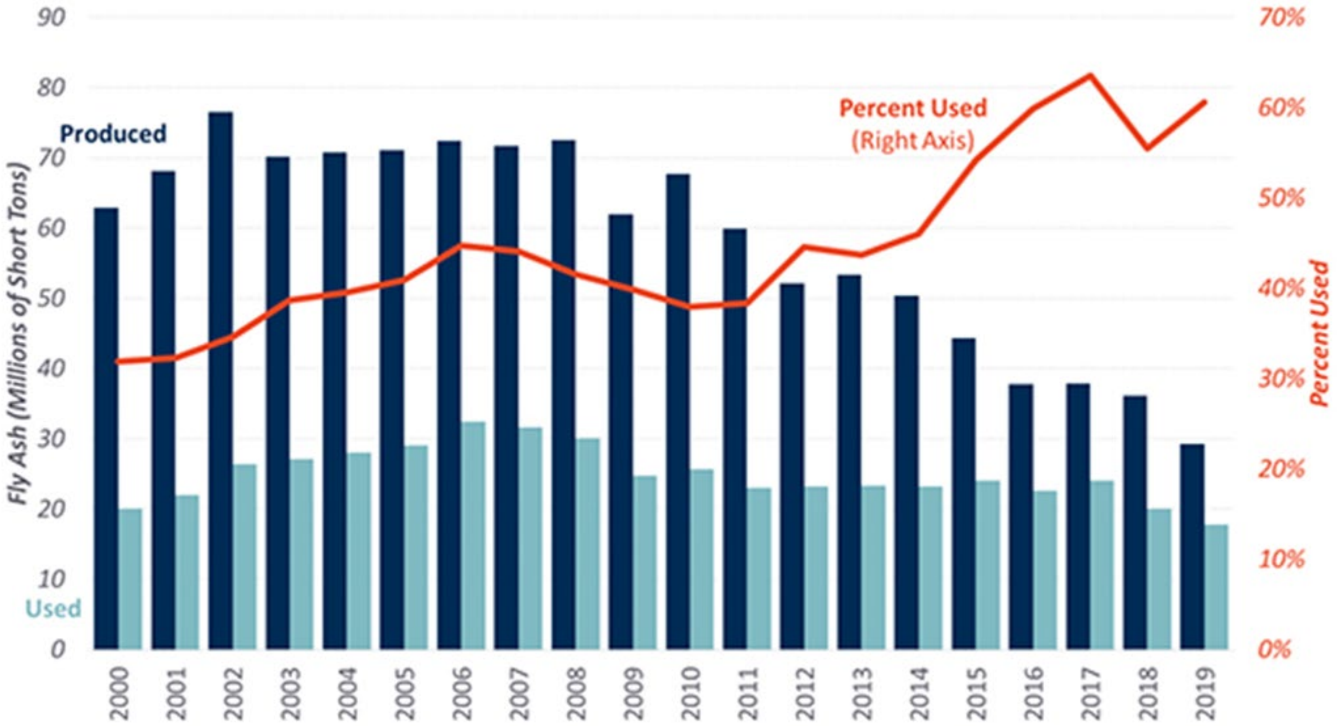


Image: CAA

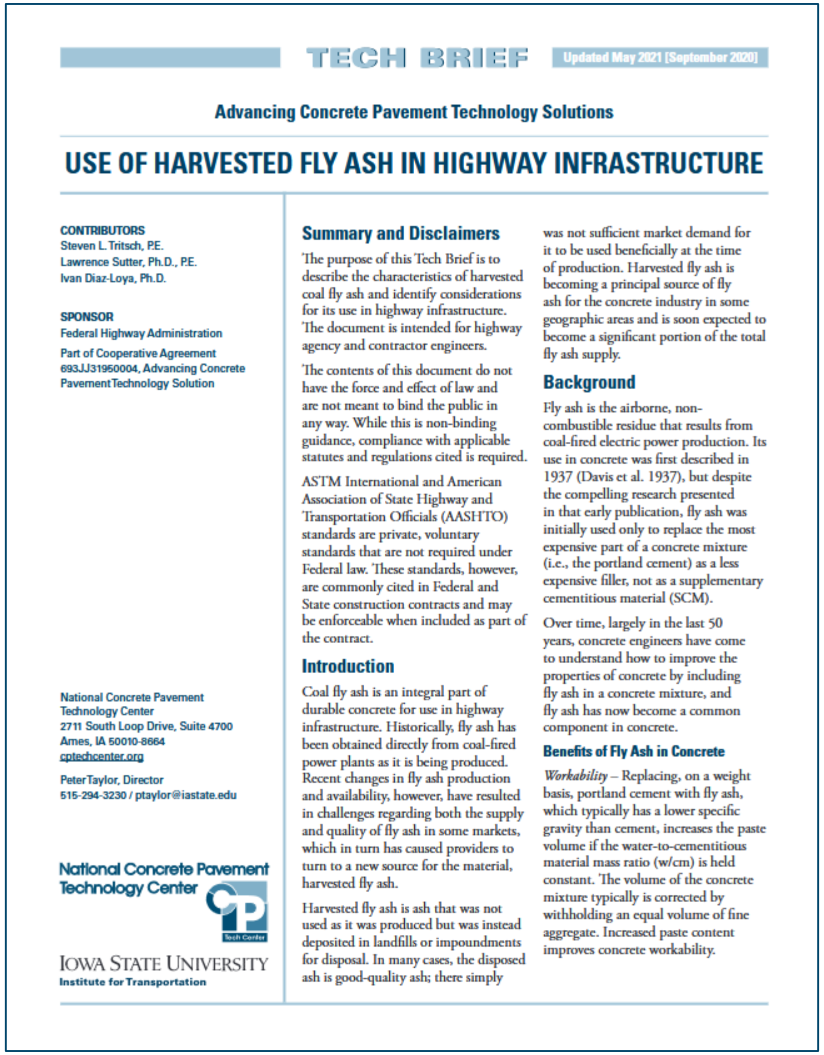
Harvested Fly Ash

- Over the past 100+ years, huge supplies of fly ash have been disposed of in landfills or impoundments
- These supplies can be reclaimed for use in concrete

Image: Eco Material Technologies

Harvested Fly Ash

- Production and beneficiation process:
  - Drying
  - Screening/sizing
  - Carbon removal
  - Grinding
  - Blending
- Final product must meet existing specifications for coal fly ash
  - Most harvested ash is Class F
  - Often more consistent than newly-produced fly ash



TECH BRIEF Updated May 2021 (September 2020)

Advancing Concrete Pavement Technology Solutions

USE OF HARVESTED FLY ASH IN HIGHWAY INFRASTRUCTURE

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Part of Cooperative Agreement 693JJ31950004, Advancing Concrete Pavement Technology Solution

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Summary and Disclaimers

The purpose of this Tech Brief is to describe the characteristics of harvested coal fly ash and identify considerations for its use in highway infrastructure. The document is intended for highway agency and contractor engineers.

The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. While this is non-binding guidance, compliance with applicable statutes and regulations cited is required.

ASTM International and American Association of State Highway and Transportation Officials (AASHTO) standards are private, voluntary standards that are not required under Federal law. These standards, however, are commonly cited in Federal and State construction contracts and may be enforceable when included as part of the contract.

Introduction

Coal fly ash is an integral part of durable concrete for use in highway infrastructure. Historically, fly ash has been obtained directly from coal-fired power plants as it is being produced. Recent changes in fly ash production and availability, however, have resulted in challenges regarding both the supply and quality of fly ash in some markets, which in turn has caused providers to turn to a new source for the material, harvested fly ash.

Harvested fly ash is ash that was not used as it was produced but was instead deposited in landfills or impoundments for disposal. In many cases, the disposed ash is good-quality ash; there simply was not sufficient market demand for it to be used beneficially at the time of production. Harvested fly ash is becoming a principal source of fly ash for the concrete industry in some geographic areas and is soon expected to become a significant portion of the total fly ash supply.

Background

Fly ash is the airborne, non-combustible residue that results from coal-fired electric power production. Its use in concrete was first described in 1937 (Davis et al. 1937), but despite the compelling research presented in that early publication, fly ash was initially used only to replace the most expensive part of a concrete mixture (i.e., the portland cement) as a less expensive filler, not as a supplementary cementitious material (SCM).

Over time, largely in the last 50 years, concrete engineers have come to understand how to improve the properties of concrete by including fly ash in a concrete mixture, and fly ash has now become a common component in concrete.

Benefits of Fly Ash in Concrete

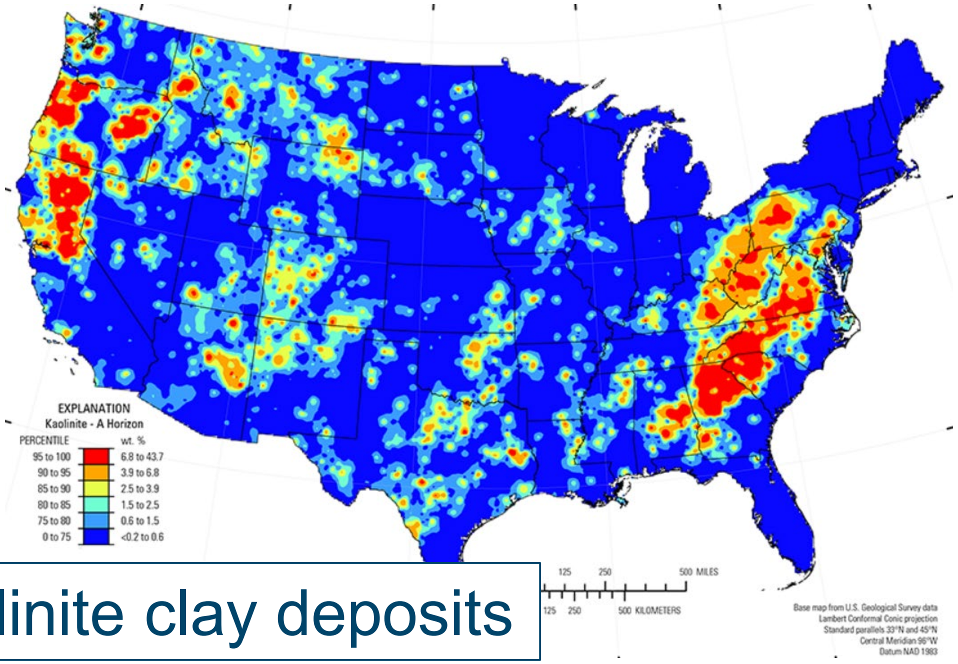
Workability – Replacing, on a weight basis, portland cement with fly ash, which typically has a lower specific gravity than cement, increases the paste volume if the water-to-cementitious material mass ratio (w/cm) is held constant. The volume of the concrete mixture typically is corrected by withholding an equal volume of fine aggregate. Increased paste content improves concrete workability.

Natural Pozzolans

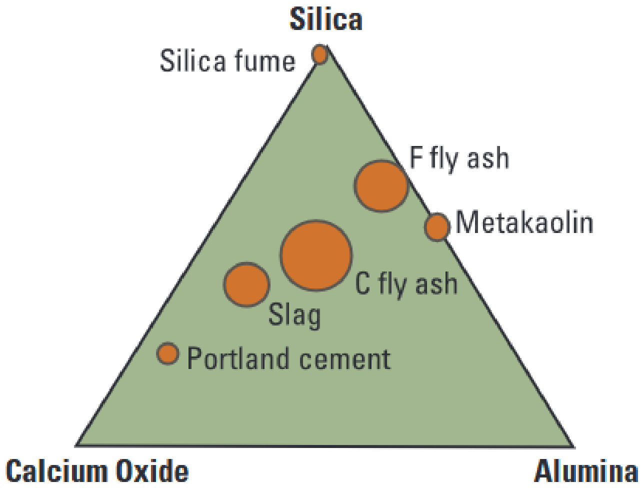
- There are a variety of additional deposits of materials around the world with pozzolanic properties that can be used as SCMs
- Specified as Class N materials in ASTM C618
- Several sources available in the western U.S.

Calcined Clay

- Produced by heating clay materials to 600°C to 900°C
- Chemistry and performance are similar to Class F fly ash
- Metakaolin: higher purity calcined clay produced from kaolinite



Kaolinite clay deposits



L Image: USGS

Alternative SCMs (ASCMs)

- Researches are exploring a number of other products for potential use as SCMs in the future:
  - Recycled ground glass
  - Recycled concrete fines
  - Ceramic waste
  - Biomass ash
  - Waste from mining and industrial processes
  - Bauxite residue

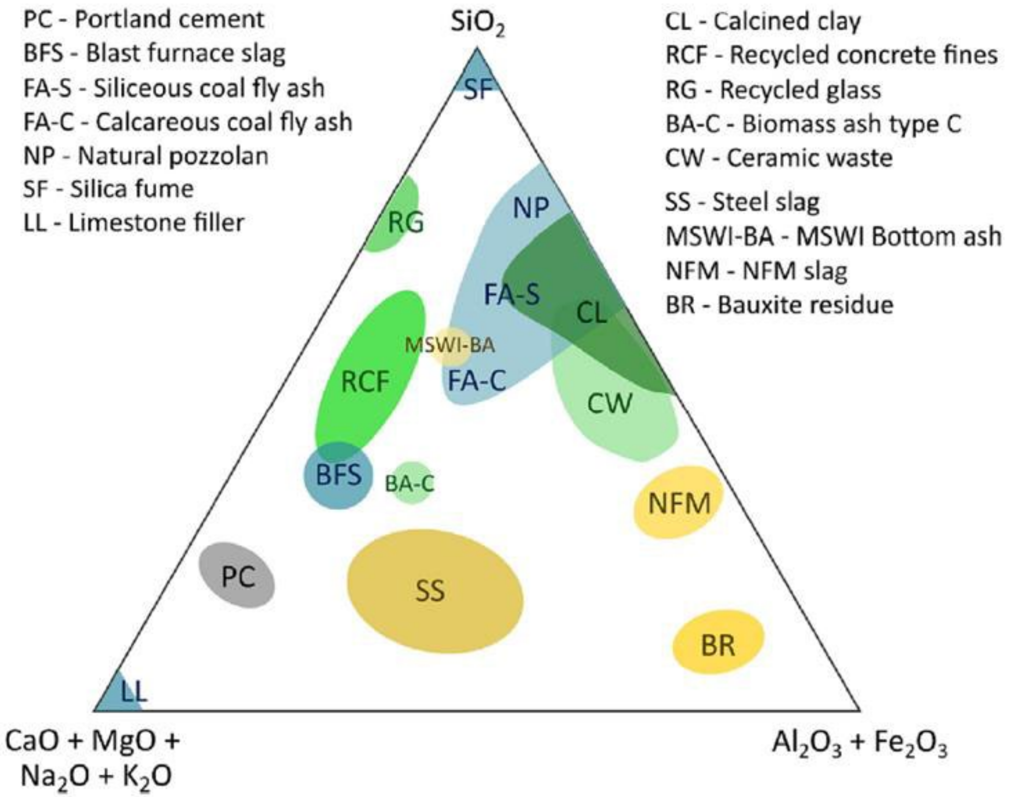
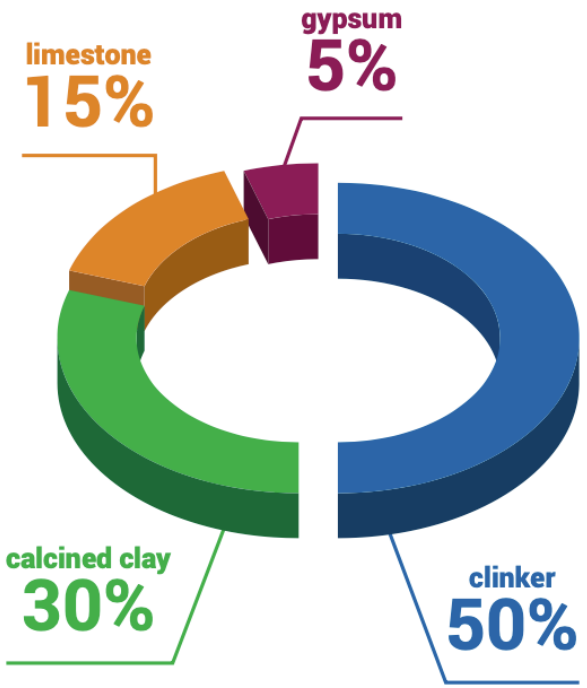


Image: Snellings et al. (2023)

Blended Cements

- With changes to SCM availability and supply chains, greater use, variety, and availability of **blended cements** appears likely

LC3 Cement:



Paving with LC3 cement at MnROAD:

Final Notes on SCMs

- While most SCMs ultimately have similar effects on concrete, each product still has its own unique behavior and properties
  - Placement (workability, finishing)
  - Setting time
  - Strength development
- When sources of SCMs change – for example, when switching between C and F ash – it's important to conduct trial batching and testing to understand how concrete behavior will change
- Future: more performance-based specifications for SCMs

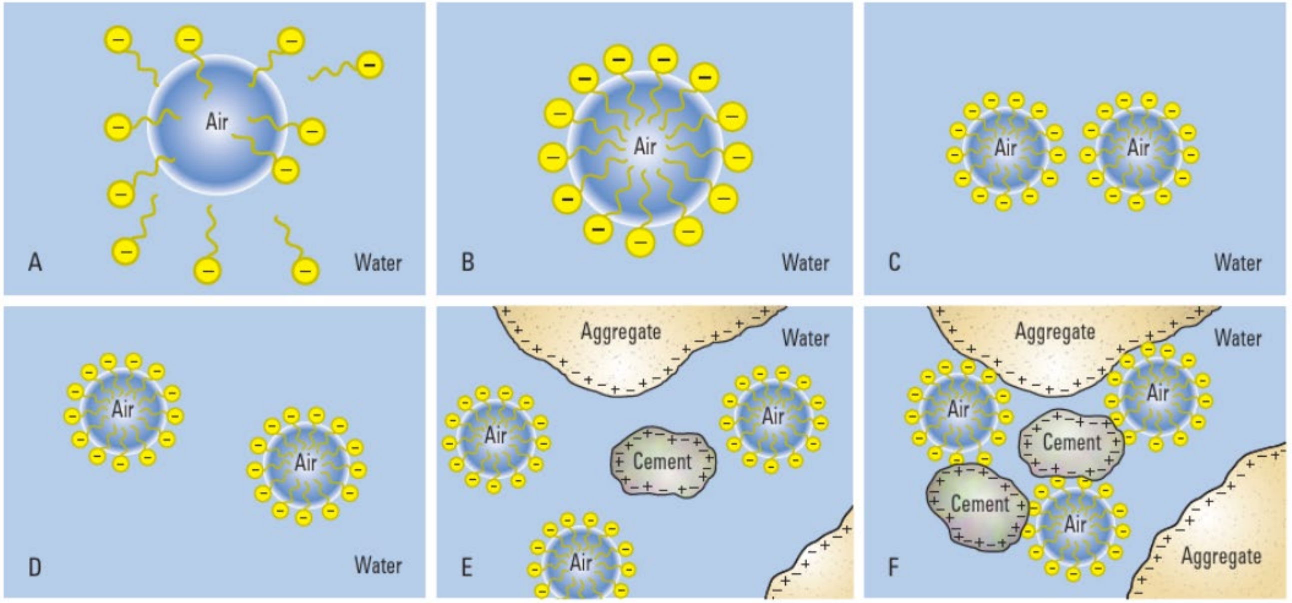
Chemical Admixtures

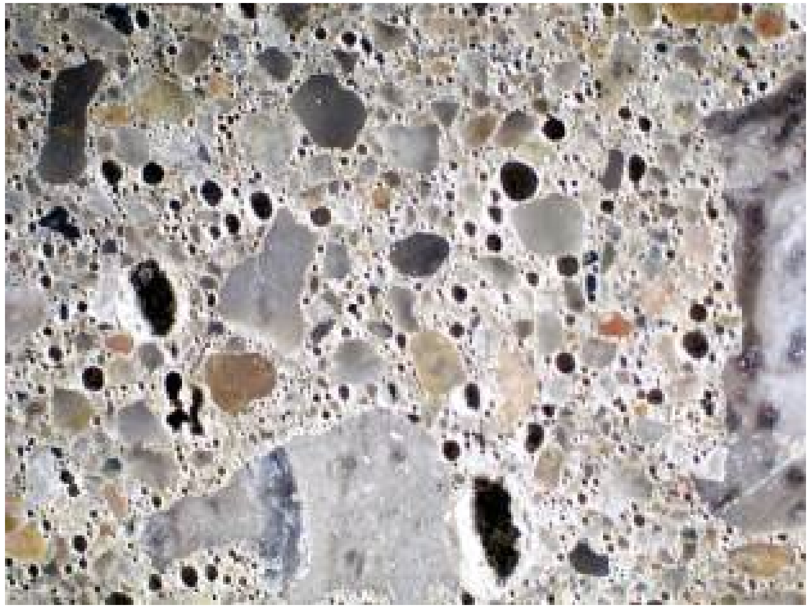
What are Chemical Admixtures?

- Substances used to modify fresh or hardened properties of concrete for design and construction purposes
- Types:
  - Air entraining
  - Water reducing
  - Accelerating and retarding
  - Viscosity-modifying
  - Shrinkage- and crack-reducing
  - Plus many more

Air Entraining Admixtures

- Provide resistance to freezing and thawing
- Added immediately before or during mixing
- Act by helping form and stabilize air bubbles inside concrete





Air Entraining Admixtures

- Other effects of entrained air:
  - Protects against scaling
  - Improves workability of fresh concrete
  - Reduces needed water content
  - Reduces strength of hardened concrete (more air, lower strength)

Air Entraining Admixtures

- Controlling air content
  - Some air may be lost in transit to the project site & during placement
  - Greater amounts of fine materials can reduce air entrainment, requiring a higher dose of AEA
  - Less air is entrained as temperature increases, so more AEA may be needed at higher temperatures

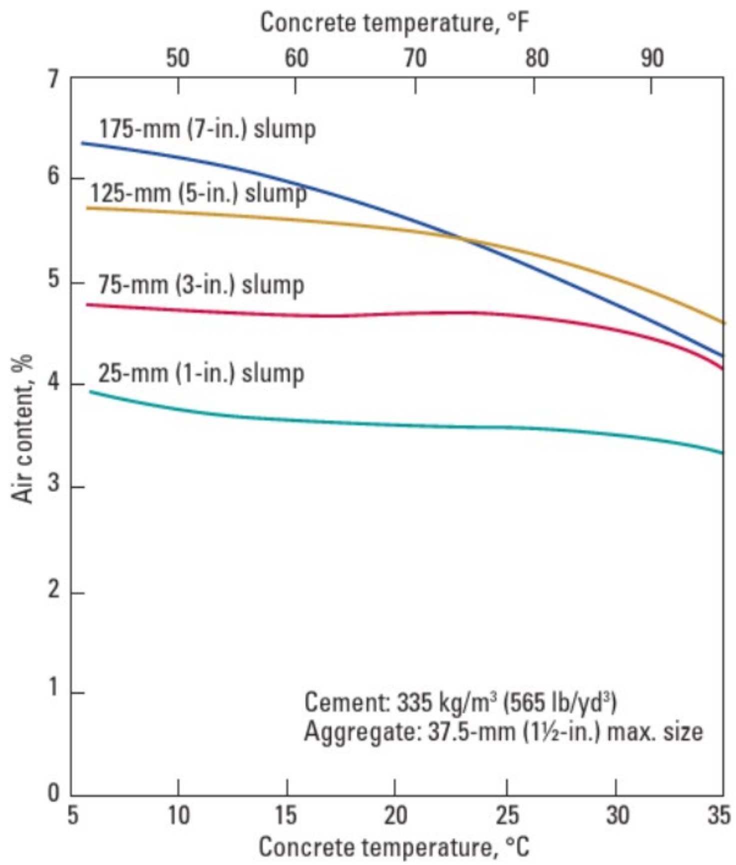
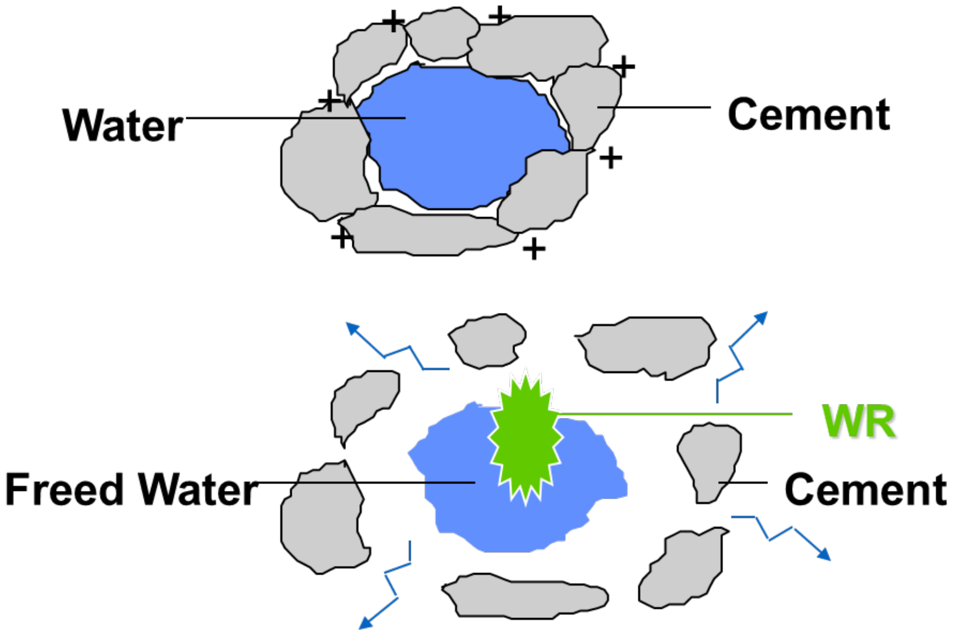


FIGURE 9-16. Relationship between temperature, slump, and air content of portland cement concrete (PCA 1948 and Lerch 1960).

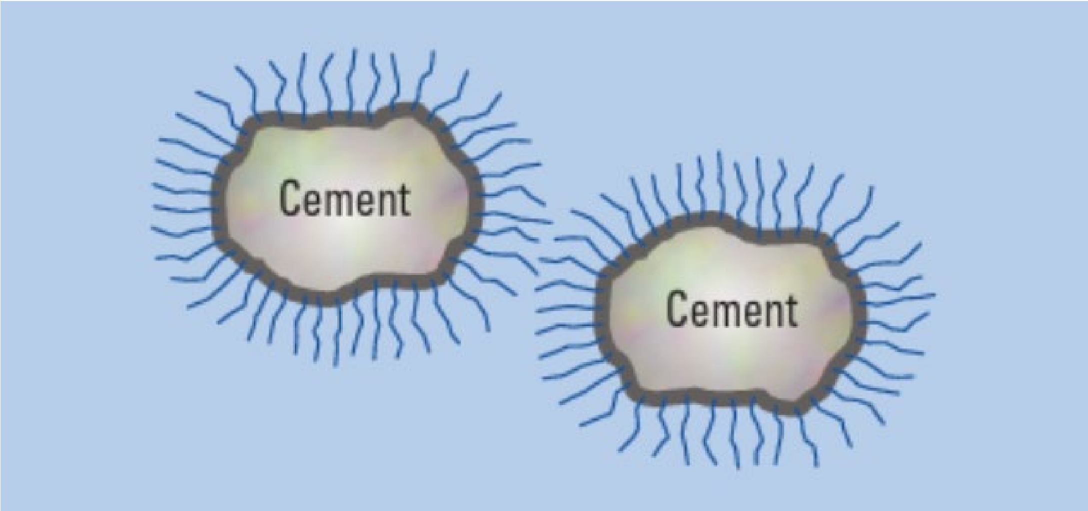
Water Reducing Admixtures

- Increase workability of plastic concrete without adding water
  - Very useful to maintain a low w/cm in certain mixes, which is important for long-term durability!
- Disperse clusters of cement particles to free trapped water



Water Reducing Admixtures

- Grades of water reducing admixtures:
  - Normal range or conventional water reducers
  - Mid-range water reducers
  - High-range water reducers, or superplasticizers
- Other effects:
  - May delay time of set
  - May affect air entrainment



Water Reducing Admixtures

- Water reducers are especially useful when placing fixed form or hand-finished pavement sections
  - Lower paste content and low w/cm (particularly for C-SUD mixes) can make the mix more difficult to finish
- CP Tech Center, ICPA, and Iowa DOT are currently working on additional guidance on use of water reducing admixtures
  - Also working on a potential new higher-durability paving mix specification for handwork (C-SUDHW)

Accelerating Admixtures

- Increase the rate of hydration of concrete
- Increase strength development at early ages
- Added with mixing water
- Most commonly consist of calcium chloride ($CaCl_2$)

Accelerating Admixtures

- Useful when:
  - Setting time is slowed during cold weather
  - Higher early strength is needed
    - Overnight roadway repair
- May increase risk of shrinkage cracking
- Caution with use in reinforced concrete
  - Corrosion risk
  - Non-chloride accelerators are available

Retarding Admixtures

- Delay setting time and extend slump life
- Consist of materials like lignin and glucose
- Useful for:
  - Slowing setting time when faced with hot weather, long hauls, or delays
  - Reducing early temperature rise
  - Special finishing techniques
    - Exposed aggregate surfaces
- Also have a water reducing effect

Hydration Stabilizers

- Newer alternative admixture for delaying setting time and extending slump life
- Consist of materials such as gluconates, phosphates, sucrose
- More expensive, but more efficient and predictable than conventional retarders
- Have minimal-to-no water-reducing effect

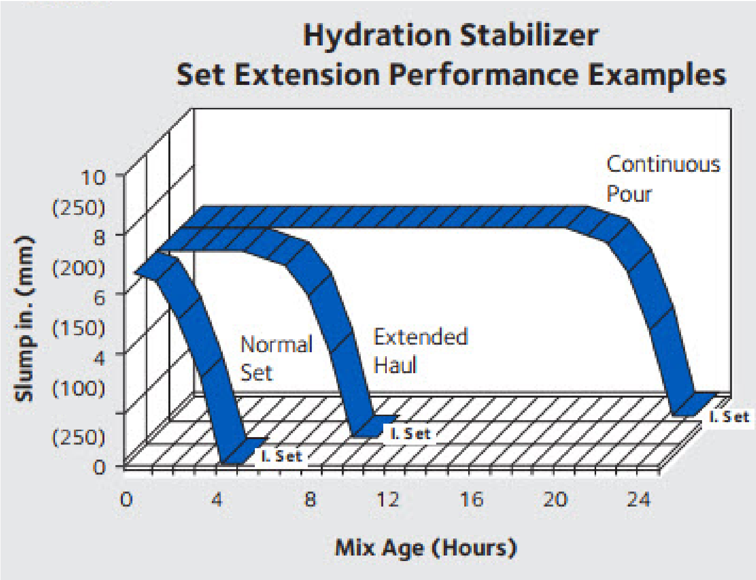


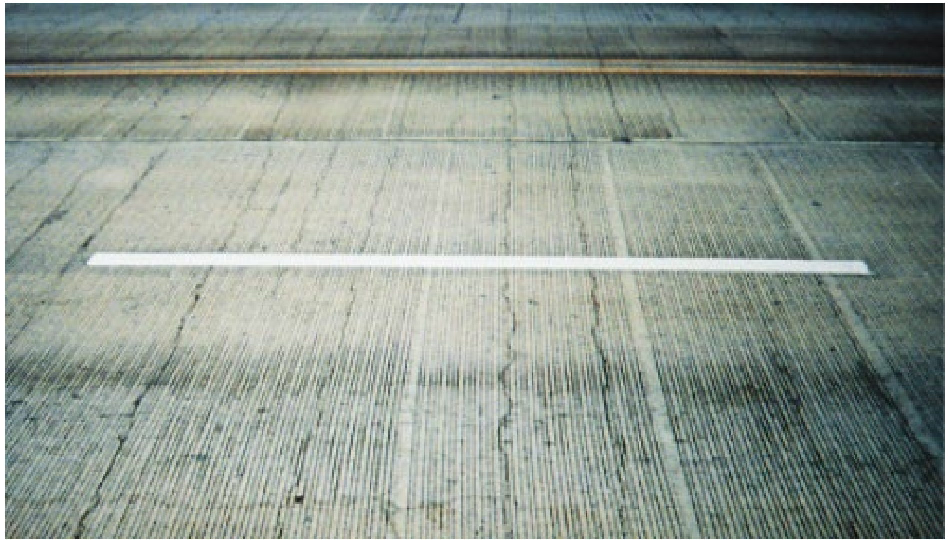
Image: Chryso Inc.

Viscosity Modifying Admixtures

- Increase the viscosity of water
- Produce a more cohesive concrete mix that is less prone to segregation when it is still in its plastic state
- Useful for:
  - Mixes prone to segregation
  - Self-consolidating concrete (SCC)
  - Pumped concrete
  - Concrete placed underwater

Shrinkage Reducing Admixtures

- Reduce drying shrinkage by reducing surface tension of the liquid phase, helping prevent shrinkage cracks
- Useful for:
  - Preventing and reducing shrinkage cracks in bridge decks
  - Minimizing curling and warping of floor slabs



Other Concrete Additives

Carbon Dioxide Sequestration

- A number of systems are available to inject waste CO_2 gas into concrete during mixing
- CO_2 reacts with constituents and mineralizes into solid byproducts
- Iowa DOT allows a 3% reduction in cement content (about 15 to 20 lbs/cy) when using a carbon sequestration admixture (IM 403)

Image: CarbonCure

Surface Sealers

- Penetrating **surface sealers** are applied to protect pavement surfaces and joints from water and de-icing chemicals
- Several types of sealers are available
  - Silanes and siloxanes (pore lining)
  - Crystalline-based, e.g. Pavix (pore blocking)
  - Linseed or soybean oil (pore blocking)
  - Others
- Application rate, timing, effectiveness, and need for re-application depend on the product

Finishing Aids

- **Finishing aids** consist of **colloidal silica**
  - Dense, amorphous $SiO2$ nanoparticles
  - Pozzolanic and highly reactive
- Applied to the surface to aid finishing and ultimately produce a more dense, durable, abrasion-resistant surface

Images: Lythic Solutions

Evaporation Retardants

- **Evaporation retardants** are water-based organic compounds that form a film on the surface to prevent rapid moisture loss
- Although they are applied to the surface, they are not finishing aids and should not be worked or finished into the surface!
- Must allow them to evaporate before finishing

Image: Deco-Crete

Nanomaterials

- A number of companies are beginning to introduce a variety of **nanomaterial**-based admixtures:
  - Colloidal silica, or nano silica
  - Crystalline C-S-H
  - Others?
- These materials are being marketed for a variety of purposes:
  - Strength enhancing
  - Hydration enhancing
  - Improved durability
  - Reduce cement content

Nanomaterials

- Work is ongoing to better understand the effects of nanomaterials on fresh and hardened concrete properties, and how to evaluate and specify different products
- Be wary of claims that external curing is no longer needed when using these types of products

Image: Justin Dahlberg, ISU


National Concrete Pavement Technology Center
Tech Center
Iowa State University
Institute for Transportation