Concrete Technology
Lecture 2

Engr. Usama Ali

IQRA NATIONAL UNIVERSITY
INU
DEFINING POSSIBILITIES, CREATING OPPORTUNITIES

Contents

Introduction

- Cement is a finely ground inorganic powder that sets, hardens and adheres to other materials, binding them together
- The most important types of cement are used in the production of mortar in masonry, and of concrete, which is a combination of cement and an aggregate to form a strong building material.
- Cements used in construction are usually inorganic, often lime or calcium silicate based, and can be characterized as being either **hydraulic** or **non-hydraulic**, depending upon the ability of the cement to set in the presence of water
- **Hydraulic cements** (e.g., Portland cement) harden because of hydration, a chemical reaction between the anhydrous cement powder and water.

Introduction (Cont'd)

- **Non-hydraulic** cements do not harden underwater; for example, slaked limes harden by reaction with atmospheric carbon dioxide (Carbonation)
- First calcium oxide (lime) is produced from calcium carbonate (limestone or chalk) by calcination at temperatures above 825 °C (1,517 °F) for about 10 hours at atmospheric pressure: $CaCO_3 \rightarrow CaO + CO_2$
- The calcium oxide is then *spent* (slaked) mixing it with water to make slaked lime (calcium hydroxide): $CaO + H_2O \rightarrow Ca(OH)_2$
- Once the excess water is completely evaporated (this process is technically called *setting*), the carbonation starts: $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$
- This reaction takes a significant amount of time because the partial pressure of carbon dioxide in the air is low. The carbonation reaction requires the dry cement to be exposed to air, and for this reason the slaked lime is a non-hydraulic cement and cannot be used under water. This whole process is called the *lime cycle*

Raw Materials for Manufacturing of Portland Cement

- Basic Chemical Components of Portland Cement
  - Calcium (60-67%)
  - Silica (17-25%)
  - Alumina (3-8%)
  - Iron (0.5-6%)

- The common Raw materials
  - Limestone
  - Sand
  - Shale, Clay
  - Iron ore
  - Gypsum

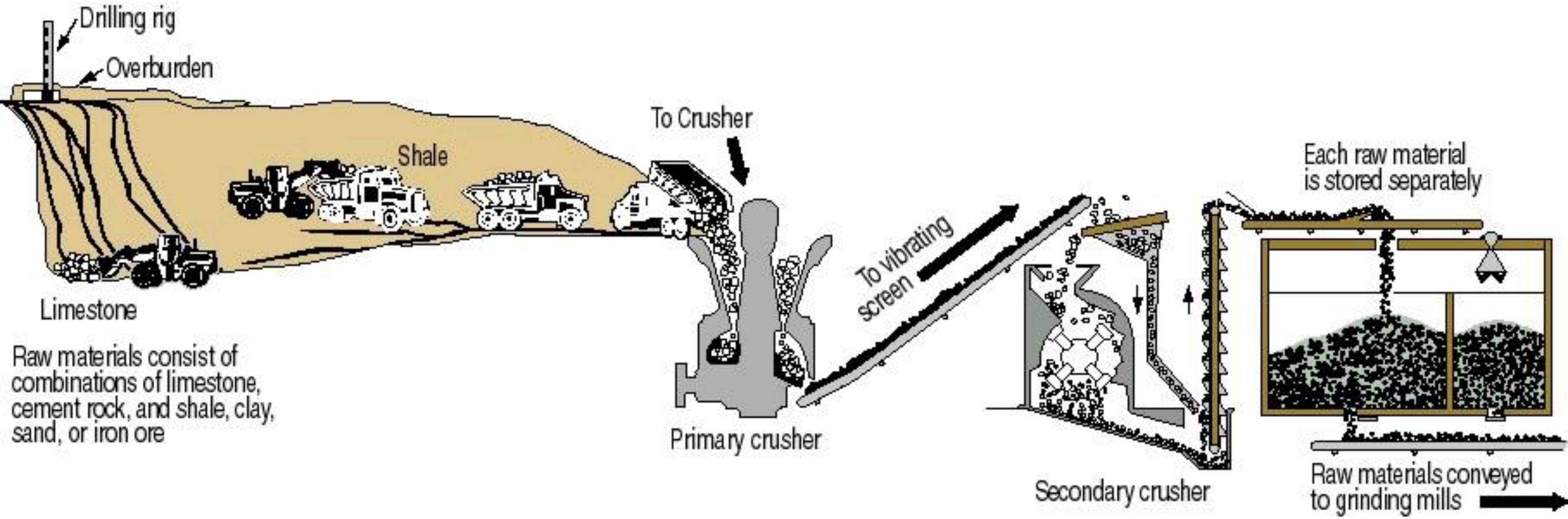
Table 1: Examples of raw materials for Portland Cement manufacture

Calcium	Silicon	Aluminum	Iron
Limestone	Clay	Clay	Clay
Marl	Marl	Shale	Iron ore
Calcite	Sand	Fly ash	Mill scale
Gypsum	Shale	Aluminum ore refuse	Shale
Marly limestone	Fly ash	Phyllite	Blast furnace dust
Sea Shells	Rice hull ash	slate	slag
Cement kiln dust	Silica		
Chalk	Sand		

Manufacturing of Portland Cement

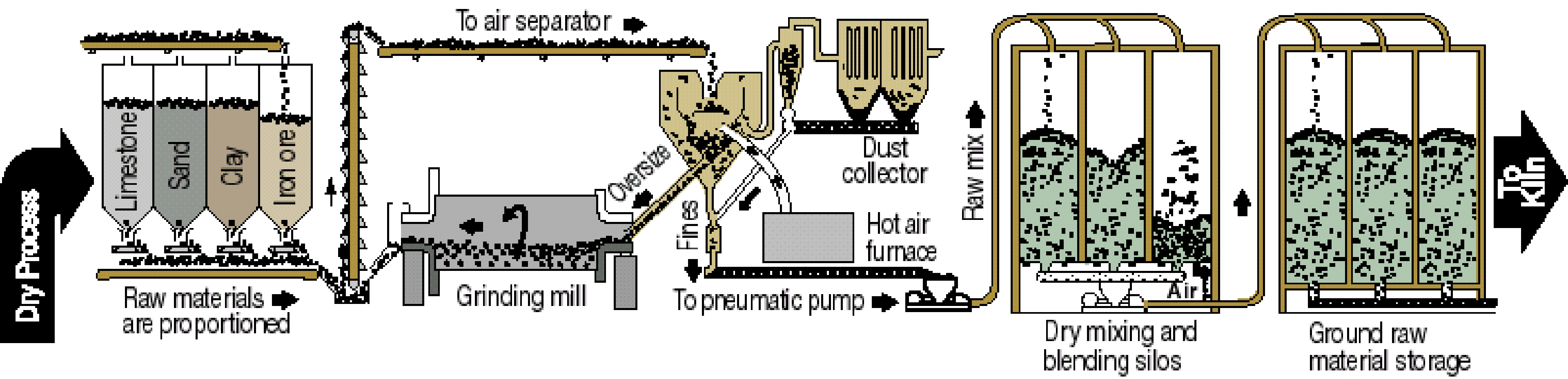
- The process of manufacture of cement consists of grinding of raw materials, mixing them intimately at certain proportions and burning them in a kiln at about 1300 to 1500°C temperature, at which the material partially fuses to form nodular shaped clinker. The clinker is cooled and ground to fine powder with addition of 3 to 5% gypsum. The product formed by using this procedure is called Portland cement.

Manufacturing of Portland Cement



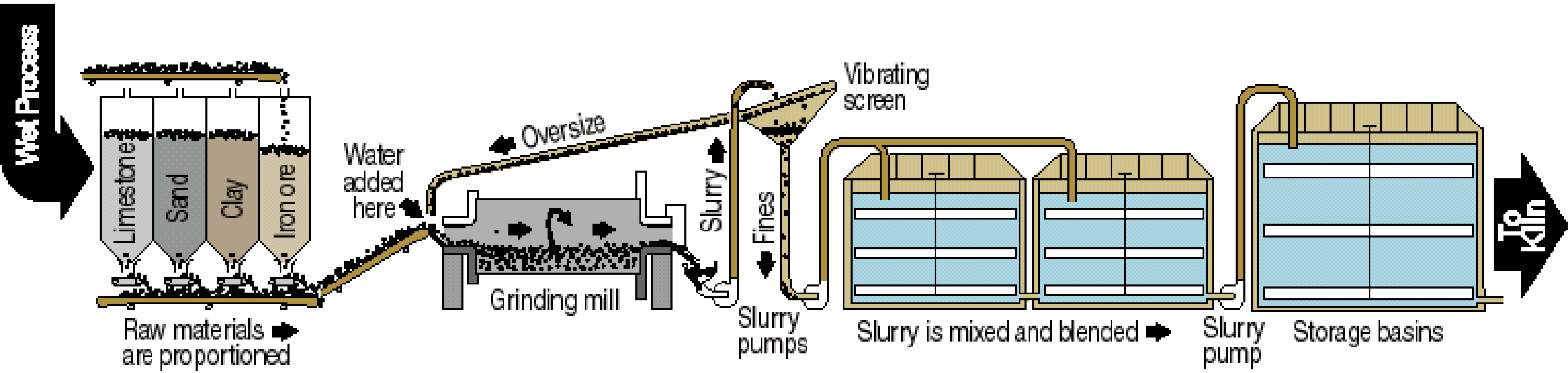
1. Stone is first reduced to 125 mm (5 in.) size, then to 20 mm (3/4 in.), and stored.

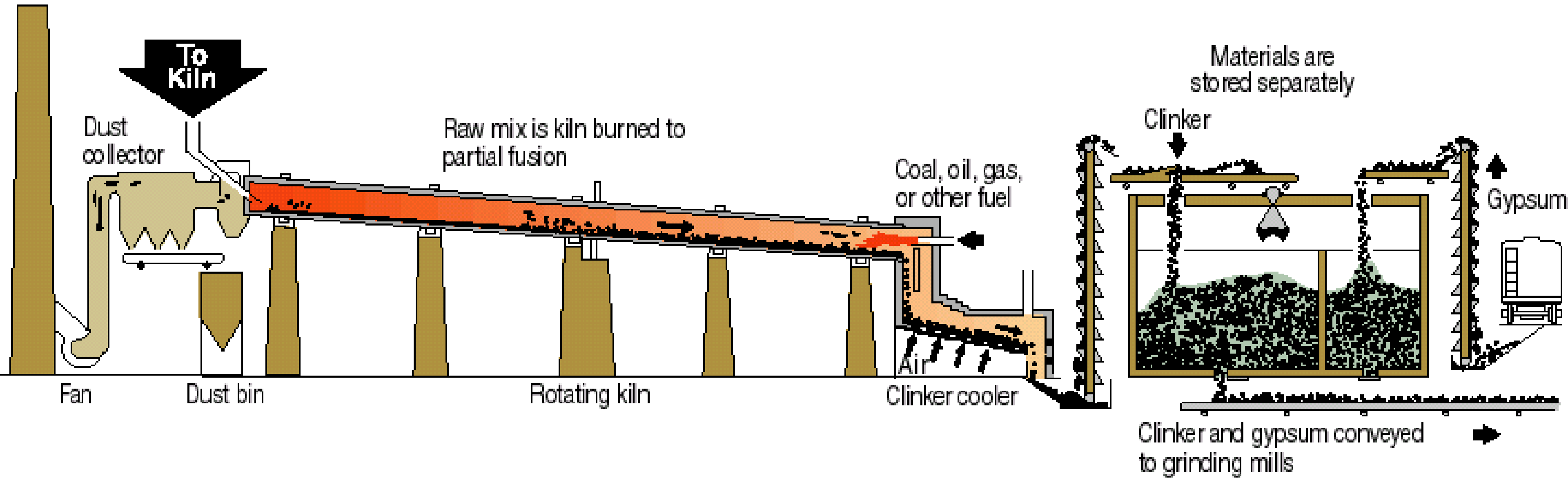
2. Raw materials are ground to powder and blended. (Dry process)



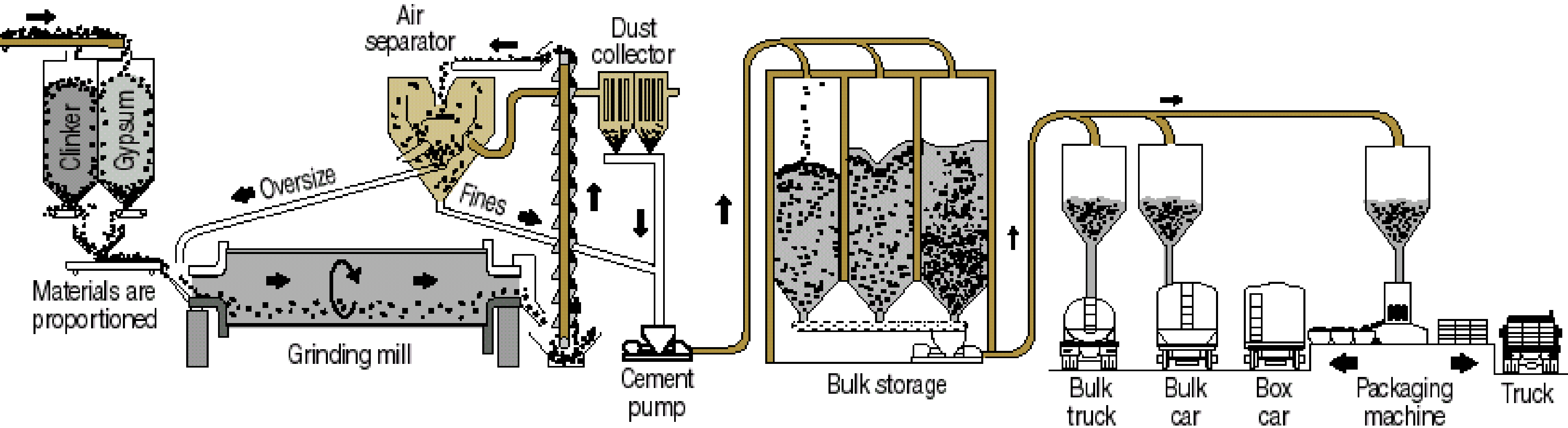
or

2. Raw materials are ground, mixed with water to form slurry, and blended. (Wet Process)





3. Burning changes raw mix chemically into cement clinker.



4. Clinker is ground with gypsum into portland cement and shipped.

Clinker

Gypsum

Portland cement clinker is formed by burning calcium and siliceous raw materials in a kiln. This particular clinker is about 3mm to 20 mm (3¼4 in.) in diameter

Gypsum, a source of sulfate, is inter-ground with Portland clinker to form Portland cement. It helps control setting, drying shrinkage properties, and strength development

Chemical Composition of Cement

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	$CaSO_4.\ 2H_2O$	$C\overline{S}H_2$	~2-6

Properties of main chemical compounds

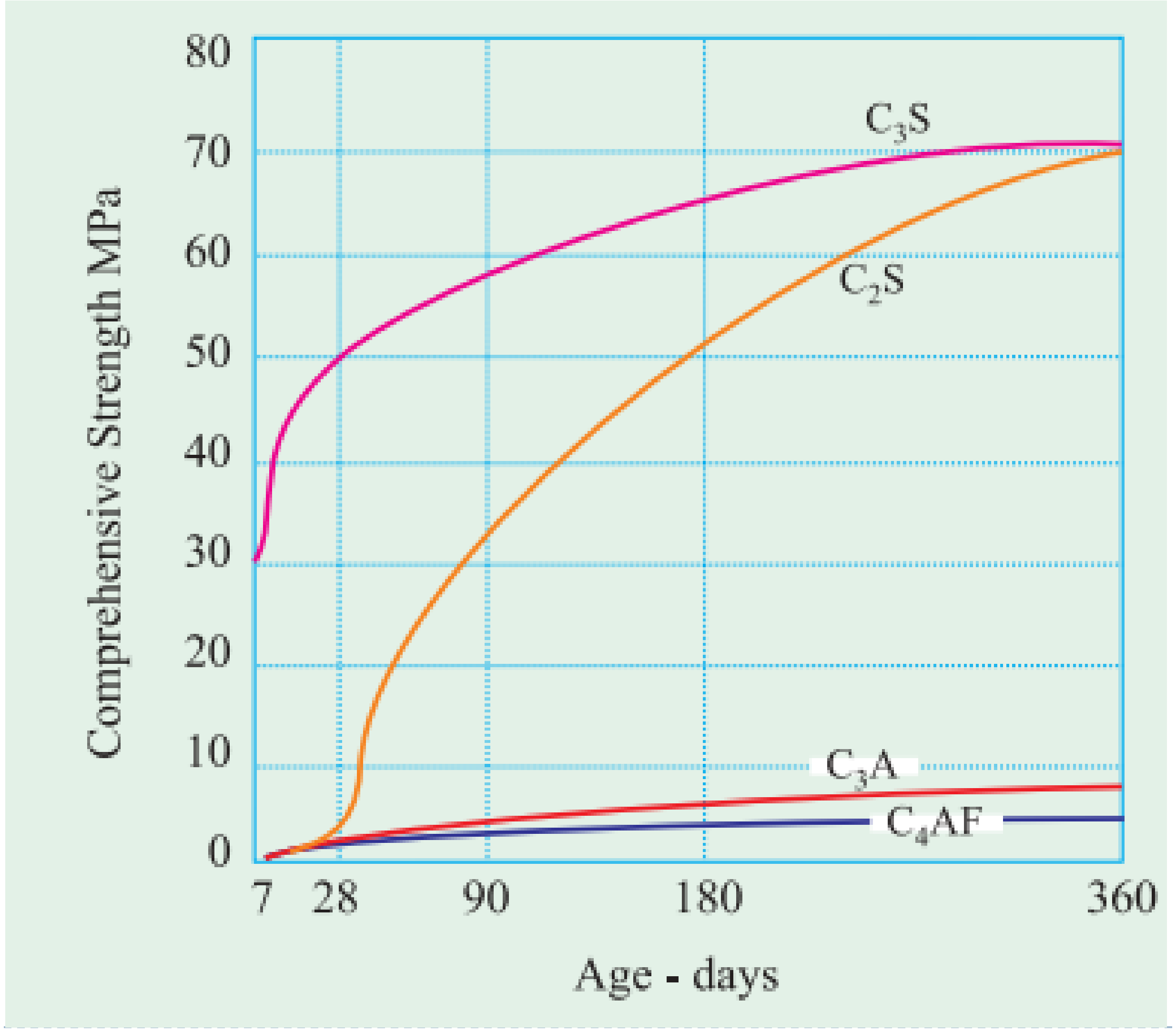
- **Tri-calcium silicate:** is responsible for early strength. Cement with high content of C_3S is favored in regions of cold climate.

- **Di-calcium silicate:** Contributes to later age strength (after one week). High percentage of C_2S is recommended in hydraulic structures.

- **Tri-calcium Aluminate:** Reacts immediately with water and defines set. In the absence of gypsum, it causes *flash set.* Generates high heat and is more reactive with soils and water containing moderate to high Sulphate concentrations and is thus the least desirable compound.

- **Tetra-calcium Alumino-ferrite:** Lowers clinkering temperature and contributes very little to strength of concrete even though it hydrates very rapidly.

Development of Strength of Pure Compounds



Hydration

- Cement acquires binding properties when mixed with water
- The chemical reaction that takes place between water and cement is referred to as hydration of cement
- The reaction of cement with water is exothermic. This liberation of heat is called heat of hydration.
- Although simple hydrates such as C-H are formed, process of hydration is a complex one and results in reorganization of the constituents of original compounds to form new hydrated compounds

5 Stages of Hydration

Reaction Stage	Kinetics of Reaction	Chemical Processes
1 Initial hydrolysis	Chemical control; **rapid**	Dissolution of ions
2 Induction period	Nucleation control; **slow**	Continued dissolution of ions
3 Acceleration	Chemical control; **rapid**	Initial formation of hydration products
4 Deceleration	Chemical and diffusion control; **slow**	Continued formation of hydration products
5 Steady state	Diffusion control; **slow**	Slow formation of hydration products

Hydration Reactions

2 $(3CaO \bullet SiO_2)$ Tricalcium silicate	+ 11 H_2O Water	= $3CaO \bullet 2SiO_2 \bullet 8H_2O$ Calcium silicate hydrate (C-S-H)	+ 3 $(CaO \bullet H_2O)$ Calcium hydroxide
2 $(2CaO \bullet SiO_2)$ Dicalcium silicate	+ 9 H_2O Water	= $3CaO \bullet 2SiO_2 \bullet 8H_2O$ Calcium silicate hydrate (C-S-H)	+ $CaO \bullet H_2O$ Calcium hydroxide
$3CaO \bullet Al_2O_3$ Tricalcium aluminate	+ 3 $(CaO \bullet SO_3 \bullet 2H_2O)$ Gypsum	+ 26 H_2O Water	= $6CaO \bullet Al_2O_3 \bullet 3SO_3 \bullet 32H_2O$ Ettringite
2 $(3CaO \bullet Al_2O_3)$ Tricalcium aluminate	+ $6CaO \bullet Al_2O_3 \bullet 3SO_3 \bullet 32H_2O$ Ettringite	+ 4 H_2O Water	= 3 $(4CaO \bullet Al_2O_3 \bullet SO_3 \bullet 12H_2O)$ Calcium monosulfoaluminate
$3CaO \bullet Al_2O_3$ Tricalcium aluminate	+ $CaO \bullet H_2O$ Calcium hydroxide	+ 12 H_2O Water	= $4CaO \bullet Al_2O_3 \bullet 13H_2O$ Tetracalcium aluminate hydrate
$4CaO \bullet Al_2O_3 \bullet Fe_2O_3$ Tetracalcium aluminoferrite	+ 10 H_2O Water	+ 2 $(CaO \bullet H_2O)$ Calcium hydroxide	= $6CaO \bullet Al_2O_3 \bullet Fe_2O_3 \bullet 12H_2O$ Calcium aluminoferrite hydrate

Characteristics of Hydration cement compound

Compounds	Reaction rate	Amount of Heat Liberated	Contribution to Cement Heat Liberation
C_3S	Moderate	Moderate	High
C_2S	Slow	Low	Low
$C_3A + C\bar{S}H_2$	Fast	Very High	Very High
$C_4AF + C\bar{S}H_2$	Moderate	Moderate	Moderate

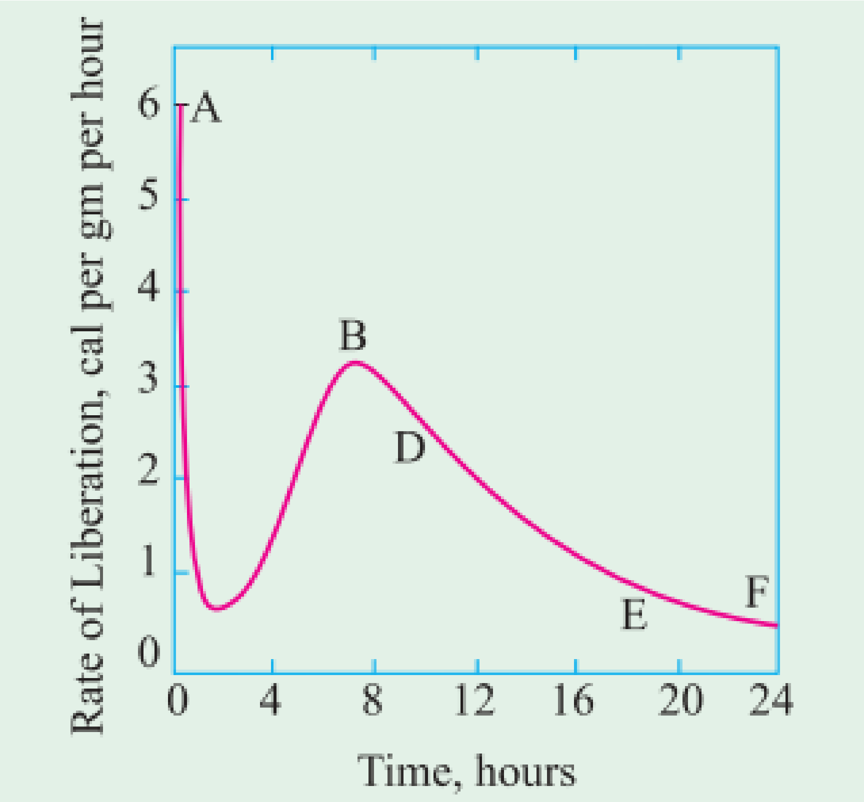
Heat of Hydration

Compound	Heat of hydration at given age (cal/g)		
	3 days	90 days	13 years
CS	58	104	122
C_2S	12	42	59
C_3A	212	311	324
C_4AF	69	98	102

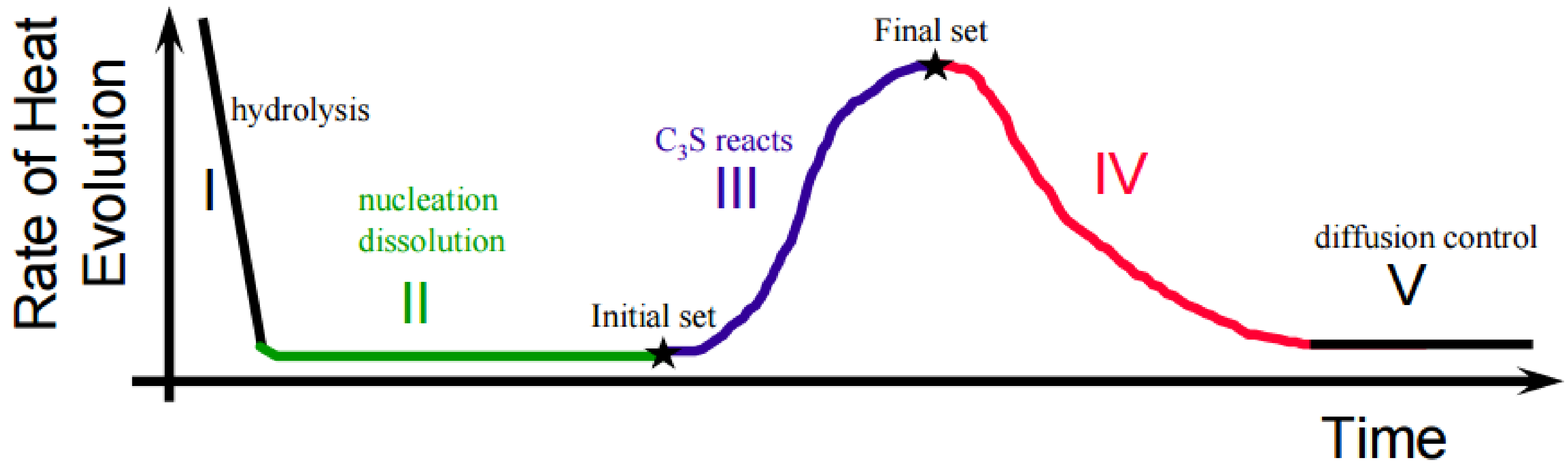
Normal cement produces 89-89cal/g in 7 days and 90-100cal/g in 28 days.

Heat of Hydration

- The reaction of cement with water is exothermic
- The reaction results in the release of considerable amount of heat known as **heat of hydration**
- **Minimum water requirement for complete hydration is 38% by weight.**



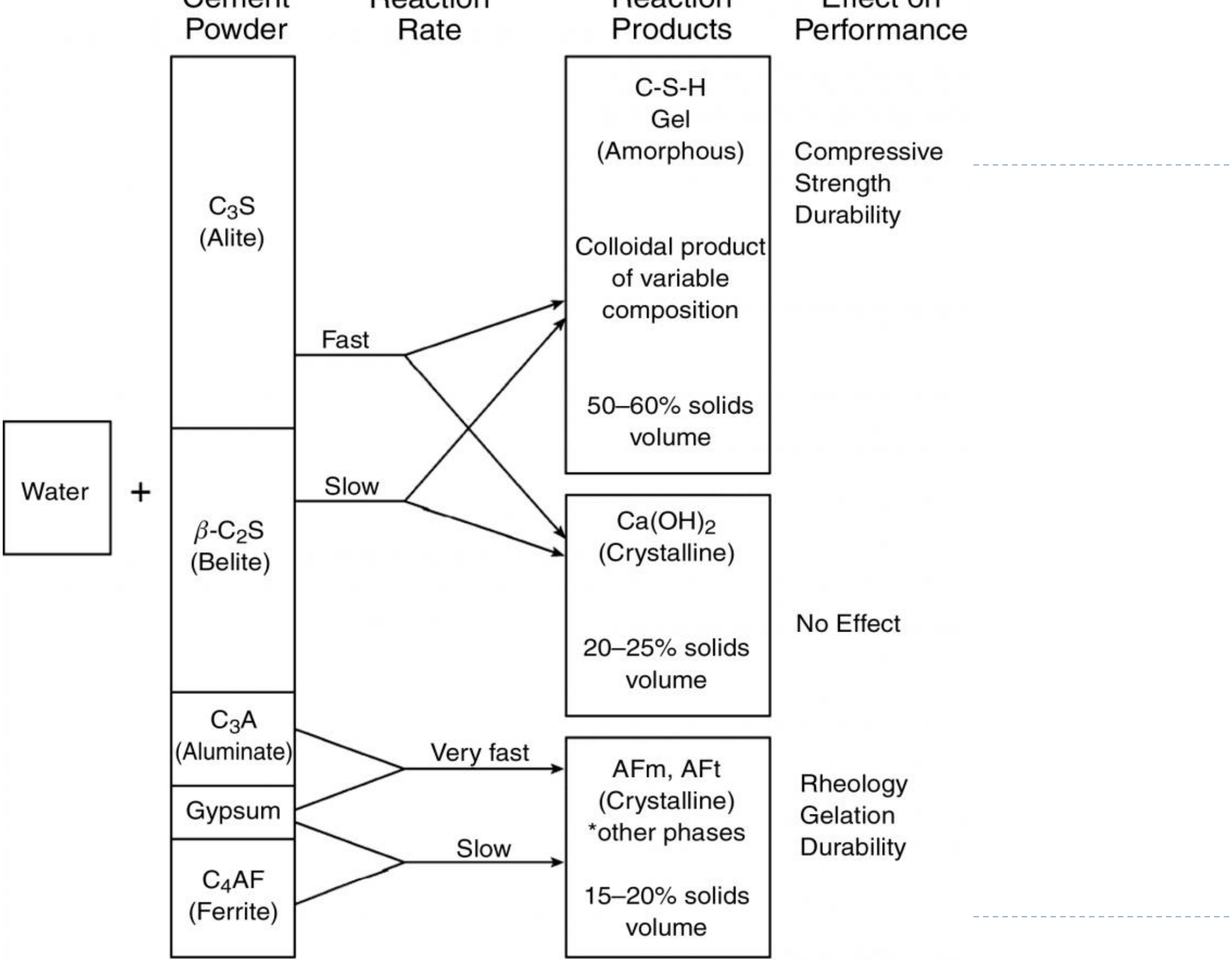
Heat of Hydration (Cont’d)



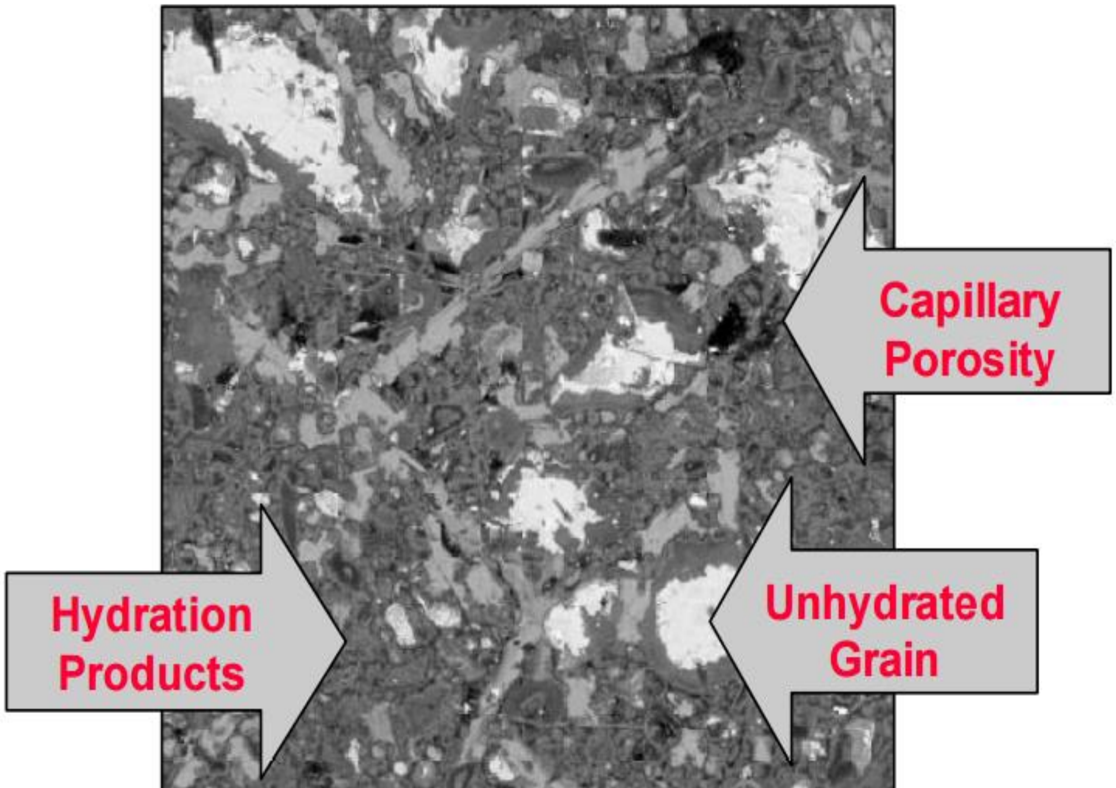
Stage I	Rapid Heat Evolution		(<15 mins)
Stage II	Dormant Period	Important for transportation	(2-4 hrs)
Stage III	Accelerating Stage	Begins with initial set	(4-8 hrs)
Stage IV	Deceleration Stage	No longer workable	(12-24 hrs)
Stage V	Steady State		

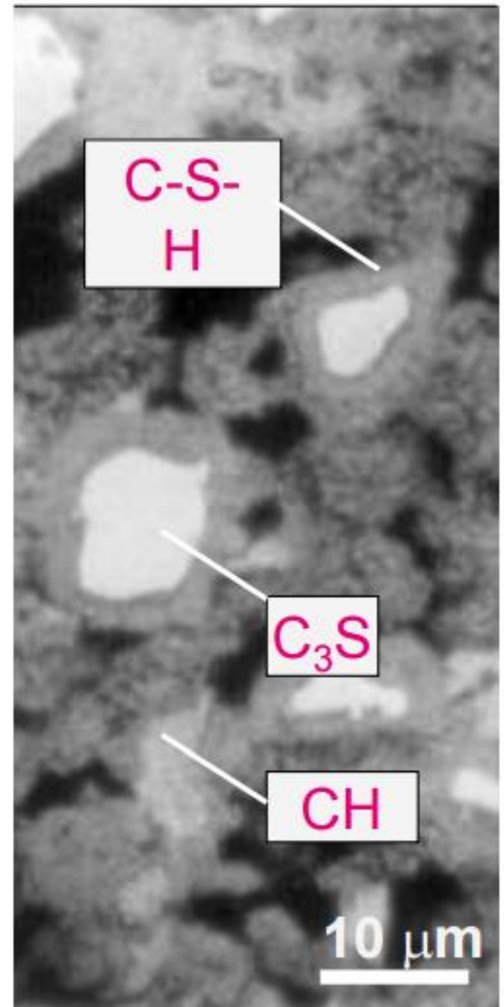
Structure of Hydrated Cement

- Hydrated cement paste consists of
  - Hydration Products
  - Un-hydrated Clinker Grain
  - Water
  - Air
- Hydration Products are
  - Calcium Silicate Hydrate (C-S-H)
  - Calcium Hydroxide (C-H)
  - Calcium Sulfo-aluminates (ettringite)

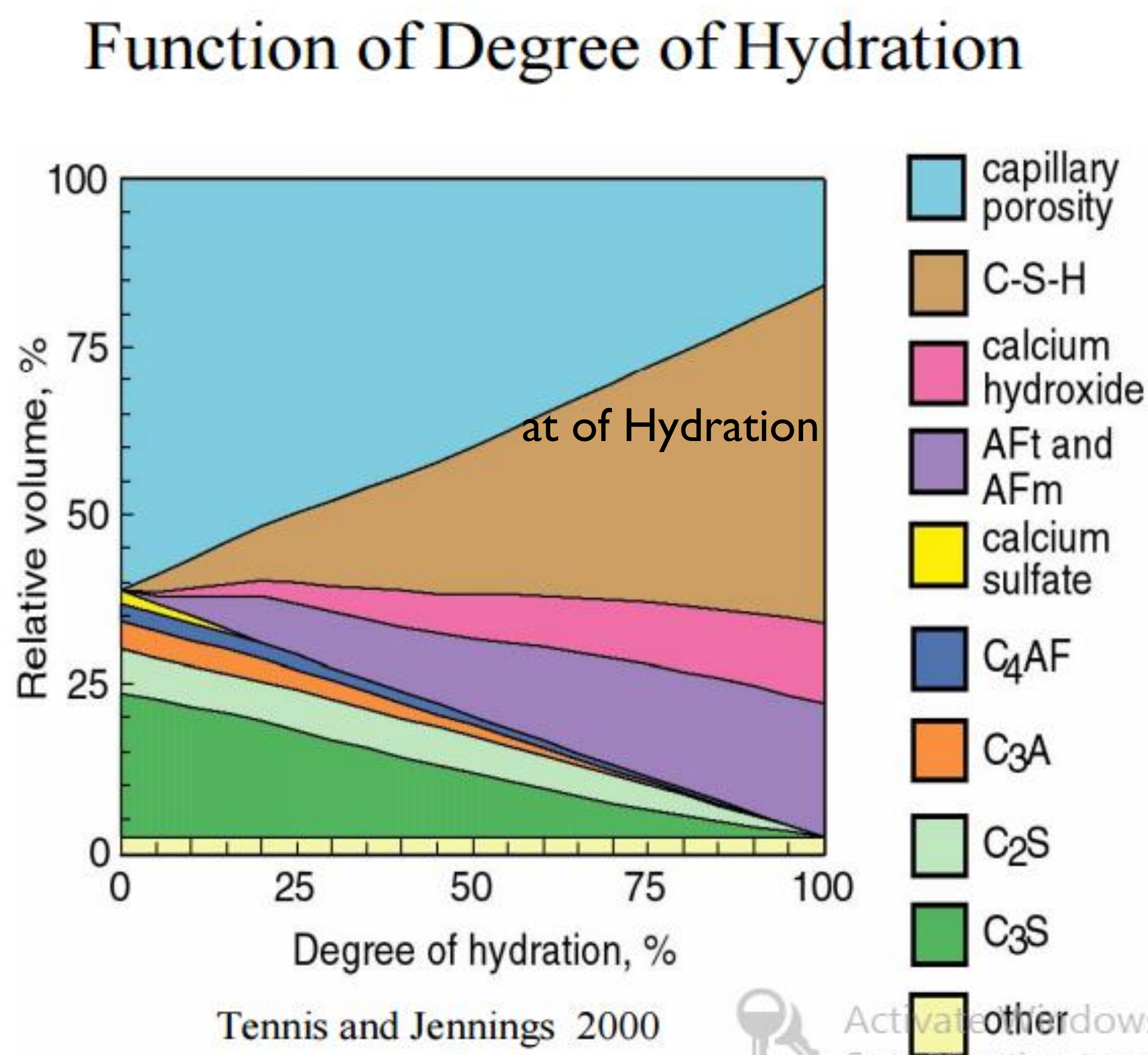

Powder
Rate
Products
Performance
Water
+
C3S
(Alite)
β-C2S
(Belite)
C3A
(Aluminate)
Gypsum
C4AF
(Ferrite)
Fast
Slow
Very fast
Slow
C-S-H
Gel
(Amorphous)
Colloidal product
of variable
composition
50–60% solids
volume
Ca(OH)2
(Crystalline)
20–25% solids
volume
AFm, AFt
(Crystalline)
*other phases
15–20% solids
volume
Compressive
Strength
Durability
No Effect
Rheology
Gelation
Durability

Structure of Hydrated Cement (Cont’d)





Relative volume of major compounds in hydrated pastes



References

- Concrete Technology by A.M Neville, J.J Brooks.
- Concrete Technology by M.S Shetty.

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