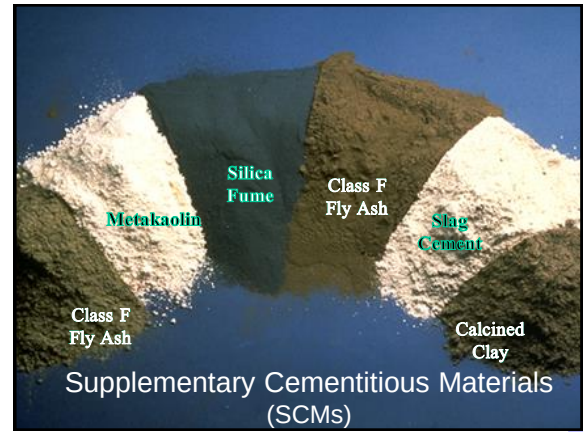
Supplementary Cementitious Materials (SCMs)

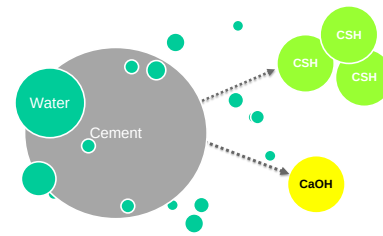
Ohio Precast Concrete Association
March 2017 Meeting

Jay Whitt
Lehigh Cement
Technical Services Engineer

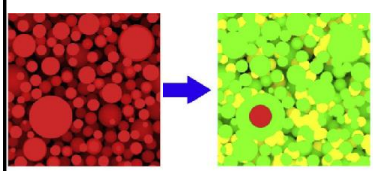


SCMs in Concrete: on a micro-scale

Cement Hydration:

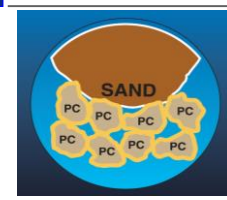


Hydration Schematic



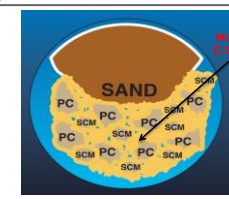
Source: Theoretical and Applied Fracture Mechanics - August 2014

SCMs effect on hydration



Ordinary portland cement (OPC) mixture

Cement hydrates:
- C-S-H is formed (yellow); this glue holds concrete together.
- Gaps in this glue provide pathways for moisture to penetrate and reduce strength.



Supplementary cementitious materials (SCMs) added

SCM hydration process:
- particles pack more tightly within the voids and additional glue forms. Fewer voids
- Concrete is less permeable and stronger.

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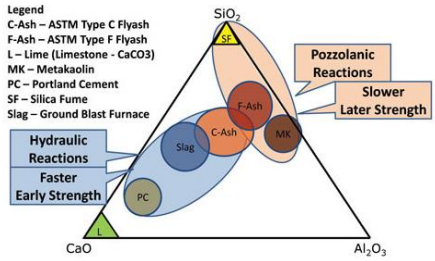
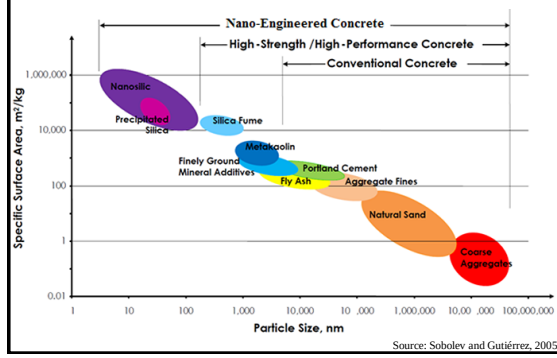
Cementitious Chemistry



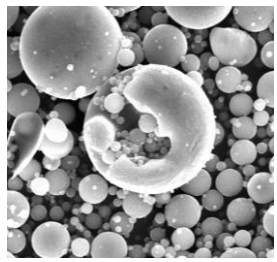
Source: IRC November 2013

Concrete Mixture Particle Sizes



Source: Sobolev and Gutiérrez, 2005

Fly Ash



Source: NCPA

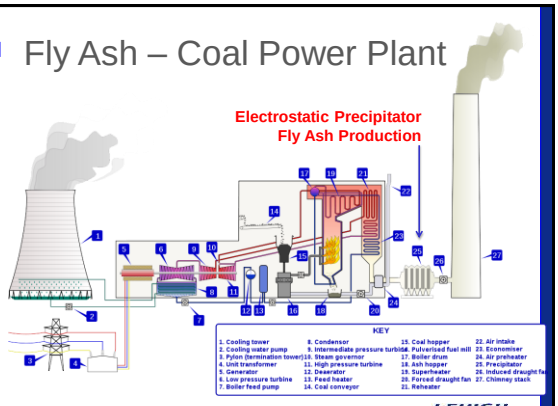
Fly Ash Overview

Defined by ACI Committee 116:
as "the finely divided residue **resulting from the combustion of ground or powdered coal**, which is transported from the firebox through the boiler by flue gases." Fly Ash is mostly a by-product of coal-fired electric plants. ASTM C618

- There are **two classifications** of Fly Ash, based on the type of coal used.
  1. Class F is produced by burning anthracite and bituminous coal.
  2. Class C is produced by burning lignite or subbituminous coal.
- More than 50% of the concrete placed in the U.S. contains fly ash.
- **Dosage rates** vary depending on the type of Fly Ash and its reactivity
  Typical dosages by mass of cementitious material:
  - Class F 10% to 20%
  - Class C 15% to 40%.

Source: ACI - American Concrete Institute

Fly Ash – Coal Power Plant



Fly Ash Benefits in Concrete

- Improves concrete workability and lowers water demand.
  Spherical particles decrease water required & increase pumpability.
- Less bleeding and segregation than plain concretes.
- **Sulfate and Alkali Aggregate Resistance**.
  Class F and a few Class C Fly Ashes impart significant sulfate resistance and alkali aggregate reaction (ASR) resistance to the concrete mixture.
- Fly Ash has a **lower heat of hydration**.
  The use of fly ash may greatly reduce this heat build up and reduce external cracking.
- Fly ash can be economical.

Consider longer set times and lesser initial strength gains

Source: American Coal Ash Association

Silica Fume

Silica Fume Overview

Defined by ACI Committee 116: as "very fine noncrystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon (SiO_2) or alloys containing silicon". It is usually a gray colored powder, somewhat similar to portland cement or some fly ashes. ASTM C 1240.

- Silica fume is a **by-product of producing silicon metal or ferrosilicon alloys** in smelters using electric arc furnaces.
- Typically, silica fume is used at dosages of 3-10% by mass of cementitious material.

Source: ACI - American Concrete Institute

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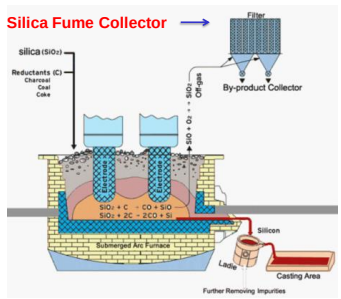
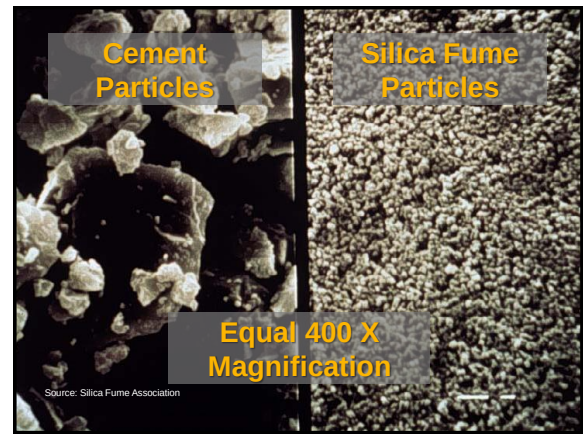
Electric Arc Furnace

An **electric arc furnace** (EAF) is a furnace that heats charged material by means of an electric arc.

Silica Fume is collected from the "off-gas" in a by product collector.

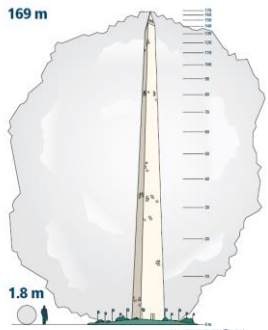


Source: Silica Fume Association



Silica Fume particle size

Silica fume consists of very fine particles about **100 times smaller** than the average cement particles.



Source: Silica Fume Association

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Benefits of Silica Fume to concrete

- **Increased compressive strength & reduced permeability**
  1. Micro-Filling: an ultra fine material that fills concrete voids & capillary channels.
  2. Pozzolanic Reaction: reacts with calcium hydroxide forming more calcium silicate hydrate gel. So water and chloride ions (from deicing salts that corrode reinforcing steel rebar) cannot penetrate
- Less expansion of the concrete due to alkali-silica reactivity
- Electrical resistivity 20-100 greater than ordinary concrete
- Increased abrasion resistance
- Superior resistance to chemical attack from chlorides, acids, nitrates and sulfates
- **Most often used** in high-performance concrete.

Consider increase water demand and /or admixtures needed, also stickiness or surface finishing challenges, and increase mixing

Source: Federal Highway Administration

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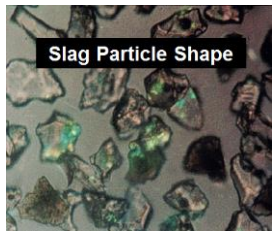
Slag Cement



Overview of Slag Cement

Defined by ACI Committee 116:
As "granulated blast-furnace slag that has been finely ground and is a hydraulic cement."

- Slag Cement is a nonmetallic product, consisting essentially of silicates and aluminosilicates of calcium and of other bases, that is developed in a molten condition simultaneously with iron in a **blast furnace**
- Typically **dosages range** from 15 to 40% by mass of cementitious material with ranges higher based on project specific.

What is Slag Cement?

- Slag Cement has similar chemistry to portland cement in that both contain almost the same chemical elements, although in differing percentages
- Non-metallic product of an iron blast furnace
- Granulated then grounded
- Cementitious material
- ASTM C989: Grade 80,100, & 120

Benefits of Slag Cement to concrete

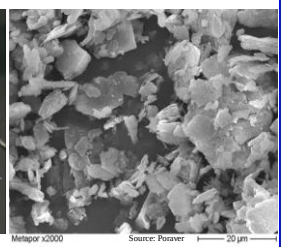
Slag cement **improves the performance** of concrete and provides for a more environmentally sustainable concrete mixture.

- Improved workability
- Easier placeability and finishability
- Higher long-term compressive and flexural strengths
- Reduced permeability
- Improved durability
  - **higher resistance to ASR and Sulfate**
- More consistent performance
- Lighter color

Consider longer set times and lesser initial strength gains

Metakaolin:

Source: Burgess Pigment Company



Metapor x2000 Source: Poraver 20 µm

a natural pozzolan

Overview of Metakaolin

Defined by PCA Design and Control:
As "a calcined clay which is produced by low-temperature calcination of kaolin clay. Consisting of predominately silica and alumina."
ASTM C618

- Metakaolin is a calcined between 600° and 850°C from **kaolin stone** that is transformed to an amorphous phase called metakaolin. Reacts with the CaOH of the cement /or lime reactions. (reference: http://www.metakaolin.info/general-description.html)
- First used for the construction of large dams in Brazil in the 1960s, to suppressing any damage due to alkali-silica reaction.
- Typically **dosages range** from 5 to 20% by mass of cementitious material.

Benefits of Metakaolin

- Increase **strength**: compression & flexural
- Reduce permeability
- Improve finishability
- Reduce efflorescence
- Lower cement content (lower shrinkage)
- Eliminate bleed water - capillary channels
- Increased chemical resistance & durability
- **Reduce ASR** (Alkali Silica Reaction) By replacing 8%-20% of the cement in a mix design

Consider: increase water demand & proper curing required to get full benefit. Slight increase in heat of hydration.

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Blended Cements & Ternary Mixes

- Ternary concrete mixtures include **three different cementitious** materials.
- The most common ternary mixes are portland, slag cement and fly ash, and portland, slag cement and silica fume.

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Performance in Concrete: Slag Cement & Fly Ash Study

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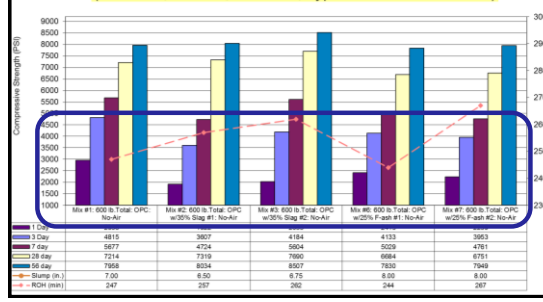
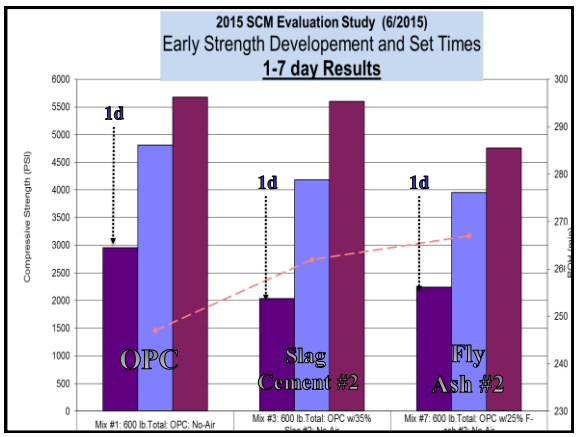
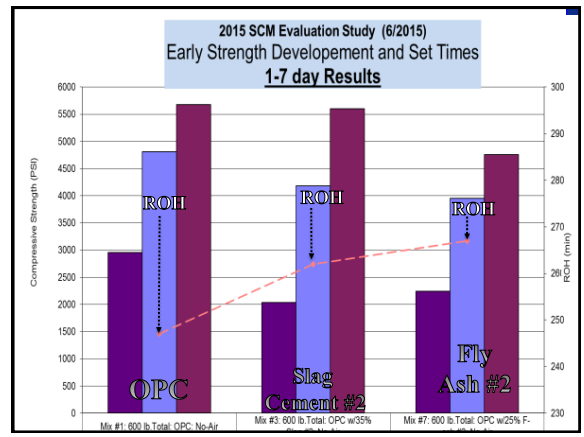
SCM Performance Characteristics

2015 SCM Evaluation Study (6/2015)
Compressive Strength (psi) & ROH & Slump
(600 Total, Non-Air, w/c=0.48, Type I/II reference cement)





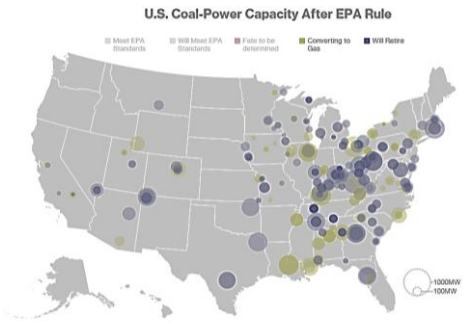


SCM Availability for the Ohio Market

Fly Ash Availability

Coal Produced Power Plants

Coal Power Plants without Fly Ash



Source: U.S. Energy Information Administration

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Fly Ash Companies in the Ohio Market

Nearly all fly ash supply is derived from coal-fired power plants with a minor supply coming from Alcoa, the world's leading producer of aluminum.

- Ameren Energy Fuels
- Boral Material Technologies, Inc.
- Charah Inc.
- Waste Management (Fly Ash Direct)
- Headwaters Resources
- Holcim Inc.
- Lafarge North America
- Mineral Resources Tech (MRT)
- SEFA Group
- Titan (Ash Ventures)

Source: Department of Transportation

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Slag Cement Sourcing the Ohio Market

- Middlebranch, OH: Terminal & Grinding
- Marysville Terminals
- Cincinnati Terminals
- Chicago, Ill.: Terminals & Grinding

See SCA website for more locations

Metakaolin Sourcing

- Several sources from Georgia
- Typically bagged available in bulk
- Slightly less than cost of silica fume