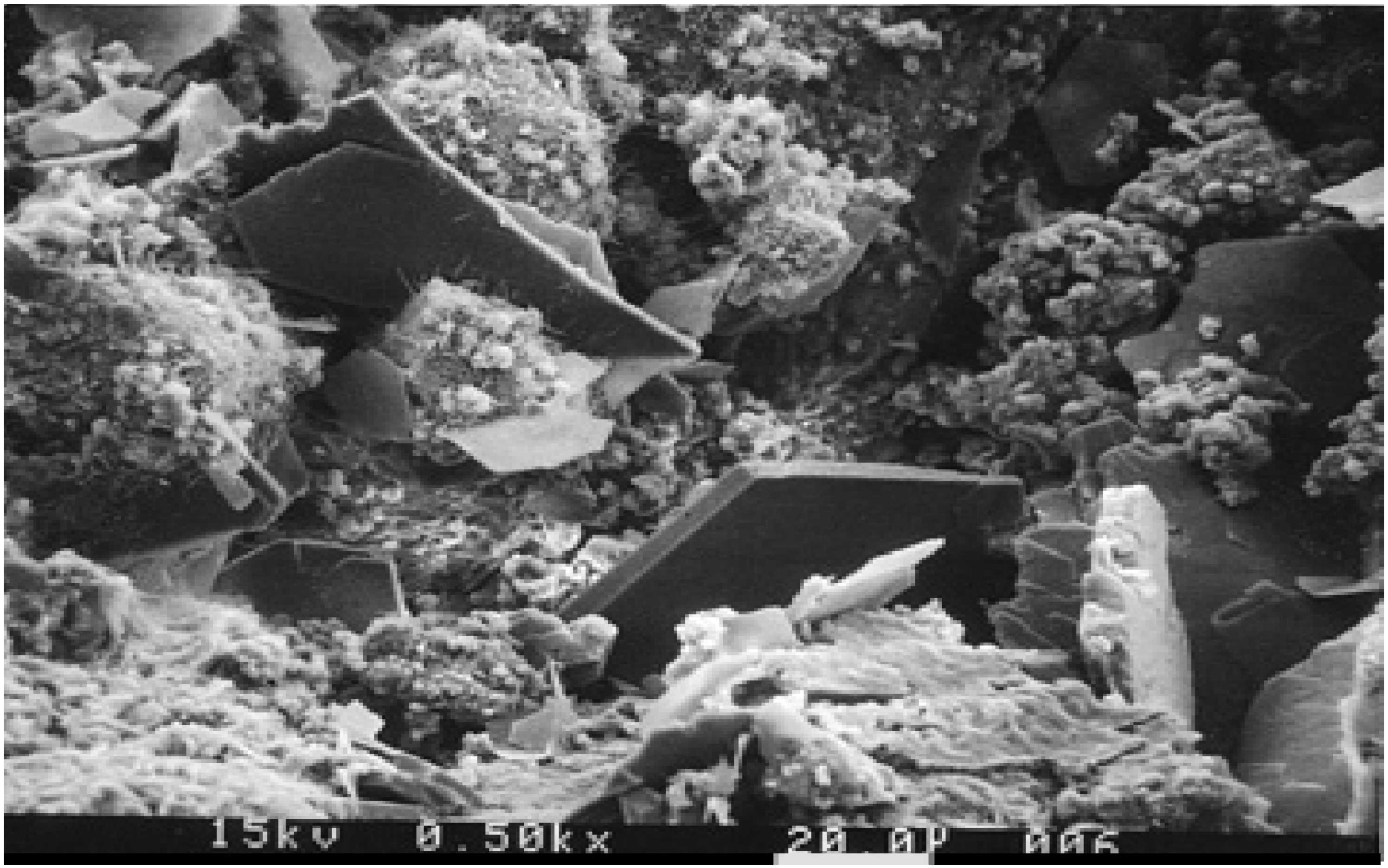
Concrete Technology and Codes

Cementitious Materials

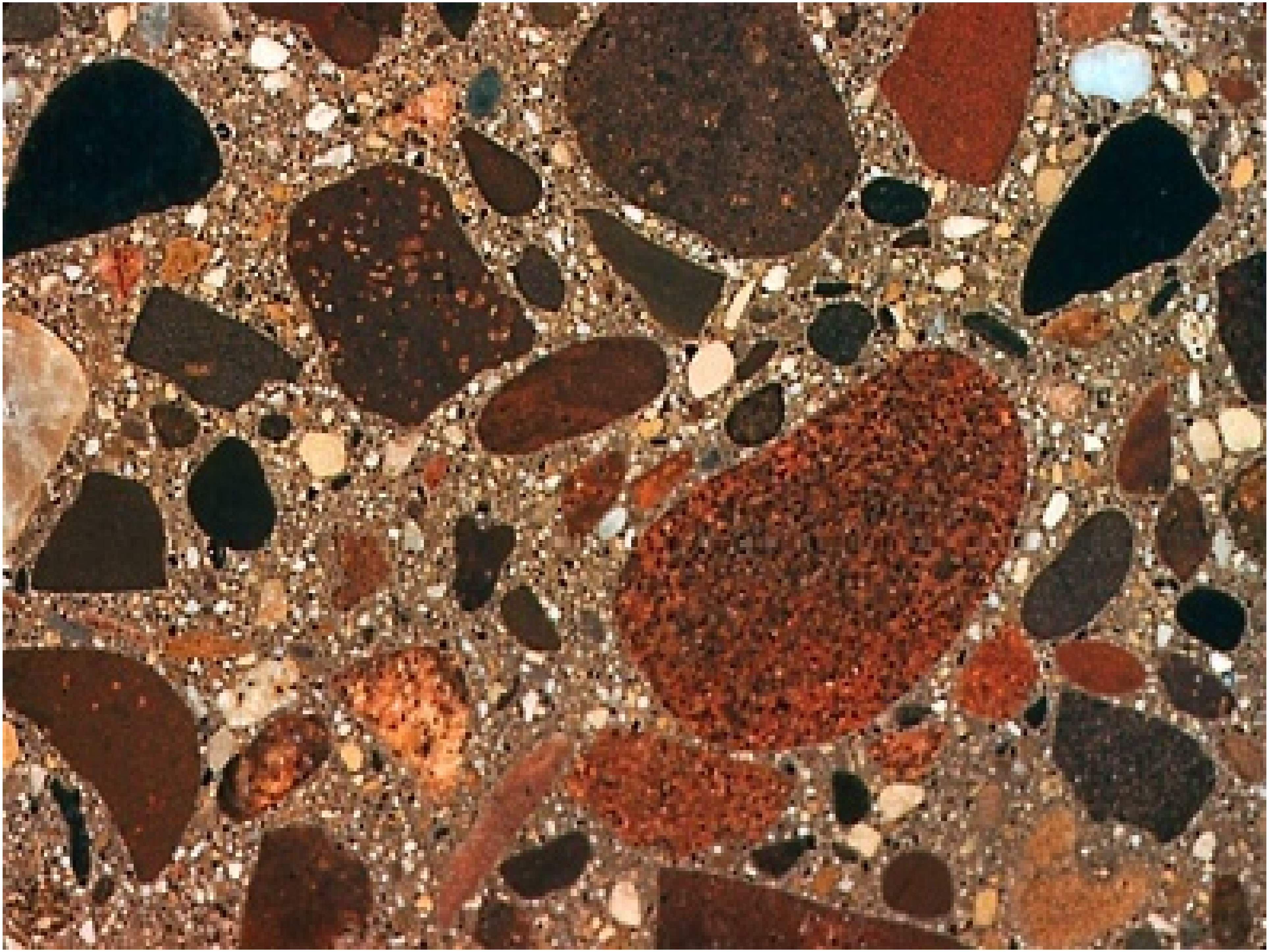



Illinois
03-04
4C0068532
6 BAG MX
B TRUCK
Land of Lincoln
BUMPER CAPACITY ONLY
VEHICLE CAPACITY
MAY DIFFER
SEE OWNER'S GUIDE

Standards

- *American Society for Testing and Materials* (ASTM) www.astm.org
- *American Association of State Highway and Transportation Officials* (AASHTO) www.aashto.org
- *Canadian Standards Association* (CSA) www.csa.ca

Cement is to Concrete as Flour is to Cake...



Paste, Mortar, & Concrete

9 - 15%
Cement

15 - 16%
Water

Paste
(cement + water)

25 - 35%
Fine aggregate

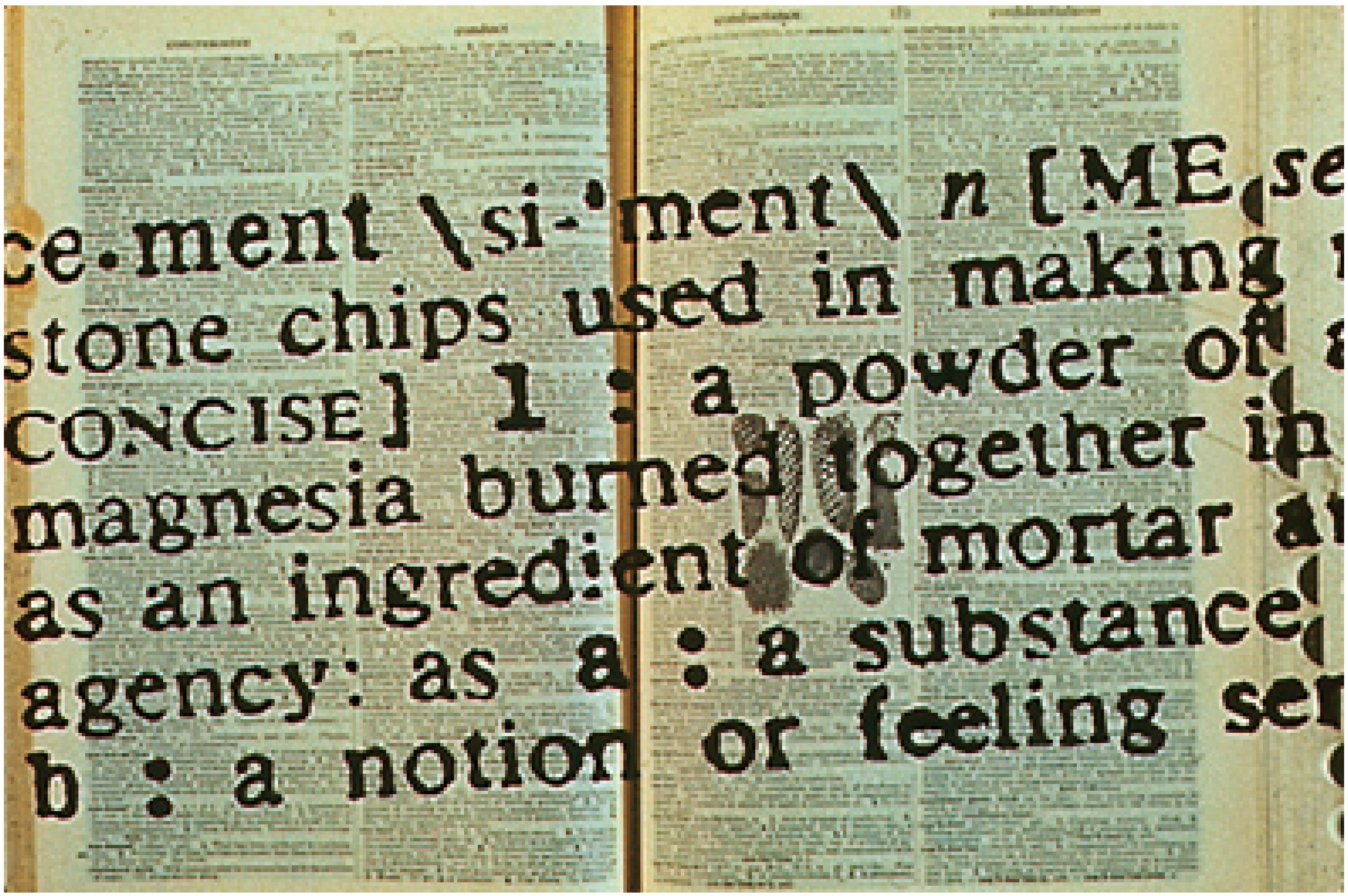
Mortar
(paste + fine aggregate)

30 - 45%
Coarse aggregate

Concrete
(mortar + coarse aggregate)

Discussion

- Properties of Cementitious Materials



Portland Cement...

A. Was named after where it was first made; Portland, Oregon
B. Was named after the man who patented it from Portland, Maine
C. Is a brand name
D. Got its name from a stone it resembled on the Isle of Portland off the British Coast.

Isle of Portland Quarry Stone next to a Cylinder of Modern Concrete

Today’s Cement

- Still relies on Aspdin’s raw materials of:
  - Lime (Calcium)
  - Iron
  - Silica
  - Alumina

Plus:

Gypsum

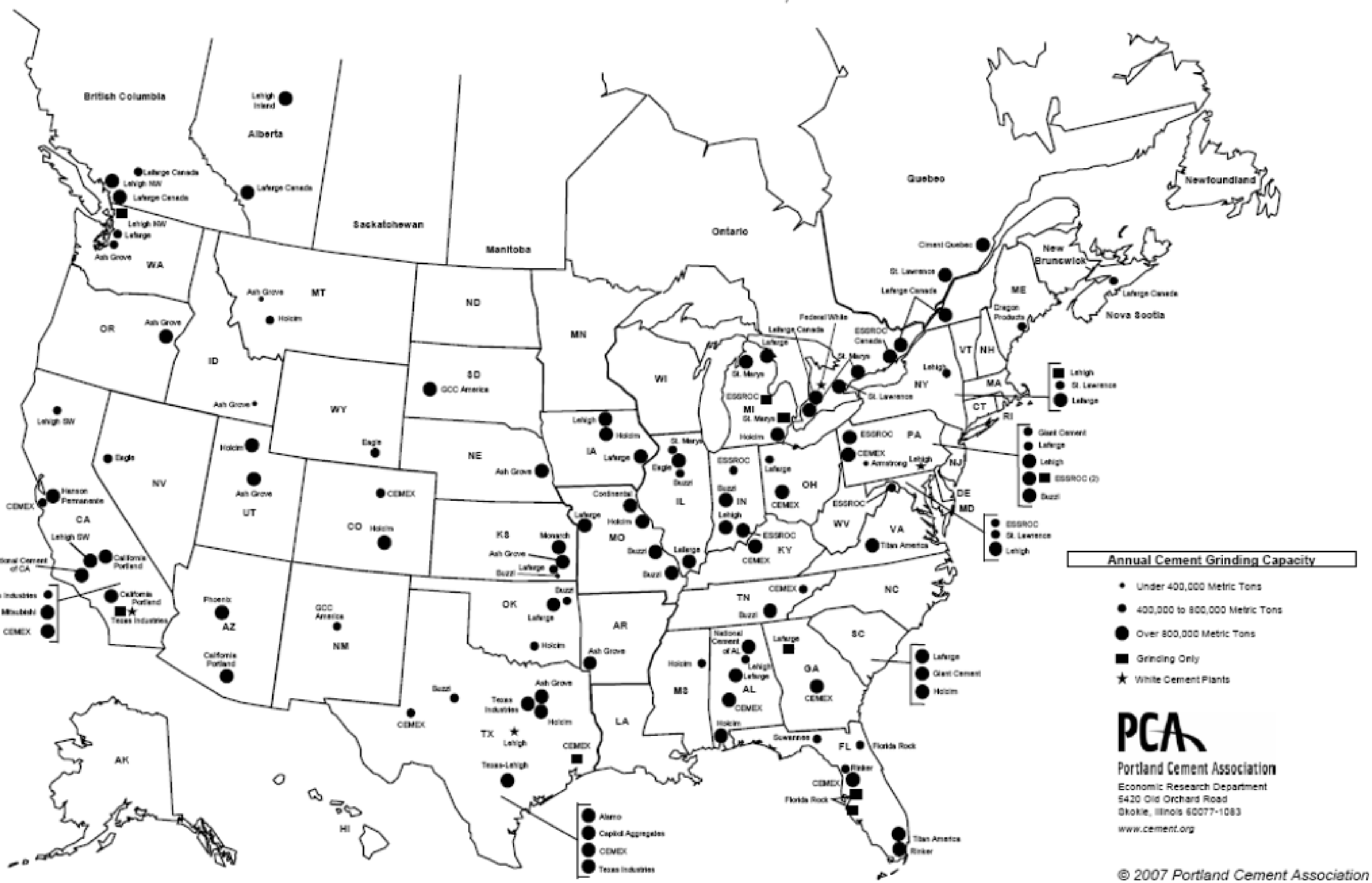
Cement Industry

- 30 cement companies in US
- 105 portland cement plants (3)
- 178 kilns
- 10 grinding-only facilities
- 94.7 MMT clinker capacity
- Top 5—about 51% of capacity

2006 Plant Information Summary

United States and Canadian Portland Cement Plant Locations

Plant Data as of December 31, 2006



Cementitious Materials

- Hydraulic cements
- Supplementary cementitious materials (SCMs)

Hydraulic cement – reacts (hydrates) and hardens under water

Pozzolan – reacts with cement and water

Specifying Cements

- Portland cement (ASTM C150 / AASHTO M 85)
- Blended cements (ASTM C595 / AASHTO M 240)
- Performance specification for hydraulic cements (ASTM C1157)

Portland Cement

- Type I- Normal
- Type II- Moderate Sulfate Resistance
- Type III- High Early Strength
- Type IV- Low Heat of Hydration
- Type V- High Sulfate Resistance

Specified by: ASTM C150 (AASHTO M 85)

Resistance to Sulfates

Examples of Sulfate Attack
in Concrete Structures

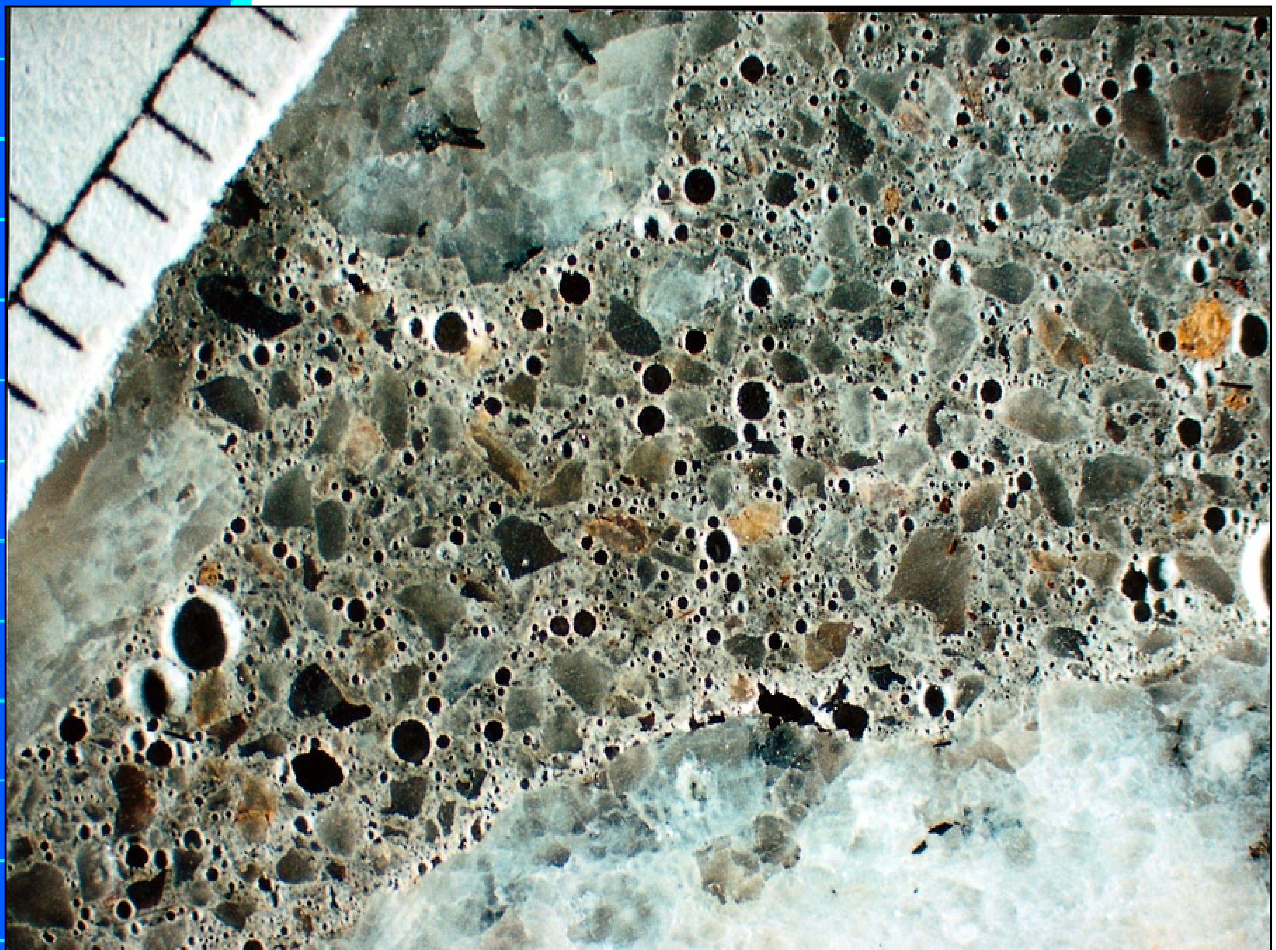
High Early Strength

Low Heat of Hydration

Low-Alkali Cements

- Low-alkali cement ≤ 0.60% Na_2O_{eq}
- To control expansion due to alkali-silica reactivity (ASR)

Air-Entraining Cement



- Type IA
- Type IIA
- Type IIIA

Specified by: ASTM C150

White Cement

Specified by: ASTM C150

Blended Cements

- IS (x)   (slag)
- IP (x)   (pozzolan)

Specified by: ASTM C595

Performance Cements

GU	General use
HE	High early strength
MS	Moderate sulfate resistance
HS	High sulfate resistance
MH	Moderate heat of hydration

Specified by: ASTM C1157

Specialty Cements

- Masonry and Mortar Cements
- Plastic cements
- Ultra-fine cements
- Expansive cements
- Oil-well cements
- Geopolymer cements
- Cements with functional additions
- Water-repellent cements
- Regulated-set cements
- Rapid hardening cements
- Calcium aluminate cements
- Magnesium phosphate cements
- Sulfur cements

Applications

	ASTM C150 Portland Cements	ASTM C595 Blended Cements	ASTM C1157 Hydraulic Cements
No special properties required	I or II	IS, IP	GU
Moderate heat of hydration	II	IS(MH), IP(MH)	MH
Moderate sulfate resistance	II	IS(MS), IP(MS)	MS

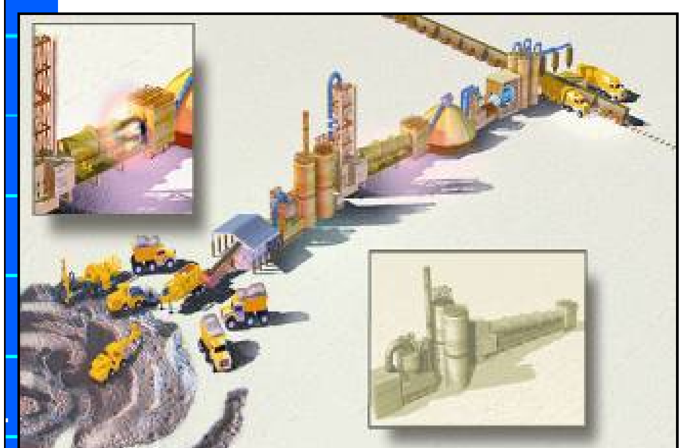
Applications

	ASTM C150 Portland Cements	ASTM C595 Blended Cements	ASTM C1157 Hydraulic Cements
High early strength	III		HE
Low heat of hydration	IV	IP(LH)	LH
High sulfate resistance	V		HS
Resistance to ASR	Low-alkali option	Low-reactivity option	Option R

Raw Materials

Table 2-1 PCA Design and Control

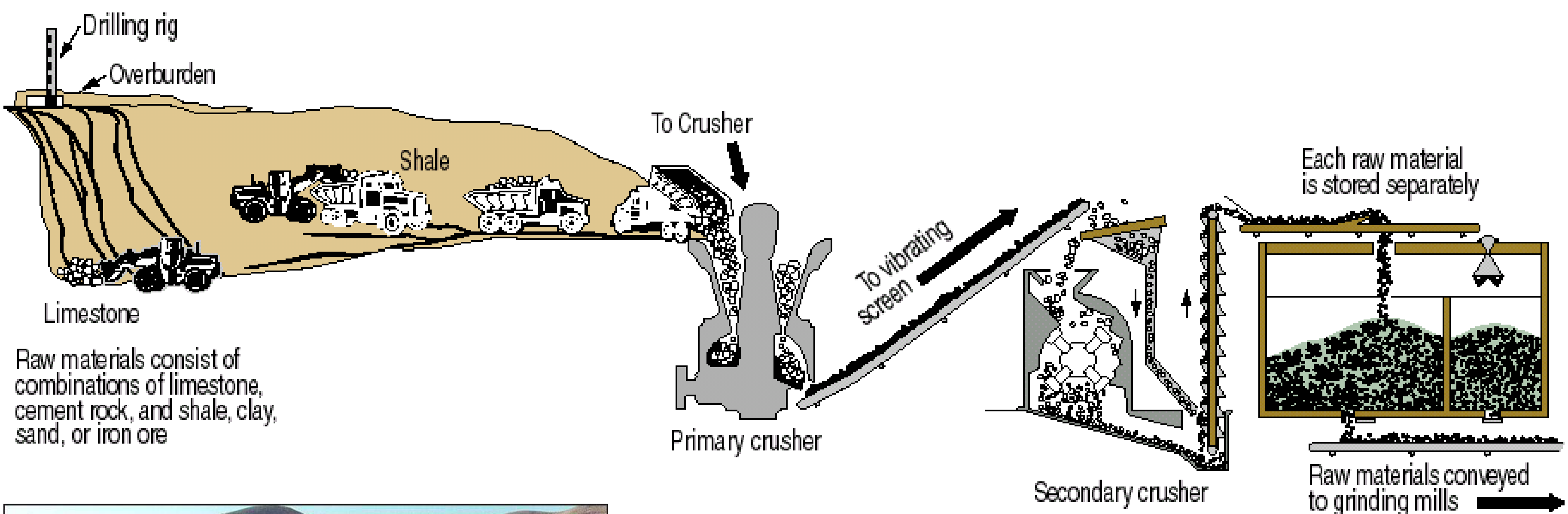
Lime	CaO (C)	~60%	Limestone, calcite
Silica	SiO_2 (S)	~20%	Clay, shale, fly ash
Alumina	Al_2O_3 (A)	~10%	Clay, shale, bauxite
Iron	Fe_2O_3 (F)	~10%	Iron ore, clay, mill scale
Sulfate	SO_3 ($\bar{S}$)	~3%	Gypsum, anhydrite

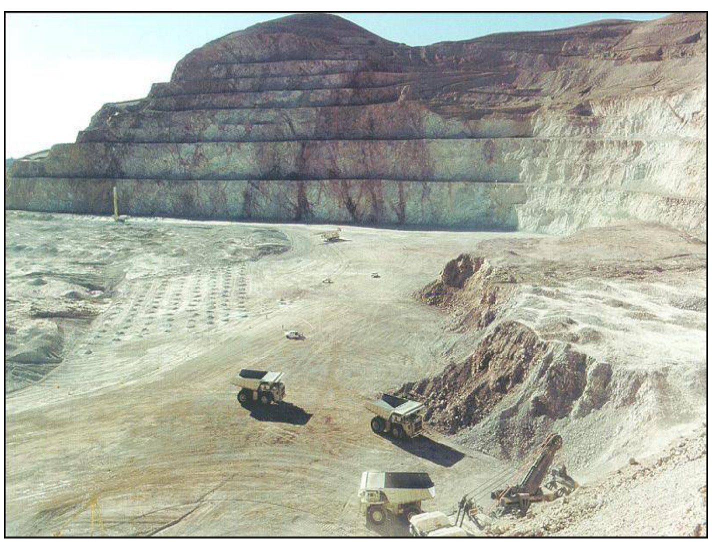


"LISA" + Gypsum

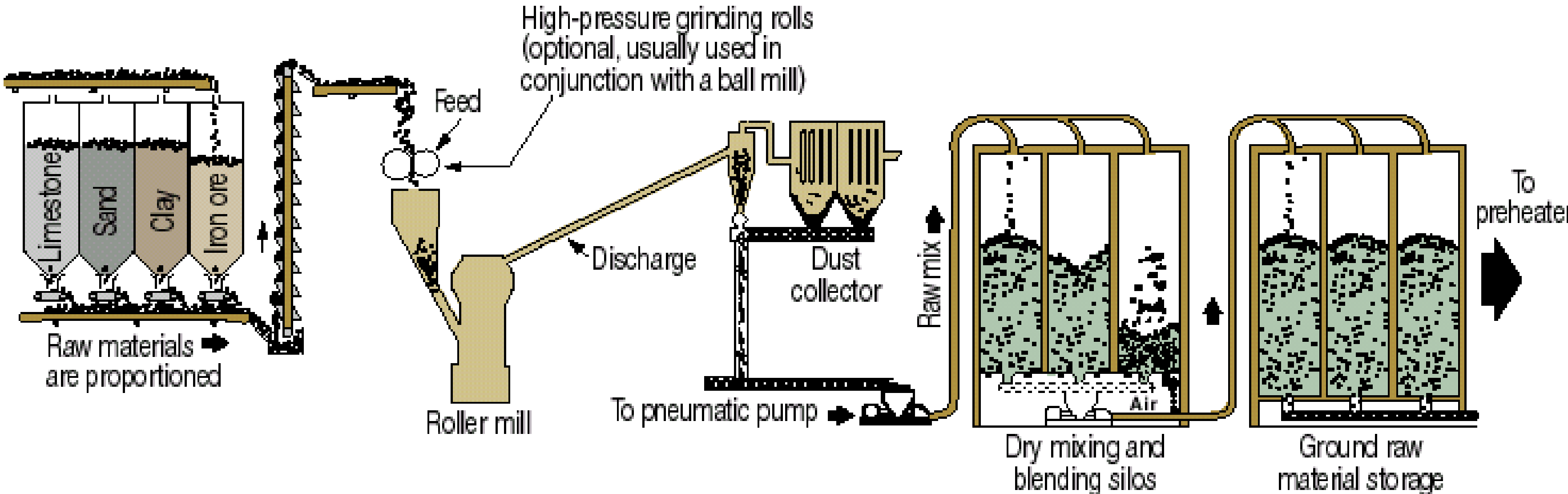
Baking a Cake...

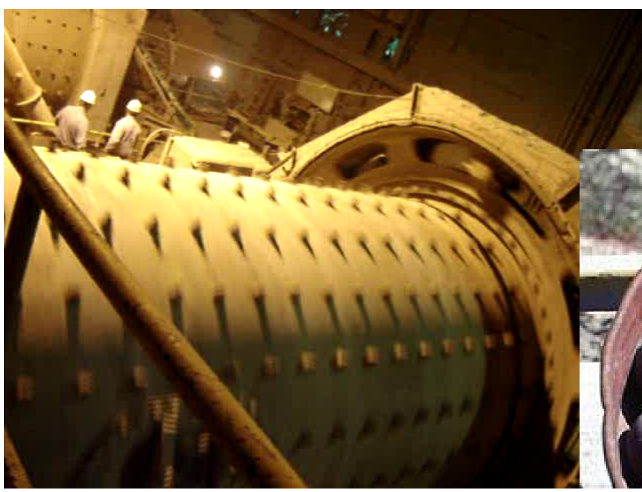
Manufacturing Portland Cement



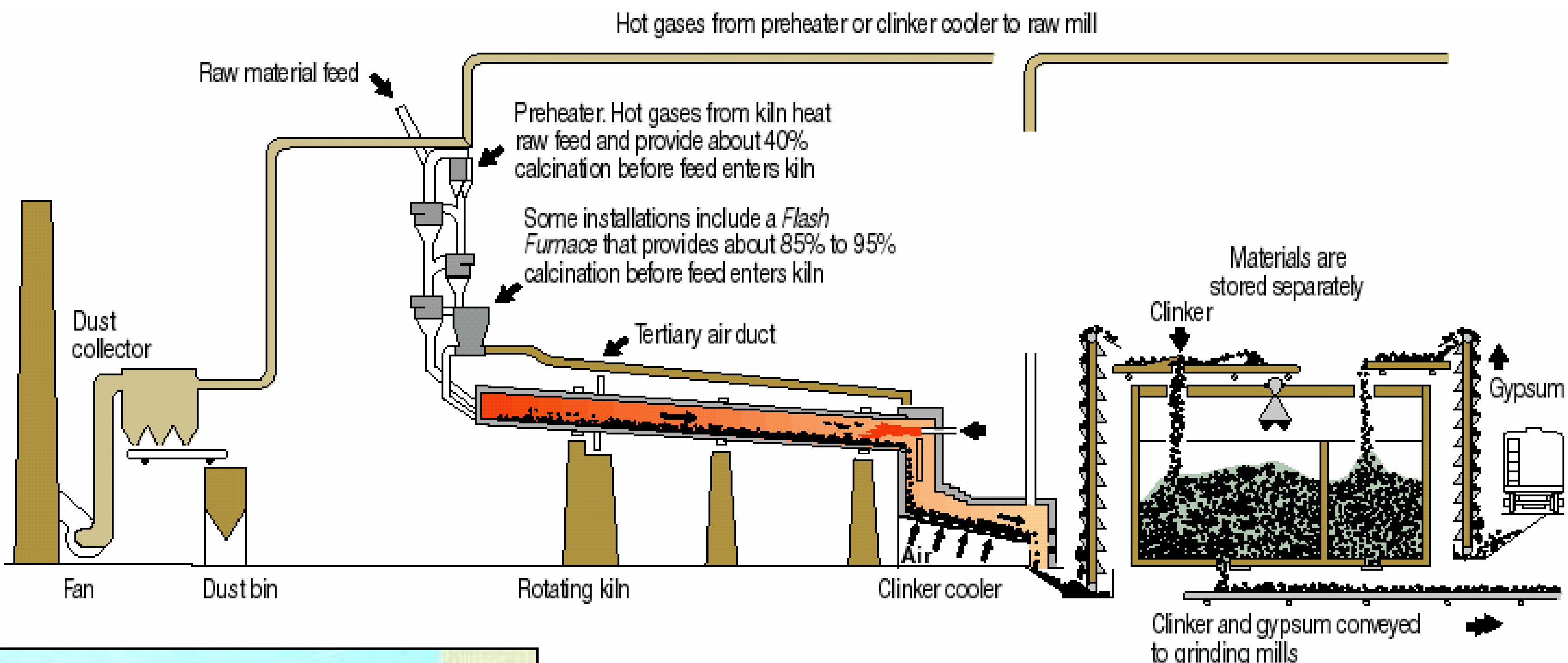


Manufacturing Portland Cement

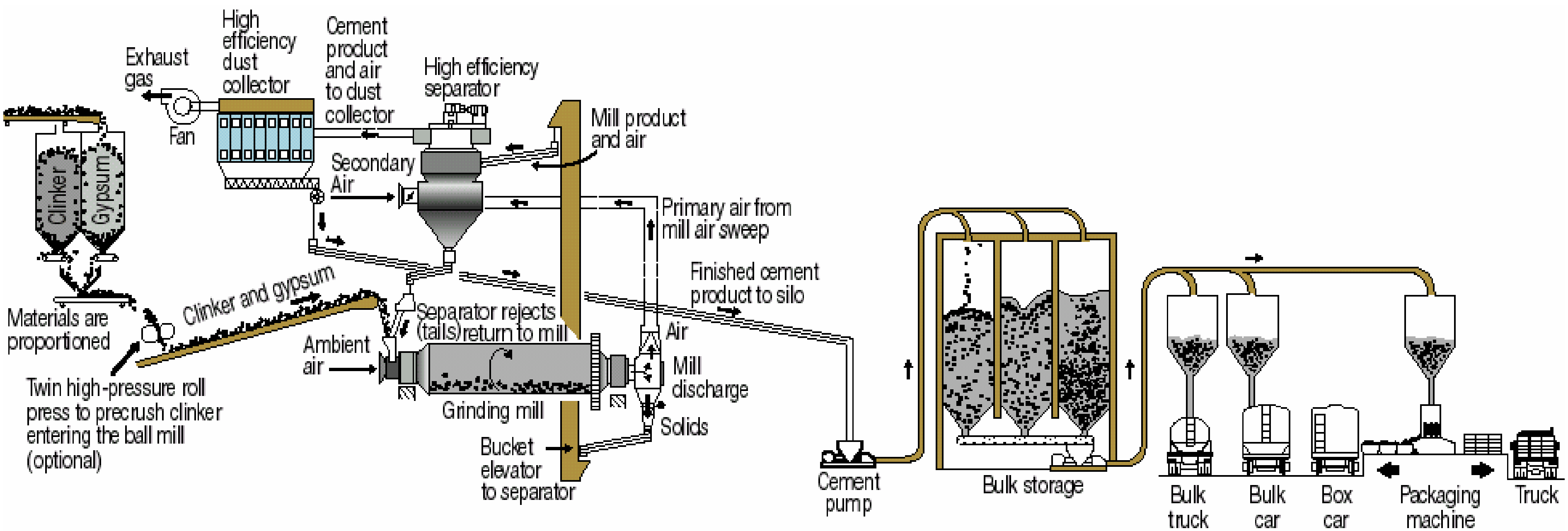




Manufacturing Portland Cement

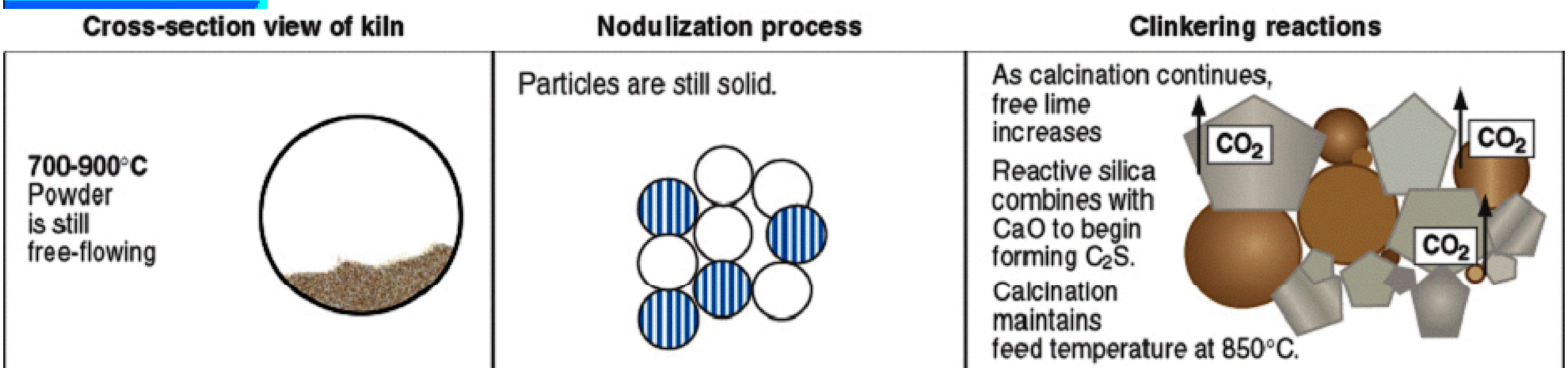


Manufacturing Portland Cement

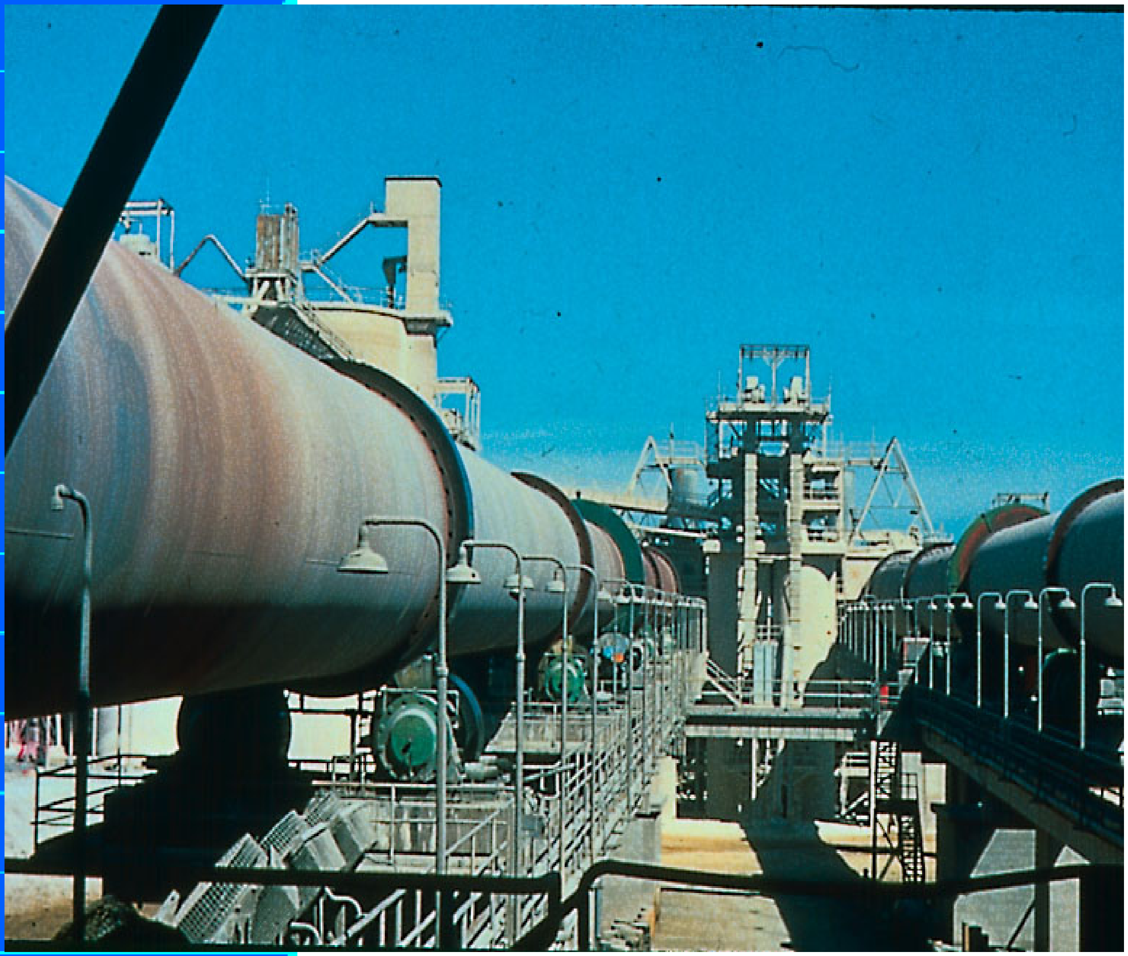


The Oven… A Cement Kiln

- 1300-1650°F: Starting at 1100°F - Calcining, decomposition of $CaCO_3$ (endothermic)
  - Calcination: $CaCO_3 \rightarrow CaO + CO_2\uparrow$



How do we fuel the kiln?



- Coal
- Oil
- Natural gas
- Waste

Waste?

- Scrap Tires
- Used Motor Oil
- Paper Industry By-Products
- Sludge
- Agricultural

ASTM C150

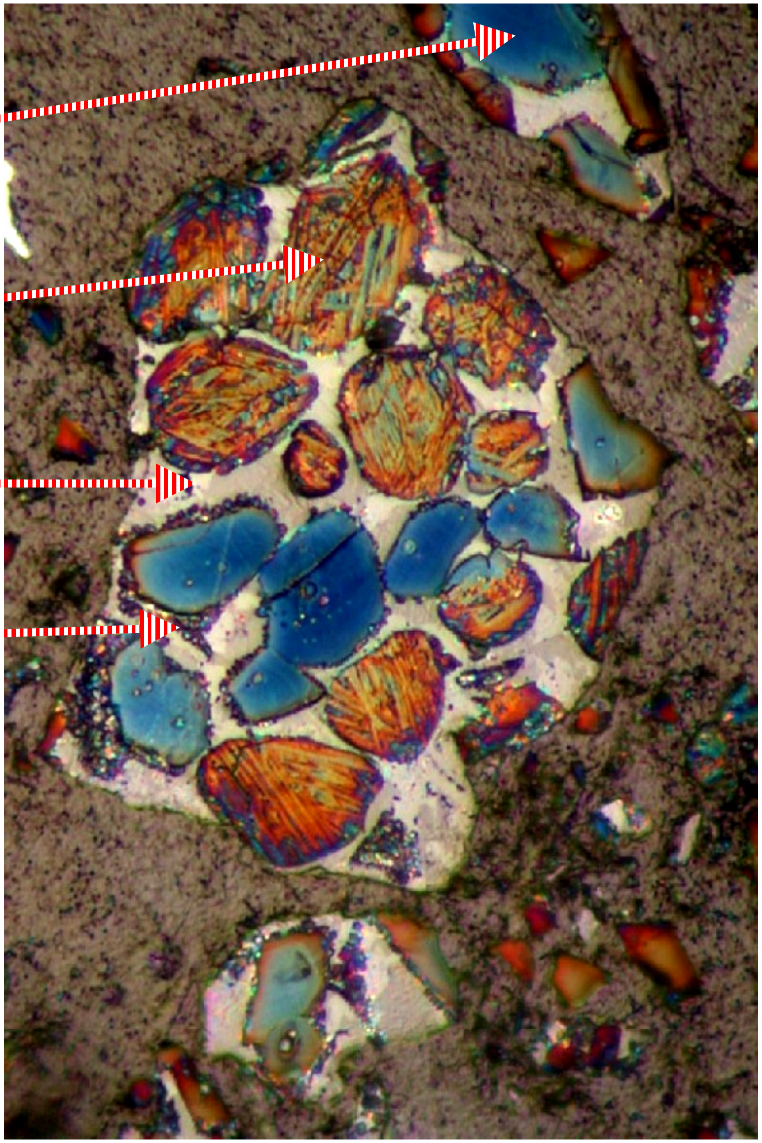
- Chemical Requirements
  - **Alkali Content- 0.6% max w/reactive agg.**
  - **Loss on ignition - ASTM C114**
  - **Heat of hydration- ASTM C186**
- Physical Requirements
  - **Air content- ASTM C185**
  - **Fineness - ASTM C204 and C115**
  - **Strength- ASTM C109**
  - **Time of setting- ASTM C266 and C191**

Transporting Cement

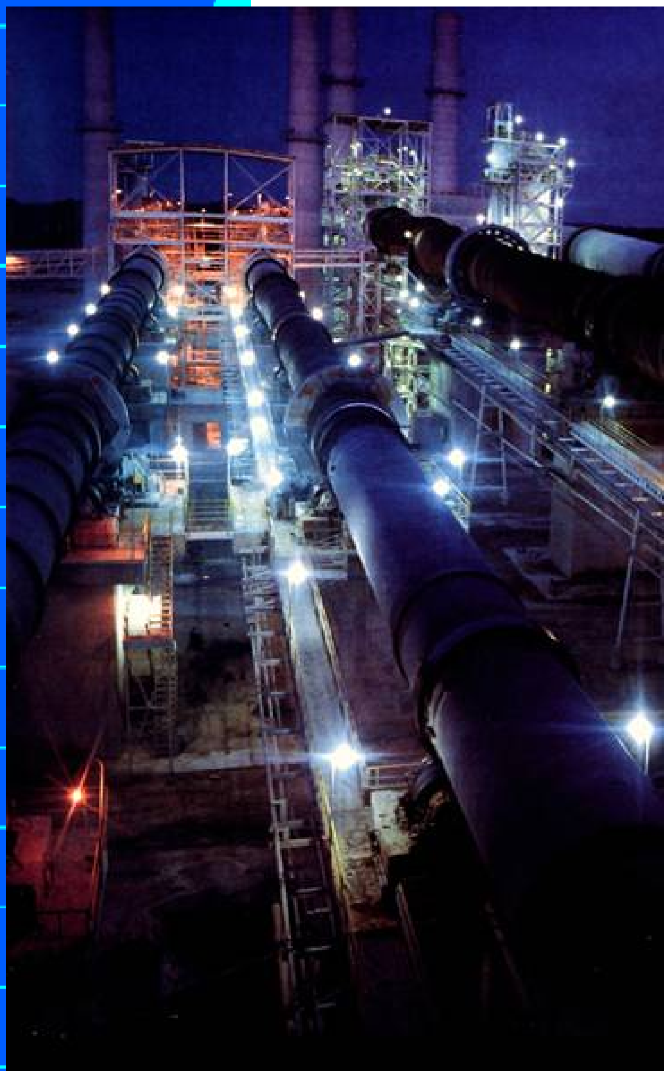
Packaging and Storage

What is Cement?

- C_3S – alite
- C_2S – belite
- C_3A – calcium aluminate
- C_4AF –ferrite

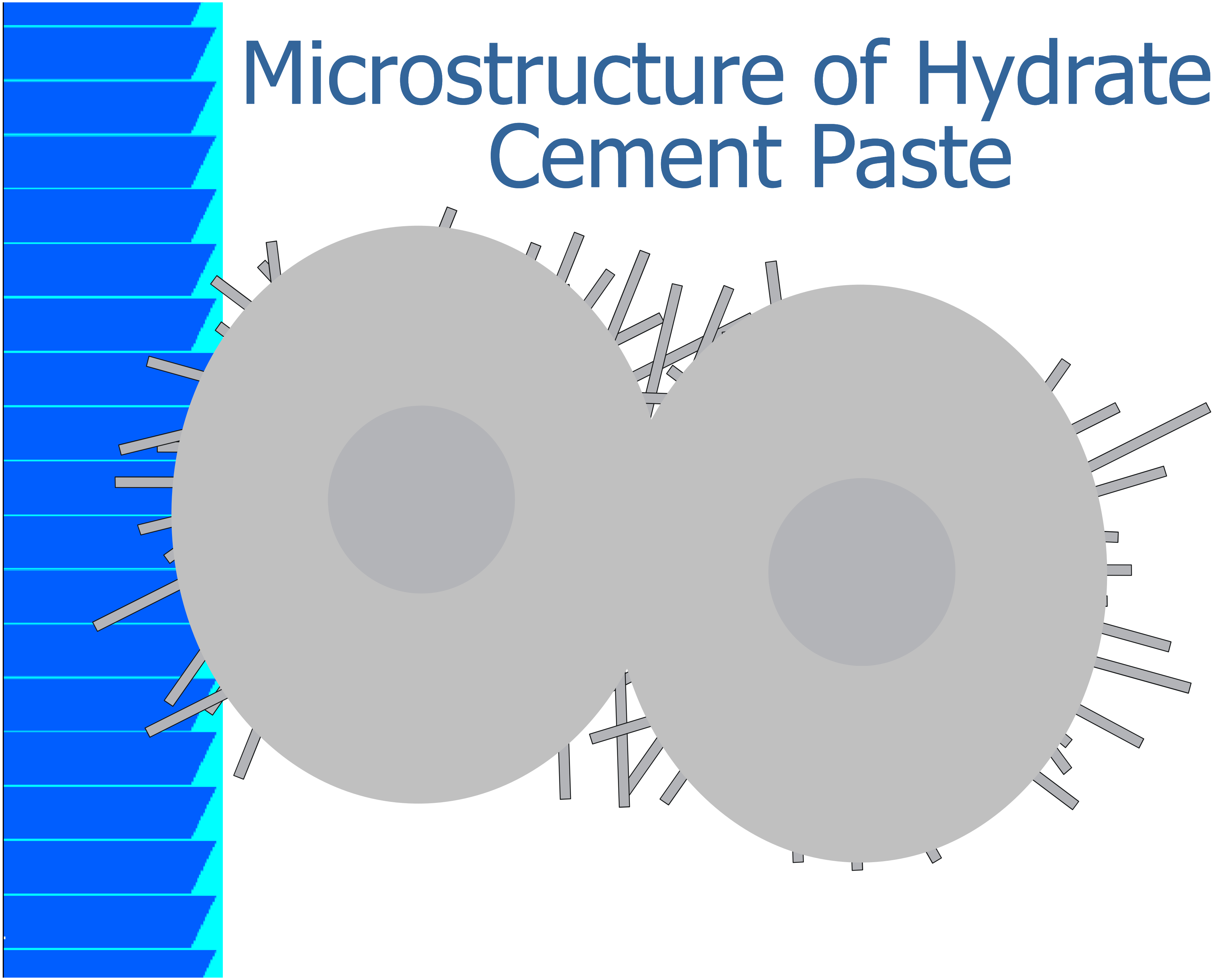


Shorthand Notation



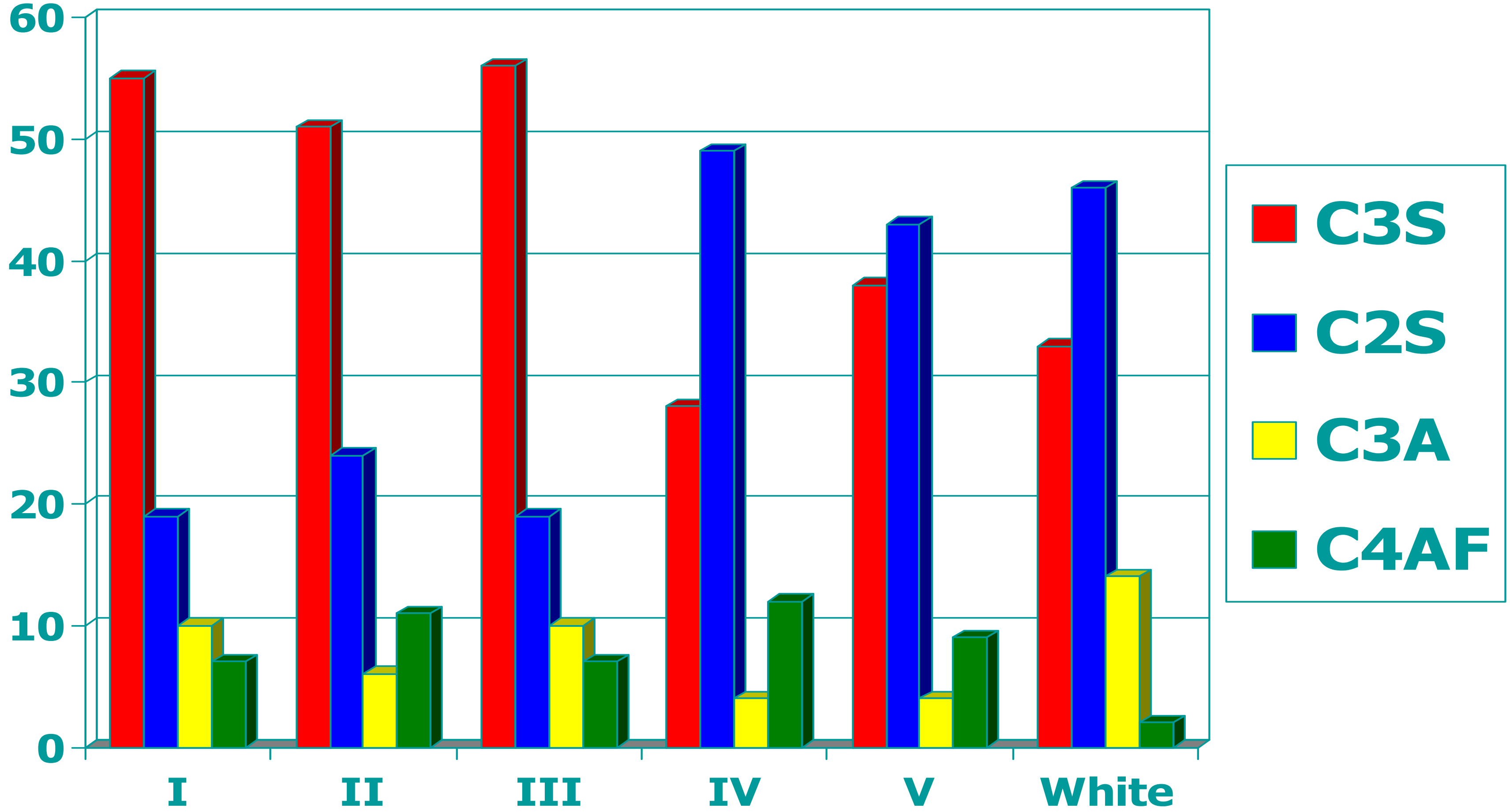
CaO	C	lime
SiO_2	S	silica
Al_2O_3	A	alumina
Fe_2O_3	F	ferric oxide
MgO	M	magnesia
K_2O	K	alkalis
Na_2O	N	alkalis
SO_3	$\bar{S}$	sulfate
CO_2	$\bar{C}$	carbonate
H_2O	H	water

Microstructure of Hydrated Cement Paste



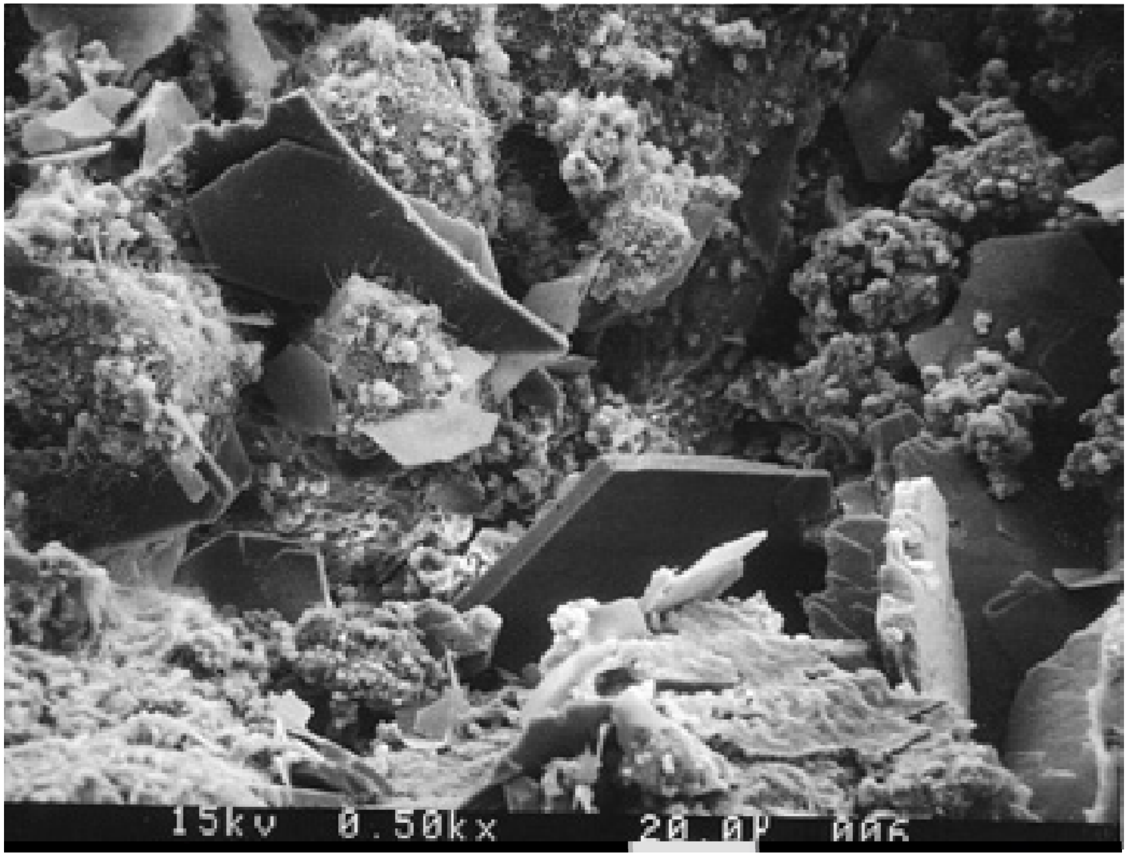
Typical Composition

Phases	Amount, %	Property
C_3S	50 – 55	Early strength Heat
C_2S	20 – 25	Later strength
C_3A	5 – 12	Heat Sulfate resistance
C_4AF	~ 8	Color
$C\bar{S}H_2$	~ 5	Setting Strength/shrinkage Admixture performance



Portland Cement

Hydration

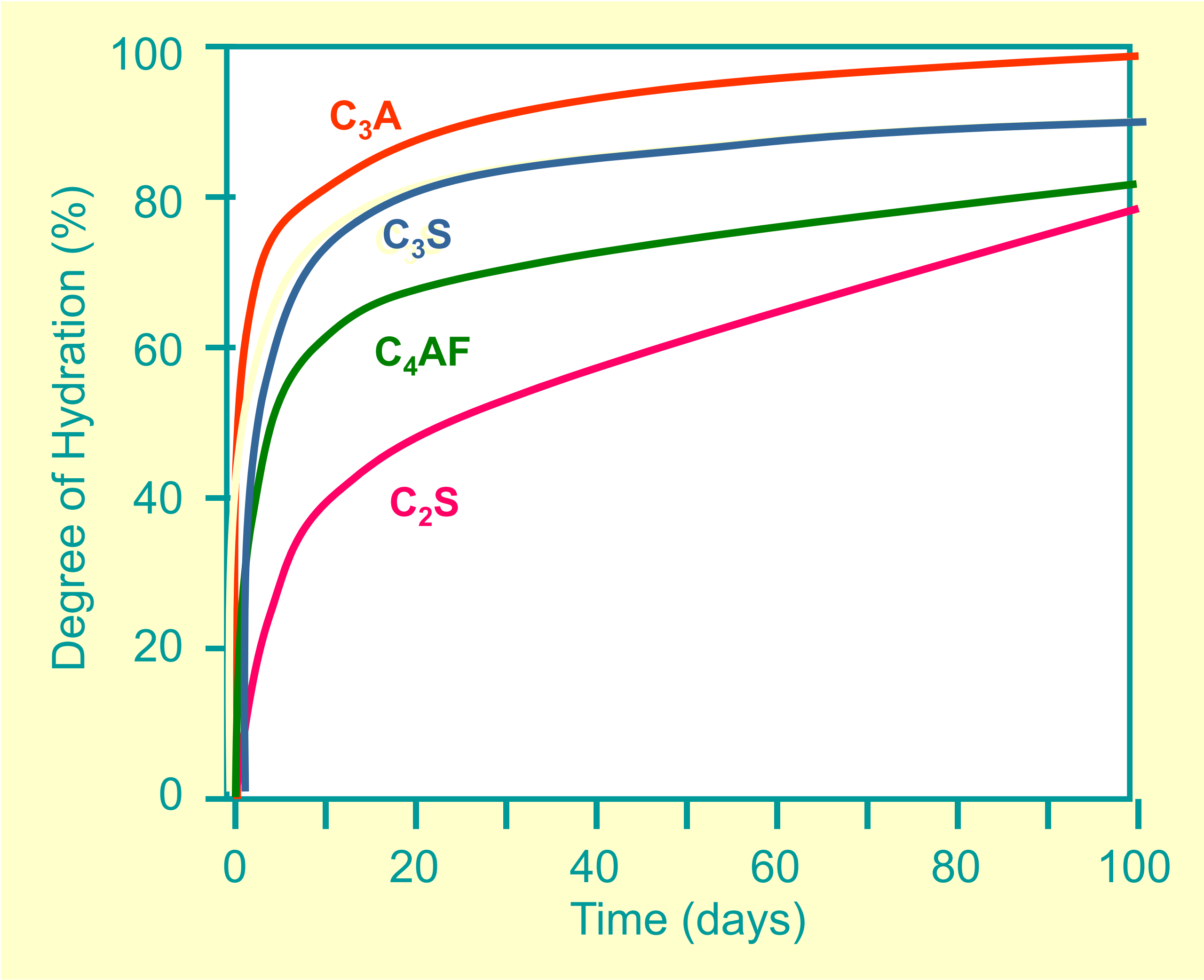


<u>Cement + Water</u>

$C_3S + H_2O = C\text{-}S\text{-}H + CH$

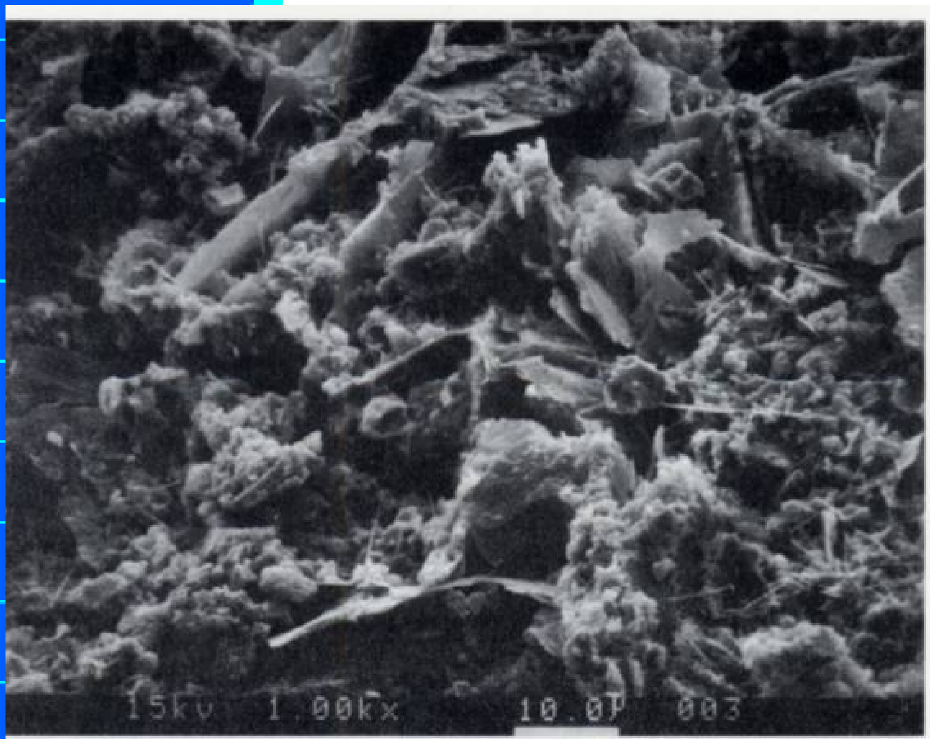
$C_2S + H_2O = C\text{-}S\text{-}H + CH$

Hydration Rate

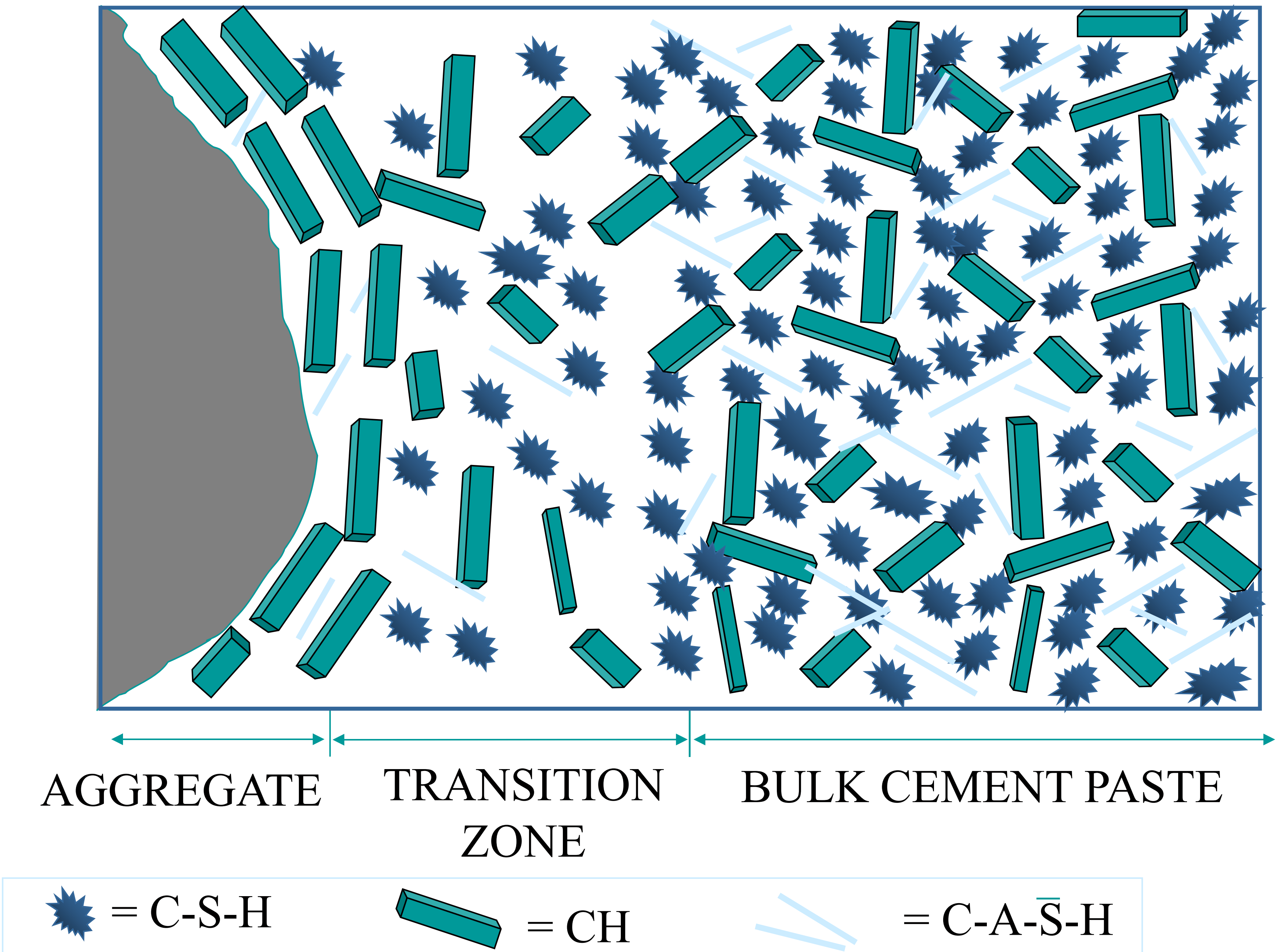


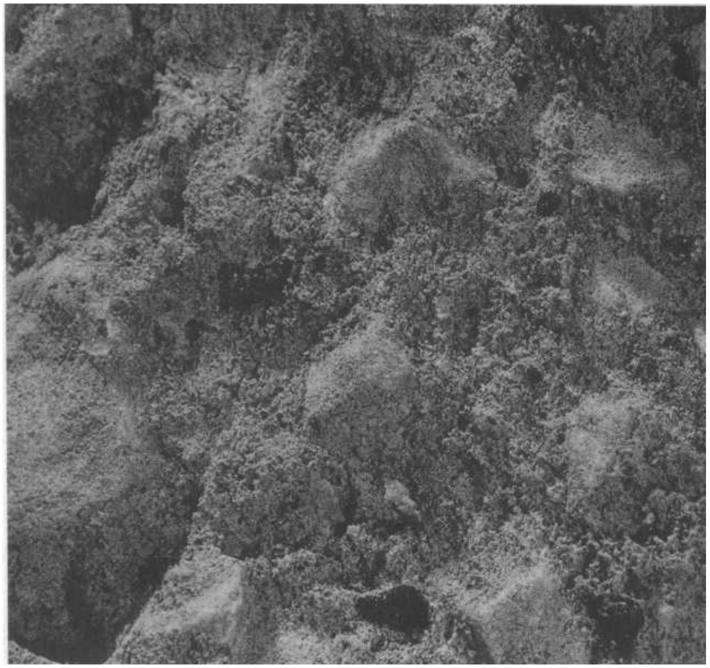
Tennis and Thomas 2004, PCA CD050

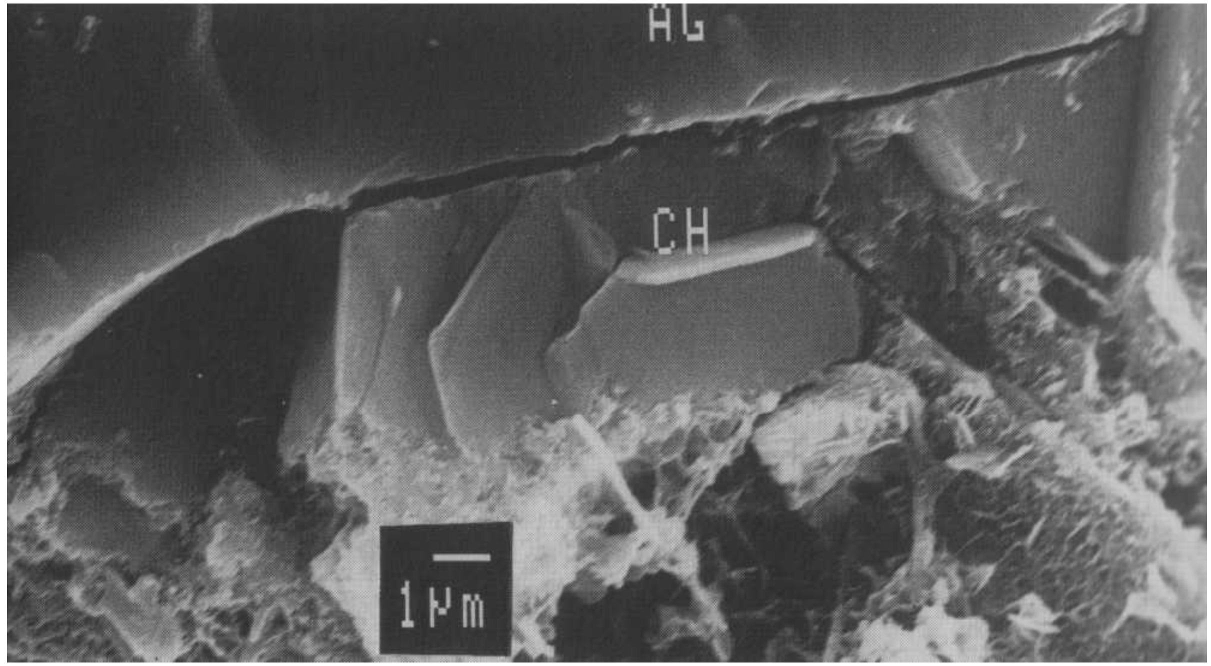
Use of Supplementary Cementing Materials

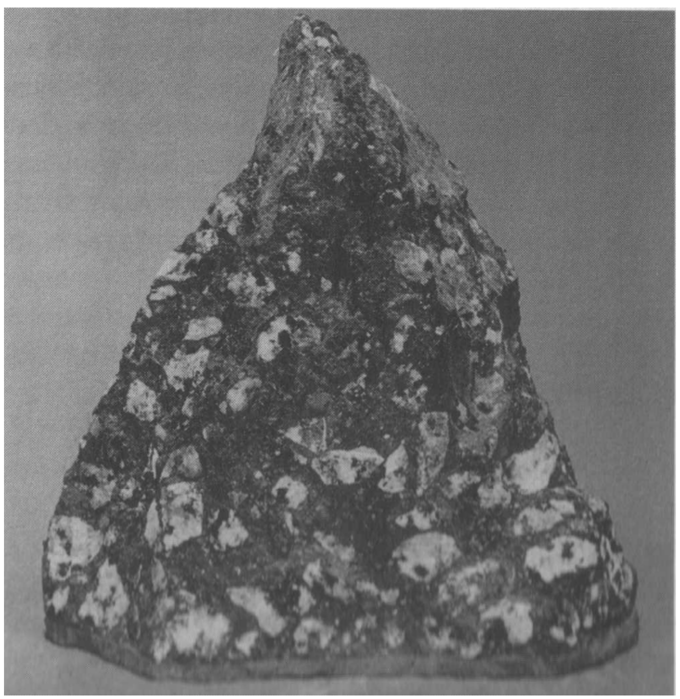


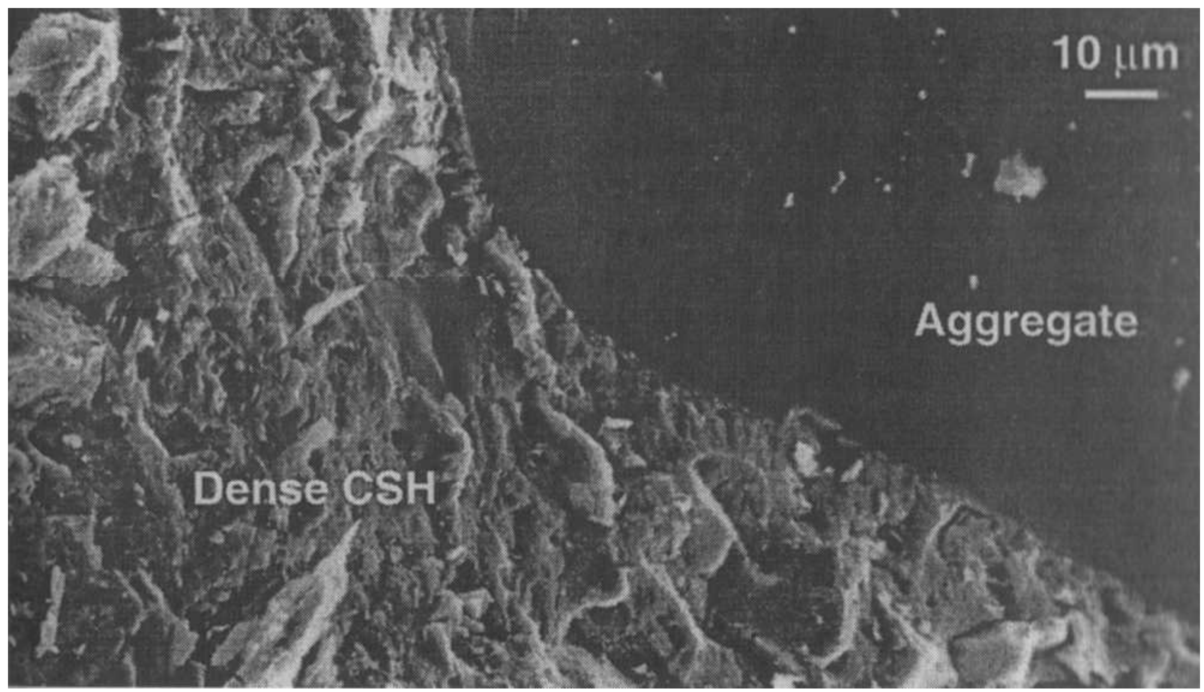
- Silicates in SCMs react with Calcium Hydroxide (CH)
- More C-S-H, less CH formation!


AGGREGATE
TRANSITION ZONE
BULK CEMENT PASTE
= C-S-H
= CH
= C-A-S̄-H



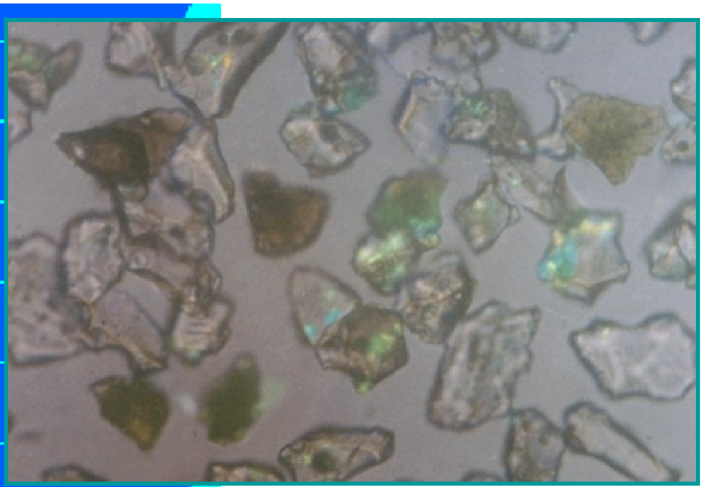

AG
CH
1 μm

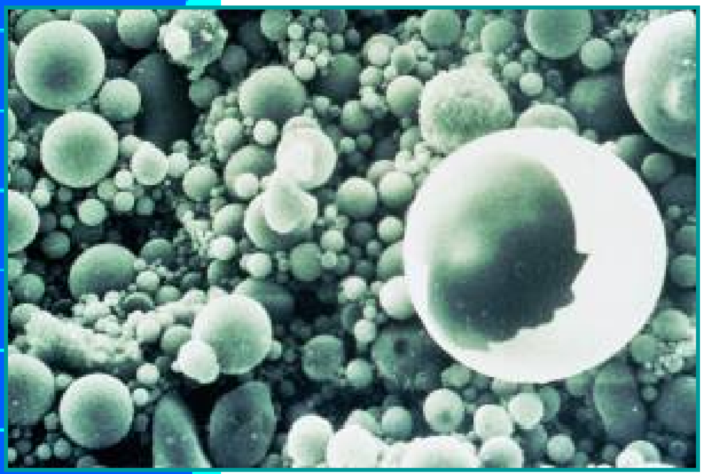



10 μm
Aggregate
Dense CSH

Pozzolanic Reaction

The rate of pozzolanic reaction is influenced by:





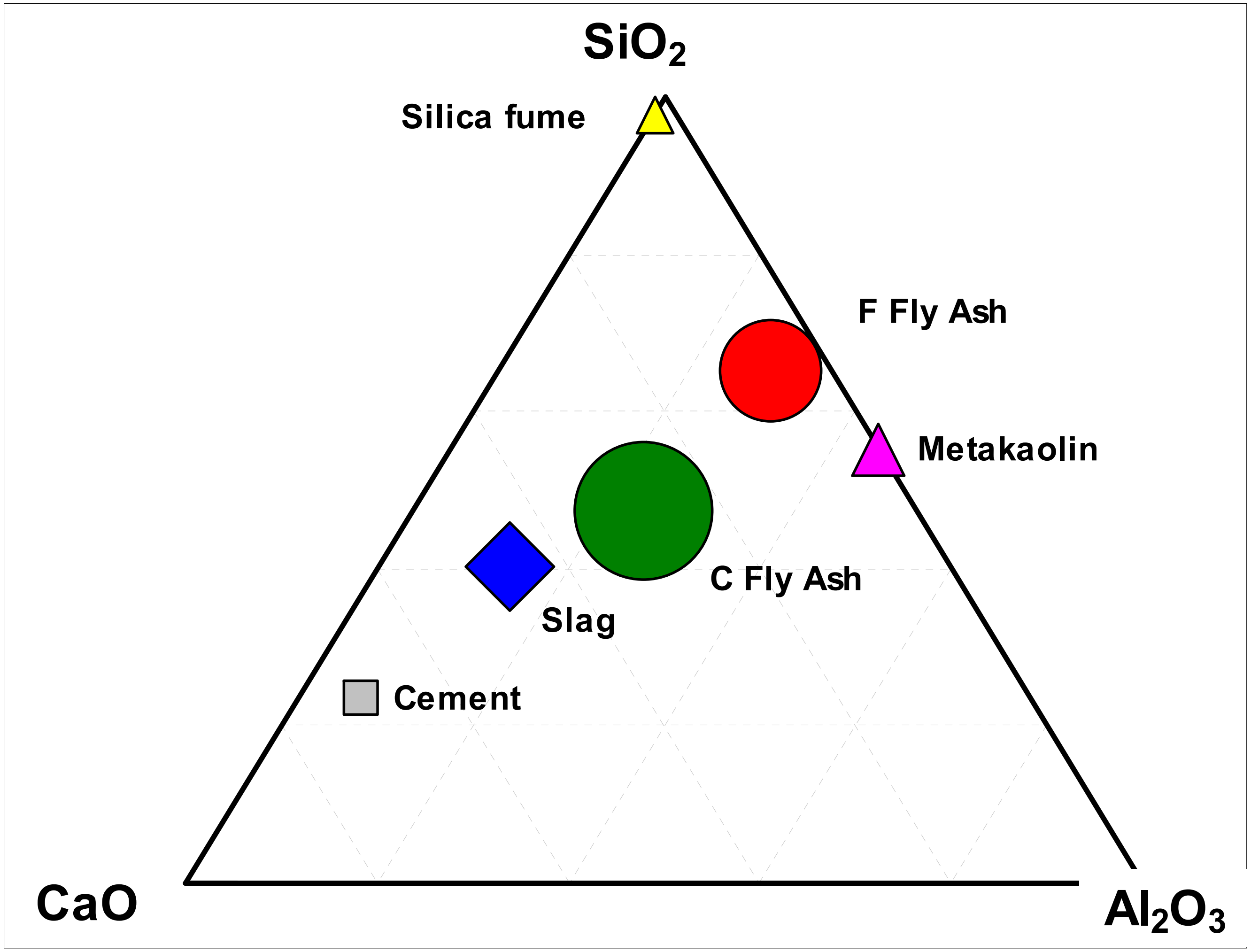
- Fineness and surface area
- Glass composition
- Temperature
- pH
- Concentration of alkalis

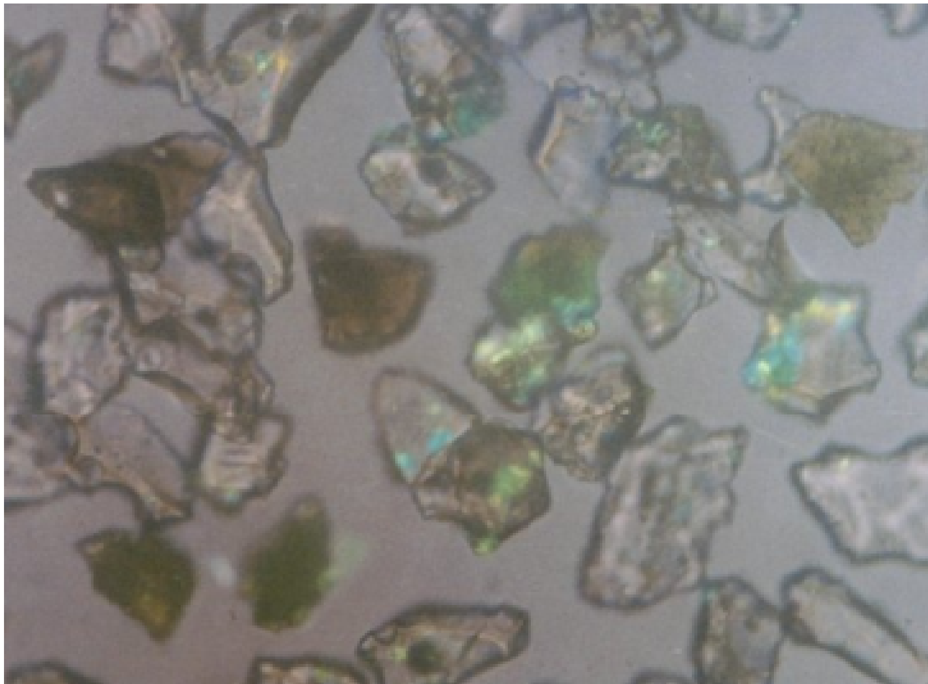
Nature of the Reaction of Different SCM's

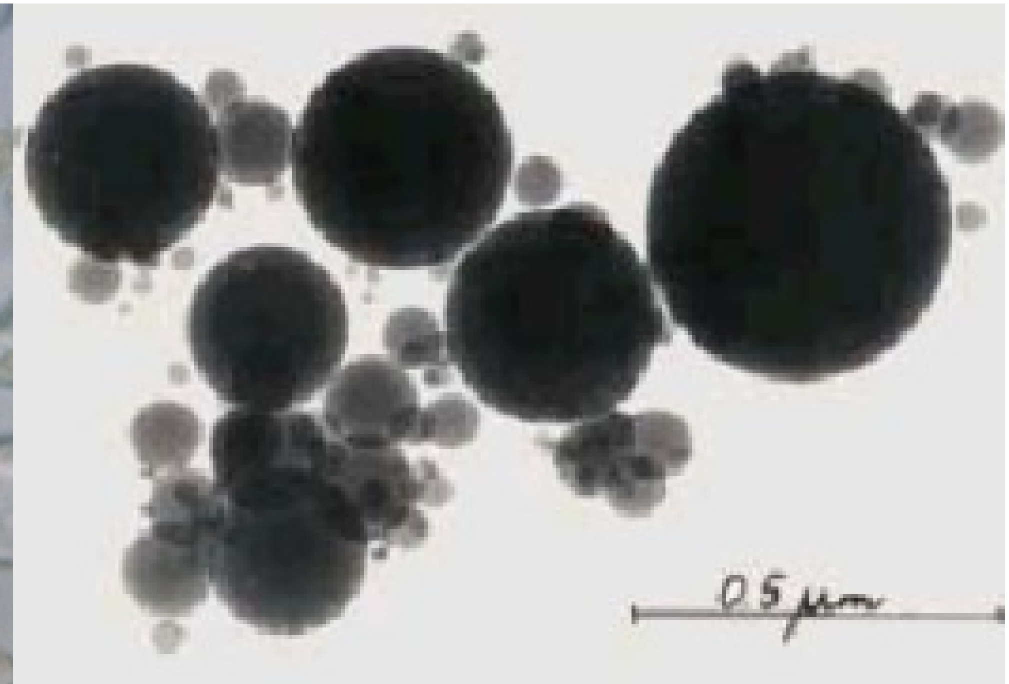
Increasing Calcium Content ↓

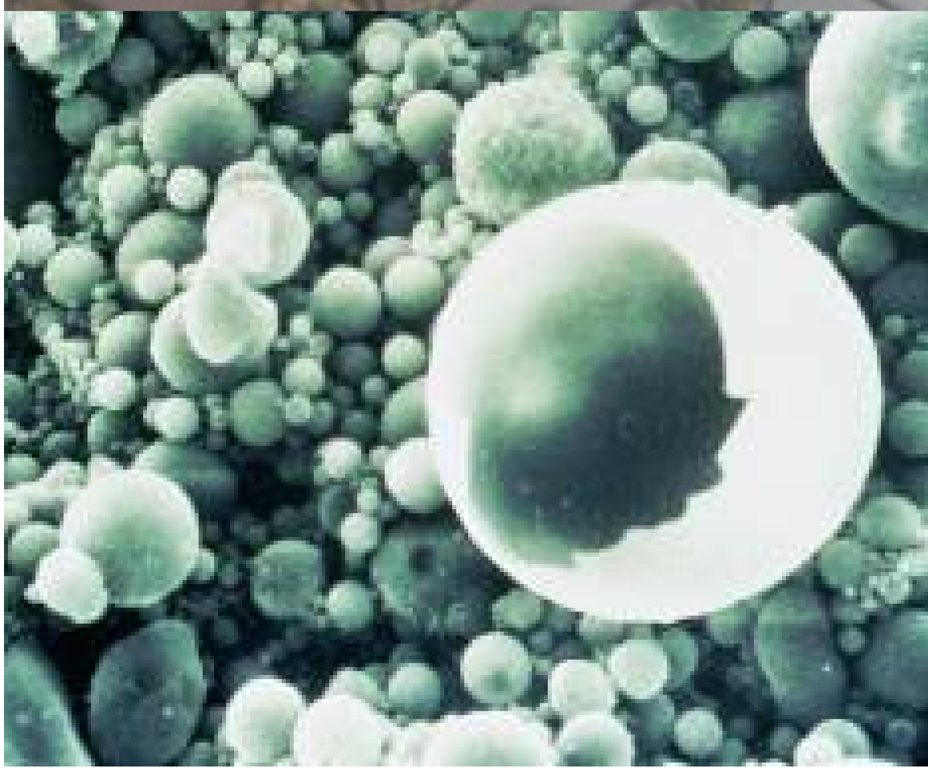
	Pozzolanic	Hydraulic
Silica Fume	XXXXX	
Low-CaO Fly Ash	XXXX	
Moderate-CaO Fly Ash	XXXX	X
High-CaO Fly Ash	XXX	XX
Slag	X	XXXX

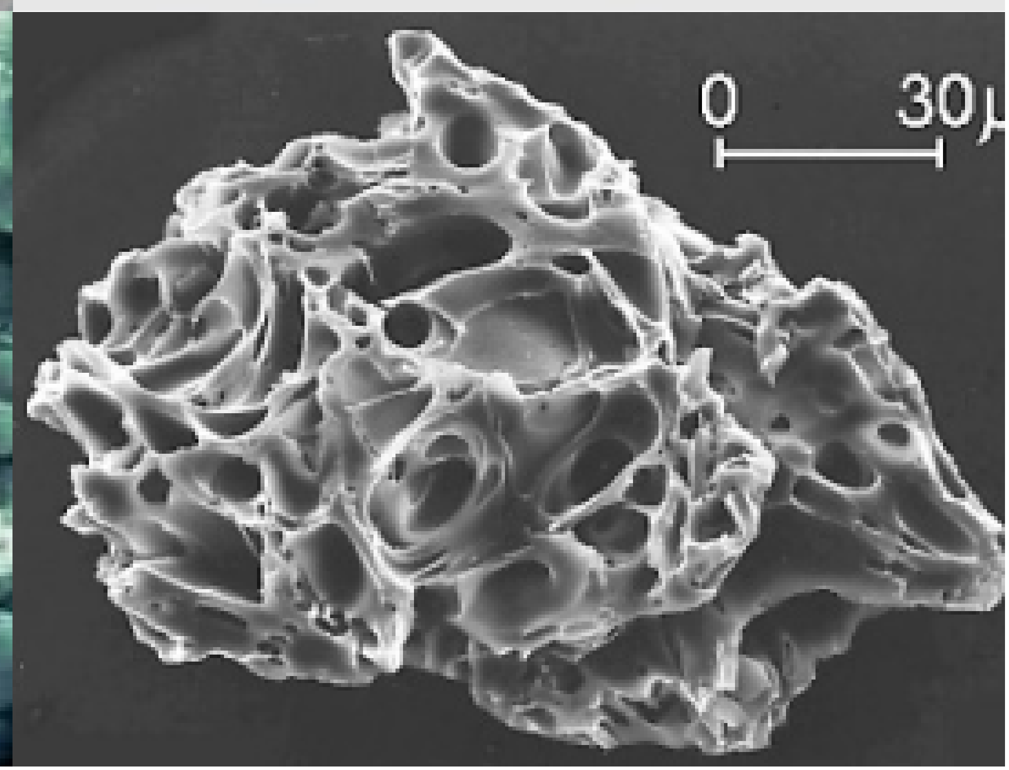
Composition



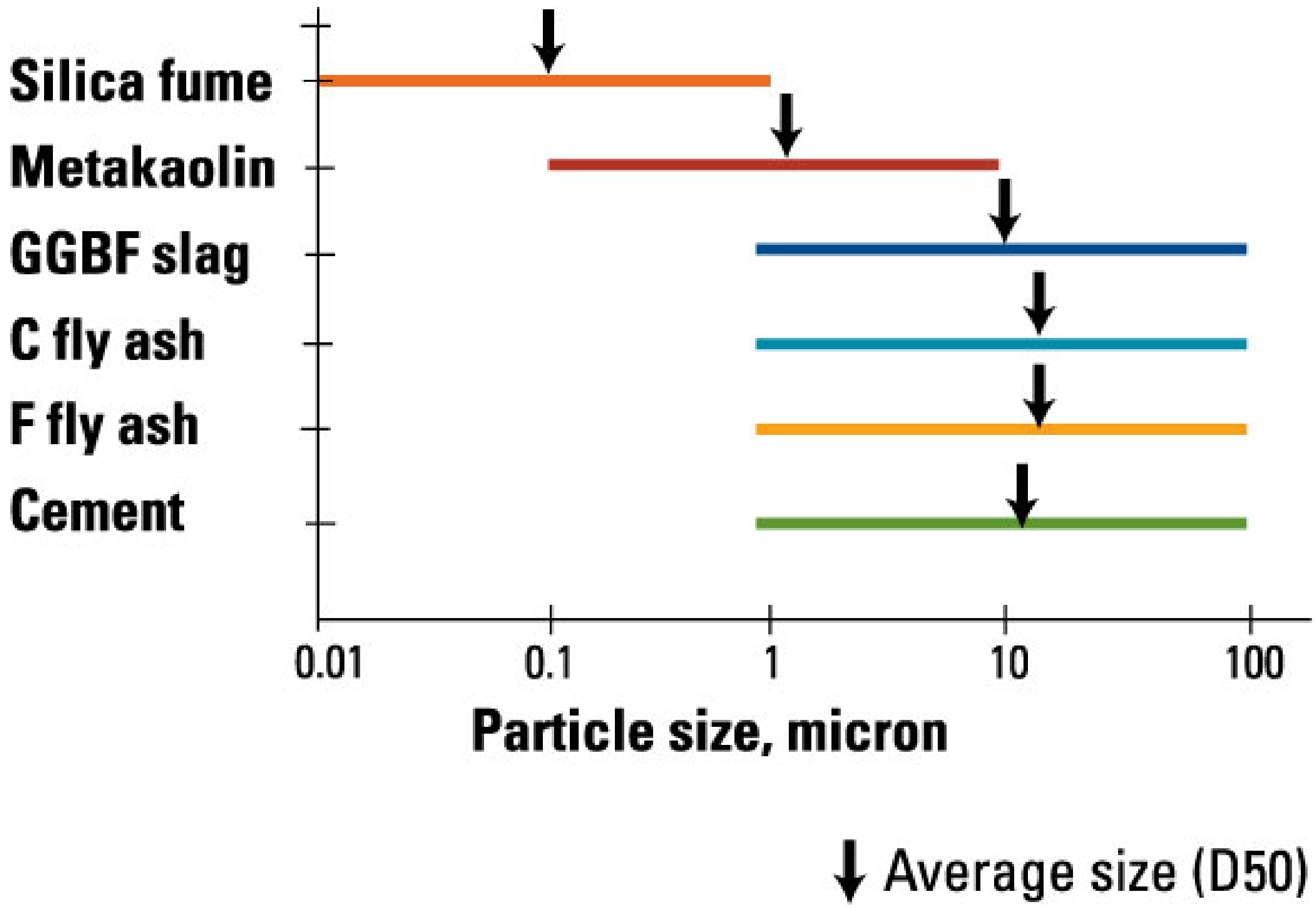



0.5 μm

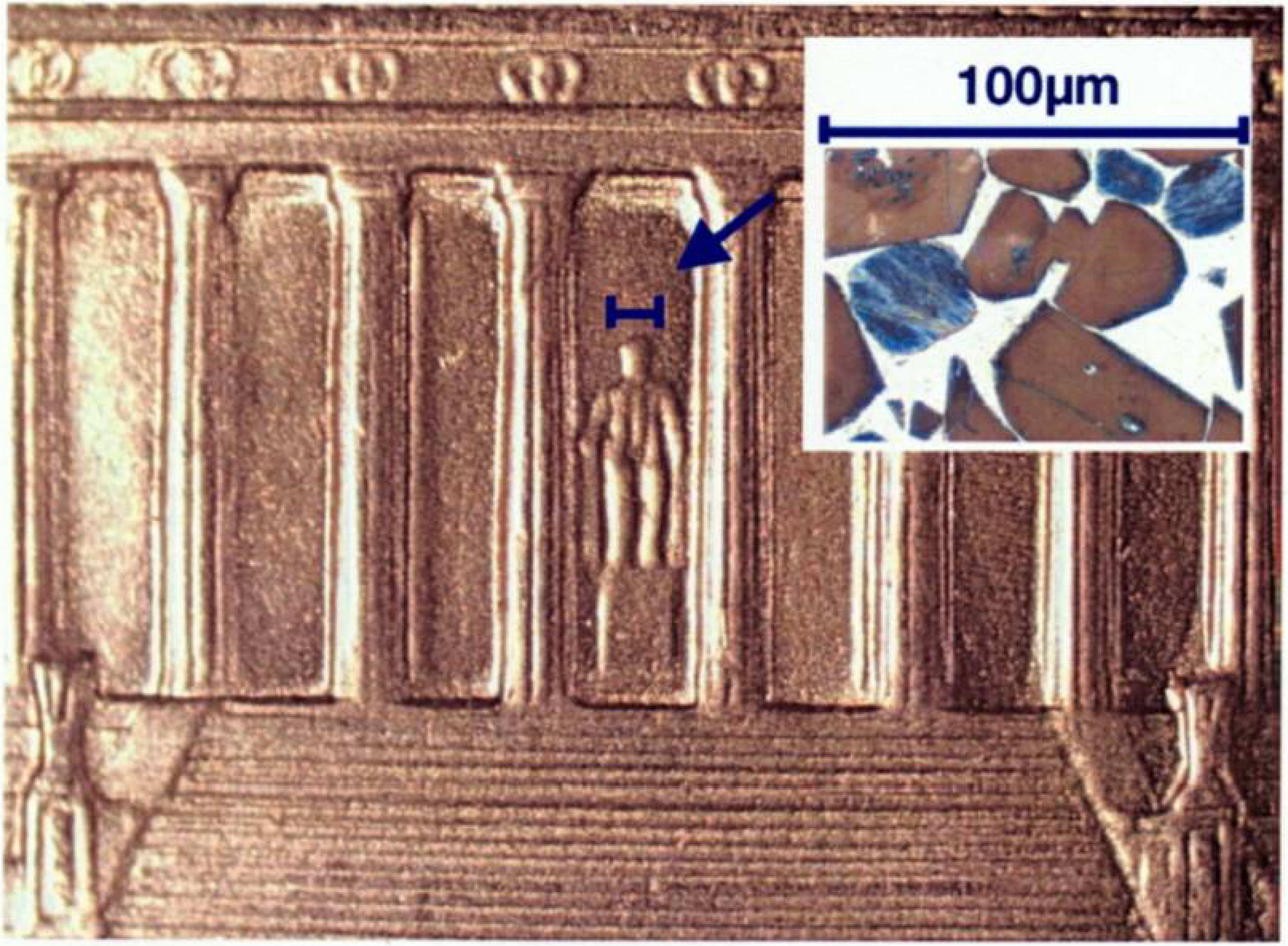



0
30μ

Sizes



Silica fume
Metakaolin
GGBF slag
C fly ash
F fly ash
Cement
0.01
0.1
1
10
100
Particle size, micron
Average size (D50)



This photomicrograph shows the size of typical cement clinker phases in relation to President Lincoln's head on the tail-side of a U.S. penny.

Blaine vs. PSD

- ASTM C204

	m^2/kg
Type I:	300-421
Type II:	318-480
Type III:	390-644
Type IV:	319-362
Type V:	275-430
White:	384-564

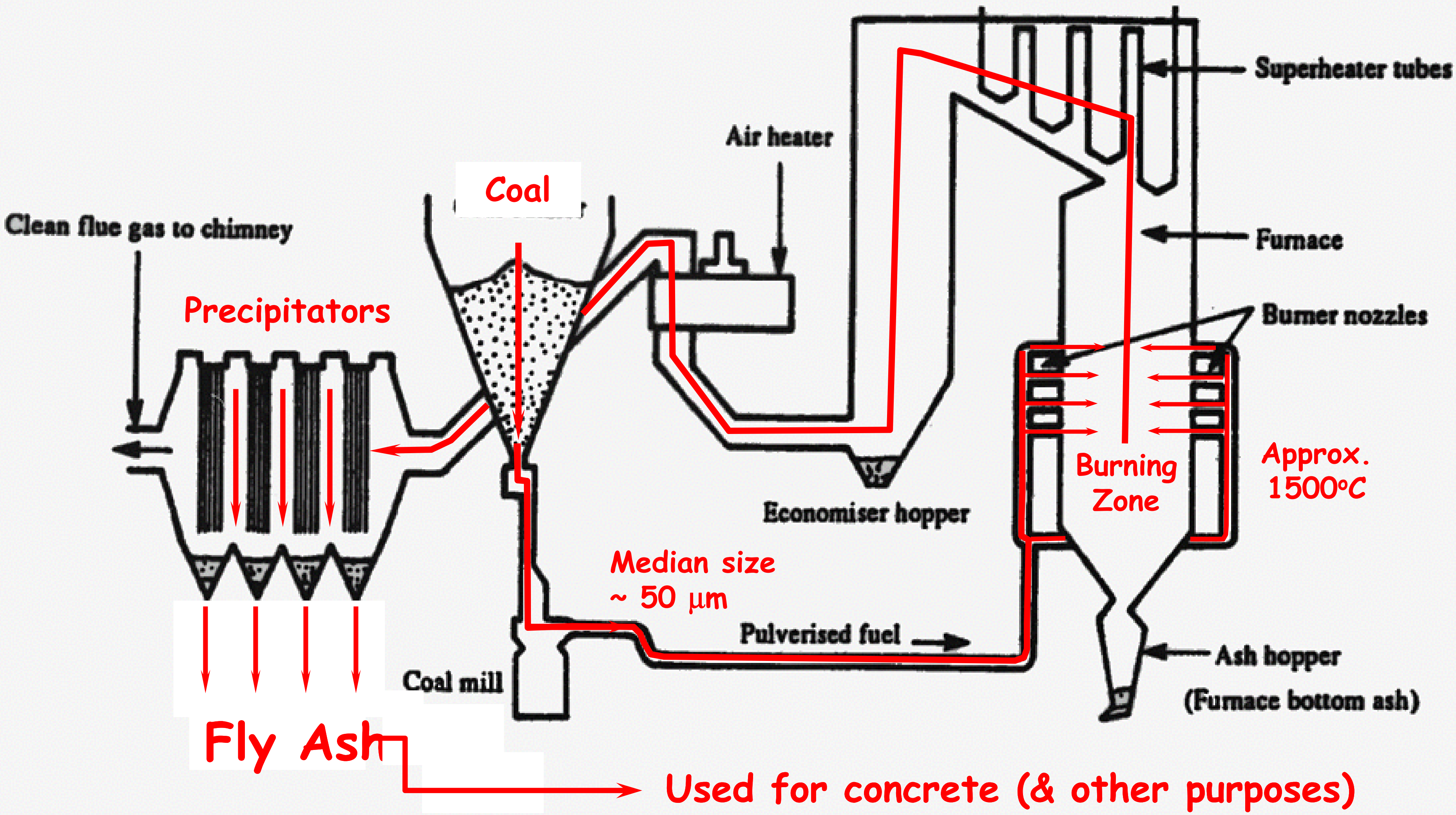
SCM Specifications

ASTM C618	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete
ASTM C989	Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
ASTM C1240	Standard Specification for Silica Fume for Use as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout
ASTM C595	Standard Specification for Blended Hydraulic Cements
ASTM C1157	Standard Performance Specification for Blended Hydraulic Cement

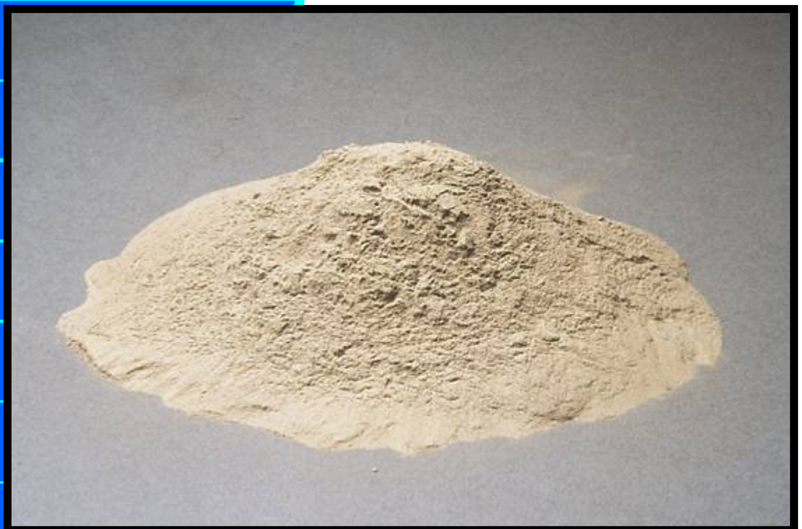
Fly Ash

Fly ash is the finely-divided residue produced in coal-fired electric power generating plants as an industrial by-product of the combustion of ground or powdered coal

Production of Fly Ash



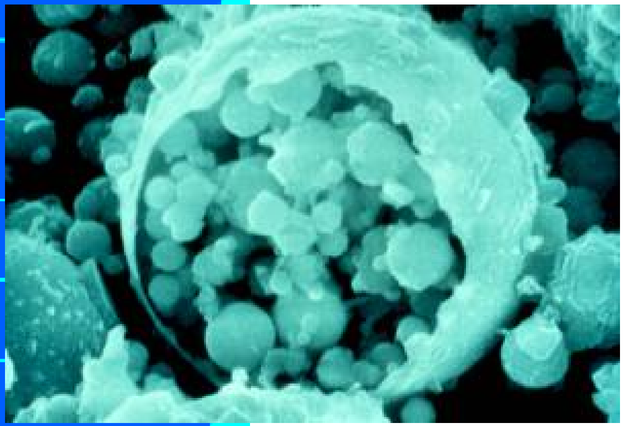
Specifications and Classes of Fly Ash

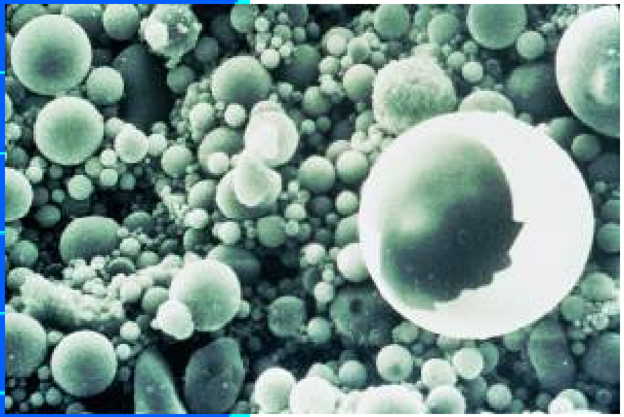


ASTM C618
(AASHTO M 295)

- Class F - **(low calcium)- from burning anthracite or bituminous coal, is pozzolanic**
  - $SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$
  - Low in CaO (calcium)
- Class C - **from burning sub-bituminous or lignite coal, is somewhat cementitious**
  - $SiO_2 + Al_2O_3 + Fe_2O_3 \geq 50\%$
  - High in CaO (calcium)

Physical Characteristics of Fly Ash





Particle size ranges from
< 1 μm to > 100 μm
Median particle size ~ 5 to 20 μm.

Surface area ranges from
300 to 500 m^2/kg.

Specific gravity ranges from
1.9 to 2.8

Color ranges from an off-white (buff) to light gray

Fly Ash

- Improves workability
- Reduces bleeding
- Reduces heat of hydration
- Increased set time
- Reduces permeability
- Improves sulfate & ASR resistance
- Increases ultimate strength

Ground Granulated Blast Furnace Slag

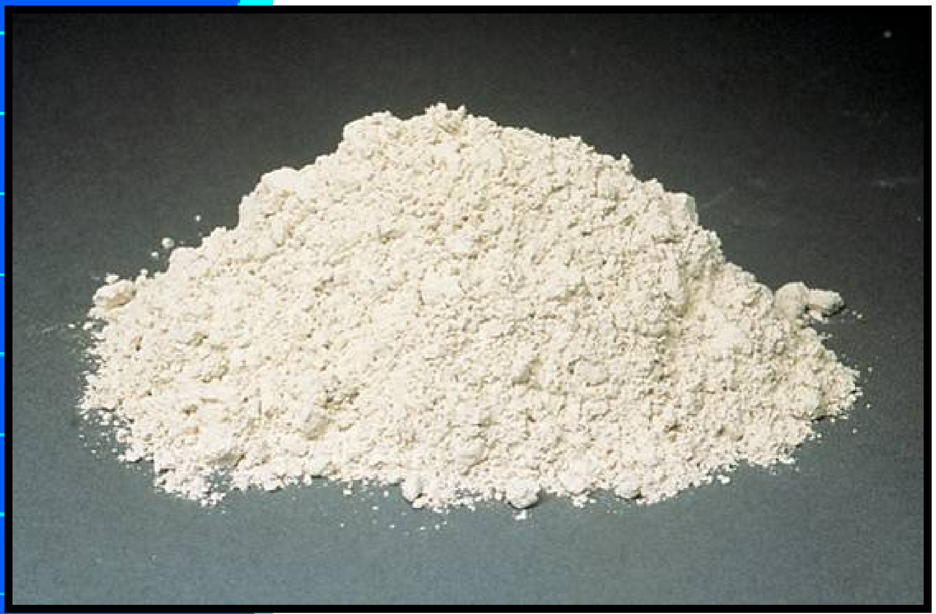
Ground granulated blast furnace slag (GGBFS) is the glassy material formed from molten slag produced in blast furnaces as an industrial by-product from the production of iron used in steel making

To make iron blast furnace slag suitable as a cementing material for concrete it must be:

- Quenched (cooled rapidly) by water granulation of pelletization
- Dried to remove water from the quenching process
- Ground to a fine powder

Specifications and Grade of Slag Cement

ASTM C989 (AASHTO M 302)



- Grade 80

  Slags with a low activity index

- Grade 100

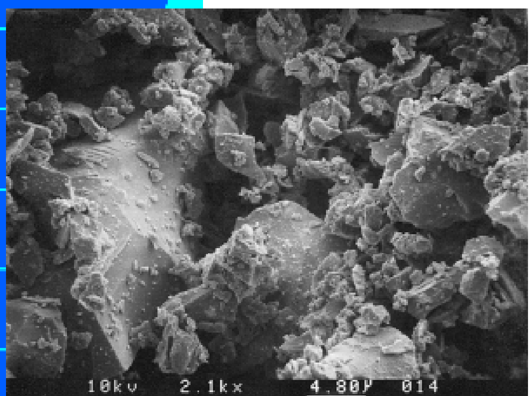
  Slags with a moderate activity index

- Grade 120

  Slags with a high activity index

Physical Characteristics of Slag Cement

The granulated material is ground to less than 45 μm using ball mills or similar equipment



Surface area ranges from 400 to 600 m^2/kg, but may be ground finer in some cases

Specific gravity ranges from 2.85 to 2.95

Angular particle shape

White to off-white in color

Slag

- Need less water
- Better workability
- Increase set time
- Increased Sulfate resistance
- Increased ASR resistance
- Strength initially reduced- increased 28 day age

Silica Fume

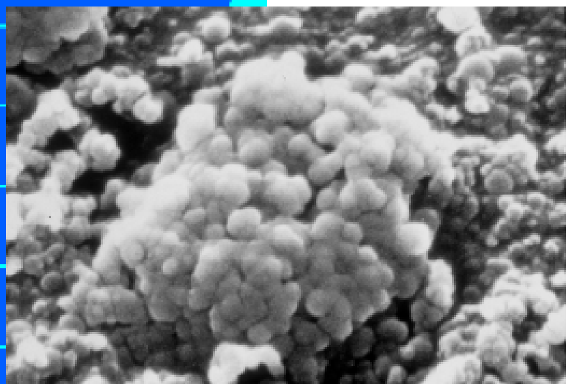
Silica fume is the ultra fine non-crystalline silica produced in electric-arc furnaces as an industrial by-product of the production of silicon metals and ferrosilicon alloys

Specification for Silica Fume

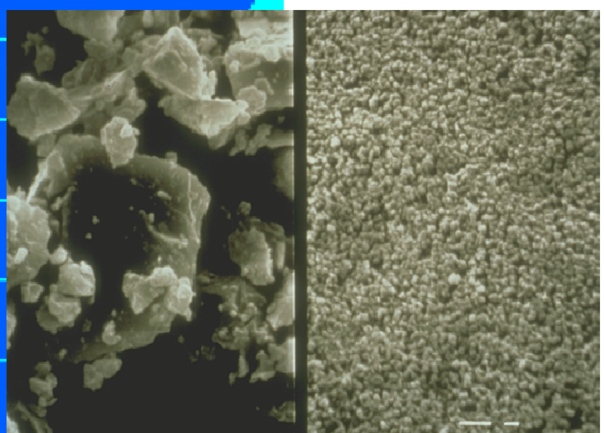
ASTM C1240

- As-produced
- Slurried
- Densified or compacted

Physical Characteristics of Silica Fume

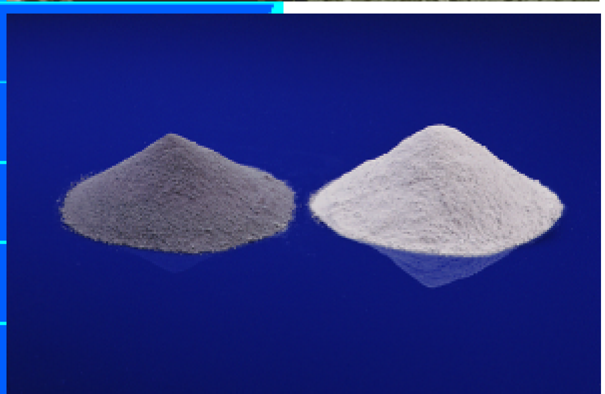


Silica fume forms as very fine glassy spherical particles



Most particles are sub-micron with an average particle size of $0.1\ \mu m$

Specific gravity ranges from 2.20 to 2.25 but may be as high as 2.5



Generally dark gray to black in color, but white silica fume is available for special purposes

Silica Fume

How it helps...

- 100X smaller than avg. cement particle
- Reduces permeability of hardened concrete
- Less segregation and bleeding
- Used to control reactive aggregates

Implications...

- Reduced workability ...HRWR (1-2 times)
- Requires more water
- Requires more air (1-4 times)
- “Sticky” mixes

Natural Pozzolans

Natural pozzolans are raw or calcined materials originating from natural deposits such as volcanic ash.

Examples that have been used in concrete in North America include:

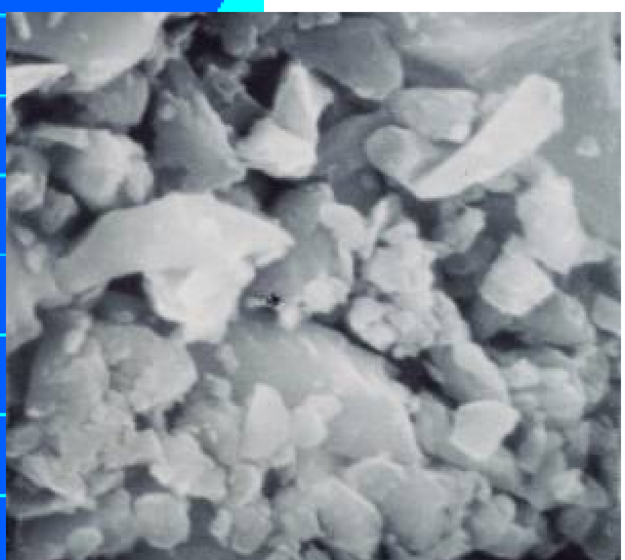
- Volcanic ash or pumicite
- Diatomaceous earth
- Opaline cherts & shales
- Calcined shale
- Calcined clay
- Metakaolin

Specification and Class of Natural Pozzolans

ASTM C618 (AASHTO M 295)

Class N-

Raw or calcined natural pozzolans



Most natural pozzolans used today are processed materials:

Calcined clay or shale most common

Heated in range 600 to 1100°C (1100 to 2000°F)

Temperature is critical to optimize (pozzolanic) reactivity

Ground to a fine powder

Metakaolin

Special type of calcined or "thermally-activated" clay

Thermally-activated at specific temperature (650 – 800^{o}C) to maximize reactivity

Ground to fine particle size (avg. 1 to 2 μm)

Typical S.G. = 2.5

High "Hunter L" whiteness value (> 90)

Summary

- Cement Types
  - ASTM C150, C595, C1157
  - Applications
- Cement Manufacturing Process
- Properties of Cement and SCMs
  - Physical
  - Chemistry
- Hydration

What should you look at?

- <u>Cement</u>
  - C_3S, C_2S, C_3A, C_4AF
  - SO_3 content
  - Alkali content
  - Fineness, PSD
- <u>SCMs</u>
  - Mineralogy
  - Calcium Content (Fly Ashes)
  - Fineness, PSD
  - Carbon Content of Fly Ash

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