CIVE1194 –
Construction Engineering

Susanna Lin

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1194 Module Format

- Core course 1st year students
  - Civil ONLY!!!
  - Enviro students enrol in 1186

1194 Module Format

- Lecture: L1 – Wednesday 14:30 – 16:30
  - 16.1.1
- Tutorial Tuesday - 14.30-16.30
  - 80.11.10
- Tutorial Thursday -16.30-18.30
  - 5.3.1
- Weeks 1, 2, 10-12
  - Lab Bundoora Building 253
    - Weeks 3-9
    - Register on Blackboard
    - Attend 2 consecutive weeks, register for first week
- Check Blackboard
- Announcements
- Weekly Guide

1194 Module Format

- Laboratory Assignment (25%)
  - Weeks 3-9
  - One week after 2nd lab (testing concrete)
    - Friday, Blackboard, 4.30pm
    - Late submissions will receive a 5% penalty per day
- Mid Semester Test (35%)
  - Week 6 Lecture slot
  - Mix Design (15%)
  - Characteristic Strength (10%)
  - Weeks 1-5 (10%)
- Exam (40%)
  - Weeks 1-12

Laboratory Assignment - (25%)

- Three groups each tutorial, each group attends consecutive weeks
  - Sign up on Blackboard
  - ONLY register for first week
  - If unable to attend or late apply for special consideration
- YOU MUST have safety boots (and long sleeve shirt)
- Group Assignment 25%
  - Group report
  - Submission 1 week after 2nd Lab
  - Late submissions will receive a 5% penalty per day
  - Single submission per group
  - Failure to attend either lab will be 50% deduction

Lectures

- Week 1
  - Cement manufacture
  - Hydration and strength
- Week 2
  - Types of cement
  - Replacement materials
- Week 3
  - Concrete manufacture and properties
- Week 4
  - Site safety
  - Formwork and Scaffolding
    - Chamila Gunasekara
- Week 5
  - Steel
    - Ricky Chan
- Week 6
  - Mid Semester Test
  - 45 minutes in two groups

Lectures

- Majid Nazem

- Week 7
  - Bridge Construction
- Week 8
  - Cofferdams
  - Caissons
- Week 9
  - Pile driving
- Week 10
  - Harbours and Dredging
- Week 11
  - Ground support
  - Slope stabilisation
  - Tunneling
- Week 12
  - Earthworks

Tutorials

Note only run for 2 hours
(lab classes run for three hours but individual groups are one hour)

- Week 1-2
  - Mix Design
  - Characteristic Strength
- Week 3-9
  - Videos
    - List on Blackboard
  - Tutorial Questions
  - Study in own time
- Week 10-12
  - Tutorial Questions
  - Worked examples
- Students Time
  - Watch videos on Blackboard (content may be in exam)
  - Learning materials on Blackboard

Background Reading

- Recommended References:

  Neville A M, Properties of Concrete (4th Edition) Pitman Publishing

- Antill, J.M., Ryan, P.W.S. and Easton, G.R., Civil Engineering Construction (6th ed.) McGraw-Hill, 1988, Sydney.

  Harris F. 1994 Modern Construction and Ground Engineering Equipment and Methods 2nd edition Longman Scientific & Technical (Pearson).

- Also papers and videos on Blackboard

Background Reading

Other References

- Spence, W.P. Construction Materials, Methods and Techniques, Delmar Publisher, 1998
- Simmons, H. Leslie. Construction Principles, Materials and Methods, 7th edition, John Wiley & Sons, 2001.
- Allen, E. and Iano, J. Fundamentals of Building Construction: Materials and Methods, 4th edition, John Wiley & Sons, 2004.
- Peurifoy, R.L. and Schexnayder, C.J. Construction Planning, Equipment and Methods, McGraw Hill, 2002.
- Illingworth, J.R. Construction Methods and Planning, Spon, 1993
  IEAust National Committee on Construction Engineering, Guidelines for Successful Engineering Construction, IEAust 1995

Recommended Texts

- Properties of Concrete, *Neville A M*
- Materials in Construction, *Taylor G D*
- Civil Engineering Materials, *Jackson N & Dhir R*
- Concrete Construction Handbook, *Waddell J J & Dobrowolski J A*
- Materials, *Mitchell B S*
  - *On line*
  - *Extracts of Neville and Waddell have been put on Blackboard*

Concrete in Construction

- Most widely used construction material
- 1 Billion tonnes produced per year
- First used in Stone Age
- Widespread use by Romans
  - Natural pozzolan's
  - Mt Vesuvius
    - Volcanic ash

Historical Development

2^{nd} / 1^{st} Century BC : Greeks and Romans

- Extensive use of lime mortars (non-hydraulic)
- Hardened by reaction with atmospheric carbon dioxide
- Reaction (hence strength development) is very slow and summarised by:

For production of lime:

$CaCO_3$ (heat ≈850°C) → CaO (quicklime) + CO_2

$CaO + H_2O \rightarrow Ca(OH)_2$ (slaked lime)

For hardening:

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Historical Development

<u>18th Century</u>

- 1793: John Smeaton found that the calcination of limestone containing clay gave a lime which hardened under water (hydraulic lime). He used hydraulic lime to rebuild Eddystone Lighthouse in Cornwall, England which he had been commissioned to build in 1756, but had to first invent a material that would not be affected by water.

Historical Development

19th Century

- 1812: Louis Vicat in France prepared artificial hydraulic lime by calcining synthetic mixtures of limestone and clay.
- 1822: James Frost prepared artificial hydraulic lime like Vicat's and called it 'British Cement'.
- 1824: Joseph Aspdin of England invented Portland cement by burning finely ground chalk with finely divided clay in a lime kiln until carbon dioxide was driven off. The sintered product was then ground and he called it Portland cement named after the high quality building stones quarried at Portland, England.

Historical Development

19th Century

- 1828: I. K. Brunel is credited with the first engineering application of Portland cement, which was used to fill a breach in the Thames Tunnel.
- 1845: Isaac Johnson claims to have burned the raw materials of Portland cement to clinkering temperatures.
- 1849: Reinforced concrete invented by Joseph Monier for flowerpots
- 1860: The beginning of the era of Portland cements of modern composition.

Modern Concrete Structures

Cement and Concrete: Overview

- Concrete : A building material made of cement, sand, stone and water that hardens to a stone like mass

Cement and Concrete: Overview

Concrete is a heterogeneous mixture of:

- Cement (binder)
- Water (potable)
- Sand (fine aggregate)
- Gravel (coarse aggregate)
- Occluded air
- Admixtures (chemical/mineral)

The basic ingredients for concrete

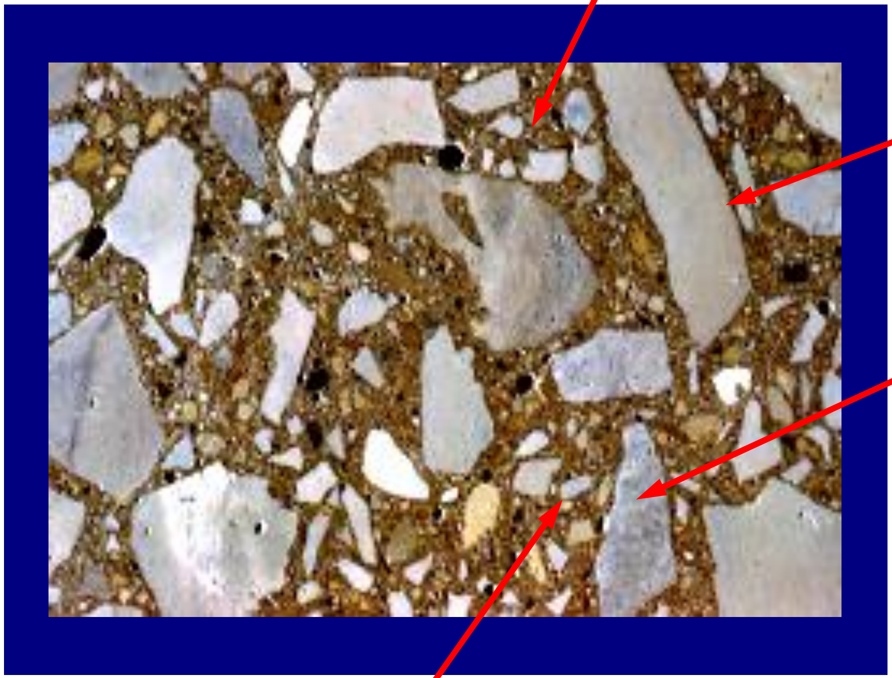
Batched on site - quality can vary.

Ready Mixed – better quality control.

Cement and Concrete: Overview

Cement paste matrix (grout)

Bond between aggregate and cement paste important



Coarse aggregate

Fine aggregate

Fresh Concrete:

- ✓ workability

Hardened Concrete:

- ✓ Strength
- ✓ Durability

Cement Manufacture

Over one billion tonnes of Portland cement used annually.

Two processes:

- Wet process
- Dry process

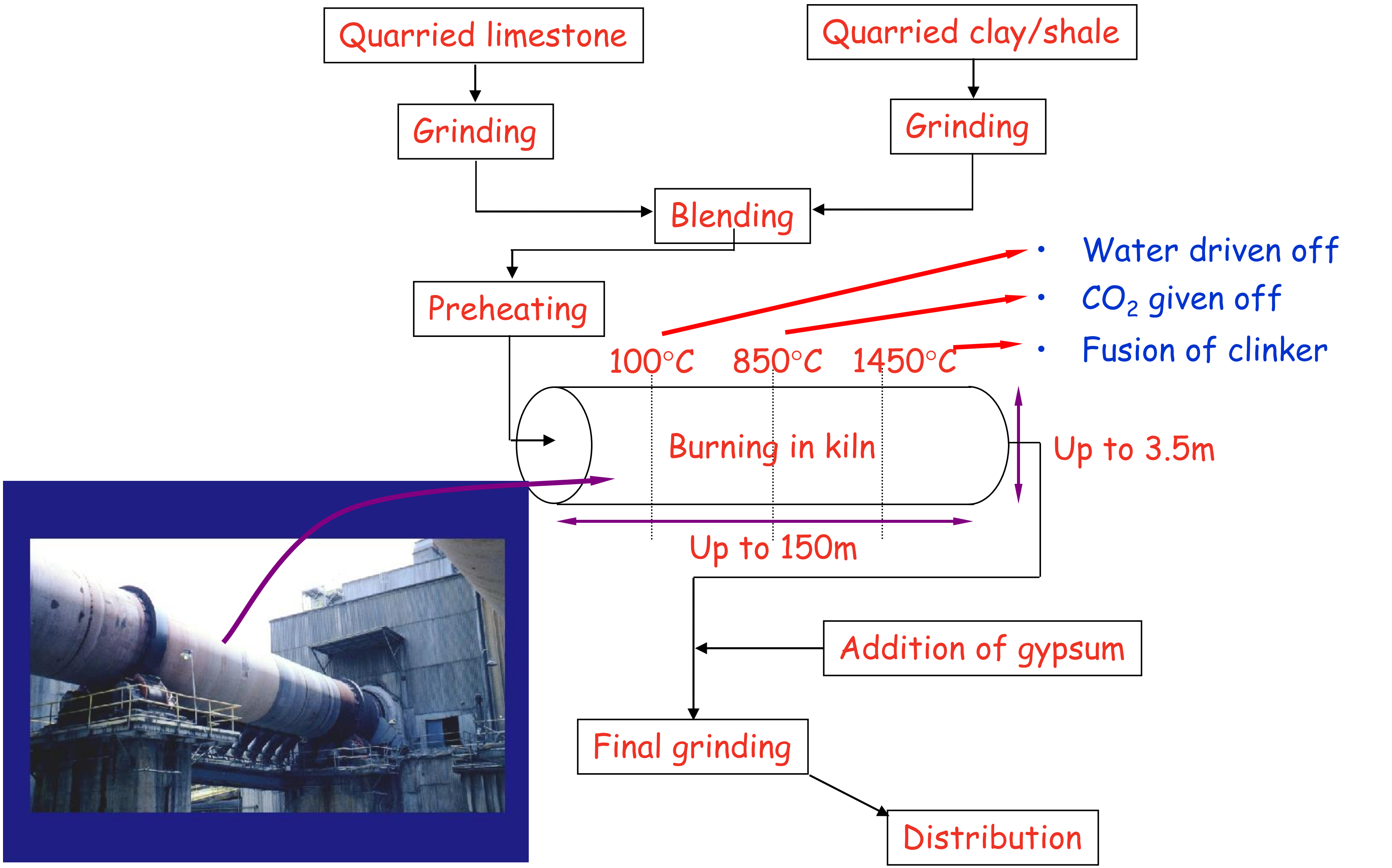
The same raw materials are used for both:

- Calcareous - limestone, chalk (calcium)
- Argillaceous – clay, marl (silica, alumina)

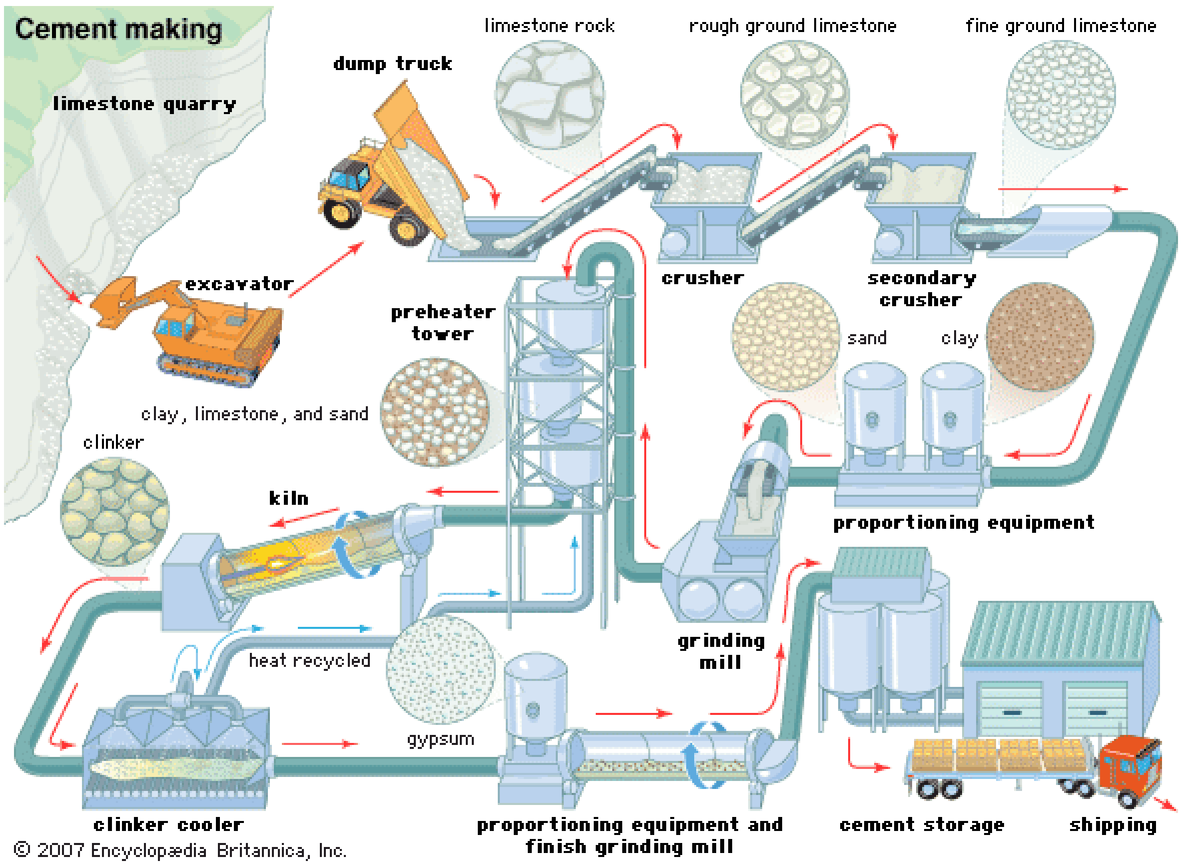
Manufacture of Portland cement

- Chalk/limestone crushed to a fine powder and dispersed in water
- Clay is broken up and mixed with water
- These two mixtures are added together in predetermined proportions to form a slurry
- Slurry fed into a kiln and heated to ≈1500°C
- Materials fuse together to form a clinker
- Clinker ground to a fine powder and a small amount of gypsum added ($CaSO_4.2H_2O$)

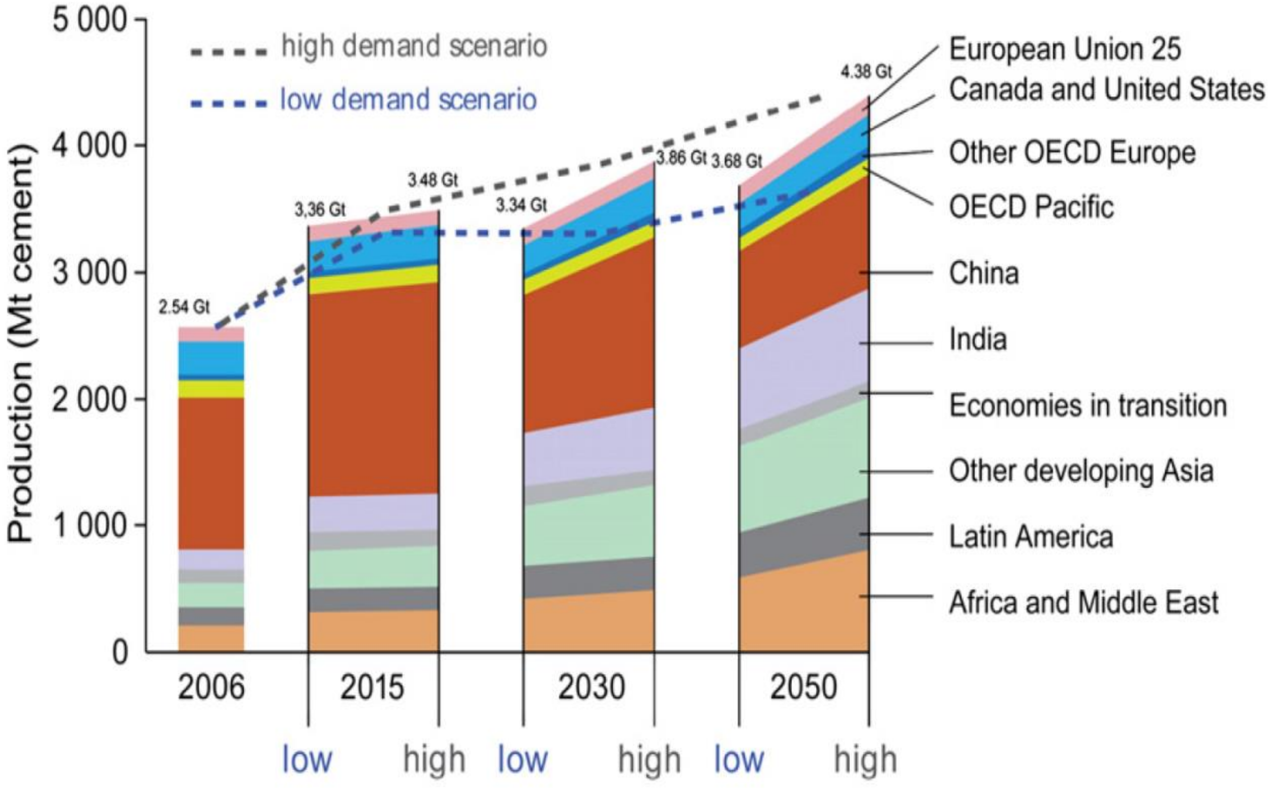
Schematic diagram of Portland cement production



Production Process



Cement Demand



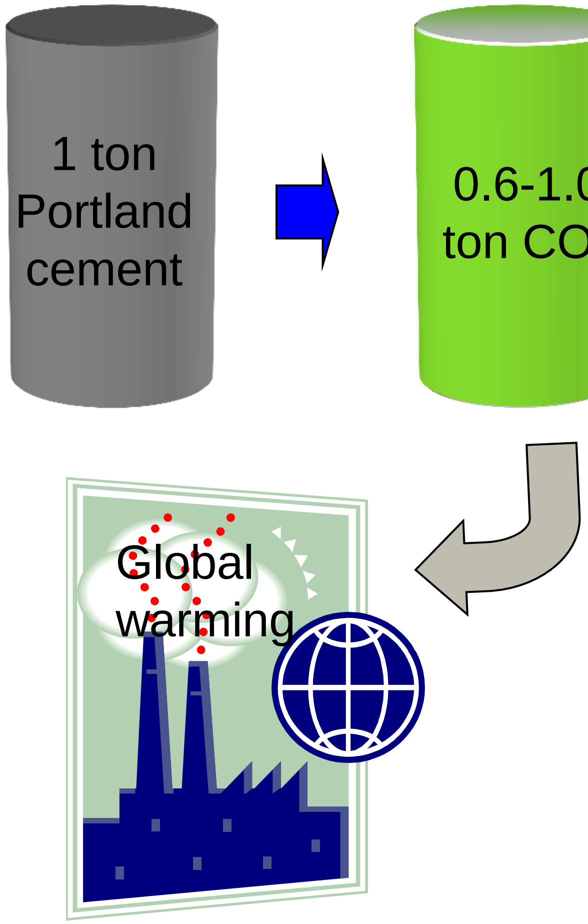
Why use Concrete

- Advantages
  - Well established
  - Availability
  - Durable
  - Low maintenance
  - Fire resistant
  - Range of use

- Disadvantages
  - Low tensile strength
  - Low ductility
  - Low strength:weight
  - Steel corrosion in reinforced concrete
  - Environmentally unfriendly

Sustainability issue

- Portland cement, an essential component of concrete
- The production of Portland cement accounts for 6-8% of human-generated carbon dioxide (CO2)



Chemical composition of Portland cement

The main chemical compounds present in Portland cement:

- Tricalcium silicate — $3CaO.SiO_2$
- Dicalcium silicate — $2CaO.SiO_2$
- Tricalcium aluminate — $3CaO.Al_2O_3$
- Tetracalcium aluminoferrite — $4CaO.Al_2O_3Fe_2O_3$

Simplified terminology:

CaO = C (not carbon !)

SiO_2 = S (not sulphur !)

Al_2O_3 = A

Fe_2O_3 = F

H_2O = H (not hydrogen!)

Compounds become:

C_3S also known as **alite**

C_2S as known as **belite**

C_3A

C_4AF

Typical Oxide Composition

Calcium Oxide (CaO: C):	**63.95%**
Silicon Dioxide (SiO_2: S)	**20.68%**
Aluminum Oxide (Al_2O_3: A):	**4.83%**
Ferrous Oxide (Fe_2O_3: F):	**3.17%**
Magnesium Oxide (MgO):	**2.53%**
Sulphur Oxide (SO_3: S):	**2.80%**
Potassium Oxide (K_2O):	**0.54%**
Sodium Oxide (Na_2O):	**0.08%**
Loss on Ignition:	**0.8%**

Letters in brackets indicate shorthand form of Oxide in cement chemists' nomenclature

Chemical composition of Portland cement

- Ordinary Portland Cement contains, typically (by weight) :

  C_3S : 50-55%

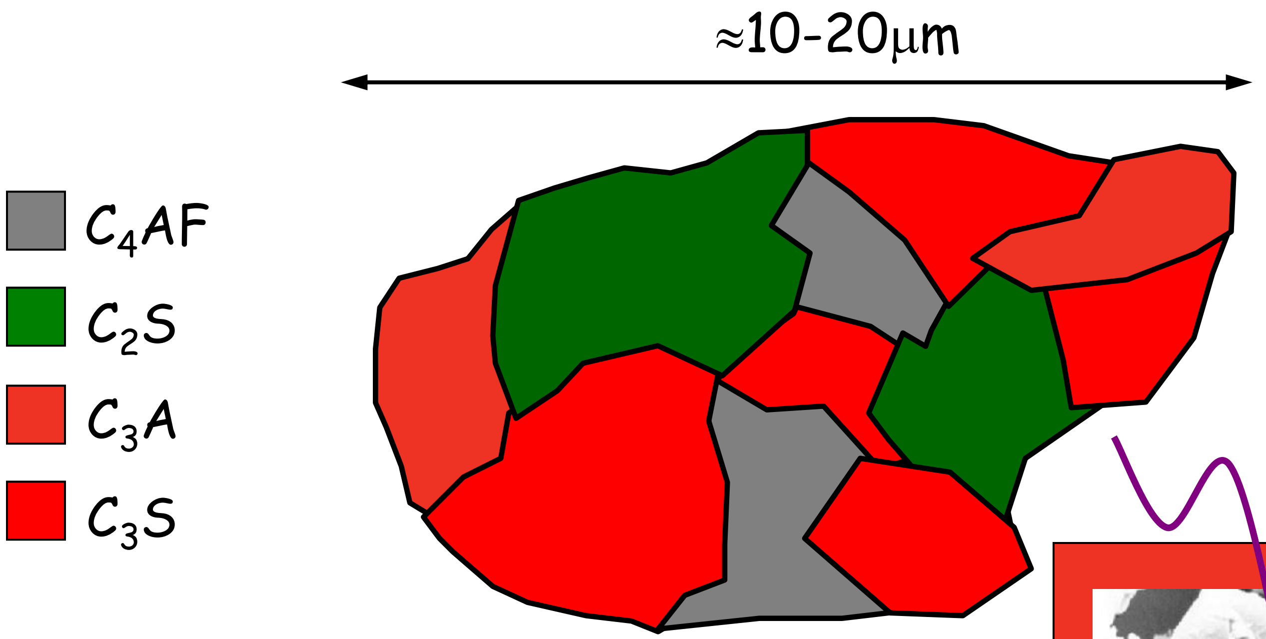
  C_2S : 20-25%

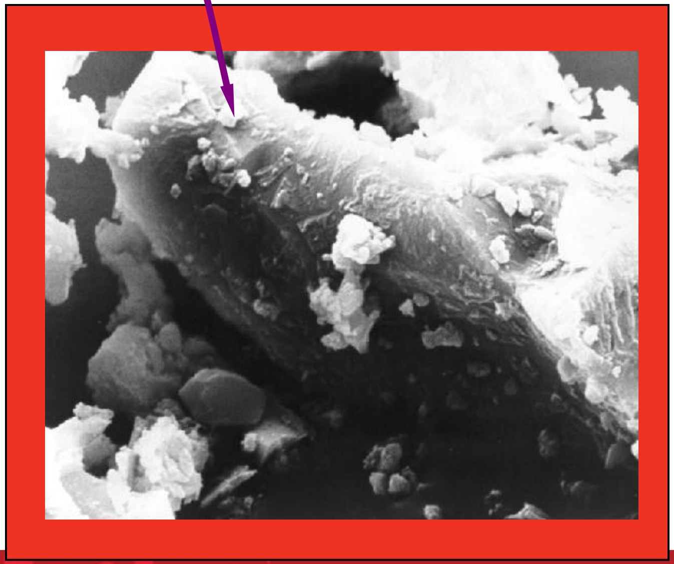
  C_3A : 10-12%

  C_4AF : 5-10%

- OPC covered by AS 3972 2010
- In Europe EN-197-1 (CEM I)

Suggested structure of a cement grain





Role of cement in concrete

Cement .....

- bonds the constituents together
- forms crystalline products of hydration creating intrinsic strength and other engineering properties
- generates heat during the setting
- determines the ease with which liquids and gases move through concrete
- creates an alkaline environment

Hydration of cement

- Cement compounds react with water to form a hard, strong mass. This overall process is called **hydration.**
- The change from the fluid state to solid sate is termed **setting.** The cement still has not much strength just after setting
- The subsequent increase in strength with time is called **hardening.**
- Reactions start rapidly then slow down with time.

Hydration of cement

The overall chemical reactions are:

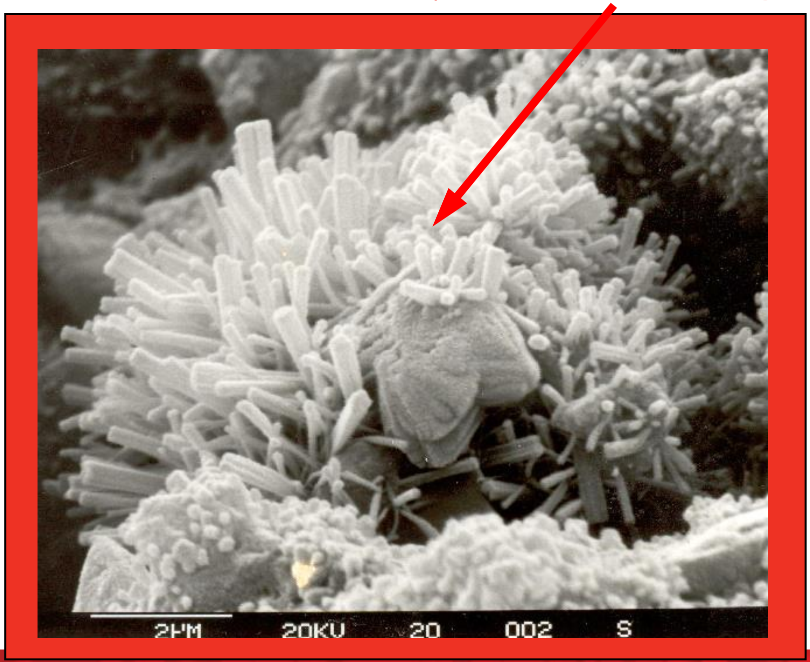
C_3S and C_2S

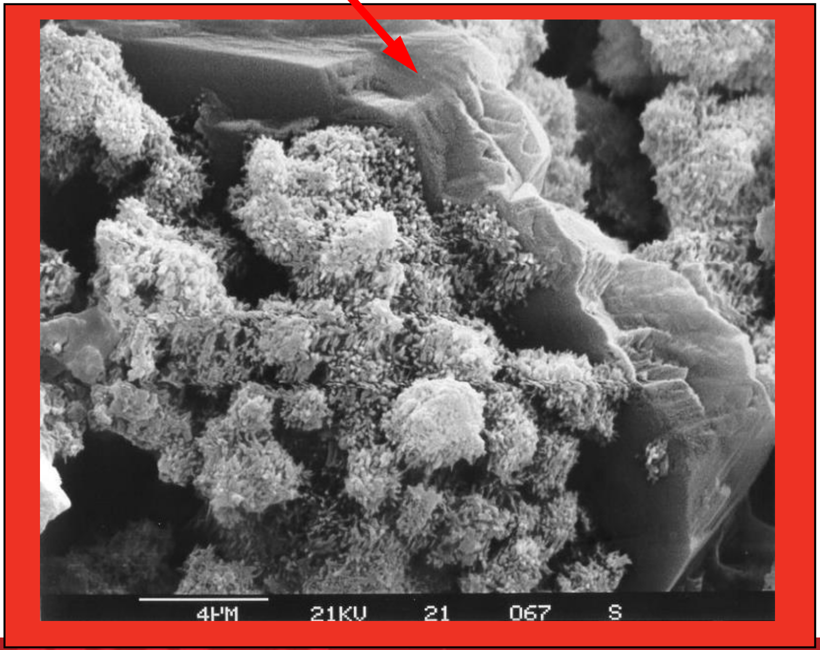
$2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$ (fairly fast + heat)

$2C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2$ (slow)

$\uparrow$ $\uparrow$

Calcium-silicate-hydrate (CSH gel) + calcium hydroxide (Portlandite)





Hydration of cement

C_3A

- Straight reaction to form calcium-aluminate-hydrate:

$$C_3A + 6H \rightarrow C_3AH_6$$

- This reaction is both rapid and violent and would cause **flash set** of the cement

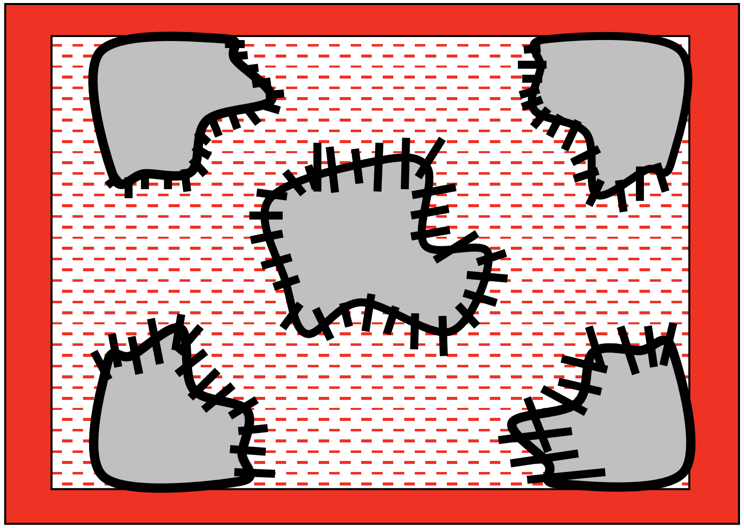
- In the presence of gypsum (calcium sulphate: $CaSO_4.2H_20$), the reaction is suppressed and ettringite (AFt) is formed:

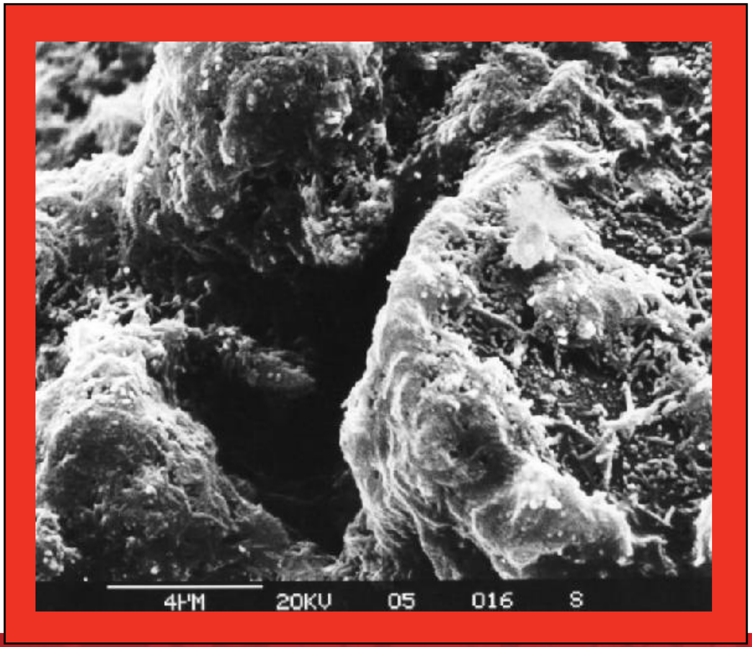
$$C_3A + \text{Water} + \text{Gypsum} \rightarrow \text{Ettringite (AFt)}$$

- As the gypsum is consumed, there is a phase transition and the AFt converts to monosulpho-aluminate (AFm)

$$\text{AFt} \rightarrow \text{AFm (monosulpho-aluminate)}$$

Hydration of cement

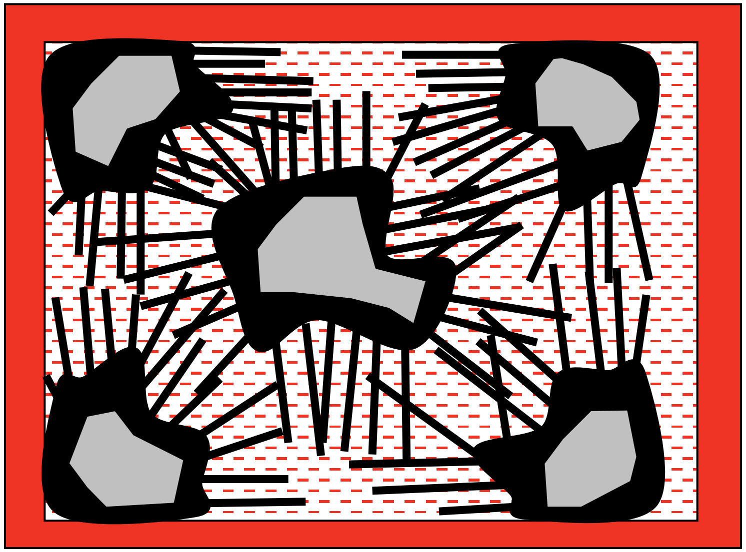


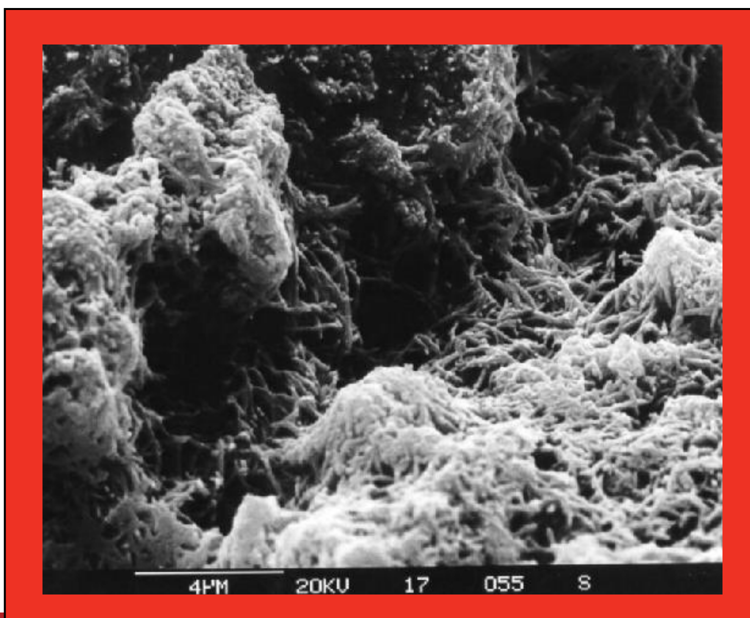


Stage I

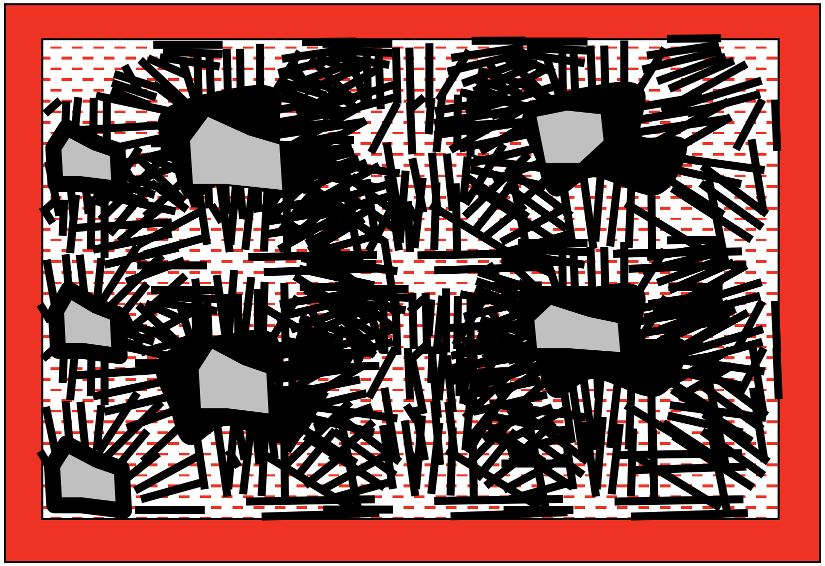
- Initial 5 minutes or so
- Alkalinity (pH) of water rises to 12-13
  - pH governed by CSH and $Ca(OH)_2$
- Some crystal growth (C_3A)
- Generally an amorphous coating on the cement grains (C_3S) which slows down reactions
- Leads into a dormant period (Stage II) where there is little chemical activity within the paste.

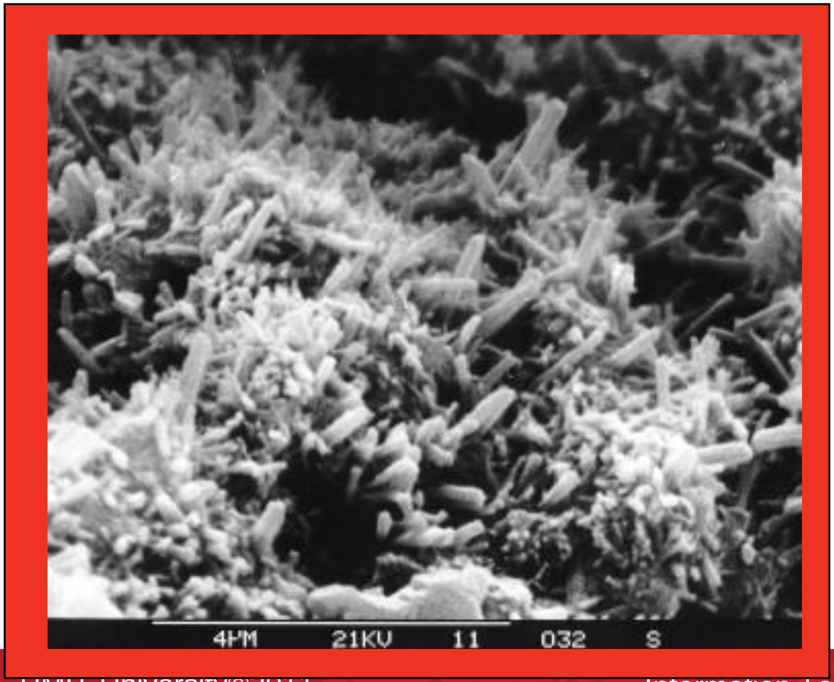
End of Stage II – Stage III





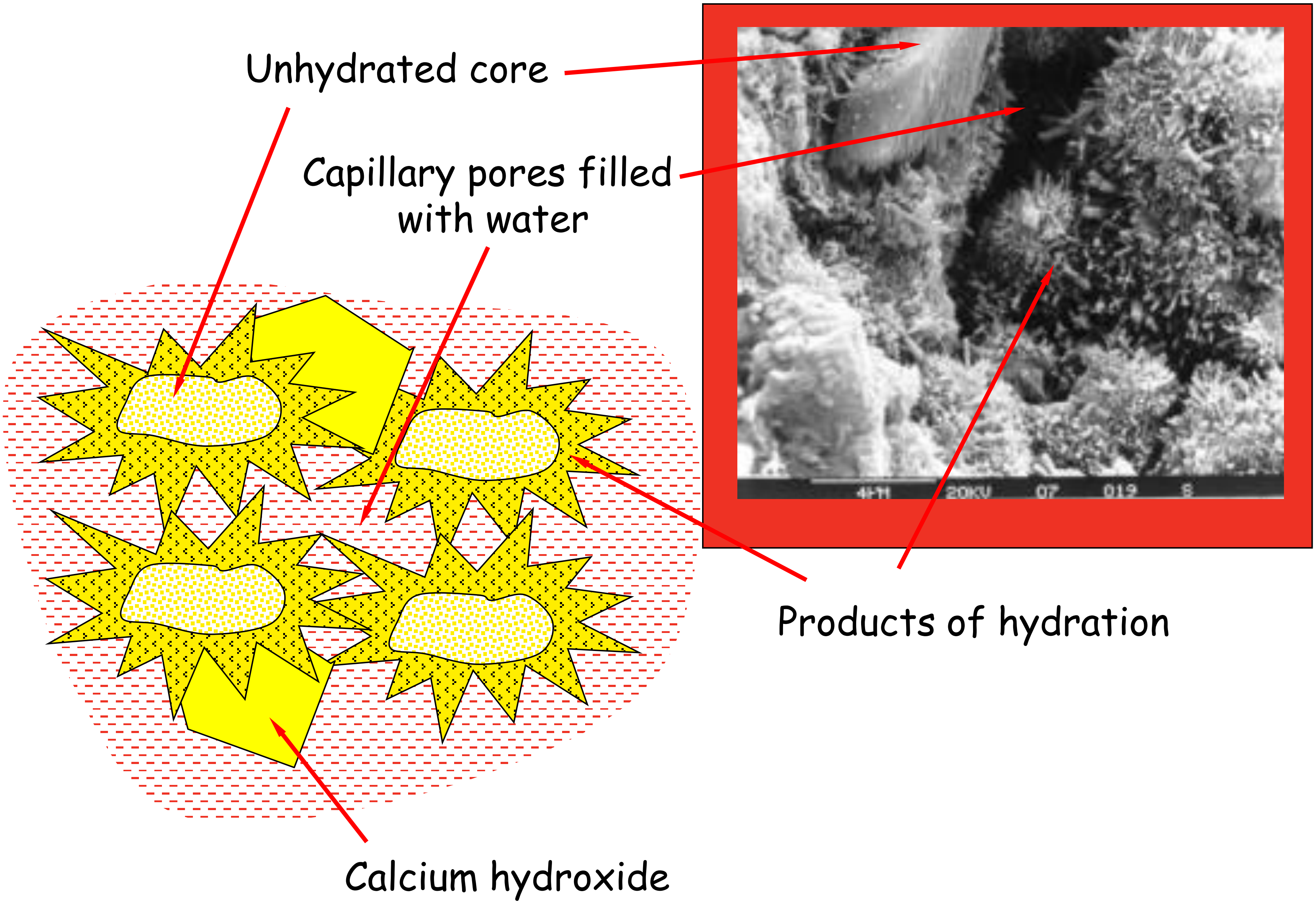
- End of Stage II (dormant period) after ≈2 hours and marks the change from fluid to solid state i.e. setting
- Reactions mainly on the C_3S phase and more crystalline microstructure
- Temperature within the paste increases
- Leads to Stage IV





Stage IV

- Temperature within paste begins to decrease
- Reactions become slower
- Continued crystal growth (on C_3S phase).
- Start of the period of hardening


Unhydrated core
Capillary pores filled with water
Products of hydration
Calcium hydroxide

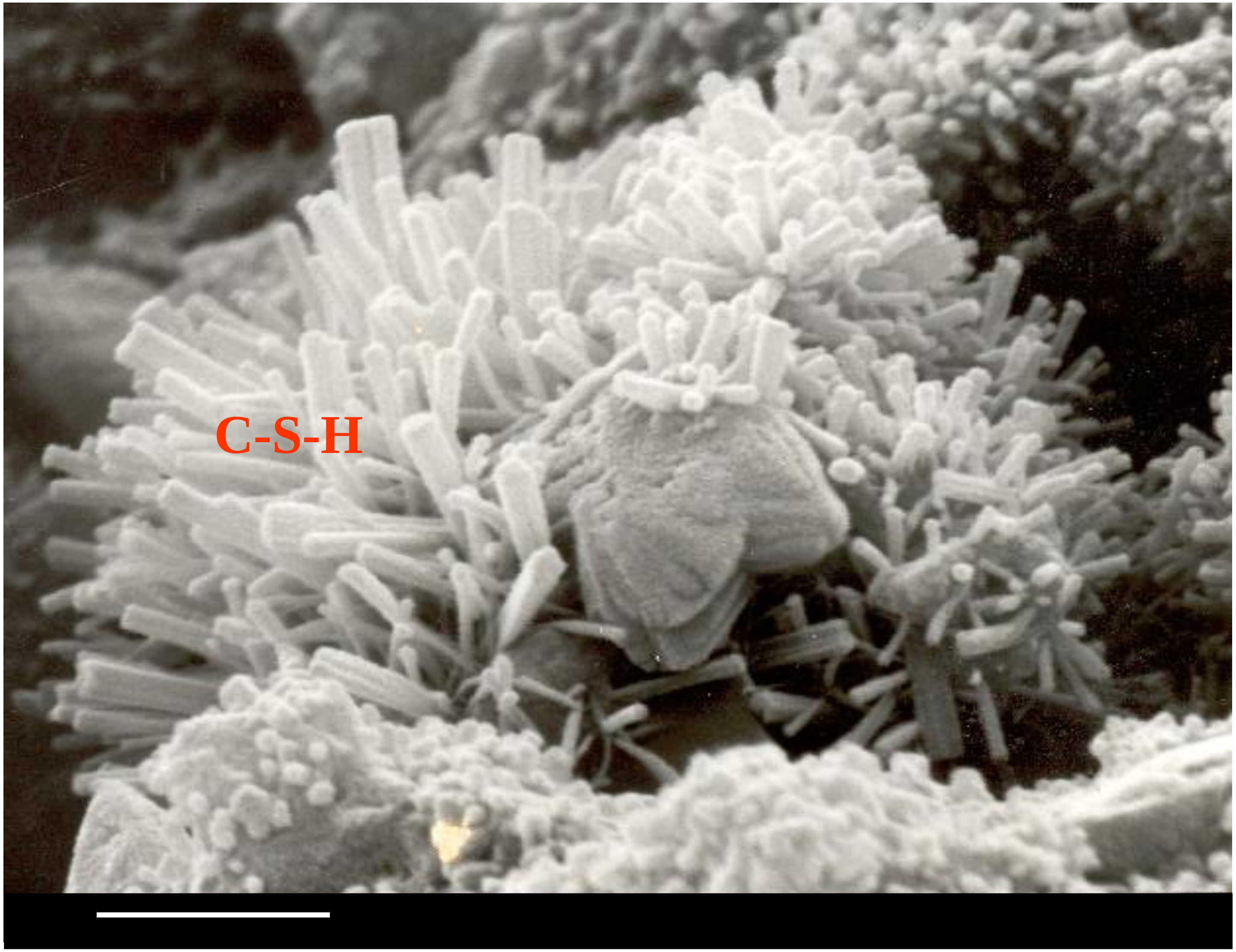
Hydration of cement

Hydration continues until:

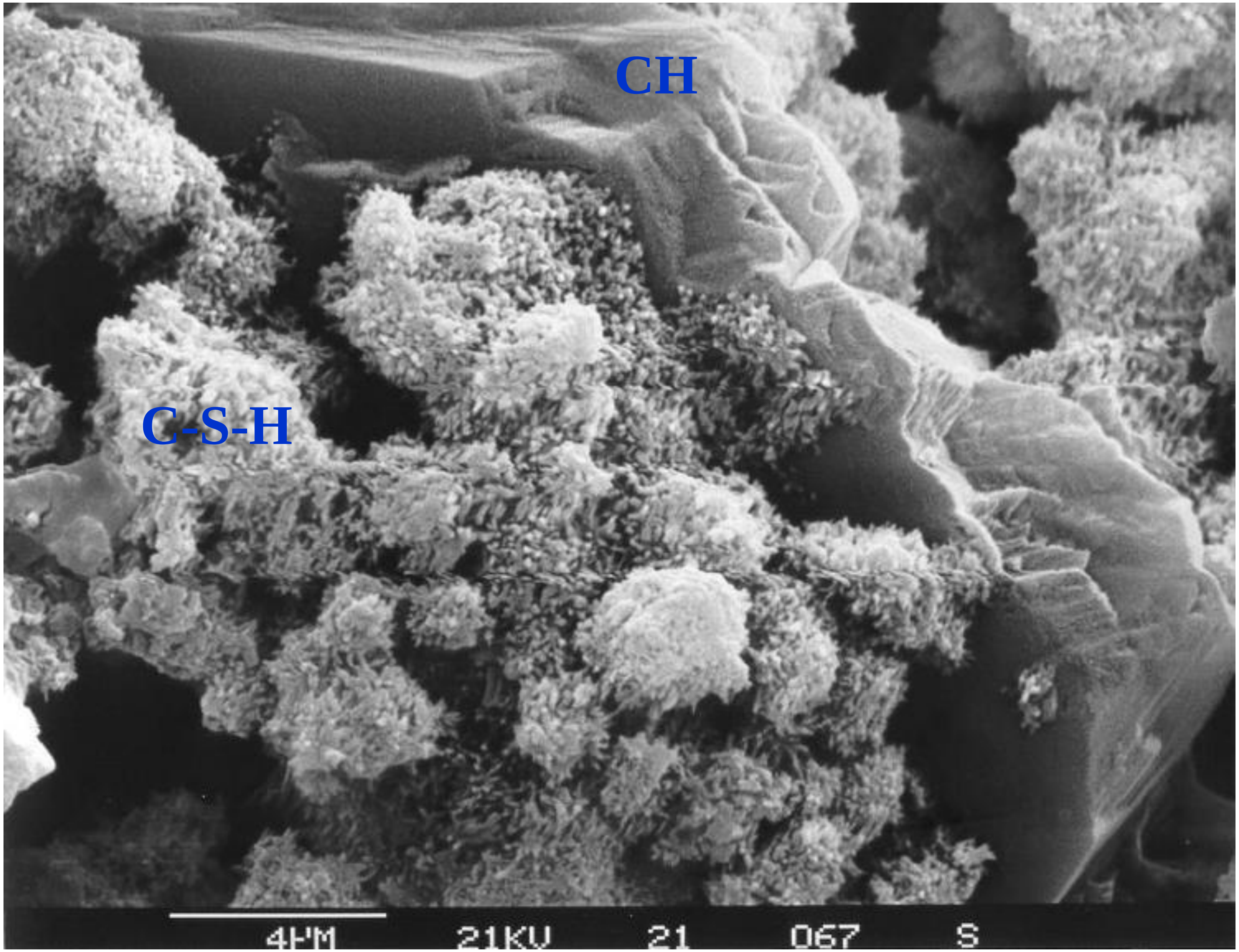
a) All unreacted (i.e. unhydrated) cement is used up.
b) Products of hydration fill all the space.
c) All the water within the paste is used up.

Even in very mature cements, some unreacted cement will be present. Hydration continues over the whole life of a structure and the properties of the concrete continue to change

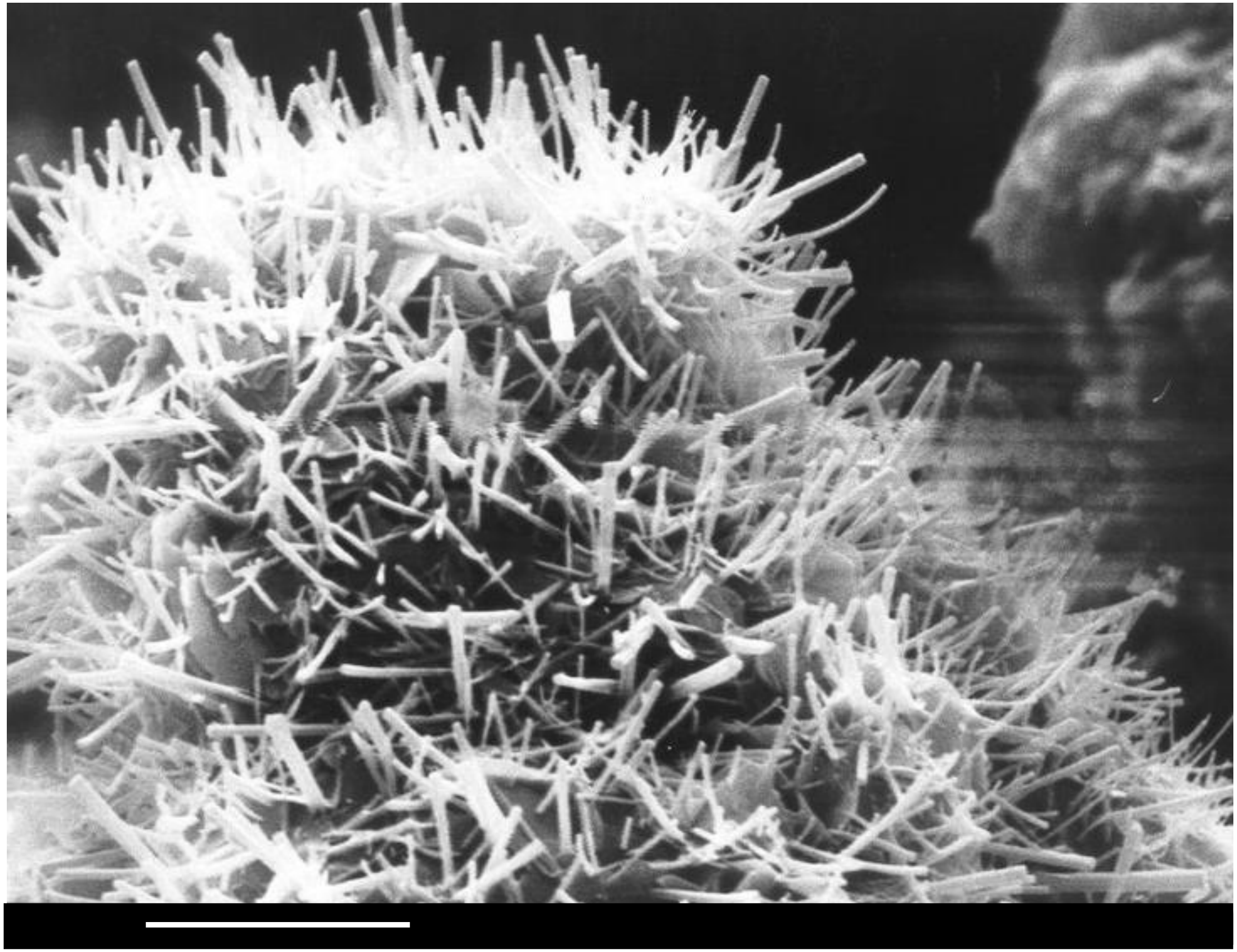
Calcium Silicates: Products of Hydration



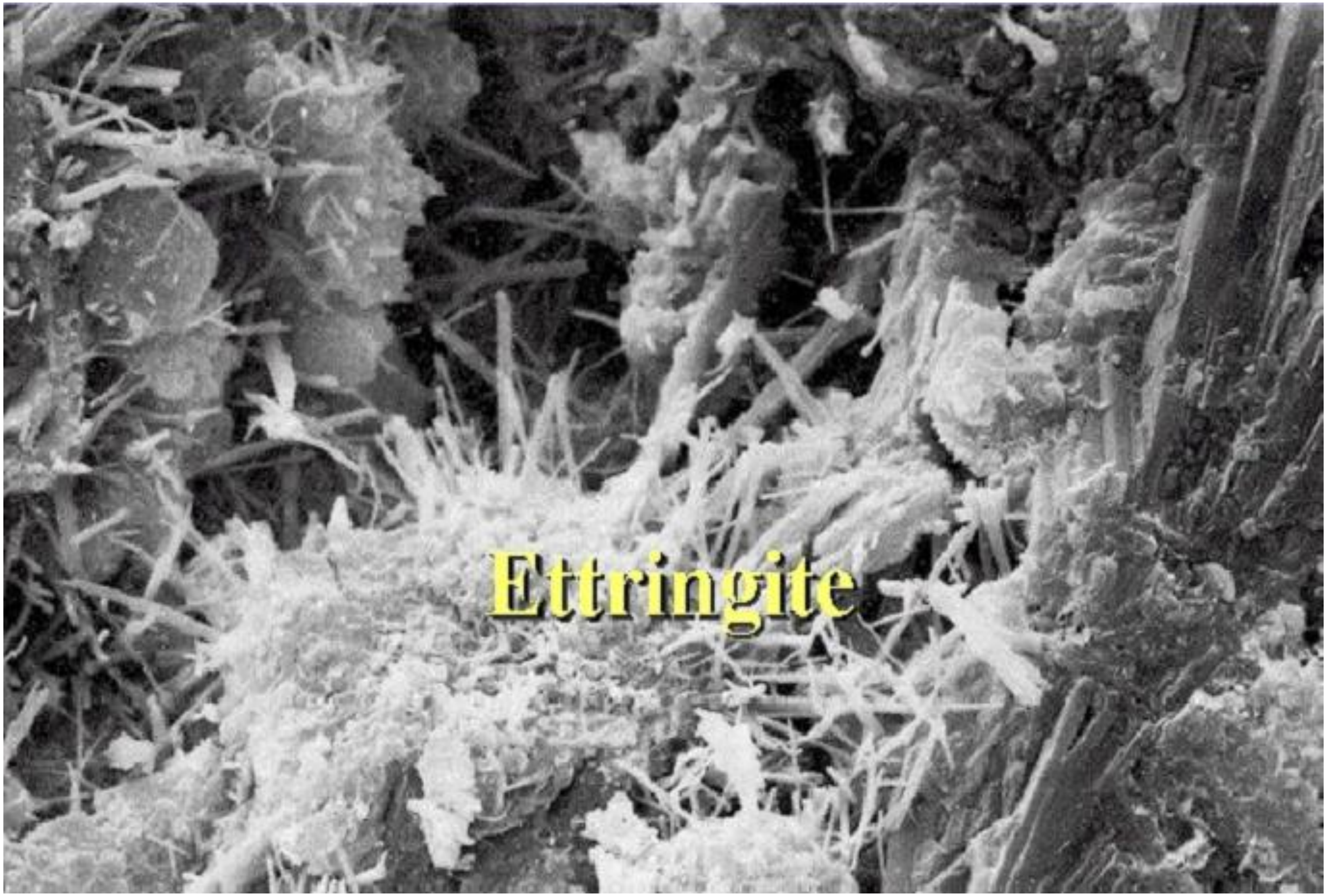
Calcium Silicates: products of Hydration

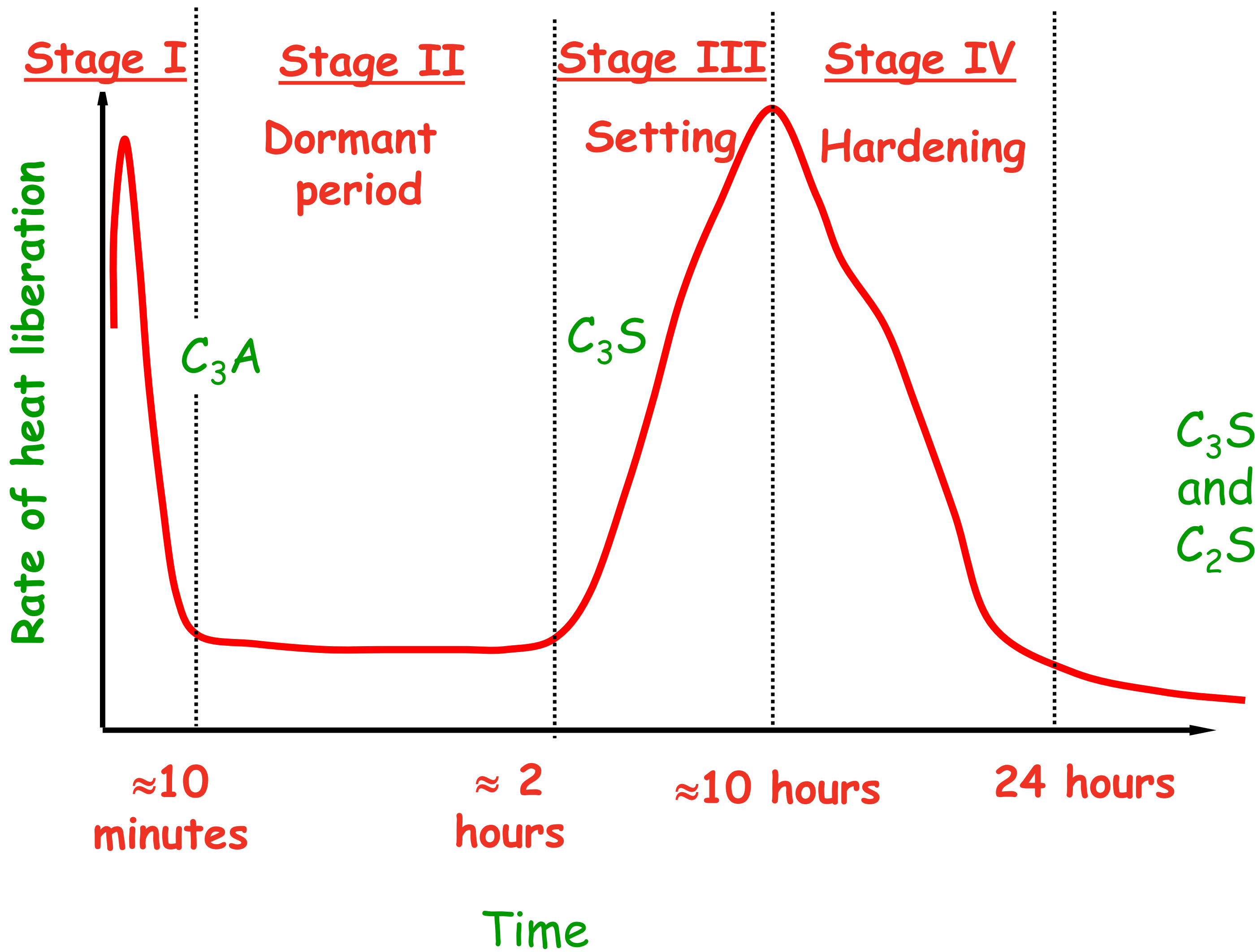


Hydration of cement



Ettringite (AFt) growing on C_3A phase


Ettringite


Stage I
Stage II
Stage III
Stage IV
Dormant period
Setting
Hardening
Rate of heat liberation
C_3A
C_3S
C_3S and C_2S
≈10 minutes
≈ 2 hours
≈10 hours
24 hours
Time

Hydration of cement

At any stage in the hydration process, the cement paste will comprise:

- unreacted cement
- products of hydration
- calcium hydroxide
- water (different types)
- an interconnected capillary pore network

Capillary pores are the void spaces between the hydrating cement grains which are filled with water and/or air.

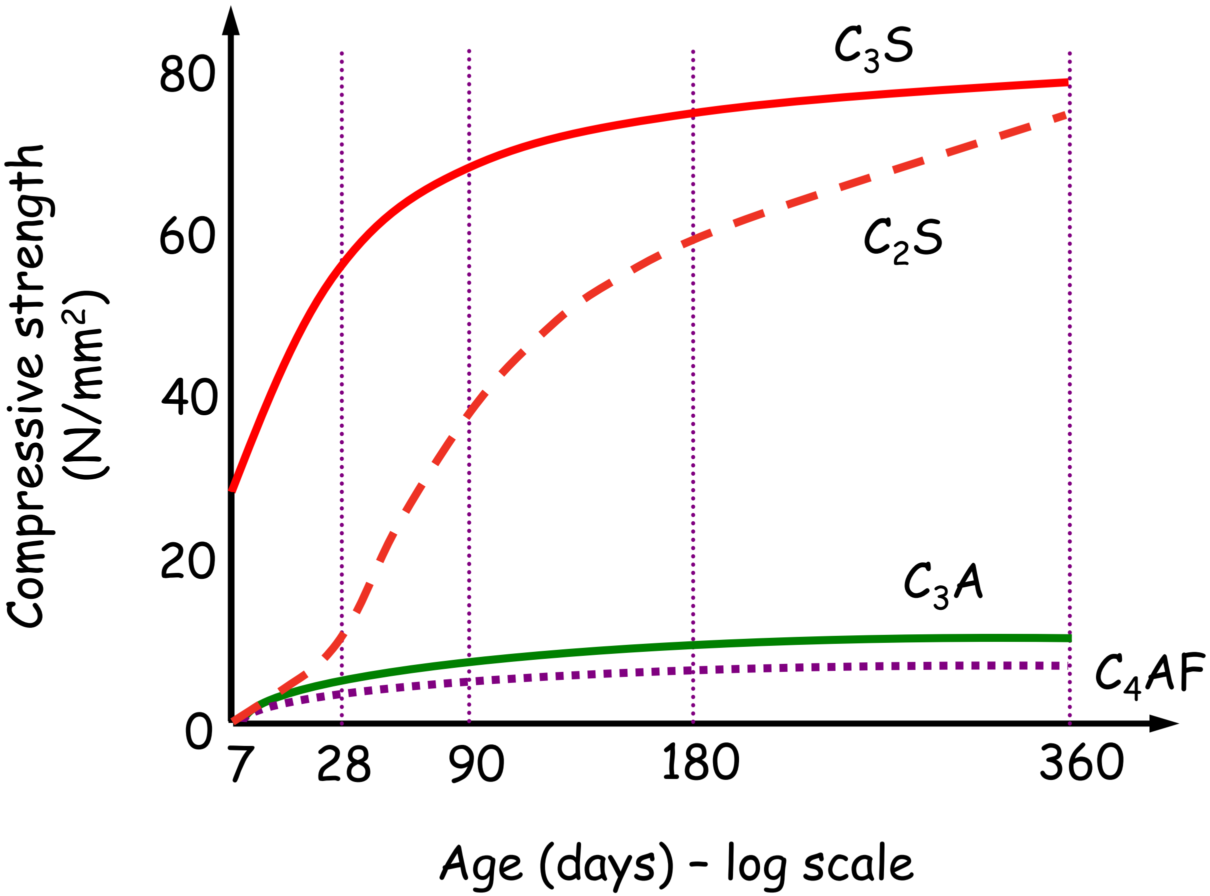
Strength gain of pure compounds

Compounds in cement hydrate (hence gain strength) at different rates:

- C_3S contributes to initial strength - within 24-hours and over the first few weeks
- C_2S contributes to strength development in the longer term – two weeks and beyond.
- C_3A and C_4AF - contribute little overall strength

In Portland cement, strength increases only gradually after 4 weeks due to relative proportions of components.

Strength gain of pure compounds



Setting and Hardening of cement paste

Portland cement + water

↓

Plastic / workable paste

↓

Initial set

↓

Stiff / unworkable paste

↓

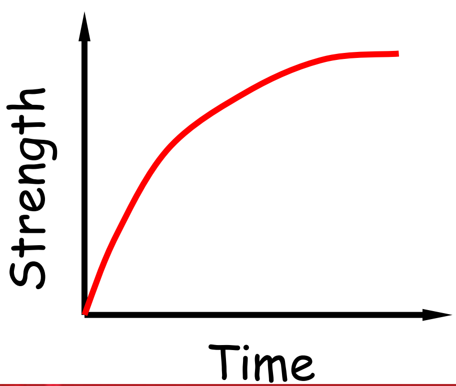
Final set

↓

Rigid solid gaining strength with time

Setting

Hardening



Mortar in Sydney Harbour

- http://edutv.informit.com.au.ezproxy.lib.rmit.edu.au/watch-screen.php?videoID=671375