Cements – Composition, Types

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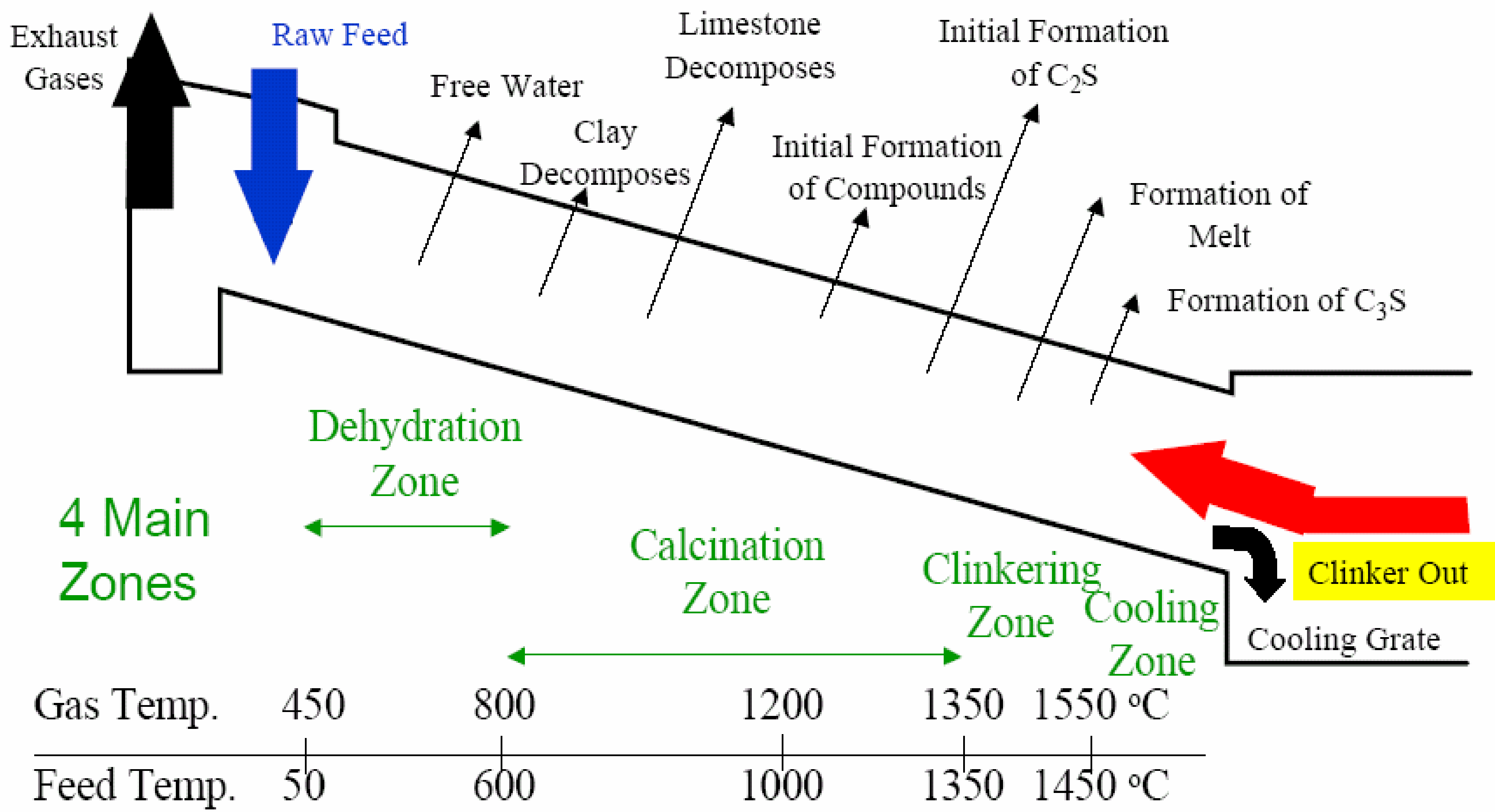
- Finish up cement manufacture
- Properties of component phases
- Types of cements

- Chapter 2 – Properties of Concrete – Neville
- Chapter 6 – Concrete….Mehta and Monteiro

Summary of Kiln Reactions



After Mindess and Young Figure 3.2

CLINKER

- Clinker is what comes out of the kiln
- 3 to 25 mm in diameter
- 20-25% Molten

Compound Composition of Clinker / Cement

- Four major compounds formed from the oxides under high temperature in the kiln
- Name (Oxide Notation) - Shorthand
- Tricalcium silicate ($3\ CaO.\ SiO_2$) – **C_3S**
- Dicalcium silicate ($2\ CaO.\ SiO_2$) – **C_2S**
- Tricalcium aluminate ($3\ CaO.\ Al_2O_3$) – **C_3A**
- Tetracalcium aluminoferrite ($4\ CaO.\ Al_2O_3.\ Fe_2O_3$) – **$C_4AF$**

Summary of Cement Compounds

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Name	Formula	Shorthand	Weight %
Tricalcium silicate (Alite)	$3\ CaO.\ SiO_2$	**C_3S**	~55-60
Dicalcium silicate (Belite)	$2\ CaO.\ SiO_2$	**C_2S**	~15-20
Tricalcium aluminate	$3\ CaO.\ Al_2O_3$	**C_3A**	~5-10
Tetracalcium aluminoferrite	$4\ CaO.\ Al_2O_3.\ Fe_2O_3$	**C_4AF**	~5-8
Gypsum	$CaSO_4.\ 2H_2O$	**$C\bar{S}H_2$**	~2-6

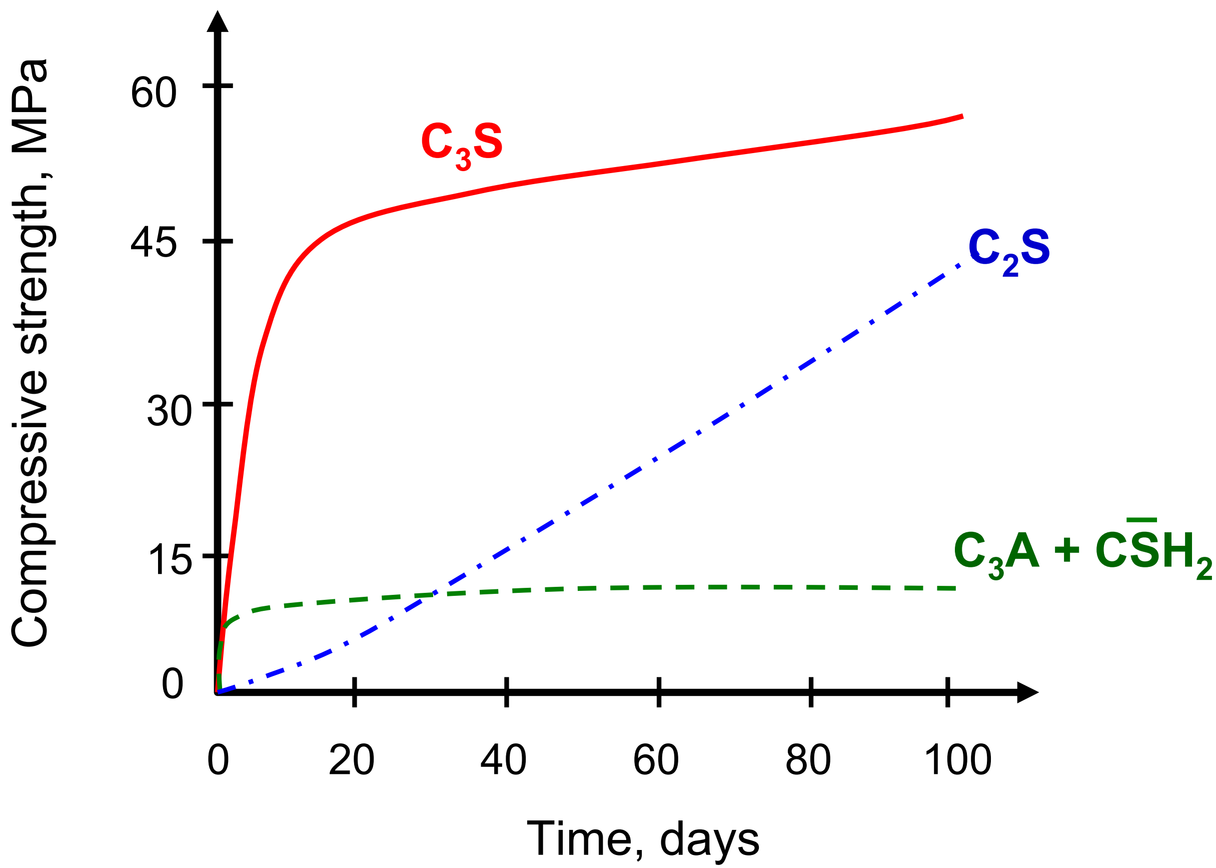
Implications of compound composition

- Determines the physical and mechanical characteristics of the cement
- Determines its chemical activity
- Determines its scope of use
- Determines the cost

Contributions of Compounds to Strength

- C_3S contributes to high early strength – to make high early strength concrete, higher C_3S proportions needed
- C_2S contributes to later age strength – defines the long term strength
- C_3A reacts immediately with water – defines set
- In the absence of gypsum, C_3A causes flash set

Compressive strength development of pure cement compounds



- C_3A reacts instantaneously
- Final strength determined by C_3S and C_2S
- Increase C_3S for high early strength

Making Life Harder - I

- Remember the compound name, oxide notation, and the shorthand notation…
- Just to make sure that cement and concrete is complicated, tricalcium silicate in its impure form in clinker is historically called **Alite**
- Even more complication arises – various crystalline polymorphs of tricalcium silicates exist
- Similar troubles for other compounds also

Making Life Harder - II

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- Not all cement components can be expressed by the oxide formulae and shorthand notation
  - Chlorides, Fluorides etc
  - Expressed using normal chemical formulae
- Mineral names are commonly used for raw materials (calcite, quartz) and for some cement hydration products (ettringite, portlandite etc)

Beware of "LIME"

- Be clear what you mean when you say "Lime"
  - "Lime" can be used for CaO, either by itself or in combination with other components
  - "Lime" can be used for Calcium hydroxide (also called portlandite, abbreviated as CH)
  - "Lime" is sometimes used for limestone rock or its major chemical component calcium carbonate

Manufacturing control criteria in the Kiln

- Silica Modulus (SM) : 2.3 to 3.5 (desired at least 3.0), slow reaction if SM is high

$$SM = \frac{SiO_2}{Al_2O_3 + Fe_2O_3}$$

- Alumina Modulus (AM): ~2, controls melt temp

$$AM = \frac{Al_2O_3}{Fe_2O_3}$$

- Lime Saturation factor (LSF): 0.92-0.96
  - Designed to insure against equilibrium free lime

$$LSF = \frac{CaO}{2.2SiO_2 + 1.18Al_2O_3 + 0.65Fe_2O_3}$$

Bogue's Equations – Compound composition

- To calculate the amounts of C_3S, C_2S, C_3A, and C_4AF in clinker (or the cement) from its chemical analysis (from the mill certificate)
- Assumptions in calculations
  - Chemical equilibrium established at the clinkering temperature
  - Components maintained unchanged through the rapid cooling period
  - Compounds are "pure"

Bogue's Equations

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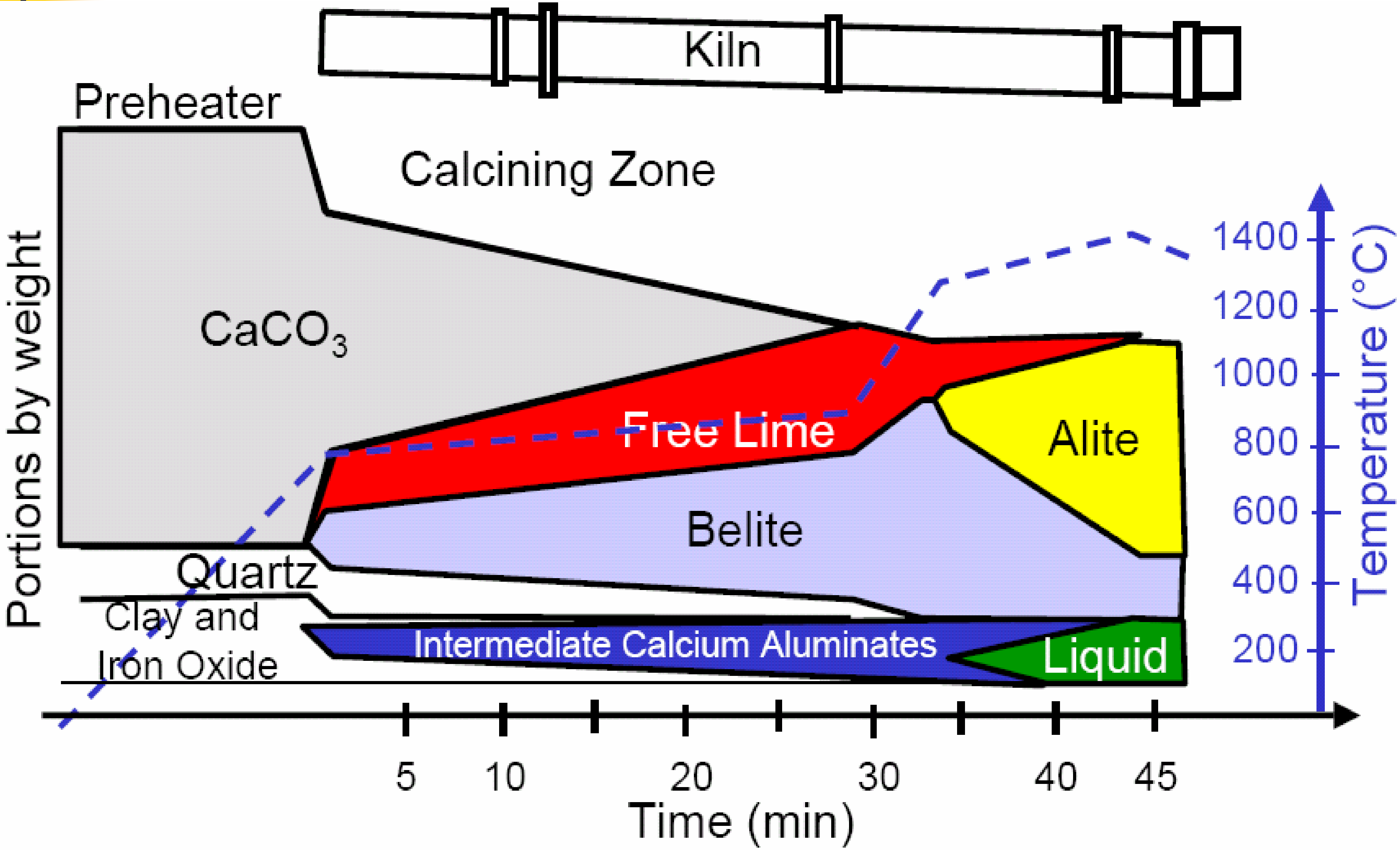
- Case 1 : A/F >=0.64
  - $C_3S = 4.071C - 7.6S - 6.718A - 1.43F - 2.852\bar{S}$
  - $C_2S = 2.867S - 0.7544C_3S$
  - $C_3A = 2.65A - 1.692F$
  - $C_4AF = 3.043F$

Bogue’s Equations

- Case 2 : $A/F < 0.64$
  - $C_3S = 4.071C - 7.6S - 4.479A – 2.859F - 2.852\overline{S}$
  - $C_2S = 2.867S - 0.7544C_3S$
  - $C_3A = 0$
  - $C_4AF = 2.10A + 1.702F$

Clinker components and Temperature



Summary of Kiln Reactions

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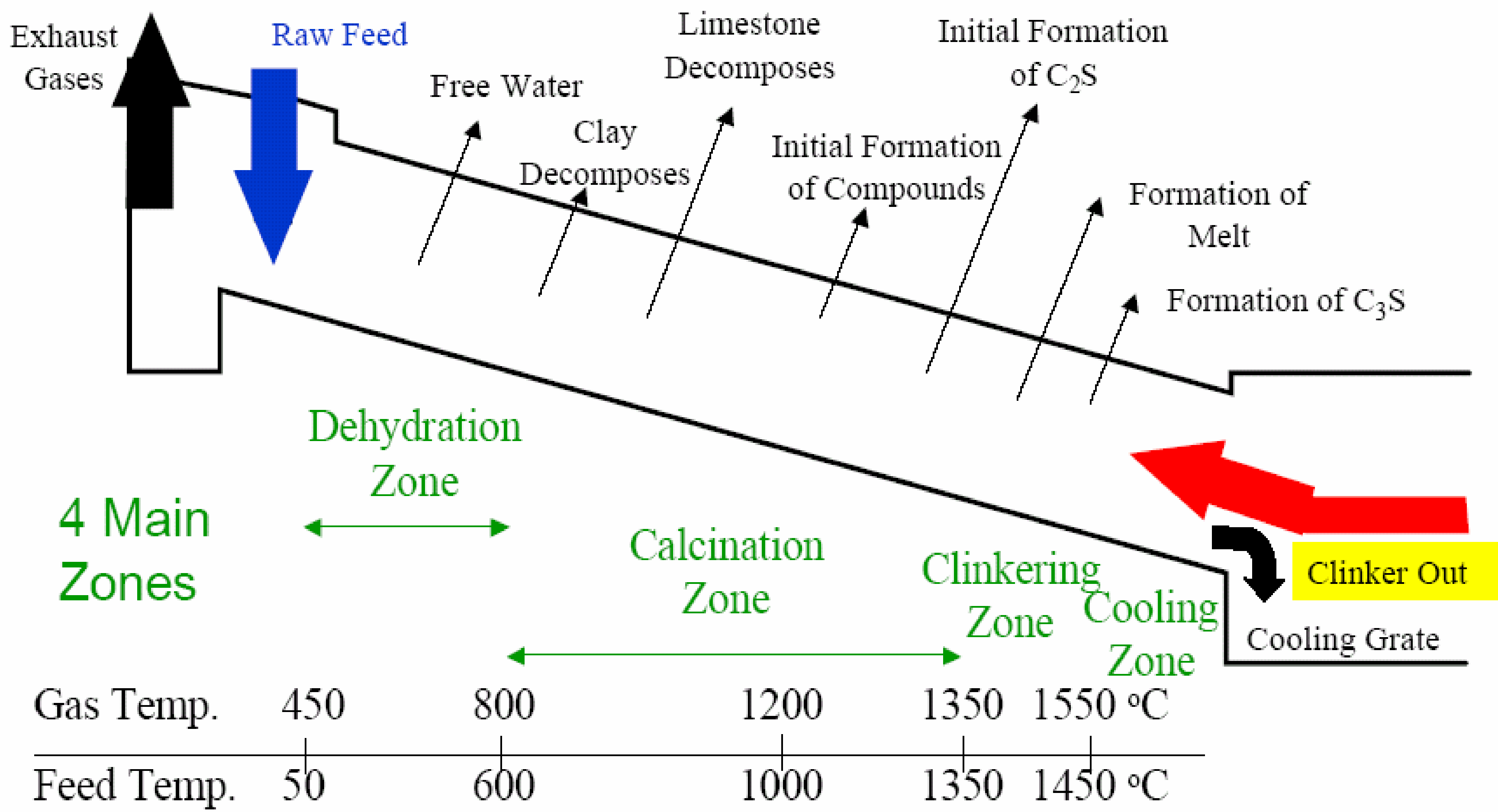
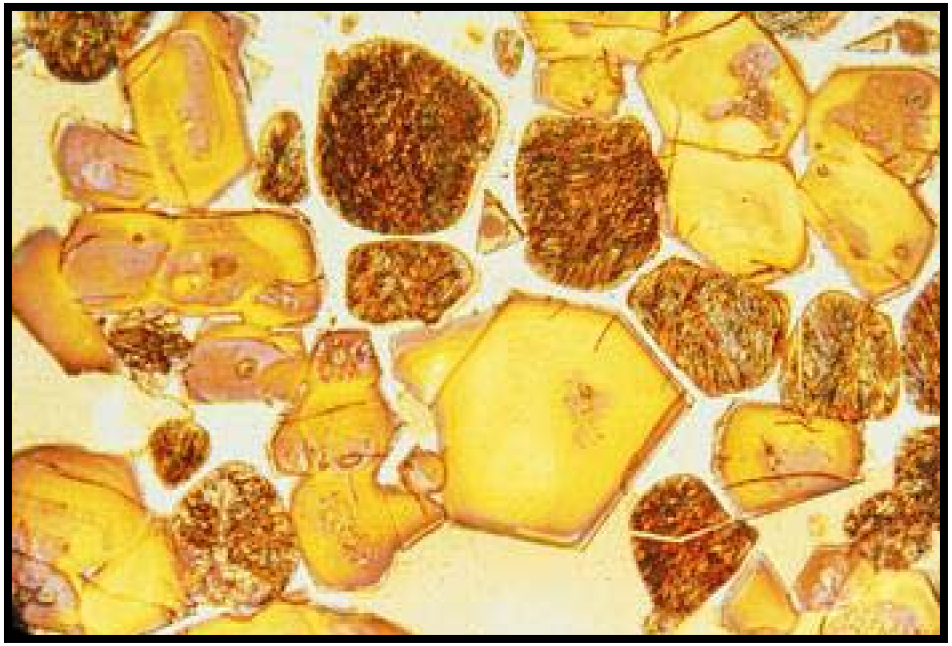


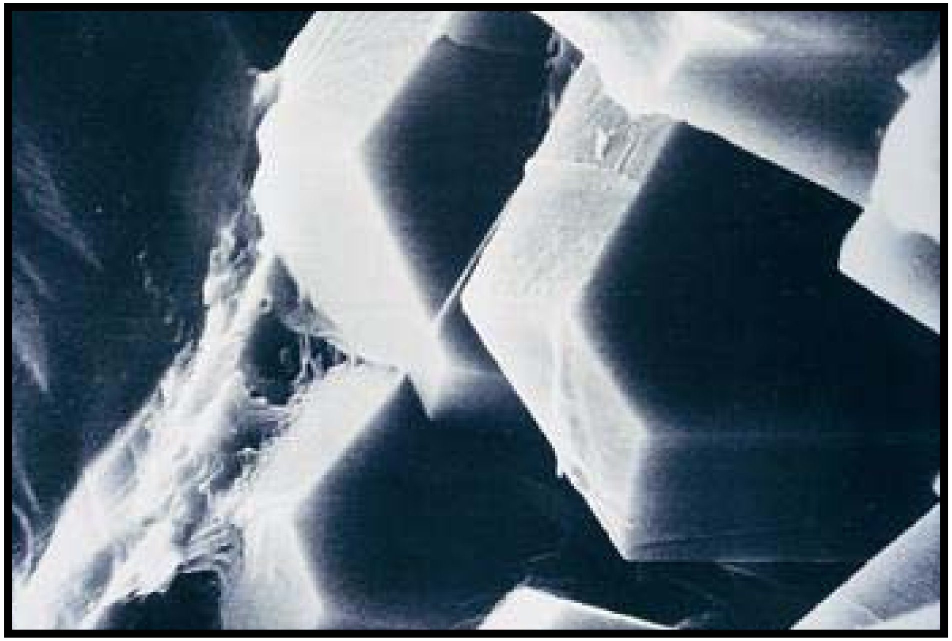
After Mindess and Young Figure 3.2

Clinker Microstructure

Dark, Rounded – C_2S

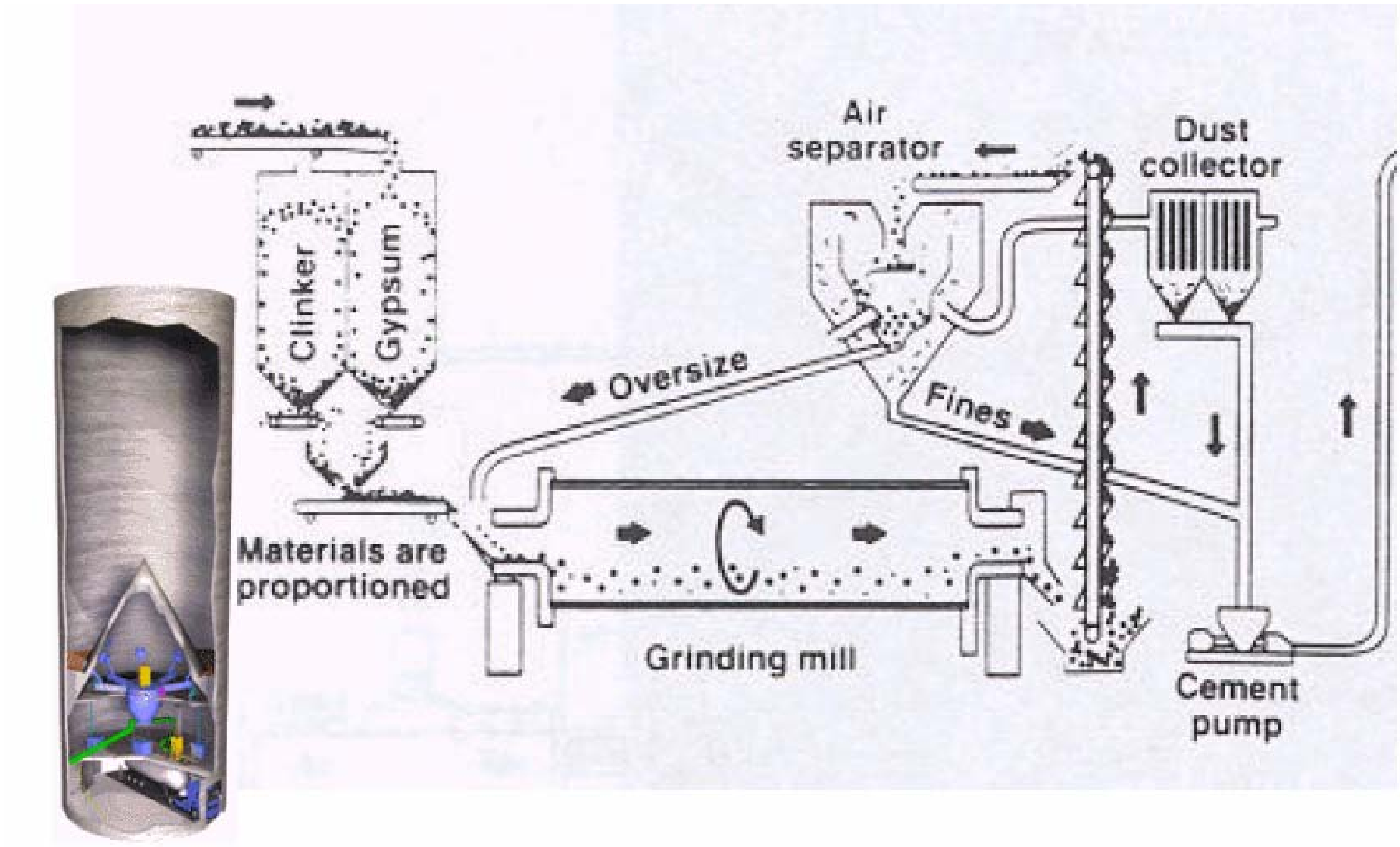
C_3S crystals magnified 3000 times





Light, Angular – C_3S

Schematic of a Grinding Mill



Grinding Mill

Loud Process

Fineness Influences Performance

Fineness of cement

- Grinding is the last step in processing
- Measures of fineness
  - Specific surface
  - Particle size distribution
- Blaine's fineness
  - Measure of air permeability
- Typical surface areas
  - ~ 350 m^2 / kg (Normal cements)
  - ~ 500 m^2 / kg (High early strength cements)

PSD of cement

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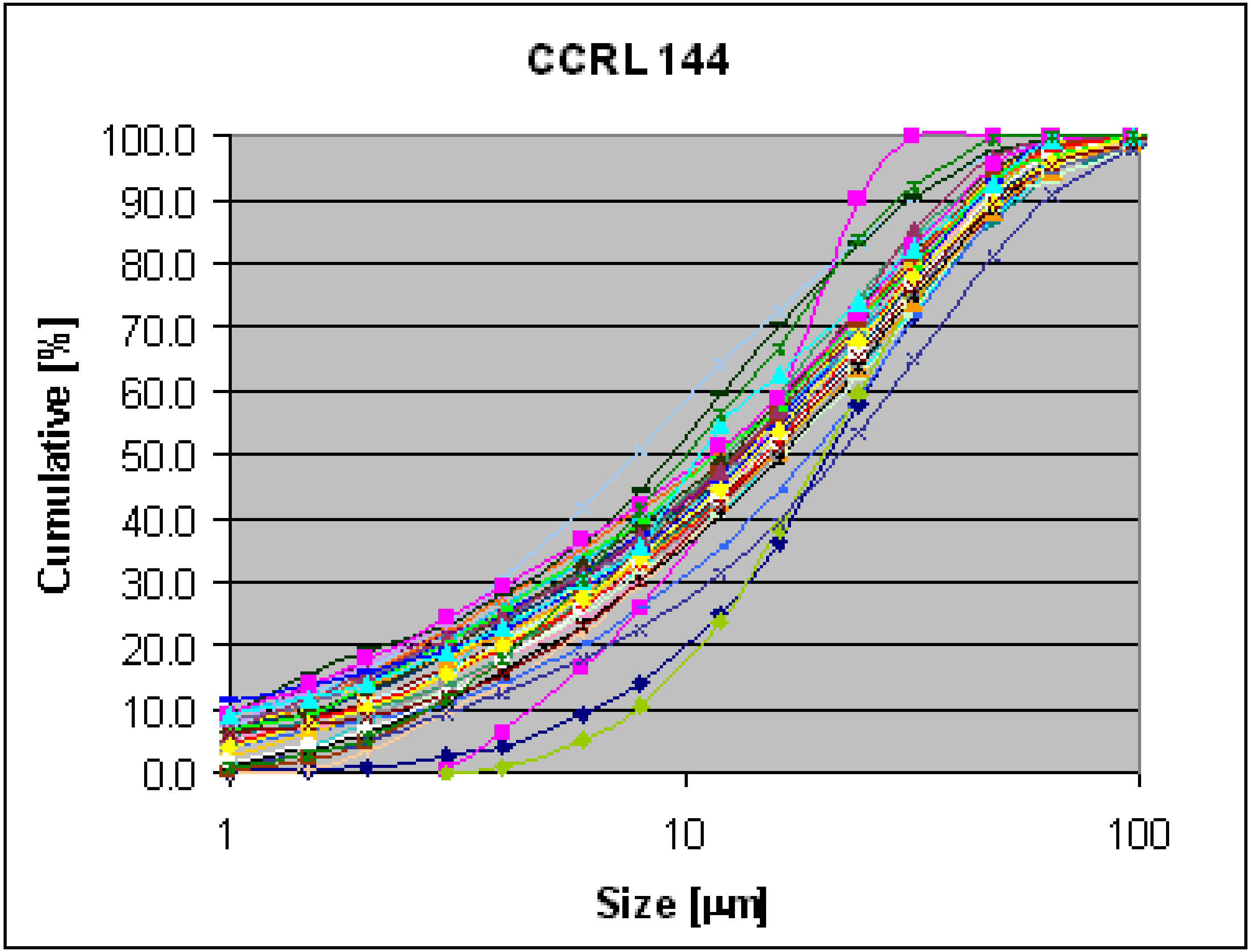

ciks.cbt.nist.gov/~garbocz/ nistir6931/node29.htm

Significance of fineness

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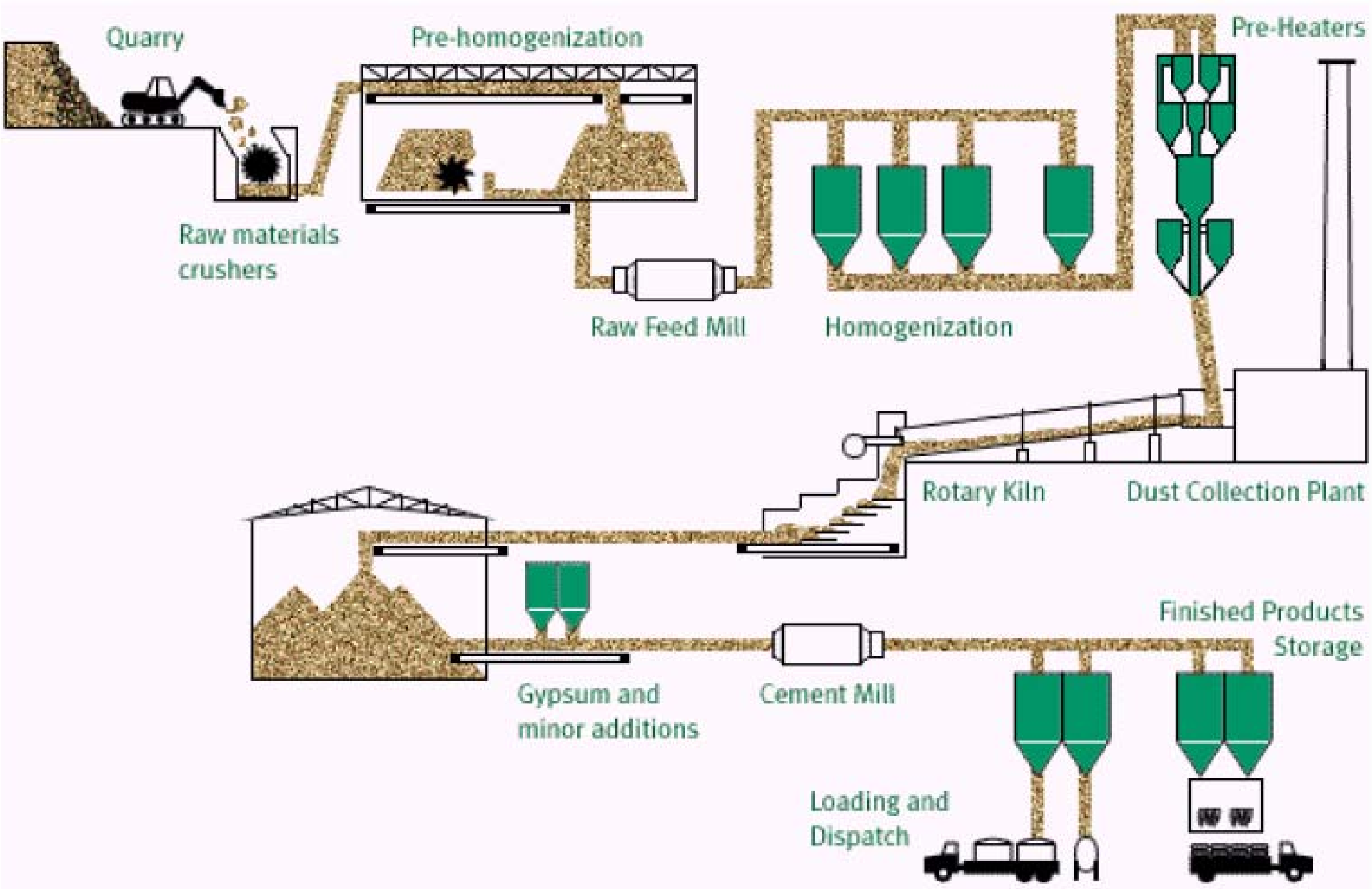
- Finer cement = Faster reaction
- Finer cement = Higher heat of hydration
- Large particles do not react with water completely
- Higher fineness
  - Higher shrinkage
  - Reduced bleeding
  - Reduced durability
  - More gypsum needed

Summary of the Cement Making Process



Some practical issues about cement making

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- Scale of the business (local / national)
- LOCATION
- Plant operations
- Wet versus Dry process
- Energy savings – Preheaters, Dust
- Energy and fuels
- Environment

The economics of cement making

- Transportation costs – when shipped further than ~ 200 miles
- About 175 plants nationwide
- Cost of maintenance – plant and the environment
- Rising fuel costs – raw material quality and fuel dependence
- Continuous operability

Portland Cement Types (ASTM C 150)

- ASTM C 150 (AASHTO M 85)
- 5 types in general – types I to V
- **Type I – Normal (OPC)**
- **Type II – Moderate Sulfate Resistance**
- **Type III – High early Strength**
- **Type IV – Low heat of hydration**
- **Type V – High Sulfate Resistance**
- Chemical compositions different

Other special Types

- Not very commonly used or manufactured
- Type IA – Normal (OPC) – air entraining
- Type IIA – Moderate sulfate resistance –air entraining
- Type IIIA- High early strength – air entraining

Typical Compositions

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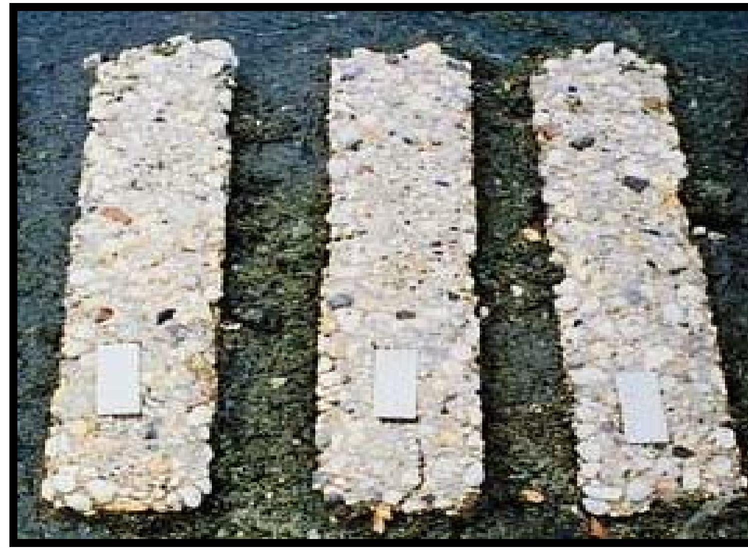
ASTM Type		C_3S %	C_2S %	C_3A %	C_4AF %	B. Fineness Kg/m2
I	General Purpose	55	19	10	7	370
II	Mod Sulfate Mod Heat	51	24	6	11	370
III	Early Strength	56	19	10	7	540
IV	Low Heat	28	49	4	12	380
V	Sulfate Resistant	38	43	4	9	380

Applications of Type- I cement

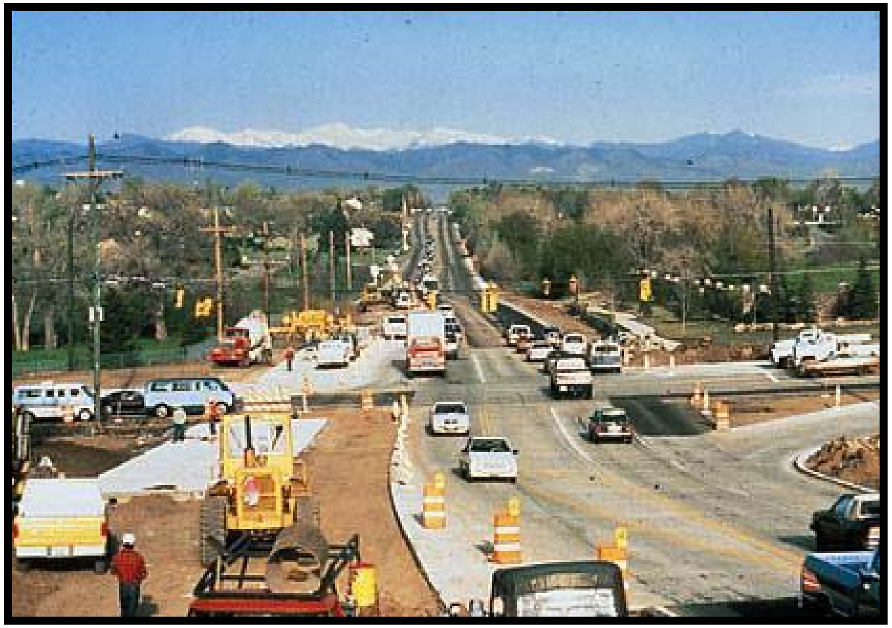
Applications of Type II and IV

BE AWARE OF THIS

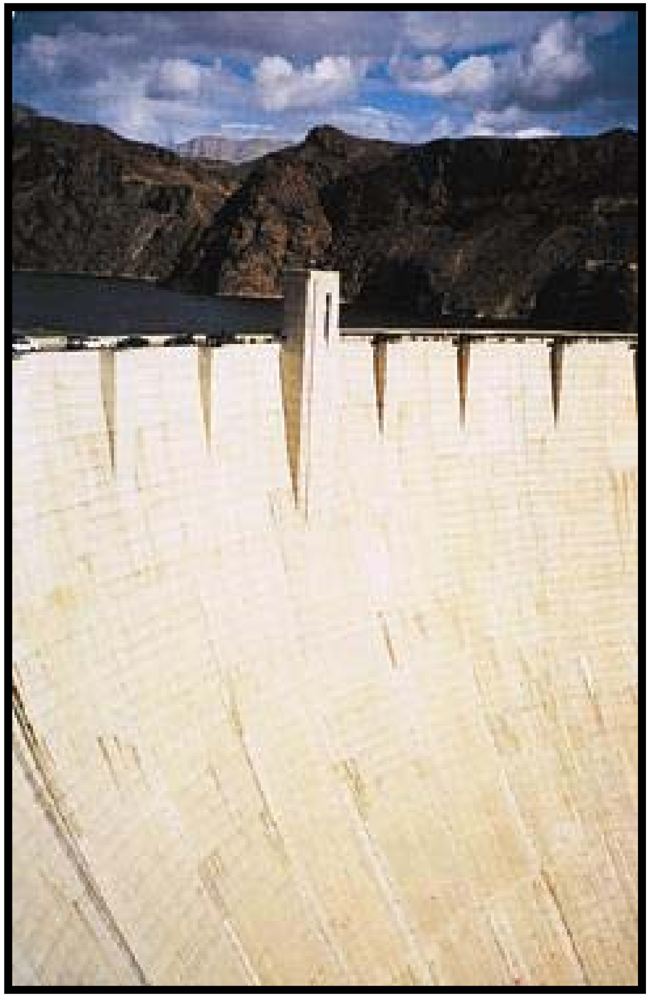
- Type of cement is no guarantee against other bad concreting practices
- To be durable, you have to get the basics right: the cement type is just an aid
- Water-cement ratio is key
- Top picture – w/c 0.69, Type V
- Bottom picture – w/c 0.35, Type V



Applications of Type III (High early strength)



Applications of Type IV (Low Heat)



White Portland Cement

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Blended Hydraulic Cements

- ASTM C 595 (AASHTO M 240)
- Blending supplementary materials into OPC
- Improves properties (we will see in detail how this is effected)
- Reduces cost – materials like fly ash are waste products from other industries
- Environmental effects –concrete acts as a sink to hazardous products

Blended Cements

- Type IS –Portland blast furnace slag cement
- Type IP, Type P – Portland Pozzolan cement
- Type I(PM) – Pozzolan modified Portland cement
- Type S –slag cement
- Type I (SM) – Slag modified pozzolan cement

Other Hydraulic Cements

- ASTM C 1157 – 6 types
- Type GU – General Use
- Type HE – High early strength
- Type MS –Moderate sulfate resistance
- Type HS – High sulfate resistance
- Type LH – Low heat of hydration
- Type MH – Moderate heat of hydration