

# **Course: Concrete Technology**

## **Lecture 2: Cement: Composition and Manufacturing**

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# Session Objectives

- Understand cement as a hydraulic binder
- Analyze hydration and strength development
- Study manufacturing processes (dry & wet)
- Review production stages (extraction → grinding)
- Identify main clinker phases ( $C_3S$ ,  $C_2S$ ,  $C_3A$ ,  $C_4AF$ )
- Classify types of Portland cement and applications



# Content

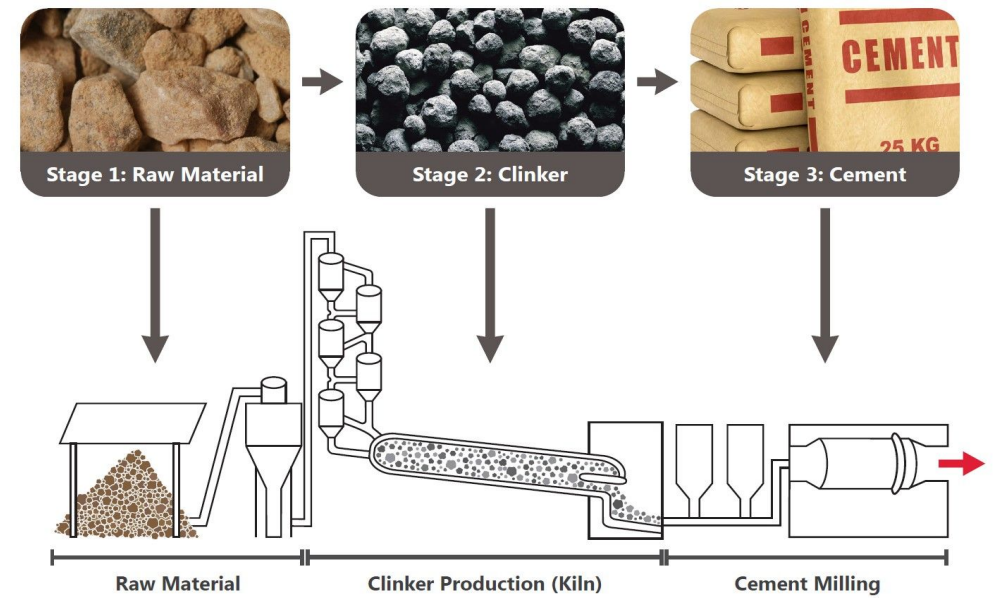
- Cement manufacturing process
- Cement chemistry and hydration
- Classification of cement types
- Quality control tests and criteria



# **Manufacturing Process**

# Cement Fundamentals

- Hydraulic binder (clinker + gypsum)
- Produced at high temperature
- Setting controlled by gypsum



Source: Cement Industry Federation (2026)

# Manufacturing Methods

- Dry process: standard, efficient
- Uses preheaters and precalciners
- Wet process: higher energy demand
- Dry method → lower cost and emissions



Source: CUK Department for International Development (2013)

# Dry Process Stages

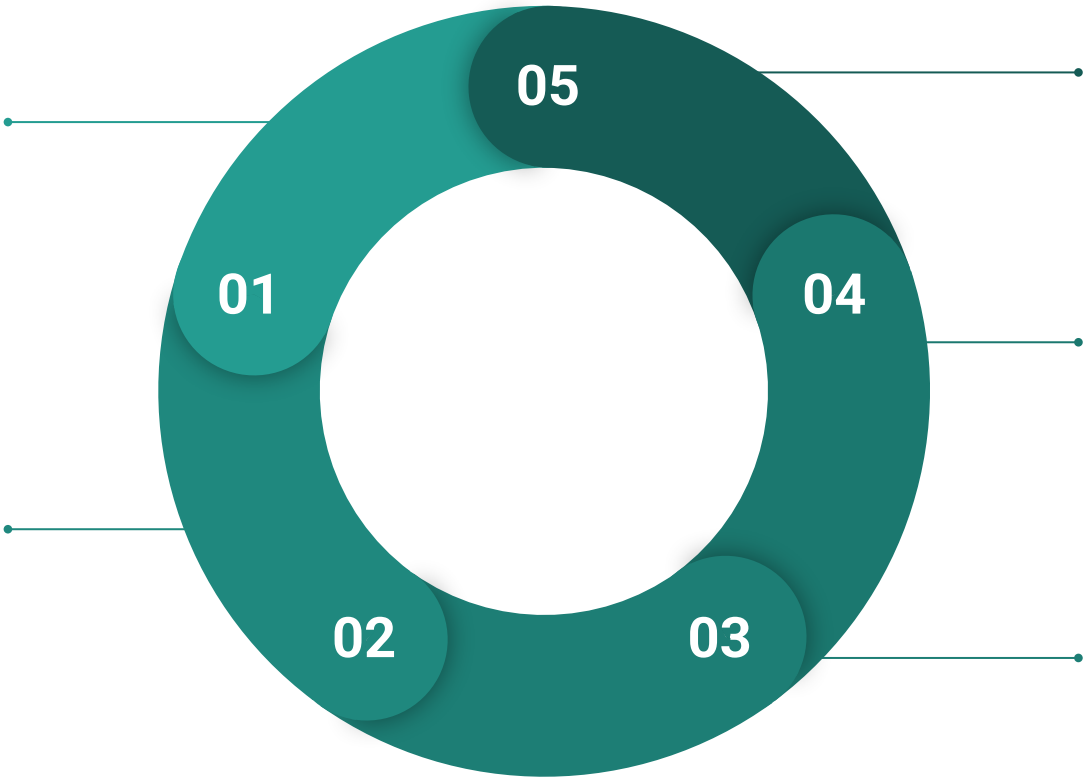
**Extraction and  
preparation**

**Crushing and  
proportioning**

**Cooling, final grinding  
, distribution**

**Preheating and  
clinkerization**

**Grinding and  
homogenization**



Source: Author's own elaboration

# Raw Materials & Crushing

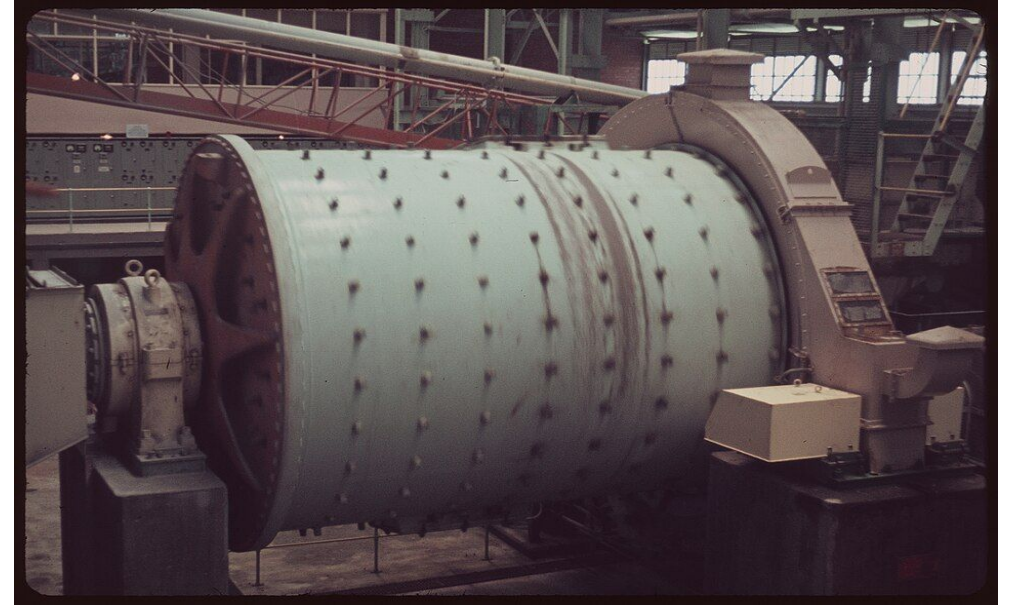
- Limestone → CaO source
- Clay → SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>
- Primary crushing (~5 in)
- Secondary crushing ( $\frac{3}{4}$ "–1½")
- Particle size control is critical



Source: Thomas Bjørkan (2011)

# Grinding & Homogenization

- Grinding (ball mills / VRM)
- High fineness (Blaine)
- Typical ratio  $\sim 4:1$  (L:C)
- Homogenization in silos
- Ensures chemical uniformity



Source: Guus Gorter (1963)

# Clinkerization

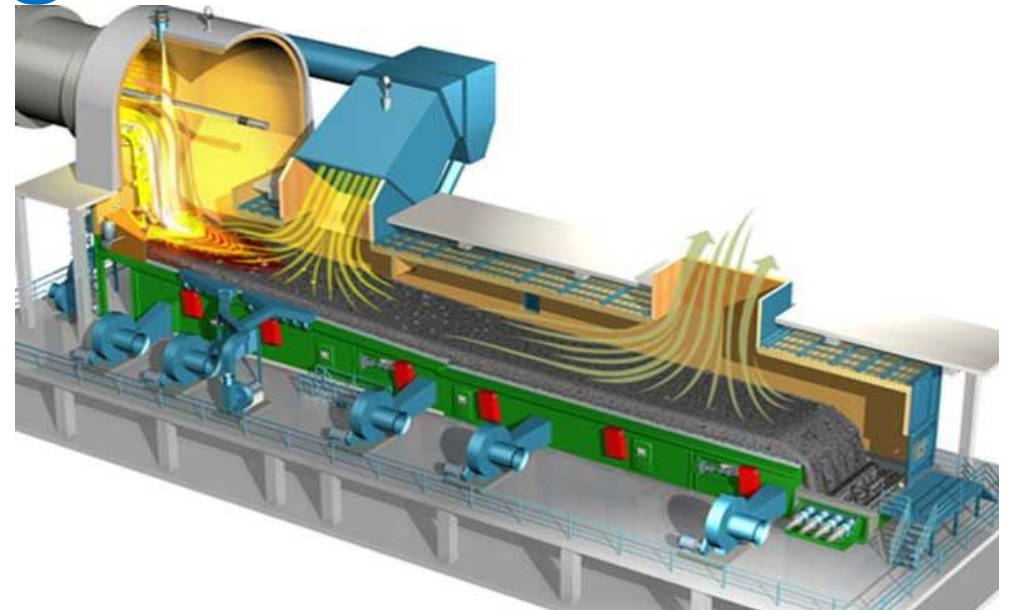
- Occurs in preheater, precalciner, rotary kiln
- Key processes: dehydration, decarbonation, phase formation
- Reaction:  $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$  (major emissions source)
- $\sim 1450\text{ }^\circ\text{C}$   $\rightarrow$  formation of clinker phases



Source: Kintek Solution (2026)

# Clinker Cooling and Grinding

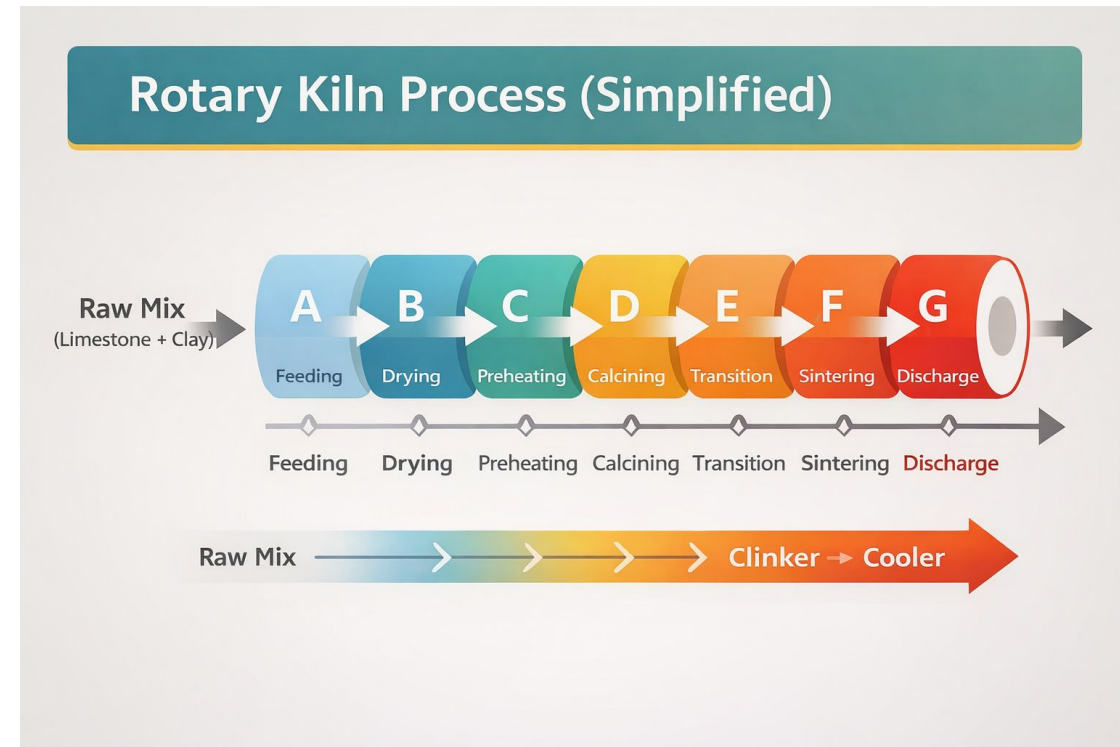
- Rapid cooling stabilizes mineral phases
- Recovers thermal energy
- Affects reactivity and strength
- Ground with gypsum (+ additions) → cement
- Cooling rate controls MgO stability



Source: AGICO Cement Machinery Co., Ltd. (2019)

# Rotary Kiln Zones

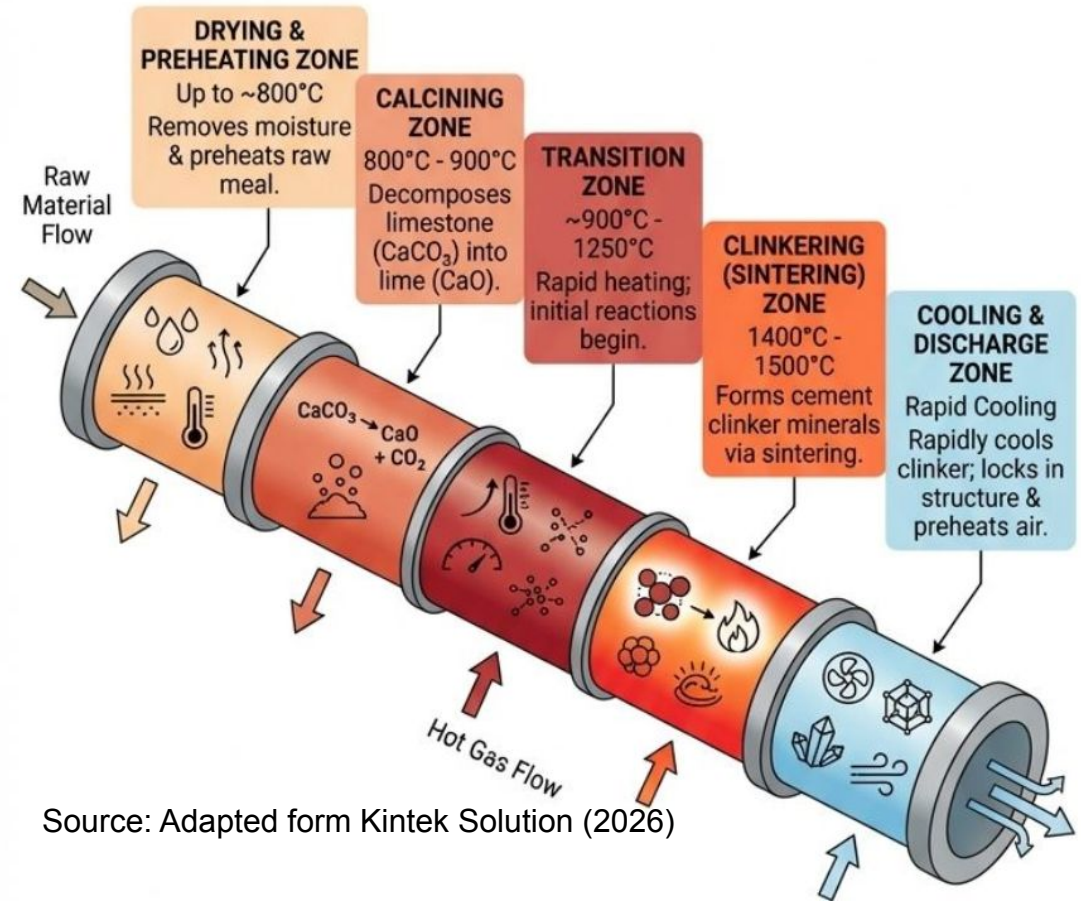
- 7 zones with increasing temperature
- Moisture evaporation → dehydration → decarbonation
- Phase formation begins ~900–1200 °C
- Liquid phase forms ~1250 °C
- ~1450 °C → final clinker phases



Source: Infographic generated using ChatGPT (2026).

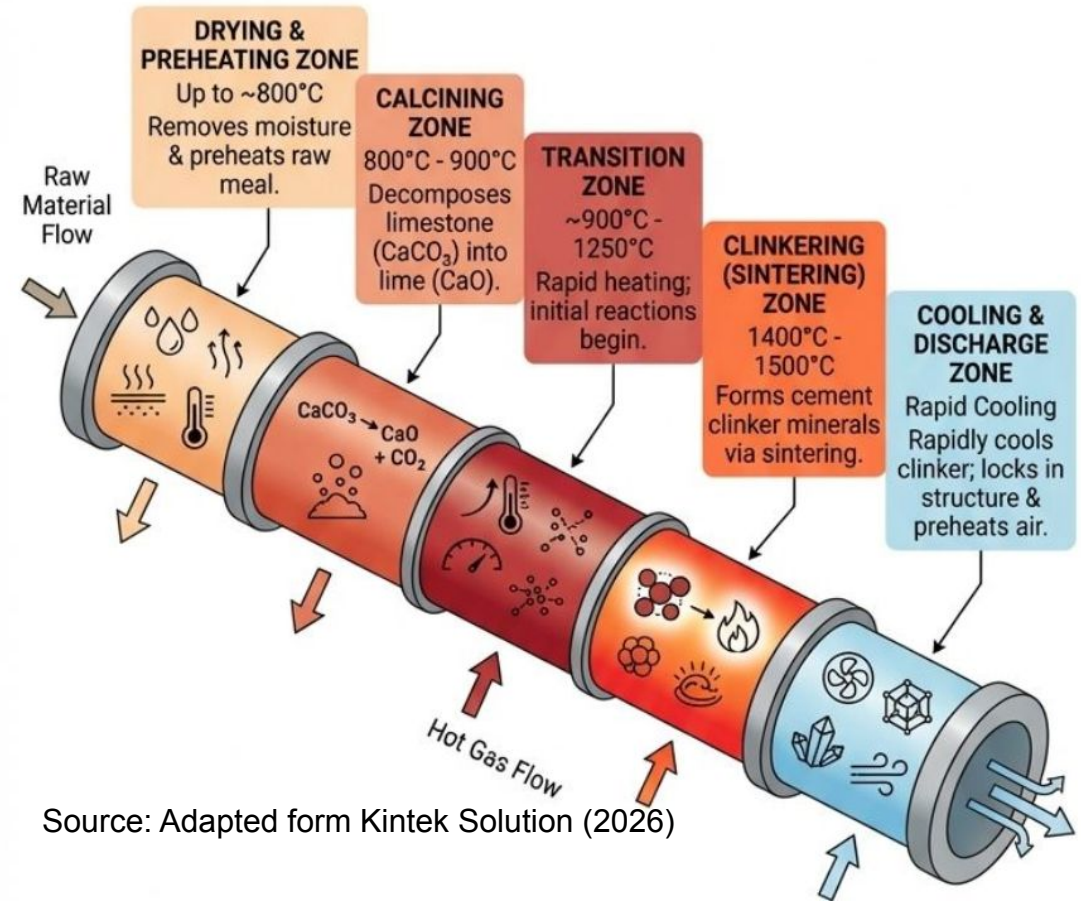
# Reactions vs Temperature

- <700 °C: physical processes dominate
- ~900 °C: solid-state reactions begin
- Formation of C<sub>2</sub>S (belite)
- Key for long-term strength



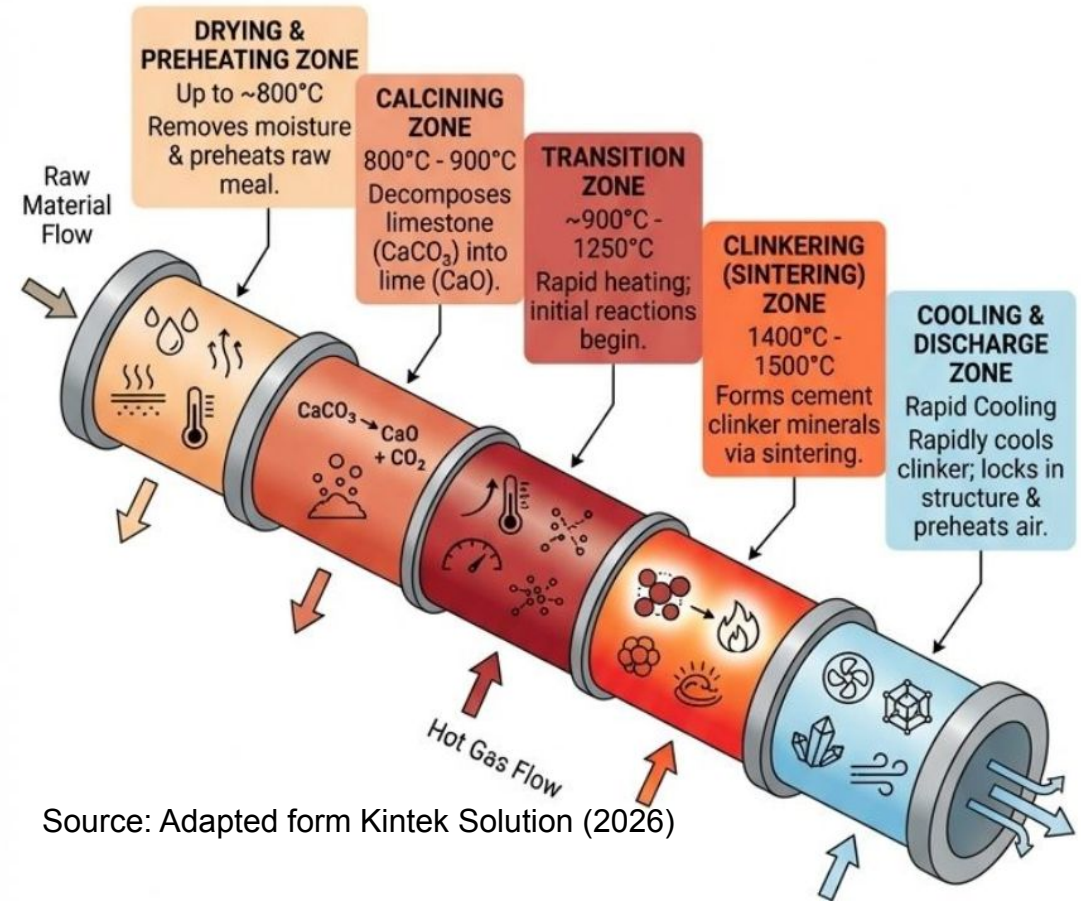
# Sintering and Alite Formati

- ~1200 °C: sintering begins
- ~1350 °C: liquid phase formation
- Particle agglomeration occurs
- $C_2S + CaO \rightarrow C_3S$  (alite)
- Alite  $\rightarrow$  early strength



# Clinker Nodule Formation

- ~1450 °C: clinker nodules form
- Alite increases; belite decreases
- Final phases:  $C_3S$ ,  $C_2S$ ,  $C_3A$ ,  $C_4AF$
- Determines cement properties



# Clinker Characteristics

- Nodules (3–4 cm), dark gray
- Rapid cooling to  $\sim 70$  °C
- Improves reactivity and stability
- Prevents expansion issues
- Enhances grindability



Source: Amit Kenny (n.d.)

# Final Grinding and Distribut

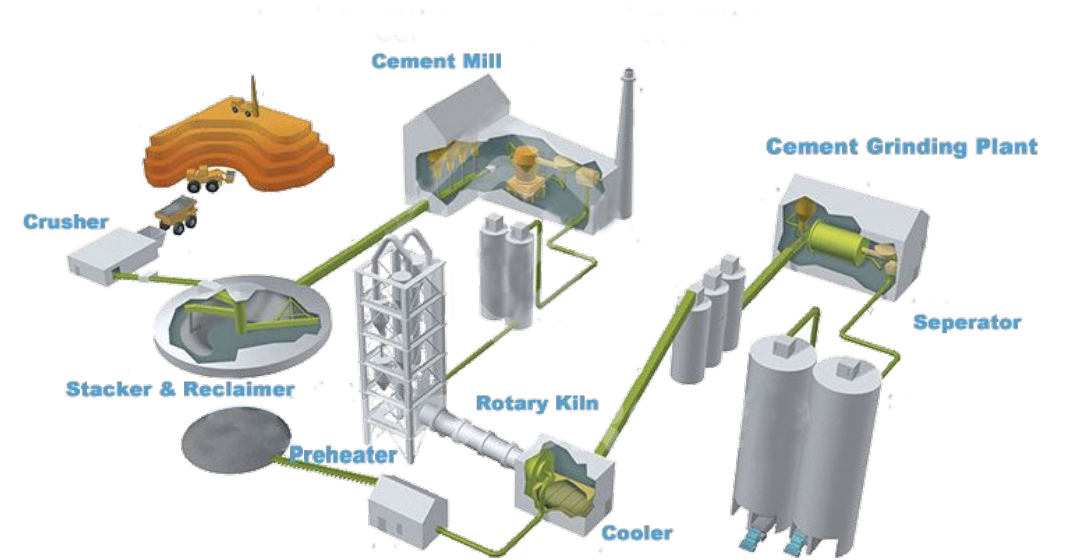
- Fine grinding of clinker
- Addition of 3–6% gypsum
- Controls setting time ( $C_3A$  hydration)
- Storage and distribution systems:
  - Bulk (silos)
  - Big bags (1.5–2 tons)
  - Paper bags (20–42.5 kg)



Source: Great Wall Construction Machinery Editorial Department. (2019)

# Process Overview

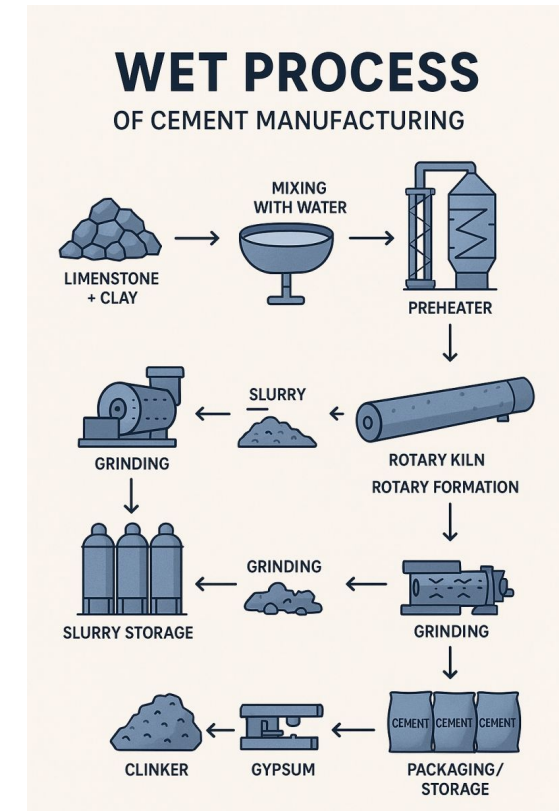
- Integrated cement production system
- Raw material storage and homogenization
- Clinkerization in rotary kiln
- Clinker cooling
- Final grinding with additions
- Packaging and distribution



Source: AGICO Cement Machinery Co., Ltd (2019)

# Wet Process

- Raw materials mixed with water (30–40%)
- Forms slurry for homogenization
- Higher energy for water evaporation
- Less efficient, higher CO<sub>2</sub> emissions
- Limited current use



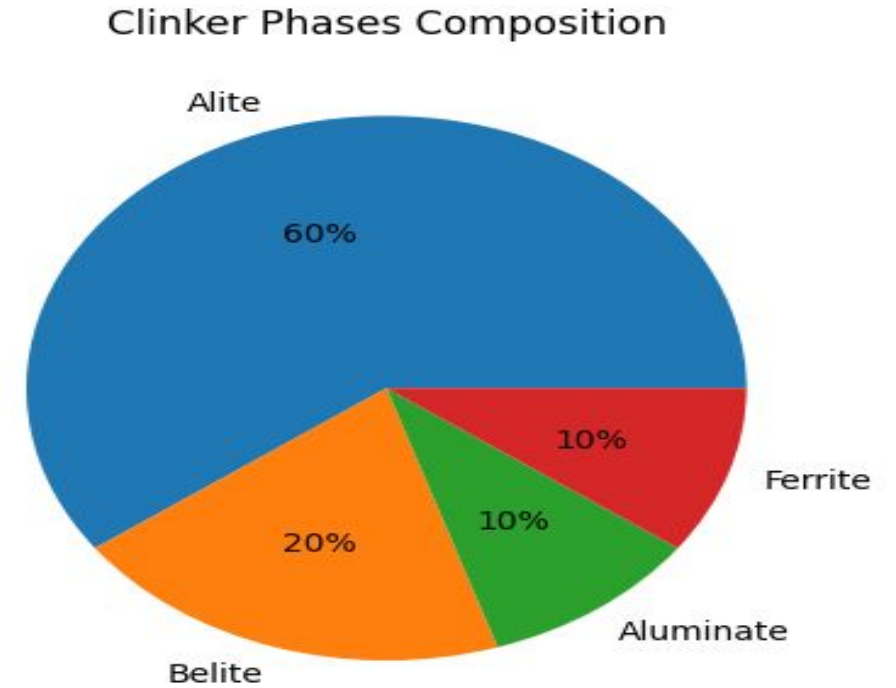
Source: Mayank (2026), generated with ChatGPT



# **Introduction to Cement Chemistry**

# Main Clinker Phases

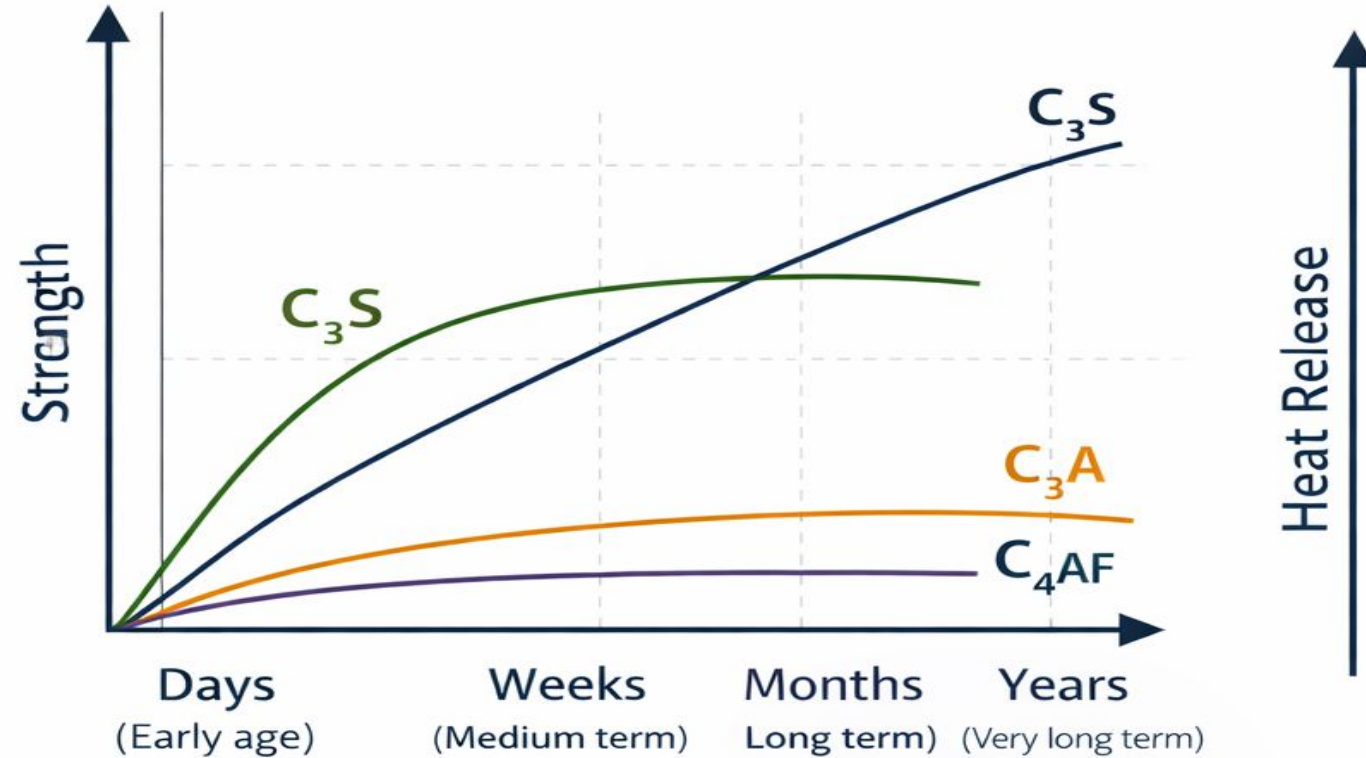
- Four main compounds (~90% of cement):
  - Alite ( $C_3S$ ): 50–70% → early strength (3–7 days)
  - Belite ( $C_2S$ ): 15–30% → long-term strength (>28 days)
  - $C_3A$ : 5–10% → rapid reaction, high heat
  - $C_4AF$ : 5–15% → minor strength contribution
- Different roles in mechanical and thermal behavior



Source: Author's own elaboration

# Strength Contribution of Phases

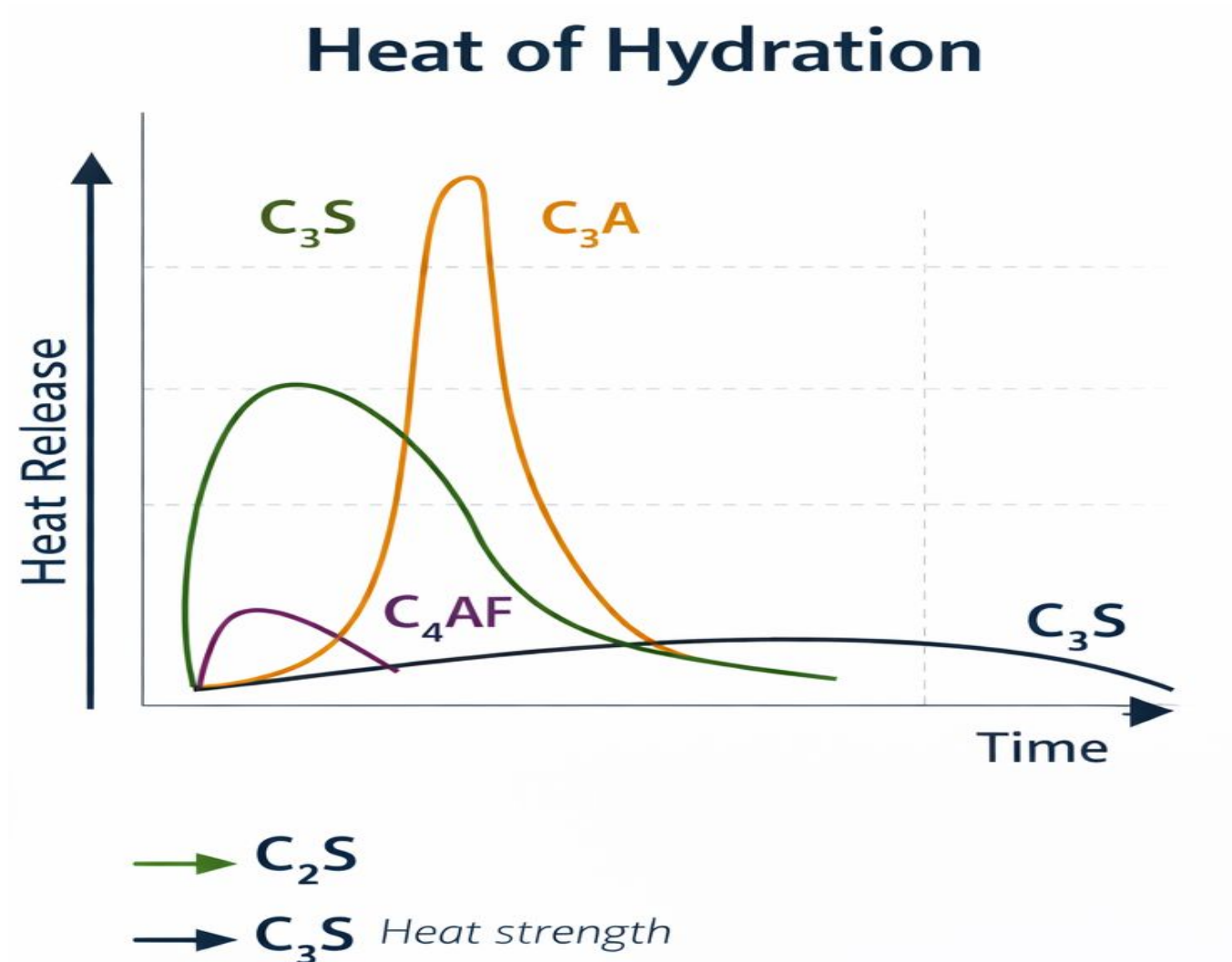
## Compressive Strength



→  $C_3S$  Early strength    •  $C_2S$  Long-term strength  
 →  $C_3S$  Long-term strength

Source: Adapted from Gomezjurado, J., Osorio, J., & Niño, J. (2014)

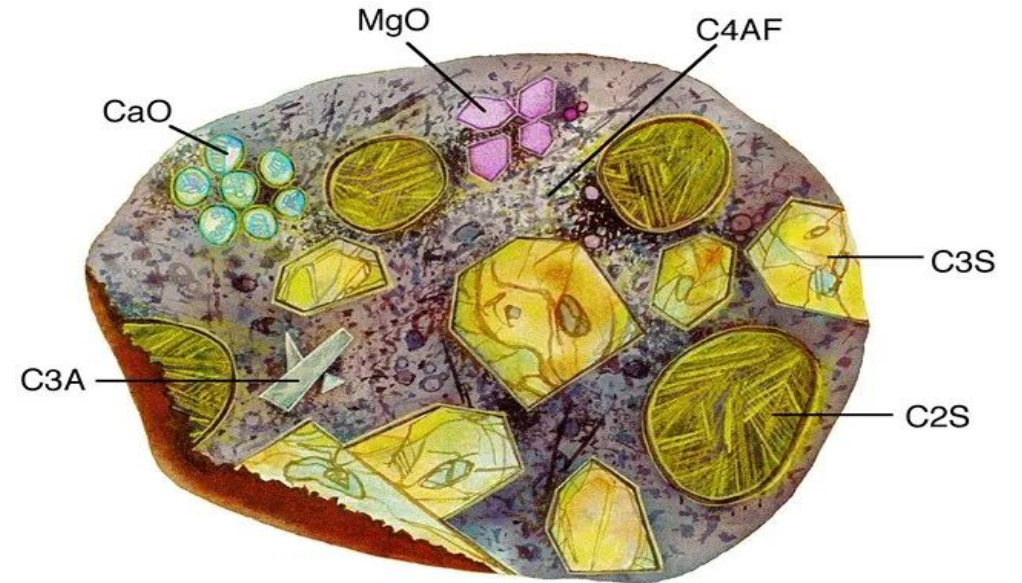
# Heat of Hydration



Source: Adapted from Gomezjurado, J., Osorio, J., & Niño, J. (2014)

# Secondary Compounds

- ~10% of cement composition
- Main oxides: CaO, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>
- Secondary components include:
  - MgO
  - Na<sub>2</sub>O, K<sub>2</sub>O (alkalis)
  - Traces: P, Ti, S
- Affect expansion, reactivity, durability
- Require strict control



Source: Suryakanta (2017)

# Alkali-Aggregate Reaction (AAR)

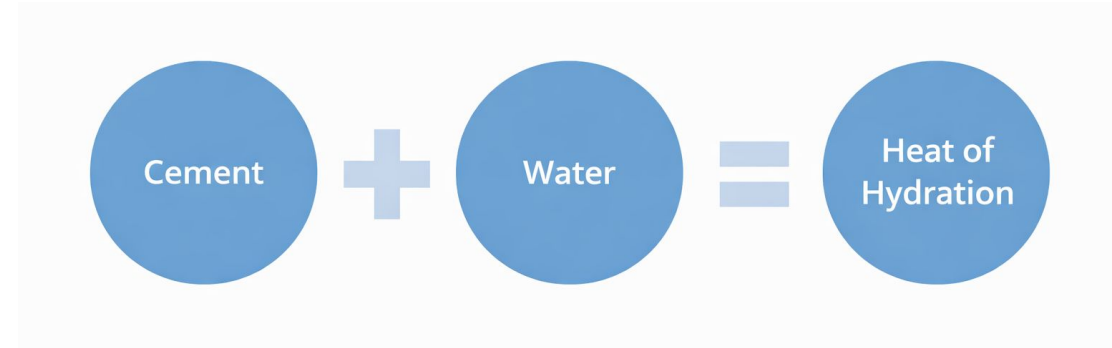
- Caused by  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$
- Occurs under moisture and temperature conditions
- Produces expansive gels
- Generates internal tensile stresses
- Leads to cracking and degradation
- Critical for durability design



Source: Shinkolobwe (2017)

# Cement Hydration

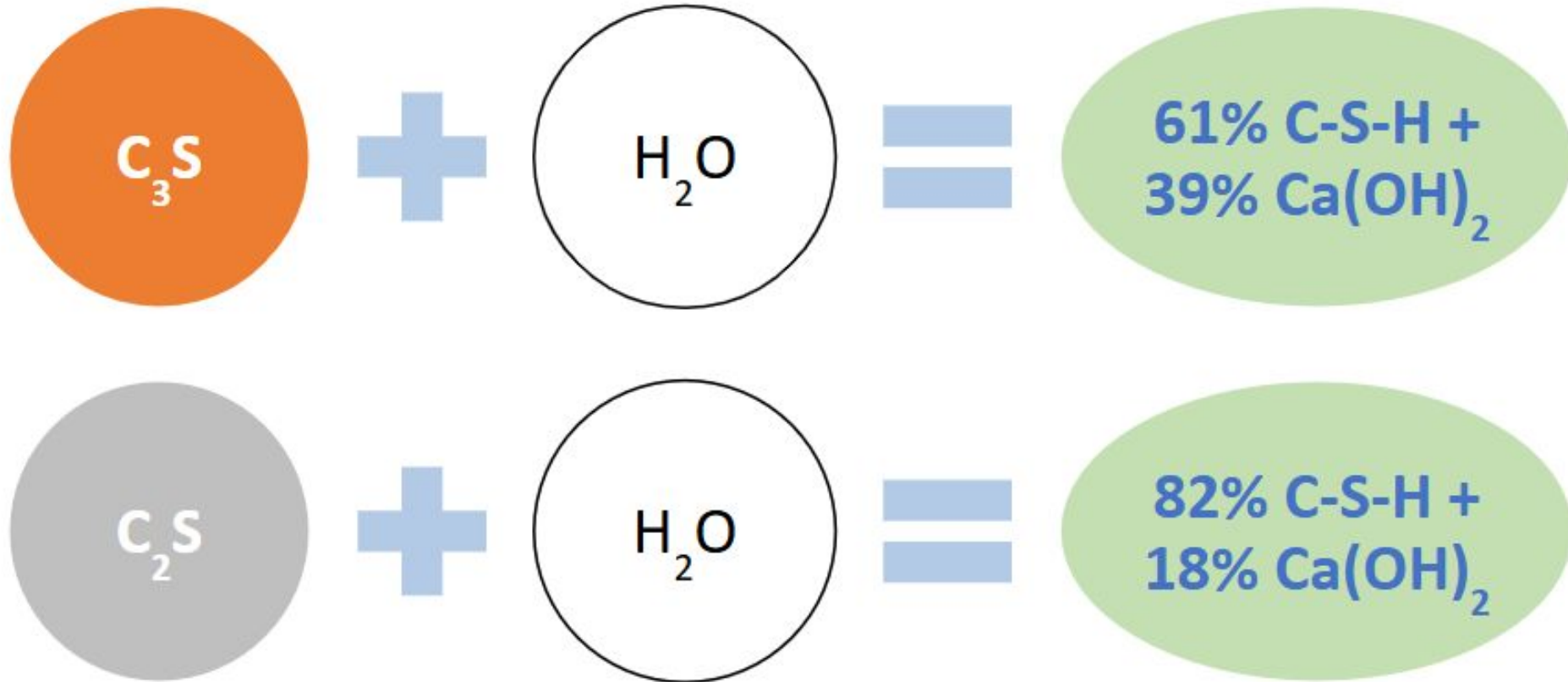
- Chemical reaction between cement and water
- Formation of hydrated products
- Exothermic process (heat of hydration)
- $C_3S$  and  $C_3A$  → fastest reactions
- High early heat release
- Continuous process over time
- Importance of curing conditions



Source: Author's own elaboration

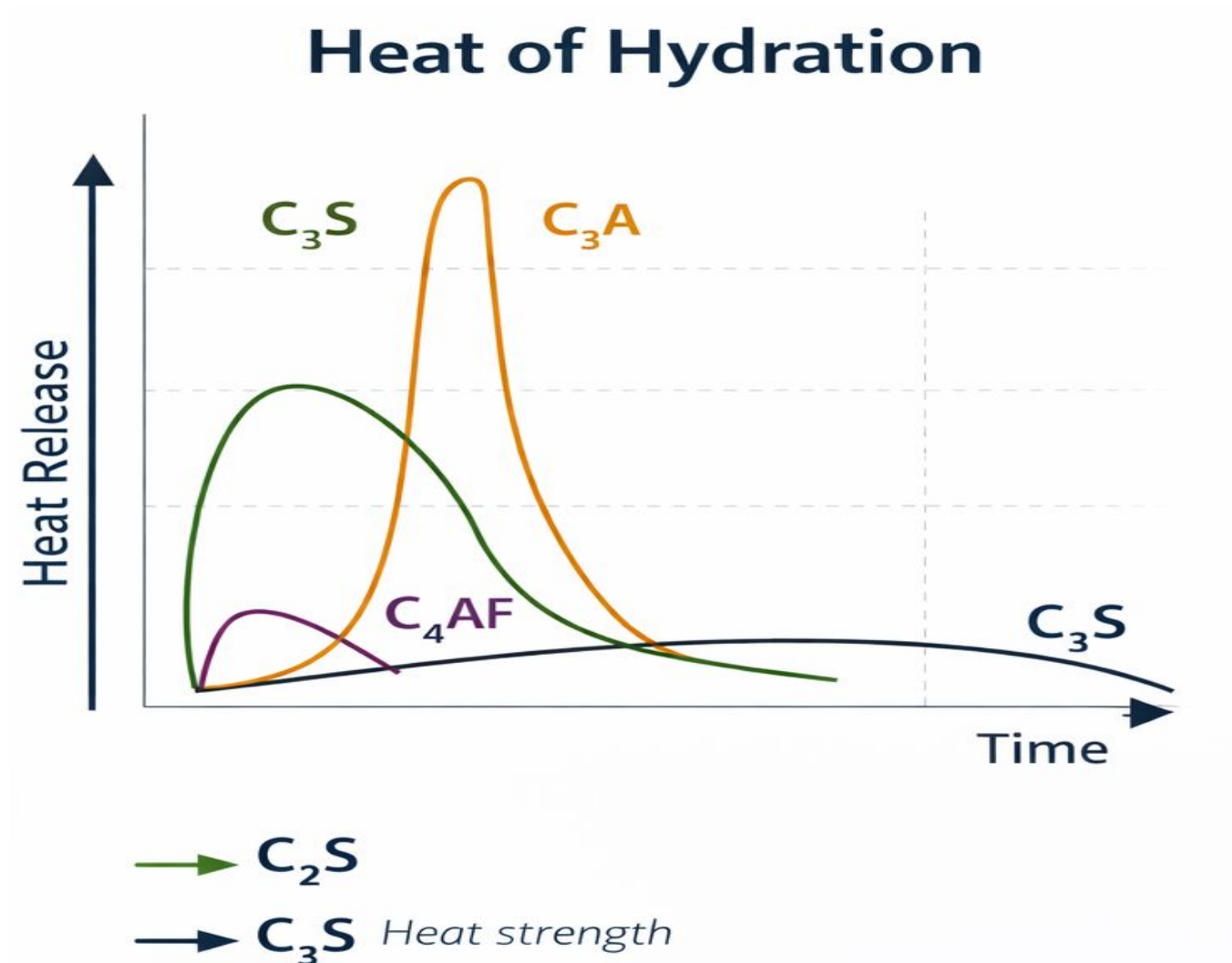


# C-S-H Formation



Source: Author's own elaboration

# Heat of Hydration Factors



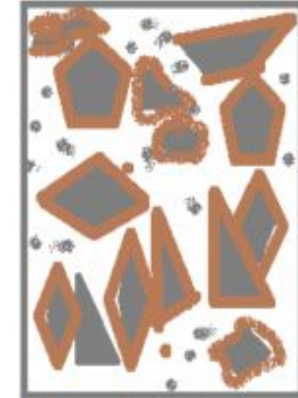
Source: Adapted from Gomezjurado, J., Osorio, J., & Niño, J. (2014)

# Hydration Stages (Plastic State)

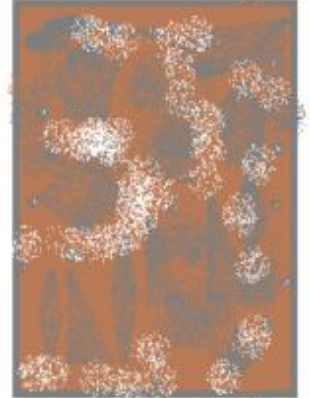
- Plastic phase of hydration
- Paste formation and early reactions
- Structural network begins
- Induction period (40–120 min)
- Maintains workability
- High pH protects steel



Cement Particles in Mix  
Before the Hydration  
Reaction: No Water



During Hydration:  
Hydration Products  
precipitate on the  
surface of cement  
Particles



Hydration Products  
Completely fill the mix;  
Leaving certain amount  
of porosity

Source: Adapted from Bay-Lynx Manufacturing Inc. (2026)

# Setting and Hardening

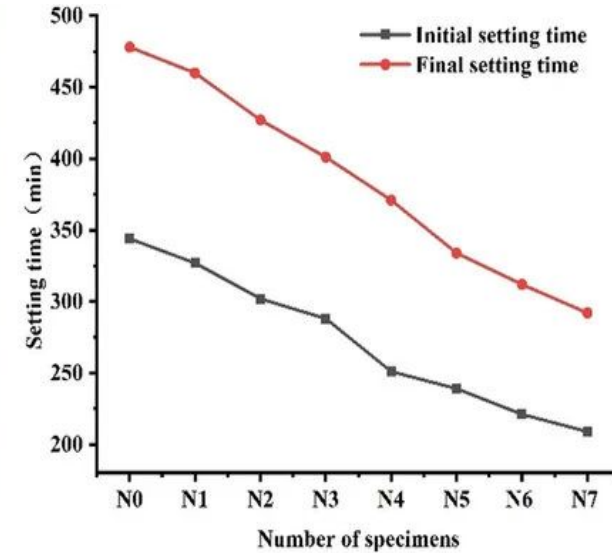
- Setting: loss of plasticity
- Hardening: strength development
- Initial setting: rigidity begins (2–4 h)
- Final setting: full loss of plasticity
- Hardening follows



Source: Reproduced from John Eek & Son Ltd. (2026)

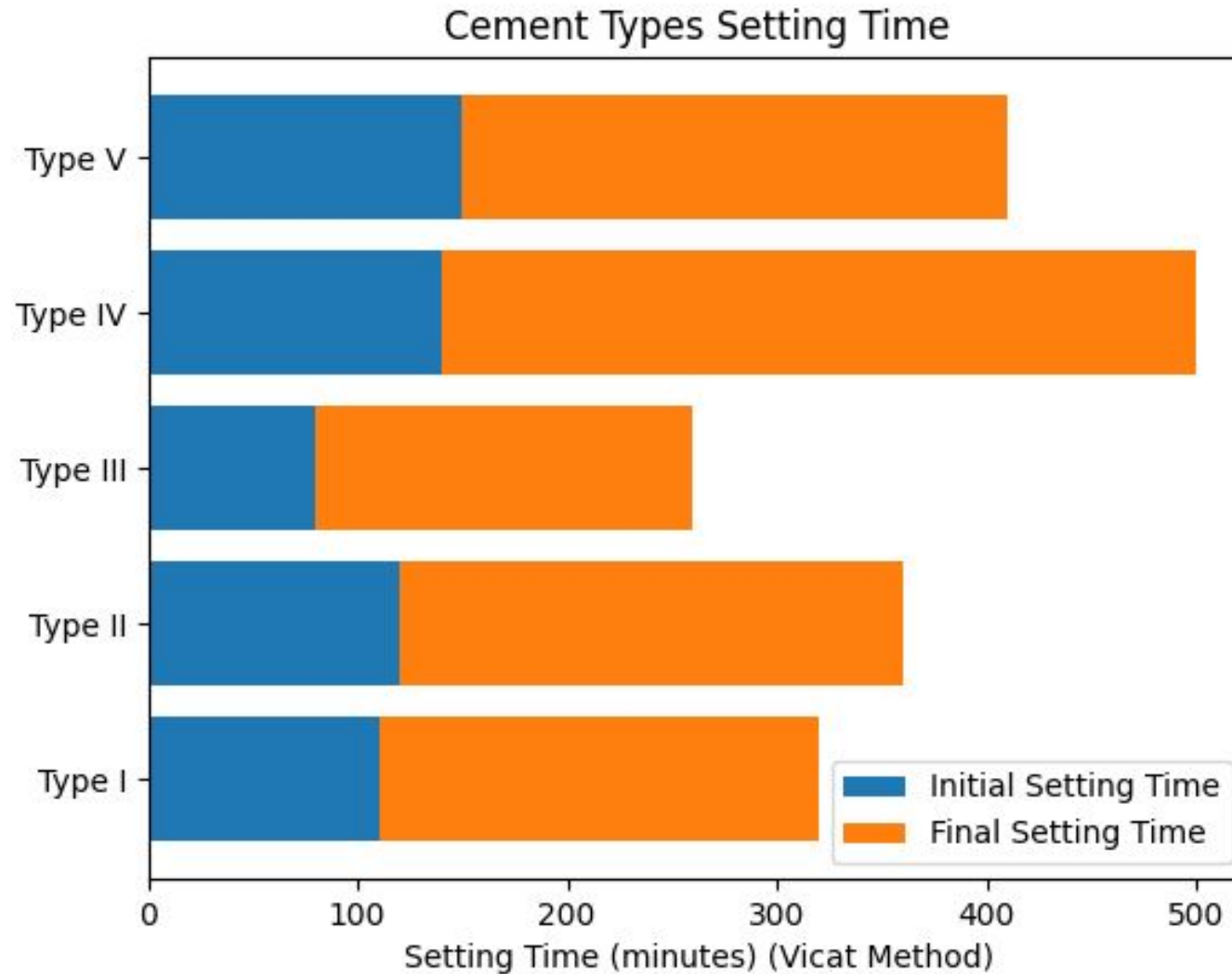
# Setting Mechanism

- Initial setting: reduced workability
- C-S-H bonds begin to form
- Final setting: structure consolidates
- Material gains rigidity



Source: Cropped from Liu et al. (2021)

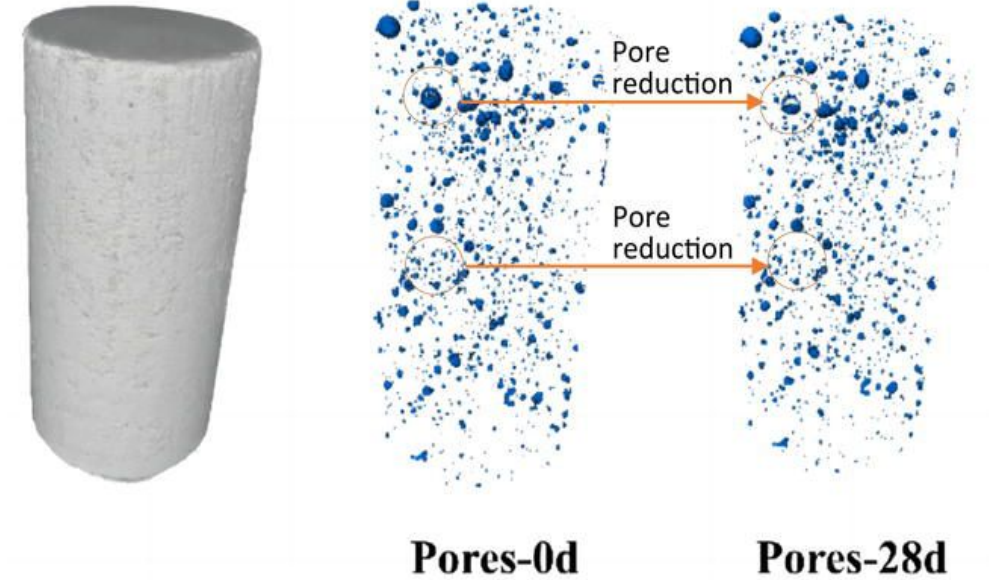
# Setting by Cement Type



Source: Adapted from Pasquel (1998)

# Hydrated Structure

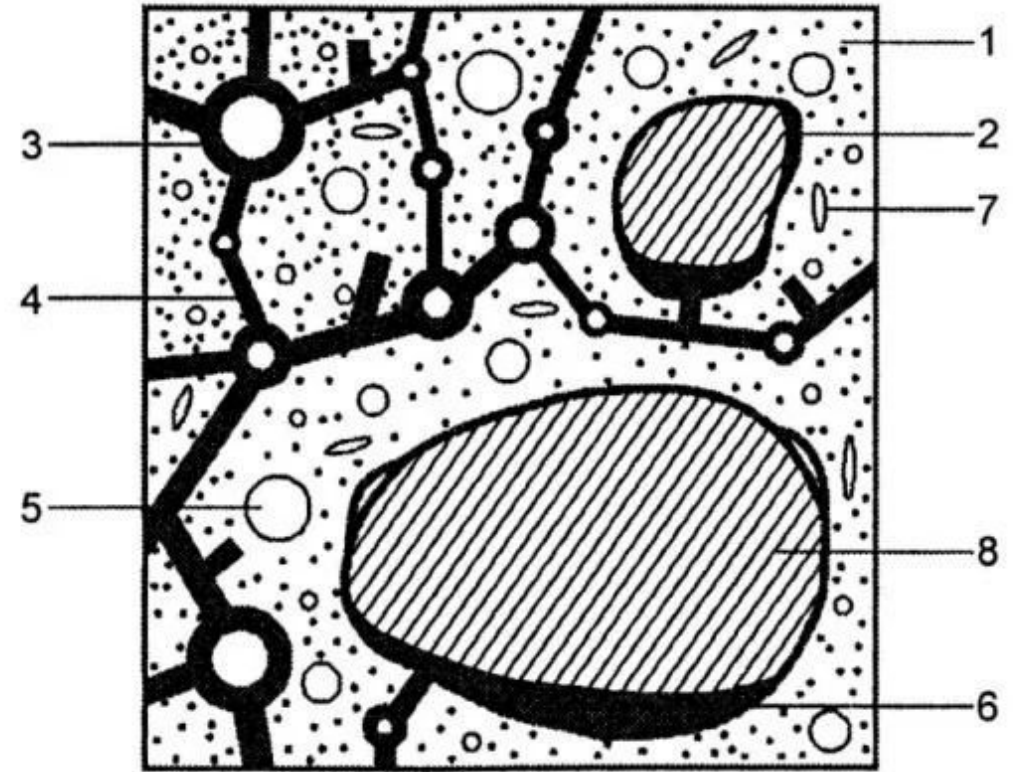
- Formation of porous network
- Internal microstructural changes
- Reduced porosity over time
- Improved strength and durability



Source: Reproduced from Zhang et al. (2024)

# Microstructure

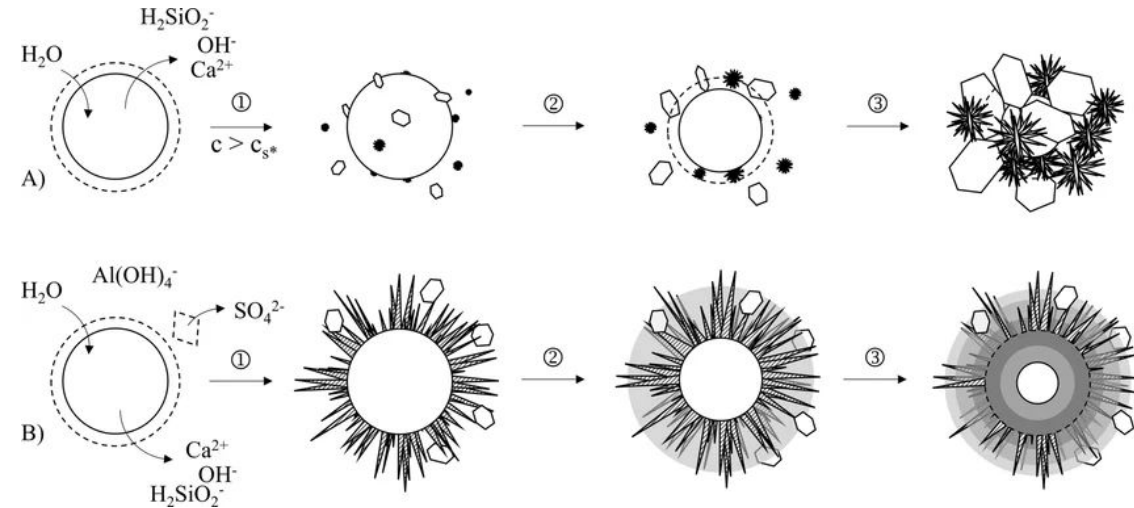
- C-S-H gel: strength phase
- Gel pores: adsorbed water
- Capillary pores: affect durability
- Pore structure controls performance



Source: Reproduced from Bołtryk & Pawluczuk (2010)

# Particle Hydration

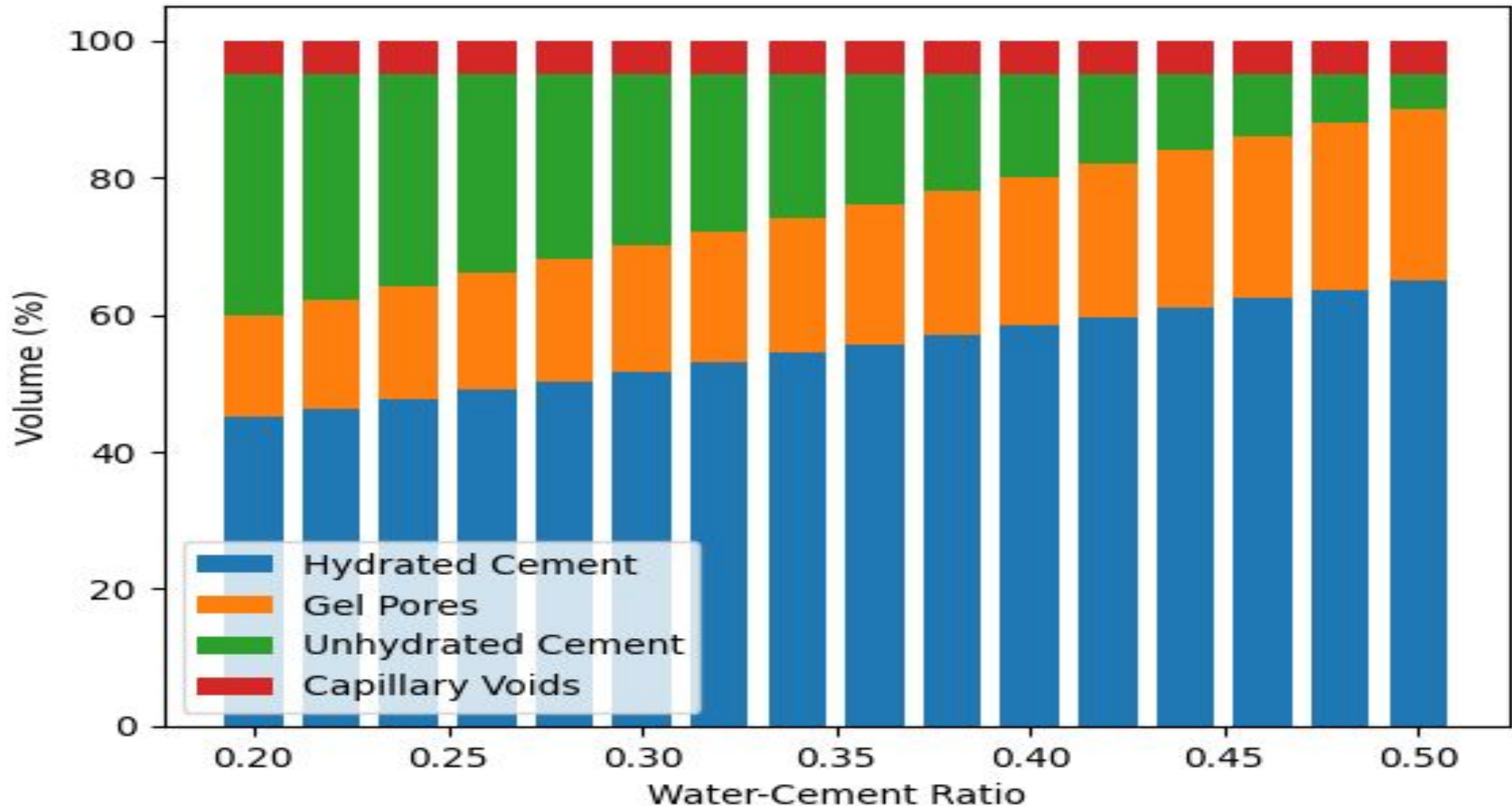
- Surface hydration of cement grains
- Gel layer formation and densification
- Progressive structure development
- Volume reduction (~20–25%)
- Influences porosity and strength



Source: Adapted from John & Lothenbach (2023)

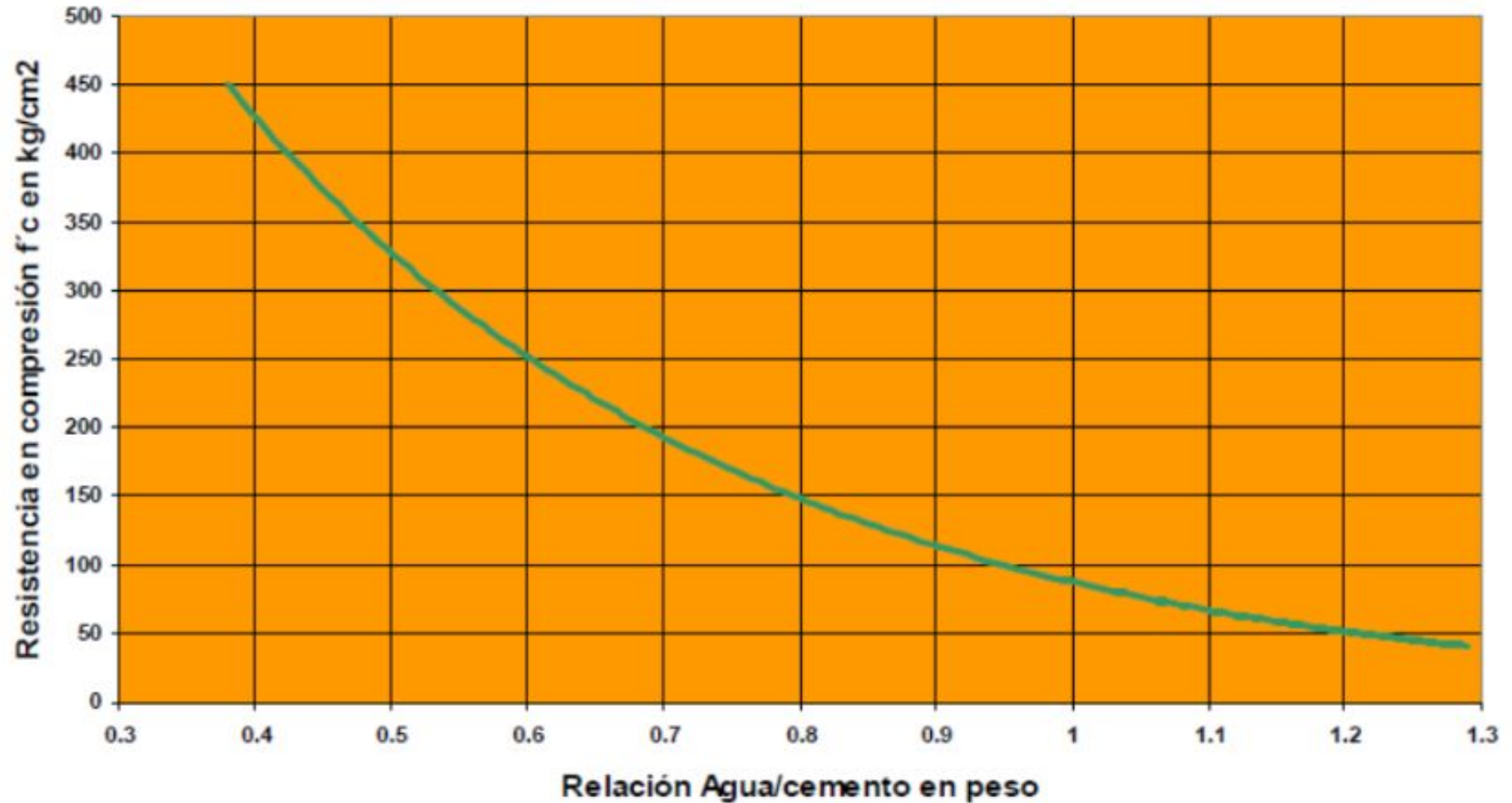
# Water/Cement Ratio

Structure of Cement Paste as a Function of Water-Cement Ratio



Source: Adapted from Pasquel (1998)

# Water/Cement Ratio



Source: Adapted from Pasquel (1998)



# Types of Portland Cement

# Types of Portland Cement (ASTM C150)

- Type I: general use
- Type II: moderate sulfate resistance
- Type III: high early strength
- Type IV: low heat (massive structures)
- Type V: high sulfate resistance
- Selection depends on exposure conditions



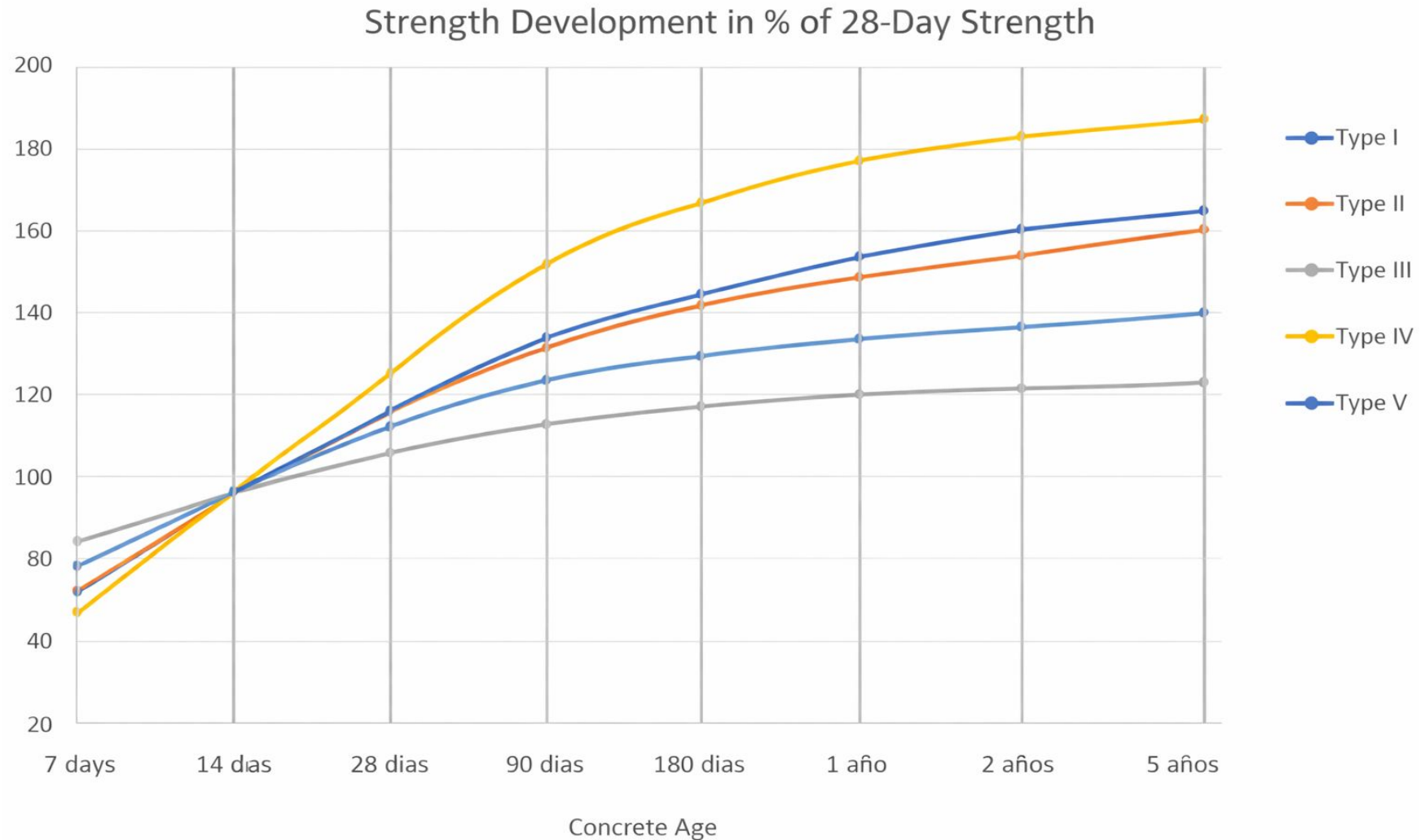
Source: Reproduced from Tanthang Cement Plant (2025)

# Composition by Cement Type

Cement	Chemical Composition in %			
<b>Portland</b>	<b>C<sub>3</sub>S</b>	<b>C<sub>2</sub>S</b>	<b>C<sub>3</sub>A</b>	<b>C<sub>4</sub>AF</b>
Type I	48	27	12	8
Type II	40	35	5	13
Type III	62	13	9	8
Type IV	25	50	5	12
Type V	38	37	4	9

Source: Adapted from Pasquel (1998)

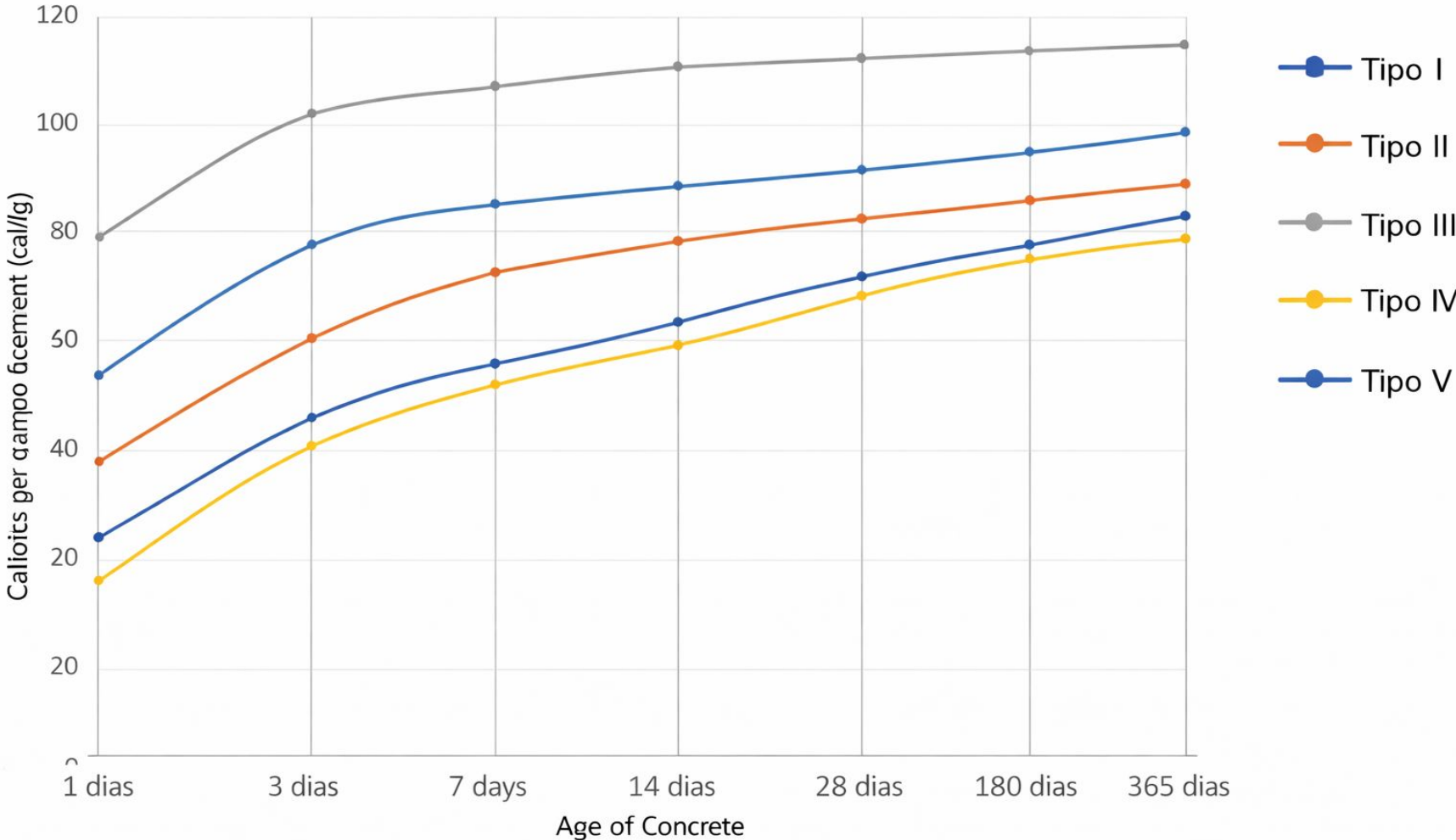
# Strength Development



Source: Adapted from Pasquel (1998)

# Heat of Hydration

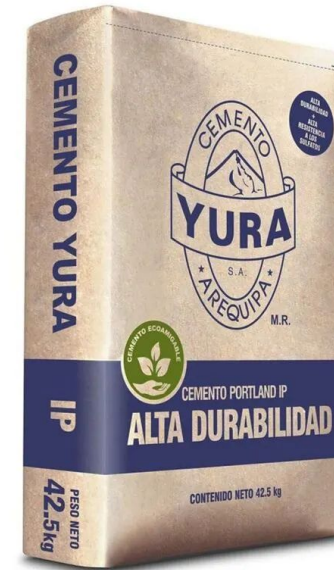
Heat of Hydration Development for Portland Cements



Source: Adapted from Pasquel (1998)

# Blended Cements (ASTM C595)

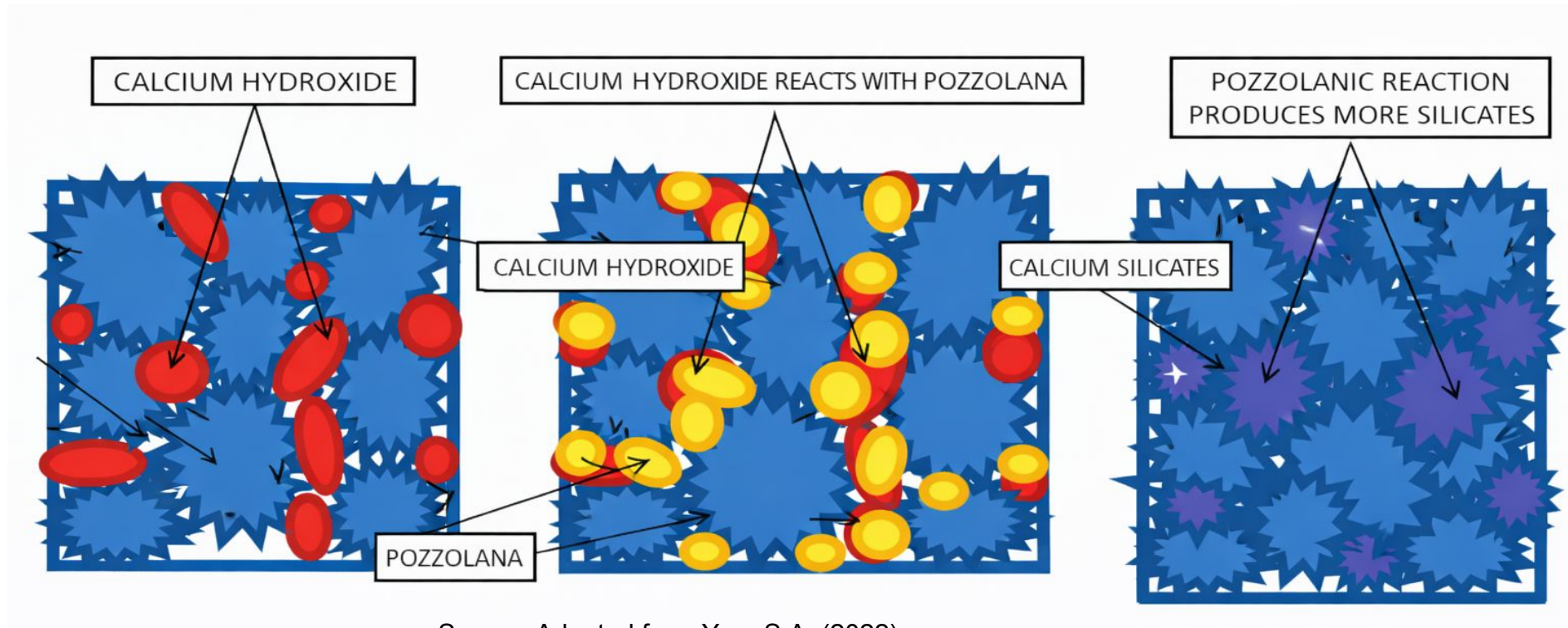
- Contain slag or pozzolans
- Type IS: slag cement
- Type IP: pozzolanic cement
- Improve durability, reduce heat



Source: Reproduced from Yura S.A. (2022)

# Pozzolanic Materials

- React with  $\text{Ca}(\text{OH})_2 \rightarrow$  form C-S-H
- Increase strength and durability



Source: Adapted from Yura S.A. (2022)

# Performance-Based Cements (ASTM C1157)

- Classified by performance, not composition
- Types: GU, HE, MS, HS, LH
- Greater flexibility in cement design



Source: Reproduced from Revista Constructivo (2026)

# Special Cements

- Masonry cement (ASTM C91)
- Used for mortars, not structural concrete
- Lower strength and different composition



Source: Reproduced from Fairborn Cement Company (2026)



**Quality control**

# Storage and Handling

- Bulk cement: up to 3 months storage
- Bagged cement: strength loss over time
- Protect from moisture
- Store elevated and limit stacking



Source: Reproduced from Haseeb Jamal (2017)

# Laboratory Quality Control

- Tests: fineness, setting time
- Volumetric stability and specific gravity
- Compressive strength evaluation
- Ensures cement quality



Source: Reproduced from UltraTech Cement Ltd. (2021)

# Conclusions

- Cement = key component of concrete
- Performance depends on:
  - Manufacturing
  - Composition
  - Hydration
- Selection based on project conditions

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# Course: Concrete Technology

## Lecture 2: Raw materials: Portland Cement

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